
Volume V

Advancing products and services

Edited by
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Nebil Achour (eds.)

**WBC16 Proceedings: Volume V**

Advancing Products and Services
Preface

The aim of this last volume of the CIB World Building Congress (WBC), 2016 Intelligent built environment for life, is to explore the various needs of modern construction and offer new ways and techniques to address them. In recent years, stakeholder expectations have led to political, social and economic pressure on the construction industry. Modern buildings are expected to be innovative, sustainable, resilient to hazards and other risks as well as being easy to manage. In addition, clients expect to be part of the decision process to ensure their needs are met and often tied to legal bonds with professionals, a situation that can generate conflicts.

More than 200 authors have contributed to the 98 papers included in this volume. The vast majority of this research work is led by academics (70 papers) who discuss problems from a theoretical background and suggest solutions; whilst the remaining is led by industry researchers (28 papers) who provide an insight on real life through case studies. The present research work is led by researchers in 28 countries representing east and west, north and south of the globe. We hope that product and service enhancement will result from our sharing of information and collective experience.

Papers were classified into seven areas, including:

- Procurement, finance and conflicts (10 papers);
- Stakeholder involvement and satisfaction (12 papers);
- Innovative design and construction (17 papers);
- Risk mitigation, resilience and health and safety (13 papers);
- Sustainable construction (15 papers);
- Building information modelling (BIM) (16 papers); and
- Facilities management (15 papers).

Many lessons could be learned from each area and each research paper. However, one of the key lessons to be learned from this body of international research outputs is the need to better integrate design, construction and post-occupancy management in a construction lifecycle specifically with advancement of technology and availability of BIM tools. The second key lesson is the increasing acknowledgment of resilience and sustainability as a major part of modern construction.

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SECTION 1

Procurement, finance and conflicts
Multi-organizational PMOs for Interface Management between Construction Megaprojects and Its Sociological Context in China

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Abstract

This conceptual paper aims at providing an in-depth understanding of the role of the project management office (PMO) as a coordination mechanism between its complex multi-organizational settings of construction megaprojects and the sociological context in China. In the project practice of some large infrastructure in China, the coexistence of multiple organizational PMOs (with members from several independent organizations) is a common situation to coordinate the interface of sociological context and construction mega-project. The proposed conceptual framework builds on three main foundations: social conflict theory, governance mechanisms, and, the multi-organizational PMO. The proposed methodology is based on in-depth case studies, both of which are airport projects in China. By taking a sociological perspective, this research offers a novel and promising approach to the study of mega-projects and PMOs.

Keywords: Construction Megaprojects, PMO, coordination mechanism, social conflict theory

1. Introduction

The New York Times had an article in an early 2015 edition, title: “In China, Projects to Make Great Wall Feel Small.” (Barboza, 2015, p. B7). Among others, five major Chinese infrastructure projects were described, each one breaking some of the previous infrastructure limits. For instance, there is the Jiaozhou Bay Bridge, the world’s longest sea-crossing bridge at 26.4 miles. These mega-projects are not only about engineering and construction; they are about building a national identity, said Bent Flyvbjerg, as interviewed in this article (Barboza, 2015).

Recent decades have shown a significant increase in the number of mega-projects and their value worldwide (Flyvbjerg, 2014b). In China, as elsewhere, these projects have a major impact on the global economy (Bredillet, Yatim, & Ruiz, 2010). Moreover, this tendency toward mega-projects is expected to continue with an increase in both their number and value (Flyvbjerg, 2014b). However, a worrying aspect of these projects is an extraordinary high level of failing to meet their objectives (among others, Flyvbjerg, 2014b).
Since the birth of project management in the 1950s, construction megaprojects have been a continuous and important object of inquiry, first with military projects, than extending to the construction of buildings, transportation and power systems (Peter W.G. Morris, 2013). Recently, Flyvbjerg edited *Megaproject Planning And Management: Essential Readings*, a collection of about 70 influential articles and book chapters dating from 1951 to 2012 from various contributors in the field (Flyvbjerg, 2014a). The sections of this collection proposed are relevant to understand the current issues and plural views with regards to megaprojects, which are: The History of Megaprojects, Project Post-mortems, Front-end Management, Governance and Institutions, Stakeholder Management, Finance, Delivery, Social and Environmental Impacts, Innovation, and Case Studies. Whereas some themes, related to the technical core of project management (such as planning, control, and engineering complexity) have long been studied in project management, strategic issues in megaprojects have gained more recognition in the past decades (Morris, 2013).

For example, the attention of scholars has been oriented towards innovation (Davies, Brady, Prencipe, & Hobday, 2011; Miller & Lessard, 2000), governance regimes and frameworks (Klakegg, Williams, & Magnussen, 2009; Miller & Hobbs, 2005) and quest for success (Klakegg et al., 2009; Samset & Volden, 2013). However, researches on the social environment taken into consideration when studying mega-projects have been scarce, and some scholars have called for research development in that direction (Morris, 2013; Scott, 2012). From a social context perspective, there are numerous stakeholders in these projects. Their coordination and the adaptation of the mega-project to its social context is an important issue to solve.

This paper aims at proposing a conceptual framework for the study of the sociological context of construction mega-projects in China, as well as the role of the inter-organizational PMO as a coordination mechanism. Lessons learned from this research, we believe, will contribute to the theoretical and practical understanding of the management of mega-projects globally.

The following section presents the research background from the literature on three themes: mega-projects, sociological context, and the inter-organizational PMO. Following the literature review is the proposed conceptual framework, and the proposed methodology. The conclusion suggests the contribution of this paper, as well as its limitations and the direction for future research.

## 2. Research Background

### 2.1 Mega-projects

Progress in science and technology has spurred the launch of construction mega-projects globally, especially in developing countries such as China. For example, China’s high-speed railway project is one of the world’s largest mega-projects. However, despite their significant character these mega construction projects also bring great difficulties and challenges to project management (Flyvbjerg, 2004).

Considering the main characteristics of construction mega-projects, they involve a huge number of participants and they have significant social and economic impacts, extensive work loads, large geographical coverage and close connection to other major developments (Mok et al., 2015).
There are also different types of mega-projects, especially in terms of their level of ambition, lead times, complexity, and stakeholder involvement (Flyvbjerg, 2014a). Construction mega-projects present challenges to project management in their complexity, uncertainty, integrated management, etc. (Sun & Zhang, 2011). Complexities in managing mega construction projects can be viewed from three aspects: technical, social and managerial. Social aspects relate to complexities from the inadvertent impact of mega-projects on the environment and social systems within their location of implementation (Li & Guo, 2011).

The research of mega-projects has reached a new stage in the context of globalization. For example, the IMEC research program on large engineering projects included the benchmark of sixty projects at an international scale to identify best practices (Miller & Lessard, 2000). Results of this influential study have emphasized the central role of project sponsors, who need to ‘shape’ the front-end of the project as well as institutional arrangements (defined as laws, regulations and agreed to practices) in order to allow flexibility and ‘governability’ of the project, which are critical for success (Miller & Lessard, 2000). Another global study is that of Merrow (2011), who concludes from the analysis of a dataset of 318 megaprojects from around the world that two thirds are failures, mostly due to endogenous factors. Finally, an important initiative to study megaprojects using a global perspective comes from Scott and his colleagues from the Collaboratory for Research on Global Projects (CRGP) of the Stanford University. In an edited book of 11 chapters, the authors, based predominantly on the 3 pillars of Scott (2008) (regulative, normative and cultural-cognitive), emphasize the importance of an enlarged understanding of the role that both culture and politics play in global projects.

As research has shown that mega-projects are qualitatively more complex and riskier than usual operations and smaller scale projects, they therefore require governance regimes that are different from those of more routine and less risky endeavours (Miller & Hobbs, 2005). Better planning methods and changing governance structures are important to counteract the main problem of misinformation about costs, benefits and risks of mega-projects (Flyvbjerg, 2007).

As other megaprojects around the world, in China, some construction megaprojects also failed to meet their objectives. For example, the PX case in Xiamen, China. The government of Xiamen planned to build the Haicang PX project, which had been agreed by the State Council, Environmental Protection Administration and National Development and Reform Commission. However, once plans were revealed to public, strong oppositions aroused among citizens in Xiamen and even incurred concerns nationwide. The government of Xiamen only focused on the economic benefits of the project before the project announcement while omitting public outreach and public opinion. At last, the government of Xiamen bowed to public opinion and shifted the project to a remote island.

Another example is the Sanmenxia Hydropower Station in China. This project was put into operation without considering the impact of sediment deposition in the Weihe River. The project was cancelled, and resulted in repeated severe flooding (Chen, Le & Ren, 2006).
These failures in meeting project targets were caused by a neglect of the social context of the projects. Increasing complexity of mega construction projects require increased study of their social context. Traditional project management with appropriate method and data cannot meet the needs of mega construction projects (Sun, Zhang, 2011). The social responsibility activities associated with these projects need to be managed throughout (Salazar et al., 2012), and especially considered through their life-cycle (Zeng et al., 2014). Construction mega-projects have more interactions with the society and require a wider perspective for their study, such that a comprehensive point of view is needed for their study (Mao & Jia, 2011).

Besides its inherent project properties, mega-projects also have social attributes, the dominant feature in social context. The mega-project has close connections with globalization and civilization, but few articles have addressed the social analyses of mega-projects. From a perspective of social conflict theory, there are strong connections between mega-projects and social conflict (Jia et al., 2011). The social attributes of construction mega-projects include four aspects: 1) the construction project is the material basis for human survival; 2) the construction project is a matter of social activities; 3) the process of construction project is that human beings transform the world; and, 4) the construction project is the representative of social culture and civilization (Mao & Jia, 2011). It is adaptation to the social context is the ultimate goal of a construction mega-project (Tian & Chen, 2013).

2.2 PMO and the inter-organizational context

Emergence and deployment of PMOs in organizations followed the increasing use of projects in the innovation and development of economy and societies (Aubry, Hobbs, & Thuillier, 2007). Scholars have shown the wide diversity of the PMO (Hobbs & Aubry, 2010) and the difficulty to classify them empirically (Hobbs & Aubry, 2008), or explain their performance (Hobbs & Aubry, 2011). Their constant transformations have also been the object of research leading to a theoretical approach of an evolutionary process view (Aubry, Müller, Hobbs, & Blomquist, 2010) or other conceptualizations such as emptying process (Pellegrinelli & Garagna, 2009) and sustainability (Hurt & Thomas, 2009). Their role has also been scrutinised in different ways such as deconstructing the PMO to better understand their function (Crawford, 2010), or to critically assess their lack of engagement in integrating organizational change (Artto, Kulvik, Poskela, & Turkulainen, 2011), and acknowledge their impact on the knowledge management in project-based organizations (Pemsel & Wiewiora, 2013).

Most of the research has focus on the entity itself or its transformation process. Few studies have focused on the different roles of PMOs when tightly associated with activities of portfolio management with the exception of Unger and colleagues (2011), who specifically study the role of a portfolio PMO on project and portfolio performance.

In the last 10 years, research on PMOs has provided a good understanding of the phenomenon by looking at the what and the how its evolution, or in ontological and epistemological words, as a thing and as a process (Van de Ven & Poole, 2005). However, there are limitations to what the research has covered on PMOs, mainly in isolating this entity from the rest of the organization.
To our knowledge, none of the research on PMOs has studied this entity as a governance mechanism and included it within the organizational design (Winch, 2014). This missing link contributes to the difficulty of positioning project management as being part of the organization’s strategy, project management being responsible of strategy implementation, and of strategy formulation, at a lesser degree (following, Jacobs, 2010). To engage project management at the strategic and institutional level (Morris & Geraldi, 2011) requires, among others, to study these governance mechanisms embedded in the overall organizational governance.

2.3 Stakeholders in the sociological context

2.3.1 Stakeholder Identification and Classification

Stakeholders include individuals, groups or organizations affected by the project, and can be classified as: beneficiaries, losers and neutral parties (Housing and Urban-Rural Development Department of China, 2014). The stakeholders of construction mega-projects can be divided into eight classifications (Mao & Jia, 2011): the government, investors, owners, contractors, volunteers, departments (e.g., NGO), the public, and other stakeholders. According to a stakeholder party-classification method, illustrated in Table 1, the eight classifications of the stakeholders of construction mega-projects can be divided into four parties: the government, the construction mega-projects, the benefited public, and the impaired (impacted) public.
Table 1 Stakeholder Identification and Classification

<table>
<thead>
<tr>
<th>Four Parties</th>
<th>The Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Government party</td>
<td>The Planning Bureau</td>
</tr>
<tr>
<td></td>
<td>The Land Bureau</td>
</tr>
<tr>
<td></td>
<td>The Housing and Urban Construction Bureau</td>
</tr>
<tr>
<td>The Construction Mega-Projects party</td>
<td>Investors</td>
</tr>
<tr>
<td></td>
<td>Owners</td>
</tr>
<tr>
<td></td>
<td>Contractors</td>
</tr>
<tr>
<td></td>
<td>Sub-contractors</td>
</tr>
<tr>
<td>The Benefited Public party</td>
<td>Groups benefited from the project construction</td>
</tr>
<tr>
<td></td>
<td>The other benefited stakeholders</td>
</tr>
<tr>
<td>The Impaired (impacted) Public party</td>
<td>Groups impaired by the project construction</td>
</tr>
<tr>
<td></td>
<td>The other impaired stakeholders</td>
</tr>
</tbody>
</table>

2.3.2 The Interactions between Stakeholders

The relationships between different stakeholders and their interactions are dynamic network (Miller and Hobbs, 2005). Through the four roles of different stakeholders in the practice of construction mega-projects, they form a complex interaction in a logical network during the project as shown in Figure 1 (Mao & Jia, 2011).

![Figure 1 The Interactions between stakeholders of construction mega-projects (Mao & Jia, 2011)](image-url)

In the study of the interaction between construction mega-projects and its social context, the literature focuses on social evaluation of construction mega-projects (Housing and Urban-Rural Development Department of China, 2014). But there has been problems regarding implementation of the management plan; which is, to mitigate the negative social impact of construction mega-projects. In the actual practice of projects, the establishment of multi-organizational PMOs have been shown to respond to corresponding problems (Headquarters of...
Shanghai Hongqiao Integrated Transportation Hub [ITH], 2011). Therefore, we propose the following assumption from organizational perspective.

2.4 Research questions

Building on the review of the literature, the proposed research should investigate:

- The nature of the sociological context of construction mega-projects
- The characteristics of the construction mega-projects under its sociological contexts
- The role of the multi-organizational PMO at the interface of sociological context and construction mega-projects.

From what has been said above, the following research questions have been identified: RQ1: What is the impact of sociological context on the construction mega-projects? RQ2: What is the role of multi-organizational PMOs in this relationship?

These questions will address the specific coordination tasks of the PMOs in two preliminary stages (Shizhao, 2014) of construction mega-projects: the initial proposal stage and the feasibility stages.

During the initial proposal stage, the main task of the multi-organizational PMOs is to coordinate the project planning and design, identify stakeholders of the construction mega-projects and risks the project may face. During the feasibility studies stage, the main task of the multi-organizational PMOs is to give a comprehensive analysis of the interactions between the various stakeholders and to propose measures to mitigate adverse social impacts on early phase of the construction mega-projects.

The Unit of Analysis is the PMO as a coordination mechanism on multi-organizational settings in public construction mega-projects. The level of analysis spans from the societal via, the organizational to the unit level. Thus, the study follows the suggestions for more multi-level studies (Courgeau & Baccaini, 1998; Baccaini and Courgeau, 1998; Rousseau, 1985).
3. Conceptual Framework

The proposed conceptual framework brings together three different but complementary theoretical perspectives. Scholars studying phenomena in organization are facing complex situations in pluralist setting (Denis, Langley, & Rouleau, 2007). In their paper, Denis et al. (2007) argue for adopting multiple theoretical perspectives to understand or to explain pluralistic contexts defined as “organizational contexts characterized by three mains features: multiple objectives, diffuse power and knowledge-based work processes.” (Denis et al., 2007, p. 179). In their paper, they propose a multifaceted theoretical framework combining three theories from sociology and theory of organization: actor-network theory, convention theory and social practice theory. There is no doubt that mega-project are situations in pluralist context as the three main features can be identified:

- Multiple objectives. In mega-project context, objectives are set by a vast array of stakeholders having different, and sometimes conflicting, expectations as illustrated by Jia and colleagues (2011) in social conflicts.
- Diffuse power. Governance mechanisms generally define the formal power system and the decision making process. In mega-project, the power system is complex having multiple organizations forming a dynamic network of (Klakegg et al., 2009) in which informal power is developed making difficult (or impossible) to make a decision in a unique central locus (Miller & Hobbs, 2005). Moreover, public mega-projects do face particular situations of dual power systems – elective versus administrative. Governance frameworks developed in western world have specifically this role of regulating the power system.
- Knowledge-based work processes. Little is known at early stage of any project. Knowledge develops during the project on what to do and how to do it (Midler, 1993; Turner & Cochrane, 1993; Winter & Szczepanek, 2009).
The conceptual framework for the study of construction mega-projects in China is built on three major theoretical components: the sociological context, the construction mega-projects, and the multi-organizational PMOs. Altogether, the three components are embedded in each other, forming a coherent model having reflecting the tall ontology proper for the study of pluralism setting (Seidl & Whittington, 2014) (See Figure 2).

Following Hughes (Hughes, 1987, 1998), innovations are shaped by their socio-technological environment, as they also shape their environment. Not only does innovations happens at a specific point in time, they are the result of the evolution and history of other elements in the environment (Petroski, 1994). For mega-projects, we will take into consideration the context in which this project happens. In some cases, projects do have a long history before a decision is made to initiate the project. In social context, we will consider the conflict theory to explore the relationship between different stakeholders where tensions and conflicts are more likely to happen (Aubry, Hobbs, Müller, & Blomquist, 2010). It is very much in line with the call for turning to theories form the sociology of organizations to enlighten project management situations (Floricel, Sergi, Bonneau, & Aubry, 2013).

Mega-projects require that governance arrangements be put in place in order to clarify the formal decision-making process. Decision-making process for mega-project could certainly be looked at throughout economic theory such as transaction-cost theory (Williamson & Masten, 1999) or agency theory (Jensen, 2000). Klakegg and colleagues (2009) have identified some resonance of these perspectives in some aspects such as control, incentive, information, asses
specificity, etc. (Klakegg et al., 2009). While these theories would certainly enlighten governance aspects, this research would rather turn to more institutionalism perspective with a sociological and political understanding of governance. In this sense, we adopt the paradigms view on governance where single organization manage different projects under different mix of project output (behaviour or outcomes) and project orientation (shareholder or stakeholder) (Müller, 2011). In this context, governance frameworks are good artefacts to understand the governance regime in which those construction mega-projects are executed (Klakegg et al., 2009).

Then, the multi-organizational PMO has to be understood in different aspects. A first aspect refers to the process of organizational for projects. In this aspect, we will base our work on the work of Miller (Chen & Miller, 2010; Greenwood & Miller, 2010; Miller, 2005). We will also work with the three domains identified by Winch (2014) specific to the field of project management. Description of the PMO formal structure will be done using the model developed by Hobbs and Aubry (Hobbs & Aubry, 2010). The structure will also be explored through actor network theory (ANT) to take into account the construction of the network around a certain number of artefacts, one of which being the governance framework. ANT provides a dynamic view connecting actors and non-human actants together in building and maintaining some controversies (Aubry, 2011).

4. Methodology

We develop the study’s methodology following the approach of Saunders, Lewis and Thornhill (2007) by starting with the philosophical perspective, then determine the inductive, deductive or abductive approach, followed by the research strategy and the time (cross sectional or longitudinal) and methods (mono, multi or mixed method) approach, and finally determine the type of data to be collected.

A study with the indicated scope and level of analysis requires a comprehensive underlying ontology that allows for the integration of subjective societal and organizational worldviews with more objective worldviews of planning, control and coordination in projects. Therefore we take a critical realist perspective (Bhaskar, 2008). This ontology is based on three layers, namely mechanisms, events, and experiences. This ontological approach is to be put in relation with Seidl and Whittington (2014) call for adopting taller ontology aiming at expressing the organizational context in more precise terms. Here the lowest level, named mechanisms, represents the underlying generalizable laws or the assumptions thereof, such as those of objective planning of projects, measurable benefits of projects etc. These mechanisms give rise to the second layer, events. Enabled through the mechanisms, events constitute both objective and subjective representations, such as mega-projects’ final products and the use of them. These events (of usage) give rise to the top layer, experience. This is the most subjective layer and represents the idiosyncratic experience of individuals, contingent on the events, which, again, are contingent on the underlying mechanisms. Critical realism integrates these three layers of worldviews into a single research perspective (Archer, Bhaskar, Collier, Lawson, & Norrie, 1998; Bhaskar, 1975).
To leverage existing theories for the ‘sense making’ of the data collected in the study we use an abductive approach in the sense of Alvesson and Sköldberg (2009). This approach allows for going back and forth between existing theories, collected empirical evidence, and the experience of the researchers in order to make sense of yet non-understood phenomena.

Four in-depth case studies in the sense of Yin (2009) will be done, using ‘maximum variation’ sampling to allow for broadest understanding of the phenomenon. In addition we prefer this approach over a quantitative study because of potential problems in achieving a sufficient sample size when concentrating on public construction mega-projects only (Müller, Pemsel, & Shao, 2014).

At first place, search for public documents will take place to acknowledge the media communications and their possible effects on project team. Research design will provide opportunities to capture data at different levels and from a variety of actors, as described in our conceptual framework. Data collection strategy will include semi-structured interviews with 20-30 actors for each project. Each interview will last an average of an hour and will be transcribe in Word files and then analyzed using Atlas.ti (ATLAS.ti Software Development, 2004). When possible, observations on site will take place. This will provide data on the practices in each site. Field notes will be taken and processed based on as ethnographical techniques. This should provide a good understanding of each sociological context of the projects. Documents and other artefacts on the projects or on the organizations will be collected and analyzed to provide information on the socio-politico-technological context of the project.

Different strategies will be used for data analysis following Langley (1999). Among others, grounded theory will serve as a strong inductive approach to listen to what the interviewees will have to say, graphical views will provide visual setting that is helpful in clarifying concepts, and some quantitative analysis may be possible in counting different activities or facts. In combination to these strategies, related data analysis techniques will follow the suggestion by Miles & Huberman (1994) to help make sense of large quality of data.

Validity will be ensured using the suggestions by Yin (2009). For that we do within-case and across case analysis, look for convergence and cross validation of the collected data, best possible respondents, and use theoretical saturation for interviewee sampling. Reliability will be assured through the development of a case study protocol and its usage throughout the study.

5. Discussion and Conclusion

This paper addresses problematics related to the management of megaprojects. Challenges in this field are crucial as megaprojects in general are often associated with failures in one hand, and on the other hand, the tendency is going towards more and larger megaprojects (Flyvbjerg, 2014b). Megaprojects have been defined as pluralistic contexts (Denis et al., 2007). Based on a review of the literature, this paper proposes a conceptual framework combining three layers of theoretical approaches to capture in an integrative way the pluralism setting of construction
megaprojects. This conceptual framework is intended to drive a wide research taking place in China (Chen & Miller, 2010).

Novelty of this research bears on two main elements. First, as of now, the sociological aspects of megaprojects have been neglected in the research on megaprojects. This research aims at including social context and more particularly, social conflicts among stakeholders as key elements of the environment. In doing so, the context is becoming personified instead of being a grey undefined area (Seidl & Whittington, 2014). Second, the PMO is deliberately interpreted as a governance mechanism which is worth to be considered within the organizational design for projects.

There can be many perspectives to study the management of mega-projects, but from the perspective of sociology and PMO is promising. This article mix sociology and PMO to study the impact of sociological context on the construction mega-projects and the role of PMO as a coordination mechanism and give a conceptual framework which put mega-project in the social context and use PMO to coordinate them.

This paper is conceptual. This raises a first limitation as no empirical evidence comes to validate our conceptual approach. However, this is a first step for a larger research to be undertaken in the following months. A second limitation is associated with the conceptual approach based on multi facet theories. While this approach fits well pluralistic contexts (Denis et al., 2007), it may cause the analysis to stay at higher level of interpretation instead of going in depth in one single theory. Impact of this would be the incapacity to provide new theoretical insights. Globally, we think that this conceptual framework is promising for many other researches in the field of megaprojects.

References


Barboza, D. (2015, 2015/13/01). In China, Projects to Make Great Wall Feel Small,


A Traditional, Large Engineering Service Adopts the Best Value Approach

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Abstract

The BV environment was introduced into the Netherlands in 2006. By 2008 testing was being done by a partnership of Arizona State University and Scenter [Sicco Santema, professor from Delft University]. In 2010, the $1B fast track projects were procured by the Rijkswaterstaat, and by 2012, the BV approach had become the “buzzword” of procurement. However, in the delivery of professional engineering services, larger, more traditional services which were built on a system of relationships between clients and vendors, MDC from the clients’ experts, and the importance of “billable man-hours”, the transition from a traditional approach to a best value approach is very challenging. Large traditional professional organizations naturally will have more difficulty adapting to the new approach. The BV approach utilized the expertise of experts to replace the need for relationships and owner management, direction and control [MDC]. It also places less value on traditional practices that have been used by professional services to get business [relationships and working together with the client in a trust based relationship]. The study captures the efforts of a very successful engineering firm [the largest in the Netherlands] as they attempt to become successful in this new approach. The best value team that they have put together has had outstanding results in using the BV approach to changing their paradigm.

Keywords: professional services, best value, Netherlands, Royal Haskoning DHV, delivery of services

1. Introduction to the Selection of Design Services

Professional services were always selected differently from other construction services. They were identified as professional services which used engineering principles to solve and provide solutions to owner requirements. They developed a selection system called Qualification Based System or QBS, which selected designers based on the professional’s past performance, professional licenses, professional relationships and technical knowledge in the firm (Child, Sullivan & Kashiwagi, 2010; D. Kashiwagi, J. Kashiwagi & Child, 2014). The QBS system resulted in a system where the owner’s selected the professional firm based on relationships, marketing brochures and firms’ reputations. The selection process resulted in client’s selection boards deciding who was the best qualified. In many government environment’s, price was not a selection criteria. After the QBS was performed, a professional service is
selected and price is negotiated. Oftentimes, it is a fixed percentage of the construction cost, and not what the actual professional services would cost.

The QBS and other similar selection systems resulted in professional services having the following practices (Child, Sullivan & Kashiwagi, 2010; D. Kashiwagi, J. Kashiwagi & Child, 2014; Sullivan & Michael, 2011):

1. Depending on marketing and relationships to get their work.
2. Professional services becoming more reactive to the clients’ needs.
3. Strong relationships become the solution for engineering and design issues.
4. Design schedules becoming less important leading to design change orders and redesigns.
5. Large design services becoming more fixated on maintaining “billable man-hours” than utilizing their expertise.
6. More administrative and meeting duties than utilizing technical expertise.
7. A void of project management skills which concentrated on profit margin, efficiency, effectiveness and maximizing profit/return to the company.

These practices led to the following results (Egan, 1998; FMI / CMAA, 2004; FMI / CMAA, 2010; Sullivan & Michael, 2011; Tucker, 2003):

1. Poor customer satisfaction.
2. Clients reviewing the professional’s work, and managing, directing and controlling the professional services.
3. The owners/clients’ had a poor perception of designers and engineer’s capability, quality of work and professionalism.
4. An inability in a large design firm to identify the expert, select the expert for a project and allow the expert to plan the project from the beginning to the end [utilizing their expertise to estimate quantities and identify the risk that other stakeholders bring to the design project and mitigating the risk by creating transparency and through a risk mitigation plan].
5. Work was procured through a marketing/relationship process called the Qualification Based System or QBS. The selection of the firm is done through an owner’s selection board that decides who is the best qualified, then negotiates a contract with the selected vendor.

These design practices are in all countries and cultures [underdeveloped, developing and developed countries]. The authors have been in Africa, Malaysia, China, U.S. and Europe in which the practices are observed to be the same.

The Best Value approach has been in the Netherlands since 2007. The Rijkswaterstaat [tasked with maintaining roads and waterways in the Netherlands] delivered the “fast track projects” using the Best Value approach [known as best value procurement or BVP]. The following results were realized (Van de Rijt, Witteveen, Vis & Santema, 2011):

1. Procurement transactions and costs were minimized by 50%.
2. Construction time was minimized by an average of 25%
3. 95% of all project cost and time deviations were caused by the owner/client and their professional services.

Professional services were also procured by the BVP approach. Immediately the following problems were realized (J. Kashiwagi, Sullivan & D. Kashiwagi, 2009; Kashiwagi, 2014b):
1. The design professionals were reactive and not used to being accountable to setting a plan, identifying the deliverable to be delivered, making the assumptions that should be made utilizing their expertise, and having a risk mitigation plan that minimized the risk that they did not control.
2. The owner/client’s project managers were confused and thought that the clarification period was a time to make the contractors do work to identify all the unknowns.
3. The design services faced the challenge of how to identify and utilize expertise in their own organizations.
4. Large design organizations were confused how to match their need to transform their approach from concentrating on “billable hours” to utilizing expertise.

The Performance Based Studies Research Group (PBSRG) identified the following about the Dutch Best Value movement:
1. Per capita, it was the most progressive best value (BV) effort in the world, with most number of certified experts, the largest number of BV technology licenses, more major government clients involved in best value tests and the only country where the professional procurement group [NEVI] and the professional group [RISNET], which includes the professional organization of the design firms, are all licensed in the BV technology from Arizona State University (ASU) and their technology licensing group AZTECH (PBSRG, 2012).
2. BV consulting groups proliferating the BV practices including Scenter [led by Sicco Santema, the best value visionary of the Netherlands], NEVI [3rd largest professional procurement organization in the world], Best Value Europe [organization committed to spread BV throughout Europe] and the Dutch Professional Engineering Organization which is a member of the European Professional Engineering Organization (Kashiwagi, 2014b).
3. The largest government organizations in the Netherlands were participating with the BV effort including Rijkswaterstaat, ProRail, Netherland Rail Service, waterboards, and major cities such as Rotterdam, Amsterdam, Utrecht, and Groningen (Kashiwagi, 2014b; Van de Rijt & Santema, 2013).

### 2. Problem: How to Transform Professional Services to a Performing Industry

For the BV effort to be sustainable, PBSRG was interested in three major areas: professional services, medical services and IT or ICT services. Professional service was a primary target because the traditional delivery of the professional services was an area where (Child, Sullivan & Kashiwagi, 2010; D. Kashiwagi, J. Kashiwagi & Child, 2014; Egan, 1998; FMI / CMAA, 2004; FMI / CMAA, 2010; Sullivan & Michael, 2011; Tucker, 2003):
1. Management, direction and control was being utilized to minimize risk.
2. It is a commodity area that was being differentiated based on relationships.
3. The professional services had a very poor customer satisfaction rating.
4. The professionals are the first to touch the delivery of construction services and were identified in the Netherlands billion-dollar infrastructure project as the source of 90% of the project cost and time deviations (Van de Rijt & Santema, 2012).

5. In PBSRG construction project tests, the design services and the owner’s decision making was the largest source of project cost and time deviations. The owner’s representatives and the design services were indistinguishable. They were one entity and the largest problem in the delivery of construction services (J. Kashiwagi, Sullivan & D. Kashiwagi, 2009; Kashiwagi, 2014).

To have a larger and more sustainable impact on the performance of professional services, PBSRG searched for visionaries in one of the more traditional larger professional services companies.

3. Methodology

3.1 Approach

The research approach was simple:
1. Identify one of the largest professional services company.
2. Identify if there were visionaries who understood the BV approach in the company.
3. Identify the strategic plan to transform the large organization into an organization that could utilize the BV approach to increase efficiency, effectiveness and margin/profit for their organization.

3.2 Research

PBSRG set on the following plan to meet the research objectives:
1. Present to all the large professional organizations.
2. Identify one of the organizations who had visionaries.
3. Educate and train the visionaries in the best value approach.
4. Identify if they could follow the BV approach to give their organization the ability to utilize the best value approach.
5. Convince the core group to utilize metrics.
6. Identify if the metrics can be refined to increase the support of the rest of the organization.
7. Pick a case study which shows the success of the BV approach.

4. History of BV with Professional Engineering Groups

From 2011 – 2012, PBSRG started to brief professional engineering firms. The Dutch professional engineering group [under RISNET [Dutch risk management professional group]]. In 2014 RISNET licensed the BV approach technology from ASU, and the Dutch professional engineering group is a subset of RISNET, giving access to all the training material to the engineering group. The Dutch professional engineering group under the leadership of Paul Oortwijn, started presenting the BV approach at the European Engineering Association in 2013, resulting in interest from Norway and Poland. Partnering with the Scenter group [private group which partnered with PBSRG to bring the BV effort into the Netherlands], the Dutch Best Value Procurement (BVP) book is being translated into both Norwegian and Polish
languages, with the Polish book to be introduced to the Polish professional engineering group in March 2016.

In 2012, PBSRG was contacted by the second largest engineering and design firm in the Netherlands, Royal Haskoning DHV. Royal Haskoning DHV is an independent, international engineering and project management consultancy with over 130 years of experience. Our professionals deliver services in the fields of aviation, buildings, energy, industry, infrastructure, maritime, mining, transport, urban and rural planning and water. Backed by expertise and experience of nearly 7,000 colleagues across the world, they work for public and private clients in more than 130 countries on five different continents (Royal Haskoning DHV, 2014). A visionary, Elske Bosma, in the company reached out to PBSRG for some guidance, and PBSRG started a relationship to assist them become a best value expert.

4.1 Development of the RHDHV Best Value Effort

PBSRG had already researched how to transform a large organization to have the capability of providing the best value. It had to take the following approach and assumptions:
1. There is no controlling any individuals in the company to change their conceptual thinking by management, direction or control (MDC) or influence.
2. To expect anyone to change was to increase risk.
3. Visionaries had to be identified by their affinity to the concepts of Best Value (BV) and Information Measurement Theory (IMT) which include logic, consistency, leadership characteristics and proactive motivation to make things better.
4. The group should start small.
5. Education is very important to identify more visionaries.
6. People in the organization who do not understand BV, are focusing on amount of work or turnover and profit margin.
7. The BV core group will have to develop metrics that minimize decision making of the organization as soon as possible.
8. The BV group must have a mentor.

The following is a historical account of dates and activities of the development of the RHDHV best value effort led by Elske Bosma, Marcus van der Ven and Oscar Kerkhoven (E. Bosma, Personal Communication, December 9, 2015):
1. April 2012: Elske Bosma starts a BVP network within DHV
2. June 2012: Elske meets Marcus van der Ven, Oscar Kerkhoven and Fred Haarman, who gained experience with BV at Royal Haskoning DHV. They start with the effort to improve the Best Value tender success rate within the new company RHDHV. This was the start of the Best Value core team.
3. September 2013: The BV core team meets with Dean Kashiwagi. The BV core team also brings 2 colleagues of the higher management of RHDHV. Dean is very much interested in the BV effort of the core team.
4. December 2013: The BV core team presents their strategic plan to the executive board of RHDHV. The board approves the plan. A member of the execute board becomes the sponsor of the BV core team.
5. January 2014: Marcus, Oscar and Peter Edward attend the BV Conference in Phoenix, Arizona
6. May 2014: Dean visits the RHDHV’s head office in Amersfoort. Over 100 employees of RHDHV attend his presentation and/or the workshops.
7. October 2014: Marcus obtains the A+ certification [Highest BV certification]
8. November 2014: The BV core team starts to give the 2.5-day Best Value course to educate colleagues for the B-certification [Entry level certification]
9. January 2015: The BV core team and 5 other colleagues attend the BV Conference in Phoenix, Arizona
10. June 2015: Dean visits the RHDHV head office in Amersfoort. Appr. 80 persons of RHDHV attend his presentation and/or the workshops.
11. October 2015: Oscar obtains the A+ certification.
12. October 2015: BV team expands group with 3 more persons [One of the three is in the higher management of RHDHV]. Of the BV core team 6 persons of RHDHV will attend the Best Value Conference in Arizona in January 2016.
13. December 2015: The core team has educated over 50 colleagues (B-certification) in 2014/2015.

### 4.2 RHDV Metrics

One of the objectives of the BV approach is to use metrics to minimize decision making inside and outside of the organization. The BV core team had the following objectives (Royal Haskoning DHV, 2015):

1. Show increased value of the core team activities.
2. Show that if the BV approach and the BV core team was utilized, the amount of work acquired and the success rate should increase. When the numbers become dominant enough, policies will be set by the company that help the non-BV experts to utilize the BV core team.

Table 1 shows the core teams’ metrics. Table 2 then shows the metrics that minimize decision making, and will lead to changing RHDHV policies. The RHDV core team also identified a BV expert who began keeping metrics on his procurement projects [Table 3]. PBSRG will continue to work with RHDHV and the engineering consulting professional groups in the Netherlands, Norway and Poland to assist the industry to transform itself into a best value industry.

**Table 1**: Royal Haskoning DHV Performance Metrics to Minimize Decision Making

<table>
<thead>
<tr>
<th>Performance Criteria</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td># years BV core team</td>
<td>3+</td>
</tr>
<tr>
<td># BV procurement as client PM</td>
<td>12</td>
</tr>
<tr>
<td># BV tenders for engineering consultancy projects</td>
<td>24</td>
</tr>
<tr>
<td># won</td>
<td>11 (46%)</td>
</tr>
<tr>
<td># BV tenders in consortium for construction projects</td>
<td>13</td>
</tr>
<tr>
<td># won</td>
<td>2 (15%)</td>
</tr>
<tr>
<td># BV interview training key personnel</td>
<td>50+</td>
</tr>
<tr>
<td># BV procurement educations</td>
<td>20+</td>
</tr>
<tr>
<td>Performance Criteria</td>
<td>BV Support</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td># of Tenders</td>
<td>14</td>
</tr>
<tr>
<td>Tenders Won</td>
<td>7 (43%)</td>
</tr>
<tr>
<td>Scored 1st or 2nd in PC Submittals</td>
<td>13 (93%)</td>
</tr>
<tr>
<td>Risk Assessment Score</td>
<td>5.8</td>
</tr>
<tr>
<td>Value Added Score</td>
<td>6.2</td>
</tr>
<tr>
<td>Level of Expertise</td>
<td>7</td>
</tr>
<tr>
<td>Interview</td>
<td>7.4</td>
</tr>
</tbody>
</table>


**Table 3: Individuals Performance Metrics on Procure Company Projects**

<table>
<thead>
<tr>
<th>Project</th>
<th>Budget (M euro)</th>
<th>Contract value (M euro)</th>
<th>Progress</th>
<th>Time deviation</th>
<th>Cost deviation</th>
<th>Client Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping Station Schore</td>
<td>2.6</td>
<td>2.4</td>
<td>60%</td>
<td>0%</td>
<td>0.4%</td>
<td>8.4</td>
</tr>
<tr>
<td>Pumping Station Schilthuis</td>
<td>0.69</td>
<td>0.68</td>
<td>95%</td>
<td>2%</td>
<td>0%</td>
<td>7.3</td>
</tr>
<tr>
<td>Ankie van Beek Ohrlaan</td>
<td>0.56</td>
<td>0.54</td>
<td>30%</td>
<td>0%</td>
<td>0%</td>
<td>7.7</td>
</tr>
<tr>
<td>Gemaal Essenburgsingel</td>
<td>1.95</td>
<td>1.94</td>
<td>35%</td>
<td>0%</td>
<td>0%</td>
<td>8.1</td>
</tr>
<tr>
<td>Sewage System Triangel</td>
<td>1.2</td>
<td>0.74</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>7.00</strong></td>
<td><strong>6.30</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


**5. Conclusion**

The professional engineering organization in the Netherlands has been proliferating the Best Value approach and the Information Measurement Theory (IMT) concepts. They have been successful in moving the technology into Norway and Poland. PBSRG has identified and is mentoring the second largest engineering firm in the Netherlands, RHDHV into increasing its BV capability and utilizing metrics to minimize the decision making in their organization.

The following have been successfully achieved in this case study research which uses mixed methods to verify the changes. The results include:

1. Selected Royal Haskoning DHV as the large engineering service.
2. RHDHV selected a core team.
3. Core team educated their organization and used metrics to show their activity.
4. Core team refined their metrics to show their organization that the core team should be utilized to increase their competitiveness on potential projects.
5. Identified a BV expert to run BV projects. The BV projects were extremely successful.

The RHDHV organization has BV capability. They will become more competitive and successful as they continue to change their paradigm. Their case study shows that a large organization whose traditional paradigm do not match the BV approach, have the capability to transform itself into the BV paradigm. Their success ensures that the Dutch BV effort will be more sustainable.

References


Experience with the Use of Building Commissioning Advisor - from Design to Operation

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Abstract

The increased focus on building energy performance has intensified the need to ensure consistency between energy requirements, design, construction processes and operation in construction projects. With the introduction of the new Danish DS 3090 standard, "The commissioning process in buildings - installations services in new buildings and major renovations" it is expected that this consistency can be ensured. Building Commissioning is a comprehensive quality-assurance process that can be used to ensure and document that a building's systems and installations are designed, installed and tested to comply with the client's requirements. However, experience and knowledge of the impact of the commissioning process on the construction process and the building's performance in practice is still insufficient.

In order to shed light on the role of energy commissioning in construction and on how well it functions, this paper report from the design phase of a large municipal school project in Copenhagen. This project has strict requirements for the building's energy performance, as previous municipal projects have realized a large gap between the calculated energy consumption in the design phase and the actual energy consumption in operation. Hence, Copenhagen Property has chosen to test whether the use of a commissioning adviser can contribute to a process that ensures that operation and use of the building is already mainstreamed in the design stage of the building’s technical systems.

The method in the research project is explorative, which means that focus is on the specific use of commissioning in order to learn from the experience and translate it according to Copenhagen Property's long-term strategies, including the need to establish a new internal infrastructure between operations, planning and construction. Drawing on ethnographic methods and theories, this paper will analyse and discuss what the use of a commissioning adviser in the design stage means for the interaction between design and operation. It may seem that "technical solutions" are made before “ongoing learning processes” in which new themes are articulated and understood across the different knowledge boundaries. Since there is a tendency for "technical solutions" to remain after a project, it seems that a solution strategy to develop standards and new consulting services could lead to increased fragmentation of construction projects.

Keywords: Commissioning, construction project, property management, design phase
1. Introduction

There has been increased focus on commissioning in Denmark in the wake of the increased complexity of the buildings' technical systems. At the same time, more advisers have started offering commissioning as a consultancy service to their clients. In 2013 the Industry Initiative Value-Added Construction-process published instructions on the commissioning process, and in 2014 the new Danish standard, DS 3090, “The commissioning process in buildings - installations services in new buildings and major renovations” was published. In the standard, a commissioning process is described as follows:

“The commissioning process for a building is a quality-assurance process that is performed to obtain, verify and document that a building’s technical facilities, installations and systems are planned, designed, installed and tested, and that they are operated and maintained so that they meet the requirements for the total economy of the building, requirements in building regulations and other legislation as well as the client's clearly defined requirements.” (DS 3090, 2014).

Therefore, there are many expectations to what commissioning can add to the construction sector. Furthermore, there is ongoing debate as to whether commissioning should be introduced as a legal requirement for large buildings.

From the client side, several large property managers have started to develop ways to make performance requirements for building projects. However, R. O. Agustsson and P.A. Jensen indicate that even if commissioning is gaining momentum in Denmark, there is still a long way to go before it is common practice in construction. They also point out that high performance is not guaranteed throughout the life of a building, even if it is high in the beginning of the operating period. To maintain high performance, it is also necessary that the staff is able to operate and maintain the building systems.

Knowledge transfer between construction projects and operations departments is not a new area, either in practice or in research. However the new focus is on buildings' technical systems. In connection with the integration of facility management (FM) knowledge in the design process, Per Anker Jensen argues that the challenge of integrating FM in the design process is the transfer of knowledge. He points to four mechanisms that are in play in the transfer of knowledge:

- “Codification of knowledge from building operation, which can increase the awareness among designers."
- “Competences among facilities managers, which can increase the awareness among designers."
- “Power to ensure that designers take considerations for building operation seriously by using the competences of facilities managers."
- “Power to ensure that codified knowledge from building operation is used by the design team.” (Jensen, P.A.; 2009 p. 131-132).
P.A. Jensen points out that there are several ways to integrate operations considerations into the design phase, including direct involvement of FM managers, the use of specialist consultants and/or specialists from FM providers. He argues that continuous involvement of FM in a building project is best placed in the FM function which will subsequently be responsible for the building, as they need to know the building and can influence building design on the basis of their knowledge of the client organization and end-users (Jensen, P.A. 2009).

**Coordination of knowledge in heterogeneous networks in emerging areas in construction**

In construction projects, there is a need to coordinate knowledge across many different professions. Commissioning is presented as a quality-assurance system that can help to ensure that the building's engineering and installations work in operation, after the building has been handed over, but what is commissioning?

Integration of information across different professions, professional groups and users in relation to new priorities is thus not only about how data and information flow between the various actors. It is also about the various actors’ opportunities to use the information locally in a meaningful way, i.e. as a basis for architects and engineers in the design process and as a basis for operations departments to formulate their requirements for operation in construction projects. In Denmark, new priorities in construction, in this case an initiative concerning the energy performance of buildings, are often followed up by new standards, which include new types of consultant services and coordination-tools. Drawing on ethnographic methods and theories, this paper will analyse and discuss what the use of a commissioning adviser in the design stage means for the interaction between design and operation. The theory of boundary objects in particular is used to analyse the ways in which commissioning supports the need for knowledge sharing across the construction project and the operations department. This approach has been chosen to enhance the analysis of information integration as a knowledge-sharing process across knowledge boundaries. The different objects are characterized according to the typology of Star and Griesemer (1989) and Star (1999, 2010). Each of these boundary objects has different structures that allow them to coordinate knowledge sharing in different ways across communities. Star and Griesemer (1989) have developed four different types of boundary objects from their empirical analysis. They are:

Repositories: “These are ordered piles of objects which are indexed in a standardized fashion” (Star and Griesmer, 1998 p 410). (e.g. a library or museum). Individual can use or borrow from the pile for their own purpose. They do not need to negotiate difference in purpose.

Ideal types: “This is an object such as a diagram, atlas or other description which in fact does not accurately describe the details of any one locality or thing. It is abstracted from all domains, and may be fairly vague. However it is adaptable to a local site precisely because it is fairly vague” (Star and Griesmer, 1998 p 410).
Coincident boundaries: “These are common objects which have the same boundaries but different internal contents” (Star and Griesmer, 1998 p 410), (e.g. a map). “Work in different sites and with different perspectives can be conducted autonomously, while cooperating parties share a common referent” (Star and Griesmer, 1998 p 411)

Standardized forms: “These are boundary object devised as methods of common communication across dispersed work groups” (Star and Griesmer, 1998 p. 411). “The advantages of such objects are that local uncertainties are deleted” (Star and Griesmer, 1998 p 411).

The key objects that are described in the commissioning standard are: Cx meetings, Cx log, and Cx scrutiny. In the case study, the different elements are described with regard to whether they act as boundary objects across the communities. In the case described in this paper, the essential knowledge boundaries that the objects operate in are defined as being between client, energy consultant, operation-team, and Cx adviser. Since the focus is on the design-phase technology, suppliers and contractors are not currently involved. Each community is described with respect to how knowledge is localized, embedded and invested (Carlile, 2002). The way the different communities at micro level use the different objects depends on how the various objects are able to transfer, translate or transform information across the knowledge boundaries, as well as the various communities’ ability to use the information in a meaningful way locally. Carlile (2002) has found that knowledge needs to be transformed between knowledge boundaries in connection with product development. It is not enough to transfer or translate information across knowledge boundaries. In this case, it is not a product-development process, but establishment of a new infrastructure across different knowledge boundaries to handle new requirements, and therefore it can be perceived as a parallel to a product-development process. The analysis highlights how the communities relate to the different objects and the importance of the information integration.

2. Research setting and methods

2.1 Setting

The case is from the design phase of a large municipal school project in Copenhagen. The aim of the project was two-fold: to build a new school that meets the requirements for building energy performance, both in the project phase (designed / intended) and operational phase (the actual use), and to test commissioning as a method to obtain the objective. The central actors in the construction project in question were the City of Copenhagen, a Danish architectural firm, a Danish energy engineering company, and an engineering company functioning as client adviser on the project, including the commissioning adviser function. The original purpose was to examine the possibilities for commissioning in the construction industry. Since only a limited number of studies with this focus have been reported, an inductive, qualitative approach based on an in-depth analysis of the case was chosen.

Two social factors played a significant role in the project's genesis. In 2006, the Danish Building Regulations (BR06) introduced a new requirement for the energy performance of buildings based on energy frames, which represents a shift from descriptive regulation to
performance-based regulation. The use of energy frames as the main requirements of new construction was a result of the EU Directive on Energy Performance of Buildings. With the shift from descriptive to performance-based regulation of energy requirements for buildings, the need arose for new energy solutions in the construction industry. This increased focus on, and requirements for, the energy performance of buildings challenged both traditional project-organized companies and large operating departments. The need for information integration across construction projects and large operating departments in order to handle these challenges is not only about sharing new types of information across actors. It is also about developing new relationships between practices of information integration within a project setting and an operations department setting, respectively. Vertically within the project, there is a need to develop and articulate the client’s technical requirements so that the technical requirements can be input to the design team in the design-process. This is a knowledge-sharing process across architects, engineers and operation teams in construction projects. Longitudinally across portfolios of buildings in major operating departments, there is a need to integrate operational experience with technical systems as a platform for articulating technical requirements for new buildings and to qualify operational departments for performance-based operation.

In 2014, the new Danish Commissioning standard was released and introduced as a way to handle information integration across the construction project and the client. This raises the question of the impact of the standard on the knowledge transfer between the construction project and the operational department.

In connection with the construction of schools in The City of Copenhagen, three units are relevant:

1. Children and Youth Administration, which handles the ordering function of the school and is responsible for user involvement.
2. Construction Copenhagen is the client organization of Copenhagen Municipality and is responsible for carrying out construction of the school.
3. Copenhagen Property, which manages and services the properties owned by the City of Copenhagen and is subsequently responsible for operation of the school.

Copenhagen wants to be CO2-neutral in 2025, which places special demands on the energy performance of municipal buildings. Much experience indicates that today there is often a gap between the designed - and hence projected energy consumption - and the actual energy consumption of buildings, which means that it can be difficult to achieve the desired CO2 reductions. To meet these challenges, in the recent years Copenhagen Property has among other things:

- Reorganized and strengthened the energy operational organization
- Initiated the From Build to Operation (BtD) project to support the interplay between Copenhagen Construction and Copenhagen Property with special focus on early involvement of operational experience and requirements in the design phase of
construction projects. At the beginning of the school project, Copenhagen Construction was part of Copenhagen Property, but was later demerged as a separate unit.

- Increased focus on data and data systems, including facility management systems

In connection with the construction of the new school, the municipality has entered into a contract with a commissioning adviser (Cx adviser). In this connection it is Copenhagen Property’s intention to put a clear focus on the energy consumption of the new building and its optimum operating options. The Cx adviser has to coordinate incoming client data regarding requirements for technical facilities and follow-up on meeting these. The contract refers to the standard "commissioning process for buildings - installations in new construction and major renovations", but the consultant services have been adapted to the needs of Copenhagen Property. This means that it is intended that the roles of the Cx adviser is to support increased contact and dialogue between Copenhagen Property and Copenhagen Construction.

2.2 Data

With respect to the qualitative approach, data is collected through observations, qualitative interviews and building case documentation. The construction project was followed in the period 2014 - 2015, when the school was designed. The design process was divided into four phases: program, outline, project and main project. At each stage, the client adviser completed a review of the project documents. The commissioning-function was handled by the client adviser and therefore scrutiny in connection with the commissioning process has been coordinated with the cross-scrutiny process. Since focus is on commissioning, Cx meetings in particular have been observed continuously throughout the design period. In addition, special working meetings occasioned by the commissioning process have been followed. In connection with the observations, it was noted, 1) which actors use the various potential boundary objects and what they use the objects for, and 2) the themes brought up at the meetings and the decisions that were taken. In addition, all documents and minutes of meetings were collected. In the study, the research team had access to the project web, meaning that all documents from the project have been available, including basis, prepared project proposals and all examination reports.

Qualitative interviews were conducted with the client, the Cx adviser, the architect, the energy consultant responsible for the design of all the technical facilities, the operation coordinator and the operation officer working with energy systems, and finally an employee from the department that ordered the school. All interviews were of one-hour duration. The interviews were conducted as a semi-structured interviews, in which the central themes were: local work-tasks, local work-processes, the use of methods, theories and tools in the work-processes, success parameters for a well done job and perception of the commissioning-process’ contribution with respect to the improvement of information integration between the various actors. All interviews were transcribed.
3. Tentative findings

In the following the four central communities are described with respect to how knowledge is localized, embedded and invested (Carlile, 2002) and the impact of the standard on the knowledge transfer between the communities.

3.1 The client

The client is an architect and has many years of experience. The client's task is to put the project organization together to solve the task that has been ordered and comply with the City of Copenhagen’s policies. In this case, the Children and Youth Administration ordered the school and the Culture and Sport Administration ordered the sports hall. They are responsible for formulating visions and making functional requirements for the project. Historically, both administrations have developed general functional requirements which may form the basis for the preparation of a building program. There had never been a tradition of involvement of the operational users of a building from so early in the building program. In this sense this commission initiative is new. The client's task is to get the services performed in the construction sector’s contract system, which includes preparation and conclusion of contracts with architects, engineers, specialist consultants, contractors and client advisers – all those who need to help to carry out a construction project. Furthermore, it is the clients’ task to follow up on all agreements that are made, and in this way the client has process responsibility. Process responsibility is about running the process so that the ordering body and all the various construction companies deliver on time, so that the process does not become blocked through the various phases. The key person within the client organization (Copenhagen Construction) the client work together with is a lawyer with respect to the tender documents and contracts and the manager of the department. In addition, the client adviser is the client's main sparring partner. The client perceives the Cx adviser as the Copenhagen Property client adviser. The technical staff in Copenhagen Property has previously had the problem that they have primarily performed emergency operations and have had no time for planning and maintenance. By supporting participation of the technical staff in the construction project with a Cx adviser, the client has experienced that the operational department has become a better project participant, in the sense that the Cx adviser has helped the department to qualify their input for the design process. The regular Cx meetings and the ongoing scrutiny make it possible for the client to take decisions on technical aspects. In previous projects, the client had to spend time searching for the relevant staff in the operating department. The client thinks the Cx log as the Cx advisers’ documentation that he has done his work. The client experienced that the commissioning process adds operational experience to the construction project important and challenges the design team on their solutions. Scrutiny processes mean that the client has a denser net to assess the project documentation at each phase, which means that the client can comment on the project documentation, where in the past the client often simply accepted the project documents. The client is very careful to keep the various actors in their roles, and experiences that it can be difficult from time to time to keep the Cx adviser and the team behind him in his role. There can be a tendency for technical staff to come with proposals that are not appropriate since the client
thereby risks that the design team can disclaim responsibility by referring to the Cx adviser, who represents the client.

### 3.2 The operational department

Two years ago, a task force group was set up with four members from Copenhagen Property and Copenhagen Construction, respectively, to develop a concept for participation by Copenhagen Property in construction projects. The group has partly developed an operational log in which they have gathered experience from operations; partly as a process structure for participation in the construction project. The operation of the municipal property is shared between a local operation, with staff from the local users of the property, and a central operation, with Copenhagen Property’s own technicians. The structure of the process is that the operation staff should be involved in the conceptual design, project proposal and just before delivery to prepare the operating personnel to take over the building. The aim is that the users (end-users, local operations staff and Copenhagen Property’s own technical staff) should be able to use the building appropriately and take ownership of it. There have been major problems in deliveries of the new buildings where the users have not been able to figure out how to use and operate the building, which costs a lot of time and money for Copenhagen Property. Therefore, Copenhagen Property has experienced a need to be involved in construction projects as a way to clarify expectations as to: the type of building the users want, how technically complex it must be and the type of skills required by the local operational staff.

The task force group follows a number of projects and holds meetings every 14 days. They arrange workshops for colleagues and are continuing their work on the operational log and the process concept. The coordinator's task is to involve the right people from Copenhagen Property at the right time in the construction process in relation to reviewing project documents, including ensuring that they receive information and submit comments for scrutiny on time. The Cx process in this project is an extended process in relation to BtD. In this process, the coordinator has involved technical staff from four different areas: the emergency operation, ventilation, electrical installations and energy management. There is only one engineer with experience within control systems in Copenhagen Property, so he is often busy. He has been involved in the Cx process but has largely left his work to the Cx adviser. In this project, the operational log was split into a Cx log and an operational log. For the coordinator and the technical staff, this meant that they left responsibility for issues in the Cx log to the Cx adviser. Conversely, they used many resources to attend more meetings than usual. The Cx adviser was perceived as the consultant. The coordinator experienced that the Cx adviser was active himself, which she prefers. In other situations, she has experienced Cx advisers expecting that themselves (Copenhagen Property) have to know what different solutions mean and what they should choose. In these situations, the coordinator will retain the Cx adviser in the role as the expert who is to help them. The coordinator assesses that in this project the operational staff have had good opportunities to influence the design process, but this is not necessarily because of the Cx process. The energy consultant company, who are responsible for the technical design convened four workshops concerning plumbing, building automation, lighting and electricity, and fire from the beginning, but this was not part of the Cx process. Already in the making of the construction program, there was much openness on operational requirements and
experience. The coordinator perceives the process as a situation in which there is knowledge from each side of a date. In the process, both sides become aware of problems and challenges with design and use of technical systems, for example, she assesses that the Cx meetings strengthen this process and it is constructive that the Cx adviser manages the meetings and gathers the threads. A second version of the operating log has been made based on all projects in which it is used. The adjustment is about reformulating the requirements so they can be better understood by consultants; reformulating simplifications so there are no contradictions; taking out requirements because they are covered by legislation; and adding new conditions. It is a dynamic tool which evolved from being a communication tool into a technical program basis. Entering construction projects involves a responsibility. From sitting outside and criticizing to the active participation and being responsible for the choices made is an issue for the technical staff. At the same time they mentioned that they have had a better understanding of the construction project, the choices taken and the priorities. This also means that the requirements for the operation must be substantiated and not just based on personal opinion. The operational log was therefore sent around to the technical specialists in-house in Copenhagen Property to ensure that the foundation was as it should be. This process has been a learning process and taken time. The function of the log today is to ensure that Copenhagen Property is heard in construction projects.

3.3 The energy consultant

The energy consultant company, which is responsible for the design of the technical system, is a medium sized company. The company is part of the team set up by the main consultant for the design process. The energy consultant distinguishes between integrated energy design, traditional design and follow-up, including the commissioning of the various phases of a construction project. Integrated energy design is about having a dialogue with the architect right from the start of the design process as a way to integrate energy considerations in the design of the building. In this project they used integrated energy design from the start. The energy consultant perceives the strong focus on operation and maintenance early on in the building program as in this construction project as an unusual but important aspect. In this way the operational employee can be seen as a new user. When technicians design the technical systems they use different calculation methods, simulation tools, standards and regulatory basis. The main success criteria for their work are to deliver projects that clients are subsequently satisfied with. It can often be difficult for clients to communicate what it is they want, also because they are often not close to the users. It is best when clients are fully aware of their ambitions for the new buildings. From the consultant's perspective, he believes that the client will have to pay too much for commissioning as it is organized in this project. He is baffled as to why the consultants who designed the systems are not brought in to ensure the operations and the handover to the operational staff, as it is these who know the system best. Now a Cx adviser is paid to follow the entire project. At the same time the Cx adviser has no responsibility for the design. The energy consultant believes that the problem is that the Cx adviser gathers and coordinates a lot of information for the various users to use, but he does so without responsibility. The energy consultant and his team therefore need to check all information, since they are responsible. The consultant points out that the Cx adviser does not do something he
should not do in advance. The energy consultant has the perception of the Cx adviser as the client's adviser, including the role that the Cx adviser must gather information from operations and coordinate their contributions. The energy consultant experiences that it is a clear benefit to the process if a Cx adviser arranges to obtain and systematize operating experience and creates forum (Cx meetings) in which a dedicated group of people meet and discuss operation, maintenance and user-oriented features of the building. The commissioning process has meant solutions that users could relate to have been presented early on in the different phases and this has given rise to a number of considerations together with the users early in the project. The process has pushed the focus on user needs and experience to operate the building to earlier in the design process. The consultant's experience with scrutiny is that it has worked well with the various users, but it has given rise to problems with the client-adviser team, i.e. third parties. The user base is the finished building and the issues related to the operation. Third parties, who are also technicians, however, asked about issues that seemed as if they were on a wrong level of detail in relation to the level of the individual phases. The energy consultant assesses that the level of detail for the various design phases is a gray area, and that he experienced problems with both the language and level. The energy consultant perceives the operational log as a collection of everything from small to large. He does not consider the users’ requirements in the operational log and in the review as mandatory requirements, but more as a matter of dialogue and clarification from both sides. In contrast to this, the scrutiny comments made by other engineers (third parties) have the style that they think things should be done differently. For the energy consultant, the interaction with the operating team in particular has been good and this counteraction would be beneficial each time in a design process. Scrutiny comments have also had the function that the energy consultants have been able to lean on them and thereby strengthen their own arguments against the architect in the design process. For example it was often pointed out that the technical rooms were too small, and this became the final argument for the architect, who conversely had trouble getting the area consumption to meet the objectives for the building.

### 3.4 Cx adviser

The Cx adviser comes from a large consulting firm. He has many years of experience in the engineering field. He works with both technical design and commissioning, and he believes it is necessary to design in order to make commissioning lead to constant updates based on the latest standards, techniques and experiences. Furthermore, commissioning means that you know the conditions for a design process, for example the conflict between the architects’ prioritization of design and the engineers’ need for room for technology and pipes. The Cx adviser perceives that the key success factors of his work are that the building works from the first day and how the building can be serviced has already been thought about. He sees the commissioning process as a task on how to use the various standard templates to achieve a good result, and in this process the Cx adviser is very dependent on the input from the operation. The Cx adviser feels that it is an advantage that there are many users from operating activities, as it gives them the opportunity to understand all the choices that need to be taken in connection with a construction project. Copenhagen Property and Children and Youth Administration are also challenged in terms of the interface they have built around their two-part operation. The two-part operation
has meant that certain concepts for solutions have been established that are not necessarily optimum from the standpoint of energy. Therefore, it is beneficial to have both parties in the commissioning process. He believes it is necessary to separate the operational log and the Cx log as many things in operational log are outside the scope of the technical systems that are the commissioning task.

4. Discussion

After several years of increased demands on buildings’ energy performance in Denmark, the experience is that there appears to be a large gap between the designed and expected energy consumption in the design phase and the actual energy consumption during operation. This has centred focus on the need for information integration across construction projects and large operating departments. In Denmark, commissioning is one of the upcoming methods for handling this problem. Commissioning is a quality assurance system that is designed as a project delivery. However this analysis shows that the transition towards design and operation of buildings with high energy performance is not only about the creation of information integration across the design phase and use phase based on existing knowledge, which can be ensured through a quality assurance system on each project. Rather, there is a need of development and adaptation of practices of the involved communities based on a mutual learning process. This raises the need of evaluating critically which potential boundary objects that may function as information integration structures in construction projects and support communication and coordination across design and operation of buildings.

The experiences from the case shows that the different commissioning objects are not stabilized as boundaries objects that coordinate work processes across the various actors. The tendencies are that the different objects structures information integration in different ways and new dilemmas emerge in the interaction between the various actors. The findings illustrate that (i) all communities benefit from the Cx meetings, where information is transferred, translated and transformed across the different communities. The meeting structure has contributed to the operational department have had a better understanding of the construction project, the choices taken and the priorities, which in turn may have contributed to a generalisation of the operational log. At the same time the increased possibility of knowledge creating across the boundaries, may shape new priorities in the design work in favour of operational conditions. (ii) The Cx-log is not established from the beginning with articulated client requirements for the technical system, but is built up through the design process as a common checklist. This point to the fact that client requirements for the technical system it is not common knowledge that already exist. From the perspective of the energy consultant, priority of operational conditions and visibility of the "new user" can qualify the client's requirements for the building. This makes it easier to deliver a building that lives up to expectations. However the technical system is separated from other operational condition, which may increase the risk of a low priority of other operational condition. The new version of the operational log as earlier mentioned may have the potentials to be a new boundary object in future projects to increase collaboration across actors on the building's energy performance. (iii) The Cx scrutiny is a standardized scheme in which all the different communities have the opportunity to comment on the project.
documentation in the different phases. The results show that where the users and the operations department commented on the different solutions and had clarifying questions, the client adviser’s technical staff suggested new technical solutions. In this way, the two columns of the scrutiny table act as two competing engineering paradigms rather than qualification of the design team’s proposal. From the client’s perspective, increased process documentation may increase the client’s possibility for controlling the project material. However use of scrutiny may also take time from the design process as it takes time to fill in answers in the table. In addition competing engineering paradigms may keep both design methods and solutions in traditional design mode. In worst case it may take focus from adaptation and development of new design methods and solutions based on experiences from operation of buildings.

The experience from this case suggests that instead of maintaining the technical solutions in the form of standard methods and new consulting services, which follows as a natural extension of a project focus, it may be more appropriate to consider the various ways this process can be organized. Aspects of commissioning can contribute to this, but this solution should be challenged on the relevance of each element and where the function should be placed.

1. When placed with a third party, this function can increase the control aspect of the client, but will conversely be a costly solution. At the same time, it can give rise to competing engineering paradigms, which can detract focus from the new user and inhibit development of new design methods based on new perspectives.

2. When placed with the consulting engineers, this function can support the development of new design methods and be a natural development of their design delivery. Costs can be reduced, since there will not be two engineering consulting companies that have to know the technical system in detail, but conversely control aspects will be reduced.

3. When placed with the operational department, this function can strengthen their capacity on this area and support their organisational development, but it may require specialist knowledge that can be difficult to maintain in operation organisations.

5. Conclusions

In the context of new priorities in construction, there will always be a need for new forms of information integration between new actors. It may seem that "technical solutions" are made before “ongoing learning processes” in which new themes are articulated and understood across the different knowledge boundaries. Since there is a tendency for "technical solutions" to remain after a project, it seems that a solution strategy with development of standards and new consulting services could lead to increased fragmentation of construction projects. In addition the case illustrate that the commission process influence not only knowledge sharing across different communities but also the distribution of roles, responsibilities and control. Based on these results it will be useful to know more about, the socio-technical aspects of the development of new forms of information integration in construction projects in the context of new priorities in construction.
References


Text Analytics on Construction Tender Documents for Project-Oriented Risk Mining

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Abstract

Construction tender documents contain owner’s project requirements so that a contractor can make project plan. However, tender documents might not always be clear and adequate. Furthermore, since there are many potential project risks behind the documents, close analysis on tender documents should be implemented. This paper discusses a project-oriented risk mining approach which could detect and extract project specific risk factors based on text analytics. From the risk mining process composed of text mining step, risk classification step and risk assessment step, project specific risk factors could be effectively managed initially. Furthermore, the project-oriented risk mining approach is expected to effectively reflect project characteristics to the project risk management and could provide contractors valuable business intelligence.

Keywords: Tender document, Risk management, Project-oriented management, Text mining

1. Introduction

Contractors can understand owner’s design intent and requirements from the tender documents. However, the tender documents might not always be clear and adequate. Brook (2004) indicated that major problems associated with quality of information in drawings, specifications and bills of quantities include missing information, late information, wrong information, insufficient detail, impracticable designs, inappropriate information, unclear information, provisional information, poorly arranged information, uncoordinated information and conflicting information (Laryea 2011).

Besides, as construction projects are getting bigger and more complex, especially in international projects, close analysis on tender documents is very required. Although the tender documents are crucial for understanding project characteristics, tender document analysis is not sufficiently conducted in many projects. According to one of the major contractor’s internal survey, most of cost overrun factors in international projects are related to construction tender documents, such as poor review on ITB (Instruction To Bidders), design errors and omissions, and discrepancies among tender documents. This shows tender document study should be managed from a risk management aspect since many potential project risks are existed behind the documents.
There are many concerns regarding risk management skill as many contractors suffer major losses in international projects. In the view of risk management’s life cycle, the effect of risk management in the early stage is greater than the late risk management while available information is poor at a beginning step. Because tender documents are the only information available at the project initial phase, document-based risk analysis should be conducted. Moreover, unclear and wrong information in the tender documents should be clarified in order for maximizing initial risk management effects.

Even though the importance of early risk assessment and management have been emphasized, however, current risk management practice at the project beginning step does not fully deal with project risks. Majority of typical risk management studies focus project’s external and unexpected risks on such as political risks and financial risks. Those external risks are hard to manage and prevent, risk management should be concentrated on project inherent risks.

In the real construction world, there are many situations where the quantitative and detailed information to evaluate uncertainty is not available. These conceptual factors can be expressed in qualitative or linguistic terms, that is, so called fuzzy information (Kangari, R. and Riggs, L. S. 1989). This explains those linguistic risk terms should be managed in order to assess project’s potential risk factors. Therefore, this study suggests a project-oriented (internal) risk-mining framework which can detect and extract project-specific linguistic risk factors based on text analytics for tender documents.

2. Background

2.1 Overview of current research

Extensive research has been done in risk evaluation and risk management at the project beginning step. Zhi, H. (1995) developed a method of managing various risks for overseas construction projects and how to effectively identify the vital risks in overseas projects. Gunhan and Arditii (2005) evaluated risk factors affecting international construction projects by surveying the executives in charge of international construction of large U.S based contractors. Sonmez et al. (2007) presented a quantitative methodology to determine financial impacts of the risk factors during the bidding stages of international construction projects. Lin and Chen (2004) suggested bid/no-bid decision making by using a fuzzy linguistic approach. In that approach assessments were described subjectively in linguistic terms, while screening criteria were weighted by their corresponding importance using fuzzy values.

However, almost the whole risk evaluation and risk management studies are weighted toward high level of risks, such as political risks and financial risks, not project-oriented (low-level) risks. Moreover, most existing risk assessment systems are based on quantitative techniques which require numerical data. However, much of the information related to risk analysis is not numerical. Rather, this information is expressed as words or sentences in a natural language (Kangari and Riggs 1989). Besides, many researches relies on survey-based statistical analysis which could be easy to have biased personal opinion and experience. That are the reasons current
risk evaluation and risk management studies does not fully deal with each project’s characteristic. Therefore, this study approaches from the bottom of the project risks, which is document-based analysis and project-oriented (internal) risk analysis.

2.2 Research Objective and Research Question

Risk management is typically carried out during a whole project life cycle. If risk evaluation is not sufficiently performed and project risks are not fully detected at the project beginning step, however, potential project risks could be presented during the project. In other words, successful project performance cannot be guaranteed without pre-emptive risk management in the project early stage.

Based on this premise, this study suggests a framework which gives a concept of project-oriented (internal) risk mining in order for preventing and minimizing of great losses caused by poor risk evaluation at the project initial phase (tendering process). To extract project-oriented risks, this study concentrates on project tender documents which includes many project potential risks. However, close analysis on huge amounts of tender documents is always a challenging task since the tendering period is not enough. Furthermore, tender documents might not always be clear, consistent and adequate. Thus, text mining concept is adopted in this study in order to analyse large amounts of tender documents and extract related risk factors. The project-oriented risk mining process is expected to be used as bid decision making materials so that contractors can judge whether the project is profitable or not in advance.

From the previous literature review, not only project external risk (high-level risk) factors but also project-oriented risk (low-level risk) factors should be managed in the early stage of construction project. Because project tender documents contains many information about project characteristics, this study should start with analysis on tender documents. The concept of this study has been named as “Project-oriented Risk Mining”. In order to proceed the study the following questions should be addressed in advance:

- What type of risks should/could be solved?
- What kinds of project-oriented (internal) risks are existed in tender documents?
- How to identify project-oriented (internal) risks?
- How to extract/mine text-based risk factors?

What are the proper evaluation method for various types of risks?
3. Research Framework

3.1 Project-Oriented Risk

Project-oriented risk could be defined as project-specific risk factors which exist project inside. Project-oriented risk is related to the quality of tender documents’ information in drawings, specifications and bills of quantities included missing information, wrong information, insufficient detail and impracticable design, etc. Poor quality tender documents can lead to inaccurate estimates, higher margin in bids, claims and disputes (Laryea 2011).

From a review on previously performed project documents, we could derive some risk types associated with tender documents as follows:

- Problems caused by specific clauses or terms written in tender document
- Problems caused by omitted information in tender document
- Problems caused by discrepancies between information
- Problems caused by wrong information in tender document

Those types of risks related to the tender documents could be identified as project-oriented risks, and those risk factors should be detected at the tendering process for successful project.
3.2 Text Analytics for Tender Document

Tendering is one of the stages in a construction project that requires extensive information and documents exchange. Such tender documents often contain the information about a client’s project plans so that a contractor can price it (Laryea 2011).

Tender documents may include (Designing Buildings Wiki 2015):

- A letter of invitation to tender
- The form of tender
- Preliminaries: including pre-construction information and site waste management plan
- The form of contract, contract conditions and amendments. This might include a model enabling amendment for building information modelling (BIM), making a BIM protocol a contractual document
- A tender pricing document (or contract sum analysis on design and build projects)
- Employer’s information requirements for BIM
- Design drawings, and perhaps an existing building information model
- Specifications

Since tender documents are contractual documents, the information written in tender documents have legal force. If a contractor misses some wrong information or omitted information in tender documents during tendering process and decides to proceed the project, the contractor should take the risks which could be arise due to the wrong or omitted information. To prevent and take preemptive action on the project risks hidden in tender documents, tender documents analysis should be managed from a risk management aspect.

Because construction tender documents are written in text which is unstructured data, various type of data analytics, such as text analytics, are required. Text analytics helps analysts extract meanings, patterns, and structure hidden in unstructured textual data. The term “text analytics” has evolved to encompass a loosely integrated framework by borrowing techniques from data mining, machine learning, natural language processing (NLP), information retrieval (IR), and knowledge management (Chakraborty G. et al. 2013). Text analytics is useful method to analyse great amounts of documents with short tendering period. Text analytics enables to have term frequency and related terms in documents so that potential risk factors existed in tender documents could be detected.
3.3 Text Analytics for Tender Document

This study defined the concept of risk mining as a progressive methodology which detect unstructured textual data, and categorize risk types, and assess them. Figure 1 shows the project-oriented risk mining framework. This framework is divided into two parts, which is risk identification step and risk mining step.

![Figure 1 Project-oriented risk mining framework](image)

‘Risk Identification’ step is based on two types of literature review, previously performed project’s tender document analysis and construction claim/dispute case analysis. From the previous project cases which experienced losses because of a poor analysis on tender documents, we could understand what issues written on tender documents influenced the project’s success and fail. Those issues might be the type of project-oriented risk factors. Another way to draw project-oriented risks is investigation into construction claims and disputes related to the tender document problems. Since claims and disputes are caused by project various risks, we could figure out project-oriented risk factors from claims and disputes cases. Those risk factors derived from the literature reviews could be collected in order to define risk vocabulary dictionary. The risk vocabulary dictionary could be used at the ‘Risk Mining’ step during imported project tender document’s risk assessment.

In the ‘Risk Mining’ step, newly imported tender documents are firstly text-mined according to the risk vocabulary dictionary, and each risk terms are categorized by risk categorization step, and finally evaluated at the risk assessment step. The result of risk mining is summarized as a risk report. The risk report shows project risks and project opportunities so that risk mining results could support project bid decision making.
4. Illustrative Example

To illustrate the proposed research framework, this study performed risk identification step as an illustrative example using construction cases on adjudication. In this example, we investigated into construction adjudication cases in order to identify risk factors. Project-oriented risk factors could be figured out from the claims and disputes cases. For the purpose, 549 adjudication cases were collected from 1999–2015 in UK construction industry. Text mining for analysis of construction adjudication cases was conducted using SAS Text Miner 13.1.

Since this illustrative example was performed for extracting project-oriented risk factors from the claims and disputes cases, the adjudication cases which written in text was analysed according to the following steps. Text import, text parsing, text filtering, and text clustering. Text importing is the first step in the text mining process. Collecting and setting up textual data is performed in the text importing step, and the source data is imported into the text mining tool. The textual source data is called as ‘corpus’. Corpus is a large set of texts, and they are used to do statistical analysis and hypothesis testing (Wikipedia 2015). After the text data is imported, it is ready to be analysed.

Once the text-based documents are imported, the documents should be disconnected in order to quantify information about the terms. This step is ‘text parsing’ step which convert the collected textual documents (unstructured form) to a structured form using vector representation.

<table>
<thead>
<tr>
<th>Terms</th>
<th>Role</th>
<th>Term Frequency</th>
<th>Document Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>adjudicator</td>
<td>Noun</td>
<td>13,772</td>
<td>343</td>
</tr>
<tr>
<td>decision</td>
<td>Noun</td>
<td>10,520</td>
<td>366</td>
</tr>
<tr>
<td>clause</td>
<td>Noun</td>
<td>5,331</td>
<td>261</td>
</tr>
<tr>
<td>payment</td>
<td>Noun</td>
<td>5,394</td>
<td>327</td>
</tr>
<tr>
<td>notice</td>
<td>Noun</td>
<td>4,668</td>
<td>315</td>
</tr>
<tr>
<td>issue</td>
<td>Noun</td>
<td>4,465</td>
<td>355</td>
</tr>
<tr>
<td>pay</td>
<td>Verb</td>
<td>4,026</td>
<td>347</td>
</tr>
<tr>
<td>provide</td>
<td>Verb</td>
<td>3,794</td>
<td>352</td>
</tr>
<tr>
<td>cost</td>
<td>Noun</td>
<td>3,645</td>
<td>321</td>
</tr>
<tr>
<td>agree</td>
<td>Verb</td>
<td>3,477</td>
<td>363</td>
</tr>
</tbody>
</table>

There are two broad-based approaches to analysing text. The first is the bag-of-words method, where the basic assumption is counting words in the text, plus understanding how these words are syntactically (structurally) related to each other in regard to laws of grammar, etc. This method is sufficient to summarize and classify text documents. The second approach, which is linguistic, posits that truly understand and classify text, you have to move beyond syntax (structure) to semantics (meaning of words). In order to apply either approach, the text document is first parsed to find the words contained in it (Chakraborty G. et al. 2013).
The first step of text parsing begins with breaking down the text stream into terms. Texts in the documents are tokenized and normalized during text parsing step. Table 1 shows the result of text parsing of construction cases on adjudication. Typically, ignoring parts of speech, ignoring types of entities and attributes are additionally conducted in order to make text parsing more simple and fast.

Next step is ‘text filtering’. Text filtering eliminates extraneous information caused by the presence of noise terms and other terms, so that only the most valuable and relevant information is considered. Moreover, user-defined terms could be excluded at the text filtering process. Some general construction terms, such as ‘contractor’ and ‘construction’, etc., was added to the stop list to focus on the terms and documents that are most likely to enhance the result. Creating appropriate stop list is crucial in obtaining valid and useful results. Figure 2 shows the text filtering process using stop list.

![Figure 2 Text filtering process using stop list](image)

After text parsing and filtering is finished, ‘text clustering’ could be performed in order for grouping a set of related risk terms. Text clustering is the task or grouping a set of text words that words in the same cluster are more similar to each other than to those in other clusters. Text clustering enables to define, discover, and modify sets of topics contained in the documents. In order for text clustering two algorithms are available. The expectation maximization algorithm clusters documents with a flat representation, and the hierarchical clustering algorithm groups clusters into a tree hierarchy. Both approaches rely on the singular value decomposition (SVD) to transform the original weighted, term-document frequency matrix into a dense but low dimensional representation (SAS 2014).

Table 2 is the text clustering result of construction adjudication cases. Each word included individual cluster represents each clustered documents. However, the clustered words do not give detail information about cluster’s distinction. Even if the word groups were made by some
clustering algorithm, it is difficult to define individual cluster’s distinction without understanding the context where the term is being used. Therefore, examining full text and related sentence where terms are being used should be performed repeatedly to define each cluster’s topic. As a result, 6 clusters were identified as follows:

Table 2 Result of text clustering

<table>
<thead>
<tr>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
<th>Cluster 4</th>
<th>Cluster 5</th>
<th>Cluster 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>damage</td>
<td>breach</td>
<td>completion</td>
<td>structure</td>
<td>change</td>
<td>cost</td>
</tr>
<tr>
<td>delay</td>
<td>design</td>
<td>plan</td>
<td>installation</td>
<td>document</td>
<td>fee</td>
</tr>
<tr>
<td>date</td>
<td>document</td>
<td>debate</td>
<td>industry</td>
<td>clear</td>
<td>solicitor</td>
</tr>
<tr>
<td>notice</td>
<td>contract</td>
<td>certificate</td>
<td>supply</td>
<td>engineer</td>
<td>pay</td>
</tr>
<tr>
<td>extension</td>
<td>evidence</td>
<td>damage</td>
<td>light</td>
<td>variation</td>
<td>evidence</td>
</tr>
<tr>
<td>provision</td>
<td>place</td>
<td>complete</td>
<td>site</td>
<td>breach</td>
<td>money</td>
</tr>
<tr>
<td>payment</td>
<td>detail</td>
<td>submission</td>
<td>house</td>
<td>comply</td>
<td>letter</td>
</tr>
<tr>
<td>claim</td>
<td>price</td>
<td>cross-claim</td>
<td>fee</td>
<td>dispute</td>
<td>instruct</td>
</tr>
<tr>
<td>challenge</td>
<td>site</td>
<td>doubt</td>
<td>contend</td>
<td>state</td>
<td>submission</td>
</tr>
</tbody>
</table>

- Cluster 1: Liquidated damage related terms
- Cluster 2: Design liability related terms
- Cluster 3: Practical completion related terms
- Cluster 4: Site establishment liability related terms
- Cluster 5: Variation related terms
- Cluster 6: Payment related terms

The result of text clustering could be used to define risk vocabulary dictionary. The risk related terms by risk type is potential risk factors, and those terms enrich the risk vocabulary dictionary. By drawing risk factors from many cases, risk vocabulary dictionary could be used at the risk mining step during imported project tender document’s risk assessment.

5. Discussions

This study discusses a project-oriented risk mining approach which could detect and extract project specific risk factors based on text analytics. Moreover, a part of risk identification step which is included in research framework was conducted as an illustrative example using construction cases on adjudications. However, the result from the adjudication cases should be linked to the result from tender document analysis which did not deal with at this illustrative example. Since all the terms derived from the adjudication cases might not directly matched to the tender documents, further study should be required to make project-oriented risk mining framework more effectively. If the study of previously performed project’s tender documents will be followed later, more practical risk factors could be derived. Using those risk factors, project-
oriented risk mining process could be more materialized with computer-aided skills in the future study.

6. Conclusions

The purpose of the study is to propose a new approach for managing text-based project-oriented risks. Since available information in the early stages is not enough and clear, identifying owner’s design intent written in tender documents is important for proceeding construction projects. However, current risk evaluation and risk management studies dose not fully deal with project risks. Thus, this study presented project-oriented risk mining approaches from the bottom of the project risks, which is document-based analysis, using text analytics techniques. Although the illustrative example was only a part of drawing project-oriented risk factors, this study is one of the meaningful attempts to investigate unstructured text data in construction field. Furthermore, the project-oriented risk mining approach is expected to effectively reflect project characteristics to the project risk management and could provide contractors valuable business intelligence.

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References


Abstract

There has been a renewal of public-private partnership (PPP) in France after 2004. Until 2013, this procedure was relatively popular to deliver integrated solutions to public authorities who were demanding for packaged product and service delivery. Street lighting projects aiming at reducing electricity consumption are dominant among PPP. These projects are a category of energy performance contracting (EPC). The question is why EPC is dominant for street lighting projects and not for buildings. A case study focusing on a street lighting project indicates that they are less complex. Uncertainty is limited and beneficiaries have no influence on the end result whereas occupants can have a strong impact on the energy consumption of a building. Moreover, formal contracts are adapted to this type of projects with limited uncertainties and relational governance can be limited.

Keywords: PPP, complexity, governance, public lighting, energy performance contracting

1. Introduction: private finance procurement in France

France has a long experience in private finance procurement. It concerns mainly infrastructure projects where an asset (such as a road) is provided for which users pay directly. The first concession arrangement was signed in 1554 for the construction and maintenance of a canal over a period of ten years (Bezançon, 2005). During the 19th century, the concession system was dominant for all public works. Contractors were systematically associated to maintenance works for six to ten years. More recently, during the sixties, concessions mainly concerned public infrastructures such as bridges, tunnels, urban facilities and roads (motorways). Under this scheme, the concessionaire is partly paid by the users of the public service conceded.

During the late eighties, some schools and prisons were delivered under a Design, Build, Operate and Finance scheme. However, the procurement method was opaque and it led to illicit agreement practices between contractors. Thus, public private partnership (PPP) for buildings was banned for about ten years and the development of the market in France was delayed. However, most large French contractors were able to benefit from the PFI experience in the UK.

At the beginning of the 21st century, there was a strong debate for the renewal of PPP in France. Architects were strongly opposed to any kind of PPP for buildings. They considered that
contractors would become relatively more powerful and that financial issues will took over architectural matters. Conversely, large contractors saw PPP as an opportunity to modify their traditional business models and to move into new kinds of value-added activities. Between 2002 and 2004, several ministries (home Affairs, Justice, Health and Defence) introduced a new legal framework for projects concerning facilities such as prisons, police stations, and healthcare facilities. Finally, in June 2004 a new law was enacted to spur partnership contracts (“Contrats de partenariat”). It was strongly influenced by the Private Finance Initiative in the UK. From June 2004 to December 2013, 194 contracts were signed representing an investment of approximately 14 billion euros (table 1).

Table 1: Economic value of Partnership contracts at the end of 2013

<table>
<thead>
<tr>
<th>Actors</th>
<th>Projects signed</th>
<th>Investment (million €)</th>
<th>Global value (million €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local authorities</td>
<td>145</td>
<td>4 119</td>
<td>10 185</td>
</tr>
<tr>
<td>State</td>
<td>49</td>
<td>10 346</td>
<td>26 436</td>
</tr>
<tr>
<td>Total</td>
<td>194</td>
<td>14 465</td>
<td>36 621</td>
</tr>
</tbody>
</table>

Source: CEF-OPPP (2014)

Knowing that public investment reaches about 90 billion euros every year, the vast majority of investments in the French public service is still procured through conventional means. Partnership contracts were mostly used for buildings at the State level, and for urban facilities, at the local level (table 2).

Table 2: Sectoral breakdown of partnership contracts signed at the end of December 2015

<table>
<thead>
<tr>
<th>Type</th>
<th>Local authorities</th>
<th>State</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>34</td>
<td>32</td>
<td>65</td>
</tr>
<tr>
<td>Sports and cultural infrastructure</td>
<td>22</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Energy / waste</td>
<td>11</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>Urban facilities</td>
<td>63</td>
<td>0</td>
<td>63</td>
</tr>
<tr>
<td>Information and communication technologies</td>
<td>13</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>Transport</td>
<td>10</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Training</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>153</td>
<td>56</td>
<td>209</td>
</tr>
</tbody>
</table>


1 After 2013, the number of deals collapsed. 9 and 6 projects were respectively signed in 2014 and 2015.
Among urban facilities, street-lighting is dominant. These contracts aim at refurbishing street lighting in order to reduce the electricity consumption of local authorities. As such, they can be associated to energy performance contracting (EPC). According to the European Parliament’s definition (2012), “energy performance contracting means a contractual arrangement between the beneficiary and the provider of an energy efficiency improvement measure, verified and monitored during the whole term of the contract, where investments (work, supply or service) in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criterion, such as financial savings”.

Partnership contracts have seldom integrated issues dealing with energy performance in buildings. Conversely, cutting energy consumption was the main target of PPP focusing on street-lighting. The aim of this paper is to understand this gap.

To launch a partnership contract, it is necessary to prove that the project is “urgent” or “complex” or brings value for money. More than 90% of PPP projects were considered as complex. Thus, the paper will examine the notion of complexity in construction and its impact on project governance. Then, a case study focusing on street lighting will be presented. The aim of the discussion will be to understand why energy performance contracting is dominant in street lighting projects and frequently omitted in building projects.

2. The impact of complexity on governance

2.1 Complexity in construction project

It is widely recognised that construction projects become progressively more complex (Baccarini, 1996). This complexity is also put forward by Hobday (1998) who introduced the notion of complex products and systems (CoPS) to characterise one-off projects. While the focus is on the production process with goods and services, the emphasis with CoPS is on design, project management, systems engineering and systems integration. Several dimensions characterise complexity: the degree of technological novelty, extent of embedded software in product, quantity of sub-systems and components, feedback loop from later to earlier stages, uncertainty/change in user requirements... As construction is moving away from its production-based focus and is developing new service activities (financing projects, operating and maintaining systems...), interfaces are multiplied, and project complexity becomes stronger. Project management does not anymore concentrate on the internal project team and external supply chains. It also integrates downstream service delivery. (Alderman et al., 2005).

This move from the building activity to the service provided by the built environment (Carassus, 2002) is accompanied by a change of procurement. Traditional design and build contracts based on input specifications are more and more replaced by service-led contracts where the output to

---

2 A new law will be enacted soon. The aim is to simplify all sector-specific legislation and to comply with the European directive on public markets. According to the first draft (July 2015), partnership contracts will only be signed if they offer value for money.
be delivered is specified. The competitive dialog procedure is particularly adapted to these situations since it helps to match the demand of the client with the possible solutions that contractors can offer (Hoezen et al., 2010). According to Lewis and Roerich (2009), it is possible to assess the complexity of the procurement process in terms of two dimensions: performance complexity and infrastructural complexity. The first refers to “a function of characteristics such as the level of knowledge embedded in the performance” (p.127). The second refers to “the complexity of the infrastructure through which performance is enacted” (p.128). According to this framework, traditional design and build contracts based on input specifications would be considered as less complex in terms of performance than service-led contracts which go further than design and build and encompass operation and maintenance.

Complexity can change over time. Wang and von Tunzelmann (2000) show that each functional area of the firm (technology, markets and products, production processes, administration and management) is in interaction with each other and that the evolution of the complexity of one function will impact other functions. Complexity will also depend on the competencies developed by public authorities. This issue is central for the European Commission (2004) who considers that a public contract is particularly complex when the contracting authorities: “(1) are not objectively able to define the technical means (...) capable of satisfying their needs or objectives, and/or (2) are not objectively able to specify the legal and/or financial make-up of a project.”

### 2.2 Complexity in EPC

Simple building constructs cannot be associated to CoPS. Conversely, EPC for buildings are complex on several dimensions:

1. **Design based on collection of information and data, and dynamic thermal modeling and simulation:** Dynamic thermal modeling and simulation is a complex activity as illustrated by the frequent gap between predicted energy performance of buildings and measured energy use once buildings are operational (de Wilde, 2014).
2. **Works such as the removal and installation of efficient heaters, measurement and monitoring equipment, insulation of buildings, cover a broad range of activities and usually involve subcontractors. Moreover, works usually concern buildings with different architectural style, different year of completion… and require the development of specific technical solutions. Works are also done in occupied buildings and they have to take into account the occupants to avoid disturbances and conflicts.**
3. **Operation and maintenance of buildings:** the performance of these activities is based on day-to-day maintenance but also on occupancy conditions. To reduce the impact of users during the operation of the building, the operator may develop actions to promote environmental awareness. The complexity is due to the necessary cooperation between two actors (the operator and the occupants) with antagonist goals.
4. **Project financing:** The financial arrangement is very complex. There are mainly two financing approaches: self-financing or third-party financing (Lee and al., 2015). In some cases, project financing is made with a mix between debt and equity. Public authorities
who are not familiar with these complex financial schemes regularly receive the support of lawyers and financial consultants.

5. Measurement and verification: they are the cornerstone of EPC since it is used to allocate risks between the ESCO and the client, to assess energy savings and reckon penalties / bonuses, to monitor equipment performance and to improve operations and maintenance (USDE, 2015). There has been effort to standardized M&V by developing protocols. Moreover, technological development in monitoring and data mining techniques have contributed to improve performance predictions and building energy management decision-making (Ahmed et al, 2011). However, this is still complex since it is difficult to get reliable building operation data before the signature of the contract and to monitor behavioural changes during the project life time.

Moreover, project complexity is influenced by the experience of the stakeholders with EPC projects. Energy Service Companies (ESCOs) which are at the core of EPC are not equally developed among countries. Bertoldi and al. (2006) classified French ESCOs in the “second European league”. Similarly, public authorities who have a great experience with delegating the management of public services are still not familiar with performance contract and performance procurement process. As indicated by Hartmann et al. (2010), public authorities need to develop capabilities to contract for service-led projects and manage the relationships with their service providers. Developing simultaneously contractual and relational capabilities is difficult since contractual documents are still the main references.

### 2.3 Governance issues

Developing a transaction cost analysis, Winch (2001) considers that low asset specificity, low transaction frequency, and high uncertainty characterise construction. According to this theoretical framework, hierarchy should be preferred to drive construction procurement because of the uncertainty surrounding the project (unknown natural conditions, temporary coalition between actors, unique features of each project). However, market governance is the most adapted to clients’ preferences since asset specificity is low (resources required are available from a large number of suppliers and contractors) and transactions are not frequent (even experienced clients do not procure many buildings every year). The move toward service-led projects modifies this framework and requires more contractual safeguards to mitigate the uncertainty (Hartmann et al., 2010). According to Bijlsma-Frankema and Costa (2005), the effectiveness of control of formal contracts depends on three elements: (1) the codification of the tasks and the behaviours, and the measurability of outcomes; (2) the monitoring of the actions performed by the parties; (3) the creation of a structure that enforce the contract.

However, formal contracts are difficult to specify for service-led projects since outcomes are frequently intangible. Moreover, service-led projects have a longer lifespan and are subject to technological changes. Specifying everything ex-ante would raise transaction costs and render the contract difficult to enforce. Indeed, it would be necessary to create a specific structure in charge of monitoring opportunistic behaviour and applying contractual clauses. This would be costly and would create additional complexity. Consequently, it is more efficient to accept incomplete
contracts, to introduce some contractual flexibility and to rely on relational governance and trust between partners to avoid conflicts. “Relational governance refers to those inter-organizational exchange mechanisms that are not sanctioned through formal contractual positions (...) but are manifest in custom and practice” (Roehrich and Lewis, 2010, 1157). Relational governance has its own enforcement mechanisms such as threat of social sanctioning and reputation effects. Formal contracts and trust are complementary. The negotiation process that leads to the contractual agreement is frequently at the origin of a common understanding between parties. The contract also offers protections necessary for the creation of a relationship based on trust. It is a solution to enforce the trust between partners and to limit opportunism.

3. Case description: the EPC dealing with street-lighting in two municipalities

3.1 The project and its context

The PPP project concern two municipalities: city A and city B hosting respectively 117,000 and 23,000 inhabitants. Most street lighting facilities of city A were outdated (more than 45 years old) and highly inefficient. In 2007, 26% of the 5298 lights would have required to be replaced within five years and 40% within two years. The power of the lighting system was also defective. Consequently, the network was not anymore safe and reliable. Operation and maintenance were entrusted to municipal employees and outsourced to one company who signed a one year contract renewable three times. The situation of the neighbouring city (B) was less dramatic. Only 25% of its 2,647 lights had to be replaced in the short run. One private partner was in charge of operating the network. Indeed, in 1994, this city signed a PPP including financing, operation, maintenance and renewal of street lighting and traffic lights.

Annual operating costs were different between cities. City A spent about EUR 335,000 each year. City B with a network twice as small spent EUR 400,000. In 2004, competencies dealing with street light were transferred to a regional community. PPP was seen as the solution to modernise the lighting network and to introduce environmental criterion and energy performance objectives. City A had a limited borrowing capacity and was not able to borrow €30 million for the modernisation of its public lighting network. City B already experienced PPP and was also looking for a solution to finance, renovate and operate its network.

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3 Since there is apparently nothing in the literature about street lighting the case study approach appears appropriate. It is based on face-to-face interviews with the client, the legal consultant, and two people representing the private partner. A report comparing the conventional public procurement process and the PPP option was also used as complementary source of information.

4 At that time, PPP was still seen as a way to account public investments as off the balance sheet. According to the Eurostat rule in 2004, it was possible to classify investments made through PPPs as non-governmental if the construction risk and either availability or demand risk were transferred to the private operator. Thus, debt hiding was a motivation for PPP. Since 2011, both existing and new projects have to be considered as public debt. “On the balance-sheet, the capital value of the investment is recorded within the assets, while the already-paid investment and the remaining debt are recorded within the liabilities” (Buso and al, 2013).
The criterion of complexity has been put forward to justify the PPP procedure. Both municipalities did not have the technical know-how to refurbish street lighting. Moreover, the regional community who represented both municipalities and took in charge the project had no expertise to assess the level of investment and to operate and optimize the energy related installations.

Legal, financial and technical consultants assisted public authorities during the redaction of the comparative analysis and the competitive dialog. According to the public sector comparator, PPP offered the best value for money both in terms of costs and service quality. The call was launched in December 2006. The first round for the competitive dialog was organised in September 2007 and the second in November. The contract was awarded in June 2008 and signed in July for 20 years. The company, who won the competition for the deal, covers the entire value stream of public lighting, from design, to renovation works and operation. Consequently, there was no need to create a Special Purpose Vehicle as for most PPP projects. The company borrowed money to one bank. The initial costs of the deal reached EUR 92.3 million. However, it was renegotiated during refurbishment works due to a decrease of interest rates. Thus, the final deal reached EUR 86 million over the 20 year period.

3.2 The complexity of the project

According to Wang and von Tunzelmann (2000), complexity covers several dimensions: the technology, the markets and products, the production processes, and the administration and management. The complexity of this project mainly concerned the technological and organisational dimensions:

- A large part of civil engineering was performed with micro slicers in order to reduce both the time in which roads cannot be used and the quantity of excavated volume. The private partner also anticipated future works by performing all civil engineering during the first three years of the contract. In the future, when a cable will be laid, no additional trench will be opened. This approach minimised the environmental impact and the nuisance caused by the construction sites.
- The use of the micro slicers completely changed the organization and the conduct of the project. The work was closely coordinated with private companies in charge of managing the gas network and relevant community services. The objective was to avoid interventions from municipal employees shortly before or after the action of the private partner. A specific team was also created to inform residents about the works in progress. Moreover, to optimise the micro slicers, trenches had to cover a length of 500 meters for one week. Such length was unusual and required further communication.
- The installation of a centralised control station was another major innovation. It is commonly used for building but it was the first time for public lighting. Moreover, a wireless network was set up to link luminaires to the central station. This solution aimed

5 With the traditional approach, the company digs a trench of 80 cm deep and 40 cm width while with this technique, the hole is limited to 35 cm deep and 15 cm width. This technology is traditionally used for the installation of fiber optics in the countryside.
at monitoring the intensity of every light\textsuperscript{6} and providing complementary services to local authorities (such as video protection, tricolour stop lights).

### 3.3 Results

The private companies renovated 70\% of the street lighting system on time (at the end of the contract, 95\% of the park will be renovated).\textsuperscript{7} By concentrating most of the renovation works on the first three years, the goal of the company was to reduce as soon as possible the power of the network by 38\% and to reach its energy performance objectives on the long run. Over the 20 year period, total energy consumption has to reach 94 GWh. If the savings are not achieved, the private partner will pay compensation. Conversely, gains will be invested in energy performance works. However, there are no yearly milestones. The private partner just needs to write a report every year in order to present how contractual obligations are respected. Public authorities also hired a subcontractor who ensures that the private company adheres to the performance and standards stipulated in the contract.

After two years, the energy consumption was slightly over its target. However, the private partner was still optimistic since the centralised control station was not operational in both cities during the first years of the contract. Moreover, life cycle costing approaches were not neglected because the operator contributed to the elaboration and he success of the deal. According to Swaffield and Mc Donald (2008) and Rintala (2005), this issue is frequently ignored in PPP projects because budgets are constrained, clients are unable to understand the maintenance requirements and the associated costs, and there is a lack of information about the different options and about the past performance of products. Moreover, operators have usually less influence on the service provision solution than contractors. Consequently, operational solutions are not frequently optimised.

Both partners considered that the contract lacks flexibility, particularly to resolve unforeseen actions. For example, the contract does not mention that the private partner is responsible for exceptional lighting events such as the National Day or the “Night of the Stars”. So far, the private partner accepted to support these costs. However, he would like to open a special account for financing contingencies that were not anticipated and to introduce information disclosure for this account in order to preserve the stability of the agreement.

The public person in charge of following the contract was satisfied with the service quality. However, he was sceptical about the length of the contract. Even if the best technology available were selected\textsuperscript{8}, several technological changes may affect street lighting system and the actual contract may create a lock-in effect.

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\textsuperscript{6} Lights can be shut down in streets that do not need to be lighted in the middle of the night.

\textsuperscript{7} The competitive dialog helped the laureate to improve its initial offer. His first proposal was to renovate 62\% of the candelabra over a period of five years. In addition, at the end of the twenty years contract, only 88\% of the Park would have been renovated.

\textsuperscript{8} At this time LED technology was not considered as the most interesting option. It was twice as expensive as other technology available. Moreover, there was a lack of feedback studies for LED.
The main objective of this paper was to understand why energy performance contracting was dominant in public lighting projects following a PPP procurement process and frequently omitted in building projects. To answer to this question, it appears first necessary to compare the complexity of EPC for buildings and public lighting. The five aforementioned dimensions can be examined: design, works, operation and maintenance, project financing, and measurement and verification.

Design: design is usually integrated in order to achieve higher energy savings. Lots of data are frequently missing in these types of projects even when the preferred bidder is selected. Time and money spent for data collection (information on buildings / current state of street lighting) are probably similar. However, dynamic modelling and simulation are more complex for buildings since the users (operational hours, behaviours…) have a strong influence on the results. Conversely, user will not interfere with the operation of street lighting system. Moreover, architectural issues are omnipresent in building projects but limited for street lighting.

Works: in both cases, it is necessary to coordinate a large number of subcontractors. Before and during the works, communication with the residents / the users of the buildings is a key action. In the case study, technologies used during the refurbishment of street lighting were innovative. Moreover, 70% of the park was renovated over a three year period. All these elements increased the complexity of the works. The implementation of a centralised control station appears as complex for buildings as for street lighting systems.

Operation and maintenance: in the case of public lighting, it is a standardised process. Unforeseen events are limited (e.g.: light time can be anticipated for the length of the contract). In buildings, it is harder to anticipate the evolution of the activity. For example, occupancy may vary according to the activity from one year to the other. Thus, uncertainty is stronger.

Project financing: there is a large spectrum of financial arrangements. Complexity varies from one project to the other. Apparently, it is as complex for buildings as for street lighting. However, the risk supported by the financing party is probably stronger for buildings because of the frequent gap between predicted energy performance of buildings and measured energy use once buildings are operational.

Measurement and verification: establishing the baseline is probably the most difficult task of EPC for buildings. The conceptual framework published by the U.S. Department of Energy (2015) for quantifying the savings resulting from energy efficiency equipment, improved operation and maintenance, is complex. Even if the steps are well defined, each item is subject to interpretation and several options are available. The public lighting project presented in this paper does not reflect such a high level of complexity.

Table 3 summarises complexity of EPC projects in the cases of street lighting and buildings.
Table 3: Complexity of EPC: public lighting versus buildings

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Level of complexity on a scale going from 1 to 5</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Public lighting</td>
<td>Buildings</td>
</tr>
<tr>
<td>Design</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Works</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Operation and maintenance</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Project financing</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Measurement &amp; Verification</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

According to table 3 based on the author’s experience with EPC in buildings (Bougrain and al. 2014) and the case study, street lighting projects integrating design, works, operation and maintenance, appear much less complex at the operational level than building projects. The absence of users who interfere with the operator and the predictability of most events occurring during the life of the contract, limit the risk. Moreover, the codification of the tasks and the measurability of outcomes are easier to implement. Thus, the control is more effective. Formal contracts seem adapted. Conversely, uncertainty is strong for EPC in buildings. Actions performed by private partners such as ESCO, are difficult to monitor. Users can adopt opportunistic behaviour. To mitigate these aspects, cooperation based on trust is essential for the success of a project.

The limited complexity of street lighting projects at the operational stage, probably explains why these projects represented about 40% of partnership contracts signed by local authorities (table 2). The paradox is that complexity was frequently cited by public authorities to justify PPP for street lighting. Conversely, the high level of complexity of EPC for buildings in operation and the uncertainty attached to this contract, explained probably the infrequent use of EPC in building projects.

5. Conclusions

The case study indicates that EPC for street lighting are very complex during design and construction phases. This complexity decreases when one moves downstream to the operation of the public network. This is due to a diminution of uncertainty: most events having an impact on the performance of the network in operation are predictable. Conversely, EPC in building projects tend to face unforeseen events during the operation: cooperation between occupants and operators is subject to tensions; protocols to measure and verify energy consumption are standardised but their implementation is still complex. This difference of complexity has an impact on the governance of each project. While pure contractual relationships may be adapted to EPC in street lighting projects, relational governance needs to be introduced in EPC for buildings. Trust can compensate the uncertainty surrounding these projects.
By investigating only one case study, the research has limitations. Further research is required to extend applications to this field. It would be interesting to examine how complexity evolves over time and impacts on governance.

References


Life-Cycle Economics of Rentable Prefabricated School Facility Units in Municipal Real Estate Procurement

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Abstract

The purpose of this paper is to study the economic feasibility of rentable prefabricated spatial units as a part of the public real estate procurement strategy. Ensuring the resource effectiveness of the municipal real estate procurement is a matter of great significance. In 2013, the gross investments of the Finnish municipalities were approximately 4.7 billion euros from which the investments on real estate were 1.7 billion euros. Thus, the investment decisions should be made based on thorough life-cycle analysis. However, the prevailing practice of public real estate procurement weights strongly on initial costs. Recently, there have been indications of interest toward industrially produced spatial units. Rapid product delivery times combined with the spatial flexibility provided by the systems can be considered as the main benefits when compared to more traditional forms of construction. Also, the diminishing quality risks made possible by the controlled facility environment in the production phase can be seen as a major advantage. Studied business model – which relies on renting – helps to transfer the risks related to functionality of the building from the municipality to the unit provider. The research hypothesis is that using rentable prefabricated spatial units helps municipalities to avoid costs related to difficulties in predicting future space requirements.

School properties where chosen for the analysis because of the ongoing public debate considering, for example, health hazards caused by mould and moisture damage occurring in this type of buildings. Net present value (NPV) method was used to compare the municipal life-cycle costs of two school property investment alternatives in Finnish context. The comparison was made between municipality developing and owning a school property and renting the wooden spatial units needed.

The results suggest that different kinds of municipalities can benefit from prefabricated rentable spatial units. The feasibility of spatial modules improves compared to the property built using traditional methods the more the amount of students fluctuates during the analysed time period. Additional benefits include the reduced need of school transportation as well as enhanced social cohesion made possible by children attending the school in local neighbourhood together with friends from the same area.

Keywords: Prefabricated spatial units, public real estate procurement, school facilities, municipal economics, life-cycle economics
1. Introduction

Enterprises should always aim to deliver products that meet the customer’s needs as well as different legislative requirements as cost effectively as possible (Asiedu, 1998; Janz and Westkämper, 2007; Niazi et al., 2005). Similar thinking can be extended to the public sector and its services, such as education facilities or even entire residential areas. Efficient procurement practices are playing an essential role when striving to meet these goals. Both in the private and public sector, different investment options should always be evaluated using proper tools to guarantee as effective use of resources as possible. This particularly applies to real estate developments since those are recognised as capital heavy long-term investments. Thus, municipalities should be long-sighted when analysing the economic outcomes of these projects.

Recently, there have been indications of interest towards rentable industrially produced spatial units. Rapid product delivery times combined with the spatial flexibility provided by the systems can be considered as the main benefits when compared to more conventional building methods. In addition, the diminishing quality risks made possible by the controlled facility environment in the production phase can be seen as a major advantage. Studied business model – which relies on renting – helps to transfer the risks related to functionality of the building from the municipality to the unit provider. The amount of modules can be swiftly adjusted when there is a change in space requirements, for example, because of demographic changes in the area. Aforementioned leads to the following research hypothesis: Using rentable spatial units helps municipalities to avoid costs related to failures in predicting future space requirements.

In Finland, the school properties have been a topic of public debate in the past couple of years. According to Reijula et al. (2012) 12–18% of the schools and day cares in Finland are affected by considerable moisture and/or mould damage. Because of this 172 000–259 200 children could be exposed to different health hazards. When thinking of how to replace the school properties that are damaged beyond the renovation threshold, the municipalities are forced to make a decision between renting and owning new properties. The economic impacts should be carefully studied especially when the population of the school-aged children in Finland is predicted to decline rapidly in the future (Official Statistics of Finland (OSF), 2015a). Thus, owning of a permanent solution with possible low utilisation rate in the near future is questionable to say the least.

In this study, the net present value method is used to compare the life-cycle costs of two different kinds of school property investment options from the viewpoint of municipality: First, where a municipality invests to a property which is built using traditional production methods mainly relying on prefabricated concrete sandwich wall elements and hollow core concrete slabs, and second, where the municipality rents the spaces required from the manufacturer of wooden spatial units. What makes this study unique is the fact that it is the first of its kind to combine the predictions of the student population development and the cost data of municipal real estate procurement and thus providing evidence how the variation in the demand of space over time impacts on the economic equation. The next section covers the relevant literature considering public real estate procurement and prefabricated spatial units. In the third section, the data for the analysis as well as applied research method are described. The fourth section presents the results of the LCC-calculations carried out. The final
chapter includes conclusions and discussion about the relevance of the results as well as underlines the need for future research.

2. Background

It has been estimated that in 2011 the total expenditure of EU member states on education was on average 5.25 % of their GDP respectively. In Finland, the government carries an essential role in providing educational services thus the corresponding number is a bit higher being 6.76 % (Eurostat, 2015). In 2013, the investments of Finnish municipalities were approximately 4.7 billion euros from which the investments on real estate were 1.70 billion euros (Finnish Ministry of Finance, 2015). It is safe to say that municipal real estate procurement plays a major role from the viewpoint of national economy.

Statistics Finland has presented a projection that the population of children that fall into the category of compulsory education (aged 7–16) will decline rapidly in the upcoming decades (Figure 1). The estimation was made based on the assumption that the birth rate remains constant in the future and the mortality continues to decline in a similar fashion as when comparing the data from 1987–1991 and 2010–2014. Migration is assumed to be 17 000 persons per year between 2016 and 2065. (Official Statistics of Finland (OSF), 2015a.) However, the areal differences in population development should not be overlooked. The demand for educational facilities is likely to continue to increase in the centres of growth and decline elsewhere.

![Projected development of the population of 7-16 year old Finns between 2015 and 2065](image)

*Figure 1: Projection of the development of the amount of children between 7-15 years old in Finland between 2015-2065 (Official Statistics of Finland (OSF), 2015a).*

The amount of schools owned by the Finnish municipalities has declined rather rapidly since 2005 (Figure 2). In 2005 Finnish municipalities owned approximately 3 300 school properties and that number has decreased to 2 400 by 2014. However Due to the increase in unit size of new school and tendency to close down the smaller units, this statistic can be deceiving because it does not take into consideration the actual volume of school buildings.
Public procurement has been covered from many different angles in the existing body of literature. Most countries have a strict legislation considering public procurement of services and goods. Public tendering procedures have been a predominant mechanism for granting construction contracts in municipal sector. Usually the choice between the bidding contractors is made weighing strongly on the tender price. However, there are some studies showing that this practice leads to lacking quality and prolonged project deliveries (Cheng et al., 2000; Drew and Skitmore, 1997). Because public procurement is responsible for significant share of demand of goods and services, it is often seen as major source for potential innovations (Aho et al., 2006; European Comission, 2005; HM Treasury, 2004). However, Edler and Georghiou (2007) argue in their article how despite public procurement representing a key source of demand for the firms, for example, in construction, health care and transport industries, the potential of using public procurement for source of innovation has been largely ignored conceptually as well as in practice.

Environmental and sustainability related aspects of prefabricated buildings are well documented. Jaillon et al. (2009) investigated in their study how utilising prefabrication in building construction could help to mitigate the growing problem of building waste generation in Hong Kong area. They found out that the average waste reduction level was about 52 % compared to the conventional on-site construction projects. Bonamente et al. (2014) used LCA approach to model carbon and energy foot prints for different size buildings. The results indicate that the main environmental impacts arise from the operational phase of the buildings. Similar results were found by Faludi et al. (2012) who studied the life cycle impacts of a 5000 ft² prefabricated commercial building constructed in San Francisco. However, it was also stated that in the case of nearly zero energy buildings impacts from manufacturing are the most dominant. Pons and Wadel (2011) concentrated specifically on the environmental impacts of prefabricated school buildings in Catalonia. Using simplified LCA modelling, they compared the CO₂-emissions of four technologies; non-prefabricated building.
technologies as well as prefabricated school facilities made out of wood, steel and concrete. The results show that prefabricated solutions have lower environmental impacts through analysed time period. However, according to the study there is still room for improvement in the processes to further reduce the CO₂-emissions and especially the waste generation related to manufacturing and recycling.

The economic literature considering prefabricated spatial units is very limited. The report of National Audit Office (2005) claims that in British context construction projects carried out using modern methods, such as modular spatial units, are usually more expensive than the ones applying the more conventional methods. However, there is an overlap in the price ranges thus in certain conditions modern techniques could prove to be more cost effective. Pan et al. (2005) argue in their study which is based on survey of the top 100 housebuilding firms in UK that the cost savings of the off-site manufacturing are achieved, for example, in the areas of reduced risks and maintenance costs, shorter construction times and cost certainty.

This study contributes to the existing body of literature by being the first to focus on the municipal school property investment in Finnish context by combining the official cost data from various sources and the student population projection provided by Statistic Finland. The result is the most comprehensive analysis yet regarding the subject and can be used as a starting point when aiming for decision-making based on facts in the field of public real estate procurement.

3. Data and Methodology

In this paper, life-cycle cost (LCC) analysis is carried out to compare the economic feasibility of two different educational facility investment alternatives from the perspective of a municipality. The analysis was made between renting a school property built using prefabricated spatial modules, and the traditional alternative, in which a municipality invests to a new property and owns a building after development is finished. The analysed investment alternatives are not based on real-life counterparts. However, the cost data used in the analysis is gathered from different official sources. The main purpose is to provide information about the economic feasibility of rentable spatial units compared to more conventional method of construction by taking into account differing costs of the investments throughout their life-cycle. Also, the presented approach makes it possible to figure how the changes in the student population impact on the economic feasibility of the studied alternatives.

3.1 Data

For the purposes of the LCC calculations the data was acquired from various official sources to perform a comparison between the studied investment alternatives. The values of different variables and the data sources are listed in table 1.
Table 1: The municipal expenditures of the analysed investment alternatives.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of students</td>
<td>250/214</td>
<td>Official Statistics of Finland (OSF), 2015a</td>
</tr>
<tr>
<td>Required floor area</td>
<td>4 500 m²</td>
<td>Finnish National Board of Education, 2012</td>
</tr>
<tr>
<td>Investment cost</td>
<td>2 308 €/m²</td>
<td>Haahtela and Kiiras, 2015</td>
</tr>
<tr>
<td>The cost of maintenance</td>
<td>8,2 €/m²</td>
<td>Lonka et al. 2012</td>
</tr>
<tr>
<td>The annual growth rate of real maintenance costs</td>
<td>2,8 %</td>
<td>Official Statistics of Finland (OSF), 2015c</td>
</tr>
<tr>
<td>Annual inflation rate (15 year average)</td>
<td>1,8 %</td>
<td>Official Statistics of Finland (OSF), 2015d</td>
</tr>
<tr>
<td>The annual cost of technical deterioration</td>
<td>2,3 % of the investment cost</td>
<td>Nippala et al. 2006</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
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<tr>
<td>Amount of students</td>
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</tr>
<tr>
<td>Required floor area</td>
<td>4 500 m²</td>
<td>Finnish National Board of Education, 2012</td>
</tr>
<tr>
<td>The costs of foundations and utilities</td>
<td>103 €/m²</td>
<td>Haahtela and Kiiras, 2015</td>
</tr>
<tr>
<td>Transportation and installation</td>
<td>250 €/m²</td>
<td>Parmaco Ltd., 2015</td>
</tr>
<tr>
<td>Monthly rent</td>
<td>14 €/m²</td>
<td>Parmaco Ltd., 2015</td>
</tr>
<tr>
<td>Annual inflation rate (15 year average)</td>
<td>1,8 %</td>
<td>Official Statistics of Finland (OSF), 2015d</td>
</tr>
<tr>
<td>The annual real increase of the rent</td>
<td>1,2 %</td>
<td>Parmaco Ltd., 2015</td>
</tr>
</tbody>
</table>

City of Kouvola was chosen as the location for the theoretical example for a school facility investment. Kouvola is situated in southeast Finland about 140 kilometres northeast from the Finnish capital Helsinki. In the end of 2013, the population of Kouvola was 86 926. Kouvola was chosen for the study area because in 2014 a school for approximately 250 students situated in the city was closed down. Another reason for the selection is the fact that according to Statistics Finland the population of the city is declining (Official Statistics of Finland (OSF), 2015e) which supports the assumptions made in the analysis. All of the expenditure variables are presented in the current price-level of Kouvola region.

Only the costs differing between the two investment alternatives were taken into account. In Finland, the technical quality of the new production practically always follows the requirements set in the part D3 of the National Building Code (Finnish Ministry of Environment, 2011). It defines the minimum requirements considering the energy efficiency of new buildings. Thus, the specific heating energy consumption (kWh/m²) can be assumed to be similar between the two studied alternatives. When combining this fact with the predominant position of the district heating in the Finnish building stock,
the utility costs in the both alternatives are very similar and thus are omitted from the analysis. Land value is not considered in the analysis based on the fact that comparison is made between two exclusionary investment alternatives for the same geographical location. In both cases, the floor area of space required is expected to be the same 15 m²/student. The main differences between the investment alternatives are the large initial capital cost and the cost of maintenance and technical deterioration included in the alternative where municipality invests to a new school property. The costs of maintenance as well as the cost of deterioration are included in the monthly rent in the second alternative. However, also in the case of rentable spatial units there are some initial construction costs including the building of foundations and surrounding utilities as well as the costs of transportation and installation of the units. The cost information regarding the rentable spaces was provided by Parmaco Ltd. (www.parmaco.fi) which is one of the few manufacturers in Finnish real estate market producing and renting spatial units aiming to reach similar architectural and technical quality as more conventional developments.

In this study, the residual value of the investment alternatives was ignored. This is mainly due to the fact that if municipality procures the spaces using the renting model the ownership of the modules stays on the manufacturer who will reclaim them after the service agreement ends (if there is no redemption rights clause in the contract). In the case of municipality developing and owning a new facility, the residual value is really hard to define. Technical value based on the age of the building can be quantified using various methods but the specific characteristics of education facilities make this problematic. Large school facilities are not often appealing from the perspective of real estate investors. Usually they require significant amount of alterations to modify the spaces to support other possible activities. In the case of demolition, residual value can even thought to be negative if the costs of the demolition process and waste management are taken into consideration.

3.2 Net Present Value method

Net present value method (hereinafter referred to as NPV) can be used to estimate the life-cycle costs of the investment alternatives. The NPV method is based on the time value of money, meaning that a cash flow in the future is less valuable than an identical cash flow today. The two most central reasons behind this phenomenon are inflation/deflation and a simple fact that a present cash flow can be invested immediately to earn future returns, whereas a future cash flow cannot be invested yet. The NPV method takes the time value of money into consideration by discounting the future cash flows by an appropriate discount rate. The mathematical form of the NPV equation used in our model can be written as follows:

$$NPV = \sum_{t=0}^{n} \left( \frac{Expenditures_t}{(1+r)^t} \right)$$

(1)

Where:

- t = cash flow period
- r = the chosen discount rate
- n = calculation period

In the model the cash flow period (t) is one year, whereas the analysed calculation period of a
development project (n) is 26 years. Choosing a proper discount rate (r) is one of the most crucial elements in any type of medium- to long-term investment calculation. The discount rate describes the yield requirement for the investment, including the perceived risks, capital costs as well as desired profits. As a rule of thumb, the minimum discount rate should be at least high enough to cover the financing costs of an investment. A high discount rate gives more weight to cash flow events at the beginning of the analysed life-cycle. Thus, usually investments with low initial capital costs seem more tempting when using high discount rates. Instead, the lower the discount rate, the more the impact of the cash flow events occurring further in the future will have on the results of the analysis.

There is an extensive academic literature on the uncertainty related to public investments and selection of a proper discount rate (e.g. Arrow and Kruz, 2013; Arrow and Lind, 2014). Woodward (1997) states in his article that the appropriate discount rate in LCC analysis varies from 3 percent to over 20 percent depending on the nature of the investment and investor. For the purposes of this analysis, a real discount rate of 5 percent is used. A real discount rate does not include inflation/deflation, whereas the so-called nominal rate does. Whenever a real discount rate is used, the cash flows discounted must be presented in real values as well. The utilisation of real rates and costs is chosen because it is really hard to predict the inflation for long calculation periods. The significance of this matter grows the longer the calculation period is.

4. Results

The economic feasibility of school facility investments was studied comparing two alternatives: First, where a municipality invests to a property which is built using conventional construction methods, and second, where the municipality rents the spaces required from the manufacturer of wooden spatial units. In addition, two alternative student population development scenarios were studied. One where the amount of students stays constant through the studied time period and other where there is a decline in student population. The decline was modelled based on the estimation presented by Statistics Finland.

The results based on the calculation scenario where the amount of students is assumed to stay constant throughout the calculation period (2015–2040) are presented in Figure 3. It is noteworthy that the renting model does not include costs for the first year of the studied time period. This is based on the assumption that after the foundations and other preliminary works are finished the modular building system is really fast to put together. However, when building using more traditional methods, the development will take at least a year for the project of this scale. From the figure can be seen that the cumulative discounted costs of the renting model by pass the ones caused by owning the property in 2037 (22 years after the start of the development). In other words, if the purpose of the municipality is to own and use the property longer than 22 years it is more cost effective to develop and own the property. Alternatively, if the strategy is to keep the property only as long as the students can be located to other facilities in the area and the required time is shorter than 22 years the renting model will be a better choice from the viewpoint of economics.
Figure 3: Cumulative discounted costs of two studied investment alternatives assuming that the amount of students stays constant during the calculation period.

One benefit of the rentable prefabricated modules is the fact that the system is spatially very flexible and responses well to changes in space demand. The calculation results presented in Figure 4 support this claim. This scenario is based to a projection made by Statistics Finland about the population development of school-age children in Kouvola, Finland. In 2015, the student population is assumed to be 250 and according to the projection it decreases to 214 by 2040. In addition, the amount of spatial units is adjusted in every ten years (2024 and 2034) by removing the units not needed anymore because of the decline in the student population.

Figure 4: Cumulative discounted costs of two studied investment alternatives assuming that the amount of students declines during the calculation period according to projection made by Statistics Finland.
By comparing the previous two figures it can be seen that the decline in the student population favours the rentable spatial units because of the system’s ability to adapt to a new situation. The break-even point moves to year 2039 which means that renting the facility is now more profitable if municipality plans to own the property 24 years or less. It should also be noted that the selection of the discount rate affects a great deal to the results. The higher the discount rate, the more it favours the renting model. This is due to the fact that high discount rates favour the investments with low initial cost, and the significance of the future renting costs diminishes.

5. Conclusions and Discussion

It is foreseeable that different kinds of municipalities can benefit from prefabricated rentable spatial units. The results presented in this paper suggest that rentable prefabricated spatial units should be considered as an option especially in municipalities that have an uncertain future and thus will have a decrease in population of school-aged children in forthcoming decades. The same phenomenon is present also in growing cities where the amount of children may vary drastically by city districts. The feasibility of rentable spatial units improves when comparing to a property built using traditional methods the more the amount of pupils fluctuates during the analysed time period. Also it is worth mentioning that avoiding the unnecessary transportation of children brings many economic benefits, reduces the environmental impact, and may even enhance social cohesion when the children may attend the school in local neighbourhood together with friends from the same area.

It should be noted that the holistic economic analysis considering the procurement of any public construction project is far more complicated issue than just an LCC-calculation covering the variables related to building and maintaining properties. Every project is its own unique entity requiring customized analysis to determine the best performing procurement method. Regarding the educational services, there are many real-life cases where municipalities have tried to achieve budgetary savings by closing out schools and locating the students to other schools in the region. Usually the savings have not been reached because of the analyses are not including all of the externalities caused by the change. For example, closing down a school usually leads to costs in other areas such as transportation, re-establishing the teaching groups elsewhere, the necessary spatial modifications in substitute school, lost state subsidies, etc. Evaluating different alternatives is a complicated task. However, because of the long lasting effects and capital heavy nature of these investments, the tools and decision-making should be approached with the significance of the matter in mind.

One interesting, yet underexplored, area is so-called hybrid-models where permanent parts of the property are complimented with the prefabricated spatial units. This would enable to capitalize on the benefits related to both systems. This kind of system when in balance would make the use of the cost effectiveness of conventional construction methods and the spatial flexibility of prefabricated spatial units. However, if the Finnish municipalities continue to rely heavily on owning the public properties and procurement procedures emphasising strongly the role of the initial investment costs, the focus should be on flexible designs where the alteration of use can be carried out with minimal changes leading to increased resource effectiveness.
References


Arrow, K.J., Kruz, M., 2013. Public Investment, the Rate of Return, and Optimal Fiscal Policy. Routledge.


Official Statistics of Finland (OSF), 2015b. Providers of education and educational institutions.


Parmaco Ltd., 2015. Winning offer of Lauritsala’s school facility.


Abstract

According to the latest reports of United Nations, the biggest challenge facing the world at the present and in the next decades is water scarcity. Trans-boundary water resources from history to present either lead to cooperation or to confrontation and conflicts.

For the last six decades, it has not been possible to solve the Arab-Israeli conflict, and the water issue has been raised as one of the keys for solving the conflict or having a successful discussion.

The history of the water conflict in the Middle East began by the foundation of the Israeli state in 1948. Since that time Israelis have tried to secure the state water supplies using different water resources in the area. The rapidly growth of the driving forces (Nexus) has become a source of numerous conflicts with their neighbours.

The whole area has suffered from water shortage and unsuccessful managing of the water resources. Palestinians, Israelis, Jordanians, Syrians and Lebanese are sharing the major part of their water resources, the Jordan River and the aquifer of the West Bank and Garza Strip being the main sources of water resources for Israelis and for the Palestinians. Dividing the land will not be a solution to water gaps. It is likely to make the situation even worse.

Several methods and tools have been developed worldwide to assist the riparians to manage their own shared water resources, part of which are technical and other social -political methods. Scarcity index is one technical numerical method developed to assist the parties to allocate the shared water resources and to assist on recovering the water gaps. Based on the mentioned methods numerous agreements have been made and discussions have been held between the riparians to achieve peace and co-operation. Some of them have been implemented, the other remain open due to the political changes in the area.

**Keywords:** modelling trans-boundary water resources, water conflict, water balance and scarcity, Middle East water
1. Introduction

Worldwide water resources are unevenly distributed and they are generally scarce in arid and semi-arid zones such as the Middle East. Lack of water, growth of tensions, distrust as a consequence of poor relations, use of force to solve conflicts and inefficient management and use of water resources are the problems besetting water resources and the Arab-Israeli shared natural resources in particular.

This paper aims at contributing to resolve the complex relationship between riparian parties resulting from mutually shared and limited water resources in general, with special focus on the Israeli-Palestinian shared water resources.

The specific purpose of the paper is to find sustainable ways to evaluate and allocate transboundary water resources and to determine the scarcity of water resources in the Israeli-Palestinian area.

This paper refers to a model for calculating and evaluating the water scarcity index for the present as well as for the long-term future based on analysing the rules of the international water law and the role of the United Nations in sharing and allocating the shared water resources. The computation is based on evaluating the expected demand as a consequence of population growth.

This scarcity will increase with time due to the rapid population growth, drought, as well as other constraints. With the expected population growth the gap will be approximately some 40 percent in the Palestinian and 60 percent in Israeli areas by 2020. There is an urgent need to maintain a balance in water use between the parties in the area, to reduce water scarcity, as well as to bridge the water gaps.

A joint vision based on sustainable development is formulated for the application at hand as well as alternative scenarios. The one based on joint cooperation is selected. For implementing this scenario, alternative strategic means are presented. They include especially minimizing water use, re-using the water, looking for new options for increasing the total number of water sources, and strengthening the cooperation between the parties. To support the developed model, integrated water resource management, building of institutions and development of human resources are investigated and some alternatives are suggested.

Since the water scarcity around the world can be a result of lack of accessibility, water quality deterioration, fragmentation of water management, decline of financial resources, lack of awareness by decision makers, and endangering world peace and security. The Palestinian and Israeli water conflict is an example including of the two last parameters.

When considering the major driving forces that determine the development of the mankind and its environment, we have to first set the time scale that we want to look at. To put the analysis in the framework of sustainable development, the most appropriate scale would be one generation.
backward and one ahead. This scale is typically used in global assessments. In this frame, the following issues are the major driving forces:

- Population growth, especially in the developing countries

One indicator for the water scarcity based on this driving force is explained later in this paper (Asheesh scarcity index), in which the author completed his case study 2002.

- Urbanization and other patterns of migration
- Changes in climate, environment, and nature
- Economy, and human capital, technology, and industrialization.

The main question which should be asked is how we can control these forces and how the international community controlled them during the last three decades.

One driving force of the above mentioned clearly appearing currently in the whole world is the migration to Europe which is a consequence of unsustainability and lack of water resources which is related to domestic use or agriculture in which will effect food production aspects and energy need (the Nexus).

2. Water sharing and riparian rights (international and national level)

The Israeli-Palestinian Water Joint Commission (WJC) announced a joint declaration for keeping the water infrastructure out of the cycle of violence and from becoming a source of conflicts. The Israelis and Palestinians view the water and wastewater sphere as the most important matter and strongly oppose any damage to water and wastewater infrastructure. The two sides are taking all possible measures to supply water and treat wastewater in the West Bank and Gaza Strip, even in the difficult circumstances of the Intifada movement that started in 2001. The two sides wish to bring to public attention that the Palestinian and Israeli water and wastewater infrastructure is mostly intertwined and serves both populations. Any damage to such systems will harm both Palestinians and Israelis.

In order to for this effort to succeed, the joint commission works based on mutual cooperation and support of all the population, both Israeli and Palestinian. The general public is asked not to damage the water infrastructure in any way including pipelines, pumping stations, drilling equipment, electricity systems and any other related infrastructure. The two sides also call on those involved in the crisis not harm water resources, the professional teams that conduct regular maintenance or repair damage and malfunctions to the water and wastewater infrastructure. Both sides wish to take this opportunity to reiterate their commitment to continued cooperation in the water and wastewater spheres.
In the United Nations proposal for water management and international sharing of water resources declared in 2000, the right to water was one of the essentials to be achieved, right to a standard of living adequate for the health and well-being of himself and family” (Universal Declaration of Human Rights Article 25, United Nations 2000). The right was to be for everybody regardless of his/her financial status. In recognition of the absolute need for water for survival, governments should regard the quantity of clean water necessary to ensure a decent standard of living for all people as sacred. An adequate supply of water must also be reserved for preservation and natural regeneration of the environment. Priority should be given to allocating the limited water resources according to the purpose of the use (Asheesh, 2003).

In the Palestinian-Israeli case the inhabitants of Israel and the Palestinian Territories share their main sources for drinking water. The largest resource is the Jordan River. Compared to other rivers in the Middle East like the Euphrates, the Tigris or the Nile, the Jordan River is a rather modest one – in length as well as in flow. Its main tributaries are the Hasbani, Dan, Baniyas and Yarmuk. The first three rivers converge in Israel, north of the Lake of Galilee, to form the upper Jordan River. Only the Dan originates within Israeli borders. The Hasbani springs lie in the part of Lebanon that was until June 2000 incorporated into the occupied Israeli security zone in southern Lebanon, and the Baniyas water drains from the Golan Heights – a territory formerly under Syrian control and since the war of 1967 occupied by Israel (Asheesh, 2003).

A holistic view needs to be taken of the water resources problem in the Arab world including the Israeli territory. The following aspects should be considered: Water requirements are calculated on a minimum basis known as “minimum water requirement” (MWR) which is 1,200 cubic meters/year (CM/Yr). The population of the Arab world is presently nearing 235 million; the quantity of available water per person is about 750 CM/Yr, which is below the MWR. If the population reaches 295 million by the year 2020, then a person’s share of water will drop to 575 CM. If the average population growth is 25 per thousand, then the water requirement will reach 295 billion CM by the year 2020, i.e., a deficit of 120 billion CM. (Tamimi 2012).

Water struggles and water resources conflict will be always the key for peace and stability in the area. Using force over water resources undermine these goals in long term. For example the Nile conflict and water allocation have been between the parties. Appeared after almost 100 years. The Kenyan government decided to build a new dam to secure their sustainable water resources and energy. The Arab-Israeli water conflict parties should learn a lesson from this case. The water issue always weave as the most difficult and changeable issue of the five conflict issues in the Palestinian and Israeli the other issues in dispute, Jerusalem, borders, settlements and refugees are not so susceptible to the same effective and often usefully politically silent solutions provided by socio-economic development.

2.1 Framework for negotiation and cooperation

It has been widely accepted that the political, economic, social, technical and environmental (PESTE) and resource problems directly affect regional and international security. Although these PESTE aspects have not been so far sufficiently incorporated into the approaches to reduce the
risk of water conflict, a framework needs to be constructed that encourages scholars and policymakers to apply new tools, to set new priorities, to organize responses, to recognize water rights, share control and monitoring and portioning of water resources and to eliminate a range of environmental threats to peace and security (Asheesh 2001a). Based on the mention the main question is how a Palestinian State should approach the principles of sovereignty and cooperation over water.

In October 1994, a peace treaty between Israel and Jordan was signed which addresses water allocations, sharing of water information, and joint management policies for the Jordan River Basin. The Convention on the Non-Navigational Uses of International Watercourses based on article 6 of the treaty reads as follows:

The Parties agree to recognise the rightful allocations of both of them to the waters of the Jordan River and the Yarmouk River and Araba/Arava groundwater in accordance with principles set in Annex II of the Jordan Intelligence Agency agreement (JIA 1998).

The Parties jointly undertake to ensure that the management and development of their water resources does not harm the water resources of the other party.

The Parties recognise that more water, to meet their needs, should be supplied through various methods, including projects of regional and international cooperation.

Parties agree to search for ways to alleviate water shortage and to co-operate in the following fields:

- Development of existing and new water resources
- Prevention of contamination of water resources
- Mutual assistance in the alleviation of water shortages
- Transfer of information and joint research and development in water-related subjects.

Unless all the people who depend on the resources concerned are included in the agreements, conflicts will persist. In particular, definitions of equitable utilisation of existing water resources must be negotiated and applied. These negotiations include discussing the priority of using the resources, like in the Israeli-Palestinian and California cases and other cases in other parts of the world, to resolve the wrestling between the demand for domestic and agricultural or urban and rural sectors (Gleick 1996). The framework for cooperation will help in the formulation of criteria and prioritisation of the realisation of any of the proposed activities. As the water authority in the area is presently unorganised and the water itself is a quickly diminishing natural resource, direct involvement and efficient cooperative water administration is obviously essential and thus this factor cannot be handled separately from the technical issues.
Based on the above mentioned understanding between the both sides, the Palestinians and the Israelis, the joint water institutional framework could strengthen the management of the operation and maintenance of the shared water resources.

The precondition for formation of such a framework is that the respective parties start to base their understanding of the need to improve the water situation on trust, good faith and respecting each other’s sovereignty. In this way using the water resources may happen in a reasonable and equitable way in accordance with the rules of the international joint committees (Israelis and The Palestinians). A joint water framework may be built first through negotiations about allocation the shared water respecting the hydrological distribution of the sources (and not according to geographical areas) and second in spirit of cooperation.

In light of the above, the following joint water framework could be considered in Palestinian-Israeli negotiations over water issues. The joint institutional framework illustrates the future administration and management functions in the area (Figure 1).

![Institutional framework for arrangement of water resources and services](image)

The role of the Water Authorities of both sides is to control and monitor the shared resources, since the sub roles of Jerusalem Water Undertake (JWU) and Joint Services Council Provider Department (JSCPD) to provide the services to the Palestinians side and Mekorot (Israeli water providers) to the Israeli side are essential to the framework.

The framework for cooperation should include the management of wastewater also, which poses a risk to the environment, since the groundwater lies relatively close to the surface and is easily contaminated (Nashashibi 1995). There are only a few wastewater treatment plants in the area, and the wastewater network is not large enough. Consequently, proper planning and locating of treatment plants and expansion of the wastewater network make up an important part of this research. Water re-use, which represents a new possibility to increase water resources in the area, can eventually help conserve significant amounts of fresh water, but much more research is needed to determine how water could be re-used in agriculture and industry.
According to (Kuttab & Jad 2000), three major issues concerning the Israeli-Palestinian conflict have to be analysed and ranked with regard to cooperation in water resources by the Palestinian West Bank and Gaza Strip Territories and the Israeli state.

The first issue relates to water resources that originate and are discharged completely in the Palestinian West Bank and Gaza Strip. The most obvious example of this sort is the Eastern aquifer resulting from rains within the catchment area east of the hydrological line that crosses the West Bank towards the Ghor Valley.

Figure 2 The hydraulic line locates the aquifer basin in the West Bank (Asheesh 2003)

The Israeli West Bank Mountain Aquifers have three general basins. The west aquifer, providing more than a half of the total yield in Israel, is called the Taninim aquifer, the second aquifer is the northern aquifer and the third one is the eastern aquifer. The last one lies on, and enters the West Bank. The second and the third aquifers as well as the most important west aquifer, qualify as trans-boundary basins, and any water distribution solution should be based on principles of sharing the watercourses under international law.

The second issue relates to the riparian waters, which flow into the Jordan River. The Palestinians in the West Bank together with Jordan, the State of Israel and Syria share these resources. Despite the absence of clear precision, there are sufficient guidelines in international law pertaining to surface water.

The third issue pertains to water resources resulting from rainfall in areas west and northwest of the hydrological line and which feed two main aquifers that are shared with the State of Israel. The major portion, about 80 percent, (Asheesh 2000) of the waters in these aquifers originates from the West Bank catchment areas.

The aquifer itself flows and actually straddles the border between the two areas with the majority of it found in the West Bank Territories. The consumption of water based on withdrawal from
those aquifers (the eastern and northern aquifer) it shows that the main and the biggest share is consumed by the Israeli settlements in the West Bank area.

Since the shared water resources between the neighbours are the main issue for peace and security, the cooperation on the operation and maintenance of the water system in general is the main key in the hands of the decision makers on solving the gaps of water in the current situation and securing the demands for long term. The joint institutional water framework to joint water authorities on both sides, water Authorities which can be based on the recognizing the right of both nations and based on the international water right declared by the international water law.

3. Indicators for International Water Gaps and Water Stress

In the past 20 years many indices have been developed to quantitatively evaluate water gaps and needs. Several indicators has been made to avoid conflict and to promote the cooperation and to prevent the conflict, struggles and distrust of controlling of the water resources.

The Falkenmark indicator is perhaps the most widely used measure of water stress. Gleick (1996) developed a water scarcity index as a measurement of the ability to meet all water requirements for basic human needs. Ohlsson (2000) integrated the “adaptive capacity” of a society to consider how economic, technological, or other means affect the overall freshwater availability status of a region. The UNDP Human Development Index (HDI) is a widely accepted indicator used to assess these societal variables. The International Water Management Institute (IWMI) used a similar water scarcity assessment though on a slightly larger scale across the entire globe. They conducted an analysis that considered the portion of renewable freshwater resources available for human requirements (accounting for existing water infrastructure), with respect to the main water supply.

Indicators of physical water scarcity include: acute environmental degradation, diminishing groundwater, and water allocations that support some sectors over others (Molden, 2007). Countries having adequate renewable resources with less than 25% of water from rivers withdrawn for human purposes, but needing to make significant improvements in existing water infrastructure to make such resources available for use, are considered “economically water scarce” (Seckler et al., 1998).

Freshwater scarcity is commonly described as a function of available water resources and human population. These figures are generally expressed in terms of annual per capita water and mostly on a national scale. The logic behind their development is simply that if it is known how much water is necessary to meet the human demands, then the water that is available to each person can serve as a measure of scarcity and these human demands (Asheesh 2003) (water right) can be identified by the riparian themselves. This can be schemed and established the visions and strategies of the shared water resources (the case of the Palestinians and the Israeli shared water).
4. Water Scarcity Based on Population Growth (the scarcity index)

Combining the population growth with the minimum water requirement (MWR) water gaps have been calculated. Table 1 illustrated the water gaps for some of the Middle East countries. This estimation was made disregarding the impact of the Syrian civil war. Since the war started in Syria millions of Syrians escaped from their homes to the neighbouring counties like Jordan, Lebanon and Turkey, which most likely escalates the water stress in those countries.

Based on the population growth the prediction equation 1 is illustrated as follow:

\[ A_n = A_c \left(1 + \frac{P}{100}\right)^n \]

Equation 1

Where

- \( A_n \): number of inhabitants
- \( A_c \): Current number
- \( P \): Growth percentage
- \( n \): Prediction length

To apply the term of minimum water requirement for all parties the following calculation for water projection for 2015 illustrated in Table 1 was carried out.

Water shortage can be calculated according to water minimum water requirement illustrated in the table 1. The total water requirement used in the table assumes that the riparian are using the potential water resources in equitable reasonable way. Water uses in the area are divided as follows: domestic use 120 m3/C/Y (Shuval 1994) in addition to the demand for the industrial uses is 10% 25% from the total use, and 70% for the agricultural uses. The Israelis currently are using 300 l/c/d in the settlement areas for different purposes.
### Table 1 Minimum water requirement for some of the Middle East countries

<table>
<thead>
<tr>
<th>Area</th>
<th>Population in 2013</th>
<th>Population in 2025</th>
<th>Water resource potential (Million m3/Y)</th>
<th>Total water per capita per year in 2013 (m3/P/Y)</th>
<th>Total water per capita per year in 2025 (m3/P/Y)</th>
<th>Total MWR in 2025 (Million m3/Y)</th>
<th>Total excess or shortage (Million m3/Y)</th>
<th>Growth rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Israel</td>
<td>8</td>
<td>9,5649</td>
<td>1500</td>
<td>187,50</td>
<td>156,823</td>
<td>2152,113</td>
<td>-652,1127</td>
<td>1.50</td>
</tr>
<tr>
<td>Jordan</td>
<td>8.5</td>
<td>13,6088</td>
<td>1100</td>
<td>129,41</td>
<td>80,830</td>
<td>1117,621</td>
<td>-17,6206</td>
<td>4.00</td>
</tr>
<tr>
<td>Palestine</td>
<td>3.88</td>
<td>5,8629</td>
<td>300</td>
<td>77.32</td>
<td>51,169</td>
<td>481,494</td>
<td>-181,4945</td>
<td>3.50</td>
</tr>
<tr>
<td>Syria</td>
<td>18.2</td>
<td>25,3506</td>
<td>10500</td>
<td>576.92</td>
<td>414,191</td>
<td>2081,921</td>
<td>8418,0795</td>
<td>2.80</td>
</tr>
<tr>
<td>Lebanon</td>
<td>5.8</td>
<td>6,8530</td>
<td>3700</td>
<td>637.93</td>
<td>539,906</td>
<td>562,806</td>
<td>3137,1938</td>
<td>1.40</td>
</tr>
<tr>
<td>Turkey</td>
<td>79.4</td>
<td>94,9321</td>
<td>105000</td>
<td>1322.42</td>
<td>1106,054</td>
<td>7796,297</td>
<td>97203,7027</td>
<td>1.50</td>
</tr>
<tr>
<td>Egypt</td>
<td>89.85</td>
<td>135,7695</td>
<td>60000</td>
<td>667.78</td>
<td>441,925</td>
<td>11150,072</td>
<td>48849,9283</td>
<td>3.50</td>
</tr>
</tbody>
</table>

4.1 Water scarcity and the balance of water resources based on the scarcity index calculation

Balancing of the system is accomplished by covering the gaps or preventing the depletion of water resources and monitoring the relation between the inputs and outputs of the system. *Equation 2* is presenting the parameters related to the balancing the system. In the case of depleted national or international river basin aquifers, covering of gaps or controlling and stopping the flow of the shared transboundary aquifer can be an alternative to balancing the situation inside and outside the system on the national and the international level, the scarcity index is an indicator that shows developments in the water situation of a riparian country. It points out the size of the gaps that should be covered or amounts to be returned into the system in order to secure the balance between available water and water demand.

\[
W_{sci} = \frac{W_{av}}{W_{tad}} - 1
\]

*Equation 2*

Where

\[
W_{av} = \text{Average water availability}
\]

\[
W_{tad} = \text{Total water demand}
\]

97
$W_{sci}$: Water scarcity index  

$W_{av}$: Available water resources in shared basin (in the state)  

$W_{tad}$: Total annual demands for all riparian/states  

The scarcity index developed reflects the relationship between the water system inputs and outputs from the system based on population growth in a given time. The scarcity index is expressed as a shortage or gaps (expressed as percentages), as the relationship between the parameters of available water and demands as illustrated in Equation 3. The main element of the equation is population growth, which determines all demand parameters in the water sector.

$$W_{sci} = \left[ \frac{\alpha}{\beta} \exp \left( \frac{\gamma + \delta}{\epsilon + \frac{\lambda}{100-k}} + h + b \right) \right]^{-1}$$

Equation 3

Where:

$W_{sci}$: Scarcity index  

$\alpha$: Input into system (A or B riparian)  

$\epsilon$: Annual domestic demand (m3/c/y)  

$\gamma$: Demand for green areas (m3/c/y), it depends on population growth  

$\delta$: Demand for irrigation (m3/c/y)  

$\lambda$: = Ln (1+r), population growth rate  

$\Delta t$: Length of time for which the estimation is made, the period can be calculated as the difference between the present and the future (t-k);  

$\beta$: Population  

$t$: Present time  

$h$: Yearly evapotranspiration of water, depends on climate of country  

$b$: Water needed to maintain the environment, depends on the length and depth of the water body  

$k$: Estimated losses  

$p$: Industrial demand as a percentage, depends on country structure, its value can be determined as 15-25 percent of the domestic demand
5. Conclusions

Over more than 30 years in conferences and seminars worldwide, experts have been talking about managing the international water resources and improving the cooperation between the riparian parties. All these talks and papers remain a theory. Still the United Nation agreements and conventions remain on paper and not binding any party. The riparian parties are not learning the lessons and there is more and more suffering due to water gaps and water stress. In this paper two mathematical methods were illustrated to help the parties in allocating the shared water resources, the two methods, the minimum water requirement (MWR) and the scarcity index, are just a tools developed to help the riparian to manage their national water resources also.

While the MWR method gives an indication of the shortages for a certain period, the second tool describes in detail the water gap and the way how to save water and how to control and recover the gap.

Since these two methods and worldwide others methods developed to assist the international community to avoid conflicts but few of those riparian are considering and applying them. Several of the riparian are using water as a weapon and water resources as a good to solve country economic crises in the upstream downstream cases.

In global scale a lot of tools and methods have been developed, water engineers finding them as useful tools, but unfortunately the decision makers are not understanding the means of these tools.

The International Joint Institutional Water Framework in the areas of conflict can be also one tool to push the parties for cooperation, the role of the international community as a mediator is to support the decision makers in being active to support their local water authorities to participate in the established joint Institutional Framework and as well as developing the joint capacity building programme.

Clearly, migration to Europe as a consequence of unsustainability and lack of Nexus is a phenomenon affecting the whole world currently. Water rights and international law should be followed and recognized. Cooperation between the riparian should be continued even when players at high political levels are changing. Exchanging the data related to renewable water, operation, demand and services on all levels should be continued.

Implementation of the United Nations’ rules to riparian should be done to all shared water resources without any enforcement limitation.
6. References


Isaac J & Shuval H (1994) Water and Peace in the Middle East, Proceedings of the First Israeli-Palestinian International Academic Conference on Water, Zürich,


Mediation in Construction Disputes: A Review of Turkish Case

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Abstract

Construction contracts often become subjects of disputes, mostly as a result of multiparty, time barred and complex nature of construction projects. Construction disputes are remarkable both by their values and numbers, so it takes money and time to resolve them. Although litigation is the customary way of resolving construction disputes, alternative dispute resolution techniques have been developed to obtain shorter and better dispute resolution. Mediation, for example, as an Alternative Dispute Resolution (ADR) method is viewed as "beneficial, allowing an element of a dispute to be settled, narrowing the disputes or contributing to a greater understanding of the other side's case generally". Alternative Dispute Resolution techniques have been used in countries like UK, USA, for many years and considerable experience have been gained since then. In UK, researches reveal that construction industry is well aware of ADR methods and effectively uses them to resolve disputes. For Turkish construction sector, on the other side, ADR techniques are not as familiar as they are in UK. “Law on Mediation in Civil Disputes No. 6325” was enacted in 2012, though it has been rarely used since then, especially for commercial and construction cases. Using mediation as a dispute resolution method in construction cases is currently an unfamiliar process for Turkey; Industry professionals have little knowledge about mediation, legal professionals approach mediation suspiciously and there is limited knowledge about what could be expected from mediation in relation to commercial cases, especially construction disputes. This paper aims to find out and discuss the developments in use of Mediation as a dispute resolution method for construction cases in Turkey since enactment of Turkish Mediation Law in Civil Disputes. After a review of past literature and researches on mediation as an alternative dispute resolution method for construction industry in Turkey, cases referred to mediation since the enactment of “Law on Mediation in Civil Disputes No. 6325” has been analysed in order to find out current practice. Results reveal the fact that mediation has rarely been used by construction industry until now.

Keywords: Construction Disputes, Mediation, Alternative Dispute Resolution
1. Introduction

Alternative Dispute Resolution methods have emerged as an alternative to traditional litigation due to their ability to provide faster, cheaper and undisclosed solutions to commercial disputes. Although alternative dispute resolution methods such as mediation and arbitration have their roots in ancient laws of Middle East as old as 1800 BC (Boulle 2005) or ancient Far East approaches to dispute resolution (Özmumcu, 2011), modern usages have mainly emerged in early 20th century from USA and Western Europe. Of these methods, arbitration has provided a convenient method to dispute resolution, especially for cases that emerged from contracts related to international commerce. 1958 New York convention has offered the parties who hesitated to go to local courts for disputes arising from international contracts, a relative protection in signatory countries. (1958) Fast globalisation of international markets has been seen as a factor in parties’ willingness to use ADR methods, thanks to their pragmatic character. (Tanrıver, 2006) Growth of international trade from Second World War moved away side by side with growth of usage of Alternative Dispute Resolution processes. Large expansion of capital movements and international investments after Second World War can also be seen as a catalyst for rising interest in ADR methods. (Newcombe and Paradell, 2009) Besides its advantages, arbitration process still constitutes an adversarial process and costs could be high. Gradual, stepped dispute resolution methods have been adopted to overcome these difficulties. Flexible, hybrid methods that provided cheaper solutions for dispute resolution process became popular in commercial as well as construction contracts. (Arıcı, 2012)

Turkish case has followed its Western counterparts in adopting ADR methods to find cheaper solutions for dispute resolution and prevent litigation whenever possible. In context of Mediation, a special legislation was enacted by Turkish Parliament that regulates Mediation in Civil Disputes in 2012. This paper aims to discuss use of mediation in construction disputes by comparing survey results conducted between construction industry professionals prior to enactment of law and official statistics published since enactment.

2. Way to “Law on Mediation No.6325”

One of ADR methods, used as a pre-litigation method, is mediation. Mediation has its origins in traditional Far East dispute resolution culture. Its modern use in construction contracts has emerged first in US and spread to UK (Özmumcu, 2011). It was started being used in early 1990s in UK, though its progress in construction industry has been slow until late 1990s. However, researches conducted in UK on use of mediation reveal that construction industry is now well aware of ADR methods and effectively uses them to resolve disputes. (Gould and King, 2010)

On the EU side, EU Commision has encouraged member and candidate countries towards enacting legislation concerning usage of Alternative Dispute Resolution methods in commercial disputes. In 1999, the Heads of State or Government of the Member States “called for the
creation of alternative, extrajudicial procedures for dispute resolution in the Member States in order to improve access to justice in Europe”. (Europa Press Releases, 2008)

On 2002, EU Commission presented a Green Paper on alternative dispute resolution in civil and commercial law. The objective of Green Paper (2002) was presented as “to initiate a broad-based consultation of those involved in a certain number of legal issues which have been raised as regards alternative dispute resolution in civil and commercial law.” The paper listed the interest in ADR in European Union then, according to three main reasons; increasing awareness of methods, legislation encouraging usage of ADR methods and political priority given by EU Institutions to promote ADR methods.

In 2004, European Commission adopted its Proposal for a Directive (IP/04/1288) establishing rules on civil procedure to ensure a sound relationship between mediation and judicial proceedings. The European Code of Conduct for Mediators was launched in 2004, developed by a group of experts as a self-regulatory instrument, to deal with matters concerning issues on accreditation and appointment of mediators. The Code of Conduct (2004) stated that it was aimed at setting out “a number of principles to which individual mediators may voluntarily decide to commit themselves, under their own responsibility. It may be used by mediators involved in all kinds of mediation in civil and commercial matters”.

On 23 April 2008, European Parliament approved the Directive on certain aspects of mediation in civil and commercial matters. Directive aimed to “facilitate access to alternative dispute resolution and to promote the amicable settlement of disputes by encouraging the use of mediation and by ensuring a balanced relationship between mediation and judicial proceedings.” Directive stated that member states shall adopt necessary laws, regulations and administrative provisions into national law to comply with the requirements of the Directive.

Trends in Turkey have also evolved towards adopting special legislation regulating use of ADR methods. Although, concepts of ADR methods such as mediation, conciliation are seemed as unfamiliar to Turkish Law, Turkish Law contained concepts of compromise, settlement agreement and similar concepts in various laws. However, rather than being regulated under a special law, various laws contained provisions including these concepts. (Özmumcu, 2011)

Since 1990s, in tandem with developments in Western countries, an increasing academic interest in ADR methods could be seen in Turkey as well. Process of adaptation of national laws in compliance with EU Regulations as part of EU accession process and the ongoing academic debates on regulating ADR under special laws opened the way for the “Law on Mediation in Civil Disputes No. 6325”. A commission was formed to prepare draft law and various legal sources were considered in preparation of draft. Draft law was approved in Turkish Parliament in 07.06.2012 and was enacted. Provisions of Draft Law were generally in compliance with EU Directive and before its enactment it was stated by the researchers that the Draft Law “provides the main directions for possible implementations in the Turkish construction industry”. (Dikbaş and İltür, 2008)
3. An overview of “Law on Mediation in Civil Disputes”

“Law on Mediation in Civil Disputes No.6325” stresses that mediation employs systematic techniques, it is a voluntary process and requires the participation of an impartial and independent third person with specialty training. (Clause 2.1) Article 3 defines voluntariness and equality as basic principles of mediation. Confidentiality, one of the most important strengths of ADR methods when compared to litigation is dealt under Clause 4. Article 9 states that mediators are liable of carrying out their jobs carefully and impartially. Article 13 states that resorting to mediation can be done “before filing a law suit or during the course of a law suit” as long as it is done on basis of agreement of both parties. Article 15 provides the opportunity for the parties to choose their own mediation procedures. Parties shall not be bound by strict rules and procedures can be chosen on a flexible basis. Article 17 determines the circumstances when a mediation process is considered to be concluded. Under Article 18, agreement of parties is considered. In compliance with the flexible nature of mediation, no rules on the scope and form of the agreement are imposed on parties.

In respect of agreement, it is stated that unless the parties will desire the agreement to have the force of a verdict, the document will be subject to general provisions. Article 19 requires that Ministry of Justice “shall keep the register of the persons who attained the authority to mediate in private law disputes”. Under Article 20, only persons who hold an undergraduate law degree with at least five years of experience are allowed to register as mediator. Article 22 determines that any person willing to register as a mediator shall receive a “mediation training”. Article 33 deals with the situations when the rule of confidentiality stated in Article 4 is violated. Violation of confidentiality may result in imprisonment up to six months and prosecution of the offence depend on complaints.

4. Mediation in Turkish Construction Industry

Research conducted in 2008 by Dikbaş and İlter reveals that Turkish construction industry was unaware of the mediation as an ADR method. Findings at the time revealed that prior to enactment of Mediation Law, %85 of respondents of research have never been involved in mediation process as part of resolving disputes arising from construction contracts. On the other hand, Dikbaş and İlter point the fact that 90% of the respondents said that they would consider using mediation.

Another survey conducted prior to enactment of Mediation Law seems to support these results. According to the survey, conducted in 2010 by Gül and Acar, participants from construction industry stated that they use mediation as a dispute resolution technique between never and rarely for disputes arising in international markets and they rarely use mediation for disputes arising in local markets.

Another data obtained from construction industry professionals in 2012, by Arıcı, reveal the level of knowledge on ADR methods. Survey was conducted in 2012, in the same year with
enactment of Mediation Law. According to survey, public officials working in construction projects have little to medium knowledge on mediation. For those working on contractors, knowledge of mediation seems to be between medium to high. The same survey reveals that public officials have been involved in a mediation procedure between “rarely to sometimes”. Contractors on the other hand have responded that they have been involved in a mediation process in past projects between “never and rarely”.

Findings of the surveys conducted by Dikbaş and İlter (2008), Gül and Acar (2010) and Arıcı (2012) seem in line with each other. It seems that level of knowledge has slightly increased from 2008 to 2012 while mediation experiences of industry participants have been rare.

More than 3 years have passed since the enactment of Mediation Law and Department of Mediation established under Ministry of Justice after the enactment of legislation, publishes the statistics about mediation regularly since then. Statistics reveal that in only 1053 cases mediation has been chosen as a method for dispute resolution. When compared with huge number of cases dealt in civil courts, 2,024,056 new cases were brought to civil courts while number of open cases reached as high as 3,293,090 over the year, number of disputes referred to mediation seems marginal.

Number of cases referred to mediation, on the other hand, seems to increase rapidly; only 7 cases were referred to mediation in December 2013, number increased to 196 in 2014 and 850 in 2015 until the end of October. This rapid increase may be parallel to the increase in rising number of mediators and increasing awareness in public as a result of efforts to promote ADR by using advertisements, panels etc.

Table 1: Number of civil cases referred to mediation from December 2013 to October 2015 in Turkey

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases</td>
<td>7</td>
<td>196</td>
<td>850</td>
</tr>
</tbody>
</table>
According to official statistics, construction industry hardly seems to consider using mediation until now. Number of cases concerning residential building contracts between landlord and contractors referred to mediators are only four. Of these four cases, two were referred in 2014 and two were referred in 2015. Three of these cases were resolved with an agreement between parties, while one case could not be resolved by agreement.

Statistics are published according to the subjects of cases and cases under headings “compensation” may involve disputes related to construction contracts. However, only 82 cases arising from damages were referred to mediation and this constituted an overall %8 of total cases.

Statistics reveal the fact that 70% of total cases referred to mediation were cases related to labour law and 15 % were related to copyrights. This large number of cases containing disputes arising from employment contracts might be commented as a continuance of familiar practices since the Labour Law contained provisions regarding conciliation even before the enactment of Law on Mediation in Civil Disputes.

Table 2: Distribution of total cases referred to Mediation in Turkey according to their subjects

<table>
<thead>
<tr>
<th>Total Cases Referred to Mediation in Turkey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour Cases</td>
</tr>
<tr>
<td>Copyright Cases</td>
</tr>
<tr>
<td>Damages</td>
</tr>
<tr>
<td>Residential Construction Contracts</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>
5. Conclusions

This paper aimed at getting a balance of Turkish Mediation practice, in the context of Turkish construction industry, after the enactment of Law on Mediation in Civil Disputes in 2012. Pre-legislation researches and post-legislation statistics were compared to provide an overview of current situation.

Surveys conducted by researchers in 2008, 2010, 2012 respectively showed that Mediation practice was unfamiliar for construction industry. However, slight increase in awareness prior to enactment of legislation and positive approach of industry participants towards using ADR and mediation in future disputes provided a suitable background for future of ADR and Mediation in Turkey.

However after three years of mediation experience, an analysis of statistics reveals the fact that mediation is still an unfamiliar and unknown process in Turkey. Besides large number of cases referred to courts each year, a marginal number of cases were referred to mediators. Of these cases, construction cases remain insignificant in portion, which indicates the unwillingness or unfamiliar approach of the industry participants towards using new methods in dispute resolution.

On the other hand, rapid increase in cases referred to mediation each year, increasing awareness of society due to strong support of public bodies, time and cost problems arising in arbitration processes as well as in litigation and the trend that was followed in Western countries all point to an increased use of mediation by construction industry in future.
References


9. Law on Mediation in Civil Disputes No 6325 with Comparisons (2012)


Housing Dispute Settlement System in Japan; Part 1 - The housing dispute settlement system and the background to the legislation

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Abstract

In this report, we summarize the Japanese system for settlement of housing disputes. We will detail the background of the legislation and the establishment of the system, along with its current state and operational results.

We posted two related abstracts to WBC16. In the first abstract, we report on the system’s background and processes. In the second, we discuss the operational results and present conditions of the system application.

Keywords: Housing defect, Housing dispute settlement, ADR, Legal & Technical advice, Consumer

1. Introduction

This report introduces the Japanese system for the settlement of housing disputes.

We mentioned Japan's housing situation and the need for a system for settling housing disputes. Next, we will outline the origins of the housing dispute settlement system Japan. Finally, we provide an overview of the system for settlement of the housing disputes in Japan.

We will also mention two related services that contribute to housing dispute resolution – telephone consultation and face to face expert advice that lawyers and registered architects attend.
2. Japan's housing situation and the need for a system for settling housing disputes

2.1 Japan's housing situation

From the viewpoint of the housing stock, the total number of housing units in Japan is 61 million units according to the results of 2013 survey\(^1\) by the Ministry of Internal Affairs and Communications, Bureau of Statistics. This includes 52 million residential units, which consists of 29 million detached houses and 23 million apartments. Many detached houses and low-rise apartments, totalling more than half of Japan's housing units are wooden structures.

From the viewpoint of newly supplied houses, approximately half of the dwelling units in Japan are built by big housing companies, with the remainder built by small and medium-sized housing companies. In terms of the number of housing companies, 99% of the whole housing companies are small and medium-sized companies and 1% are big housing companies in the market.

Figure 1 shows the number of houses built in Japan\(^2\) every year since 2000. In the 5 years after the 2007-2009 slump, which was due to the subprime mortgage crisis, 800 to 900 thousand newly units have been built. The ratio of apartments is approximately half of the total houses.

![Figure 1: An annual number of newly built houses in Japan 2000-2014](image)

There are various trial estimations\(^4\) of the service life of houses. Figure 2 shows the data estimated by the Ministry of Land, Infrastructure, Transport and Tourism as an example of the service life of houses in Japan\(^3\). The average service life of houses in Japan is shorter than that in the US and the UK. This means new family builds new house and their children’s generation don’t succeed to stay nor doesn’t another family stay at the house. The following reasons may be significant.
- Japanese people strongly prefer new houses to existing ones. (e.g. in 2008 fiscal year 13.5% of the housing transactions was for existing houses.)

- There is a tendency to treat that the value is lost for existing houses over a certain age in Japan

- Implementation of future renovation is not considered in the initial design concept of houses

- During the high economic growth period, people paid much attention to the quantity than the quality. The renovation of less performance houses needs much more cost.

![Figure 2: The average service life of houses](image)

2.2 The need for the system for settlement of the housing disputes in Japan

The following three features are key differences between houses and other goods and services.

1. Houses are very expensive. For many people it is the most expensive purchase in their life. Usually they will buy their own house with the help of a long-term mortgage of 25 or 35 years. If the purchased house had the defects, the purchasers feel the great disappointment and would like to know how to handle.

2. Despite the largest purchase of their life, the homebuyer usually has less knowledge or information about the construction quality of the house.

3. Houses are built by combining a variety of materials and construction methods. Because technologies and terminology related to architecture are relatively complex, the consumers do not generally understand them. The purchaser is trying to verify the construction
quality, but because the construction work is carried out over a long period, and because access to some areas (such as sub-basements and roof spaces) is difficult it is not feasible for the consumer to check all of the components and processes. Additionally, there are a number of elements that cannot be tested in a non-destructive way. Verification that design specifications have been met in the actual building is very difficult.

In Japan, because the service life of houses is short, residential new construction opportunities are greater than the other countries. For the above reasons, to resolve disputes related to housing, a neutral expert is desirable.

Dispute resolution has traditionally meant a court trial. In general, court proceedings are slow and expensive. Litigation related to architecture has a strong tendency to take longer than the normal civil litigation. The reasons for prolonged proceedings are in part due to the time it takes time to verify the professional knowledge and to separate objective evidence from emotional conflict (such as the owner’s feelings for their own house).

There are alternative dispute resolution ADR procedures that seek to solve conflict outside the court system. ADR is the dispute resolution process that experts such as lawyers encourage, where resolution is achieved by agreement between the parties by involved.

Conflict resolution in housing requires the participation of both lawyers (as legal experts) and technical experts such as architects – who provide knowledge of the technical aspects related to the building. ADR is a simple procedure and can provide a rapid resolution when compared to a trial. We can say that the advantage of the ADR is it allows for agreement between the parties without disclosing that disputes have occurred.

3. The background of Institutional establishment and legal basis

3.1 The background of Institutional establishment

The housing dispute settlement system in Japan is supported by “The Housing Quality Assurance Act HQAA” and "The Act for Secure Execution of Defects Warranty Liability under HQAA”.

Prior to enactment of “The Housing Quality Assurance Act HQAA”, housing defects have been considered under the provisions of the Civil Code. The provisions of the warranty for the building construction contracts are stipulated in the Civil Code Article 634 and 638. The article 638 defines the warranty period for new houses. The defined period is five years for buildings of light structure (e.g. wooden buildings), and ten years for building constructed of
reinforced concrete or similar materials. The provisions of the warranty for the sale contracts are Civil Code Article 570 and 566.

Contracts with different warranty periods were also allowed by the freedom of contract principle. This act has since been defined as invalid as it could adversely affect a purchaser.

Around the end of the 20th century, many poorly-performing houses were sold. It became the social problem. As a result “The Housing Quality Assurance Act HQAA” was passed, calling for the establishment of a House Performance Indication System, Housing Dispute Resolution System, and Special Case for Defects Warranty Liability.

Several years later, the seismic building code scandal happened. It was discovered that the structural capacity of some multiple-dwelling complexes had been deliberately lowered. According to the ruling of HQAA, repair expenses should be demanded by the house owner and met by the vendor. But some house vendors went bankrupt before being able to meet these demands. As the result, many consumers could not receive compensation for housing defects, and some people were not only obliged to continue to pay the remaining mortgage, but also lost their houses in the multiple-dwelling. Following this social problem, a policy to secure the compensation was introduced.

3.2 “The Housing Quality Assurance Act HQAA” and assessed houses

“The Housing Quality Assurance Act HQAA” was enforced in April 2000. The main details of this act are outlined below

1. 10-year warranties for principal structural parts and parts used to prevent rainwater leakage became mandatory in new housing sales and constructions contracts

2. Common rules for housing performance indications were established by the government

3. A housing dispute settlement system was introduced

The house vendors and contractors of new houses had to bear the warranty responsibility of 10 years for the elements necessary for structural resistance and the elements used to prevent rainwater leakage. The Act is limited to the important parts required to maintain structural rather than targeting all parts of the house. Figure 3 shows an image of the applicability of defect liability under the Act. The left and right figures show applicability for a detached house and co-housing, respectively.
The mandatory 10-year guarantee determined was accompanied by the concept of optional labelling. A new house which has been evaluated for performance is called an “Assessed House”. Figure 4 shows the number of households receiving residential delivery of a construction housing performance evaluation report\(^7\). The number of assessed houses increased steadily from establishment of the evaluation system in 2000 until 2007. Since then a relatively constant 20% percent have received a construction house performance evaluation. Under the HQAA, disputes related to the contract should be solved by alternative dispute resolution (ADR) where possible. Approximately 20% of new houses apply the labelling, which has the benefit that both the house vendor and the purchaser are guaranteed the option of using ADR as a dispute settlement system.
3.3 "The Act for Secure Execution of Defects Warranty Liability under HQAA" and insured houses

In April 2008, "The Act for Secure Execution of Defects Warranty Liability under HQAA" was enforced. A housing defect liability insurance scheme and an associated dispute resolution system were introduced. Eighteen months later, in October 2009, mandatory measures were enacted to ensure that new house suppliers have adequate financial resources. The Act demands that suppliers either participate in deposit schemes or purchase defect warranty insurance. New houses are covered by housing defect liability insurance called an “Insured house”.

Figure 5 indicates the annual number of dwelling units and the percentage of insured houses. The number of insured houses has increased sequentially from 2008 to ensure measures are mandatory of resources. By 2010 (the third year after the introduction of the system) approximately half of new houses were covered by housing defect liability insurance.

The Ministry of Land, Infrastructure, Transport and Tourism reported the share of types of financial resources that housing suppliers have selected to use. Figure 6 shows the results. More than 99% of housing companies have chosen insurance. The deposit schemes are used by less than 1% of housing companies. Taken together with the fact that the ratio in the number of units is roughly 50:50, the deposit scheme means that there is a strong tendency for many leading companies use deposit scheme.

Figure 5: An annual number of newly built insured houses in Japan 2008-2014
The new ADR scheme is also applied to “insured houses”. Ignoring overlaps, the proportion of insured houses is 2.5 times greater than that of assessed houses, and housing defect warranty insurance will cover more than 99% of the companies. So, one of the notable points of this act is the expansion of the ADR scheme has included many small and medium-sized enterprises that have a relatively weak financial base.

3.4 The system for settlement of the housing disputes in Japan

The dispute resolution scheme that is applied by the two laws is the same. The overall flow for the system for settlement of the housing disputes in Japan is shown in Figure 7. This scheme is private type ADR which does not receive the financial support from the government.
Based on the HQAA, the 52 bar associations in Japan are designated as housing dispute settlement bodies. Housing dispute settlement (for assessed houses and insured houses), disputes concerning sales and constructions contracts are available when they occurred. This housing dispute settlement treats the very broad issue, such as agreement, payment and delivery, post-purchase incidents and so on.

If the dispute about the contract between the vendors-purchasers and the contractees-contractors relating to assessed or insured houses has occurred, the parties will be able to apply for the dispute settlement to the housing dispute settlement bodies. On acceptance of the application, housing dispute settlement begins.

Lawyers and registered architects who are neutral fair third parties participate in housing dispute settlement as committee members. The committee promotes solution by mutual agreement. In the process of dispute resolution, a hearing will take place or the parties’ documents will be examined. If necessary a site survey and appraisal will be performed.

The housing dispute settlement support center (the support center) is the only institution has been specified in Japan by the provisions of the Act. The support center will introduce a housing dispute settlement system to the questioners when the support center has received a consultation on assessed and insured houses. Also the support center introduces a nearby Bar Association to the parties as required.

The support center provides a number of services including the subsidy required for dispute settlement cost, advice based on similar previous cases and judgements, provision of building technology information.

4. Related services that contribute to the housing dispute settlement

This chapter introduces the two services to support the housing dispute settlement.

4.1 Telephone consultation

A telephone consultation service is provided for consumers who suffer from anxiety or trouble related to the acquisition or renovation of houses. It covers both technical and legal issues, Telephone counsellors are registered architects. Answers to legal issues are provided by a resident lawyer. Telephone consultation is available on weekdays except for the year-end and New Year holidays. Consultation will have been carried out in a manner to reduce the burden of telephone charges. Figure 8 shows the flow of telephone consultation8).
4.2 Expert advice

Services of the face-to-face consultation in cooperation with 52 bar associations across Japan are provided to the people who would like to further help with problems related to the assessed houses, insured houses or housing renovation. This service is free; lawyers and registered architects have attended, and give advice from both the legal and technical sides. This consultation is called expert advice. In the face-to-face consultation, participants can bring the relevant documents such as the contracts, the drawings and the photographs, and advice is provided on the basis of those materials. Figure 9 shows the flow of expert advice.  

Figure 8: Housing consultation flowchart of telephone consultation

Figure 9: Expert advice flowchart
5. Conclusions

Part 1 was an overview of the system of private type of housing dispute settlement in Japan. We described the condition of Japanese houses as a background to institutional establishment and related services that contribute to the housing dispute resolution. We illustrate the application performance of the system in Part 2.

References

1) Ministry of Internal Affairs and Communications, Bureau of Statistics web site

2) Ministry of Land, Infrastructure, Transport and Tourism MLIT web site
   (available online http://www.mlit.go.jp/common/001088648.pdf [accessed on 30/11/2015])

3) Ministry of Land, Infrastructure, Transport and Tourism MLIT web site
   (available online http://www.mlit.go.jp/common/001082620.pdf [accessed on 30/11/2015])


5) Ministry of Justice, Japanese Law Translation web site
   (available online http://www.japaneselawtranslation.go.jp/law/search_nm/?re=02 [accessed on 30/11/2015])

6) The Building Center of Japan BCJ “A Quick Look at Housing in Japan June, 2015”, pp49-50, BCJ
   (available online http://e2102.secure.jp/~e2102002/form/mail.cgi?id=quicklook02 [accessed on 30/11/2015])

7) Center for Housing Renovation and Dispute Settlement Support CHORD web site
   (available online http://www.chord.or.jp/tokei/pdf/soudan_web2015.pdf [accessed on 30/11/2015])

8) Center for Housing Renovation and Dispute Settlement Support CHORD web site
   (available online http://www.chord.or.jp/english/support.html [accessed on 30/11/2015])

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Abstract

In this report, we summarize the Japanese system for settlement of housing disputes.

We will detail the background of the legislation and the establishment of the system, along with the current state of the system and operational results.

We posted two related papers to WBC16. In this second paper, we discuss the operational results and present conditions of the system application.

Keywords: Housing defect, Housing dispute settlement, ADR, Legal & Technical advice, Consumer

1. Introduction

This report introduces the Japanese system for settlement of housing disputes.

We previously mentioned Japan's housing situation, the need for the system for settlement of the housing disputes and the background of the housing dispute settlement to the legislation in part 1.

In this paper we show the results of an analysis of data that collected in the process of providing the housing dispute settlement service, the telephone consultation service and expert advice.
2. Assessed houses and Insured houses can use the housing dispute settlement

2.1 Assessed houses

“The Housing Quality Assurance Act HQAA” was enforced in April 2000. Under the act vendors and constructors of new houses have to bear responsibility for the elements necessary for structural resistance and the elements used to prevent rainwater leakage via a 10-year warranty. Figure 1 shows an image of the applicability of defect liability under the Act. The left and right figures show applicability for a detached house and an apartment house, respectively.

![Diagram of Assessed Houses and Insured Houses](image)

*Figure 1: Part of the house that is the subject of the Act*

New houses utilising Housing Performance Indication System are called an “Assessed House”. Figure 2 shows the number of the houses receiving the evaluation reports. The number of assessed houses increased steadily from the establishment of the evaluation system in 2000 to 2007. After that a relatively constant 20% percent have received the evaluation reports. The HQAA enables both vendor and the purchaser of an “assessed house” to utilise newly introduced ADR as a dispute settlement system.
2.2 Insured houses

New houses are covered by housing defect liability insurance called an “Insured house”.

Figure 3 indicates an annual number of insured houses and the percentage against newly built houses. The number of insured houses has increased sequentially from 2008 to ensure measures are mandatory of resources. By 2010 (the third year after the introduction of the system) approximately half of new houses were covered by housing defect liability insurance.
3. The application results of the system for settlement of the housing disputes in Japan

The overall flow for the system for settlement of the housing disputes in Japan is shown in Figure 4.

![Figure 4: Dispute settlement flowchart](image)

Figure 5 shows the dispute settlement filings after the system started. The first dispute application for an assessed house was processed the fiscal 2001, and number of applications has then gradually increased. Between 2005 and 2009, there were 20-30 requests per year.

"The Act for Secure Execution of Defects Warranty Liability under HQAA" was enacted in 2008, and as a result insured houses became subject to the same dispute settlement scheme as assessed houses. This has led to a significant increase in dispute settlement filings from fiscal 2010. In future, continuous increase in the number of applications predominantly from insured houses will be expected.

![Figure 5: Dispute settlement applications received 2000-2014](image)
Figure 6 shows the number of the dispute settlement applications after the process of the expert advice and the proportion against all dispute settlement applications. The proportion indicates an increasing trend.

![Graph showing the number of dispute settlement applications after expert advice 2010-2014](image)

*Figure 6: Number of the dispute settlement applications after expert advice 2010-2014*

Figure 7 shows the results of the dispute settlement process for a total of 684 cases processed by 2014. 53.5% (366 cases) have been resolved by mutual agreement.

![Pie chart showing the results of dispute settlement (n=684)](image)

*Figure 7: Results of dispute settlement (n=684)*

Figure 8 shows a length of the conflict resolution process. The greatest proportion of cases took between three and six months, although the average case took 6.6 months (close to our target 6 month timescale). The number of consultations for each case is shown in figure 9. Around two-thirds of cases (66.5 percent) required less than 5 times consultations. The average was 4.7 times.
Figure 8: Trial period (n=684)  Figure 9: Trial number of times (n=684)

Figure 10 shows the desired resolution when the application filed. The Resolution in the resolved cases (n=366) are shown in Figure 11.

The most common outcome desired was “repair”, followed by “repair plus compensation” and “compensation only”. The most common outcome was “repair” followed by “compensation” and “repair plus compensation”.

Figure 10: Initial hope (n=684)  Figure 11: Agreed solution (n=366)

The issues in dispute are listed in Table 1 & 2. The most common problem in detached houses is “Cracking” whilst “Noise” issues are most common in apartments.
4. The application results of the related services that contribute to the housing dispute settlement

This chapter introduces the two services that support housing dispute settlement.

4.1 Telephone consultation

The telephone consultation service, covering both technical problems and legal issues, is provided for consumers who suffer from anxiety or trouble related to the acquisition or renovation of housing. Figure 12 shows the flow of telephone consultation.
Figure 12: Housing consultation flowchart of telephone consultation

Figure 13: A new number of telephone consultations 2000-2014

Figure 13 shows the corresponding record of telephone consultation. In the first year (fiscal year 2000) of the service, about 4000 calls were handled. The number of consultations increased after the enforcement of "The Act for Secure Execution of Defects Warranty Liability under HQAA" in 2008 and exceeded 26,000 in the fiscal 2014. In recent years the support center has been receiving telephone consultations for over 100 new cases per day. Approximately 60% of consultations relate to new houses, with the remaining 40% being consultation about renovation.
Figure 14 shows a breakdown of the consultations about housing issues for 2014. The pie chart on the left shows the reasons for the consultation across 16,831 incidents. The pie chart on the right shows the percentages for assessed and insured houses. The group on the right shows a 10% greater proportion of consultations relating to troubles. This trend was similar in the fiscal 2012 and 2013.

Figure 14: The proportion of telephone consultations about trouble on 2014

4.2 Expert advice

Face-to-face consultation services are provided in cooperation with 52 bar associations across Japan. Figure 15 shows the flow of expert advice.

Figure 15: Experts advice flowchart

Figure 16 shows the number of the expert advice consultations since they were introduced in April, 2010. The number of consultations has increased every year to more than 1,800 in the fiscal 2014. The expert advices concerning the renovation accounted for 50% of the cases.
Figure 16: An annual number of expert advice 2010-2014

Figure 17 indicates the number and the percentage of people using expert advice that had previously received a telephone consultation. Of the 178 cases relating to assessed housing, just 22% had previously had a telephone consultation; even fewer of the 744 insured housing cases (just 14.2%) used telephone consultancy first. Cases to proceed to expert advice through the telephone consultation are a minority. There is a possibility that telephone consultations are to contribute to the prevention of housing dispute.

Figure 17: The number and proportion of the expert advices after telephone consultations

Figure 18 shows the reason for the use of the expert advice. The total is greater than 100 percent, as multiple reasons can be given. Nearly 90% of users chose the reason that lawyers and architects have attended, giving the user expert advice from both legal and technical perspectives.
Figure 18: Why the expert advice used (multiple choices)

Figure 19 shows how satisfied users are with expert advice consultations. User satisfaction is considered high based on the fact that 90% were “Highly satisfied” or “Satisfied” with the service.

Figure 19: User satisfaction of expert advice (n=1345)

In the case of consultation on assessed or insured houses, the support center will introduce a housing dispute settlement of the Bar Association in response to the consultation.

5. Conclusions

Part 2 has shown the results of the housing dispute settlement, the face-to-face expert consultation and the telephone consultation as well as the cause of the housing dispute and the satisfaction of the users. The users of all three services have been increasing year by year. This means that the Center For Housing Renovation and Dispute Settlement Support CHORD has accumulated the data of those three services. Under the condition that the secret of these data should be kept, the accumulated huge data should be analysed and utilised for the housing consumers and suppliers to prevent housing disputes and to do the prompt and effective dispute settlements.
References


SECTION 2

Stakeholder involvement and satisfaction
Housing association objectives and the results of indices in the Netherlands

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Abstract

Housing associations make too little a contribution to Society, the government has to step in too frequently because of maladministration, and the associations’ executives are often unaware of the far-reaching impact of their decisions. These are the conclusions of new academic research conducted by Jan Veuger of Rotterdam School of Management, Erasmus University (RSM). In his dissertation, he asserts that in numerous cases there is no correlation between social and financial objectives. The Dutch House of Representatives debated the results of the report ‘Ver van huis’ from the Parliamentary Committee of Inquiry on Housing Associations in early December 2014. After extensive exploration of the literature and PhD studies on the period from 2005-2009, the research design inspired based on the grounded theory, which has a certain bias as a result of the extensive literature study. In the line of thinking of the grounded theory, interviews with directors contacted more or less uninhibited according to a narrative method. Afterwards these interviews, independent of the researcher, thematic and labeled by a single Delphi method have been submitted to an expert group which created a storyline. The results of this Delphi method were submitted to a peer group of directors. The conclusions were presented in a survey to 60 selected directors and the subsequent conclusions. There has thus been more than a triangulation of research than just interviews, Delphi method and survey. Hypotheses are thereby omitted because of the difficulty of fitting in within the chosen research design inspired by grounded theory. At his request Stef Blok, Minister for Housing and Kingdom Relations, has received the thesis Material Immaterial (Veuger 2014) on December 4, 2014. On December 11, 2014, the Minister decided to change its proposed policy through the establishment of an inspection model in which the financial and social objectives of the corporations are tested and assured, with the Minister as the final responsible. The parliament has unanimously agreed.

Keywords Control – housing associations – social values – board – MSCI IPD index

1. Introduction: in the eye of the hurricane

Before starting the study of control and appreciation of housing associations there was in my opinion a real chance that housing corporations might actually end up in a danger zone of legitimacy and the right to exist. The question I then asked about the contradictions there are in the social values of housing associations that affect the way they are governed, is still relevant. The reputation and trust in housing corporations has also decreased dramatically in recent years. The question is what is really going on at housing associations about control and appreciation.
An extensive study of literature and (PhD) studies on the period from 2005 until 2009, with a present potential of 720 professional magazines in the field of housing and real estate, 149 articles were found to be relevant with the inclusion criteria: values, control and corporations. Therefore are these 149 articles all included in the bibliography. From these articles emerges a picture about values and control of housing associations which are mostly financially oriented and much less socially. Reason to start a PhD research to get a grip on societal values and control of housing associations. After the extensive exploration of the literature and (PhD) studies on the period from 2005 until 2009, the research design was inspired on the basis of the grounded theory, which has a certain bias due to the extensive literature study. Following the line of thinking of the grounded theory, interviews with directors, have started, more or less unprejudiced, according to a narrative method. Afterwards these interviews were, independent of the investigator, thematically labelled by a single Delphi method - appropriate in the line of grounded theory - and submitted to an expert group creating a narrative. The results of this simple Delphi method have been submitted to a peer group of directors. Afterwards these conclusions were presented in a survey to 60 selected directors to raise the subsequent conclusions. So there has been more than a triangulation of research by interviews, Delphi method and survey.

After this introduction, this article is based upon the methodology of the survey, the results of research on control of housing associations in the Netherlands, the European context of housing associations and final justification of the IPD Netherlands Housing Property Index over the policy of housing associations about a certain period of time in terms of returns.

2. Methodology

The grounded theory is a method developed in the 1960s by Glaser and Strauss (1967). The emphasis of the method is to generate a theory based on data. Because not expressly in advance is to determine what the missing operating and monitoring questions are, it is of interest to collect data to a saturation point because it may be assumed that there is no more new information to generate on this topic. The grounded theory is flexible and is able to highlight questions that have not been previously asked. Fed by the pragmatic legal theories, ethnographic research – bringing information about dividing lines between different communities – and explicitation of qualitative methods, Glaser and Strauss intended to codify procedures. They can be summarized by reasoning, to handle more deliberate on the one hand and, on the other hand, they become to theory. Glaser and Strauss's approach indicates that the quality of a theory can be evaluated by the process by which a theory is constructed.

Methodical over a period of five years of literature, ten years of stakeholders, instruments and behaviour and a hundred years of housing corporation history, the developments in the field of value thinking and the governance of housing corporations have been studied. This qualitative study with a positivistic approach of values and governance of housing corporations has answered the research question What social values underlie social housing and are there contradictions that affect the control of a
social housing corporation? The grounded theory is the research method chosen as a line of thinking, because that method emphasises the generating of theory-based data. Because it is flexible, it enables us to highlight questions that have not been asked before. These questions have been evaluated by the process with which the theory of this study has been constructed.

**The Process of this Research**

This research inspired by the grounded theory follows an inductive method for development of that theory. This process of collection of data about thinking in terms of values and control begins with the open encoding – a combination of the concepts of values, control and corporations – data in the professional literature in the field of opinion and scientific research over the period of 2005-2009. The found fragments are reduced to a number of concepts such as those in the relevant chapters are examined. By the interaction of comparisons of terms a smaller number of concepts is created to which different dimensions can be awarded. This is leading to a certain saturation process. By the relating of concepts arises a theory that flows into a storyline. This storyline is surrounded by tables and overviews for a rich presentation of evidence and a clear statement of arguments.

The final result of this research is a description of missing operating and monitoring questions, the collected and saturated core concepts that explain certain events. By this methodology an understanding of patterns and processes is revealed. This makes clear how a group of people, through their social interactions, their reality and defines acts’ (VOC 2010:17). Not the theory is leading, but the practice on which research is being done. The choice for this theory formative research is has been made because the research question requires insight in missing operating and monitoring questions. The answer need not to be found in the existing practice or theory, but lies in not yet asked questions that can offer a solution in the area like Einstein this describes as ‘the actual problems cannot be solved at the same level of thinking, in which we were when we created them’. The power of the grounded theory is that it is detailed in the descriptions of the method of data analysis and gives a possibility for the research draft anchoring and accountability. This allows that difficulty of validation and generalization can be parried. Later on additional literature research and findings in the study are faced with the insights from the theory. By this method of constant reflection additional insights in the analyses are created; the dialogue between theory and practice and enhances the consistency of the description of this research to understand. The process of this research is from step to step, where each step validity is ensured. The different phases, with underlying steps of this study are included in the following figure, inspired by Pandit (1996). The phases and steps are related to the chapters of this study.

**3. Control of Housing Corporations in the Netherlands**

Why this qualitative research into control of housing associations? To understand and to discover patterns about the how and why of the operation of housing associations in society as they do now. This qualitative research is about the search for ideas, backgrounds, motives, resisters and rationale and is therefore suitable for the following central question to answer: are there contradictions in the social values that underpin housing associations that have an impact on the way they are governed? Partial questions here are: (1) how can be arranged that the social
objective behind the values becomes transparent?, (2) what is that social enterprise Housing Corporation, what is its role in society and what is social real estate?, (3) how can values and orientation of corporations on the basis of the criterion be of social relevance?, (4) how does the executive now operate in practice, does he usefully apply operating models and the theories about Corporate Real Estate Management (CREM), which are based on the commercial sector?, (5) how does innovative control of housing corporations look like? and (6) how to get an insight in operating questions about social real estate?

Methodical literature over a period of five to ten years, instruments and stakeholders behavior and hundred-year history of the housing corporations, the developments in the field of values in thinking and driving housing corporations are examined. This qualitative research into values and control of housing associations, the research question answered. The grounded theory is chosen as a line of thinking for the qualitative research method because the emphasis is on generating the data based on theory. By being flexible, being able to highlight questions that have not been previously asked. These questions are evaluated by the process by which the theory of this study is constructed.

In this review values are examined in relation to social real estate. The social real estate as an object is made up of material value. This material value is necessary for the commercial power of the Corporation, with which they control public real estate and the organic value. The social real estate is a prerequisite for the operation of the Corporation, the social value. Particularly in the relation of public real estate and the Corporation is that they can exist separately, but the Corporation is not able to operate without social real estate. The social real estate retains its values without the Corporation, but not the other way around. The combination in its entirety creates an intellectual value. Corporations are focused on creating social value by deliberately allocating resources for social objectives and want to preserve, restore and refresh this value. Social integration and planning of the sector are important in determining which behavior is preferred. The Corporation executive appears however to stick to its own accumulated power and can hardly be influenced. Looking inside the Organization, it is noticeable that the investment behavior within the Corporation is generally in line with the personal conduct of the executive. Performance indicators as power and money, in which the executives are neglecting the current financial crisis, are still leading.

It is also not about a new organizational infrastructure, but above all improving the effectiveness, efficiency and financial position fueled by the pneumonia – in the spirit of the work – related to the statement of the Corporation. The interpretation of this and the raison d’être of the Corporation can be found in a more offensive cooperation, new forms of mutual solidarity and thriving on the added values of the Corporation. In improving the social objectives of corporations three partly domains are to be distinguished: (1) housing the primary target group, (2) investing in the living and housing environment and (3) contributing to the socio-economic developments of districts. In doing so, its financial position, efficiency, effectiveness, transparency and planning of value-drivers are of importance. The Corporation also has three balanced values: (1) the fixed value (continuity), (2) the direction value (initiator) and (3) the profitability value (the mutual influence of neighborhood quality and real estate value translated into social and financial value). In the task demarcation are thus the effectiveness and efficiency of importance. It comes to the maximization of the financial value, but on maintaining a
minimum acceptable ability. A more conscious control on social returns is a prerequisite for effective and efficient work. The effectiveness of housing corporations can mainly be considered to be a responsibility of the State and the municipalities.

In practice the Board is not controlling in coherence between financial and social returns and trust. CREM as theory can play a role in conjunction of values. In contrast to criticism of corporations, it is professionalizing, but the question is whether they are sufficiently keeping the focus on the sustainability of professionalization. Otherwise chaos is organized. Why worrying about the instrumentation for comparisons and why is it not possible to have a quick fix arranged by the Corporation directors among themselves? The answer to this lies in three reasons: (1) the quality and reliability of the information flows is not on the desired level, (2) the Government is not steering and leaves it to the perfect free market operation and (3) the discipline of behavior of the Corporation which leaves much to be desired. Striking is that an explicit evaluation of the destination goal, related to previous objectives, is rarely measured. Could be assumed that this is not about rational led settings but to a controlled chaos. By Corporate Real Estate Management (CREM) the real estate portfolio can be in line with the needs of the core activity of the Corporation. The aim of this key action is not new. This creates an optimization of the added values of the result. A values-based real estate strategy not only enables a competitive Corporation, but also with a moral strategy.

The multidisciplinary nature of public real estate management is not a bottleneck as far as clear definitions and observations are available. If hard and soft skills are not related to each other they build a bottleneck in the total control of a corporation and its reporting on them. If a task and the measurement of it not defined and organized, controlling is of no use and correcting is not possible. The dimension time affects value concepts from a historical context. Changes of value definitions affect the rating and thinking in those concepts. In addition, rating is depending on the one that defines quality of life and how it should be appreciated. Real estate is a social challenge with varying meanings for people involved. The corporation is a method of financing and value in the sense of usefulness. The orientation on change has affected the innovation and agility of the Corporation and on different values. Orientation to change should be seen as proof that the Corporation is able to achieve real renewal of the built up achievements, to consolidate and enhance these. If she is able to do this, it will lead to a richer Corporation where everyone can support with new developments and ideas. The future leadership of a corporation in the Corporation world is not determined by the possession of assets, but how it can focus these funds on a particular purpose. But what would it bring us if the monopoly position of the Corporation sector is halted? In ethics, it is a question of values and value system within an enterprise. Rank, position and power are important criteria and generally more important than money. Money is the medium to rank, position and power. The financial and thus the real estate market, is a market that exaggerates by irrational behaviour. Fear of 'eat or be eaten' provides the mechanism of people. Financial and real estate markets are always so unstable and should always be regulated. The Corporation must above all have a serving and no prevailing role. Regulation is an attempt to bring together different images of reality. Anchor points for this are: private capital, manage transactions and regulation of major players, in which the State should create the counterbalance.

Part of the conclusions of this research are:
1. Improving the social objectives of the governance of corporations must be reflected in three domains: (1) housing as the primary target group, (2) investing in the living and housing environment and (3) contributing to the socio-economic developments of districts. Financial position, effectiveness and efficiency are important.

2. Existing legislation is in itself not blocking any task of the Corporation. The specific characteristic of the public real estate covers: (a) a building related to common social activity and (b) providing and facilitating stakeholders from a recognized societal interest.

3. Corporations are focused on creating social values by deliberately allocating resources for social objectives and want to preserve, restore and refresh these values. Social integration and planning of the sector are important whereas the behaviour of the executive is of importance.

4. The Executive Committee will control in practice with operating models, but does this not in coherence between financial and social returns, social confidence, effectiveness and efficiency. CREM as theory can bring a cohesion in social and financial values.

5. Stories and performance are not connected to each other by the executive. A possible solution for real innovation to the fourth age of housing corporations, is planning the cohesion of societal values that leads to its licence of existence to operate in the future.

6. The multidisciplinary nature of public real estate management is not a bottleneck if definitions and observation are clear. Not related to each other financial and non-financial assessment criteria create a bottleneck in the total control of a corporation and her reporting on them.

The summary conclusion as answer to the central question: ‘are there contradictions in the social values that underpin housing associations that have an impact on the way they are governed?’ is: *Yes. Executives who think at the highest level about how they should deal with values, ensure they control on their own, know what the consequences of their decisions are and take their responsibility.*

The research question has led to the conclusions and formed the basis for further research in the form of three follow-up propositions. These propositions deserve attention for further research on governance of corporations: the housing cooperative as a crowbar, the possible integration of Corporate Real Estate Management in between a Corporation and the Societal Autism of Corporation directors. The follow-up investigations are shown in the three propositions (a) a cooperative form – embodied by the Seven Cooperative Principles in 1844 – caused a bundle of values in socio-economic developments, (b) a non-monopolistic arrangement increases the future value of a corporation and (c) as long as social autism of Corporation directors continues, this blocks a change of Control. The Community would be leading about the objective of public housing if the inner striving for desire and power is controlled. The true value of a corporation is not organised by an executive in a controlled chaos on a sliding scale, but determined in the context of societal values that public housing can bring further. Substance is therefore immaterial: material immaterial. This science, built on facts, is like a house built of stones. And not an accumulation of facts as a pile of stones in the shape of a House.
The research is limited to the Netherlands in view of the complexity and topicality of the corporations in the Netherlands. But what makes the Dutch housing corporations now so unique in Europe? The next section places the Dutch Corporation also in the European perspective.

4. European context

Dutch politics has a general preference for a broad definition of the target group from the vision of the preventing of segregation and providing equal opportunities in the housing market, in comparison with a narrower definition in countries like Germany, Italy, Spain and Austria. Hieminga (2006) also distinguishes the social activities with support facilities – and in line with the service of general economic interest (sgei) definition – if (1) construction, rental, maintenance, renovation and possibly sales (whether or not under conditions) of rental properties in the regulated rent segment, namely the rental properties for the primary target group is clearly defined in terms of income limits, (2) the activities in the sense of promoting the quality of life and living quality as far as relating to regulated home ownership, (3) construction, rental and maintenance of social property meant for use by a social task, such as community schools, welfare buildings and such. Looking at the qualitative housing shortage and the influence of the tenants Gruis and Zijlstra (2006) conclude by means of a theoretical analysis that a client controlled stock has a very limited contribution to solve this need. European research of Gruis, Tsenkova and Nieboer (2009) shows that in addition to regulation or subsidies also working on culture change and professionalization of management organisations is of interest. Dreimüller (2008), Gruis (2009a) and Docters van Leeuwen (2009) already recalled that the definition of the ‘volkshuisvesting’ is not an easy task, which is strengthened by the call in the House of representatives in 2009 to Minister Van der Laan to get support within the European Union for the Dutch definition of housing. For European notions are the public-private characteristics and the quality of the housing stock in Netherlands considered as unique. The Dutch State ranks with the availability of social housing on the first place of the 27 Member States of Europe (35% of all houses carry the label social housing) and is at a great distance followed by England and Austria, each with 21 percent. In 18 European countries, the social rental sector has less than 8% of the total housing stock.

Cecodas Housing Europe shows in a review in 2012 again what is the balance of social, cooperative and public housing in 27 EU Member States. This is an update of the report Housing Europe (2007). The 2007 study is especially aimed at providing an overview of policy developments in the areas of housing and markets in the social, cooperative and public sector housing. The research Housing Europe Review 2012 (Pittini and Laino 2011) has focused on the way in which social housing systems are structured in the European Union and the developments in the sector. The research gives an answer to questions like, "what is social housing?, how much is the sector? Who are provided with social housing? How is social housing funded? Who has access to social housing? " The 27 Member States were questioned about these items and are analysed by country. To compare all these countries with the Netherlands is a lot of work, but this is certainly a worthy research. On many points the Netherlands show an exceptional position. A striking example of this is that in the Netherlands social housing, as the highest in Europe, has 32% of the total housing stock. This compares to
Greece where this percentage is 0%. Cecodas Housing Europe is a European Federation of public, cooperative and social housing business, a network of 45 national and regional federations in 19 countries. In total she represents a control of 27 million households. This is about 12% of the existing housing in the European Union.

On the question of European colleagues how it can be that the Netherlands, as one of the richer EU countries, is in need of so much social housing, Netherlands still owes the answer. By defining an iron stock – the number of available homes for the primary target group – and the rest of the housing stock in a subsidiary, a commercial housing stock has appeared. By this model 'Servatius' – named after the Housing Corporation Servatius in Maastricht – (Aedes magazine 2007-4) by extrapolating to the Dutch social housing stock the Netherlands shares a similar place in the rankings as England, Austria, Denmark and the Czech Republic. This would be the solution for preventing the discussion in Europe about the social housing in the Netherlands and State aid, on which European Commissioner Kroes in 2005 from the European Union have previously complained.

Now the unique position of social housing in the Netherlands is indicated in European perspective, it is important how the performance of housing associations in Netherlands can be indicated in financial and social returns, and what do these returns tell?

5. Accountability with the IPD Nederland Corporatie Vastgoedindex

IPD Netherlands (formerly aeDex) gives the performance of related corporations in returns and is a financial indicator for comparisons (Vlak 2006, 2007, 2009, Konings 2009, Vlak & Den Dekker 2008 en Vlak & Spelbos 2008). IPD is relevant because it aims to create transparency and contributes to further professionalisation of the real estate and investment market. IPD records the returns (Broek 2009) in terms of investment in direct property real estate, that were kept throughout the year. These are so-called standing investments. The independent investment efficiency concerns the so-called gross return on the basis of directly on the management and administration of the objects in the portfolio attributable gross revenue, market value and social management.

It can be concluded that 11% of the number of corporations, have a coverage ratio of 26% in 2009. This coverage ratio has dropped in 2009 compared to the increase in the previous eight years, while the number of properties within the corporations remains stable, according to the indication of IPD. The obvious rise of the size from 2004, which in 2007 and 2008 covered one third of the total home ownership of the corporations has got a relapse of a quarter in 2009, and is thus somewhat at the level of 2004 and 2005. This implies that the importance of the IPD is diminishing. The IPD Property index Corporation (2009) is a guide for the participating Corporation, and functions as a framework on (planned) results. The whole is part of a continuous process of benchmarking. The comparisons among themselves in a certain segment, as well as the analysis behind the numbers, limited to that examined market. The IPD indicates, that the index is just a means of getting information about the financial performance related to return on investment. For example, the policy impact on the primary social portfolio is only in
financial and economic terms. The more qualitative choices made are not shown. The policy effect of the IPD also records the effects of the return, arising from the specific items of control. A distinction is made in that part of the portfolio, that is maintained primary with a view to achieving the social goals – the primary social portfolio – and that part for which this does not apply, not the primary social portfolio. The social return is made clear by the real return against what might have been achieved. This under the hypothesis of what could have been fully in line with the prevailing market rent of all properties. That are than the estimated social returns.

There still remain two issues about it. First, the condition, that the size of the actual invested capital must be determined and what the minimum required rate of return on that equity should be. Secondly, the question has to be answered, whether the goals set by the company are realized on the basis of the benchmarking that is a reflection on what happened on the market for the participating parties. In Figure 18 the policy effects and the social dividend is shown for the years 2002 to 2010. The effect of the administrative anchoring that homes in the primary portfolio due to social reasons are rented below market rent, is called social dividend. About policy impact is spoken if it is transparent what the yield effects of the realized policy on the non primary social portfolio are. Providing insight into the efficiency effects of realized not primary policy portfolio is defined as policy impact. The policy effect over the period from 2002 to 2009 is measured constantly around the 1.5%. The social dividend for the same period is similar and not significantly different. When the framing-effect (Khaneman 2012:95) is applied it creates the image that 98.5% of the portfolio is not socially profitable.

Figure 2: Policy impact and social dividend 2002-2010 in % efficiency

But what do the comparisons of returns of the IPD tell and are they to be compared? For this research the Dutch IPD figures are put over the period 2000 to 2009 in cross tables with real estate index, efficiency, structure and policy impact. In some cases is chosen to omit certain figures from the cross tables to achieve correct connections. In the tables phases are introduced to indicate that classification and definition have changed over the years. The stages are 1, 2 and 3, respectively, 2001-2004, 2005-2006 and 2007, while the policy over the entire period from 2002 to 2009 has been measured. In and between the different phases are significant differences present caused by definition changes. The figures of the real estate index are processed from 2001 to 2007, over all the years the value over 3 years is annualized and therefore can be
considered as a 'common denominator' so closing conclusions can be drawn. The figures for the year 2000 are no longer included in the cross table because the figures from this year are not annualized over 3 years and do therefore not fit in the system of the other years. Reason for this could be that the index in that year has started up and therefore a possible annualization was over more than 2 years. It is striking that in 2007 (phase 3) has been chosen to have only the figures for 2005, 2006 and 2007, and that while after 2001 just about 4 respective 5 years figures are given. A possible explanation is, that the figures were not favorable and therefore were not included in the index. In conclusion, to say that the universe of the IPD Property index Corporation is not frozen. This also means that if a participant or IPD points out inaccuracies in the (historical) data, these will be adjusted. Also are each year participants are added to the index or removed. This means that the IPD Index figures that publishes do not necessarily contain the most current data, although the differences on index level are never big. Remarkable is that data is not frozen. Even more interesting is that at inaccuracies data can be changed. In itself it is defendable that data can be changed due to an error, but the assessment lies with the Corporation that is providing them. And the question then is whether the assessment is correct, or if not (again) can be interpreted differently. But if margins are clear it has no significant impact on final conclusions. Also the actual content of the digits (Hordijk 2005a, Middelhoven 2008 and Hoogen 2010) fits within that framework, because mutations can occur afterwards. Of interest is the tendency of the last ten years and especially in terms of percentages, numbers and participant fluctuation. For the period under review can be concluded that the figures are not significantly different. The problem of constructed historical time series has been acknowledged earlier by Keeris (2005).

6. Conclusions

Findings I - Why this qualitative thesis 'Control of housing associations in consistency with social values'? To understand and to discover patterns about the how and why of the functioning of corporations in society as they do now. This qualitative study is about the search for ideas, backgrounds, motives, resisters and motives and is therefore suitable for the following question: which contradictions are there in the social values that underlie housing associations that affect the way they are governed? The overall summary conclusions to answer the central question is: Directors, at the highest level thinking about how to deal with values ensure they drive on their own, monitor, know the consequences and take responsibility.

Findings II - On the question of European colleagues how it is possible that Netherlands, as one of the richer EU countries, needs so much social housing, the Netherlands still owes an answer. By defining an Iron Stock – the number of available homes for the primary target group – and the rest of the housing stock being put in a subsidiary, a commercial housing stock has appeared. By this model called 'Servatus' by extrapolation to the Dutch social housing stock the Netherlands has about the same level in the rankings as England, Austria, Denmark and the Czech Republic. This would be the solution for preventing the discussion in Europe about the social housing in the Netherlands and State aid, on which European Commissioner Kroes of the European Union has previously complained in 2005.
Findings III – The results of social housing index 2000-2014 MSCI-IPD. Corporations that want to better understand the returns of their portfolio and want to compare their figures to colleagues and competitors can participate in the aeDex / IPD property index corporation. This company comparison system offers corporations insight into their performance as an investor and manager of real estate. The aeDex / IPD property index corporation may make participants visible both their financial and economic and social performance. IPD Netherlands measures periodically the group of participating corporations and compares the results at the organizational level with the aeDex / IPD property index corporation. The aeDex / IPD analyzes the contribution of the various real estate objects to the result, the corporations compares results between themselves and makes comparison with other players in the property market as possible. The real estate index corporation aeDex Foundation aims to preserve the instrument for benchmarking and development through to its member participants.

References


Abstract

Built Environment research is beginning to pay more attention towards understanding facility end-user requirements. While this has been more of a focus within construction and architectural research, empirical investigations into how built environment professions serve facility end-user needs have been few and far between. This is due to the customary emphasis on the technical and technological aspects of built environment professions, as opposed to the managerial and social aspects of their work. The primary purpose of this paper is to identify and explore the networked relationships between various building professions during the design, delivery and early occupation of a facility. It reports the findings of an interpretive, inductive case study where network relationships were mapped with knowledge of user requirements being the key determinant of the binary relationships. The principal parties are the users themselves and the various professions serving them. Findings show that during facility design, delivery and early occupation, project sponsor and facilities manager roles remained central to this ‘knowledge network’. Users and other professions relied heavily on the knowledge of these two roles. These findings add to current built environment theory by identifying facilities professionals and project sponsors as the two primary roles that can enable the built environment to support the activities of its users. The paper further proposes that only the aggregation of the ‘operational’ knowledge of building use (held by facilities professionals) and the ‘strategic’ knowledge (held by project sponsors) can lead to a more robust theory of how the built environment can be developed around end-user needs.

Keywords: Built Environment, End-User Requirements, Network, Knowledge, Social Network Analysis

1. Introduction: A User-Centred Theory of the Built Environment

An understanding of building end user needs, whether defined through the customary triple constraint model of project management or through a much wider socio-political lens, is key to the life of successful construction projects. Research shows that an awareness of user needs leads not only to less critical, but also more satisfied clients (Kaya, 2004). It is therefore important that during construction projects, immediate and long term needs of the building users are identified.
and decisions built upon these throughout briefing, design and delivery of these projects (De wolf and Van Meel, 2002). This paper looks at a co-location (construction) project in the Scottish Borders to develop existing built environment theory on end users. Various built environment professions are mapped using Social Network Analysis with the exchange of building-related knowledge being the determinants of the actors’ binary relationships. The theory developed provides new insights and understanding of user-centred theory as defined by Vischer (2008). The purpose is to deepen our sensitivity towards the ‘theoretical’ in a widely ‘practical’ field, and to especially develop a more tangible basis of incorporating knowledge of end-user expectations to make building projects more successful.

In the editorial to the special issue of Building Research and Information on ‘Developing Theories of the Built Environment’, Koskela (2008) points out that theory plays a central and crucial role in scholarly activities and also informs public policy concerning the built environment. Koskela notes that built environment theory has been fragmented and under-resourced so far. Koskela further notes that built environment theory has also generally been providing the perspective of certain professions or groups, rather than a holistic, cohesive theory addressing the construction and use of the buildings. Koskela (2008) argues that a unified theory of the built environment be developed, especially since most problems associated with design and construction have been the outcome of inadequate theories underpinning the process.

Among theories of the built environment, those that approach users’ experiences of built space are extremely important in that they provide a lens to view the creation and management of the built environment to serve the sole purpose of supporting the needs of its end-users. Such user-centred theories then, not only explain the complex relationships between buildings and occupants, but also allow for a more robust measurement of the degree to which built environment has been successful in fulfilling user expectations (Vischer, 2008).

These user-centred theories could generally be categorised on a spectrum of ranging from the macro to the micro. Theory of building use developed around research into the project stages of planning, building and delivery of the buildings, business processes (Cooper et al., 2004), building performance evaluation theory (Preiser and Vischer, 2004), building serviceability (Davis et al., 1993) and building information systems (e.g. Lutzkendorf and Speer, 2005) for example are theories that provide a larger, all-inclusive lens of building use. The other leg of theories including post-occupancy evaluation (Zeisel, 2006), evidence-based design (Healthcare Design 90, 2006) and the effect of physical features on neural processes (Eberhard, 2007) study the micro-level perspective of specific user needs. Kuhn (2012) notes that neither categories should be seen to be exclusive of each other, as both present different lenses to view the buildings as the means to satisfy users. Furthermore, Green and Schweber (2008) make a compelling case for the development of interdisciplinary middle-range theories that build on micro-phenomenon and connect these to grand theories. The primary purpose of such middle-range theories of the built environment, they pose, is to develop a theoretical response to specific issues: solutions that draw from a wide variety of disciplines and focus on specific, identifiable problems nonetheless.
The theory developed in this paper can perhaps best be categorised as a middle-range theory proposed by Green and Schweber (2008) that brings together a technical tool of representing social relations (Social Network Analysis) with the wider theory of knowledge ownership and sharing and the existing built environment theory on the building end-user. Using a specific context of a socially complex and strategically important co-location project, it links the findings of this one context to develop a better understanding of certain built environment professions in their inherent capacity to engage with and understand the specific (immediate and long term) needs of the people and organisations using buildings. This knowledge of user needs, the paper argues, makes these roles extremely important to the whole building development process.

This paper, which is based upon an inductive, interpretive case study of co-locating higher and further education institutions seeks to address the theoretical gap discussed above, simultaneously addressing the practitioner’s need to know which building professions can best identify end-user requirements. This being a necessary step for developing successful buildings.

The structure of the paper is as follows. It begins with a brief review of the existing literature on the significance of knowledge as a means of creating value. This section discusses how knowledge of end-user expectations and needs constitutes a key components of what makes building projects ‘successful’. Subsequently, the method of inquiry and the case study is presented. Then the network of key actors is reviewed. This leads to network data analysis and then onto the final section, where conclusions regarding significant built environment professions based on the network of project actors are reached.

2. Knowledge of User Requirements

The ‘end users’ can be defined as those who occupy or use the building. These persons may not be the experts at managing the buildings, but have knowledge and opinions about its performance in relation to their own objectives (Kaya, 2004; Lai and Yik (2007). A common characteristic of successful building projects is successfully meeting end-user requirements. This user satisfaction contributes to much wider benefits to the client organisation through sustained loyalty to the firm, repeat purchase, increased market share and profitability (Mbachu, 2003). The widely cited Latham Report (Latham, 1994) published by the UK government had reasoned that an important cause of built spaces falling short of client expectations was that construction professions usually designed and executed projects with environmental constraints, longevity and aesthetics in mind rather than the need of the user-clients. Such an observation either postulates that the construction professions involved either lacked clear knowledge of client’s needs, or those professions which do have clear insights usually retained a less central role in the construction process. Either way, it is important to identify professions that hold the key to knowledge regarding built environment use.

The significance of knowledge as the means of creating value in the organisation has also increasingly come to the fore in management literature especially in the past fifteen years (Schreyogg and Geiger, 2007). Knowledge is now considered a significant resource (David and Foray, 2002) with knowledge work emerging as a dominant theme in the context of the knowledge
economy (Robertson et al., 2003; Alvesson, 2004). Related concepts focus on the growing significance of social capital (Tsai and Ghoshal, 1998) the need to leverage knowledge assets (Newell et al., 2002) and improving the accessibility of knowledge (Rifkin, 2000). This literature establishes the significance of knowledge and knowledge sharing processes as the means of value creation.

Knowledge of end-user expectations and needs constitutes a key component of what makes building projects ‘successful’. Hence its ‘value’ to the organisation undertaking the project, as well as the developer/consultant is immense.

3. Case site and Research Methods

The AB co-location case study presented here is part of a much wider exploratory case study undertaken to assess a number of theoretical questions. The objective of this particular enquiry was to use Social Network Analysis in a mixed-method design to explore wider underpinnings of knowledge sharing within a project system. While the unit of analysis for the wider study was the project itself, the unit of analysis for the analysis presented in this paper is the ‘core network’ of also built environment professions and other managers which constituted of nine project actors identified by the ‘ego’ (the most central actor) in the wider network of the entire project, constituting of 52 project actors. The ‘ego’ was the individual with the most central location in the project network, with the widest number of ties with other actors and hence was in the best position to identify key project players.

The case site was a construction project of a co-locating campus undertaken by two established Scottish educational institutions: one Further Education (FE) institution and the other a Higher Education (HE) institution. Org-A is an FE institution while Org-B is an HE institution. The co-location project, now complete, was undertaken under the Scottish Executive’s ‘Shared Services Initiative’, the purpose of which was providing better financial value FE/HE through modern, shared, co-located facilities to replace outdated, dispersed campuses. Within the new campus, which jointly hosts both Org-A and Org-B, most of the physical infrastructure (services and spaces such as the libraries, catering, common areas and classrooms) was designed as shared areas for both Org-A and Org-B. However, within the campus, each institution continues to maintain its own autonomy as a separate entity with separate spaces for staff, research students, administration and specialist laboratories and teaching areas.

Apart from the advantage of providing a wider scope of academic collaboration across subject areas common to both institutions, both organisations saw this project as the means to offer far superior facilities and services to both students and staff, than what might have been possible for any single institution to provide on its own. As the new campus fulfilled the ‘shared services’ aims of the Scottish Executive’s policy initiatives, this co-location was partly funded by the Scottish Funding Council (SFC), which remained an important stakeholder throughout the life of the project. For these reasons the project was perhaps the most important physical undertaking for both institutions quite possibly for the next decade.
Apart from the differing end-user they serviced (in terms of a different student and faculty body)-since Org-A was a further education body and Org-B a higher education institution- Org-A and Org-B were vastly different in terms of size and organisational structure as well. Org-B was physically dispersed over different campuses, and had an estates function with one senior management person was attached to each of its campus locations with responsibility for the estates, facilities, and services. Org-A, on the other hand, was a large organisation with a multi-tiered organisational structure. Although its presence in the region was small, it had a layered organisational structure with a high powered Director of Estates formally responsible for the management of all campuses and estates and a Director of Campus Services (who was supported by a formal in-house facilities services team) responsible for the campus in question.

The case site was studied during its final completion year and post-occupancy (Figure 1), however the data used in this paper was collected prior to full occupancy: hence capturing relational data during the development of the buildings, a requisite aim of the enquiry.

![Figure 1: Timeline of the case](image)

Key actors in the co-location project identified by the ‘ego’ in the wider project network were those with a high value as sources of knowledge. Together, these nine actors were identified as the ‘core network’ of the project. These actors were the Vice Principal (Org-B), Director Planning (Org-B), Director Campus Services (Org-B), Director Finance (Org-B), Building Surveyor, University Secretary (Org-B), Project Sponsor (Org-A), Project Manager and the Principal (Org-A). Questionnaires were then distributed among these primary actors and their responses solicited regarding their interdependencies and knowledge of:

- Real estate and strategic needs of organization (knowledge area 1)
- Operational requirements of the buildings (knowledge area 2)
- Human and environmental factors in buildings (knowledge area 3)
- Planning and project management involving built facilities (knowledge area 4)
- Facility and service delivery (knowledge area 5)
- Communication (knowledge area 6)
Knowledge area 6 was added as a particular knowledge area since practitioners find great difficulty in making end-users see a longer-term perspective as well as overcoming cultural barriers to understanding real end-user needs (Pemsel et al., 2010). Both these challenges can be overcome through effective communication and hence the profession with the superior knowledge of communication channels and structures was better equipped to be able to engage with the end-users.

4. Network Data and Analysis

Previous efforts on capturing relationships of built environment professions holding key knowledge of users has typically been limited to pre-identified professions in the project. Pemsel et al. (2010), for example, focuses on three players only: end users, end users project manager (EPM—which they define as a selected end user) and the facility planners (FP). This paper, however, uses a case study of a complex, phased co-location project of two Scottish educational institutions (one Further Education, the other Higher Education) and maps 52 key players and their dyadic knowledge-dependent relationships identified through interviews with stakeholders. The mapping is carried out using Social Network Analysis (SNA), which is a method of exploring social structures through the use of network and graph theories. SNA describes networked structures in terms of nodes (individual actors, people, or organisations within the network) and the ties (i.e. relationships or interactions) connecting these nodes or actors. A broad majority of social network studies either use the “whole network” or the “egocentric” design. The first: whole network studies, examine sets of interrelated actors that are related. Egocentric studies, on the other hand, focus on a focal person and the relationships in its locality (Marsden P., 2006). The matrix representation of this common form of network data is known as a “who to whom” matrix or a sociomatrix. The results presented in this paper follow the whole network design where the ‘core network’ is identified from a wider network of the entire project. Data regarding knowledge sharing (the relationship) between primary actors is developed. The data obtained was directional and valued (i.e. the flow of knowledge had a direction and the collaborative tie had an intensity assigned by the recipient actor), and the analysis was carried out using the Ucinet 6 software (Borgatti et al., 2002).

The data on the level of collaboration and knowledge sharing (collaborative relationships) between the key actors was collected using a questionnaire. The other eight key actors comprising the core network were the other eight ‘alters’ identified by the ‘ego’ of the wider network of 52 actors. By ‘collaborative ties’ the research means the existence and strength of knowledge-sharing between the key actors on issues related to the six knowledge areas identified. Each questionnaire respondent was asked to identify the other ‘alters’ in the core network with whom they discussed, shared or developed knowledge relating to any of these FM competencies. The responses were not dichotomous (dichotomous responses are binary, with a value of 0 or 1, showing only the existence or non-existence of a tie) but valued (where respondents placed a value between 0 and 5 on their knowledge sharing ties with the other ‘alters’) and directional (where knowledge sharing relation had an origin and a destination). This ego-centric core network had nine actors, i.e. N=9, where N was the total number of nodes in the network.
\[ N = \{ n_1, n_2, n_3, n_4, n_5, n_6, n_7, n_8, n_9 \} \]

The lines between the actors (for example line \( l_{1,2} \) between \( n_1 \) and \( n_2 \)) as shown in figure 3 and 4 depict the degree of reliance of \( n_1 \) on \( n_2 \) for building-related knowledge. Line \( l_{1,2} \) depicts the degree of reliance of \( n_2 \) on \( n_1 \)'s expertise. Figure 3 shows only the ties, while Figure 4 shows the ties and the strength of the tie i.e. the intensity of knowledge dependency on a certain actor, for knowledge area 3: Human and Environmental Factor.

The sociomatrices for each of the knowledge areas were valued and non-symmetric and took the following form shown in Figure 2 below:

```
1 2 3 4 5 6 7 8 9
1 1 0 4 5 0 0 3 0 0
2 2 4 0 5 4 1 3 4 1 3
3 3 4 4 0 3 4 4 4 2 4
4 4 3 2 5 0 2 4 5 2 5
5 5 0 1 5 2 0 0 3 2 2
6 6 0 1 5 1 3 0 1 2
7 7 0 3 4 2 1 1 0 3 5
8 8 0 0 0 0 1 0 1 0
9 9 0 4 5 3 0 0 4 0
```

*Figure 2: Sociomatrix for Knowledge Area 3-Human and Environmental Factors*

Similar sociomatrices were developed for each knowledge area. Two digraphs (the graphical representation of the relational data) for the above adjacency matrix of knowledge sharing of human and environmental factors are shown below. The first diagraph (Figure 3) shows only the direction of the knowledge sharing without tie strength (i.e. the intensity of the relationship). The second diagraph (Figure 4) is a valued graph, with the thickness of the lines depicting the tie strength between the actors. Figure 4 is obtained by adding the tie strength data to the diagraph in Figure 3. The arrows (in Figure 3) depict the flow of knowledge and line thickness (in 4) depicts the tie strength of the collaborative relationship. Similar digraphs were created for all knowledge areas.
The analysis of the ‘human and environmental factors’ knowledge area is discussed here in detail. What is immediately evident from Figure 3 is the fact that despite the core network being a closely knit unit, not all actors were approached by others as sources of knowledge. Human and environmental concerns are a vital component of any workplace and the individuals that contribute to decisions relating to it, inevitably affect workplace usage, social interactions and overall user experience. In the core network, certain actors for example the vice principal of Org-B and the construction project manager were not sources of knowledge for this particular competency. At least five or more other actors said they had never approached these actors for human and environmental issues. They were, nevertheless, important for the knowledge sharing process supporting the overall decision-making process during design and construction. On the other hand, the network analysis shows that there were certain individuals who were repeatedly approached for expertise related to knowledge of human and environmental factors and were approached by almost all actors in the core network. These were the Project Sponsor (Org-A) and the Director of Campus Services (Org-B). The degree of reliance on these individuals for human and environment-related knowledge was consistently given a very high value by other actors. Two other actors, the Director of Finance (Org-B) and Principal (Org-A) were also approached by six other actors. However the degree of reliance on them for expert knowledge was considerably lower.
Figure 4: Diagraph of Knowledge Area 3 (Human and Environmental factors) with tie strength

Figure 4, which shows the tie strengths, provides a visual picture of the intensity of collaborative ties between the members of the core network for this competency. Interestingly, the ties are also strongest for the four individuals noted above, who were the primary sources of human and environment-related knowledge during the co-location project. This finding shows that together not only were these individuals a source of expertise to others, but that they remained close to each other for collaboration and to complement each other’s knowledge relating to this competency.

Similar findings, with varying degrees of tie strengths were found for the other five knowledge areas. Table 1 below gives a synopsis of the findings from the sociomatrices and diagraphs of all the six knowledge areas, including competency 3 discussed above. In the table, a single ‘X’ denotes a low status as source of knowledge for each of the FM competency areas, while an ‘XX’ denotes a high status as a source of knowledge for each of the FM competency areas for an actor.
A comparison of the various digraphs (not shown here) demonstrates that while differences existed across different knowledge areas, overall the core network had close knowledge sharing and collaborative ties. Nevertheless two individuals, the Director of Campus Services (the top facilities manager) and the Project Sponsor (senior manager responsible for the overall success of the project) remained central as sources of vital knowledge for all competencies. These two actors were also the individuals with the strongest ties with other actors in the core network. The analysis of the wider whole network (not shown here) also showed that these two individuals were strong ‘connectors’ between the other actors in the whole network as well (i.e. some actors would have been totally disconnected from the rest of the network were it not for these individuals). The analysis of the core network’s relationships primarily showed the emergence of two individuals as critical disseminators of building-related knowledge and a clear indication by other actors that not only were the top facilities manager and project sponsor the source of expertise for real estate strategic planning, but also operations, communication, the management of the entire project, facility service delivery and environmental factors.

In order to investigate the direction of knowledge sharing, the research also computed the nodal degrees of the knowledge sharing phenomenon within the core network (see table 2). The ‘degree’ for a node, defined as the total number of relationships involving that node and it permits comparisons between network participants. Individuals with higher degree values are more active than those with lower values. The ‘indegree’ for a node is the number of relationships in which a particular node is the target (in this case, approached for certain building-related knowledge). Both nodal degrees are measures of a node’s connectivity with other nodes: the higher the node degree, the higher its connectivity. Again, the two actors: the facilities head (Director of Campus Services) and the project sponsor (Vice Principal, Org-A) came out as the leaders when it came to being the source of building-related knowledge for all core network actors. The implications of these findings are discussed in the conclusions section.
Table 2: Nodal Indegree of actors in the network

<table>
<thead>
<tr>
<th></th>
<th>Vice Principal (Org-B)</th>
<th>Director Planning (Org-B)</th>
<th>Director Campus Services (Org-B)</th>
<th>Director Finance (Org-B)</th>
<th>Building Surveyor</th>
<th>University Secretary (Org-B)</th>
<th>Project Sponsor (Org-A)</th>
<th>Project Manager</th>
<th>Principal (Org-A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>15</td>
<td>29</td>
<td>36</td>
<td>20</td>
<td>17</td>
<td>15</td>
<td>35</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>K2</td>
<td>8</td>
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5. Discussion and Conclusions

As discussed earlier, established theories of the built environment tend to be either product-oriented (how the building and its associated services function post-completion) or process oriented (how buildings are procured and produced). In neither set of theories do end-users play a pivotal role. A likely gap in built environment theory, therefor, exists around the nexus of end-users, perhaps due to the ‘technical’ focus of built environment research that does not capture softer, human aspects of the context. It is therefore important that built environment theorists make a conceded effort to capture the perceptions, needs and expectations of facility end-users in order to develop a coherent, integrated theory that assimilates end-users into previously developed theory. The widely cited Latham Report (Latham, 1994) has also reasoned that an important cause of built spaces falling short of client expectations was that construction professions usually designed and executed projects with environmental constraints, longevity and aesthetics in mind rather than the need of the user-clients. Such an observation either postulates that the construction professions involved either lacked clear knowledge of client’s needs, or those professions which do have clear insights usually retained a less central role in the construction process. Either way, it is important to identify professions that hold the key to knowledge regarding built environment use.

This paper therefor asserts that one way is to identify built environment professions/ roles that best capture end-user requirements- be they related to strategic real estate needs of the organisation, operational requirements of the buildings, human factors affecting building design and use, the planning and execution of building projects, or the facility and service delivery during the operational life of these built assets. The analysis of network data presented in the previous section helps built environment theory by identifying certain professions and roles that remained pivotal in knowledge dissemination (leading to policy and strategy development as well as project execution) related to several aspects of end-user needs within the core project network. The findings from the network analysis show that during facility design, delivery and early
occupation, project sponsor and facilities manager roles remained central to this ‘knowledge network’. Users and other professions relied heavily on the knowledge of these two roles. These findings add to current built environment theory by identifying facilities professionals and project sponsors as the two primary roles that can enable the built environment to support the activities of its users. The paper further proposes that only the aggregation of the ‘operational’ knowledge of building use (held by facilities professionals) and the ‘strategic’ knowledge (held by project sponsors) can lead to a more robust theory of how the built environment can be developed around end-user needs.

The findings help develop an understanding that certain built environment professions (the project sponsor and the facilities head) in their inherent capacity to engage with and understand the specific (immediate and long term) needs of the people and organisations using buildings, can be pivotal in developing a closer understanding of end-user needs throughout the life of the construction and occupancy of built assets. This inherent knowledge of user needs makes these two roles extremely important to the whole building development process.

These findings support earlier theory developed within facilities management domain such as McLennan’s (2000) work which argues that building (or facilities) knowledge that has strategic value is that which pertains to its understanding of the relationship between the performance of physical resources and the customer/end user being served. Pathirage et al. (2008) view such knowledge to be vastly tacit in nature and assert that it is necessary for facility managers to realise that they hold the unique information on the physical resources and their use over time. In their proposed Intellectual Capital Framework for FM, FM’s knowledge capital is the outcome of the knowledge it derived from strategy, systems and assets (‘structural capital’); customer’s orientation and market positioning (‘customer capital’); and the knowledge and capabilities of individuals to provide solutions to facility customers (‘human capital’). Together this knowledge base, they argue, can be used to create value for the organisation. The findings from practice, presented in the paper augments this key role of facilities managers. The role of project sponsors as carriers of important tacit knowledge regarding end-users has been less explored in theory and this research must be taken forward to explore this aspect further.

References

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Emerging Issues of Stakeholder Management in PPP Projects and Improvement Measures: An Australian Study

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Abstract

Many countries around the world are in search of new means to engage the private sector in managing and financing infrastructure through Public Private Partnerships (PPPs). However, most of the PPPs have faced issues during design and concession period. When considering Australian context Stakeholder Management (SM) related issues have been reported as one of the main reasons for failure in several instances. PPPs involve many stakeholders whose interests might not be in agreement leading to conflicting objectives. In such situations SM has a high level of importance to avoid the conflicts and to achieve the success of projects. Therefore, this research aims to determine the current emerging issues related to SM in Australian PPPs and to investigate the strategies to cope with those issues. Mixed methods of research were adopted in this research. Initially critical review of literature was undertaken followed by 19 semi structured interviews and a questionnaire survey. The findings revealed twelve critical issues related to SM. A variety of SM strategies to cope with the critical issues were also established. The proposition that the Government sector is better equipped to manage the general public involving in economic decision making was further confirmed via the findings. Also the findings insisted the necessity of a strong Government in managing the stakeholders of a PPP project. Nonetheless in reality the Government tries to transfer the entire SM risk to the private sector.

Keywords: Public-Private Partnerships, Stakeholder Management, Issues, Government

1. Introduction

PPPs are a popular form of major project procurement for the delivery of building and infrastructure facilities. Service contracts, management contracts, lease contracts, build operate transfer and similar arrangements, concessions and joint ventures are some different formats of PPPs (Felsinger, 2008). According to Grimsey and Lewis (2002), achieving value for money in the services delivered and allowing the private sector entities to meet their contractual obligations are the primary objectives of using PPPs in delivering public infrastructure. PPPs have become a popular method to procure infrastructure projects in Australia. The PPPs in
connection with building and infrastructure procurement constituted around 5% of the new investments in Australia in 2009 (Chan et al., 2009).

However, Johnston (2010) highlighted many implementation issues in Australian PPPs. The Sydney Cross City Tunnel, the Southern Cross Station in Melbourne and the Southbank Technical College and School are some examples where the public has been disappointed which led to adverse publicity for the Government and commercial losses for the private sector (Wilson et al., 2010). Johnston (2010), Hodge (2004), Siddiquee (2011), Johnston and Kouzmin (2010) and Regan et al. (2011) pointed out many issues in Australian PPPs. Some of these issues in border context can be viewed as: lack of transparency of the PPP arrangements, lack of monitoring during the operations, lack of collaboration between the public and private parties, lack of trust towards PPPs, political agenda towards PPP projects and lack in addressing the interests of the general public. These issues can be directly associated with ineffective SM practices. Similarly stakeholder opposition towards the PPPs has been reported as one of the main reasons for the failed PPP projects globally (El-Gohary et al., 2006, Siemiatycki, 2009, De Schepper et al., 2014, Smyth and Edkins, 2007). As such the issues related to SM should be further explored to investigate the strategies to cope with those issues. Chinyio and Akintoye (2008) confirmed the importance of SM in the modern forms of construction procurement such as partnering and private finance initiative. Accordingly many stakeholders are involved in this process whose interests are not always likely to be in agreement. According to a report published by World Bank, the first factor out of seven major points that are holding up private investment in infrastructure is the wider gap between the Government and the private sector interests (De Schepper et al., 2014). However, according to De Schepper et al. (2014) these stakeholder issues do not merely emerge because of this gap but due to the concerns related to ineffective SM approaches. Despite the literature have suggested proper SM a systematic SM framework for PPPs is yet to be developed in addressing the current emerging issues in PPPs.

The objective of this paper is to address the aforementioned gap and contribute to the knowledge base of SM in PPP projects by presenting findings regarding the current emerging issues in the Australian PPP market. Also to propose a list of SM strategies in addressing the current emerging issues. This study is part of a larger research project which aimed at developing a SM framework for PPP projects in Australia. The next section will discuss SM implications in PPP environment highlighted by previous studies. Then it will explain the research methodology of the study followed by research findings and the discussion of the findings. Finally some conclusions were drawn.

2. Stakeholder Management Implications in PPP Environment

2.1 SM in PPPs

SM concepts continued to evolve from general management to construction project management literature. Many authors have highlighted the importance of stakeholder consideration in construction projects. Assudani and Kloppenborg (2010) and Cleland (1998)
suggested that success in construction projects significantly depends on meeting the needs of stakeholders. Bourne and Walker (2005) and El-Gohary et al. (2006) highlighted that stakeholders play a decisive role in construction projects which can make or break a project. Before discussing the SM in PPP project environment it is worthwhile in defining SM in a project. Rowlinson and Cheung (2008) provided a definition for SM by using the studies undertaken by Brammer and Millington (2004) and Pajunen (2006). Turner (2003) and Yang and Shen (2014) also provided definitions for SM. According to these scholars this research defines SM as “A process of identifying, negotiating, engaging stakeholders and developing relationships among stakeholders to achieve minimum project risks and facilitating projects to deliver the project timely and effectively.”

El-Gohary et al. (2006) initiated the development of a SM model for PPP projects. This semantic model was developed to capture and incorporate stakeholder input in the design. But according to Henjewele et al. (2013), the proposed semantic model is too complex to adopt in real projects and has only focused on the design stage. Also this model has only concentrated on the public involvement process of PPPs. Henjewele et al. (2013) developed a SM model for the whole life of a PPP project which insisted the importance of incorporating the ideas of the general public. However this model is too generic and has not considered the actual level of complexities associated with the PPP procurement structure. Ng et al. (2013) and Ahmed and Ali (2006) also highlighted the importance of considering the people as partners. Ng et al. (2013) developed a framework for the successful public engagement. Majamaa et al. (2008) also did a study on how to build the fourth P into the PPP process using some case studies in Finland. However no study has focused on exploring SM related issues and the strategies to cope with those issues. These SM strategies will help to develop a proper SM framework for PPPs. To achieve the main aim of this study it is worth to investigate the issues highlighted by the previous studies that are directly related to SM practices.

2.2 Lessons from Recent Experience in PPPs in Australia

Political agenda towards these infrastructure project decisions have created many issues from the start of several PPP projects in Australia. According to Siddiquee (2011), the Sydney Cross City Tunnel project was politically advantageous in a PPP structure and in reality the way it was structured didn’t produce the best outcomes. Lack of information dissemination to the public is another critical issue identified in the wider PPP literature (Linder, 1999). While general public tend to ask for more information of PPP projects, the Government had to maintain a balance of what information to be disclosed and what are commercially sensitive. This has become problematic in many cases and led to citizens’ distrust towards these infrastructure developments. Serving the wider community is one of the main objectives of using PPPs in infrastructure development. However, Wilson et al. (2010) highlighted that the Sydney Cross City Tunnel, the Southern Cross Station in Melbourne and the Southbank Technical College and School are the examples where the interests of the general public are not well addressed. Johnston (2010) highlighted another critical issue as longer-term performance monitoring is lacking in the Australian PPPs which is often need to sustain the defence of the long-term operational viability or success of a PPP versus traditional procurement. Further Siddiquee
(2011) pointed out that there is no sufficient staff capability for the PPP delivery. According to Kwak et al. (2009) this can lead to tensions between public and private partners and, if not remedied, it could lead to project failure. Another critical issue is the conflicts between the public and the private partners are not well managed. According to Johnston (2010), this may affect the core value of PPPs and potentially represent a major, but usually silent, pitfall within the model.

Table 1 summarises the above issues in PPPs explored by the previous studies. Most of the issues in Australia have been echoed by the authors in global context demanding urgent research efforts. All the above issues can be directly related to SM practices of a project. For example political agenda deals with stakeholder interests and effective stakeholder analysis might help to solve those issues to a greater extent (De Schepper et al., 2014). The issues related to the general public interest also can be directly related to SM as public engagement is one of its major components (Leung, 2010). Performance monitoring issues also can be directly associated with SM practices as it involves following-up the strategies and actions that have been implemented (Karlsen, 2002). Staff training aspect and conflict resolutions are two of the major components of SM framework of a project (Yuan et al., 2009).

Table 1: Summary of the issues in PPPs

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<td>Lack of information dissemination to the public</td>
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<td>Interests of the general public are not addressed</td>
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<td>Lack of longer-term performance monitoring</td>
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<td>Lack of staff capability in the PPP project delivery</td>
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<td>Conflicts are not well managed</td>
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<td>Difficulty in assessing the expectations of each stakeholder</td>
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<td>Lack of interaction with the stakeholders</td>
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3. Research Methods

3.1 Data Collection & Analysis

The eight SM related issues explored by the literature review were discussed in the previous section. Subsequently semi structured in-depth interviews were adopted as means of further investigating the SM related issues in the Australian context. Also to explore the strategies to
cope with the SM related issues. At present nineteen semi-structured interviews were conducted. Due to the involvement of multiple numbers of stakeholders in a PPP project, we stratified the sample into two professional groups to obtain the public and private professional insights into the research questions. Respondents were selected randomly by contacting the Government Departments and the private companies that have dealt with a variety of Australian PPPs. Successively a questionnaire survey was conducted to further evaluate the criticality of the identified issues from the literature review and the interviews. The online survey tool ‘Qualtrics’ was used to distribute the survey. Stratified and random sampling was again used. The survey was distributed to the contact lists in public and private company websites which have dealt with PPP projects in Australia. Additionally, many respondents were found from the LinkedIn social network where pools of professionals get in to contact. In order to identify the relative significance of SM related issues for different stakeholders, Likert-style rating questions, using a five-point scale. The scale intervals in this research can be interpreted as follows: (1) not critical at all; (2) not critical; (3) Neutral; (4) critical; (5) extremely critical. Overall, 357 responses were received of which 341 were valid and used for further analysis.

The interview results were analysed using the content analysis via NVIVO software. The questionnaire data were analysed using the IBM statistical package SPSS22 soft-ware. Initially descriptive statistics such as mean and standard deviation were used. The responses given by the respondents were tested for the null hypothesis (i.e. that means between groups do not differ significantly) using non-parametric tests suitable for small and unequal sample group sizes. As such the Mann–Whitney U-test can examine the level of agreement. The null hypothesis is that the mean significance of each factor is equal between any two groups. If the value of U exceeds its critical value at some significance level (0.05), there is evidence to reject the null hypothesis.

### 3.2 Analysis of the background of respondents

The interview participants were all senior managers involved in the bidding, construction and operational phases of PPP projects. All of the interviewees had more than five years’ experience in any type of PPP project with some SM experiences. 10 Panel members represented the private sector, 5 the public sector where as 4 have involved in both the sectors. Considering the questionnaire survey 37% of the respondents had more than ten years of professional experience and 32% had more than 5 years of experience. Also nearly 50% of the respondents had the exposure for 2-5 number of PPP projects. Therefore, the respondents can be considered as well experienced in this field. There were representations covering both the private and public sector views. Figure 1 shows the sample structure for the interviews and the questionnaire survey respectively.
4. Research Findings

4.1 SM related issues in PPPs

Table 2 summarises the interview and the questionnaire survey results. It shows the number of interviewees agreed for each of the issues. Also it reports the mean response rating values for the questionnaire survey results. After the interviews four new issues (Issue_3, Issue_4, Issue_5 and Issue_7) were added into the SM related issues identified from the literature review. Interview respondents agreed that all these issues are critical in PPP environment. One interviewee highlighted that it is essential to identify the issues in the past projects and implement corrective actions from a SM point view. Considering the questionnaire survey results no mean value scores fell into the ‘extremely critical’ (4.50) and ‘not critical at all’ (1.5) categories, which indicates that all of these 12 issue are critical for each group.

Both the interview and survey results have confirmed the Issues_4 is critical in Australian PPP environment. This was captured from one of the interviewee representing the private consortium. Accordingly they are interacting with multiple Departments when working on a PPP. However, these departments provide contradicting information which has leaded to many conflicts within the partnership. The Issue_6 is a well-recognised issue in the wide PPP literature. Interviewees highlighted that most of these PPPs are in existence due to a political party pushing through for its political gain. And they stressed that in reality this decision should be longer term economic and social decision rather than political. The representatives from the private consortium explained the Issue_5 as, the project brief and the reference design prepared by the Government is not sufficiently comprehensive leading to many issues during the operations. Regarding the Issue_12 the interviewees highlighted that there are many loopholes in the PPP contracts which have leaded many conflicts. Therefore, they underscored the importance of the relationships between the parties to the contract demanding urgent research effort for proper strategies to improve the strength of relationships. Private sector consortium members were desperate about the Issue_2 and they urged the need for more stakeholder engagement by the Government. Issue_7 was recognised from the interviewees representing the private sector. Accordingly there is a lot of nervousness around the financiers due to the current conditions in Victoria (the fact that the Government could change at any point in time). This has leaded to less financial support for the PPP development process. Interviewees from both the sector highlighted that as the PPP concept is fairly new to Australia there is a lack of sufficient resources to manage these projects (Issue_11). Also the interviewees highlighted that some of the managers consider moving on to the operations as the focal point of these projects. However they stressed that it should not be the case. Therefore they stressed the issue of lack of monitoring during the operations (Issue_10). Further the interviewees from both the sector highlighted the difficulty in forecasting the stakeholders and their interests throughout the project life cycle especially due the long term nature of these projects (Issue_1). The Issue_3 and Issue_9 have reported low mean values as opposed to the literature review and the interview
results. For example the Issue_9 was a well-recognised issue in literature and also the interviewees confirmed it. One of the interviewees highlighted that there are many PPP projects that have pushed into the industry without considering the needs of the general public. Although the questionnaire survey reported low mean values for these issues they are in acceptable level with a mean value above 3.0 and therefore considered as critical.

Table 2: The SM related issues in PPP projects and their scores and rankings in different groups

<table>
<thead>
<tr>
<th>Code</th>
<th>Issue</th>
<th>Interview results</th>
<th>Questionnaire Survey Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No of agreed interviewee</td>
<td>Overall</td>
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<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Rank</td>
</tr>
<tr>
<td>Issue_4</td>
<td>Responsibilities overlap between different Government agencies</td>
<td>15 out of 19</td>
<td>3.70</td>
</tr>
<tr>
<td>Issue_6</td>
<td>Political interests push PPP project decisions rather than social and</td>
<td>19 out of 19</td>
<td>3.66</td>
</tr>
<tr>
<td></td>
<td>economic</td>
<td></td>
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<tr>
<td>Issue_5</td>
<td>Incomprehensible project brief and reference design leads to</td>
<td>16 out of 19</td>
<td>3.44</td>
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<td></td>
<td>uncertainties</td>
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<tr>
<td>Issue_12</td>
<td>Not efficiently managing conflicts between the private and Government</td>
<td>17 out of 19</td>
<td>3.44</td>
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<tr>
<td>Issue_2</td>
<td>Lack of early stakeholder engagement</td>
<td>13 out of 19</td>
<td>3.43</td>
</tr>
<tr>
<td>Issue_7</td>
<td>Financier's nervousness due to changes in the Government</td>
<td>14 out of 19</td>
<td>3.40</td>
</tr>
<tr>
<td>Issue_11</td>
<td>Lack of staff capability in the PPP project delivery</td>
<td>15 out of 19</td>
<td>3.23</td>
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<tr>
<td>Issue_10</td>
<td>Lack of monitoring in stakeholder needs and issues during operations</td>
<td>18 out of 19</td>
<td>3.18</td>
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<tr>
<td>Issue_1</td>
<td>Difficulty in identifying stakeholders and their interests throughout</td>
<td>15 out of 19</td>
<td>3.15</td>
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<td></td>
<td>the PPP life cycle</td>
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<tr>
<td>Issue_8</td>
<td>Lack of information dissemination to public</td>
<td>17 out of 19</td>
<td>3.09</td>
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<tr>
<td>Issue_3</td>
<td>Not disclosing the history behind PPP project to the private consortium</td>
<td>16 out of 19</td>
<td>3.02</td>
</tr>
<tr>
<td>Issue_9</td>
<td>Interest of the general public is not well addressed</td>
<td>15 out of 19</td>
<td>3.01</td>
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</table>

Reliability analysis is conducted to test the internal consistency of the survey variable data. Cronbach’s alphas are 0.853. It is much higher than the 0.70 of Nunnally’s guideline (1978). The results of reliability tests show that the stakeholders agreed on most of the SM related issues. However, there are some disagreements reflected by the scores and rankings in different stakeholder groups. For example, the mean and the ranking of the issue “Issue 12” is higher for the private sector when compared with the public sector. However it is important to investigate whether these differences are statistically significant. Therefore, Mann–Whitney U-test was used to explain these disagreements between stakeholder groups. The test results of pairwise comparisons between public and the private sectors are summarized in Table 2, which indicates
that there are significant differences in the opinions between groups for the issues “Issue 6”, “Issue 7”, “Issue 8”, “Issue 9” and “Issue 11”. All these issues have become critical for the private sector side of the partnership.

4.2 SM strategies for PPP project success

Interviewees were asked to propose some improvement measures to cope with the above identified SM related issues. The following section will discuss the strategies proposed by the interviewees for each of the issue.

The interviewees emphasized the importance of having a good understanding on each others objectives in a team. Appointing an independent party to monitor the stakeholder matters during initial stages was another recommendation. Representatives from the private sector proposed that extensive initial consultation by the Government will help to understand the stakeholders and their needs more sensibly. These were proposed to address the Issue_1. The following were proposed to address the Issue_2. Both the sectors highlighted the need for extensive stakeholder engagement during the initial stages by the Government. Also the private sector representatives highlighted the necessity of participating in the very early information sessions conducted by the Government. The interviewees from the private sector proposed to maintain a register of all commitments made to stakeholders before bidding by the Government sector to address the Issue_3. Accordingly that register should be shared with the project company within the tender. Also the private consortium members proposed to have a process to streamline the overlaps between different Government agencies (Issue_4).

As the project brief and the reference design prepared by the Government is not sufficiently comprehensive (Issue_5) the representatives from the private sector urged the need to have more certainty within the Government’s tender document. Most of the interviewees couldn’t give a solution to cope of the Issue_6. They highlighted that the political forces are a pain for them. The interviewees from the private sector highlighted that the Government should approach PPPs with honesty. Further they proposed that the Government can follow a by-partisan approach to the stakeholders through engaging with all political parties during bidding. The private sector representatives proposed to provide regular updates to the financiers to cope with the Issue_7. Also more engagement with the state before approaching the financiers is also recommended.

The private sector participates proposed to improve the websites allowing people to access the information easily, to communicate clear information to general community at the correct time and to make the independent reviewer’s opinion available to the general community to improve the transparency of the project (Issue_8). Interviewees highlighted the importance of the Government’s role in protecting public interest (Issue_9). The interviewees urged the necessity of engaging with the general public during the initial stages. The interviewees highlighted many improvements to cope with the Issue_10. The representatives from both the sectors proposed to develop more KPIs related to SM and to measure the KPIs via stakeholder surveys. Also they proposed to monitor the stakeholder relationships during operations. And they advocated the
importance of proper issue escalation process to efficiently address the stakeholder issues. Regular strategic stakeholder meetings and on site engagement meetings were suggested. The interviewees from the Government proposed to appoint an independent party to monitor the stakeholder matters during operations. They highlighted the need to embed the SM into business case and contract manuals.

The representatives from both the sectors proposed to create a system which accumulates the lessons learnt via regular stakeholder workshops to cope with the Issue_11. Also providing training for the people who are working around PPPs is also important. SM experts highlighted that the project directors do not see the clear advantages of SM to a project. As such they advised to expose project managers into real cold phased stakeholder issues. The representatives from the private sector highlighted the importance of developing comprehensive reference designs in dealing with Issue_12. This will lead to fewer conflicts during the construction and operations. Also the interviewees highlighted the need for more stakeholder engagement by the Government sector at the very initial stages. Moreover they proposed appointing an independent party to monitor the stakeholder matters during the initial stages.

5. Discussion

The issues identified from the literature review and the interview results were further validated via a questionnaire survey. “Responsibilities overlap between different Government agencies” and “political interests push PPP project decisions rather than social and economic” have become the most critical issues based on the mean score ranking. Interview results also confirmed that “political interests push PPP project decisions rather than social and economic” is the most critical issue related to PPP projects. Further according to the interview results “lack of monitoring in stakeholder needs and issues during operations” and “not efficiently managing conflicts between the private and Government sectors” are the second most critical issues. Questionnaire survey also confirmed that these issues are critical with a mean score value of 3.18 and 3.44 respectively. Surprisingly although the literature review and the interview results confirmed that all the issues are very critical to PPP project success, questionnaire survey have reported few low mean values for some of the issues. However all the mean values were above 3.0 and considered that all these issues are critical.

The Government and the private sector parties had common opinions on the criticality of some of the SM related issues in PPP projects. However there are evident differences as well. As shown in Table 2 most of the issues have become critical for the private sector when compared with the public sector. “Difficulty in identifying stakeholders and their interests throughout the PPP life cycle at the bidding stage”, “non-disclosure of the history behind PPP project to the private consortium”, “incomprehensible project brief and reference design leads to uncertainties”, “lack of early stakeholder engagement” and “not efficiently managing conflicts between the private and Government sectors” have become critical for the private sector. “Non-disclosure of the history behind PPP project to the private consortium”, “incomprehensible project brief and reference design leads to uncertainties” and “lack of early stakeholder engagement” are directly associated with the activities related to the Government sector side of
the partnership. As “not efficiently managing conflicts between the private and Government sectors” has become a critical issues to private sector it can be viewed that the Government should become the main driving party in managing the conflicts of a PPP project. As such these results highlighted the importance of the Government sector role in SM for PPPs. One interviewee from the private consortium also confirmed this point in relation to public engagement as “... then the Government has someone to blame if the community is not happy with the outcome. But we have no control over the public benefit of the project as we are not the once who created those projects.” Further it was noted that in reality the Government is trying to transfer the total SM related risk to the private consortium. Chung et al. (2010) confirmed this point in relation to risk management in PPP projects in Australia. As such the findings insisted the importance a strong Government with robust SM practices for successful PPP projects.

The identified issues and strategies proposed were summarized and assigned into the sector that is mostly relevant. The following Figure 2 summarizes the findings. Accordingly most of the issues and the strategies identified are related to the government sector side of the partnership. This finding also confirmed the importance of the Government sector role in managing stakeholders.

<table>
<thead>
<tr>
<th>Issues</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of early consultation with all stakeholders (by the Government agency)</td>
<td>Maintain a register of all commitments made to stakeholders before bidding</td>
</tr>
<tr>
<td>Political interests push PPP project decisions rather than social and economic</td>
<td>Share the register of all commitments with the private consortium</td>
</tr>
<tr>
<td>Lack of information dissemination to the public</td>
<td>Communicate clear information to general community at the correct time</td>
</tr>
<tr>
<td>Not disclosing the history behind PPP project to the private consortium</td>
<td>Allow private consortium to participate in information sessions conducted by Govt.</td>
</tr>
<tr>
<td>Incomprehensible project brief and reference design leads to uncertainties</td>
<td>Improve Govt. websites allowing people to access the information easily</td>
</tr>
<tr>
<td>Responsibilities overlap between different Govt. agencies</td>
<td>Govt. agency engages with general community to develop tender doc</td>
</tr>
<tr>
<td></td>
<td>Govt. makes the independent reviewer’s opinion available to Public</td>
</tr>
<tr>
<td></td>
<td>Allow private consortium To engage with all political parties during bidding</td>
</tr>
<tr>
<td></td>
<td>Ensure the responsibilities do not overlap among different Govt. agencies</td>
</tr>
<tr>
<td>Difficulty in identifying stakeholders and their interests throughout the PPP life cycle at the bidding stage</td>
<td>Be honest with general community</td>
</tr>
<tr>
<td>Lack of monitoring in stakeholder needs and issues during operations</td>
<td>Develop more Key Performance Indicators (KPIs) related to stakeholder management</td>
</tr>
<tr>
<td>Not efficiently managing conflicts between the private and Government sectors</td>
<td>Measure possible KPIs via stakeholder surveys</td>
</tr>
<tr>
<td>Lack of staff capability in the PPP project delivery</td>
<td>Appoint an independent party to monitor the stakeholder matters during initial and operations</td>
</tr>
<tr>
<td>Interest of the general public is not well addressed</td>
<td>Monitor relationships of stakeholders during operations</td>
</tr>
<tr>
<td></td>
<td>Create a system which accumulates the lessons learnt via regular stakeholder forums</td>
</tr>
<tr>
<td></td>
<td>Embed stakeholder management into business case, procurement and contract manuals</td>
</tr>
<tr>
<td></td>
<td>Establish issue escalation process to efficiently address stakeholder issues</td>
</tr>
<tr>
<td></td>
<td>Regular stakeholder meetings and on site engagement meetings during operations</td>
</tr>
<tr>
<td>Financier’s nervousness due to changes in the Government</td>
<td>Early involvement of the financial institutions</td>
</tr>
</tbody>
</table>

Figure 2: Overview of the issues and the strategies proposed by the interviewees

6. Conclusions

Both the interview and the questionnaire survey results investigated 12 critical issues related to SM in PPPs. It is necessary to address the current emerging issues related to SM in the research agenda. The comparative study between the private and the Government sector highlighted some differences in the views on the criticality for some of the issues. And it was noted that most of the issues have become critical for the private sector side of the partnership enquiring
improvements in the Government sector. As such, the findings insisted the importance of a strong Government sector in dealing with SM for PPPs. However in reality the Government is trying to transfer the total SM risk to the project company leading to many confusions and issues in the later stages. This study emphasised an urgent research interest to develop a set of strategies to improve the SM related to the Government sector side of the partnership. Interview results identified a variety of strategies to cope with the SM related issues in PPPs. These strategies should be further validated from a questionnaire survey which is currently in progress. This study is part a larger research project which aimed at developing a systematic framework for SM in PPPs.

References


Uncovering the Real Needs of Customers

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Abstract

In this paper an inventory will be given of methods and tools currently available in the construction industry and other sectors to make the needs and wishes of clients explicit, in order to incorporate them into the design, engineering and building process. In order to be able to create value from a client’s point of perspective, it is necessary to find out what really matters to clients and what their real needs are. However, professionals in the construction sector with a genuine interest in making needs and wishes from clients and customer organisations explicit, know this is not an easy task. In contrast with the field of construction, it is more common practice in most industries to involve all different stakeholders in order to make requirements explicit. There are also different methods and tools available, which leads to the question what tools are most effective and reliable to discover requirements? Research in the domains of marketing, cognitive linguistics and psychology shows that customer needs can’t be clarified by expression in words alone. A lot of choices are made unconsciously, without the use of language. Important associations people have can be made visible by using metaphors or pictures. These insights from other sectors can be of advantage to professionals in the construction industry. Based on this insight evaluation criteria are formulated to assess the available methods to uncover requirements. Based on the outcomes of this evaluation an improved tool is proposed, in which pictures are used to unravel customer needs.

Keywords: requirement engineering, MCDM+, stakeholder requirements, photo elicitation
1. Introduction

It seems an easy job: to collect the requirements for a new building. Just ask the stakeholders what they want, write it down in a programme of requirements and translate it into a design. But even when we spent a lot of time talking to stakeholders, about their needs and wishes, it is still a difficult job to develop something that will meet all the requirements. On the one hand this happens of course because there are a lot of different stakeholders with often conflicting requirements and it is impossible to develop something that will meet all demands. But on the other hand are we able to uncover the necessary requirements with the methods we use in construction today? Looking at research into current failure costs it becomes visible that a large part of these costs is caused by bad or a lack of information. Recent research in the Dutch building sector shows that sloppy information exchange and a lack of communication are the most important causes of high failure costs (almost 11% from the total returns) (USP Marketing Consultancy BV, 2010). Getting the right information and sufficient data will help to decrease these failure costs. This starts with clear information on what it is end-users, clients and other stakeholders want. How can we make sure we get the right information on stakeholder requirements? What are the questions behind the questions when clients demand a specific building? What are the underlying motives? And which tools are the most effective and reliable to discover the requirements? To answer these questions additional research is needed, therefore the following research question was formulated: What are efficient ways to discover the real requirements and needs of stakeholders, based on what we know on the functioning of customers (unconscious) minds from marketing research, cognitive linguistics and psychology? In order to be able to make a proper inventory of stakeholder requirements in an efficient manner, research was conducted into what is known about the functioning of customer’s minds. This knowledge was used to formulate criteria to evaluate the different methods used in construction and in other sectors on this aspect. This evaluation is presented in section 3.4.

2. Inside the customer’s mind

According to marketing expert Zaltman (2003), most marketing managers operate from a paradigm – a set of assumptions about how the world works – which prevents them from understanding and serving customers effectively. In the construction sector we seem to have the same problem. Professional clients think to know what the requirements of the users are, but quite often when the building is realised, it appears that it does not meet the users’ needs in the

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1 When the term “stakeholders” is used in this paper, the different users of the building (employees, visitors, cleaners, etc.) are meant, as well as the parties involved in the development process of a building (e.g. architect, municipality, fire department, contractor, electrician).

2 Tools used to visualize the requirements found are beyond the scope of this paper and are not discussed.
way it was intended. One of the reasons this happens is that people don’t understand how their own and their customers minds interacts. We can explain this by taking a look at figure 1 (Jastrow, 1900). At first you’ll see a rabbit or a duck. What you will see the first is different from person to person. This demonstrates a very important point; two people can look at the very same information and have two totally different interpretations (Jastrow, 1900). Miscommunication can come into existence quite easily. This is one of the reasons new buildings do not always fit the needs of the users of the building. It occurs even when developing parties can and do involve the users and other stakeholders. In a lot of cases however, they are not even invited to participate, or are not involved on a regular basis, so their needs are not even heard. Jerome Kagan, a professor of psychology at Harvard University, is regarded as a key pioneer in the field of developmental psychology. According to him ninety-five percent of our thinking takes place in our unconscious mind. Therefore the selection process is relatively automatic and is influenced by social and physical context (Kagan, 2002).

Most people also think that people’s thoughts occur in terms of words. They think they can find out how people think by using standard interviews or questionnaires. Of course, words do play an important role in expressing our thoughts, but they don’t outline the whole picture. This leads to the question, if the methods currently used to uncover needs are the right ones and the most effective ones. It seems smart to make more use of people’s unconscious thinking and decision making. This means that we shouldn’t use ‘words’ alone to find out what the real needs are, but also use pictures to tap into emotions and to discover needs. On top of that, decisions in construction are often quite complex and not transparent. Usually the client does not know what exactly they will get from the contractor or architect. “Human thought arises from what neuroscientist call images. Words can trigger our thoughts and enable us to express them. That’s why people believe that thought occurs largely as words” (Zaltman, 2003). Metaphors often help us express the way we feel about important aspects in life (Zaltman, 2003; Johnson & Lakoff, 1980). “We have found, on the contrary, that metaphor is pervasive in everyday life, not just in language but in thought and action. Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature.” (Johnson & Lakoff, 1980). Researchers who make use of photo elicitation (PEI), which is mostly used in social and anthropology studies, also support this view. Therefore Marisol Clark-Ibáñez concludes in her paper “Framing the Social World with Photo-Elicitation Interviews” that using the PEI alone or in combination with other methods such as interviews or observations can discover insights that wouldn’t be found when using other approaches.

Figure 1: Duck-Rabbit (Joseph Jastrow, 1900)
Based on this information on the functioning of our brains, we formulated the following criteria to evaluate existing methods to reveal stakeholder requirements:

1. *Taps into emotions*; are the instruments fit to pinpoint the emotions that drive the stakeholders involved?
2. *Closes the content gap*; can part of the method close the interpretation gap that exists between stakeholder and the person who is conducting the workshop/interview/discussion (caused by different experience, backgrounds, education)?
3. *Uncovers the underlying motivation*; is the method able to reveal the underlying motivation of the needs of the participant/stakeholder?
4. *Gives depth and detailed information*; can the method provide detailed information about the requirements of the participant/stakeholder?
5. *Breaks into the unconscious part of our brain*

### 3. Existing methods to explore customer needs

Different methods are used in various sectors to uncover the needs and requirements of users when developing products or services. Basically the questions that developers have and the information they need are the same, only the approach to gather this information sometimes differs.

#### 3.1. Popular methods in the construction sector

When new buildings are developed, requirements of end-users are often filled in by the client. Although sometimes methods from other industries are used to explicitly investigate those, the methods most commonly used in the construction sector are described below. The advantages and disadvantages of the methods are listed in table 1.

**Surveys**
Surveys are also regarded as an easy way to discover needs and requirements. It’s a frequently used method in many different industries. With the use of surveys a lot of people can be reached to gather a substantial amount of information, that enables researchers to extract general conclusions valid for a large part of the population.

**Interviews**
Interviews are frequently used as a user requirement gathering method. This method is also used to discover the requirements of other stakeholders. Interviews can provide a lot of important information. Aspects that can cause problems or result in wrong conclusions when conducting interviews are that stakeholders and engineers usually have different backgrounds, experiences, and expectations from the system-to-be (Burnay et al, 2014).
Focus groups
A focus group is a special group of people in terms of purpose, size, composition and procedures. The purpose of a focus group is to get more insights in how people think and feel about a certain subject, idea or service. The group discussion is repeated several times with similar types of people. The aim is to find trends and patterns in the perceptions from the different participants (Krueger & Casey, 2015).

Multi Criteria Decision Method (MCDM)
The MCDM is a new tool in the construction sector, initially introduced to come to an Integrated Building Design (IBD) for new construction projects in which the environmental issues are addressed properly. The selection and prioritisation of design criteria among stakeholders at the beginning of the project is considered crucial (Balcomb et al, 2002). Additionally alternative design solutions should be evaluated in the process in relation to these criteria. The MCDM method is developed to assist in both. With this method it becomes possible to make the requirements of the different stakeholders explicit by discovering what is important to the different departments of the client organisation. It starts with a discussion to formulate priorities for the organisation as a whole, thereby transferring detailed information on what has value to the parties that will design, engineer and construct the building. Since the introduction in 2002 this method is also used for refurbishment projects (Alanne & Klobut, 2003; Hofman et al, 2012). The MCDM is therefore an instrument that is developed to clarify and prioritize the different aspects that are important to clients and end-users. The MCDM discussions starts with a list of major aspects (Hofman et al, 2012). Valuable aspects are divided in sub-themes in order to make the different facets from a specific aspect explicit for the client. Subsequently the importance of the aspects are indicated by marks. The higher the mark, the more important the aspect is in the eyes of the entire client organisation. Finally the outcome will be a map of the most important aspects and their priorities (Hofman et al, 2012).

3.2. Methods from other sectors
In other industries they use different methods whereby also visualisation is used. These methods are described below. In table 1 an overview can be found of the strengths and weaknesses of each method.

Photo elicitation
Photo elicitation is used in anthropology and sociology. Basically photo elicitation is the introduction of photographs into an interview. Compared to standard interviews, it can be noticed that people respond differently when photos are shown. Interviews whereby photos are used not only produce more information, but also different kinds of information, because images evoke deeper elements of human consciousness than words are capable of (Harper, 2002).

Metaphors
In the IT sector the requirements elicitation process is quite difficult, because it’s often about a new sort of system and specifications hereof that has not been built before, as is also the case in
construction. In this sector metaphors are often used to find out what the real users’ needs are. A metaphor is an imagery and suggests a similarity between two things or ideas that are not equal in reality. Metaphors therefore help to better understand unknown abstractions (Visscher et al, 2005).

**Personas**

What working with personas is, can best be described with a citation from Sim and Brouse (2014): “The concept of persona is an emerging new paradigm in user requirements modelling. Personas are fictitious and concrete representations of a specific group of target users. Personas are constructed to resemble real people. Personas contain information about the users’ names, ages, occupations, educational backgrounds, knowledge, abilities, interests, goals, concerns, usage patterns, environment the users engage in, and so forth.”

Some might expect Systems Engineering (SE) to be included in this overview. SE is a method that is commonly used in Civil Engineering and is used more and more in the development process of buildings. With Systems Engineering more time is required in an early stage of a project. First all the stakeholders will have to be identified and the project team will determine if and how the stakeholders should participate in the project. This creates support for the project and it helps to clarify all requirements. An important aspect of Systems Engineering is the requirement analysis for which usually standard methods are used such as interviews, surveys and focus groups. This means that all the information is gathered by verbal methods. It is therefor not a method in itself that is used to determine the requirements in the initial phase only, but more like an overall approach that is used throughout the development process as a whole. This is the reason SE is not included as requirement gathering method in this paper.

### 3.3 Evaluation of the methods

To determine the value and appropriateness of the different methods, the strengths and weaknesses are listed in table 1.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
</table>
| Survey     | • Delivers a lot of data  
• Fit for questioning large groups of people  
• Fit to derive conclusions valid for a large group of people  
• Less social desirable answers  
• Cheap | • The results are incomplete and not always correct, because 95% of our decision-making is unconscious  
• Not able to uncover the underlying motivation of people  
• No in depth information  
• No influence on the response  
• Often a low response  
• Additional questions for clarification are not possible  
• Most of the time answers are predefined |
<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interview</strong></td>
<td>- Provides detailed information</td>
<td>- The results are incomplete and not always correct, because 95% of our decision-making is unconscious</td>
</tr>
<tr>
<td></td>
<td>- You can ask additional questions to get more information</td>
<td>- Not appropriate if you are looking for information from a large sample of the population</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Can take significant time to conduct</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Interviewer and stakeholder will probably have different backgrounds, experiences and expectations (Burnay et al, 2014)</td>
</tr>
<tr>
<td><strong>Focus groups</strong></td>
<td>- Will gain insights in how people think and feel</td>
<td>- The results are incomplete and not always correct, because 95% of our decision-making is unconscious</td>
</tr>
<tr>
<td></td>
<td>- Provides information quickly with low costs</td>
<td>- Participants in a group are inclined to give socially appropriated answers</td>
</tr>
<tr>
<td></td>
<td>- Researcher can interact directly with the participants</td>
<td>- Will not tap into emotions, while emotions are the key drivers of behaviour</td>
</tr>
<tr>
<td></td>
<td>- Possible to obtain rich and large amounts of information</td>
<td>- Participants can feel forced to make up answers when they don’t know the answer</td>
</tr>
<tr>
<td></td>
<td>- People can react and build on responses by others</td>
<td>- Results can be trivial</td>
</tr>
<tr>
<td></td>
<td>- Flexible (Krueger &amp; Casey, 2015)</td>
<td>- Dominant participants can influence the outcomes (Krueger &amp; Casey, 2015)</td>
</tr>
<tr>
<td><strong>MCDM</strong></td>
<td>- Contradicting needs and interests will become transparent</td>
<td>- Costs more time in the initial phase of the project</td>
</tr>
<tr>
<td></td>
<td>- Provides insight in what is most important to clients and why</td>
<td>- Can be difficult to keep the main question in focus therefore experienced moderation is important</td>
</tr>
<tr>
<td></td>
<td>- Gives insight in what the client really wants</td>
<td>- Can be difficult to clarify all the different aspects that are important to the client</td>
</tr>
<tr>
<td></td>
<td>- Leads to better communication and understanding between the different departments in an organisation</td>
<td>- Providers think in technical specifications and solutions (can lead to misunderstanding or miscommunication)</td>
</tr>
<tr>
<td></td>
<td>- Helps to structure the requirements within user organisations</td>
<td>- It is really hard for the representatives of client organisations to represent the organisation as a whole (Hofman et al, 2012)</td>
</tr>
<tr>
<td></td>
<td>- Helps to prioritise the different requirements</td>
<td></td>
</tr>
<tr>
<td><strong>Photo elicitation</strong></td>
<td>- Images evoke deeper elements of human consciousness that words do</td>
<td>- Finding useful photos can be difficult</td>
</tr>
<tr>
<td></td>
<td>- With photos the unconscious part of our thinking is stimulated</td>
<td>- Using unsuitable photos can be harmful</td>
</tr>
<tr>
<td></td>
<td>- Better and more reliable information</td>
<td>- More time consuming than standard interviews (Pommeranz et al, 2011)</td>
</tr>
<tr>
<td></td>
<td>- Provides more detailed information</td>
<td></td>
</tr>
<tr>
<td><strong>Metaphors</strong></td>
<td>- Helps to understand unknown abstractions</td>
<td>- The client can interpret the metaphor in a way that is not anticipated</td>
</tr>
<tr>
<td></td>
<td>- Are dynamic</td>
<td>- Problems can occur due to cultural differences.</td>
</tr>
<tr>
<td></td>
<td>- Deliver a collective conceptual reference model</td>
<td>- The search for the right metaphor can be a difficult process (Visscher et al, 2005)</td>
</tr>
<tr>
<td></td>
<td>- Suggest features and sometimes relations</td>
<td></td>
</tr>
</tbody>
</table>
Clients and developers are talking on the same level
- Metaphors can break through existing thinking patterns
- Metaphors makes us use multiple parts of our brain (Visscher et al, 2005)

**Personas**
- More focus on the end-user, their tasks, goals and motivation
- Leads to better design solutions
- Make the needs of the end-user more explicit
- Strengthen the focus on the end-user, their tasks, goals and motivation
- Can improve communication
- Facilitates more constructive and user-focused design discussion (Long, 2009)

- Considerable resources are required
- Developing personas costs a lot of time and effort
- A scaled-back or low-budget version of personas can be harmful
- If details and goals of the persona are not correct then the alignment of the design can be inappropriate
- Requires training at an organisational level (Long, 2009)

If we compare different requirement gathering methods, it can be concluded that surveys and interviews aren’t the most useful methods to discover the real in depth requirements. Surveys will only help to get a general view of needs. Interviews can be used to get more detailed information, but both methods give only insight in the conscious thoughts of people, while actually information about the unconscious motives of people can be much more valuable. Burnay et al (2014) also conclude that a standard interview doesn’t provide all the necessary information to develop an optimal system (in this case a building). Although focus groups will gain more insights in how people think and feel by participating in a group discussion, it still doesn’t tap into their emotions. People are inclined to give socially appropriate answers. Often people are unaware what really drives their behaviour. Many decisions are non-rational and often emotional responses to circumstances. According to Barry Feig (as cited in Krueger & Casey, 2015) emotions are the key drivers of behaviour. Most people are not aware of the emotions that influence their behaviour. In a focus groups it is hard for the moderator to get to relevant insights. The MCDM method seems therefore a better method to make the requirements of the client organisation explicit. It also leads to better communication and understanding between the different departments in an organisation and between the organisation and the suppliers. Another strong aspect compared to some other methods is that this method helps to prioritise and structure the requirements. This will finally result in a building that meets the needs and requirements better than it would be when the building was developed in a traditional way. Despite the fact that it makes requirements more clear and transparent, it still is a method that makes use of words only. This means that there is still hidden information that will not come to the surface. Pommeranz et al (2011) concluded in their paper “Elicitation of situated values: need for tools to help stakeholders and designers to reflect and communicate” that standard methods (for example interviews and surveys) don’t provide the real life context needed for people to understand and express their values. They have compared different methods and concluded that photo elicitation seems well suited to uncover real values. They tested the method by using a normal questionnaire and a photo elicitation interview. The most detailed information came out of the photo elicitation interview (Pommeranz et al, 2011). With photos or images you can stimulate the more unconscious part of
our thinking, which leads to more accurate and more reliable information. While most projects in construction are rather complex and meant for a long lifespan, we should not exclusively use linguistic methods to uncover needs. Making use of pictures or photos can help to get more insights into the real needs, and it provides more detailed information, which will automatically lead to a better understanding. During requirements elicitation clients and developers often have the problem that they don’t understand each other. The client thinks in organisational and business terms, while the engineer thinks in technical terms. To close this gap metaphors can be an appropriate tool (Visscher et al., 2005). This communication gap, as it is referred to in the IT sector, also exists when developing buildings. Yet metaphors are not or rarely used in the construction sector. They are used in the design, but not in the initial phase of a project where the first requirements are gathered. The construction parties speak a more technical language and think mostly in technical solutions, while the client and other stakeholders think and communicate in other terms (organisational or financial). Besides, another related problem is that clients generally do not really know the requirements of their end users. The client also speaks another language than the different user groups, so there’s another gap. Metaphors can help to break through existing thinking patterns and can also help to talk on the same level. Because of that metaphors stimulate us to use multiple parts of our brain, there for more detailed and reliable information can be gathered. Sim and Brouse (2014) claim that by empowering the concept of personas into requirement engineering activities, a greater comprehensive understanding of the users’ needs and behaviours can be realized early in the requirements engineering process, thus allowing engineers to identify missing demands. According to Long (2009) there is more focus on the end-user, on their tasks, goals and motivation. It makes the needs and requirements of the end-user more explicit. Using personas therefore could be helpful for the requirement analysis when developing buildings.

### 3.4 Evaluation of existing methods

In the multi criteria analysis in table 2 the different methods and the five criteria are listed as introduced in chapter 2. For every criteria a method can score on a scale from 0 – 5. 0 means that it doesn’t apply at all and 5 means that it strongly applies.

<table>
<thead>
<tr>
<th></th>
<th>Tap into emotions</th>
<th>Closes the content gap</th>
<th>Uncovers the underlying motivation</th>
<th>Gives depth &amp; detailed information</th>
<th>Breaks into the unconscious</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey</td>
<td>0</td>
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When looking at the mca, it can be concluded that the survey is the most ineffective method to discover customer needs. It will not provide detailed information and is thus not useful in finding out the underlying motivation. Utilizing interviews is a bit better, but also with this method it is hard to tap into emotions and it still doesn’t trigger the unconscious part of our brain. The methods that really do break into the unconscious part of our brain are the photo elicitation and the metaphors. Since these methods break into the unconsciousness part of the brain, these two methods also have a high score in ‘tapping into emotions’. These two criteria make them score a lot better than the other methods to reveal customer needs. Because most of what we do or decide occurs unconscious, an effective method should tap into this decision process.

A lot of stakeholders are involved when developing buildings. Not only the requirements of individuals are important, also the requirements of different departments or user groups is needed. Therefore not only individual information should be collected, but also information from groups. Photo elicitation or the use of metaphors are worthwhile methods to get the needed information from the individuals, but a different method is needed to disclose information of groups. Looking at the strengths and weaknesses of all the methods evaluated in this paper we see that especially the ‘visual’ methods (using metaphors and photo elicitation) have a lot of important advantages that really contribute to better end results. Besides that, there are not a lot of weaknesses known from these methods. The weaknesses that are mentioned can be prevented. Personas also have a lot of strengths that could contribute to better results, however, attention should be given to known weaknesses. Developing personas is already a project in itself and cost a lot of time and effort. Using photos or metaphors is therefore to be preferred. This is also proven in other sectors e.g. the IT sector, anthropology and sociology.

3.5 MCDM+

Based on the conditions described above a new tool is evolving. The general aim is to develop a tool that triggers the unconscious parts of the users minds to get better and more valuable information about the real needs and requirements from different users. At first the focus is on professional end-users of a building. The tool should also help to articulate the needs of specific client groups consisting of the different departments of an organisation by making use of photos and pictures, since needs and requirements within an organisation depend partly on the activities, working methods and subcultures within the different departments. Because the MCDM method does this, it makes requirements more explicit and helps to prioritize them, it is chosen as a basis. When this method is combined with a tool that addresses the unconscious part of peoples thinking, a more complete and wider supported set of requirements can be made. This new method is called MCDM+. A first concept is ready and has been tested in two workshops during the 2015 edition of the LEAN Construction Symposium in the Netherlands with sustainability & lean as central theme.
Aim

The main aim is finally to give insight into the needs of different organisation departments to arrive at a shared view of the needs of an organisation as a whole, including the most relevant priorities therein. An important part is to give insight into the differences and provide understanding of each other’s motives and point of views. To get a total list of all the requirements, the tool should be used in several rounds to discuss different topics. In the tests of the concept method the topic ‘sustainability’ was addressed.

How the tool is used

(1) For each subject there is a large amount of pictures related to the subject (at least 30). Every individual collects a maximum of five pictures that symbolises the main aspects concerning this topic from his or her point of view. When choosing the pictures the person should reflect from his or her function and department, but personal preferences should also be ventilated. (2) People from the same department show each other the pictures chosen and explain to each other why they have chosen these and what it is they think matters. (3) When every member of the group has done this, they discuss were the similarities and differences appear. (4) The group put the pictures that symbolises the most relevant aspects for them as a group on a large piece of paper and clarify (e.g. with different colours, text, drawings and clustering of pictures) their motivation. (5) In the next step each group presents what the topic, in this case ‘sustainability’, means for them as a department. The most important differences between the departments will start to emerge in this stage. (6) Finally, when all groups have presented, the moderator will try to reach consensus about the most important priorities of the organisation as a whole on this specific topic.

4. Summary

An evaluation was made in this paper of the methods that can be used to make an inventory of stakeholder requirements. Considering the methods that are used to discover stakeholder needs in the construction sector, we can conclude that methods commonly used in construction only make use of words and verbal communication. Using these methods leaves a lot of important information undiscovered. This clarifies for an important part the inability to meet the needs of the users and other important stakeholders. Construction parties and clients are not able to tap into the unconscious level of stakeholders’ minds, even when they are focused on involving important stakeholders and put a lot of time and effort in the start-up phase and the requirement analysis with Systems Engineering. While the final outcome of this process may have less shortcomings, usually only linguistic methods are used, thereby missing important information which results in an incomplete listing of requirements. Knowing that most information rests in the unconscious parts of our mind, unable to come out with verbal research methods, this isn’t really surprising. Looking at the evaluation of seven existing methods, four from construction and three from other sectors, the construction industry could benefit from the use of photo elicitation and/or metaphors to discover requirements. Using photos and metaphors seem to be a welcome addition to the existing methods in construction, because they can gather more specific and reliable information and help different parties to communicate on the same level. This is really an important issue, because a lot of problems and failure costs are caused by
miscommunication and a lack of information exchange between the different parties. In order to improve this a new method was developed: MCDM+. The MCDM was used as a basis, combined with the use of pictures, thereby ameliorating the requirement gathering process to reveal in a more complete and supported set of requirements.

References


Toward an Occupant Satisfaction Measure for Office Building Retrofits

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Abstract

It has been widely acknowledged that failing to address occupant needs and expectations has severe negative effects on the outcomes of building retrofitting efforts, resulting in a performance gap in energy saving as well as occupant satisfaction and productivity. When evaluating performance metrics such as occupants’ thermal comfort, indoor air quality, space use and control by occupants, literature indicates a particular success of occupant feedback in comparison to the code defined standards and physical measurements since no assumptions is made and all contextual influences are taken into account. Analysis of the existing post occupancy evaluation tools, however, reveals the lack of an empirically validated and structured framework to measure occupant satisfaction with a holistic approach embracing different aspects of occupant comfort. In this paper, as a first step in developing the occupant satisfaction measure, occupant satisfaction dimensions and indicators in the literature have been reviewed systematically and organized in a hierarchical structure to ensure content validity of the model. Occupant satisfaction was configured under eight dimensions and under each dimension, the related indicators were identified. In addition, possible sources of dissatisfaction for each indicator were determined from the literature, which are intended to be used for determining the needs of the occupants and priority areas to focus on in the pre-retrofit phase.

Keywords: Retrofit, occupant satisfaction, post occupancy evaluation, office, workplace satisfaction.
1. Introduction

The commercial building sector is widely accepted as the sector with highest potential for energy savings (Tobias and Vavaroutsos, 2009; DOE, 2012; Ma et al. 2012; Jazizadeh et al., 2014; Azar and Menassa, 2015). The energy demand of commercial buildings is growing faster than any other economy (Azar and Menassa, 2015) and is expected to grow by more than 20% by 2035 (EIA, 2003). To reduce the environmental impacts of buildings, the construction industry is undergoing a transition toward the development of a more sustainable built environment, often called as green buildings (World Green Building Council (WGBC), 2009). Riley et al. (2004) defined a green building as ‘the one that minimizes resource consumption during design, construction, and over its life, and provides healthy and productive environments for occupants through the application of sustainable principles’.

The green movement initially focused on the design and construction of new buildings and importance of energy efficiency improvements in existing building stock (retrofitting) have been underemphasized (Tobias and Vavaroutsos, 2009). During the last decade, however, it’s been realized that retrofitting existing buildings have even more significant effect on the total energy demand since many of the buildings in 2050 are the ones that exist today (McGraw-Hill, 2009; Ma et al. 2012; Asadi et al, 2013). Today, retrofitting is considered as the key approach to realistically achieving substantial energy saving in building sector and many governments and international organisations have put significant effort towards energy efficiency in existing buildings (Ma et al. 2012). Research has shown, however, that especially commercial and office buildings may show higher-than-expected energy consumption levels, even when energy-efficient building systems are installed in the retrofit process (Azar and Menassa, 2015). This ‘performance gap’ or ‘energy efficiency gap’, as commonly referred in the literature (Brown and Gorgolewski 2014), is mostly around 30% and can reach up to 100% for more energy intensive buildings (Turner and Frankel 2008; Yudelson 2010). Apart from estimation errors, a major driver of the gap is diagnosed as people (i.e., occupants and building management) in the recent studies (Azar and Menassa, 2015). Studies show that energy consumption is significantly correlated with the occupant behaviour (Shrestha and Kulkarni, 2013) and if occupants understand the building and environment control systems, provided that the systems are designed to meet their requirements, they may contribute to lower building energy use (Day and Gunderson, 2015).

In office buildings, retrofitting do not only save energy and reduce operating costs but also contribute to the occupant’s health and comfort, resulting in decreased absenteeism and increased productivity (Ardente et al., 2011; Chidiac et al., 2011), and therefore increased return on investment (Korkmaz et al., 2010). Aktas and Ozorhon (2015) reports employee satisfaction is one of the prominent drivers why private companies choose to green their existing buildings. Similar to the energy efficiency gap, green office buildings may underperform in terms of occupant satisfaction and comfort. In the current practice retrofit design is generally based on code defined occupant comfort standards, however studies have shown weak and context-dependent correlations between standard-defined comfort ranges and occupant-reported comfort ranges (Wagner et al. 2007). Observations showed that a significant portion of the occupants remain dissatisfied with environmental conditions in offices after retrofits and dissatisfaction with
physical conditions may lead to misuse of building systems, which worsen the overall occupant satisfaction and increase energy consumption (Jazizadeh et al., 2014).

To minimize the performance gap, in terms of both energy consumption and occupant satisfaction, occupant needs and expectations should be determined in detail before a retrofit process in an office building. There has been a vast amount of research on post occupancy evaluations to understand how actions performed by building occupants and facility managers affect energy consumption, and to what degree occupants are satisfied with specific physical conditions. However an empirically validated measure to determine the occupant satisfaction and requirements before an office building retrofit is missing in the literature. Therefore, significant potential for energy savings, occupant satisfaction and productivity gains, which could be realized through a more appropriate retrofit design, remains untapped.

The aim of this research is to develop an empirically validated and structured framework to measure occupant satisfaction and determine the needs and expectations of occupants in the pre-retrofit phase in office buildings. This paper explains the first phase of the research, which is the identification of the occupant satisfaction dimensions and indicators through a detailed literature survey. This research is expected to be a timely contribution to the green retrofit movement, which is expected to intensify even more in the coming years due to national and international legislations imposing more stringent standards and wide-spaying voluntary certification schemes embracing the green transformation of the existing building stock.

2. Previous Work on Occupant Satisfaction Measurement

Occupant satisfaction measurement is most widely adopted in Post Occupancy Evaluation (POE), which typically focuses on assessment of client satisfaction and functional fit with a specific space after occupation (Turpin-Brooks and Viccars, 2006). Presier (1995) defines POE as ‘a diagnostic tool and system which allows facility managers to identify and evaluate critical aspects of building performance systematically’. In comparison to the code defined standards and physical measurements, literature indicates a particular success of occupant feedback when evaluating performance metrics such as occupants’ thermal comfort, indoor air quality, space use and control by occupants, as no assumptions is made and all contextual influences are taken into account (Jazizadeh et al., 2014; Azar and Menassa, 2015). So, despite its general use in the facility management phase, it is beyond any doubt that occupant feedback can and should be used to complement physical measurements and code defined standards for the goal of identification of retrofit actions in office buildings.

Occupant satisfaction measurement tools may also be named as Indoor Environmental Surveys or Building Performance Evaluation Surveys in the literature. Table 1 presents an overview of the most widely used occupant satisfaction measurement tools and their comparative metrics. These tools may be classified into two sub-categories as (1) mostly academic in-depth studies that embrace a limited number of parameters to investigate a particular occupant satisfaction dimension, and (2) more comprehensive but unstructured surveys mostly used in the industry where dependencies among the constructs are not described.
### Table 1: Occupant satisfaction measurement tools*

<table>
<thead>
<tr>
<th>Dimensions / Criteria / Measures / Metrics</th>
<th>Indoor Environmental Surveys</th>
<th>Occupant Satisfaction Measurement Tools / Models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Survey</strong></td>
<td><strong>POE Surveys</strong></td>
<td><strong>Building Performance Evaluation Surveys</strong></td>
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<tr>
<td><strong>Leaman, 2010</strong></td>
<td>BUS, ASHRAE, Moshkina-Bekker</td>
<td>BUS, ASHRAE, Moshkina-Bekker, NABERS, BOSSA, BQ, NUTAU, USP, Walden (1999, Brazil)</td>
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<td><strong>Choi, 2006</strong></td>
<td>HVSQ</td>
<td><strong>Building User Questionnaire</strong></td>
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<td><strong>Pape, 2002</strong></td>
<td>COPE (Cost/Effective Productivity)</td>
<td>Building User Questionnaire</td>
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<td><strong>Access 2002</strong></td>
<td>CREF-UCB Survey</td>
<td>Building User Questionnaire</td>
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<tr>
<td><strong>Azar, 2015</strong></td>
<td>HFSQ</td>
<td>Building User Questionnaire</td>
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<tr>
<td><strong>Carlopio, 1996</strong></td>
<td>(Bluyssen et al., 2011)</td>
<td>Building User Questionnaire</td>
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<tr>
<td><strong>CBE, 2004</strong></td>
<td>Remote Performance Evaluation</td>
<td>Building User Questionnaire</td>
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<td><strong>CBE, 2007</strong></td>
<td>Indoor Environmental Surveys</td>
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<tr>
<td><strong>Preiser 2005</strong></td>
<td>Indoor Environmental Surveys</td>
<td>Building User Questionnaire</td>
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</table>

*For references used in Table 1, please see Appendix 1.*
A deeper analysis on the occupant satisfaction measurement tools reveals that most of these surveys and studies do not involve any information on the selection of indicators, or validation of the indicator constructs used. A few studies that present some form of validation of the constructs are limited to a particular occupant satisfaction dimension such as thermal comfort or lighting. Thus, analysis of the existing tools reveals the lack of an empirically validated and structured framework to measure occupant satisfaction with a holistic approach embracing different aspects of occupant comfort.

Developing a measurement framework requires a systematic approach to the identification of the dimensions and indicators of the phenomenon to be measured. Normative refinement analysis of occupant measurement tools listed in Table 1 revealed that dimensions and measures used in these tools are different but mostly complementary. Presented in the next section, as a first step in developing the occupant satisfaction measure, occupant satisfaction dimensions and indicators in the literature have been reviewed systematically and organized in a hierarchical structure to ensure content validity of the model.

The existing tools investigated also present important limitations making them ineffective in identifying the real causes of inefficient building operation since they do not aim to investigate the dissatisfaction sources, which would enable to determine the needs and expectations of occupants in the early stages of a new retrofit project. So, in addition to dimensions and indicators of occupant satisfaction, possible sources of dissatisfaction for each indicator were also determined from the literature and presented in the next section.

### 3. Occupant Satisfaction Dimensions and Indicators

In the quest to find the relevant dimensions and indicators of occupant satisfaction, a literature search was performed using the key terms ‘occupant satisfaction’, ‘post-occupancy evaluation’ and ‘workplace satisfaction’ in four major research databases, namely, Science Direct, Taylor and Francis, Emerald and ASCE. A total of 317 articles published between 2000-2015 were analysed with regards to indicators proposed to measure occupant satisfaction or sub-dimensions of occupant satisfaction such as thermal comfort, indoor air quality, spatial comfort. Post-occupancy evaluation tools and standards presented in the previous section were also used to identify dimensions and indicators of occupant satisfaction.

Frequency analysis and normative refinement methodology were adopted in merging indicators found. The detailed literature review procedure adopted ensures the content validity of the occupant satisfaction measurement model to be developed in the following stages of the research. As a first step in the development of the model, the dimensions and indicators identified from the literature were organized in a hierarchical structure. Table 2 presents these dimensions and indicators along with their sources.
### Table 2: Occupant satisfaction dimensions and indicators*

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<th>Dimension</th>
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<th>Indicator</th>
<th>References of Indicator</th>
<th>Dissatisfaction Source</th>
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<td>Audial / acoustical / sound comfort</td>
<td>HVAC devices, natural ventilation</td>
<td>Visual comfort</td>
<td>Workplace level of light, work surface level of light, warmth, shadow, flicker (frequency)</td>
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Occupant satisfaction was configured under eight dimensions and under each dimension, the related indicators were identified. For example, for thermal satisfaction dimension, indicators were determined as temperature, radiant temperature, relative humidity and temperature shift. In total, twenty nine indicators were identified. It should be noted that while determining the indicators, the goal was to define the unobservable facets of occupant satisfaction via indicators that can be assessed by the users. Therefore, the indicators which require data collection at buildings by using devices (e.g., CO₂ emission) are not included in the scope of this study. In addition, possible sources of dissatisfaction for each indicator were determined from the literature. For example, for temperature sources of dissatisfaction were identified as ‘too cold’, ‘too hot’ and ‘unstable’. These dissatisfaction sources are intended to be used for determining the needs of the occupants and therefore priority areas to work on in the pre-retrofit phase.

### 4. Conclusions

Occupants can be a useful and inexpensive source of information in identification of the retrofit actions required in office buildings. In this paper post-occupancy evaluation tools and standards as well as academic studies were analysed in order to understand the approach, dimensions and indicators used to measure occupant satisfaction. According to Turpin-Brooks and Viccars (2006), an effective occupant satisfaction measurement tool needs to give comparable results, be reliable and address all factors that relate to the needs, activities and goals of the people using the specific type of the building considered. Existing occupant satisfaction measurement tools however, lack an empirically validated construct and a holistic approach embracing different aspects of occupant comfort in office buildings. As a first step in developing the occupant satisfaction measure, occupant satisfaction dimensions and indicators in the literature have been reviewed systematically and organized in a hierarchical structure to ensure content validity of the model. The proposed occupant satisfaction construct is intended to be empirically validated with an appropriate method in the following stages of the research, also determining the possible maintenance scheduling, renewals of equipment and installations, durable and maintainable materials, repairs, insects and rodent, leakage, cracks, seepage, dampness

*For references used in Table 2, please see: Appendix2.*
interactions with comfort conditions, occupant health and productivity. This study is expected to help identify and solve existing problems that hinders occupant satisfaction and guide the design of retrofits in the office buildings to maximize building performance and users’ needs.

References


Appendix1: https://docs.zoho.com/file/07ojpcfe1018a0f0845e686860bfea2cf16e8

Appendix2: http://docs.zoho.com/file/07ojp0fa4a43c3b6348e7b65f02b7d9f53438
An Analysis of Student Experiences at South African University Construction Programmes

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Abstract

A good student experience at the university is important for both the student and the institution as it has been shown to improve student progression rate and improve the throughput of students. The quality of the academic experience enjoyed by students is determined to a large extent by the teaching and learning philosophy employed. For education in construction related studies, the general teaching and learning philosophy used is the traditional lecture approach which is strongly instructive in nature. However, for the Architecture programme, the studio approach, which exhibits attributes of a constructivist approach, is the modus operandi philosophy of teaching and learning. Notwithstanding that the Architecture studio approach is coupled with the instructive lecture approach, differences in student learning experiences are expected to prevail between students of Architecture compared to students of other construction related programmes such as Quantity Surveying and Construction Management due to the differences in teaching and learning philosophies. This study therefore sought to determine if there are in fact any differences in learning experiences offered by the Architecture programme compared with learning experiences in Quantity Surveying and Construction Management programmes due to the studio approach to Architecture education. To achieve this, a self-administered questionnaire survey was conducted with students at three South African universities offering Architecture, Construction Management and Quantity Surveying programmes. A total of 194 registered students were surveyed. Using the Kruskal Wallis test and the Mann-Whitney U test, significant differences were found in some experiences between Architecture and the combination of Construction Management and Quantity Surveying and also in individual associations between Architecture and Construction Management and between Architecture and Quantity Surveying. However, as expected no significant association was found in any of the measured constructs between Quantity Surveying and Construction Management. The results therefore suggest that there are significant differences in learning experiences between Architecture and other construction programmes due to the studio approach to Architecture education. However, the differences are moderated by the fact that Architecture still relies on a significant amount of instructive lectures alongside the studio approach.
1. Introduction

The quality of the student academic experience during university education is cardinal to the success of both the student and the institution and is critical for producing quality graduates (Morgan 2016). Student experience refers to all the aspects of student life including academic, social, welfare and support (Ibid). The academic student experience is significantly determined by the general philosophy underpinning the delivery of the education. Generally, the philosophy of education delivery can be broadly divided into the two groups of the traditional instructive approach and the more contemporary constructivist or student centred approach. Construction education has largely been delivered through the traditional instructive approach with the exception of architecture, which, through the use of the studio approach, exhibits strong attributes of a constructivist approach.

A constructivist learning approach is distinctive from the traditional instructive approach in a number of ways. It is structured so that the learning is centred on the student by having the student actively participating in the learning. The approach is also based on a two-way communication system between the learner and the instructor with both parties sharing knowledge and experiences to promote active construction of knowledge by the learner. The traditional instructivist teaching approach on the other hand is characterised by a passive and rather uninvolved learner receiving knowledge in a one-way transmission process. Some educators have described the instructivist approach as being unsuited to learning and suggested that it perpetuates the production of graduates who are ill prepared for professional practice (Jungst, et al. 2003).

Notwithstanding that architecture uses the constructivist studio based learning, it also incorporates a fairly significant amount of instructive lectures as well. However, the equally significant use of the studio learning is very likely to significantly impact on the academic experience of the students. Therefore, compared to the rest of the construction programmes which do not make any significant use of the studio based learning, differences in the academic experience of architecture students are very likely to exist. This study therefore investigates the academic experiences of students undertaking construction studies and posits that there are significant differences in academic experiences of students of architecture and the rest of the students pursuing construction studies.

2. Studio-based Learning

Studio-based learning (SBL) is an instruction approach which is centred on the collaborative application of several module contents and skills in a project the solution of which is presented for peer review and revised based on peer review (Vest, et al. 2011). It has received widespread application on architectural education practice whereby, while different design modules are taught separately, students are expected to demonstrate their understanding of these different distinct modules by applying their understanding to a design
problem called a studio project (Hundhausen and Brown 2008; Nasir, et al. 2011; Vest, et al. 2011). In the SBL approach, students must construct a solution to a complex problem, present the solution to peers, participate in a critique (‘crit’) of the solution to peers and respond to criticism by revision or rebuttal (Hundhausen and Brown 2008). The lecturer plays the role of an instructor who both critiques and provides appropriate guidance to the student (Nasir, et al. 2011). The SBL approach is so central to the development of architects that no architecture programme is taught without it. Therefore, the results of the SBL approach to architecture education can be seen in its strict application of the philosophy. Owing to its remarkable success with architecture, other fields of learning have also embraced SBL. For example, Hundhausen and Brown (2008) applied the SBL approach to a computer science class where the students were tasked with developing the solution of an algorithm problem and reported evidence of the efficacy of the studio-based learning approach in a setting other than architecture education.

The studio approach in architecture education is based on the ‘atelier’ system which has its history in the prestigious Ecole des Beaux Arts in Paris (Fricker and Fricker 2010; Lackney 1999; Oh, et al. 2012; Simon 1996; Van-Alen-Institute nd). The ‘atelier’ system is an educational approach whereby apprentices in fine arts and architecture were trained by experienced ‘masters’ in an atelier, which is the French word for ‘workshop’ or ‘studio’ (Simon 1996). The Ecole des Beaux Arts, which is perhaps the oldest formal learning institution offering education in fine arts and architecture, used this approach since its inception in 1648 (Fricker and Fricker 2010). The approach was borrowed from the training of apprentices before formal education which involved experienced ‘masters’ taking on a small number of apprentices in their ateliers until the apprentices had mastered the art (Simon 1996). The atelier system lent itself very well to the training of architects because of the practical nature of art rather than science of architecture, and subsequently the need for apprentice architects to practice their craft in an architectural studio. The system worked so well that in fact as professional education shifted from the atelier to colleges and universities, and even as architecture education spread from Europe to America, and to the rest of the world, the studio approach became the modus operandi in architecture education (Lackney 1999; Van-Alen-Institute nd).

The student centred approach inherent in SBL is very similar to approaches found under constructivist learning models. Loyens et al. (2009) suggested four characteristics of a constructivist learning approach, namely, knowledge construction, cooperative learning, metacognition and authentic learning tasks. Knowledge construction in a SBL takes the form of the student piecing together knowledge from different modules and applying it to a novel problem thereby constructing new knowledge. The presentation of the suggested solution to peers and the instructors allowing for feedback through rebuttal or revision permits cooperative learning to happen. Metacognition, is built into the process by allowing students time to carefully reflecting on the responses provided by the peers and the instructor and subsequently revise their solutions after a ‘crit’ session. The studio project itself is normally the development of a solution to an authentic task. While this analogy between SBL and a constructivist lesson are drawn based on only one description of a constructivist lesson, even
with other differently named characteristics of a constructivist lesson, the central tenets among all constructivist approaches are the same and so the analogy remains valid. Therefore, SBL very closely resembles a constructivist lesson.

### 3. Constructivist Teaching Approach

As illustrated in Figure 2, the constructivist teaching model allows a creative process to take place during the interaction between the different parties via the learning situation designed by the teacher. The constructivist teaching model facilitates students’ creation of their own knowledge, as they are allowed to think more over the problems together and generate original ideas. So constructivist teaching is characterised by students’ active participation in class when they construct knowledge.

The focus shifts from the teacher transferring knowledge, to students constructing knowledge by themselves; that is, from teacher-centredness to student-centredness in a multi-directional manner (Yuen and Hau, 2006). Interchanges between student and instructor as well as between student and student are permitted and encouraged. Constructivist teaching by nature is empowering, because teachers assist students in developing new insights and making connections with previous knowledge while leaving the discovery of the knowledge to the students. This way, students are able to develop their own understanding of the subject matter based on previous knowledge and can correct any misconceptions they may have had. By explaining their ideas to other students, they are active participants in their own education and are able to come to a clearer understanding of the concepts being learnt (Ibid).

![Figure 1: The constructivist teaching model as adapted from Yuen & Hau, 2006](image)

### 4. Instructivist Teaching Approach

The traditional lecture approach to learning differs significantly from both the constructivist approach and SBL in that the traditional approach is strongly instructivist in nature. Instructivist teaching is most commonly understood as being a traditional, direct instruction,
teacher/instructor-centred approach whereby students in the classroom are passively receiving information and knowledge. Put very simply, direct instruction means teachers/instructors telling students the things they need to know (Nasir, et al. 2011). The traditional classroom can sometimes resemble a one-person show with a captive but largely uninvolved and passive audience. This teaching approach can be seen graphically in the Yuen and Hau (2006) model shown in figure 2. The model illustrates how the traditional approach is instructivist in nature with a one-directional flow of information. Students are expected to passively receive the knowledge from the teacher with very little engagement with the lesson. In this approach, the teacher seeks to transfer thoughts and meanings to passive students, leaving little room for student-initiated questions, independent thought, or interaction among students as well as between students and the teacher. This teacher-centred method of teaching also assumes that all students have the same level of background knowledge in the subject matter and are able to absorb the material at the same pace (Lord, 1999).

Figure 2: The teacher-centred teaching model as adapted from Yuen & Hau, 2006

5. Instructivist and Constructivist student experiences

Arising from the differences inherent in the teaching approaches of the constructivist and the instructivist models, differences in student experiences abound. In a constructivist academic environment, students experience a learner-centred approach rather than the teacher one-directionally communicating defined bodies of knowledge (Kember 1997). Active learning occurs multi-directionally with students engaged in discussing, questioning and solving problems and taking more responsibility for their own learning (Gibbs and Unit 1988; Prince and Felder 2006). In the instructivist teaching methodology, students are passive learners, receiving information without question. In a constructivist model, students actively construct their own meaning of knowledge (Bruner 1990) while in the instructivist model, they merely receive information.

The constructivist characteristics intrinsic in the SBL approach in the architectural design studio module therefore carries some, if not all, the differences in student learning experiences highlighted. Based on the description of the studio approach, four distinct differences in studio experiences with the traditional instructivist approach would be expected. Firstly, the role which the lecturer in an architectural design studio lesson plays changes from source of knowledge to critique and guidance instructor (Singer and Moscovici, 2007). Secondly, the nature of problems administered to students in an architectural design studio are complex with no single accepted solution and require students
to combine knowledge from several modules to synthesize the solution. Thirdly, the students are engaged more actively with their lessons because of the ‘crit’ sessions which provide very effective formative assessment and the opportunity for the students to explain their thinking and therefore more effectively demonstrate their understanding of key design concepts (Hundhausen and Brown, 2004). Finally, the architecture design studio is different from the traditional lecture approach in that the mode of lesson delivery is strongly student centred as opposed to the strongly teacher centred approach in the traditional lecture system. These differences and others can be seen in Table 1.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Students Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role, commitment and involvement of instructor</td>
<td>Constructivist</td>
</tr>
<tr>
<td></td>
<td>• Critique</td>
</tr>
<tr>
<td></td>
<td>• Facilitating</td>
</tr>
<tr>
<td></td>
<td>• Guiding</td>
</tr>
<tr>
<td>Nature of problems</td>
<td>Complex</td>
</tr>
<tr>
<td></td>
<td>Generation of ideas</td>
</tr>
<tr>
<td>Student engagement</td>
<td>Active</td>
</tr>
<tr>
<td></td>
<td>Knowledge sharing</td>
</tr>
<tr>
<td></td>
<td>Knowledge</td>
</tr>
<tr>
<td></td>
<td>creation/construction</td>
</tr>
<tr>
<td>Mode of delivery/transmission</td>
<td>Group work</td>
</tr>
<tr>
<td></td>
<td>Two-way transmission</td>
</tr>
</tbody>
</table>

### 6. Research Design

Research was conducted to establish whether there are any differences in learning experiences between architectural students and the rest of the students engaged in construction studies due to the conceptual differences in instruction approaches used in the design studio of the architecture programme and the instructive approach used for the rest of the construction programmes. The research was designed to measure the perceptions of students about their educational experiences. The design of any research study is concerned with the plan to assemble suitable data for investigating and testing the research hypotheses (Welman and Kruger, 2001). The methods used to gather information depend on the type of data and the problem to be researched (Leedy and Ormrod, 2001). For this study, a self-administered questionnaire survey was conducted with students at three South African universities offering construction management, quantity surveying and architecture programmes. The student survey forms part of a larger national study that evaluates the experiences of students in their academic construction programs. The data were analysed using SPSS version 22.

The population of interest was all South African universities offering construction related programmes. However, due to resource limitations, convenient quota sampling was used to select a sample of three universities. Time and cost conveniences were the main criterion.
used for selecting the quotas. All students in the selected universities were then targeted for inclusion in the sample.

Four constructs measuring aspects of learning experiences identified from literature as being likely to exhibit differences between architecture students and the rest of the students pursuing construction studies were investigated. The four constructs are “Role, Commitment and Involvement of Instructors”, “Nature of Problems”, “Student Engagement” and “Mode of Delivery/Instruction”. Each construct had items ranging from 8 to 12 and responses were measured using a five-point Likert scale with 1 = “Strongly Disagree,” 2 = “Disagree,” 3 = “Neutral,” 4 = “Agree” and 5 = “Strongly Agree”.

The questionnaires were administered to all students present at the time of sampling in each programme at the selected universities. The sampling was done at different days for each of the universities. A total sample of 194 registered full-time students from all three universities was obtained.

7. Discussion and findings

The convenience sample comprised of 194 full-time registered students at three universities in South Africa, made up of 88 (45%) male and 105 (54%) female students with one student not responding. Students were registered in all years of study as follows:

- Architecture – 81 (42%);
- Construction Management – 41 (21%); and
- Quantity Surveying – 72 (37%).

The degree of internal consistency or Cronbach Alpha scores for the scales used for the four student experience constructs is shown in Table 2. All the constructs were found to have statistically high internal reliability, namely Cronbach Alpha values >0.700. The scores ranged from 0.902 (role, commitment and involvement of instructors) to 0.799 (nature of problems). There is therefore between 90.20% and 79.90% probability that the constructs each measure a single underlying concept with an error of at most 5%. The scales used to measure the four selected areas of student experiences are therefore reliable in their measure of the constructs.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Cronbach’s Alpha</th>
<th>No of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role, Commitment and Involvement of Instructors</td>
<td>0.902</td>
<td>14</td>
</tr>
<tr>
<td>Nature of Problems</td>
<td>0.799</td>
<td>8</td>
</tr>
<tr>
<td>Student Engagement and Empowerment</td>
<td>0.849</td>
<td>11</td>
</tr>
<tr>
<td>Mode of Delivery/Transmission</td>
<td>0.869</td>
<td>8</td>
</tr>
</tbody>
</table>

Descriptive statistics for the four constructs have mean scores ranging from 3.59 to 4.05 as shown in Table 3.
Table 3: Descriptive Statistics for Aggregate Scores

<table>
<thead>
<tr>
<th></th>
<th>Role, commitment and involvement of instructors</th>
<th>Nature of problems</th>
<th>Student Engagement and Empowerment</th>
<th>Mode of delivery/transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>194</td>
<td>193</td>
<td>193</td>
<td>194</td>
</tr>
<tr>
<td>Mean</td>
<td>3.588</td>
<td>3.863</td>
<td>3.833</td>
<td>3.772</td>
</tr>
<tr>
<td>Std.</td>
<td>0.624</td>
<td>0.570</td>
<td>0.586</td>
<td>0.641</td>
</tr>
</tbody>
</table>

The data were tested for relationships. However, before any tests of association were performed, a test of normality was performed to establish the statistical distribution of the data and therefore establish the appropriate statistical tests to use between parametric and non-parametric tests. Table 4 presents the results of the Shapiro-Wilk test of normality which tests the null hypothesis that the data are drawn from a population which follows a normal distribution. The significance values less than 0.05 suggest that there is no evidence to support the null hypothesis and so it can be concluded that the data is not normally distributed and therefore only non-parametric tests should be used.

Table 4: Test of Normality

<table>
<thead>
<tr>
<th></th>
<th>Shapiro-Wilk</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Role, Commitment and Involvement of Instructors</td>
<td>0.982</td>
<td>193</td>
</tr>
<tr>
<td>Nature of Problems</td>
<td>0.971</td>
<td>193</td>
</tr>
<tr>
<td>Student Engagement and Empowerment</td>
<td>0.976</td>
<td>193</td>
</tr>
<tr>
<td>Mode of Delivery/transmission</td>
<td>0.977</td>
<td>193</td>
</tr>
</tbody>
</table>

To establish whether there were significant associations between the constructs measuring student experience and the different disciplines with the different instruction approaches, the non-parametric Kruskal-Wallis test was used. This test typically measures whether or not there are any differences in three or more sample means (Chan and Walmsley, 1997). It tests the null hypothesis that the samples are drawn from the same population.

Test statistics for the constructs “Role, Commitment and Involvement of Instructors” and “Mode of Delivery/transmission” are less than 0.05 as can be seen in Table 5. Therefore, for these constructs, the null hypothesis is rejected and it can be concluded that there are distinct differences in experiences among the three disciplines when it comes to these constructs. The three disciplines exhibit no significant differences in their perceptions of “Nature of Problems” and “Student Engagement and Empowerment”

Table 5: Association among all Disciplines

<table>
<thead>
<tr>
<th></th>
<th>Role, Commitment and Involvement of Instructors</th>
<th>Nature of Problems</th>
<th>Student Engagement and Empowerment</th>
<th>Mode of Delivery/transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-Square</td>
<td>12.153</td>
<td>5.878</td>
<td>2.540</td>
<td>9.208</td>
</tr>
<tr>
<td>Df</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Asymp. Sig.</td>
<td>0.002</td>
<td>0.053</td>
<td>0.281</td>
<td>0.010</td>
</tr>
</tbody>
</table>

a. Kruskal Wallis Test
In order to establish whether the observed differences in the experiences of the respondents on “Role, Commitment and Involvement of Instructors” and “Mode of Delivery/transmission” can be attributed to the architectural students, individual associations between architectural students and construction management students and between architectural students and quantity surveying students and also between construction management and quantity surveying students were performed. The Mann-Whitney U test, which is a non-parametric test which compares two sample means to establish whether the means are equal or not. It tests the null hypothesis that the two samples are drawn from the same population.

Table 6: Association between Architecture and Construction Management

<table>
<thead>
<tr>
<th></th>
<th>Role, Commitment and Involvement of Instructors</th>
<th>Nature of Problems</th>
<th>Student Engagement and Empowerment</th>
<th>Mode of Delivery/transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>1317.500</td>
<td>1233.000</td>
<td>1556.500</td>
<td>1173.000</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>4638.500</td>
<td>2094.000</td>
<td>4796.500</td>
<td>4494.000</td>
</tr>
<tr>
<td>Z</td>
<td>-1.861</td>
<td>-2.235</td>
<td>-0.458</td>
<td>-2.648</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>0.063</td>
<td>0.025</td>
<td>0.647</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Table 6 shows that the experiences of students in Architecture are significantly different from those of Construction Management students in the constructs of “Nature of Problems” (0.025) and “Mode of Delivery/Instruction” (0.008) since these are not coming from the same population. Also, Table 7 shows that when architecture students and quantity Surveying students are compared, significant differences in student experiences are found in “Role, Commitment and Involvement of Instructors” (0.001) and “Mode of Delivery/Transmission” (0.015).

Table 7: Association between Architecture and Quantity Surveying

<table>
<thead>
<tr>
<th></th>
<th>Role, Commitment and Involvement of Instructors</th>
<th>Nature of Problems</th>
<th>Student Engagement and Empowerment</th>
<th>Mode of Delivery/transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>1985.500</td>
<td>2418.000</td>
<td>2447.500</td>
<td>2254.500</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>5306.500</td>
<td>5046.000</td>
<td>5687.500</td>
<td>5575.500</td>
</tr>
<tr>
<td>Z</td>
<td>-3.404</td>
<td>-1.710</td>
<td>-1.598</td>
<td>-2.422</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>0.001</td>
<td>0.087</td>
<td>0.110</td>
<td>0.015</td>
</tr>
</tbody>
</table>
From Table 8, it is evident that there are no significant associations between the experiences of students registered for construction management and quantity surveying. This finding is not unexpected given that the mode of instruction is the same for both disciplines and firmly establishes the observed significant differences in student experiences originates from Architecture.

A correlation analysis revealed no significant correlations in student experiences when all the disciplines were grouped together. However, when Architecture was correlated individually with Quantity Surveying, significant correlations were found in the constructs of “Role, Commitment and Involvement of Instructor” (r = 0.276, p = 0.001) and “Mode and Delivery/Transmission” (r = 0.196, p = 0.015) as shown in Table 9.

When Architecture was correlated individually with Construction Management as shown in Table 10, the associated student experiences with coefficients ranged from 0.204 to -0.241 with significant association in “nature of Problems” (r = 0.204, p = 0.025) and in “Mode of Delivery/Instruction” (r = -0.241, p = 0.008). No significant correlations were found between Quantity Surveying and Construction Management.

---

**Table 8: Association between Construction Management and Quantity Surveying**

<table>
<thead>
<tr>
<th></th>
<th>Role, Commitment and Involvement of Instructors</th>
<th>Nature of Problems</th>
<th>Student Engagement and Empowerment</th>
<th>Mode of Delivery/transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>1277.000</td>
<td>1332.500</td>
<td>1339.000</td>
<td>1391.500</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>2138.000</td>
<td>2193.500</td>
<td>2200.000</td>
<td>4019.500</td>
</tr>
<tr>
<td>Z</td>
<td>-1.190</td>
<td>-0.860</td>
<td>-0.820</td>
<td>-0.506</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>0.234</td>
<td>0.390</td>
<td>0.412</td>
<td>0.613</td>
</tr>
</tbody>
</table>

a. Grouping Variable: Discipline

---

**Table 9: Architecture and Quantity Surveying**

<table>
<thead>
<tr>
<th>Role, Commitment and Involvement of Instructors</th>
<th>Correlation Coefficient</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.276**</td>
<td>0.001</td>
</tr>
<tr>
<td>N</td>
<td>153</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nature of Problems</th>
<th>Correlation Coefficient</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.139</td>
<td>0.087</td>
</tr>
<tr>
<td>N</td>
<td>152</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Student Engagement and Empowerment</th>
<th>Correlation Coefficient</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.130</td>
<td>0.110</td>
</tr>
<tr>
<td>N</td>
<td>152</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode of Delivery/transmission</th>
<th>Correlation Coefficient</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.196*</td>
<td>0.015</td>
</tr>
<tr>
<td>N</td>
<td>153</td>
<td></td>
</tr>
</tbody>
</table>

---

**Table 10: Architecture and Construction Management**

<table>
<thead>
<tr>
<th>Role, Commitment and Involvement of Instructors</th>
<th>Correlation Coefficient</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.169</td>
<td>0.062</td>
</tr>
</tbody>
</table>
### 8. Conclusions

There are significant differences in learning experiences between students of Architecture and students of other construction related disciplines. Differences in students’ learning experiences were found in comparisons of Architecture with Quantity Surveying and Architecture with Construction Management in two of the four constructs studied. No significant differences were found between Quantity Surveying and Construction Management. The significant differences found in associations with Architecture coupled with the absence of significant differences found in associations without Architecture suggest that student learning experiences in Architecture differ significantly from the rest of construction programmes.

While individual modules taught in Architecture are delivered through the traditional instructive approach similar to the rest of the construction programmes, Architecture differs from the rest of the programmes in that it is further characterised by the studio approach which is much more student centred and therefore exhibits attributes of constructivism. Therefore the difference in learning experiences found in associations with Architect and absent in associations without Architecture can be attributed to the studio nature of the learning approach used in Architecture programmes since it is the only variable of difference between Architecture and the other construction programmes. The differences found in the constructs of “Role, Commitment and Involvement of Instructors” and “Mode of delivery/Instruction” further support the notion that the studio approach is responsible for the differences since it the module where the role of the instructor differs from the role played in other modules. Also, studio is the only module where the mode of instruction is different.

Differences were expected to be larger and to be present in all four constructs studied. The absence of differences in some of constructs may be attributed firstly to the fact that even if architecture relies on the studio approach, it still has modules taught through the instructive approach and therefore the effect of the studio approach is moderated. Secondy, students may have given their opinions in some instances rather than their experiences. An element of reporting perceptions rather than experiences may have crept into the responses particularly in the responses from the construction management and quantity surveying students due to how the programmes are in fact taught in the South African universities. Therefore, in this...
kind of survey, one needs to be extremely cautious and provide very clear instructions to the participants to avoid misunderstanding of what is expected from them.

While this study has established differences in learning experiences between Architecture and Quantity Surveying and Construction Management in some learning experiences, it remains to be established whether the differences are positive towards Architecture or otherwise. This is worth establishing so that the viability of a studio approach to other construction programmes can be investigated.

References

Abstract

The purpose of this paper is to develop an analytical model for further verification of design and engineering as processes of learning. Such a model should in particular be able to uncover that design projects mature progressively through interactive processes with strong reciprocal and sequential dependencies. We assume that the linear waterfall style of project management for design and engineering is not adequate for coping with the nature of design and engineering. Following the verifications, the next step in this research is to develop a model for improved design management.

The paper addresses the nature of design and engineering and learning theory, and contributes to an improved understanding of the phenomena in question.

Keywords: design, learning, analytical model

1. Introduction

Project planning and engineering are activities that aim to create a foundation for some kind of artefact, e.g. a building with functionality defined by the customer, a bridge or a ship. Kalay (2004) refers to design as a cyclical relationship between two paradigms; design as problem solving, where the designer attempts to produce solutions to ill-defined problems, and design as puzzle making, where design is seen as a process of discovery, where given parts are synthesized into a new and unique whole. The design process, particularly in its early stages, can be characterized by a progressively clearer understanding of the scope, reciprocal interdependencies (Thompson 1967, Kalsaas and Sacks 2011) between different disciplines and subjects, and iterative processes and loops. Iterations can be positive or negative (Ballard 2000).

Several authors characterize Last Planner System (LPS) as a system of learning (e.g. Ballard, 2000; Rooke, 2005; Koskela et al., 2010), which is tied in particular to the high level of focus on involvement, and the mechanisms that are related to the evaluation of completed work plans, and root-cause analysis (continuous improvement). However, it seems like there has been a lack
of contributions to uncover, in depth, why this is the case. Some exceptions are Kalsaas (2012) and Skinnarland and Yndesdal (2012). Kalsaas analyses LPS through a learning perspective, which is based, in particular, on Kolb’s (1984) experiential learning theory and Illeris’ (2009) model of workplace learning. Skinnarland and Yndesdal (2012) focus on LPS as a system of knowledge development. The authors ties their theories to collective learning processes, inter alia, Nonaka and Takeuchi’s (1995) well known SECI model.

In the context of this paper, the authors are trying to understand the design process as a learning activity. The relevance is tied to the ability to gain a greater theoretical notion of design as a learning phenomenon, which will create an understanding that can be used to improve design management. For instance by providing a framework that utilizes the learning process in the most effective manner. The paper is structured as follows: at first we investigate the architectural design process, then we look at a selection of learning concepts. Finally, we discuss an analytical model for future research.

2. The architectural design process

Throughout the evolution of design practice, there have been countless attempts to tackle the challenge of understanding, mastering and explaining the processes behind our built environment. The first generation of design methodologists’ focus on the design process as something sequential and linear in the 1960s, has long been challenged (Lundequist, 1992). The understanding of the architectural design process as a complex universe of predictable and unpredictable interactions, interrelations and interdependencies between actors and their actions, relates to observations of the practice of architectural design made by researchers such as Cuff (1991), Kalay (2004), Lawson (2006) and Schön (1991).

According to Cuff (1991), the design process is a social construction, where buildings are collectively conceived. Kalay (2004) refers, as previously described, to design as a cyclical relationship between problem solving and puzzle making. Lawson (2006) describes the design process as “a negotiation between the problem and solution through the three activities of analysis, synthesis and evaluation,” and challenges the comprehension of the design process as a sequence of activities. He sees the design process to be a simultaneous learning about the nature of the problem and the range of the possible solutions. In the beginning of the design process, the architect, the engineer or the client do not know exactly how the building will look like, what are the problems to come or even what are the requirements to be fulfilled. Schön (1991) characterizes design practice as a reflective dialogue between the designer and the design situation and he emphasizes the crucial role of tacit knowledge. This kind of “feeling of” can be expressed, for instance, by experience-based, intuitive and unconscious habits and actions. This knowledge embodied by the practitioners involved in architectural design is crucial, but hard to grasp and unlock.

The features of the architectural design process described above are closely related to cognitive processes and design thinking. Some features are, however, also given by regulating external factors. Examples of these are (highly simplified):
• The delivery of design information and project material to the stakeholders (client, the building authorities and contractors) are regulated in phases. Each phase presents a higher level of detail and information depth, and each has to be approved by the stakeholders before moving on to the next phase.
• The time and performance related definitions of these phases are mostly specified in the project contracts. These might again be regulated by guidelines or regulatory demands on national level.
• The architectural design process is situated between the statement of the brief (more or less defined) and the start of the building production on the construction site. In practice, limited time resources, tough project budgets and the contractual models might often call for an overlap of the phases (e.g. starting up the work on the construction site before the design phase is completed).

Bearing the two above-mentioned groups of features in mind, the practitioners involved in the architectural design process must deal with an interplay between highly iterative, unpredictable and non-linear activities on the one hand, and regulated and linear activities on the other. Moum (2009) uses the metaphors of “baking bread” and “playing jazz” to highlight and simplify the different character of these features of the architectural design process. Baking bread could be seen as a linear, predictable, explicit and measurable process - based on for instance repetition and routine. This can be related to the activities described above, which are central in order to drive the processes forward due to the agreed time and cost. Playing jazz is on the contrary a rather improvised, intuitive and tacit process leading to a unique performance, based on ”the feeling of”, on talent, practice and experiences. This process might be compared with the hard-to-grasp elements of the architectural design practice described in the beginning of this section. This “something” going on in the head of the designers, is also a magical ”something” resulting in the unique and great architectural solutions and buildings. The “baking bread” and “playing jazz” metaphors are representing co-existent processes in the architectural design practice. The interplay and balance between these are crucial for what actually gets built.

3. Concepts of learning

3.1 Experience-based learning theory

Kolb (1984) emphasises that learning is a process rather than a result. He furthermore claims that knowledge is a transformation process continuously created and re-created, it is not an independent entity that can be acquired or transmitted. Knowledge creation occurs at all levels, from the most advanced forms of scientific research to the child’s discovery that being stung by a wasp is a painful experience that is best avoided in the future. “Knowledge” is the outcome of a transaction between social knowledge and personal knowledge. Social knowledge (Dewey, 1938) is the civilised objective accumulation of previous human cultural experiences, whereas personal knowledge is the accumulation of the individual person’s subjective life experiences. Knowledge results, then, from the transaction between these objective and subjective experiences in a process called learning. Hence, according to Kolb, to understand knowledge, we must understand the psychology of the learning process; and to understand learning, we
must understand the epistemology – the origins, nature, methods, and limits – of knowledge. Kolb draws heavily on Piaget (1970a) when he emphasises the need for epistemological understanding.

Furthermore, Kolb builds above all on Lewin (1951), Dewey (1910, 1934, 1938, 1958) and Piaget (151, 1968, 1970a, 1970b, 1971, 1978) when developing this well-known model for experiential learning. In this model, the process and structure of learning are depicted as a four-stage cycle involving four adaptive learning modes. These evolve from 1) concrete experience; 2) reflective observation; 3) abstract conceptualisation; and 4) active experimentation. This learning cycle can be understood as a continuous spiral where the different cycles of adaptive learning are repeated in order to allow for further learning. An onion can be used as a metaphor for this process, each layer representing a level of knowledge. Combining the four learning modes, Kolb divides them into two dimensions, where they represent pairs of dialectically opposed adaptive orientations, namely; 1) concrete experience versus abstract conceptualisation; and 2) active experimentation versus reflective observation. The abstract-concrete dialectic is one of “prehension”. Prehension is a concept invented by Kolb to describe the representation of two different and opposed processes of grasping or taking hold of experience in the world. This either by relying on conceptual interpretation and symbolic representation, a process described by Kolb as “comprehension” – or by relying on the tangible, felt qualities of immediate experience, which he describes as “apprehension”. The active-reflective dialectic is seen as one of transmission, representing two opposed ways of transforming what has been grasped through the prehension of experience. Either through internal reflection, a process Kolb describes as “intention” – or through active external manipulation of the external world, described as “extension”. There is thus a clear “division of labour” between these two dimensions of learning; namely that of capturing or grasping experience, and of ensuring that what is grasped, is transported to the level where it is translated into internal understanding and/or external action.

### 3.2 Workplace learning

Whereas Kolb’s model is primarily a model for individual learning processes, Illeris’ (2009) model, expanding on the works of Jørgensen and Warring (2002) and Botterup (2000), helps integrate an understanding of individual learning into an understanding of learning in working life. For workplace learning, Jørgensen and Warring (2002) have developed a model based on the concepts of learning environment and learning progress, where learning is seen as taking place in the intersection between the learning environment of the workplace and the learning progress of the employees. A distinction is made between the technical-organisational learning environment and the social learning environment. The technical-organisational aspect is constituted by the material conditions tied to technology and to the way the work is organised, which may, for example, facilitate or limit work variation, and thus impact on the possibilities for learning. The work community and social interaction constitute the social learning environment. Learning progress is linked to each employee’s background and stage of life, as well as to his or her capacity to be open to and benefit from learning. Learning takes place in a dynamic interaction between the learning environment and the individual’s learning progress.
Illeris (2009) divides the technical-organisational learning environment into six categories: 1) division of tasks/work; 2) work content; 3) scope for decision-making; 4) scope for using one’s qualifications; 5) scope for social interaction; and, 6) work strain. A rigid division of work can undermine the individual’s perception of the work as meaningful (Taylorism). Work content is linked to the work’s social significance and to its significance for the individual (learning progress). The scope for deciding over one’s own work is connected to the style of leadership (dialogue versus orders from above) and to the organisational structure (flat structure and decentralised decisions versus hierarchical, bureaucratic structure). Illeris points out that the opposing ideas and interests, which emerge in the encounter between different trades or professions, can create fertile learning environments. They can, however, also help consolidate mutual myths and images that place the other party in the role of being an opponent. Technological conditions are very important for the scope for social interaction and for the social learning environment. Work performance pressures (speed and intensity) can hamper learning because they interfere with the time or physiological/mental energy needed in order for learning, development, experimentation and trying out of new ideas to take place.

Based on Botterup (2000), this part of the model can be expanded to include “work practice”. Work practice is connected to society in the interface between the technical-organisational environment and the social learning environment – which is now expanded and described as “the social and cultural learning environment”. The practice concept contains what actually takes place “in practice”, but it also includes practice as a constituting expression of human consciousness and learning.

In the general learning model, which is individually oriented, Illeris (2009) distinguishes between three dimensions: the cognitive dimension; the psychodynamic dimension; and the surroundings/society. The acquisition process of learning takes place between the cognitive and the psychodynamic dimensions, which in their turn interact with society; whereas work identity is found in the tension between the cognitive and emotional dimensions. The cognitive dimension includes aspects of content and reason. It is linked to what Habermas (1984, 1987) describes as “the system”. The psychodynamic dimension covers motivational and emotional aspects, and is linked to Habermas’s “lifeworld”. It is society that provides the conditions for learning. The lifeworld is tied to communicative rationality, and the system to instrumental rationality, and the two are strongly intertwined. Lundvall (1992) relates “instrumental” rationality to the expected outcome of interaction (cause-effect); and “communicative” rationality to intuition, worldviews and other factors related to communication. Habermas’s theoretical contribution is often used in the innovation literature; see e.g. Moodysson (2007) and Kalsaaas (2011).

Illeris distinguishes between different forms of learning in the cognitive dimension. He describes “assimilative” learning as a general form of learning: it is used in everyday life in the encounter with new impressions and impulses. This is also the most common form of learning in schools, as the students’ knowledge is gradually built up over time. “Accommodative” learning is a more demanding form of learning, as it transcends boundaries. In this kind of learning, we cannot immediately understand or relate to what is happening. It requires that
existing understandings are overcome or broken down, which in turn requires creative efforts to restructure what is already known, through reflection. This is denoted “relearning” in Kolb’s work. So-called “aha experiences” and a perception that “the pieces have fallen into place” occur in relation to this form of learning. Accommodative learning is crucial in any attempt at introducing improved work practises. “Transformative” learning is the most demanding form of learning examined by Illeris. We may encounter this type of learning if we lose our job and have to retrain in order to get a new one, which often means that we have to develop a new worldview or a new basic outlook. This can be perceived as a life crisis on the personal level.

The psychodynamic dimension of learning, with its emotional, intentional and motivational patterns, is influenced by the cognitive dimension in the shape of our knowledge and skills. For example, so-called “bad chemistry” between individuals can drastically hamper our ability to learn. However, if we gain better insight into the work of those we do not initially feel sympathetic towards, such emotions may change. The reasons for defensiveness and resistance to learning are found in the emotional dimension. Illeris sees the factor of “defending identity” – which is one of several mental defence mechanisms – as crucial in this context. In our working lives we often establish an identity tied to something we master well, and which others also consider us as proficient at. For example, someone may be good at using an advanced control system, PLC controlling, programming, and so on. Strong work identities can easily lead to active resistance to any change, which might threaten these identities – such as change that involves an accommodative learning process. According to Illeris, the general tendency for adults is that the more demanding and complicated the learning requirements, the greater the psychodynamic barriers in the shape of defensiveness or resistance. Levin and Klev (2001) point out that learning is often prevented because we wish to avoid situations in which individuals might lose face. This is also a central concern in Argyris’s (1990) works. This phenomenon can be linked to the psychodynamic dimension.

The best conditions for workplace learning are found in the area where work practice and work identity overlap. It is possible to imagine that if there is no such overlap, individuals might try to modify their work practices in such a way that they become aligned with their work identity, or they might resign and look for work with a different employer.

### 3.3 Learning loops and learning cycles

Ashby (1960) and Argyris and Schön (1996) distinguish between single-loop and double-loop learning. Single-loop learning can be conceptualised as “Doing Better”, and double-loop learning as “Doing Differently”. It is part of the nature of this difference between double and single loop learning that beginning to do things in a different way is more demanding than pursuing the already established strategy, but with a few adjustments, in terms of the learning involved (in other words, assimilative versus accommodative learning). Expanding on Ashby (1960), Argyris and Schön (1996) argue that for a company, “doing differently” might require external resources to be brought in to help with the improvement work. Thus, greater competence on grasping via comprehension can be built through action research approaches.
where academics and researchers cooperate with the company. This relates to the traits considered by March (1999; see below) as limiting the value of experiential learning.

Rooke (2005) relates Kolb’s (1984) experiential learning cycle to Deming’s Quality Cycle (Deming, 1986), also widely known as “Plan-Do-Check-Act”. “Plan” relates to abstract conceptualisation; “Do” to active experimentation; “Check” to concrete experience; and “Act” to reflective observations. Deming’s quality circle, which draws on his joint work with Shewhart from 1939, is, in all its simplicity, widely applied in lean implementations and popular among consultants in the field. However, unlike Kolb’s work (1984), the quality circle does not offer any conceptualisation of learning as such. Rather, it is assumed that learning is likely to take place along the course of the Plan-Do-Check-Act cycle.

3.4 The limitations of experiential learning

According to March (1999), learning from experience does not produce perfect results by itself. It has its limitations. Firstly, experiential learning tends to exaggerate the importance of actual events relative to the events that might have occurred, and “thus to be quite sensitive to the rate of experience relative to the change in the world” (p. 332). Secondly, experiential learning tends to close the door on experimentation, according to March. It is fairly easy for a fast learner to fall into a pattern of repeating rewarding behaviour, and to stop reaching for the best possible performance. This can mainly be attributed to the ways in which strategies, competence and aspirations adapt simultaneously. Thirdly, experiential learning is not a good way to learn theories of behaviour. The starting point for March’s line of argument is that if behaviour conforming to one theory produces rewards, the other theories will tend to be neglected. Because of these problems, simple experiential learning in organisations is a flawed process. However, research and consultation can supplement this learning; not by attempting to substitute it but by helping to mitigate the limitations of ordinary and experiential knowledge.

Fujimoto (1999) avoids the problem of the limitations associated with experiential learning by distinguishing between “routinised manufacturing capability” and “routinised learning capability” on the one hand, and “evolutionary learning capability” on the other in his study of learning in the Toyota Company. Evolutionary learning capability, he argues, is a “nonroutine ability that affects creation of the above routine capabilities themselves through irregular processes of multi-path system emergence” (p. 17).

4. Towards an analytical model – design and learning

A qualitative model can be created by establishing causes and effects between internal variables, expectations, and contexts (Barth 1966). This model might appear to be similar to a quantitative model, but the variables are assigned with qualitative values, not numbers. The model is subject to empirical testing, and with the same values on the variables, the same result can be expected. Thus, different values on the same variables can provide other results. This concerns an analytical generalization where the transfer value might be larger than the case itself.
Creativity, problem solving, decision-making, and attitude change, are according to Kolb (1984) other words for experiential learning. Previously in this paper, problem solving was presented as one of two paradigms in design. The other mentioned paradigm is puzzle making, which can be connected to creativity. This part of design work, was related with «playing jazz» earlier in this paper. Decision-making is an obvious part of design, where decisions on some parts must be made in order to advance processes, even if it might be necessary to make changes later. In addition, attitude change can be connected to accommodative learning (Illeris 2009) and re-learning (Kolb 1984). During the design process it is imaginable that attitude changes are connected to the way designers and engineers work together, e.g. when transitioning the collaboration to Big Room organizing. Innovation can also be connected to design, especially when the design in question has something unique about it, e.g. signature buildings. In the innovation literature, learning is considered as a fundamental process for innovation, and knowledge as the most strategic resource.

Another possibility is to relate design to the value shop model for value configuration (Stabell & Fjeldstad 1998). This model, which is an alternative to Porter’s value chain concept for intensive technology (Thompson 1967), is represented as a circle of five generic activities: problem finding and acquisition, problem solving, choice, execution and control/evaluation. When the participants have reached the control/evaluation phase, the circle can be repeated if it is desirable. The relevance for design in the value shop model becomes obvious when we think in terms of puzzle making and problem solving, where problem finding and solving, and choice can be related to reflection and abstract conceptualization in Kolb’s learning theory. Furthermore, execution is the equivalent to active experimentation, and control/evaluation can be considered as concrete experience.

Experiences indicate that the design of complex construction projects gradually matures. The designers learn gradually during projects, thus getting a better understanding of the scope, and the issues are solved gradually towards a “good enough” design. In the context of design theory earlier in this paper, it is mentioned that design tasks includes «the joy of discovery, and the frustration of fruitless explorations». In other words, there is much trial and error in the early stages of design, and trial and error is, in this context, an apparent part of the learning process with active experimentation, concrete experience, and reflective observation/evaluation. Concrete experience is, however, virtual as the drawings represents a model of the real world. Furthermore, abstract conceptualization will be included in some cases, e.g. during structural analysis.

4.1 A minor case study illustrating project planning and learning

In order to advance the understanding of the design process and the respective learning processes, we provide an example from a rehabilitation project of a villa (Table 1). The villa was originally constructed in 1953 during Norway’s post-war period. The building was in a poor condition, compared to modern requirements for indoor climate, insulation, bathroom, etc.
Table 1. The design process and the respective learning processes in a villa project.

<table>
<thead>
<tr>
<th>Building authorities</th>
<th>The client</th>
<th>The architect</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>The client has a vision of upgrading the building to modern standards. He wants to elevate the ceiling to make room for a loft with an ocean view. In addition, he wants to upgrade the building in accordance to the latest energy standards.</td>
<td>The architect pays a visit, and discusses the vision with the client. The architect inspects the building in question, and then he sits down and starts sketching the new improved version in his notebook. Based on the knowledge he has acquired through experience, he is able to quickly understand how to implement the upgrades efficiently, e.g. create a new entrance, which gives access to both floors including stairways and storerooms.</td>
</tr>
<tr>
<td>Preliminary meeting with the local building authorities</td>
<td>The client discusses the upgrades with the architect in several iterations. One of the first changes in regards to the architect’s suggestion is the idea of building a conservatory. The client provides the architect with an idea from a magazine. He encourages the architect to come up with additions and enhancements to the conservatory. The alternative that the architect provides is chosen after discussions of functionality and esthetics.</td>
<td>The idea of partitioning the lot is put on hold after the meeting, as it requires rezoning.</td>
</tr>
<tr>
<td>Approval that the submitted drawings can be treated as an exemption from the zoning plan’s height requirements.</td>
<td>Application for building permit. None of the neighbors complain.</td>
<td></td>
</tr>
<tr>
<td>Requirements that the drawings set absolute requirements for legal height, and that the apartment downstairs will require a new application.</td>
<td>The client makes an effort to adapt the drawings to the requirements from the local authorities. The apartment downstairs is removed from the drawings in order to prevent a delayed startup.</td>
<td>The architect adjusts the drawings in accordance to the requirements of the local authorities.</td>
</tr>
<tr>
<td>The local building authorities approve the drawings.</td>
<td></td>
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After the first visit from the architect, the drawings were revised several times throughout the following months. However, the major concept and facade of the building was mainly decided during the two hour long visit by the architect. When the client had started the design process, changes was generated through internal discussions in the client’s family, discussions together with friends, and by studies of other construction projects, etc. Clearly, when the client is participating in a construction process, the buildings in the environment are observed in a new way. Ideas and inspiration are absorbed when observing and analysing other solutions. The final project change gradually, and in the context of this simple example the learning is especially happening for the client.

5. Conclusions

The paper verifies that learning is a central phenomenon in project planning, however, this version is unable to provide a complete analytical model of the phenomenon.

Future research will focus on developing an analytical model of learning in engineering. Such a model should in particular be able to uncover that design projects mature progressively through interactive processes with strong reciprocal and sequential dependencies.

References


Enhancing Student Learning Through Formative Assessment in an Enquiry Based Setting: Some Reflections

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Abstract

Across Higher Education and Further Education there is strong research evidence that assessment has a strong link with learning and a key factor in this link is formative assessment. The aim of the research project was to establish if a deeper understanding and application of enquiry based approaches to student learning could be achieved through the implementation of Enquiry Based Student Learning where continuous formative assessment strategy was adopted. Through an action research approach, the qualitative data gathered and analysed from questionnaires, focus group interviews and reflective diaries culminated in findings to show that this learning paradigm significantly improved the competence, understanding, motivation and confidence of those participating in the research. The main recommendations arising from the study were that a form of student-centred pedagogy such as enquiry based learning aligned to continuous and formative assessment could be used to better reflect projects and problems typical of those found in real-life industry situations.

Keywords: Assessment, Enquiry based learning, action research and FALLS

1. Introduction

Traditional lecture-based teaching methods are being replaced or supplemented by approaches which call for reframing the roles and identities of both teachers and learners. Enquiry-Based Learning (EBL) is one such approach. This paper reports on a study investigating the perceptions through reflection of staff and students involved in an EBL capacity building through a formative assessment approach project in a construction management undergraduate programme. An action research methodology offered an appropriate framework within which to explore and understand the formative assessment driven approach to enquiry based learning in this course and offer reflections about its effect on student learning. The findings are discussed using sociocultural learning concepts relating to activity theory and communities of practice. The paper concludes that EBL may improve the quality of teaching and learning in higher education, particularly in the context of built environment education, but careful consideration should be given to the dynamics of the specific context in which it is introduced.
2. Exploring the Landscape of Built Environment Higher Education

Education, as defined by Dewey (1938), is fundamentally about the teacher and the student and the transmission of knowledge, skills and values. This process has always remained the same. However, the manner in which the process occurs today has changed dramatically.

The BE as a holistic entity has changed considerably over many decades. These changes have been in areas as diverse as technology, materials, security, planning, utilities, design, management and finance. Involved as educators and researchers, the community of the BE has responded to these changes: it produces the ‘change-makers’ and continues to play a vital role in the management of change through the formation of craftspeople, graduates and researchers and the production of knowledge. Since the times of Aristotle and Plato society has found it desirable to categorise the different forms of knowledge in an attempt to make the world more intelligible (Gaarder, 1995). Ratcliffe (2007) proffers that while the Built Environment is both vague and elusive it is a generic phrase of distinction and pertinence and is best portrayed and understood ‘as a set of processes’ rather than one single entity. This set of processes includes planning, design, construction, regulation, finance, transportation and information. Griffiths (2004) describes it as a range of practice-orientated subjects concerned with the design, development and management of buildings, spaces and places.

In HE the discipline of BE has begun to make significant headway as a recognised discipline where schools of BE have been set up. While school and department configuration is often dependent on the culture of a HE institution, reference to BE is an acknowledgement of the existence of this discipline. In the Irish HE context, while still at a developmental stage, the field of BE has begun to be recognised and embedded as a distinct discipline with BE schools and faculty emerging in the organisational structures of HE institutions across the country.

There is a distinctly defined structure to the education of BE professionals in the US where reference to the term BE is not preferred. The BE domain is not a recognised entity, as it is in a European context. This is because the industry is more fragmented than elsewhere. Each domain/discipline has its own identity and it would appear that each performs independently. This fragmentation relates very much to the way the players in the industry act out their roles. Historically, the education of construction professionals has been aligned with the way the industry presents itself. An aspect that has an impact on where programmes are positioned is the culture and make of a university. There are a number of common approaches that have been adopted by universities that include:

- Architecture aligned with construction management/science
- Engineering where CM is aligned with engineering focused programmes.
What is much in evidence is the need for structured and embedded professional and vocational skills, knowledge and competencies for the future AEC experts and that schools where students are engaged in the collaborative learning are advancing toward this.

2.1 Enquiry Based Learning

Enquiry based learning (EBL) has the potential to develop students as a scholar (Hodge et al, 2008). It provides opportunities to engage with a range of different learning experiences and styles and, in turn, may lead to an innovation (Healey, 2005) and represents a shift away from more passive methods. This approach involves the transmission of knowledge to students to more facilitative teaching methods through which students are expected to construct their own knowledge and understandings by engaging in supported processes of enquiry, often carried out in small groups. In the context of this piece of research, it is important to highlight the student voice. For example, one of the student taking the course remarked on their experience that:

‘You go out of this class with your head buzzing, rather than feeling you’ve just passively sat there listening to what the lecturer had to say. You can’t be passive, you have to be involved and committed on this tasks set’ (student D)

Research into EBL proffers that it can improve the student experience, with the potential to enhance recruitment, satisfaction and retention. However, it should be pointed out that both students and staff need to be supported when making transitions in adopting or adapting to new approaches to teaching, learning and assessment, especially where more open-ended approaches, such as active learning, is involved in EBL (Kahn and O’Rourke, 2005). EBL is a constructivist pedagogy that intends to develop deep learning by allowing learners to use an enquiry-based approach to engage with issues and questions that are real and relevant to the subject being studied (Milentijevic et al., 2008). It also places students in realistic, contextualised problem solving environments where projects can build bridges between phenomena in the classroom and real-life experiences (Blumenfeld et al., 1991). Projects set can have varying complexity, but all will relate in some way to the fundamental theories and techniques of the chosen discipline (Mills and Treagust, 2003).

2.2 Formative Assessment Strategies

Assessment is a powerful driver of learning and lies at the heart of the learning experience. Formative Assessment within this EBL situation involved methods that focused on understanding rather than just memory recall and surface learning where elements of the Formative Assessment Led Learning Strategy (FALLS) were shared and explored by the lecturer with the participants. It was in an effort to change the perception that learning and building on your experiences is a challenge and it is not just about getting the correct solution; but more a move to gain an understanding of the meaning of the project task, that motivated this research study. As assessment ‘drives learning’ (Boud, 2007, and Boyd, 2007) the design of a EBL approach linked to an appropriate assessment strategy would result in meaningful and enhanced learning in the subject area. So, linking learning tasks with assessment tasks provided
the platform for this project. It was found that the project tasks used in the research study needed to be carefully constructed and related to real world design problems. Previous work on tasks suggests that they serve as critical links among student motivation, cognition, instruction and learning (Blumenfield et al, 1991).

Many tools can be used for assessment within EBL, but all are pushing towards the common goal of creating a framework to assist learning and understanding through formative assessment (see table 1, FALLS conceptual framework). This framework should support students in their assessment, self-assessment, and presentations whilst also facilitating reflective learning (Scott and Fortune 2013) The integration of learning, instruction and formative assessment within EBL is necessary and one cannot generally go without another The approach to this project was based on those principles and embedding four elements of FALLS.

In EBL, the process of constructing an applied distinct project (in this case a number construction detail design task), also focuses the student or student team to think through the steps of the process and complete tasks in a logical sequence, similar to a construction team in the workplace. As there was a sequential, logical and reflective path to be followed in this process, and where an understanding had to be achieved in order to progress through the design, the reason for rote learning was practically removed and it was a case of learning by doing. It is the belief of this researcher that this is more representative and worthwhile to built environment students to achieve an understanding of why and where they can use their experience and previous knowledge directly in their approaches to professional life and in many instances their own personal life.

<table>
<thead>
<tr>
<th>1) assessment for learning conception</th>
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<tbody>
<tr>
<td>2) student-centred learning pedagogy</td>
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<tr>
<td>3) preparation for feedback</td>
</tr>
<tr>
<td>4) feedback methods and dialogue</td>
</tr>
<tr>
<td>5) staff development</td>
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<tr>
<td>6) staff-student relationships.</td>
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Table 1 FALLS conceptual framework
3. Research Methodology

In the educational environment research exists in many forms and can range across a variety of topics and engage in a diverse array of methodologies and methods to answer particular research questions. All research, including Built Environment (BE) educational research, needs to be subjected to careful and considered methodological assessment and rigour. Traditional forms of theory are grounded in a logic of binary divides (McNiff & Whitehead, 2005) and thus can tend to exclude the notion of practitioner research. For example, this might be an academic applying other people’s theories to their practice or, as is the case here, a researcher engaged in examining other people’s practices and extracting a theory or framework. The primary concern, in relation to methodological issues, is to ensure that the research is conducted within the parameters of a methodology that appropriately addresses its aims. Therefore, an approach that accommodates change, such as an action methodology or participatory action research methodology, seems to offer an appropriate framework within which to explore and understand the assessment practices of BE academics on undergraduate higher education programmes.

The research itself is a study into the views of students and the researcher in the field of construction management on assessment followed by an exploration of FALLS practice that was developed to help to lead to an improvement in how students learn in construction education. The action research case study that is being presented involved cycles of interactions between the researcher and the research subjects that had two separate objectives:

1. Participant learning to build capabilities and enhance ability to understand and generate constructive behavioural change through reflective action on assessment practice

2. Generation of research findings for the researcher on the usefulness of FALLS as a tool to enhance such actions by the participants as improving their learning.

Iterative cycles of learning and development of research understandings, however, can be challenging to balance, as the motivations and benefits of the different parties can compete with each other (Steinfort, 2010). In this case study, the AR process described by Brannick and Coghlan was adopted because the research objectives aligned with their broad definitions of action research should be (2010, p. 4):

- Research in action, rather than research about action
- A collaborative democratic partnership
- Research concurrent with action
- A sequence of events and an approach to problem solving.

A significant reason an action research approach was chosen was because it combines both learning and generation of new research knowledge through a series of iterative cycles across multiple cases. This was considered to be an ideal way to explore the research objectives in such an emergent situation. The learning aspect of the research is that the participants learn some techniques that they then try to implement as part of their own environment and then reflect on
what resulted from that (and ideally go through iterative cycles to further develop their capabilities on the use of the methods to continue to enhance their ability to influence others and enhance outcomes). The research aspect is to understand how the application of the FALLS impacted the participants. In these situations, it was not possible to predict what the outcomes would be and the participants needed to use reflection before and after the intended action in order to optimise the outcomes and determine reasons as to why they got the results they did. The role of the researcher in this research was to guide the participants in the use of the FALLS, assist with planning the intended interventions and collate reflections from the participants. An aligned perspective was presented from McKay and Marshall (2001), who proposed the ‘dual imperatives of action research’ as being problem solving (a form of learning within a specific issue context) and a contribution to research. They explained the difficulties of researching the process being taken whilst actually applying the process to create outcomes in terms of developing solutions to real problems, and they suggested the AR approach was ideal for this.

Action research – which is also often referred to as Participatory Action Research (PAR), community-based study, co-operative enquiry, action science and action learning – is an approach commonly used for improving conditions and practices in a range of environments (McNiff & Whitehead, 2005). It can be used to involve practitioners conducting systematic enquiries in order to help them improve their own practices, which in can offer the potential to enhance their working environment and the working environments of those who are part of it – students, practitioners (contractors), clients, and the like. The purpose of undertaking action research is to bring about change in specific contexts, as Parkin (2009) describes it. Through their observations and communications with other people, action researchers are continually making informal evaluations and judgments about what it is they do. This approach can offer an embedded approach to reflection and so lead to improvement.

4. Analysis of the research

This research study was carried out on just one course from a very large curriculum in which rote and traditional forms of learning is seen to be extensive. Data collection took place over the period February 2014 to June 2014 for the research investigation part of this enquiry. During that period and beyond, the data collected were assembled and analysed in a phased approach. Each phase of the research process was documented and the data recorded appropriately as per good practice.

With very few exceptions, the students who participated in this study agreed that they found the FALLS method of learning, teaching and assessment more productive to their learning needs, more engaging through challenging real-life design work, and more resourceful in providing them with the competencies they need to work within their chosen discipline. What is generally agreed throughout the research literature is that modern society requires a fundamentally different conceptual discourse for assessment (Clegg and Bryan, 2004). Such assessment activities should not only address the immediate needs of certification to students on their
current learning, but also contribute in some way to their prospective learning (Boud and Falchikov, 2006).

Society now demands more than passive graduates who have complied with a rigid regime, and employers and professional groups are placing expectations on institutions to deliver graduates who are prepared for and can cope with the real world of work (Boud, 2007). Student-centred learning can foster knowledgeable, competent, reflective and committed learners (Mentkowski, 2006), that are more prepared for the unorthodox type of real work problems that are typically associated with engineering and built environment disciplines. Students may escape from poor teaching through their own activities, but they are trapped by the consequences of poor assessment, as it is something they are required to endure if they want to graduate (Boud, 2007). The more we can engage students in assessment activities that are meaningful to them and which contribute to their learning, the more satisfying will be their educational experience (Boud, 2007).

5. Discussion

What emerged from the focus group sessions and individual feedback was that most participants reported that they had never used formative assessment methods in any previous class setting. At the early stages of the research the reasons for this were not evident, as most of the participating group suggested their level understanding of assessment was that it was about ’exams’. However, further analysis of the data showed that although their understanding levels were sufficient to learn construction detailing for summative assessments, the relationship and link between these calculations and real-world construction methods tasks was unclear to most students.

In a focus group session, student E commented that, ‘I always had the ability to to prepare well for my exams, but I didn’t know why I was doing them’. There appeared to be general agreement with this from the group. Student C also reported that ‘I didn’t know where in construction or on site these methods could be used, they were just written on the board and we were told to follow them for the exam’. From the student’s perspective there seemed little reason than to continue with any effort to understand, when they could see no practical value to do so. Based on the evidence of the projects submitted by students, along with the research data analysed, it appears reasonable to suggest that the majority of the students have the ability to learn construction detailing and apply that knowledge and are happy to use them once they can see a clear and practical purpose to do so. There was a general consensus among research participants that having gone through the FALLS method and in construction tasks they could now use this knowledge and apply it to a real building situation. Student F commented that “I could now see what the construction details were doing in the project tasks; it’s more like what is expected of us in industry”.

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There was general consensus among each group that learning through FALLS was a better learning experience than they had previously. Many students expressed a sense of enjoyment in the learning experience and thought that other courses should be delivered in this manner. During the focus group sessions, it was most interesting to listen to students still discussing knowledgeably with each other, the approach to solving their particular tasks they had used in the various projects a number of weeks previously. When questioned on this they expressed an ease of understanding having used these formulas to produce an end product. Student A made the point that, “when I did construction calculations before I finished with a number that meant nothing. This time I had to go and find certain aspects to match and also make sure it would fit in the space. Now it means something to me”. Most of this group agreed that they now had a deeper understanding of this subject and they had also learned where they could be used within construction detailing.

From the research data, there is strong evidence to suggest that the students strongly engaged and were more motivated to broaden their learning about this subject area. When given an opportunity to learn and apply it to their chosen field they willingly undertook the tasks and were interested in coming up with a workable solution. Most of the comments relating to this in the focus group interviews and classroom discussions concurred that studying questions and subjects for an end of term summative assessment was not increasing their competence, knowledge or skills in the chosen area of study. In fact, all of the focus group participants agreed with the words of student F; “it would have been great to do all our subjects and design them within a project building. I would definitely have learned much more about construction management”. In addition, student C followed on to say; “if we were assessed on this it would be much better and we would learn far more than trying to remember questions for an exam”. Student B also made the point that; “it would be great to see how all the different systems like project planning and on-site supervision join up with each other in a building project. At the moment we just do everything separately for examinations. It is just read out and I can never see how they all link together”.

It would appear from the responses that the students indicated complete satisfaction with the FALLS approach but, more particularly, the linking of the assessment to their learning. The use and practice of applied processes that are task orientated with feedback contributed to a distinct increase in (construction) confidence levels over the course of the research study. With this increase in confidence, many students throughout the research period, showed initiatives to extend their (construction) skills beyond the curriculum. An example of this was the extremely high attendance during and after class throughout the semester. It is the contention of the researchers that students attend class if there is a reason to.

One of the major aims from this research project was to provide a platform that enabled students to gain a deeper understanding of construction technology and its application in the construction process through a task orientated approach with a formative assessment focus. The findings of each individual action research cycle hold that the majority of those who participated in the research reported a distinct increase in both their level of understanding and in their competence, in the use of applied construction methods.
The early interviews with students indicated that their confidence around the use and understanding of the application of calculations was lacking. However, later findings revealed that they gained confidence in their knowledge and understanding through the task orientated approach. Student B commented, “The tasks we did helped me get a better understanding of why and where the construction details could be used to building design. I now also feel more confident in my ability to use them in relation to my job”. Most felt they would now be more able to accomplish many design-orientated tasks and work-related problems from the experience of this approach. The feedback from the majority of students together with all of the research findings has shown that a task orientated approach with the underpinning of a strong formative assessment strategy, when used in the correct circumstances, has the capacity to create learning environments that are facilitative to deep levels of learning and understanding.

The findings and discussions presented in detail above, along with positive feedback from students during the course of this study, leave us confident to report that we believe a deeper understanding and application of applied calculations and calculations can be achieved through the implementation of FALLS and assessment within a construction detailing module.

In regard to the case study presented, many of those students who participated in the research still make contact (mostly via email, IM, and text messages) about the impact of this assessment approach on their learning. They reflect and report on their memories of our classes and how it allowed them to see and develop a more diverse approach to their learning, but most of all, it provided them with an opportunity to explore and achieve the best in themselves. In sharing this research enquiry and the findings, in no way is it intended to convey a naive, heroic, or triumphant tone. It is nevertheless most rewarding to share the reflections about small change and the transformation that has impacted on a small number of students. The author remains hopeful that that experience shaped and changed their lives for the better.

6. Conclusions

Much current practice as to ways of linking research and teaching reflects tradition, but there is considerable variability in approaches within subject disciplines. Enquiry-based learning, for example, may be infrequent in some disciplines, and occur at different stages of the curriculum in other disciplines. However, innovation is possible, as is shown by examples such as, inquiry-based learning in this case and the use of research based assignments in the

It is hoped that through the sharing, description and analysis of this very concrete action research case study examples, learners, educators and researchers can come to recognise students’ intelligences and cultures in the learning environment through dialogues initiated from multicultural literature, while critically exploring hard issues, such as diversity, gender equity, strength and power, and considering multiple perspectives. I do not offer an answer, as there is not a single one: what I do offer are perspectives; my perspective and that of the students who
endeavored to problematize their learning issues around assessment as a way to deal with enhancing their learning.

As an educator, much has been learned through action research alongside my students while merely seeking to provide access for all learners to a more structured and beneficial approach to formative assessment. I would like to offer encouragement to all academics and those in education development to begin ‘to re-create and rewrite [these] ideas’ (Freire, 1970: xi) and to start implementing learner centred responsive pedagogies through deep explorations and dialogues. I would further encourage the use of the FALLS in the classroom as a strategy for challenging the perceived issues that surround assessment practice.

Action research projects test knowledge in action and those who do the testing are the interested parties for whom a base result is a personal problem. Action research meets the test of action, something generally not true of other forms of social research. Conventional researchers worry about objectivity, distance, and controls. Action researchers worry about relevance, social change, and validity tested in action by the most at-risk stakeholders.

Looking to the wise words of Ralph W Tyler (1949):

“The real purpose of education is not to have the instructor perform certain activities but to bring about significant changes in the student’s patterns of behaviour”.

The real challenge lies in the fact that we as teachers need to bring about significant changes in our patterns of teaching in order to achieve that. All aspects of learning, teaching and assessment should form part of any reflection.

References


Can the Performance of the IT Industry Help the Other Industries Perform?

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Abstract

The Best Value environment was introduced into the Netherlands in 2006. By 2008 testing was being done by a partnership of Arizona State University and Scenter (private entity led by Sicco Santema). In 2010, the $1B fast track projects were procured by the Rijkswaterstaat, and by 2012, the Best Value approach had become a core practice of the professional procurement personnel. The Performance Based Studies Research Group (PBSRG), the creator and licensor of the Best Value Performance Information Procurement System (PIPS) targeted three industries which shared the management, direction and control (MDC) characteristics of the construction industry: the medical industry, the ICT industry and the professional services industry. The ICT industry has the worst performance even though it has the highest rate of change in its technology. A case study is being conducted with the large, traditional ICT vendor, to see if they can successfully implement the characteristics of the best value approach and overcome the traditional nonperformance of the ICT industry. Their progress and challenges will be compared to the challenges in the construction industry. If the issues are the same the solutions should then be applicable in the construction industry.

Keywords: IT industry, performance, supply chain issues, large organization, Best Value

1. Collusion in the Dutch Construction Industry

In the early 2000s collusion was identified in the Dutch Construction industry. The cause of the collusion was identified as contractor greed (Doree, 2004; D. Kashiwagi & J. Kashiwagi, 2011). In response to these allegations the government moved to penalize the guilty parties but discovered that the penalized amounts would be greater than the profit generated by the identified vendors. In order to maintain stability in the industry a few scapegoats were identified and penalized, while the rest of the industry was persuaded to build a case against the scapegoats by providing information on the collusion. Those who volunteered information were promised to be exonerated.
1.1 Construction Industry Structure (CIS) Model

The source of poor construction industry performance has been identified as an owner generated problem and not a vendor generated problem (Figure 1).

![Figure 1: Construction Industry Structure (CIS) model](Image)

The CIS identifies that the major difference between low performance and high performance is caused by the owner’s use decision making, and attempt to manage, direct and control (MDC) to minimize risk, instead of utilizing expertise. The results of this practice include (Kashiwagi, 2014a):
1. Poor performance
2. Higher costs
3. Inefficiency
4. Decision making
5. Need for relationships to be formed to solve problems
6. Lower value of expertise
7. Commodity practices
8. Non-transparency (an environment where the source of the problem is not easily identifiable).

The concepts of the CIS was being presented in CIB conferences in Trinidad, Tel Aviv and Singapore, and eventually led to a fellow CIB member (George Ang, Ministry of Housing). George Ang then brought Dean Kashiwagi into the The Hague, Netherlands to present to the various ministries in 2004.

2. New Academic Research Approach

At this time, the construction management academic research experts in the Netherlands did not come to consensus about the CIS model and explanation. It seemed too simple, the overriding concept being that the vendors were at fault, and the Dutch construction management researchers felt that the Dutch culture was different from the American culture. Only one source, Dr. Dean Kashiwagi from PBSRG/ASU
proposed that it was the owners and not the vendors who were at fault, and he was using deductive logic, common sense and case study tests in the United States to validate his proposal.

An effort was made by Dr. Kashiwagi to involve more researchers, but his insistence to run industry tests without consensus of all the researchers led to a failed effort. Instead of using the conventional rout of academia, Dr. Kashiwagi, began applying PBSRG’s deductive approach, using industry testing with visionary industry personnel to start the research. Bypassing the discussion and consensus of the Dutch Construction Management academic researchers in the Netherlands, Dr. Kashiwagi, went right to the industry and formed partnerships to test out the CIS concepts. Dutch visionaries in one of the major construction companies (Marc Gillissen), multiple visionaries in the Rijkswaterstaat, and a visionary professor in marketing and supply chain at Delft University (Sicco Santema) identified the CIS model explanation and the Best Value (BV) PIPS as a solution to change the environment of the delivery of services resulting in the following actions (D. Kashiwagi & J. Kashiwagi, 2011):

1. Heijmans Construction licensed the Best Value Performance Information Procurement System (BV PIPS) from ASU.
2. Rijkswaterstaat was also licensed with the BV PIPS technology from ASU.
3. Scenter (private consulting company led by the visionary Sicco Santema) and the Delft University were licensed with the technology.
4. Scenter was trained by PBSRG. They ran small successful BV PIPS tests in 2008-2009 (Van de Rijt, Hompes & Santema, 2010).
5. Rijkswaterstaat ran a huge test by procuring $1B “fast track” infrastructure projects using BV PIPS (called Best Value Procurement or BVP) assisted by Scenter and PBSRG.
6. The fast track project results using BVP minimized procurement transactions and costs for all parties by 50%, vendors reduced construction time by 25%, and tests confirm that the CIS model is accurate and 90% of all project cost and time deviations are caused by the owner. They also confirm that the MDC activities of the owner’s project managers was the source of most issues (Van de Rijt, Witteveen, Vis & Santema, 2011).
7. As a result of the “fast track” projects, NEVI (third largest organization of professional procurement personnel in the world) licenses the BV PIPS technology from Arizona State University (ASU) and begins to educate and certify all procurement personnel in BVP and the CIS and the underlying logic of the BV PIPS approach which is called Information Measurement Theory or IMT (PBSRG, 2012). The BV PIPS approach which moves the paradigm from the price based MDC environment to the utilization of expertise environment is now one of the major thrusts of NEVI. They have recently hired a new Director of BVP education and are expanding their offerings to assist all stakeholders in understanding of the BV PIPS approach.
8. The RISNET organization comprising of risk managers and professional engineering groups also licensed the technology from ASU.

The history of changes within procurement paradigm in the Dutch construction industry along with dominant project successes validated the CIS model. The model and the BV PIPS or Best Value Procurement (BVP) is now accepted and used as a mainstream model in the procurement of services in the Netherlands. The traditional academic research model of performing a literature search of existing concepts, proposal of a theoretical solution based on the literature search, survey of industry experts to
identify which industry characteristics are most influential in the collusion, and presentation in academic journals to seek consensus in the academic world was not used due to the extensive time and impracticality. The process would be too lengthy, would not assist the industry in a timely manner, and would utilize opinions of industry and academic personnel that were “a part of the existing problem.” The Dutch results are supported by the following results of PBSRG/ASU in the United States and other countries:

1. 22 years of research testing, $16M of research funding, 1,800 tests, 98% customer satisfaction delivering $6B of services (PBSRG, 2015).
2. Most licensed technology (45 licenses) developed at ASU, one of the top research universities among universities without a medical school.
3. Two five year longitudinal studies identify the client and their representatives as the largest source of project cost and time deviation. Vendors create minimal risk when transparency allows the identification of the sources of risk (D. Kashiwagi & I. Kashiwagi, 2014).
4. 250 journal conference publications showing that management, direction and control (MDC) results in poor performance. (PBSRG, 2015).
5. Validated the CIS or IS model, and identified that the paradigm must be changed for delivering construction services (Kashiwagi, 2014b).
6. CIB W117 committee on the Use of Performance Information in the Construction Industry has done research work in seven different countries and 32 different states in the United States validating the same concepts.

3. Problem in the ICT or IT Dutch Industry

The delivery of services in the IT industry is perceived as being non-performing. The following has been documented on the nonperformance of the ICT industry:

1. ICT non-performance is estimated as high as 75% (D. Kashiwagi & I. Kashiwagi, 2014).
2. Major consulting company claims that the projects are too complex, and the complexity is causing the nonperformance.
3. New project management model, the agile approach, which maximizes communication and documentation, movement in smaller increments of time, and works from beginning to end instead of from the end to the beginning (Scrum Alliance, 2013).
4. Dutch government inquiry is held to identify the source of the ICT industry nonperformance and the large amount of resources being wasted on ICT projects. The result of the inquiry shed no more understanding of the problem (Tweede Kamer, 2014).

One of the larger ICT industry partners was identified as being in collusion with Dutch government officials (Zembla, 2014). Even though the company has not been convicted of crime of collusion, the company was cast in a poor light. At the same time, PBSRG was notified of another large government client was having problems with another major ICT vendor on a best value project.
4. Proposal

Past research results show that the client/owner is the biggest source of risk in the delivery of construction services. Because the source of risk is not technical (client/buyer using MDC to deliver projects and minimize risk), the authors propose that the problem is not a technical problem (complexity of the technology, lack of technical expertise, or complexity of the requirement). The authors propose that the CIS or IS, identifies that poor performance and collusion is caused by the client attempting to manage, direct and control (MDC) projects. The authors propose that the client is creating an environment which is:
1. Nontransparent, confusing and based on relationships.
2. Does not utilize expertise.
3. Filled with decision making from non-experts.
5. Not understanding what risk is and how to utilize expertise because experts have no risk.
6. The areas of risk management and project management have to be redefined and new paradigms must be utilized to increase the performance of the ICT industry.

5. Methodology

1. The researchers will search and identify an ICT vendor that does not utilize MDC to deliver their service. Their performance will be identified.
2. If the performance is dominantly higher than the industry performance of 25% success, the authors will investigate if the problem of MDC is in the ICT industry.
3. Identify a large traditional ICT vendor and identify if they have a bureaucratic or MDC environment.
4. Identify if the large traditional ICT vendor has a performing project or a BV project.
5. Analyze the project to identify what made the project different.
6. Analyze the owner/client of the performing project and identify what they did differently.
7. Also identify if the client/owner visionary is facing resistance from MDC personnel in his own organization.
8. Identify an effort with a large ICT vendor responding to BV project request that resulted in the client using decision making and MDC to eliminate the vendor’s BV effort.
9. Identify the difference between the price based and BV environments, and identify the difficulty for a large ICT vendor to change into a BV oriented vendor.
10. Analyze the results of the case studies to see if the environment delivering ICT services is in the price based arena resulting in low performance.

6. Research Case Studies

Schuberg Philis (SBP) is one of the ICT companies in the Netherlands that is known for their high performance and unique company structure (D. Kashiwagi & I. Kashiwagi, 2014). After studying SBP it was confirmed that SBP was an expert company that delivered high performance (See table 1):

Table 1: Schuberg Philis Overall Performance Line

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1. They are the top rated ICT vendor in the ICT infrastructure area (in every category measured).
2. They have a project performance of 89.36% on time, 95.74% on budget, and 93.62% customers satisfied on 47 large projects in the last six years.
3. Of the six most critical ICT providers that support financial vital infrastructures as stated by DNB (same function as Federal Reserve Bank); they are the only vendor with 100% customer recommendation for outsourcing.
4. In the last four years, their business process uptime performance is 99.994.
5. Their customer satisfaction rating was 8.9 in 2013 – highest in the IT market for 7 years in a row, 2 full points above the market average (6.9).

Some unique characteristics about their organizations is that (D. Kashiwagi & I. Kashiwagi, 2014):
1. They have no MDC.
2. They have very high performance.
3. The authors conclude that Schuberg Philis is a BV company that delivers high performance.
4. They prove that if a vendor is BV oriented (no MDC), they will deliver very high performance.

Table 1: SBP Performance Metrics

<table>
<thead>
<tr>
<th>#</th>
<th>Criteria</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total # of projects in last 10 years</td>
<td>991</td>
</tr>
<tr>
<td>2</td>
<td># of large projects (€150K- € 3.3 Million)</td>
<td>47 (72)**</td>
</tr>
<tr>
<td>3</td>
<td>% of large projects on time</td>
<td>89.36%</td>
</tr>
<tr>
<td>4</td>
<td>% of large projects on budget</td>
<td>95.74%</td>
</tr>
<tr>
<td>5</td>
<td>% of large projects customers satisfied</td>
<td>93.62%</td>
</tr>
<tr>
<td>6</td>
<td>Highest customer satisfaction 7 years in a row (Market Average)*</td>
<td>8.9 (6.9)*</td>
</tr>
<tr>
<td>7</td>
<td>Recommended by customers by year</td>
<td>100% 5 years in a row</td>
</tr>
<tr>
<td>8</td>
<td>Business Process Availability past 4 years</td>
<td>99.994%</td>
</tr>
</tbody>
</table>

* Market average was taken from 2014 Giarte Report
**72 projects existed however; documentation older than 6 years was discarded and not available.

6.1 Case Study of Large Traditional ICT Vendor

One traditional ICT Vendor was accused of being in collusion. In their efforts to change the public perception and mentality of the company the vendor began to investigate the Best Value Approach. As the BV approach stressed “win-win” relationships and utilization of expertise to deliver high performance and low costs, the vendor formed a BV core group to achieve these results. The BV core group discovered that many of the experts within the company were already thinking and acting with the BV approach. An example of this was identified as a performing project at the Port of Rotterdam.
The project was investigated to identify its status. Five key participants on the buyer’s side were interviewed and the status of the project was reviewed. Findings include (Port of Rotterdam project participants, personal communication, June 6, 2015):

1. The owner/client’s procurement manager utilizes BVP as the procurement approach.
2. The client PM faces resistance from own organization.
3. BV approach required a change in paradigm from MDC to utilizing expertise on both the buyer and vendor side. Required vendor and buyer to go through a learning curve.
4. The paradigm shift had been a big challenge to the project for both the vendor and the buyer.
5. The project is successful, and the project team identifies the project as a success.

### Table 2: Project Participant Interview Summary Responses

<table>
<thead>
<tr>
<th>#</th>
<th>Criteria (10 is strongly agree, 5 is don’t know, 1 is strongly disagree)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The owners’ inability to utilize expertise of expert vendors is a source of risk and poor performance.</td>
<td>8.2</td>
</tr>
<tr>
<td>2</td>
<td>Unlike Schuberg Philis, which was already practicing a BV approach, many larger traditional companies (using MDC and reactive behavior) have a very difficult time changing to the BV approach.</td>
<td>7.6</td>
</tr>
<tr>
<td>3</td>
<td>Owners also have difficulty changing from the MDC approach to the best value approach.</td>
<td>8.2</td>
</tr>
<tr>
<td>4</td>
<td>Until larger vendors change their approach, the industry will not have the momentum to change paradigms.</td>
<td>6.2</td>
</tr>
<tr>
<td>5</td>
<td>Large owners would have a difficult time changing the traditional buyers and project managers’ paradigm.</td>
<td>5.8</td>
</tr>
<tr>
<td>6</td>
<td>The owner have a difficult time implementing a clarification period.</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>The implementation of a clarification period would tremendously increase the project performance.</td>
<td>9.4</td>
</tr>
<tr>
<td>8</td>
<td>A clear plan which includes the functions of all the stakeholders would increase the performance of the project.</td>
<td>8.2</td>
</tr>
<tr>
<td>9</td>
<td>The best value approach changes the project management, risk management and the definition of risk (what the vendor does not control).</td>
<td>8.6</td>
</tr>
<tr>
<td>10</td>
<td>Decision making is reduced if the expert’s plan is utilized.</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>The best value approach is the optimal approach to increase project value and performance.</td>
<td>8.4</td>
</tr>
<tr>
<td>12</td>
<td>The expert vendor can utilize the best value approach even if the selection methodology was a more traditional relationship award, if it implements a clarification period, a weekly risk report, and creates transparency.</td>
<td>6.6</td>
</tr>
<tr>
<td>13</td>
<td>Rate the vendor’s performance (1 is unacceptable, 5 is average and 10 is outstanding).</td>
<td>8.4</td>
</tr>
<tr>
<td>14</td>
<td>What would the performance be under the traditional approach?</td>
<td>5.6</td>
</tr>
<tr>
<td>15</td>
<td>Was the performance delivered by the BV vendor higher than would have been delivered under the traditional approach (MDC)</td>
<td>4 out of 5 (yes)</td>
</tr>
<tr>
<td>16</td>
<td>Is the traditional PM model (MDC) accepting of the BV approach?</td>
<td>5 out of 5 (no)</td>
</tr>
<tr>
<td>17</td>
<td>Did the PMs have to change their paradigm to do BV?</td>
<td>3 out of 5 (yes)</td>
</tr>
</tbody>
</table>
6.2 Case Study of Large Traditional ICT Vendor Submitting on a BV Effort

This large traditional ICT vendor attempted to win a Best Value project. Being coached by an A+ BV certified expert the vendor understood the BV process and knew they would require true experts in order to secure this project. Due to this the ICT vendor put their best experts on the project; one of their best project managers and best technical experts on Oracle. In responding to the request for proposal of the buyer they attempted to show how they could provide a high expertise in relation to the buyer’s project objectives. In one of the three two-page documents some of their main substantiations of their expertise include (personal communication, July 7, 2015):

(Objective 1 & 4): The key personnel of the supplier are an experienced project leader Transition and an experienced service delivery manager, which contributes to the objective of unburdening with regards to system management and a risk-free and effective transition The project leader Transition has successfully:

1. **Brought 2 ERP environments to system management through a transition in the past 4 years.** The results were:
   a. Deviation regarding time and budget 0% (Fixed Price projects);
   b. Average project budget €5.1 million;
   c. Customer satisfaction 8;
   d. On average more than 10 interfaces and 20% custom work.

2. **Taken care of 3 ERP implementations in the past 7 years, including decharge.** The results were:
   a. All 3 > 3 million;
   b. Deviation regarding time and budget less than 5%;
   c. Customer satisfaction 8.

3. **Implemented information security 1 time at a government agency so client and supplier are compliant to the information security policy (BIR).**
   a. Deviation regarding time and budget 0% (Fixed Price Project);
   b. Budget 70 days;
   c. Supplier received decharge.

The service delivery manager was responsible at two EBS & BI clients for 3.5 years for the delivered services (FAB, TAB and TB) and achieved the following results:

1. **Client 1:**
   a. System management budget €325,000 per year;
   b. Customer satisfaction: 8;
   c. 17 EBS modules, 16 interfaces and 164 custom work components;

2. **Client 2:**
   a. System management budget €1,860,000 per year;
   b. Customer satisfaction 8;
   c. 22 EBS modules, 12 interfaces and 157 custom work components;
   d. Score of 8.4 for availability and 7.1 for performance EBS platform
   e. Availability 99.98% (24/7)
(Objective 5): Provider allocates a certified experienced information security specialist on the project that has a proven track record in meeting the compliance of managed systems. This contributes to the objective of fulfilling all requirements regarding the protection of personal data and information security. Supplier allocates an information security specialist:
1. Certified CISSP (associate)
2. Who ensures the information security policy for 55 ERP contracts (34 EBS, 21 SAP) and performs 6 compliancy checks every month.
3. Finds an average of 1 customer security incident per month and manages it.
4. Supplier has been audited by an external party and holds the certificates ISO/IEC 27001 (Information Security for all types of organizations). 130 system management contracts are part of the certification. The system management contract of Buyer will also fall under this.

(Objective 1 & 3): Supplier achieves an availability of the production environments of at least 99.8%, 24*7 (excluding agreed maintenance slots), this contributes to the objectives of Buyer for continuous availability, availability outside regular office hours and makes working from home possible. Supplier achieved this high availability in 2014 at three similar clients with EBS/BI system management contracts:
1. Average availability production 99.95%;
2. Average number of managed interfaces 17;
3. Average number of users 1750.

(Objective 2) Supplier achieves the desired service levels from the SLA from day 1, this contributes to the effective cooperation with Buyer and in particular with Functional System Management. Performances of the supplier in 2014 are:
1. Handled a total of 1294 technical EBS client notifications for 34 system management contracts
2. Achieved SLA response time in 91%;
3. Achieved SLA resolution time in 92%
4. Achieved SLA resolution time for 14 technical EBS client notifications with priority “Very high” in 100%.

The results of this submittal shocked the IT vendor as they had thought they had provided sufficient information to reflect their expertise to this project. However, the client/buyer rated them neutral rating of six on a scale 2 to 10 in their claims of expertise for the following reasons:
1. Good linking support to performance targets; Applicant thus demonstrates in principle to achieve all project objectives.
2. Applicant shows experienced people which are more likely to have done ERP transitions and less frequently EBS transitions.
3. Many quantitative substantiation of the claims which the question is how verifiable (and dominant) are these numbers? Performance support is limited in relation to the actual Buyer proposed approach. This makes Vendor less clearly understand the mission.
4. Conclusion: Vendor provides a relevant achievement underpinning; here, however, shows no (dominant) added value that justifies a higher score than neutral.
6.3 Case Study of another Large Traditional ICT Vendor Winning a BV Effort

In the initial development phase of the best value approach another large IT vendor began competing and investigating the approach. The Vendor bid and won a telephone/communications integration project. However, due to the buyers and Vendors inexperience with Best Value and the current maturity of the BV approach in the Netherlands key elements of the process were overlooked such as the clarification phase. The project ended in failure with the Vendor unable to deliver the client’s expectations and the project reverting back to a traditional approach of management, direction, and control.

Since then, the Vendor has become more involved and educated in the BV effort and has formed a BV core group for the company. The BV core group has become knowledgeable and successful in winning project bids and educating company individuals to deliver high performance, some key indicator of success includes (See Table 3) (personal communication, October, 29, 2015):
1. +/- 10 members (solution consultants, bid manager, project managers)
2. Internal training sessions (since 2013 63 training sessions, > 600 participants)
3. 100% success rate in going to the interview phase of project bids when BV team is part of bid team, 67% when BV team is in a support role (less active role), and 36% when BV team is not involved at any level.
4. 56% success rate in winning bids, 25% when BV team is in a support role, and 18% when BV team is not involved at any level.
5. Vendor is expanding their effort from the sales/marketing group to the project management group and are observing that level of expertise has diminished due to long period of owner’s MDC approach to ICT services.

<table>
<thead>
<tr>
<th>Involvement of BV Team</th>
<th>% to next phase interviews</th>
<th>% to next phase: clarification/won</th>
</tr>
</thead>
<tbody>
<tr>
<td>BV team part of bid team</td>
<td>100%</td>
<td>56%</td>
</tr>
<tr>
<td>BV team support role</td>
<td>67%</td>
<td>25%</td>
</tr>
<tr>
<td>BV team not involved</td>
<td>36%</td>
<td>18%</td>
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</tbody>
</table>

7. Conclusion

The problems in the ICT industry are the same problems that were faced in the construction industry. Using deductive logic, it is clear that the ICT industry is having the following issues:
1. A vendor was identified who does not use MDC in the delivery of their service by using expertise.
2. The high performance ICT vendor has no performance issues. Their performance is dominantly better than the other large vendors.
3. The study of their performance shows that they are in the BV environment. A bank study identified the most dominant ICT vendors in the Netherlands. The high performance vendor is one of the vendors.
Two of the other large ICT vendors who are trying to gain the capability to deliver performance were approached. Both vendor environments were in the price based environment (bureaucratic, difficulty identifying expertise, and difficulty in meeting the requirements of a BV effort). Both large ICT vendors were engaged in a BV effort, and both clients had problems in implementing the BV environment due to a lack of understanding of the BV paradigm. In both cases the clients were facing the resistance of traditional approaches to delivering projects. Both clients showed that there must be a paradigm shift not only the vendor’s approach but the client’s approach. Both large ICT vendors have visionaries who realized the importance of changing the project management and risk management paradigms.

The research shows that the CIS model can be utilized for any industry. It also validates that the largest source of risk is the owner’s decision making, and their use of management, direction and control (MDC) to minimize risk and deliver performance. The authors propose that the use of expertise will reduce project cost and increase vendor profit.

The ICT industry is in the price based environment where the owners are attempting to manage, direct and control (MDC) the vendor to minimize project cost and risk. The ICT industry is facing the same issues as the construction industry. The results of this study propose that the owners can increase project value and minimize project cost by utilizing expertise. By observation of both industries and the case study results over 20 years in multiple countries and cultures, the changing of the environments from a price based environment to a BV environment requires experts who think differently (see into the future before they do a project, identify the project requirements in simple terms that all stakeholders can understand, identify everyone’s role in the delivery of the service, and minimize the risk of the project by transparency and not control to assist everyone to see into the future and not be surprised).

The ICT case studies have shown that resistant stakeholders resist because they do not understand the future outcomes, and will cooperate if they can see the future outcomes. This is the requirement of the expert, to simply and create transparency so that all stakeholders can see the future outcomes. This environment requires a new project management approach and a new risk management approach, both of which the Dutch best value effort is working to develop.

This research has also validated through deductive logic and mixed methods the Industry Structure model. It has identified that the owner/buyers have created an environment of collusion through their MDC based procurement systems. The Dutch ICT industry collusion case is no different from the Dutch construction collusion case. The research also shows that the BV model has worked in both industries and can assist vendors in the Dutch ICT industry to improve.

References


Stakeholder Integration and Innovation Effectiveness in Sustainable Construction Projects

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Abstract

This paper studies the effect of stakeholder integration in achieving effective innovations to deliver more sustainable construction. The motive is the current global shift towards innovation as nations have realized its importance as a major driver for economic growth and competitiveness in the market in addition to the rising awareness of sustainable development and its long-term benefits globally and in the construction sector specifically. The multidisciplinary and multi-party nature of construction projects though, necessitates a well-established framework to integrate stakeholders for achieving an effective sustainable innovation in their projects in addition to considering the different factors that influence that. This paper represents the literature that it derived its framework from. It conducts an exploratory literature review, where it investigates that literature on the aspects that are believed to be influencing stakeholder integration and the effectiveness of innovation such as open innovation and cross-boundary collaboration, leadership and team identity. Then the paper proposes a conceptual framework that links the different constructs together and explains them briefly. Finally, it discusses the qualitative method that it intends to use to collect data to validate the framework in future research.

Keywords: innovation, sustainability, leadership, stakeholder integration, team identity

1. Introduction

A global shift towards innovation has been witnessed as nations have realized its importance as a major driver for economic growth and its essential role in strengthening the nations’ competitiveness (Hall and Vredenburg, 2003).

The construction sector is under massive pressure to develop new practices or improve existing ones to have a less threatening effect on the environment and at the same time achieve social and economic sustainability. Although the change rate in construction is slower and the sector is considered stable,
innovation became a vital source of their competitive advantage and a major element to accommodate changes in their complex products and processes (Eaton et al., 2006).

The fragmented, yet interdependent, nature of construction projects nurtured its complexity demanding a high level of coordination and integration amongst a large number of internal and external stakeholders to have an effective innovation in their projects. This becomes more vital when dealing with sustainability, which adds a new priority and more stakeholders that have different interests. A well-managed stakeholder integration process helps the different stakeholders to work together to increase comfort and quality of life by achieving sustainable innovations that decrease negative environmental impacts.

Previous studies have derived most of the conclusions about innovation implementation influencers in firms from the social science school of thought. Rogers (2003) focused on the effect of organizational climate on innovation implementation capability, West and Anderson (1996) related it to the characteristics of top management teams while Xu (2007) found a link with entrepreneurship. All of these studies are focused on the firm level and despite the increased interest in innovation at project level there is still a significant grounds to cover in this important field. Dickinson et al. (2005) shed the light on the issue at the design phase of the project and recommended more research at the project level claiming that most research tackled different aspects of innovation and stakeholder integration at the organizational level leaving some gaps when projects at involved. In addition to that and despite the number of research that has been done about innovation in the construction sector in the past twenty years, there is an obvious lack in studying the role of stakeholders in project innovation.

Rogers (2003) states that it is vital to communicate innovation through a complex social system overtime to achieve an effective innovation. He adds that stakeholder interactions and communications are usually critical factors that may affect innovation. Hall and Vredenburg (2003), Hart and Sharma (2004), and Buchel et al. (2013) agree with Rogers (2003) and considered stakeholders interaction as a major influencer. Research has also examined the impact of leadership on innovation effectiveness such as the work of Howell and Shea (2001) who studied the influence of leadership style, the characteristics and the behavior of the leader on facilitating or hindering innovation. However the link between leadership, stakeholder integration and innovation effectiveness is missing especially in the context of construction projects. This link becomes more important in the context of sustainability due to the significant role that stakeholders play in setting the sustainability agenda.

This paper, therefore, looks carefully in the literature to find the knowledge gaps and to build a framework that links the different factors to provide a clear understanding of the impact of the dynamics of stakeholder network on the success of sustainable innovations.

2. Sustainability and the need for innovation in the construction sector

Innovation is assumed to be the main driver for economic growth. It toughens the competitiveness of countries and sectors as well as individual organizations (Hall and Vredenburg, 2003). It provides a long-term profitability of firms and plays a major role in their success and continuity. However,
competitiveness alone is no longer the sole driving force in the world economy. Recently, there is a predominant shift in strategy towards competitiveness and sustainability throughout the world. Competitiveness in such an economic environment is expected to be achieved through innovating products and services, processes and models that are environmentally, socially and economically viable and sustainable.

The construction sector is one of the most challenging sectors to achieve a sustainable innovation. Due to the size and importance of the construction industry to national economies and the amount of environmental damage it causes, a lot of pressure is put by nations on the sector to use more effective measures to deliver more sustainable projects, hence, the need for a shift to develop and implement sustainable innovations.

In the context of construction, innovation is defined by Slaughter (2000, p.2) as “a nontrivial improvement in a product, process, or system that is actually used and which is novel to the company developing or using it.”

According to Peansupap (2004) innovations in construction can be categorized into: (1) innovation in materials, equipment and methods, (2) management innovation which are new management techniques that facilitate the process of management and administration, (3) information technology innovation refers to the electronic infrastructure and equipment which can be either software or hardware.

One of the most challenging steps to achieve sustainable innovations in the construction sector though is bringing all of the multi-disciplinary stakeholders into an agreement. Since construction projects are usually the outcome of the effort of the collaboration and coordination of multiple stakeholders, within and outside the project supply chain. Although the supply chain itself is considered the primary stakeholders of the innovation project there is no doubt the significant influence “external” stakeholders have on the innovation.

Cooper and Rousseau (1999) presented a view of the supply chain in construction projects as an ‘extended enterprise’ where the different parties (including project developer, architect, engineering firm, contractor, subcontractors, suppliers, regulators and users) operate as business units in collaboration representing the different functions they deliver (marketing, design, engineering, components manufacture, supply, assembly, delivery) for an entity regardless of who owns them.

In the context of construction megaprojects, it is not enough to deal with the supply chain as it is commonly and widely known; extensive intra and inter-organizational coordination is required. Recognizing changes in the competitive environment and accordingly structuring the supply chain resources to effectively meet the customers’ real demands is crucial (Fawcett and Magnan, 2002).

Through conducting a survey across some innovative companies in construction, Egbe et al. (1998) found out that the organizational culture that allows flexibility in communication is a major influencer. Mitropoulos and Tatum (1999) also pointed out the culture of the organization that values innovation is important in adopting innovations. They also added that management’s attitudes towards new technology and the ability of management to capture improvements to existing practices are
crucial factors that influence innovation. On the other hand, Nam and Tatum (1997) noticed the importance of the role of the champions and leaders to bring out successful innovations. Blayse & Manley (2004) then identified and summarized major influencers such as the culture of the organization, the absorptive capacity, the innovation champions, knowledge codification and an innovative strategy.

Certainly, good effort from scholars is observed to enrich the body of knowledge regarding the influencers of innovation in the construction field. Nevertheless, only little research links these influencers with stakeholder management and networking techniques to facilitate innovation. Thus, more empirical studies are required in order to increase the understanding on how stakeholder integration can affect innovation in the field and how the leader play an effective role in facilitating or rendering such relationship positively or negatively.

In addition to that, it is noted that researchers unfortunately has ignored the project level and focused mainly at the firm level due to the difficulty in tracking the various activities undertaken by the heterogeneous stakeholders in the many stages of a construction project (Ozorhon, 2003; Dulaimi et al., 2002; Blayse and Manley 2004).

3. Open innovation and cross-boundary collaboration

For effective sustainable innovations in the construction sector, cross-boundary collaboration and communication and eventually the integration of stakeholders are vital.

The growth of companies in the 20th century, the increase number of knowledgeable workers and their mobility, globalization and the ease of knowledge transfer, the private venture capital market and their support for new ideas are some of the major factors that made the protection of intellectual property very difficult, Chesbrough (2003) and Heap (2010) argue.

This encouraged organizations to adopt open innovation. The idea of open innovation is not very new though it wasn’t termed as such. It has been used in the construction industry continuously as the nature of the projects requires cross-boundary collaborations within the supply chain. Nevertheless, the supply chain is considered primary stakeholders, thus, the traditional way of collaborating in the supply chain ignores secondary and invisible stakeholders that can have much influence on the final innovation product and hence its performance. Therefore, open innovation strategies that are known today can overcome this issue.

The networking nature of open innovation allows for more innovation opportunities. Koschatzky claims that those who do not inter this network will have to deal with serious competitive disadvantages and may have their knowledge base reduced making it difficult to exchange relations with other organizations (in Enkel et al., 2009).

The challenge with open innovation networks is to find the right new stakeholders and learn how to deal with them in addition to motivating the internal stakeholders that forma the supply chain towards achieving the common goal of innovation. For chains that aim to deliver innovations, it is very
important to align motivation in the supply chain to bring the different parties of the chain, which have different interests, into a mutual agreement to ensure the successful development and implementation of the innovation.

Hall and Vredenburg (2003) discussed the ambiguous and complex impact of secondary stakeholders on the attempt to achieve innovations and stressed that it is of extreme importance to consider them while initiating the innovation process. Hall and Vredenburg (2003) and Hart and Sharma (2004) argue that the traditional ways of innovation focus only on a narrow range of stakeholders; thus, unexpected rejections and hindering will be faced when attempting to deliver the innovation. They also stressed on the fact that dealing with a wide range of important yet, invisible, stakeholders in this case is very crucial.

Once the stakeholders are clearly defined and identified, they can be integrated to create positive collaborative relationships among each other for the benefit of the innovation (Sharma and Vredenburg, 1998).

4. Leadership for sustainable innovation

Leadership reflects the goal-directed influence that one person has over other members of an organization or a group in guiding, structuring, facilitating relationships and activities. Thus, the role of the leader is key for the project to function in an effective and innovative manner (Nam and Tatum, 1997). It is the leader’s role and power to introduce new ideas, goals and innovations in projects; therefore, leadership style is considered a crucial attribute in influencing innovation (Bossink, 2004). Transformational leadership (Jung et al., 2003), innovation championing (Howell and Higgins, 1990), leader-member exchange (Graen and Uhl-Bien, 1995) are the major leadership styles that have been identified to have a positive influence on innovation.

Many researchers have linked transformational leadership to innovation such as Howell and Avolio (1993) and Jung et al. (2003). According to Jung et al. (2003) this leadership style is the preferred style to enhance innovation; they introduce creativity and innovation by actively engaging followers’ and stakeholders and link their identities to the collective identity of their organization, thus raising their intrinsic motivation rather than just providing them with extrinsic motivation to perform their tasks. Through the development of important vision and mission, transformational leaders raise the followers’ understanding of the value of the desired outcome, thus raise their performance and their willingness to exceed their self-interests for the sake of the organization (Howell and Avolio, 1993). This type of leadership also promotes collaboration by stimulating collective goals, building trust, empowering people, developing competence and offering visible support (Jung et al. 2003).

Leader-member exchange style suggests that innovativeness has a direct relationship with the relationship between the leader and the followers (Scott and Bruce 1994). It relies on the effectiveness of developing mature partnerships based on trust and support. This leads the employees and stakeholders to risks and deviate from the status quo (Scott and Bruce, 1994).
The last leadership style is the championing behavior. Rogers (2003) claims that a leader with an innovation champion personality have a direct influence on innovation diffusion. The presence of an innovation champion has been widely related to the success of innovations (Howell and Higgin, 1990; Howell and Shea, 2001; Nam and Tatum, 1997).

Champions have the power to affect the internal distribution of power and resources, strategic actions, and performance either positively or negatively. In addition, they can determine some internal organizational consequences such as the speed and position of career progression and the motivation or retention of members. On the cross-functional level, champions can promote communication between stakeholders and facilitate effective decisions about the innovation projects (Howell and Shea, 2001).

These different leadership characteristics have different influences on the ability to integrate stakeholders to achieve the ultimate goal of innovation. This study will investigate this further keeping in mind that the leader can be a person in the innovation project or the entire management team of the project.

So, through literature, leadership has an influence on stakeholder integration, and stakeholder integration facilitates the effective development and implementation of the innovation. However, these are general findings and the dynamics that actually take place in the project are missing in the literature. How can stakeholder integration influence the innovation? What happens in the innovation team if stakeholders are integrated? What are the dynamics that take place at the project level?

5. Innovation team identity

Unlike innovation at the organizational level, where the norms, roles, tasks of members are defined by the corporate law, corporate governance and the formal organizational structure (Child, 1972); innovation at the project level defines the tasks and roles of members through informal rules that the team adopt to regulate team members behavior gradually (Rese and Baier, 2012). In this case, the norms that define team members’ behavior are highly dependent of the interactions among them and are related to the group identity (Postmes and Spears, 2000).

Rese and Baier (2012) argue that it is vital for the innovation team members to develop a specific self-concept as a team, which reflects the identity of that team. Here comes the significant role of the leader as discussed previously where the different styles of leadership enhance this behavior in different ways.

The formation of team identity is explained by social identity theory developed by Tajfel and Turner (1979). They claim that group identity is the feeling of belonging o individuals to certain groups that create some emotional and value significance to them and a sense of membership.

Team identity develops when team members interact with each other. Rese and Baier (2012) encourage the close communication of the project’s team members to achieve a common
understanding of the innovation project. Interacting behaviors of the team members are either presented in tasks or in socio-emotional behaviors.

The membership to a specific team is determined by group boundaries. Boundary is an important issue in construction projects as the team members are assigned to different organizations and they interact with different groups. Being aware of the goal of innovations and having a clear definition of the goal makes them in risk of having a conflict of interest with the goals of the organization that they originally come from and they might face significant opposition in this situation which leads to substantial conflicts. Thus, shedding the light of how to manage this for the favor of the innovation project is very crucial Rese & Baier 2012.

Friedlander (1987) identifies some dimensions that affect the quality of group boundaries: boundary clarity and permeability, the degree of cohesion between group members, the degree of match between group members’ functional identity and local language, and the climate within the team (in Rese & Baier 2012).

Boundary clarity is the degree to which the innovation team is independent of other teams (Rese & Baier 2012). Teams that work on projects are less structured than organizational teams, thus, they need to deal with more uncertainty and ambiguity necessitating additional clarity. This assists in strengthening team membership, thus their commitment to the common goal.

Boundary permeability on the other hand deals with information flow and the circumstances that can hinder or facilitate the inward and outward flow of communication (Alderfer 1977; Agazarian 1989). Ellemers et al. (1988) claim that the more permeable the boundary is, the stronger identity the team can have.

Cohesion is another important dimension that can affect the identity of the team. According to Festinger et al. (1950), cohesion is the desire of the innovation team members to remain in the team and to commit energy and resources to the common innovation project. This element is very important and is very much related to the development of a common understanding by pursuing common goals and tasks, which results in facilitating team identity and membership.

The last element that increases membership of the team members and consequently strengthens their identity in the innovation project is the shared perceptions of the team’s policies, practices, and procedures (Reichers and Schneider, 1990) promoting innovation, cooperation, and mutual support. These elements have been empirically proven to increase innovation project performance (Rese and Baier, 2012) and are influenced by the leadership style as discussed earlier.

6. Conceptual framework

From the literature, there are different factors that influence innovation effectiveness, however, the concepts are fragmented and not linked to give an overall picture of the dynamics that take place at the project level. Hence, this research establishes the missing links through the following framework (Figure 1). The framework suggests that in an open innovation context, leadership influence stakeholder integration, which results in decreasing ambiguity and giving a clear definition of
Having that leads to establishing a strong team identity that have a passion and dedication towards the innovation thus increasing the chance of having a successful and effective innovation.

Each of these constructs are explained below:

*Open innovation* is the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation, respectively (Chesbrough 2006, p. 2)

*Leadership* the goal-directed influence that one person has over other members of an organization or a group in guiding, structuring, facilitating relationships and activities ((Nam and Tatum, 1997).

*Stakeholder integration* is the ability to create positive collaborative relationships with a wide range of stakeholders (Sharma and Vredenburg 1998).

*Team identity* is the feeling of belonging of individuals that create some emotional and value significance to them and a sense of membership (Tajaful and Turner 1979).

*Innovation effectiveness* is the overall project’s outcome that results from implementing the innovation. In this study’s context: it is financial, social and environmental effectiveness, which arises specifically from implementing the innovations.

The following table shows the measures that are used to assess each construct based on the existing literature:

*Table 1: Measures of the study constructs*
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<thead>
<tr>
<th>number</th>
<th>name</th>
<th>Co-creation with partners</th>
<th>Alliances</th>
<th>Joint ventures</th>
<th>Cooperation</th>
<th>Customer involvement</th>
<th>Employee involvement</th>
<th>Social network</th>
<th>Spin offs</th>
<th>Selling IP</th>
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<td>1</td>
<td>Open innovation</td>
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<td>Leadership</td>
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<td>- Internal distribution of power, resources, strategic actions, performance.</td>
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<td>- Communication with stakeholders.</td>
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<td>Leader-member exchange</td>
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<td>- The effectiveness of developing mature partnerships based on trust and support.</td>
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<td>- Leads employees and stakeholders to risks.</td>
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<td>- Introducing creativity and innovation by actively engaging followers and stakeholders and links their identity to the collective identity of the project.</td>
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<td>- Empowering people.</td>
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<td>Stakeholder integration</td>
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<td>- Close links with representative organizations to avoid dealing with unnecessary people.</td>
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<td>- Mutual dependence between unlike organizations managed by processed adaptations.</td>
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</table>
This framework will be used to guide the next stage of the research that involve a deeper analysis through the production of case studies and interviews with key parties in selected case studies that are involved in sustainable developments. It will promote for open innovation and knowledge sharing and cross-boundary learning. Although it studies the concepts at a project level, it gives insights on how managing integration can lead to a better management of sustainable innovations in general. In specific, it will aid in understanding how the dynamics of stakeholders play a role in the team behavior towards achieving the sustainability goals of their projects and at the same time understand the role of the leader in steering stakeholders towards supporting the projects goal through a better integration.

### 7. Conclusion

This paper intended to build a conceptual model that explains the effect of stakeholder integration on innovation effectiveness in sustainable construction projects. The researcher investigated the theory and literature on the subject of stakeholder integration in the construction field and proposed direct and dynamic links with open innovation, leadership and team identity. These links are believed to have direct and indirect influences on the effectiveness of innovation.

Due to the multiplicity of stakeholders and their various interests, powers and urgencies in construction projects, they have a direct influence on innovation. Unfortunately, through a thorough literature investigation, empirical studies that investigate the influence of stakeholder networks and their integration in the construction project are very scarce and usually cover how the culture and climate of the organization play a role in integrating stakeholders. This leads to missing some important aspects that can be addressed in order to foster innovation through a better integration mechanism that supports open innovation in construction projects.

This research will promote for open innovation to achieve sustainable development and knowledge sharing and cross-boundary learning. Although it studies the concepts at a project level, it gives insights on how managing stakeholder integration can lead to a better management of innovations in general. In specific, it will add to the construction projects as the conceptual framework that will be developed and thoroughly validated will be applicable in projects that seek to diagnose the condition of their innovative practices. It will also offer many implications that can guide firms to strategize innovation and ultimately improve their business performance.

### References


The Impact of Client Involvement on Project Performance: Case of the Kingdom of Saudi Arabia

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Abstract

The construction sector in Saudi Arabia is the largest and fastest growing market in the Gulf region. This strong economic position has encouraged the Saudi Government to take the opportunity to implement spending and launch many construction projects. However, a United Nations Development Programme Report indicated that Saudi Arabia was not progressing well in implementing effective management and achieving good organisational performance. This was clearly demonstrated by the number of projects suffering delay, which increased from 700 projects in 2009 to 3000 projects in 2013. The lack of client involvement in the construction of public projects has been identified as the main cause of many operational problems such as cost and time overruns, disputes, errors, uncertainties in plans and specifications, and increased maintenance costs. This paper investigates client’s involvement in construction project delivery and its impact to project performances. A questionnaire survey was distributed to various government agencies of the Kingdom of Saudi Arabia (KSA). Descriptive statistical analyses were used to assess the current practices of clients’ involvement and its impact to project performances. The relatively low client involvement has a negative impact on the projects’ ultimate outcomes. This condition has negatively affected the time completion of construction projects in Saudi. It was also indicated as the main cause of quality problems in Saudi’s construction project.

Keywords: client involvement, project performance, Saudi Arabia

1. Introduction

The construction sector in Saudi Arabia is the largest and fastest growing market in the Gulf region (Samargandi et al., 2013). This strong economic standing has encouraged the Saudi Government to take the opportunity to spend money on many projects. In the last five years, Saudi Arabia has experienced a construction boom with over 16,500 ongoing public projects and a total value equal to US$956 billion (Ministry of Finance, 2012). However, a United Nations Development Programme Report indicated that Saudi Arabia was failing to make real progress in achieving good management and organisational performance (United Nations
Development Programme, 2009). This was clearly demonstrated in the number of projects experiencing delay, which increased from 700 projects in 2009 (Althynian, 2010) to 3000 projects in 2013 (Anti-Corruption Commission, 2013).

Construction project management practices in Saudi Arabia are varied (Bubshait and Al-Musaid, 1992) due to the different nationalities of the construction industry professionals. Furthermore, the quality of public projects has varied among government agencies due to the different approaches used. Some examples of problems experienced in construction projects in Saudi Arabia include cost and time overruns, disputes, errors, uncertainties in plans and specifications, and increased maintenance costs. The lack of client involvement in public construction projects has been proposed as the main cause of myriad problems (Althynian, 2010).

This paper investigates client’s involvement in construction project delivery and its impact to project performances. The paper starts with a literature section, which briefly discuss the construction sector in Saudi Arabia and the important of client involvement in delivery construction projects. It is then followed by describing the research method that was selected to achieve the aim of the paper. Results of the analysis are then presented in the subsequent section, followed by the discussion of the findings. The paper is concluded by presenting the key findings of the study.

2. Literature Review

2.1 Construction Sector in Saudi Arabia

The varying degrees of client involvement in public construction projects has been identified as a reason for the various levels of quality achieved in different construction agencies in the Kingdom of Saudi Arabia (Bubshait, 1994, MEED, 2010). In the relationship between the parties in Saudi projects, the consultant has traditionally been considered as the major player in the construction project, and this approach has served to isolate the contractors from the client (Kometa et al., 1996). This isolation reduces the client’s influence on the project and makes the client dependent on the consultant (Assaf and Al-Hejji, 2006). Furthermore, there is a perception among the clients in government projects in Saudi Arabia that the consultants are often correct, even if their recommended resolution is different from the client's preference (Alnuaimi et al., 2009).

Construction projects in Saudi Arabia experience major delays (Al-Kharashi and Skitmore, 2009). Some studies have been carried out on the causes of these delays in Saudi construction projects. Assaf et al. (1995) found that the most important causes of delay were related to client involvement in project processes such as involvement in planning and design, and slow responses when making decisions and granting approvals for materials. Al-Barak (1993) found that the causes of failure in some construction projects in Saudi Arabia were related to the clients’ lack of experience and weak involvement in project activities. Assaf and Al-Hejji (2006) found that delays in construction projects originated mostly in client-related factors. Al-
Khalil and Al-Ghaify (1999) found that slow decision outcomes by the client were a major cause of project delay in Saudi Arabia. It appears that the problems experienced in construction projects in Saudi Arabia are mainly caused by the low level of client involvement during project activities. The weak decisions in the early stage of a project will result in a conflict between all parties in the later stages. Therefore, client involvement during the formative and early design stages of a project is a critical factor that must be taken into account if a project is to be delivered on time, to budget and to the desired quality (Love et al., 1998).

2.2 Client Involvement in Construction Projects

A successfully constructed project begins with the client (Ryd, 2004). Clients who are closely involved in managing a project are usually the most satisfied with the project quality (Bubshait and Al-Musaid, 1992). However, the client has duties and responsibilities when involved in the construction process. Clients should identify and adopt effective practices that contribute to high performance in their involvement in the construction process (Al-Kharashi and Skitmore, 2009).

Involvement is determined by the degree to which the project team fulfils its responsibilities to each phase of the total construction process (Bubshait, 1994). Clients need to perform their duties and responsibilities to have the optimum involvement required during the construction project phases, namely, the planning phase, design phase, construction phase, handover phase, and operation and maintenance phase. The degree of client involvement is based on taking the right decision during the construction project processes. Generally, client involvement procedure is based on the weight of the client’s experience (Nutt, 2006). Therefore, for many construction projects, making good and timely decisions is not an easy task to accomplish.

Client has three common expectations for the project delivery: high quality, low cost; and finished on time (Forgues, 2006). Client’s objective is to get the balance right between all these elements in order to meet the client’s project delivery expectation. The importance of the client role was highlighted in the ASCE Quality in the Constructed Project Manual (ASCE, 2012). The manual describes the high impact that the client has on the construction project, which in many cases may determine the project’s success or failure. Therefore, the clients’ involvement in the early stages constitutes an initial phase of the construction process and provides the link between the client and the project (Institution of Civil Engineering, 1996).
3. Research Method

For this study, a questionnaire survey was selected as the research method. The development of the questionnaire followed Leedy (1997) four practical guidelines, which are: using clear language, meeting research aims, planning development including distribution and collection, and creating a solid cover letter. The survey was written in two languages (English and Arabic) which are appropriate for the participants. Close-ended questions with ordinal and nominal scales were employed. Instructions were also provided at the beginning of each section for completing the questionnaire.

The questionnaire consisted of three main parts. Part 1 was designed to obtain some demographic information about the participants. Part 2 was designed to identify the degree of client involvement in construction projects. Part 3 was designed to identify the impact of the current client involvement practices on the delivery of construction projects in Saudi Arabia.

A pilot survey was conducted in order to identify any further need of revision. A sample of 9 respondents was selected to complete the survey to test the content validity of the questionnaire items. The questionnaires were distributed in both languages (Arabic and English) based on the preference of the participant. Email and post were used to distribute the questionnaires.

4. Results

The questionnaire survey was distributed to 315 potential participants in 21 government agencies of the Kingdom of Saudi Arabia (KSA). 17 of the 21 (80.95%) agencies responded, with a total of 223 questionnaires (70.79%) were returned, giving the researcher more precision and more confidence in regard to understanding the sample population. Among the respondents, 42.6% worked in public agencies and 57.4% worked in semi-public agencies. The project types that the respondents built include: building; infrastructure; industrial; and other.

Descriptive statistics for the respondents’ involvement as clients were produced, using the mean as the measure of central tendency. Although the median would theoretically be a more accurate measure because the data were ordinal, the mean was used due to the nature of the data. To locate the level of involvement, the “involvement scale” was developed in five intervals: “very low”, “low”, “neutral”, “high” and “very high”. The involvement scale was calculated by dividing the four intervals in the Likert scale by the five involvement intervals. The result was
0.8 for each interval. Therefore, the “involvement scale profile” was built based on the five-point Likert scale (Figure 1). Skewness and Kurtosis test was conducted for normality distribution. The Cronbach’s alpha test was used to evaluate the consistency and reliability of the questionnaire.

Table 1 presents the results on the respondents’ level of involvement as clients in the planning phase. The average level of client involvement was considered low, ie 2.07 (Figure 1). The planning phase in a construction project is normally executed by the client. In this study, the planning phase was represented through 11 tasks.

**Table 1: Mean ranking of client involvement in planning phase**

<table>
<thead>
<tr>
<th>Code</th>
<th>Planning Phase Activities (Tasks)</th>
<th>Rank</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part2_A_6</td>
<td>Approval of the project cost</td>
<td>1</td>
<td>1.54</td>
</tr>
<tr>
<td>Part2_A_11</td>
<td>Feasibility study of the proposed project</td>
<td>2</td>
<td>1.61</td>
</tr>
<tr>
<td>Part2_A_10</td>
<td>Description of the responsibilities and powers of each member</td>
<td>3</td>
<td>1.72</td>
</tr>
<tr>
<td>Part2_A_4</td>
<td>participating in the project</td>
<td>4</td>
<td>1.86</td>
</tr>
<tr>
<td>Part2_A_8</td>
<td>Studying how to secure funds to finance the project</td>
<td>5</td>
<td>1.94</td>
</tr>
<tr>
<td>Part2_A_9</td>
<td>Studying the impact of the project on health and safety</td>
<td>6</td>
<td>2.04</td>
</tr>
<tr>
<td>Part2_A_5</td>
<td>Establishment of a criterion for the selection of project location</td>
<td>7</td>
<td>2.11</td>
</tr>
<tr>
<td>Part2_A_1</td>
<td>Estimation of the project cost and the time required for its completion</td>
<td>8</td>
<td>2.21</td>
</tr>
<tr>
<td>Part2_A_2</td>
<td>Assignment of task force (consultant, engineer etc.) to conduct</td>
<td>9</td>
<td>2.50</td>
</tr>
<tr>
<td>Part2_A_3</td>
<td>preliminary studies for the proposed project</td>
<td>10</td>
<td>2.58</td>
</tr>
<tr>
<td>Part2_A_7</td>
<td>Studying the requirements of the beneficiary of the project</td>
<td>11</td>
<td>2.68</td>
</tr>
</tbody>
</table>

The respondents’ level of involvement as clients in the planning phase tasks was varied but low across all the tasks; involvement in three tasks was ranked as very low (scale 1 to 1.8); involvement in seven tasks was ranked as low (scale 1.8 to 2.6); and involvement in one task was ranked as neutral (scale 2.6 to 3.4).

The design phase was represented through 11 tasks. Table 2 presents the results on the respondents’ level of involvement as clients in the 11 tasks in the design phase. The respondents’ level of involvement was higher in the design phase than in the planning phase. The average client involvement in design phase was 2.64, which is considered to be neutral involvement based on the involvement scale profile (Figure 1). Clients and designers usually work together during this phase. The level of involvement was low or neutral across all the tasks: involvement in five tasks was ranked low (scale 1.8 to 2.6) and involvement in six tasks was ranked neutral (scale 2.6 to 3.4).
Table 2: Mean ranking of client involvement in design phase

<table>
<thead>
<tr>
<th>Code</th>
<th>Planning Phase Activities (Tasks)</th>
<th>Rank</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part2_B_4</td>
<td>Negotiating design price with the qualified designers</td>
<td>1</td>
<td>2.04</td>
</tr>
<tr>
<td>Part2_B_3</td>
<td>Selection of design team</td>
<td>2</td>
<td>2.07</td>
</tr>
<tr>
<td>Part2_B_7</td>
<td>Evaluation of design and taking the necessary decisions</td>
<td>3</td>
<td>2.47</td>
</tr>
<tr>
<td>Part2_B_10</td>
<td>Update drawings and specifications to reflect the requirements of location or environment</td>
<td>4</td>
<td>2.54</td>
</tr>
<tr>
<td>Part2_B_1</td>
<td>Arranging the papers and documents of the construction contract</td>
<td>5</td>
<td>2.57</td>
</tr>
<tr>
<td>Part2_B_9</td>
<td>Provide the designers with the necessary information for the project</td>
<td>6</td>
<td>2.70</td>
</tr>
<tr>
<td>Part2_B_5</td>
<td>Qualification of designers bidding on the project</td>
<td>7</td>
<td>2.74</td>
</tr>
<tr>
<td>Part2_B_11</td>
<td>Use of some technical standards for the descriptions of material quality or construction methods</td>
<td>8</td>
<td>2.80</td>
</tr>
<tr>
<td>Part2_B_2</td>
<td>Monitor and guarantee design quality</td>
<td>9</td>
<td>2.93</td>
</tr>
<tr>
<td>Part2_B_6</td>
<td>Following the progress of design</td>
<td>10</td>
<td>2.97</td>
</tr>
<tr>
<td>Part2_B_8</td>
<td>Review of design documents (e.g., drawings and specifications)</td>
<td>11</td>
<td>3.19</td>
</tr>
</tbody>
</table>

Table 3: Mean ranking of client involvement in construction phase

<table>
<thead>
<tr>
<th>Code</th>
<th>Planning Phase Activities (Tasks)</th>
<th>Rank</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part2_C_3</td>
<td>Negotiating contract price with the contractors qualified to do the job</td>
<td>1</td>
<td>1.67</td>
</tr>
<tr>
<td>Part2_C_1</td>
<td>Qualification of contractors competing to implement the project</td>
<td>2</td>
<td>2.49</td>
</tr>
<tr>
<td>Part2_C_4</td>
<td>Interpretation and clarification of ambiguities in the contract documents and drawings</td>
<td>3</td>
<td>2.50</td>
</tr>
<tr>
<td>Part2_C_2</td>
<td>Explaining the objective of the project and providing the necessary information for bidding</td>
<td>4</td>
<td>2.60</td>
</tr>
<tr>
<td>Part2_C_5</td>
<td>Review the documents that submitted by the contractor</td>
<td>5</td>
<td>2.85</td>
</tr>
<tr>
<td>Part2_C_9</td>
<td>Establishment of a system and written code to ensure implementation quality, to be referred to by personnel in charge of implementation quality assurance and control</td>
<td>6</td>
<td>2.96</td>
</tr>
<tr>
<td>Part2_C_10</td>
<td>Emphasis on implementation quality by conducting necessary tests for the various implementation stages</td>
<td>7</td>
<td>2.99</td>
</tr>
<tr>
<td>Part2_C_6</td>
<td>Taking necessary decisions against contractor claims during project implementation</td>
<td>8</td>
<td>3.26</td>
</tr>
<tr>
<td>Part2_C_11</td>
<td>Regularly visit project site during implementation stage</td>
<td>9</td>
<td>3.31</td>
</tr>
<tr>
<td>Part2_C_8</td>
<td>Stress implementation quality and monitoring safety principles during project implementation</td>
<td>10</td>
<td>3.53</td>
</tr>
<tr>
<td>Part2_C_7</td>
<td>Monitoring and control of implementation methods and cost, as well as work schedule and contractor productivity</td>
<td>11</td>
<td>3.60</td>
</tr>
</tbody>
</table>
The construction phase was represented through 11 tasks. Table 3 presents the results on the respondents’ level of involvement in the 11 tasks in the construction phase. The respondents’ level of involvement as clients in the construction phase was ranked as the second highest level of involvement across all the project phases (following the handover phase). The average client involvement in the construction phase was 2.89. The level of involvement across the tasks was varied: involvement in one task was ranked as low (scale 1 to 1.8); involvement in three tasks was ranked as a low (scale 1.8 to 2.6); involvement in five tasks was ranked as neutral (scale 2.6 to 3.4); and involvement of two tasks was ranked as high (scale 3.4 to 4.2).

The respondents’ involvement as clients was the highest in the handover phase among all the phases. The average client involvement in the construction phase was 3.19, which is considered to be neutral involvement but close to high involvement based on the involvement scale profile. The handover phase was represented through three tasks. Table 4 presents the results on the respondents’ level of involvement as clients in the three tasks in the handover phase.

**Table 4: Mean ranking of client involvement in handover phase**

<table>
<thead>
<tr>
<th>Code</th>
<th>Planning Phase Activities (Tasks)</th>
<th>Rank</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part2_D_1</td>
<td>Establishment of criteria for acceptance of completed project</td>
<td>1</td>
<td>3.09</td>
</tr>
<tr>
<td>Part2_D_3</td>
<td>Monitoring the process of testing and commissioning</td>
<td>2</td>
<td>3.11</td>
</tr>
<tr>
<td>Part2_D_2</td>
<td>Review of contract documents after completion of the project</td>
<td>3</td>
<td>3.36</td>
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</tbody>
</table>

The respondents’ level of involvement in the operations and maintenance phase was the lowest amongst all the phases. The average client involvement in the O&M phase was 2.06, which is considered low involvement based on the involvement scale profile (Figure 1). Table 5 presents the results on the respondents’ level of involvement as clients in the O&M phase.

**Table 5: Mean ranking of client involvement in O&M phase**

<table>
<thead>
<tr>
<th>Code</th>
<th>Planning Phase Activities (Tasks)</th>
<th>Rank</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part2_E_1</td>
<td>Prepare the maintenance plan describing the maintenance schedules and lists the tasks</td>
<td>1</td>
<td>1.93</td>
</tr>
<tr>
<td>Part2_E_4</td>
<td>Building up the inventory including the important spare parts to maintain and operate the project with minimum “down time”</td>
<td>2</td>
<td>1.98</td>
</tr>
<tr>
<td>Part2_E_2</td>
<td>Prepare the operation information such as to assist in solving problems and prevent unexpected expensive</td>
<td>3</td>
<td>2.09</td>
</tr>
<tr>
<td>Part2_E_3</td>
<td>Record the warranties and certificates reference information</td>
<td>4</td>
<td>2.24</td>
</tr>
</tbody>
</table>

The respondents were asked, “To what extent were the projects implemented” in relation to the following goals and expectations: (1) time, (2) cost, (3) quality, and (4) operational satisfaction. Table 6 presents the results on the respondents’ level of agreement in term of the impact on the client involvement on project delivery.
Table 6: Impact on project delivery

<table>
<thead>
<tr>
<th>Code</th>
<th>Project Objectives</th>
<th>Mean</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part3_1</td>
<td>Time</td>
<td>1.87</td>
<td>.678</td>
</tr>
<tr>
<td>Part3_2</td>
<td>Cost</td>
<td>2.84</td>
<td>.793</td>
</tr>
<tr>
<td>Part3_3</td>
<td>Quality</td>
<td>3.09</td>
<td>1.083</td>
</tr>
<tr>
<td>Part3_4</td>
<td>Operation</td>
<td>3.14</td>
<td>1.203</td>
</tr>
</tbody>
</table>

For more understanding of the impacts of client involvement, this impact was investigated in three ways, which are based on: (1) the overall data; (2) organisational type (public or semi-public); and (3) project type (building, infrastructure, industrial, and other). Figure 2 presents a summary of the results.

As shown in the neutral and negative impacts depicted in Figure 2, the respondents reported that projects were implemented with time delays, higher costs than contracted, the typical quality was not high, and operations were slightly satisfactory. This indicates that a low level of involvement during the construction project phases (as presented in Table 1 to 5) has a negative impact on the end of the project regarding the desired goals of high quality, low cost, on-time completion, and no major disruptions in operations.

5. Discussion

As identified in this study, the construction project process has five phases with 40 tasks that measure most activities during the construction project cycle. The survey revealed that clients had inadequate involvement in 38 out of 40 tasks in the construction project phases. This low level of involvement is very likely to have a negative impact on the project outcomes.
In the planning phase, the average client involvement was 2.07 on the involvement scale, which is considered low. The levels of client involvement in “Approval of the project cost”, “Doing feasibility study of the proposed project”, and “Describing the responsibilities and powers of each member participating in the project” were very low. These three tasks are highlighted as an example to illustrate the importance of the planning tasks. The planning phase includes activities that require a high level of authority to make decision, such as “Approval of the project cost”. In any large project in Saudi Arabia, government agencies require formal approval from the Ministry of Finance before awarding the contract (Government Tenders and Procurement Law, 2006). The restrictions imposed by the Ministry of Finance for approval of a project reduce the ability of clients to innovate in construction due to limitations in the project budget. Therefore, according to the specialist in budget, the budgetary and financial management system in Saudi Arabia needs to reform and change (Albassam, 2011).

Another important activity in the planning phase is “Undertaking the project feasibility study” which is an analysis of the ability to complete a project successfully, taking into account legal, economic, technological, scheduling and other factors. The consequences of not doing the feasibility study correctly may be sufficient to stop the project. The risk of this consequence was evident in the low client involvement in this task. Low client involvement in the planning phase may account for the dramatic increase in the number of project delays in Saudi Arabia in the last three years (Anti-Corruption Commission, 2013).

While the planning phase is important for making the right decisions to start the project, the design phase is no less important for the project. Eighty percent of a project can be specified at this phase (Whelton et al., 2002). In this study, the average client involvement in the design phase was 2.64 on the involvement scale which is considered neutral involvement. Clients need to have advanced knowledge to be able to review the design documents. It is recognised that more involvement by project client in the early design stage has a positive impact on delivering the construction project successfully.

It is important to recognise the close relationship between the design and construction phases. The design phase is a process of creating the description of a new project, usually represented by detailed plans and specifications, while the construction phase is a process of identifying the activities and resources required to make the design a physical reality. Clarification in design documents leads to less conflict between the client and contractor (Al-Sedairy, 1994). This study found that clients did not pay enough attention to the tasks that need to be implemented well before constructing the project during the tender selection process. These tasks are “Negotiating the contract price with the contractors qualified to do the job”, “Checking the qualification of contractors competing to implement the project”, “Interpretation and clarification of ambiguities in the contract documents and drawings”, and “Explaining the objective of the project and providing the necessary information for bidding” as presented in Table 3. Lack of attention to these tasks might result in conflict in the construction project. These conflicts occur most frequently in the key relationships of the contractor and the client, and the contractor and the consultant. Research has found that the conflict was likely to occur most strongly in the later stages of a project under construction (Althynian, 2010). Therefore, it
is important to emphasise that the client needs to pay more attention to the design and construction phases.

The handover of the project to the client at the end of the construction is a very important stage of the project procurement process and facility operation success. Reflecting the importance of the handover phase, the level of client involvement in handover tasks was found to be near a high level of involvement. A well-organised, efficient and effective transfer of information from project contractors to the owner of the project is essential. The commissioning and fine-tuning of operations during handover can impact heavily on the use of the project if not managed in a structured manner.

At the end of a project, project satisfaction is measured during the operations and maintenance. However, in this study, the level of client involvement was found to be the lowest amongst all the project phases. Successful operations and maintenance of a completed project is closely associated with the level of client involvement. Therefore, the project team benefits by giving careful consideration to the operational and maintenance objectives during the project's planning, design and construction stages. One suggestion for clients to consider during the construction process is to assign a special O&M representative to advise the project team on how to complete the product in a manner that best achieves the project's O&M needs.

6. Conclusions

The construction sector in Saudi Arabia is the largest, strongest and fastest growing market in the Gulf region; however, the construction sector in Saudi Arabia has faced many challenges during the recent construction boom. These challenges include the lack of real progress in achieving good management and organisational performance, variability in quality among the projects commissioned by government agencies, increasing project delays and cost and time overruns, lack of planning and design, and weak supervision by the government agencies of the construction project process.

The findings from this study show that the current client involvement in construction projects in Saudi Arabia is at the level of neutral or low involvement. Among the five project phases of the construction process, the design phase was ranked as the priority phase for client involvement during the construction project. This is then followed by the client involvement in the planning phase. However, the study found that the respondents had low involvement as clients in both the planning and the design phases. This was suggested as the reason of weak decision-making in the early stage of the project, which could result in conflict in the later stages of the projects. The remaining phases were ranked in importance as follows: (3) construction phase; (4) handover phase; (5) operations and maintenance phase. The relatively low client involvement has a negative impact on the projects’ ultimate outcomes. This condition has negatively affected the time completion of construction projects in the Kingdom of Saudi Arabia. It was also indicated as the main cause of quality problems in Saudi’s construction project.
References


ALTHYNIAN, F. 2010. An economic study reveals the reasons for the delay in the implementation of 82% of infrastructure projects in the Kingdom. *Alriyadh Newspaper, Issue 15295*


ASCE 2012. *Quality in the constructed project: a guide for owners, designers, and constructors*, Reston, Virginia, American Society of Civil Engineers.


The Role of Product and Service Innovations in the Finnish Construction Industry

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Abstract

Indent to succeed, the construction industry must offer quality products and services that are in line with customer demands. The objective of this study was to describe the role of product and service innovation in the Finnish construction industry by sectors. This study was qualitative in nature. Research followed a two-fold process: 1) analysis of Finnish construction patent data, provided by the Finnish Patent and Registration Office (PRH), and 2) a case study. The purpose of this research was to explore patenting activity in different construction sectors and its relation to product and service innovation within construction companies.

Our results indicate that patents have a significant role in the construction product sector. The building sector is also innovative, but generally in organisational structure and market innovations rather than in product or service innovations.

The role of development activities in Finnish construction industries is complex. Innovation seems to be quite straightforward in the construction product sector because these companies are seeking to produce the ‘right’ products. The issue of innovation is more complicated in other construction sectors. Even the definition of what a ‘product’ is varies among building construction companies. As a result, the products offered to customers might be inappropriate or ineffective in meeting customer requirements. On the other hand, the provision of services has become a more important part of many companies’ operations.

The construction industry faces problems and challenges in many operational areas. Earlier studies have claimed that building construction is a very conservative field in the industry. The results of this study bear out this idea. The study provides support for managers considering development activities as a solution to better serve customers and increase innovativeness within the organisation. Innovation has a significant effect on a nation’s economy and competitiveness by expanding employment opportunities, increasing economic growth and improving the standard of living.

Keywords: Patents; Innovation; Process; Development; New products and services

1. Introduction

How does the construction industry understand development and its benefits? The construction industry is usually not considered innovative compared with other industries (Sexton and Barret, 2003; Winch, 2003). In fact, the building construction sector is sometimes accused of being backward and stuck in the 19th century. While other lines of business have been able to increase their productivity, quality and value, the construction industry has suffered from a lack of innovation (Winch, 2003).

The competitive advantage of an enterprise depends on its ability to create more value than its rivals (Porter, 1985; Brandenburger and Stuart, 1996). Industrial innovation includes not only
radical innovations but also incremental technological advances (Trott, 2012). High levels of innovation embedded in products, services and processes increase the possibility for growth and profits (Pleatsikas and Teece, 2001; Sattler, 2003). According to Trott (2012), innovations can be divided into seven typologies: 1) product, 2) process, 3) organisational, 4) management, 5) production, 6) commercial/marketing and 7) service. 

In most countries, the construction industry is known to be a slow adopter of new processes and technology, which hampers the innovation process (Wandahl et al., 2011). Many researchers argue that the whole construction sector (including manufacturers of building products and systems, designers and property managers) makes up about 15% of the gross national product of most nations (Marceau et al., 1999; Seaden and Manseau, 2001). Achievement of innovation and development and the drivers of and barriers to development are comprehensively interrelated with the features and evolution of the industry (Pavitt, 1984; Malerba, 2004).

In current markets, new product development and innovation are essential for value creation (Hurmelinna-Laukkanen et al., 2008). New product development in today’s business environment is challenging because of short product lifecycles, technical complexity, market uncertainties and rising costs of development (Bhaskaran and Krishnan, 2009; Cooper et al., 2001). To succeed competitively, enterprises need to offer products and services that meet the various needs of customers and the marketplace (Ulrich and Eppinger, 2011). The framework of development is about defining, designing and developing new products or services for the product portfolio (Ulrich and Eppinger, 2011; Cooper, 2001).

The construction industry is generally thought of as a large, dynamic and complex industrial sector which plays an important role in a country’s economy. However, the industry is commonly criticized for being non-innovative and conservative (Bygballe and Ingemansson, 2014). This underlines the crucial need for such an economically important industry to become more innovative, specifically in the area of product development. A major objective is the designing of products in response to customer demand. In general, buildings are known as the main products of the construction industry, and the industry has put much effort into implementation of new production and procurement philosophies (Ozorhon et al., 2009). Yet, the construction industry, by nature, has many unique problems, and the importance of taking measures to improve the performance of the industry has now been recognised in several countries at various levels of socio-economic development (Ofori, 2000). According to Kajander et al. (2012), the top management of companies operating in the construction sector recognise that sustainability innovations are relevant to business development. This study aimed to answer the following research questions:

RQ1: What is the role of Finnish construction patent creation in different sectors?

RQ2. What is the role of product and service innovations in the Finnish construction industry?

2. Method

The research process was divided into five phases: study design, data collection, data analysis, results and conclusion. First, background research was conducted to obtain an adequate outline for the analysis of the role of development in the construction industry. A two-part data collection phase followed: 1) a construction patent data report from 2004 through 2014 was ordered from the Finnish Patent and Registration Office (PRH) and 2) a semi-structured interview questionnaire was developed, and company representatives were selected for interviews. Company representatives were interviewed to clarify current managerial level practices of development. The patent and interview data were then analysed, and conclusions were made. The research process for this study is presented in Figure 1.
Qualitative research refers to any type of research that produces findings not resulting from statistical or other means of quantification (Corbin and Strauss, 2007). However, multiple data collection techniques can be employed in case studies and are likely to be used in combination with one another (Saunders et al., 2007, p.139). Moreover, both qualitative and quantitative evidence can be collected in a case study (Yin, 2003); in fact, Yin (2003) encourages using both techniques. In line with Yin’s (2003) guidelines, a combination of qualitative and quantitative evidence was collected in this study. However, the main focus was on qualitative analysis.

Construction industry patent data from 2004 to 2014 was ordered from the PRH. Analysis of Finnish patent data according to the construction sectors defined by the Confederation of Finnish Construction Industries (CFCI) required the creation of a mapping table that included PRH classifications, CFCI sectors and International Patent Classifications (IPC) (see Appendix, Table 4). The CFCI’s five sectors are 1) building construction, 2) construction products, 3) infrastructure, 4) heating, plumbing and air-conditioning (HPAC) contractors and 5) surface contractors.

The interviews were conducted with six companies (see Table 1). The number of cases was limited to six in order to achieve an in-depth understanding of the phenomenon studied. These companies were able to offer comprehensive study material relevant to the phenomenon, including information about products and/or services, business models, development projects, factors contributing to the development process and factors making development difficult. Topics that were company specific are not reported. The selected participants held positions related to their company’s development. Their experience and current interest in development ensured high motivation and up-to-date knowledge about the topics discussed. Semi-structured interviews were conducted in which the following questions were asked: 1) What types of products and services does the company produce? 2) Who are the company’s customers? 3) What do customers buy? 4) What is the company’s business model? 5) What kind of development does the company expect? 6) What factors contribute to the company’s development? 7) What factors make development difficult for the company? and 8) How do you see the future of the construction industry in Finland? The interviews lasted up to two hours and were recorded and transcribed. The main characteristics of the case companies are presented in Table 1.

### Table 1. Company characteristics

<table>
<thead>
<tr>
<th>Case</th>
<th>Sector*</th>
<th>Size**</th>
<th>Turnover</th>
<th>Role of interviewee</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HPAC contractor</td>
<td>Small</td>
<td>5</td>
<td>CEO</td>
</tr>
<tr>
<td>2</td>
<td>Building construction</td>
<td>Large</td>
<td>550</td>
<td>Head of regional business unit</td>
</tr>
<tr>
<td>3</td>
<td>Construction products</td>
<td>Medium</td>
<td>12</td>
<td>CEO</td>
</tr>
<tr>
<td>4</td>
<td>Building construction</td>
<td>Medium</td>
<td>82</td>
<td>CEO</td>
</tr>
<tr>
<td>5</td>
<td>Building construction</td>
<td>Large</td>
<td>730</td>
<td>Head of regional business unit</td>
</tr>
</tbody>
</table>

---

**Figure 1. Research process**

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Building construction | Large | 710 | Head of regional business unit

* Classified by CFCI.
** Company sizes by number of persons employed, classified according to the EU Commission definition (2005) of small and medium-sized enterprises (Micro, 1–9; Small, 10–49; Medium, 50–249; and Large, > 250).

3. Results

The patent propensity rate is a potentially valuable indicator for innovative activities (Arundel and Kabla, 1998). Patents are the granted exclusive rights by a government authority for an invention, which must be a new method of doing something or a solution to a technological problem. The invention can be a product or a process.

3.1 Finnish construction patents

Patent data was requested on March 26, 2015 from the PRH, and the patent data that was acquired contained information on 7,330 construction patent applications from 2004 to 2014. Information extracted from the patent data file included the following: 1) application number, 2) year of application submission, 3) patent number, 4) year of issue, 5) year of publication, 6) patent applicant, 7) patent inventor, 8) International Patent Classifications (IPC) category and 9) abstract.

The trend line of the patent data in Figure 2 shows a peak in the number of applications (871) in 2010. The drop in the number of patent applications in recent years can be explained by an 18-month protection period starting from the time of submission; during the protection period, applications are not made public.

![Figure 2. Patent applications and published and granted patents from 2004 to 2014](image)

In addition, Figure 2 shows the trend of publication of Finnish construction patents from 2004 to 2014. The highest number of patents (262) was published in 2010. The lowest number of patents (94) was published in 2004. During the time interval from 2004 to 2014, the PRH issued the highest number of patents (301) in 2012 and the lowest number (87) in 2004. The trend of Finnish construction patents that are granted by the PRH can also be seen.
3.1.1 Role of patent creation by sector

In order to determine the patent creation per sector, the classes and subclasses of construction patents classified by the Finnish PRH (Appendix, Table 3) were reclassification to match the CFIC sectors (Appendix, Table 4). One CFIC sector, surface contractors, was not found in the PRH construction patent classification. The number of patents issued in the different construction sectors is illustrated in Figure 3.

![Figure 3. Patent creation per sector in the Finnish construction industry](image)

The largest number of patents was issued in the construction product sector (90% of the total number), followed the building, infrastructure and HPAC sectors (about 7%, 2% and 1%, respectively).

3.2 Case interview results

**Case 1:** The company does not need to develop any of its own products because it is a subcontractor of HPAC installation services for municipalities and construction companies. The subcontracted installation services are the product that customers want to buy from it. The company does not have a written business model in use. It has pursued some development activities in the past, including implementing new marketing methods and changing the organisational structure. The main barriers for development are lack of available resources and time.

**Case 2:** The company offers real estate- and maintenance-based services and has several products: housing production, property development and commercial construction. The main customers are home buyers, apartment managers, institutions and the public sector. As a guarantee, the company solves customers’ problems; in general, households, institutions and the public sector entities are looking for a service to help them find a place to construct a home or building. The company’s business model is production, renovation and commercial construction of different types of housing. The company has made improvements in the areas of organisational structure and customer service. Some innovation has occurred in the construction of buildings. The main barriers to development identified in Case 2 are the attitude and ability of managers,
outdated practices, budget limitations and overall mentality of the personnel. It is common for people to believe that investing in development is not guaranteed to get results.

**Case 3:** The company’s products are concrete tiles, walls and pillars. The company also provides planning, delivery, installation and consulting services for business-to-consumer and business-to-business customers. Many customers buy concrete structures and installation services together. The business model is to provide concrete products. The company has made innovative developments in several areas, including products, processes, organisational structure and marketing. The case company has not been granted patents since they are issued by a head office. Factors hindering development activities are retirement of workers and personnel reductions.

**Case 4:** The company’s main products are apartments and office buildings. Services are provided primarily for institutional real estate investors. Customers include companies, municipalities and institutions. These customers expect professional services and prefer to buy turnkey solutions. The company’s business model is turnkey land development. The offer will provide solutions to the property developers. It attempts to do more than just offer the lowest price in the bidding process. The company has made organisational and process innovations. One example of development is an innovation in roof installation. Barriers to development are tight regulations, lack of resources and internal managerial thinking which will block progress.

**Case 5:** The company provides products related to customer demand and land development. The company offers real estate services for companies, municipalities, industry and institutional real estate investors. Customers buy a wide variety of products, from family houses and investment properties to office buildings. The business model is residential and commercial building and land development. The company has made several innovations in safety and organisation. A good example of development is a new system of schedule management. The projects themselves are the biggest barriers to development because customers tend to want the company to provide the same services they have always provided. The second biggest barrier is financial limitation.

**Case 6:** The company’s products are housing, public buildings and renovation. The offered services are related to project development, and customers are municipalities, households and institutional real estate investors. Households hope to achieve their dreams by buying good-quality buildings. The business model includes land development and residential building. Development activities have focused on organisational, marketing and service innovations. Barriers to development are reluctance to assume risks and concern about investing in development activities.

The results of the case study are summarized in Table 2.

**Table 2. Summary of development activities of case study companies**

<table>
<thead>
<tr>
<th>Case</th>
<th>Patents granted</th>
<th>Development types</th>
<th>Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>New marketing methods and reformed organisational structure</td>
<td>Lack of available resources and time</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Organisational and customer service development</td>
<td>Attitude and ability of managers, outdated practices, budget limitations and overall mentality of the personnel</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>Product, process, organisational and marketing innovations</td>
<td>Retirement of staff and personnel reductions</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>Organisational and process innovations</td>
<td>Tight regulations, lack of resources and overall managerial thinking</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>Innovations in safety and organisational development</td>
<td>The projects themselves and monetary issues</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Organisational, marketing and service innovations</td>
<td>Resistance of personnel and management’s reluctance to invest in innovation</td>
</tr>
</tbody>
</table>

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4. Discussion

As mentioned above and summarized in Figure 3, patents have a significant role in the construction product sector. The building sector also innovates, but innovations are related to organisation and marketing rather than to products or services. In contrast, the infrastructure and HPAC sectors do not generate a large number of patents.

As explained by Abbott et al. (2010), the measurement of innovation is quite difficult. From 2004 to 2014, 90% of the issued patents in the Finnish construction industry were in the construction product sector. The building sector was next, with about 7% of the total patents. The infrastructure and HPAC sectors had about 2% and 1% of the patents, respectively. This indicates that development activities occur mainly in the construction product sector, and invention very rarely takes place within the building and HPAC sectors. The surface contractor sector was not analysed in this study because this area was not included in the PRH construction patent classification index.

Many in the construction industry do not believe that investing in innovation will bring immediate profit, nor is it always certain that investment in innovation will bring benefit to the industry. Clients are considered the major drivers of innovation, so it would be beneficial to consider clients’ thoughts when developing an innovation strategy. Similarly, other innovation drivers such as the business culture, human capital, organisational structure, technology, research and development, and partnering and knowledge management should receive equal focus from management.

The role of development activities in the Finnish construction industry is complex (see Table 2). Yet, development activities appear to be quite easy to implement in the construction product sector. This is easy to understand when one considers the goal of producing the ‘right’ products. The issue of development is more complicated in the other construction sectors. Even defining what ‘product’ companies offer to customers might be difficult. This is why ‘service’ types of development are more common in these sectors.

The interview results suggest that homes, offices and public buildings are common products of the Finnish building construction sector. However, some companies provide services instead of products. Households, municipalities, institutions, and institutional real estate investors are common customers of construction companies. It was noted that some companies did not have a clear business model. That is in line with the findings of Pekuri et al. (2013) that construction companies have significant problems describing their business models and value-creation logic. This leads to the question of what impact this has on the industry.

Globally, Finland ranks seventh in innovativeness after Sweden, Denmark, Switzerland, South Korea, the United States and Japan. South Korea’s position as an innovative country has so significantly improved during the past few years that the EU now estimates it to be the world’s leader in innovation (European Innovation Scoreboards, 2015). This would suggest that the Finnish construction industry should set the construction industry of South Korea as a benchmark and as a model from which it learn and improve.

Major barriers to development in the building construction sector, noted in the interviews, were the lack of resources and resistant attitudes at the managerial level. The need for workers with new and advanced skills at all organisational levels was expressed. Other barriers mentioned were monetary issues, such as limited budgets, old-fashioned thinking, strict domestic regulations and worker retirement. In addition, some of the interviewees said that the construction projects themselves block development in the building construction. The reason for this is that the project execution does not provide any room for innovative development. On the other hand, enthusiastic managers, new competitors, customers, goals for development projects, and quality of products and services were stated as factors that contribute to development.

The results indicate that development is occurring in the Finnish construction industry. Most of the interviewees appeared to understand that innovative ideas and activities are important for their companies to be competitive in the marketplace and that they must do more than just offer the lowest price in the bidding process. Many realise that innovations are essential to
securing a solid position in the industry, whether these innovations are made by the company itself or in cooperation with universities or polytechnics. However, the interviewees did not believe that patents were the proper way to protect their innovations, which shows that the patenting process is not very familiar within the building construction sector. Also, the fact that many development projects are managed at the head office level might cause resourcing conflicts in regional business units.

The cause of this the lack of product and service innovation in the building industry must be seriously considered. One quite commonly cited justification is that the building industry is project-based and almost all construction work is carried out within a project context and project structure. A second one is that, since every project is unique, advantages from scale or repetition are not predictable. It must be examined as to whether or not these are sustainable justifications.

It is argued in this report that development activities are one of the major factors for companies to be competitive in the market. Gann (2000) mentions that competitive companies are able to make deep-rooted cultural changes while maintaining engineering and technical strengths. Thus, it is essential to focus on innovation activities.

5. Conclusions
The construction industry faces problems and challenges in many operational areas. In this study, the development activities of the Finnish construction industry were examined. Many earlier studies have claimed that construction is a very conservative field. The results of this study bear out this view. When looking at the construction product sector, development activities can be easily defined because it is a product-driven business sector. In contrast, other construction sectors do not seem to be involved in much development activity when the number of granted patents is used as an indicator.

The building construction sector implements development activities, but these tend to relate to the development of the organisation or internal processes. The reason is partly that ‘product’ as a concept is not as easily understood in other construction sectors as it is in the construction product sector. Moreover, large building construction enterprises face the challenge of head office centralization and managed development, and the ability to use resources for internal development varies among regional business units. In these cases, regional business unit managers will have a very significant role in education and in introducing new operational models.

The building construction sector is also disadvantaged by old-fashioned management models used by site and unit managers, a situation that may prevent introduction of new and advanced operational methods. Managers may ask why changes should be made if the model has operated well enough for the last twenty-five years. On the other hand, the significance of development activities has been rightly understood by some companies, and these companies have invested in development in response to market situations by changing their business models.

5.1 Limitations and future research
This study focused on the role of product and service innovations in the Finnish construction industry. The limitations of this study could be addressed by further research.

First, the number of companies interviewed in this study was limited. Second, further research should measure innovation throughout the patent life cycle. For example, a sample of granted patents could be selected, and a questionnaire related to the intended future use of the patented innovation could be sent to the company or creator. Survey results would indicate whether that particular patent was a successful innovation or not. This would give a view of the overall level of innovativeness within the construction industry. Additionally, the innovativeness of each construction sector could be evaluated and compared.

Finally, a deeper analysis must be done on how a project’s context and the structure of its working methods actually block customer preference-based innovations. Also, future research could benefit from a comparison to other industries, such as the shipbuilding and aerospace industries.
6. References
Ofori G (2000). ‘Challenges of construction industries in developing countries: Lessons from various countries.’ In 2nd International Conference on Construction in Developing Countries: Challenges Facing the Construction Industry in Developing Countries, Gaborone, : 15-17.

7. Appendix

Table 3. Finnish construction patent classification by Finnish Patent and Registration Office

<table>
<thead>
<tr>
<th>Subclass or title</th>
<th>IPC class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human necessities</td>
<td>A21, A21B, A21C, A47, A47H, A47K</td>
</tr>
<tr>
<td>Construction of roads, hydraulic engineering, water supply, building, locks, keys windows, ladders mining</td>
<td></td>
</tr>
<tr>
<td>Construction of roads, hydraulic engineering, water supply,* building, locks, keys windows, ladders mining</td>
<td></td>
</tr>
<tr>
<td>Machine in general, combustion engines, machine or engine for liquids, positive displacement machines for liquids, engineering elements or units, steam generation, combustion apparatus heating, refrigeration or cooling, drying, heat exchange In general</td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>IPC category symbol</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Building construction</td>
<td>=IF(OR(Z9='E02';Z9='E03';Z9='E04';Z9='E04D';Z9='E21';Z9='F01K';Z9='F02C';Z9='F02K';Z9='F23';Z9='F23B';Z9='F23D';Z9='F25C';Z9='F25J');'Building';'')</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>=IF(OR(Z7='E01';Z7='E01B';Z7='E01C';Z7='E06';Z7='E21C');'Infra';'')</td>
</tr>
</tbody>
</table>
SECTION 3

Innovative design and construction
Design Revolution for Affordable Housing in Tropical Country

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Abstract

Malaysian demographics are changing rapidly. With the increasing working population in major cities and towns, housing affordability problems among middle income households become widespread as many of these households are not covered by existing housing assistance programs. Prefabrication and modular construction are believed to be the solution for constructing houses that meet the vast number of demands in urban areas in a short period of time. Yet, as a housing strategy, it is still considered unresponsive to local climates and conditions with low acceptance rate, due to the lack of variability and an individual identified design. At this juncture, how prefabricated housing design can be evolved from mass repetitive production level to mass customization level that account for flexibility and variability is the primary issue to be explored. A good design can contribute to affordability through reducing the construction costs and the life-cycle costs while maintaining liveability. This paper discusses an alternative design strategy which is deemed to bring improvement to the country's prefab housing industry with respect to time, cost, and quality. The proposed design strategy entails open plan that enable retrofit and reconfiguration to be made quickly, economically, and repeatedly, without involving excessive site labour, time, and cost; as compared to the currently adopted design strategy which is associated with rigid structure, interlocking plan, and predetermined function. Besides, it is a combined design and construction system that makes use of the Industrialised Building System (IBS) construction method to produce a variety of housing design options that meet possible user requirements not yet identified at the design stage, while retaining principal uniformity to facilitate the execution of simple but accurate construction with a minimal initial cost. By taking into consideration the passive design strategies extracted from the tropical vernacular architecture – the traditional Malay house – the proposed affordable housing design makes possible the creation of dwellings that adheres to the context of contemporary technology, tropical adaptation, and cultural responses.

Keywords: Prefabrication, affordable, housing, design, customization, tropical country
1. Introduction

Due to increases in population, many world regions were forecasted to encounter an urgent need for new housing in the coming decades. According to a recent United Nations (UN) report, an additional three billion people will be needing housing across the world by the year 2030, which means that approximately 100,000 houses per day are required to be produced in order to meet such a pressing demand by 2020. Malaysia is of no exception in facing the mass housing problems when moving towards a higher level of urbanisation. In 2013, the Malaysian government, through the collaboration between the state governments and the private sector, targeted to deliver 1 million mass houses to the public in 5-year time, which is equivalent to an average of 200,000 houses annually. This challenge inevitably calls for the innovative building technology that has the dual benefits of economy as well as speed in construction.

Prefabrication is, no doubt, an obvious choice for the quick, efficient, and inexpensive housing construction and delivery, in meeting the ever-increasing demand for mass housing in the country. The strength of the prefabricated house lies in its lower capital and developmental costs by using purposely made components which are mass produced in great quantity. In some mass housing developments, industrial approaches to construction coupled with value engineering, were found to help slash cost by about 30% and delivery times by up to 50% (MGI, 2014). Since the primary determinant of mass housing construction is cost, prefabrication is always an attractive option to be adopted. However, there are some hindrances to change in this respect. Advances in technology may allow concept like standardisation and prefabrication potentially to address many of the problems facing the house-building industry, but questions arise whether mass houses being developed now are capable of adapting to occupant’s ever-changing requirements, as the current demand for new housing seems moving towards mass customisation and agile production, which greatly increases the choices offered to customers rather than culminating in the standardised housing types of past experiences. Changes in the demographic make-up due to the diversity of family typologies and household arrangements have generated a need for housing that can adapt to different privacy, space, use requirements, and life styles. Prefabricated houses, on the other hand, have rigid structure, interlocking plan, and predetermined function, in which very few of them are open plan that enable retrofit and reconfiguration to be made quickly, economically, and repeatedly (Gan et al., 2015). This, consequently, leads to the question whether mass population is being accommodated in suitable dwellings. Similarly, given the need for sustainability and the generally important consideration of environmental and social values in the longer term, it is essential that a long term view be taken and that the needs for flexibility, maintenance and eventual disposal (or re-use) be addressed at the design stage.

Studies show that residents of mass housing in Malaysia are generally not satisfied with their housing conditions (Karim 2012; Isnin et al. 2012), where a presumed need for flexibility in design, room size and fittings has precluded use. For example, criticisms have been made with regard to the People’s Housing Project Scheme (PHP) (Figure 1) – an initiative by the government to solve the problem of existence slums and squatter areas – on the architectural design including the lack of storage area, small size and deep location of the kitchen, minimum
external wall area, complicated partitions, less cross ventilation etc. (Sahabuddin and Gonzalez-Longo, 2015). Most of them end up renovating houses to tailor-suit their needs before occupancy (Rostam et al 2012; Nurdalila 2012; Erdayu et al 2010). This is largely due to the nature of the current mass housing architectural strategy, namely the convergent design system, which is a “one fits all” design initiative where housing is likely to be designed around the capability of a given product, instead of around the end-user (Zuhairi et al., 2015). Thus, houses designed for the average family are deficient in meeting the mass housing sustainability objectives as they are leading to further compromise the occupant’s needs. Besides, the convergent design system implies extreme compartmentalization and dissociation of internal elements, where service spaces such as kitchen, bathroom, etc. are built internally by interlocking with space, making the service spaces difficult to interchange (Zuhairi et al., 2015). Houses designed and built with such system are solely based on the economic concepts of housing that only measure affordability, ignoring the potential of sustainable housing design that offers social and environmental benefits, not to mention in addressing the needs of the householder with regard to emotional satisfaction and economic performance.

Apart from that, the potential social resistance to the ideas of prefabrication and standardisation in housing is still prevalent. Various perceptions, opinions, and images spring to mind when considering the prefabricated housing due to a number of buildings constructed in the past were judged to be of poor quality. In fact, prefabricated housing in Malaysia has been plagued with bad publicity such as leakage, inflexible for the repair and maintenance, as well as a resemblance of low cost housing projects which are basic and pay minimal attention to the aesthetics of the building (Figure 2). While some of the problems to prefabricated housing may not be an issue now with the application of new technology, such as using advanced waterproofing or innovative jointing method for solving the leakage problem, the image of prefabricated housing is still strongly tarnished by the general perception that the lifespan of such housing is likely to be less than that of “conventional” built housing – consists of a reinforced concrete frame and brick, beam, column, wall, and roof, which was cast in situ using timber framework. It is the programmes of poor quality and poorly designed prefabricated

Figure 1: Layout plan of a PHP unit (Goh & Ahmad, 2011)
housing that have given rise to a notion that the process of prefabrication per se, rather than particular products, was at fault. On top of that, prefabrication construction in Malaysia has been associated with a cost increase of 10% compared to conventional construction (CIDB, 2007). Since moving towards mechanized and industrialized systems involves high capital investment on heavy equipment and mechanized construction facility, along with availability of cheap foreign labour in the country, the industry players are unlikely to switch to an unfamiliar system in order to secure their projects, particularly for those small contractors who involved in the small scale development (Foo et al, 2015).

Figure 2: Examples of low cost housing projects – Tunku Abdul Rahman Flat in Kuala Lumpur (left) and The Rifle Range Road Flat in Penang (right)

2. Good Design for Mass Housing

Regardless of the barriers that influence its uptake among the industry players, prefabrication construction is still believed to be the appropriate solution for today’s mass housing problem. To allow for the successful application of prefabrication, in Malaysia particularly, the following past mistakes need to be recognised and addressed: (i) Quality – previous lack of quality has led to the perceived reduction of value associated with prefabricated housing; (ii) Attention to detail – poor detailing in the past has led to technical problems and a general perception of poor value; (iii) Life cycle performance – failure to consider the practicalities and costs associated with maintaining these buildings had led to some prefabricated housing becoming difficult to maintain. Hence, how prefabricated housing can evolve from the mass repetitive production level to the mass customization level that account for flexibility and variability, as well as becoming responsive to the local condition and social acceptability, is worth to be explored.

According to Evans (2014), a good design can be the critical difference between an affordable development that succeeds – one that satisfies its residents and neighbours, enhances the community where it is built, and continues as a stable part of the community for decades – and one that does not. Given that each dwelling unit is a primary structure which would contribute to the quality of life, and the root causes leading to housing quality problem are identified as issues related to housing layout and design, surrounding environment, maintenance, location, amenities, and building material (Živković and Jovanović, 2012), house builders should be aware of the potential for a good design in responding to the evolving social behaviour, and strike to take advantage of technology in the housing production process through integrating housing design with industrial construction system. In other words, each dwelling
unit should be designed, in such a way that it is economically and easily adjustable, while adheres to the context of contemporary technology, tropical adaptation, and cultural responses (Gan et al., 2014). The key element for a good design is the realization that lifestyle – as one of the defining characteristics of peoples’ lives as citizens, consumers, and householders – is a feature that shifts in accordance with a dynamic lifecycle process. A home that can be altered with minimum effort and expense at a time of change in the lives of its owners is a home that evolves with the lifecycles of its household rather than becoming rigidly obsolete in the conventional manner (Friedman and Krawitz, 1998).

The present paper, thus, proposes a flexible housing design system for the modern urban mass housing in tropical country. By adopting flexibility as the inherent architectural design strategy, the system is able to provide the physical spatial arrangements that are conducive for the socio-cultural wellbeing of a community along while complementing the environment. Besides, the system combines both machine production and mass customization, offering more than 10,000 possible designs including prefabricated structures, factory-made structures, dwelling plan and flexible design, to provide an affordable and sustainable housing for all. It makes possible the creation of dwellings which may grow old yet without becoming obsolete; incorporating the latest design ideas and technologies, yet have a sense of history on the Malaysian housing design (the rumah kampung design); allowing the communities to live for generations, yet incorporating the potential of adaptation.

3. Divergent Dwelling Design (D3)

Divergent Dwelling Design, or D3 in short, is a combined design and construction system directly responses to the fundamental demographic and economic pressure that heightened the need for an appropriate solution for the urban mass housing. It makes use of the open plan design concept and the Industrialised Building System (IBS) construction method, to produce a variety of housing design options that meet possible user requirements not yet identified at the design stage, while retaining principal uniformity to facilitate the execution of simple but accurate construction with a minimal initial cost.

The proposed D3 basic architectural plan is a square shaped plot (Figure 3), having a plurality of “dynamic” space lots (where the bathroom, kitchen, and other dwelling services located) arranged peripheral of the plot so as to be in contact with the outdoor environment; and a plurality of structures such as the dining room, bedroom, or any other spaces located in the “core” space lot which is capable of being arranged, modified, and customised in plurality of designs according to the user’s needs. While the plot is standardized to allow for efficient manufacturing, it can take any desired shape including square, rectangle, as well as other polygonal shapes (Figure 4). With the built-in architectural flexibility, D3 basic dwelling unit can be divided into more than one plan, in which the occupant can choose the floor plan they want to live before moving in, thereby achieving harmony between the basic structure and the various sizes of dwellings in the long term. This is similar to the automotive industry, where each individual functional unit is freely bonded with the core structure to serve different occupants’ requirement.
Every D3 building is designed and built in such a way that both the structure and infill of the building are treated as separate entities in order to optimize the efficiency of building assembly and modification. As depicted in Figure 5, the basic layout can be configured into various plans, simply by partitioning the core space lot or rearranging the location of bathroom and kitchen within the dynamic space lot. In other words, there is no one fixed plan in D3 design system but a flexible plan that houses endless of possibilities. Owning to the use of a number of interchangeable component sub-assemblies, D3 makes possible the transfer of construction process from building to manufacturing, with component manufacturers and end-users playing a much larger role in the design process. For example, the bathroom, kitchen, partition, façade etc. are mass produced which then divergently attached to the building structure (Figure 6). The occupant has wide spectrum of choice with regards to products in the market. Since each system is independently manufactured in a controlled environment, the development entails the use of technology and innovation, without the involvement of excessive site labour, time, and cost. In this sense, D3 comprehends the advances of science and technology over time, leading to a faster production at economical rate.
Once the design system is in tandem with serial production and standardization, there will be no bounds for the development of a sustainable community that can accommodate a wide diversity of users and household types. Prospective occupants can choose from a catalogue of available components which are tailored to individual lifestyles and budgets. This enables the occupants to consume only the type and quantity of features they currently require or can afford. For example, a variety of kitchen options that suit a wide range of household lifestyles can be offered by the manufacturers without significant increase of their administrative and operational costs due to the prefabricated nature of kitchen cabinetry. Besides, the variety of configurations available caters to desires for increased work surfaces, space economy, and the inclusion of washer, dryer and recycling facilities within the kitchen. Similarly, the bathroom requirements also vary according to the occupants and their individual scenarios. Normally, two bathrooms will be provided for every affordable house in Malaysia. However, the number of bathroom is not restricted in D3 housing; if the number of occupants and their schedules justify for another
bathroom, D3 open plan concept would satisfy this requirement by balancing the size and location of this additional bathroom with the remaining spaces in the dwelling unit. Consequently, the bathroom options offered by D3 housing can range in size from powder rooms to complete bathrooms with shower, bath, toilet, and sink (Figure 7). Since every individual dwelling unit is flexible enough to adapt to the changing needs of both existing families and future users, the combination of these units will enable a variety of sustainable habitual spaces to be processed, which then can constantly renew themselves without becoming obsolete (Figure 8).

Figure 7: Examples of available modular bathroom in the market
The principles underlying the design of facades are analogous to those governing the structure and plan: flexibility and individual identity. By positioning the dynamic space lot in the peripheral of the plot, a setback of walls is created where no external walls to be in contact with the outdoor environment. Such setting can be well-adopted in the apartment development, imparting a sense of individual identity and differentiating vertical occupancies or uses, yet avoiding the extremes of monotony and theme park atmospheric elements (Figure 9). One of the most common drawbacks of prefabricated housing is the homogenous and repetitive nature of the development, which is a by-product of the economies of scale. The value of providing a diversity of appearances is that it satisfies the individual user’s personal requirement for identity and self-expression, counteracting any potential feeling of anonymity resulting from increased density, and it incorporates – or rather predicts and pre-structures – the inevitable variety caused by change overtime. Residents are able to explore various options in terms of appearance, style, fenestration, and materials used through the participation in conjunction with the builder.
4. Functionality and Liveability through D3 Efficiency

As stated by Barlow (1999), current housing construction situates the industry somewhere between craft forms of production and mass production, which tends to display relatively low quality consistency, measured by the amount of rework required on completion (Figure 10). This strongly contrasts with the car industry which has been pioneering lean production concepts for many years and may be moving towards agile production as customer input into the final product, quality and after-care grow. As a housing design system that seeks to avoid the rigidities of prefabrication and less effectiveness of conventional construction, D3 has the potential to help boost a greater productivity, better quality, and an assurance of a growing and interested housing market. With the delivery of highly customized products at costs comparable with mass production, it is possible to make prevalent the concept of mass customization in the Malaysian construction industry. The following sections are devoted to describe how the housing functionality and liveability is achieved with D3 design system, in terms of construction, space, and energy.

![Figure 10: From craft to agile production in the housing and car industries (Baker, 1996)](image)

4.1 Construction Efficiency

Construction efficiency is among the most effective strategies for decreasing the cost of housing construction without reducing its liveability (Feldman and Chowdhury, 2002). In the case of D3 construction, a modular system prevails in an attempt to minimize building costs, as well as to execute simple but accurate construction. The 7.2m x 7.2m module allows for a strong element of flexibility with regard to a variety of building configurations (Figure 11). This unit module with its multiples and subdivisions form the basis of all dimensions of the dwellings. The advantage of the employment of this single unit module is that all locations and sizes of the parts with respect to the whole are precisely identified during the construction process (Figure 12), and thus, no obscure or arbitrarily unrelated measurements are involved in the unit system. This also leads to other advantage, such as the standardization of many building components (prefabricated beam, column, and slab) for mass production in manufacturing. There is usually a cost with the provision of a structure that allows for flexibility and adaptability. In a departure from the conventional mass housing design, however, D3 design system allows planners and
builders to incorporate various housing types within a single unit module in order to respond to a diverse range of values, incomes, and households (Figure 13). With such ability, a wide range of housing size is covered under one design plan, be it a 450ft$^2$ studio type dwelling, 700ft$^2$ low-cost housing, or 1,000ft$^2$ affordable housing.

Figure 11: A D3 typical structural unit

Figure 12: A D3 typical functional unit

Figure 13: Different types and sizes of D3 housing with a single modular unit
All prefabrication of structural components is made in an off-site factory and is regulated with regard to the single unit module, namely column, beam, and hollow core slab. When all components are delivered on site, they are assembled to become a home (Figure 14). Assemblage of components is easy and simple, where altering or replacing components is much the same. The construction system is a kit-of-parts solution to the affordable housing problem that does not require a highly skilled work force or special machinery. By incorporating IBS into the construction process, a compressed construction schedule is not only cost-saving in and of itself, getting the building into productive use sooner and reducing finance periods, but, especially in times of significant inflation, compressed construction schedules save additional significant sums. Therefore, a building that adopting D3 design system can be constructed at a faster pace and arranged in multiple manners, to achieve high density in the most comfortable spatial design environment (Figure 15).

![Figure 14: Comparison of trades and time frame between conventional and D3 construction](image1)

![Figure 15: Comparison of trades and time frame between conventional and D3 construction](image2)
Besides, the use of 100% machine produced components allows both the cost and structural integrity to be effectively reduced because using modern construction materials, such as lightweight partitions, modular bathroom and kitchen can all save time. In traditional construction, each sequence of construction involves different work crews that lead to the conflict in scheduling. Some trades such as formwork or pouring concrete may even stops or dramatically slow the work of others. The on-site construction of a bathroom, for example, requires nine major steps and the inclusion of more than thirty parts/components (Figure 16); as compared to a modular bathroom which is manufactured in the factory environment and is delivered to site as a complete unit. In addition, the conventional practice for installing the plumbing system involves the cutting and assembly of the various pipelines and fittings. It is obvious that prefabrication of such plumbing installations in a factory is potentially a more efficient and economical procedure, particularly when a number of essentially identical plumbing installations are to be made, as in the case of multiple dwelling, units, hotels, apartment houses, schools, and the like. This is the key of reducing conflict in scheduling, where trades and building parts are greatly reduced by coordinating dimensions and positions instead of improving on site by cutting to size. On top of that, the whole project can also benefit from those intangible benefits, such as site cleanliness, less labour, less material wastage, shorter construction period etc.

![Figure 16: Parts and components of building a conventional bathroom](image)

### 4.2 Space Efficiency

Structural system, as rigid and unchanging part of the housing unit, dictates the degree of flexibility of spatial unit set (Živković and Jovanović, 2012). The key role of this part of design process for housing unit flexibility is conceivable through the fact that these parts are the most inflexible elements of the unit. The position of technical installations is another basic unchangeable aspect of residential space. The issue of structuring the technical core is, thus,
important to be considered and resolved in the initial design phase, so as to give more flexible solution in exploitation. In D3 housing design system, space efficiency is achieved without compromising the dwelling liveability by several approaches. First, all structural elements are located at the exterior of the layout to allow for unlimited unobstructed clear spaces that can be freely arranged over the life of the dwelling unit. The dining room and bedroom are distributed along the core space lot, which is capable of being arranged and modified according to the user’s needs (Figure 17). The main entrance to the house is adjacent to the living room. All the living room and bedrooms are made to be accessible to the “landscape area”, which also functions as the laundry area or open porch, providing an excellent means of open-air drying.

![Figure 17: A typical 750ft² D3 dwelling unit](image)

The kitchen and bathroom are grouped in the dynamic space lot in order to concentrate the plumbing system, so that economic maintenance and cleaning are possible. This concentrated plumbing system consists of a modular system for routing building utilities. The current practice in many multi-floor buildings is that the distribution ducts for electrical conductor and plumbing are installed inside the concrete walls and floors. The limitation of this setting is that the arrangement of the distribution ducts cannot be changed once it is installed. Also, there are a number of times where moisture is found on the floor due to the condensation and leakages of the ducting system. To overcome the inflexible nature of the technical installations, a modular system for routing the building services connections is introduced, which is an integrated service panel installed along the periphery of the building structure carrying the building services connections including but not limited to the electrical connections, plumbing connections, solid waste transfer connections, gas supply connections, heating, ventilation and air conditioning connections, fire sprinkler piping connections, and other communication services connections associated with a building structure (Figure 18).
This routing system is easily installed and can be reconfigured whenever desired. It consists of an elongated rigid casing, having a top portion, a bottom portion, a plurality of side surfaces and a pair of ends that are configured for connecting with other rigid casings and other external building services connections (Figure 19). The top portion of the rigid casing is open to connect with the building services connections and for allowing access to the elongated compartments inside the rigid casing. An adjustable top closure means is used for closing the top portion of the rigid casing. The side surfaces of the rigid casing are provided with a number of external connectivity means configured for connecting with the building services connections. The routing system can be installed in a combination of arrangements, either at the subfloor position of the building structure, or to be vertically attached to the walls of the building structure, or even to be attached to the roof of the building structure. The interconnection means of the prefabricated integrated service panels is compatible with existing piping connections and can be installed with existing plumbing and electrical connections and existing interconnecting means for the plumbing and electrical connecting systems.
Flexibility in D3 design system is further achieved by using movable partitions. Since common walls within a dwelling unit are non-load-bearing walls, the dwelling unit floor areas can be arranged independent from boundaries to suit the size of any uses. The sustainability initiative here focuses on providing spaces to be used for a variety of purposes over time, be it the changes of household demography or the changes of resident’s living satisfaction. Since this kind of functional change can be done by merely switching of the independent units within the configuration through a simple process, the function of the dwelling unit can be cultivated and adapted to the occupant’s need whenever it is required. By enabling the floor plan to be adapted to the future users and the changing needs of families, D3 unit plan is able to take into account different family types: (i) dynamic family which is likely to have more children in future, and is thus requires a high degree of space flexibility to cater for continuously changing and increasing needs; (ii) stable family which is not going to have any more children (either the children have left home or are too small to leave home) and thus requires a relatively lower degree of space flexibility; (iii) stagnant family which is expected to live in the same dwelling for a long time and thus has sufficient opportunity to benefit from flexible building elements, which provides for lower life-cycle cost of such elements. Furthermore, a residential space can be converted into a café by just incorporating a larger kitchen and more toilets; a laboratory or playroom or computer room when added with a unit space for teaching can be used as an educational institution. So similarly the kind of unit space or constant space can change its function from residential to commercial, without ever needing to change the basic unit.

4.3 Energy Efficiency

Malaysia is situated in a maritime equatorial area, where the climate is generally the same throughout the year, with uniform temperatures, high humidity, light winds, and heavy rainfall (Hyde, 2008). The very nature of the Malaysian climate necessitates mechanically ventilated or air-conditioned interiors, especially in urban areas. However, poor design and indiscriminate use of air conditioning have resulted in huge increases in energy use. Passive and low energy design strategies are too often excluded from the affordable housing projects because they are deemed to add cost to the construction, though they are the solutions for a sustainable future. In fact, it is possible to attain energy efficiencies without incurring additional costs. As pointed out by Feldman and Chowdhury (2002), energy efficient design contributes to environmental sustainability and saves life-cycle costs. D3 directly responds to the fundamental demographic and economic pressure that has heightened the need for a new housing alternative which appropriately integrates affordability and sustainability. To ensure mass housing populations could enjoy eco-housing with affordable price, affordability is designed in at the beginning by adopting a simple design layout, which is flexible enough for adaptation and yet suits to the tropical climatic condition.

The passive design strategies adopted in D3 design system is inspired by numerous features found in the traditional Malay house that area geared towards providing thermal comfort. With a direct dependence on nature for its resources and embodying a deep knowledge of ecological balances, the traditional Malay house is best reflecting the bioclimatic housing, using various ventilation and solar-control devices, and low-thermal-capacity building materials (Figure 20).
Apart from being well adapted to the environment, a very sophisticated addition system was also developed to allow the house to be extended in line with the growing needs of the user. Such an autonomous housing process, which is using self-help and mutual-help approaches, can throw some light on the development of a modern autonomous housing model. In general, the experiences gained from the traditional Malay house evidenced that an appropriate house in tropical country should provide for the following: (i) allow adequate ventilation for cooling and reduction of humidity; (ii) use building materials with low thermal capacity so that little heat is transmitted in to the house; (iii) control direct solar radiation; and (iv) control glare from the open sky and surrounding

![Figure 20: Climatic design of the traditional Malay house](image)

In the case of D3 design system, cross ventilation is optimized by having an elongated dwelling shape together with minimal partitions or interior walls. This is not only allowing for easy passage of air and cross-ventilation, but also encouraging a good lighting of the interiors, as well as the flexible use of space (as described in Section 4.2 – Space Efficiency). Besides, the parallel arrangement of windows and the placement of high louvers on the internal walls of each bedroom also ensure adequate wind from outside flows through the house. By setting back the exterior walls 2.1m from the peripheral of the dwelling, no walls are exposed directly to the outdoor environment. Solar radiation is, thus, effectively controlled with the large thatched upper floor ceiling that acts as the overhang. Together with the installation of adjustable louvres or grilles as building façade, a barrier is created which not only provides good shading and protection against driving rain, but also to some extent maintain the quality of openness for ventilation and outdoor views. The setback also creates an open porch that makes possible the occupants to enjoy the open-air landscape. With careful planting or selection of vertical green, the open porch can function as a buffer corridor that aids in air circulation. The presence of air movement will then enhance the evaporative and convective cooling from the skin and can further increase the occupants’ comfort. Glare, which is a major source of stress in the tropical climate, is effectively controlled by using louvres or grilles which break up large bright areas into tiny ones and yet allow the interiors to be lighted up; or by planting less reflective vegetation. Figure 21 illustrates the interior views of the D3 housing.
The use of reinforced concrete skeleton structure ensures a lot of the qualities that aid flexibility in housing design, which then contribute to the housing affordability and sustainability. First, prefabrication construction allows for the design of flexible internal space layout are variable to accommodate different family structures. The constant improvement in prefabrication technology that supported by the incorporation of lightweight, durable, smooth edged, space efficient, and universally adopted specifications will ensure that mass housings remain affordable and sustainable for the long term. Second, the use of concrete as the main structural material contributes to a wide range of inherent benefits at no extra cost, such as its proven integral fire resistance, high levels of sound insulation, and robust finishes. Through its very nature, concrete provides robust surfaces for walls, partitions, columns, soffits and cladding that are easily sealed and free of ledges or joint details. All these may finally lead to the lower maintenance costs of the building while set in motion an efficient, cost effective and practical method for solving housing needs and overcrowding concerns in urban areas.

However, realizing that the concrete industry is responsible for 10% of worldwide CO₂ emissions, the limited use of concrete is also to be considered in D3 design system. For example, complicated wall arrangements are avoided in D3 housing, so that less concrete wall panels are used as internal partition. Within a typical D3 dwelling unit, walls that facing the outdoor environment is eliminated with the installation of aluminium sliding doors. Since the infills of D3 housing are prefabricated materials that are subject to change, lightweight materials that have a low heat storage capacity such as gypsum board and plasterboard with insulation can always be used in replacement of the existing one. In short, flexibility in terms of architectural and construction process is the key strategy of sustainability in D3 housing.

5. Conclusion

Affordable housing in the past has never been designed to last. It was aimed to provide a short-term solution – maximum number of houses in the shortest possible time – to meet the urgent
housing demand as if poverty and lack of affordable housing is a short-term problem. Although it is a government effort in providing adequate and affordable housing for the general population, the new contemporary household with its diversity of interior design needs in their consideration of future housing prototypes can no longer be ignored.

D3 design system introduced here can generate a better and cheaper habitat option through the application of existing science, technology and machine production capability. This concept is able to provide a new dimension in the design of comfortable and sustainable housing for the tropical country. The importance of this housing solution is reflected in its ability to solve the housing problems of especially the poor in a manner that is most appropriate to their socio-economic and cultural needs, by using environmental friendly method, contribute to the sustainable development of the construction industry, offers what people demand from a house and that they can live how they want to within it, by taking into account (i) the spatial and functional arrangement, (ii) the potential to expand spaces for increased occupant’s usage, (iii) maximizing natural lighting and ventilation, (iv) the continuity of the traditional housing concepts into a modern contemporary residential development. On a much larger scale, D3 can facilitate the shift towards a higher quality housing in the country, and eventually create sustainable dwellings for everyone in anywhere in the country.

References


Comprehensive Planning as a Platform for Environmental and Economic Development of Urban and Rural Areas

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Abstract

Urbanization in China is vast. It is foreseen that in the near future 75% of the population lives in the cities while the present share is less than 50%. The rapid urbanization has led to major problems concerning urban development and environment: Unsustainable planning, pollution and severe deterioration of ecosystems and poor quality of buildings, especially housing. Land use rights have been the engine of this development. However, revitalizing the economic model is the key to transformation of the Chinese cities. By adopting new approaches to urban policies can help to change the path China is on. Innovative urban planning and design is one of the key development areas for healthier cities and districts. At the same time it serves for both economic development and environment.

Co-operation between different stakeholders is mandatory in the development in sharing resources and possibilities. ChangJi area in Jilin province locates between two cities, Changchun and Jilin. Both cities have agreed to develop the area according to sustainable planning and design approaches. Re-thinking urban and rural structures, transport, agriculture, industrial development and industry structure and energy services aim at environmentally sound and livable urban areas and prosperous rural villages. The regional development in ChangJi focuses on piloting new methods for comprehensive and master planning and exploring possibilities on low carbon development. Environmental and economic development go hand in hand in the execution of strategies for opening up for international approaches, technological innovation, ecological city, intelligent city, urbanization system, social mode with planning as the platform. The first phase of this development was finalized in August 2015.

Keywords: Urban planning, environment, energy, emissions
1. Introduction

The urban and regional planning processes are tending to draw up optimal solutions. This will too often include solutions that are not correlating with the future reality and will further lead to very unsatisfying results; wrong investments in infrastructures or buildings, failing in function, identity and attraction among others. This can never be fully prevented but it can, however, be reduced by analyzing how the different solutions are dependent on certain circumstances.

Land use planning aims to promote economic community structure and sustainable land use. Goal is to ensure a safe, healthy, pleasant, socially functional living and working environment which provides for the needs of various population groups. China’s urbanization is rapid. Roughly 300 million people will move to cities in about 25 years. In the urbanization process the land use planning has served more for the economic growth than for the basic aims of planning. The consequences include poorly planned residential areas, pollution due to increasing energy production and industrial activities, car transport and neglecting the environment sometimes totally.

The rapid urbanization has increased energy demand in China significantly. Energy use in public sector increased by 15% between 2006 and 2010. The increase in energy use in residential sector is estimated 150 – 300 % between 1996 and 2006 (Amecke H et. al., 2013). ChangJi area locates in the severe cold climate zone in North-East China, Figure 1. The annual energy consumption in present residential apartment buildings is estimated 150 – 250 kWh/m² and in public buildings 200 – 300 kWh/m² (CIUPD, 2015). Co-generated district heat and electricity are mainly produced with natural gas but the main share of electricity still with coal fired condensing power.

<table>
<thead>
<tr>
<th>Climate Zones</th>
<th>Mean Monthly Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coldest</td>
</tr>
<tr>
<td>Severe Cold</td>
<td>≤-10 °C</td>
</tr>
<tr>
<td>Cold</td>
<td>-10 - 0 °C</td>
</tr>
<tr>
<td>HSCW</td>
<td>0-10 °C</td>
</tr>
<tr>
<td>HSWW</td>
<td>&gt;10 °C</td>
</tr>
<tr>
<td>Temperate</td>
<td>0 - 13 °F</td>
</tr>
</tbody>
</table>

Figure 1. Climate zones in China (Shui & Li, 2012)
2. ChangJi regional plan

2.1 Planning process

Forests cover approximately 28% of the land area of ChangJiest. The forest areas are saved from construction. Agricultural land and forests together cover more than 50% of the total land area of about 4000 km². The population of ChangJi is expected to grow from the present 910 000 up to 5,1 million in less than 30 years. At the same time the widely spread out development with the isolated dwelling and job areas promote private car transport. This development has already contributed to construction of wide roads and huge parking areas; the walking distances are long and implementation of an efficient public transport is problematic.

The ChangJi planning project introduced the Finnish regional planning processes and tools to Chinese planning procedures. A Sino-Finnish group of experts from various planning and design fields analyzed the direct and indirect impacts of the plan. An environmental impact assessment tool was used for cross-evaluation of development themes and targets, Table 1. The aim of the tool is to find the needs for information and possible on-site investigations.

Table 1: Through cross-evaluation of planning themes and priority target areas in planning analyzing the environmental impacts and information were recognized that various fields needed further investigations.

<table>
<thead>
<tr>
<th>Planning targets</th>
<th>Description for new development</th>
<th>Housing and living environment</th>
<th>Earth (soil and solid ground), water, air and climate</th>
<th>Flora and fauna, biodiversity and natural resources</th>
<th>Structure of built environment, infrastructure, energy and traffic</th>
<th>Visual image of the whole region, cultural heritage, archaeology</th>
<th>Source of livelihood</th>
<th>Linneas issues and knowledge needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protecting of nature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protecting of cultural heritage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clean energy production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation network</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational areas and routes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure of built environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Further analysis and information needs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The regional plan provides opportunities for a safe and healthy living environment that considers different population groups. Various provisions certify the protection of the built environment, landscape and natural values; and leave a sufficient number of areas for recreation.

### 2.2 Planning targets

The ChangJi regional land use plan takes into account the functionality, economy and ecological sustainability of the community structures. The regional land use plan bases on estimated phase-by-phase population growth. The phasing ensures the full utilization of the existing community structures.

The opportunities to re-organize traffic, especially public transport and non-motorized traffic are considered. The use of renewable energy and waste management, sufficient water supply and drainage are implemented in land use in an appropriate manner that is sustainable in terms of the environment, natural resources and economy.

The plan’s impact on community structure, the built environment, nature, landscape, arrangement of traffic, especially public transportation, and technical services, economy, health, social circumstances and culture, and any other significant impacts should be analyzed. In ChangJi, the large-scale impact analysis was already carried out but the detailed information is missing. Ground water areas to be saved from construction activities and, e.g., areas with polluted land or noise pollution from road traffic should be mapped before the final regional plan.

![Figure 2](image.png)

*Figure 2. The urbanization in ChangJi requires millions of square meters of new housing. New housing areas are often remote and not connected to existing towns. (Photo: Sanukka Lehtio)*

The regional plan of the area bases on development in three phases according to population growth. The 1st phase aims at construction in the existing areas for about 600 000 new inhabitants. The 2nd phase will expand the existing areas, and the 3rd phase brings completely new cities and
towns into the development. This way the utilization of existing infrastructure is maximized and the distances stay short. The planning and construction will promote public transportation as the primary transport mode. The areas need to be dense enough with sufficient amount of population to support the public transportation.

A specific target is to plan a new Airport City as a landmark for the area including high-tech businesses, universities, exhibition center and residential areas.

Expansion of the existing areas may start only after the areas of the 1st phase are completed. These areas can expand the structure if the growth needs more land. The practical order of construction has to be evaluated by general planning so that the new construction strengthens the existing structure. As the development is rapid, reduction of environmental consequences gives priority for a well performing public transportation. The general planning aims also at increasing the share of renewable energy or carbon neutral energy, promotion of energy efficient buildings, sustainable use of materials and material savings, and efficient infrastructure. The development should guarantee sufficient basic services for the inhabitants (day care, school, health care, and other daily services).

Sustainable transport allows for the basic access and development needs of individuals, companies and society to be met safely and in a consistent way with regard to human and ecosystem health at the same time as it promotes equity within and between successive generations. Sustainable transport system on a large area requires co-operation with different regional and municipal actors. The ChangJi area includes both regional fast trains and slower local trains which are linked to local transport systems.

The planned sustainable transport system includes all the transport modes that are considered socially and environmentally friendly. This refers to transport modes that have low carbon emissions (close to zero) or are totally emission free. It includes walking, cycling and public transportation, but also environmentally friendly carpooling systems, car share, taxis (if low on CO2 emissions) and vehicles that cause low environmental impacts in use.

The most important route planning of the public transportation system bases on a trunk line system, where the strong public transport links form the root to the system connected to housing, work places and services. Secondly, feeder links are connected to the trunk line system. The level of connectivity depends on the planned population in different areas – the higher the population the better the connectivity. Land use planning connected to transport planning helps for the estimation of successful user levels for the public transportation, but also make the new housing areas more sustainable.

Figure 3 shows part of the regional plan as an example. The markings and symbols on the ChangJi regional plan are implemented from Finnish regional planning and general planning. Figure 4 shows an example of the expansion of existing structure. Areal markings present the various development zones and subareas for further investigation or to emphasize the further detail planning. Intended land use is presented with areal markings. Symbols are used for different sites,
nodes and such land use where area need is minor. Line markings and symbols are used for roads, lines and pipes. The plan colors show the development targets (existing areas, new residential, commercial or industrial areas and other intended purpose of use. Dotted arrows show transport system development directions and, e.g., dotted circles urban development areas supported by existing public transport. Different layers in the plan include infrastructures, transportation networks waste management centers with energy production facilities etc.

Figure 3. Example of the plan and plan markings (Architect Sanukka Lehtiö)

Figure 4. Planned expansion of an existing area (Architect Anna Brunow)

The target of regional level plan of ChangJi area is to be the guideline for the sustainable land use. There is a particular need to rely the strengths of each area or district in developing regional structures, to promote the creation of networks between the areas or regions, to agree on specialization, and to create particular development zones. An efficient utilization of existing structures will also improve the economy. The quality of the living environment is an important issue with a view to ecological sustainability and prevention of significant environmental damage. The volume of traffic and division into different modes of transport, energy consumption and the cost of infrastructure are largely determined by the structure on community in general planning.
3. Sustainable energy

3.1 Energy demand

The energy demand analysis of the whole ChangJi area bases on present population and estimated growth in different development phases. The population growth from 900 000 up to 5,1 million people will altogether require 170 million m$^2$ new residential buildings and 80 million m$^2$ commercial, office and public buildings. There is no exact data on building energy use available for North-East China. Therefore, reference information (collected by Paiho et al., 2013) was used for the estimations, Table 2. The energy demand of the ChangJi area excludes energy use in the industrial processes.

Building energy use in China (Paiho et al., 2013).

<table>
<thead>
<tr>
<th>Energy application</th>
<th>Building energy use kWh/m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural areas</td>
<td>7,5</td>
</tr>
<tr>
<td>Northern cities for heating</td>
<td>60 - 130</td>
</tr>
<tr>
<td>Electricity use excluding heating</td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>10 – 30</td>
</tr>
<tr>
<td>Typical public buildings</td>
<td>26 – 60</td>
</tr>
<tr>
<td>Large public buildings</td>
<td>70 – 300</td>
</tr>
<tr>
<td>Other</td>
<td>30</td>
</tr>
</tbody>
</table>

Hot water heating Changji bases on various technologies. Residential buildings may have an apartment based electrical, natural gas water heater, or solar thermal systems. In office buildings, also separate boiler stations are used.

The total energy use (heating, cooling, electricity) excluding energy use in the industries will rise from the present 5,5 TWh up to 35 TWh. Approximately one third of the total is electricity. As the urbanization continues, household electricity use will increase more in relative terms than heating energy while the heat demand of new buildings is substantially lower than that of the present multi-story buildings. Heating season is fixed and it is presently 167 days per year. The estimate includes phase-by-phase improvement of energy efficiency of buildings and development of passive and solar districts.

Passive house is a voluntary approach to design and build an energy efficient building. There are several different definitions for a passive house in Europe. The original definition comes from Germany. The climate of Germany is quite mild compared to North-East China. The winter climate of ChangJi is comparable to Central Finland although with higher solar potential. The energy demand of a passive district or neighborhood bases on the following assumptions:

- Space heating demand 25 kWh/m$^2$
- Hot water heating demand 25 kWh/m$^2$
- Electricity demand 30 kWh/m$^2$. 

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3.2 Energy mapping

The energy plan for the district includes implementation of efficient technologies for energy production according to energy demand. There are two key issues in the energy plan: Minimized energy consumption of the district, and efficient renewable or carbon neutral production for clean energy. The energy plan includes all the energy that is needed in the district. Key element in an energy plan is energy mapping to define feasible local energy sources. The energy mapping supports the entire city design and usage process. Figure 5 shows the energy resources that can be utilized in ChangJi development.

![Figure 5. Feasible energy sources for ChangJi](image)

The ChangJi energy map shows the potential sources to cover the energy demand. Basically the energy services depend on the location of the energy use. Figure 6. Rural villages and small towns are optimal for distributed energy sources whereas cities can utilize both centralized and distributed systems. The ChangJi area lacks a proper waste management system. Waste incineration is one feasible system for large-scale CHP production.

The energy services are planned for multi-source mixed energy production. The energy production scheme depends on the population of the planning area and the possibility to combine areas under a common energy system. The systems are centralised, mixed or distributed systems.

![Figure 6. Energy production schemes](image)
3.3 Energy services

Centralised energy production bases on co-generated heat and power CHP. Environmental consequences of the production need to be reduced by renewable or low carbon fuels. In large-scale facilities, the potential fuels are municipal waste and natural gas. Natural gas is used for co-fuel in the beginning of the burning process and for improving the energy efficiency of the process. The fuels for the reference waste incineration CHP plant in Vantaa, Finland, are 44% natural gas and 56% municipal waste for production efficiency of 95%.

The potential of waste to energy for the whole Changji area is approximately 10 - 20% of the total energy demand. The share can be increased by better energy efficiency of the buildings, more efficient waste collection especially from shops and service buildings and utilization of agricultural waste. However, agricultural waste is more suitable for micro CHP systems for villages.

Waste to energy facilities can be built in the 8 waste management centres in the area. Natural gas with existing delivery infrastructure is the primary alternative and more environmentally friendly fuel as coal. Coal fired condensing boiler power plants are the most inefficient power production facilities. These production facilities have efficiencies between 30 and 40%. CO2 emissions from the old Chinese production plants vary from 800 kg/MWh up to 1600 kg/MWh. The typical existing Chinese CHP facilities have efficiencies between 60 and 80%. A modern waste to energy CHP has an efficiency of 90 – 95% and thus would reduce emissions from energy production drastically.

The purpose of mixed energy production is to utilize multiple sources of energy in addition to large-scale production facilities. These combinations are suitable for towns and villages for improvement of energy infrastructure or for small villages to cover the whole energy demand. Such systems include:

- MicroCHP for power and heat
- Ground source energy for heating and cooling
- Water source energy for heating and cooling
- Solar power for electricity
- Solar thermal as stand-alone systems or integrated to district heating
- Wind power

The wind conditions in the region do not support large-scale wind power. Therefore, only local systems with capacities below 10 kW are feasible.

There is a wide range of microCHP systems with capacities for 3 – 3000 kW electricity and 15 – 12000 kW heat. Typical agricultural wastes in the region are corn stalk, straw and husk with an average energy content of 4 – 5 kWh/kg. Total amount of the residues for energy production is estimated 400000 – 500000 tonnes.
Ground source energy can be used for single buildings, group of buildings or as local district heating and cooling system. Typically, the system runs with heat pumps but it can serve as an energy storage as well. Figure 6 shows a principle of heat pump heating and cooling system for an apartment building. There are six heat well bored down to 200 m in the ground. The heat wells are located with 15 m distances for to prevent disturbance between the wells.

Water source or combined water and ground source system are feasible as well, Figures 7 and 8. Heat exchangers either at the bottom of a lake or on the ground can be used in water source. Water filled abandoned coalmine shafts can be used for heat storage and water source heating and cooling.

Solar power (PV) system varies from Building integrated PV to large solar power plants. Solar power can serve as distributed system for all developments. It are especially usable for cooling, as the load match is perfect.
4. Conclusions

The first phase of the project produced models for further development. The environmental and economic targets set for the region are high surpassing the requirements set by the legislation and typical planning projects. Especially the to be planned Airport City can serve as a world-class example of Chinese ways and means to develop sustainable cities.

The risks involved in the development is the typical Chinese scheduling of projects and lacking knowhow in implementation of the various technologies. The hard-pressed progress may bypass the targets. It also inevitable that the city planners need to connect with technology providers and specialists to avoid misinterpretation in implementation of technologies.

References


How can Sound Absorbing Tiles Make your Stairways Sound Better?

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Abstract

As many of us live in apartment buildings, we all know that the stairways are noisy and reverberant thus disturbing the residents. Currently, no study is available to show how the amount and positioning of attenuating material in stairways impacts on the acoustic environment of apartment blocks. This study demonstrates the effect of a two stage acoustic treatment carried out in a four-storey apartment building. Measurements and sound samples were taken at three separate stages to describe the development of acoustics: before, stage one and stage two. Before: no absorption. Stage one: A-Class sound absorption material was installed on the ceilings. Stage two: sound absorption tiles were added to the underside of the staircases. Measurements tell about very significant improvements in the stairway: Reverberation time (T20) shortened by 3 seconds from 3.6 to 0.6, Speech Transmission Index (STI) increased from 0.47 to 0.81 and Sound Pressure Level decreased by 10 dB. Additionally, the sound samples recorded at each stage revealed a huge change. From these results we can conclude, that this acoustical treatment was really worth doing. The stairway is now more peaceful, harmonious and makes the residents` lives feel a bit more luxurious.

Keywords: Acoustics, room acoustics, sound absorption, stairway noise, apartment building

1. Introduction

Many of us live in apartment buildings knowing, that the stairways are noisy and reverberant thus disturbing the residents. Currently, no study is available to show how the amount and positioning of absorption material in stairways impacts the acoustic environment of apartment blocks.

The purpose of this study, with acoustical measurements and sound samples, is to give useful information to housing companies and builders, how to make noisy stairways quieter and the residents satisfied. Furthermore, the measurements taken at three separate stages, tell us also how the sound absorption material affected the acoustical parameters.
This study and acoustical measurements were carried out in a housing cooperative Hakanmetsä, in Helsinki at 2014.

2. Measurements and sound samples

Measurements and sound samples were taken at three separate stages:

• before (no absorption)

• stage 1 (absorption on the ceilings)

• stage 2 (absorption tiles were added also to the underside of the staircases)

At stage 1 and 2 the room acoustical parameters were measured on two separate floors. The measurements were taken according to SFS-EN ISO 3382 [1-3] and IEC 60268-16 [4] standard.

At stage 1 (Figure 1) 28 m² (which was also the entire surface area) of impact resistant A-Class sound absorption material (Ecophon Super G 35 mm) was installed on the ceilings of each landing. The ceiling was installed with suspension of 100 mm (overall depth of system, ods).

At stage 2 (Figure 1) the sound absorption tiles (Ecophon Super G 35 mm) were added 12 m² (the entire surface area was 18 m²) to the underside of the staircases.

The measurements were performed by using impulse response method (test signal log-sweep, 10 s, 2 source and 6 microphone positions at each floor). The following acoustical parameters were calculated in octave bands (63 Hz – 8000 Hz) from measured impulse responses:

• Reverberation Time, \( T_{20}(s) \)

• Sound Pressure Level, \( L_{Aeq} \) (dB)
- Speech Transmission Index, STI (values between 0 - 1)

Speech Transmission Index value of 1 means that speech is perfectly intelligible. The closer the STI value approaches zero, the more information is lost.

In addition the Sound Pressure Level passing through the door from the stairway into the apartment, was measured at each stage by using reference noise (pink noise, LwA= 92,0 dB).

The sound samples in the stairway were digitally recorded (Olympus LS-5). Recorded samples were typical sounds in everyday life such as noisy children and a woman coming downstairs with high heel boots on. Additionally one sample was recorded by using a short sentence which was recorded earlier in an anechoic chamber. Then that sentence was played back in the stairway with Genelec 6010A loudspeaker and recorded at each stage like all sound samples were.

3. Measurement results

Figures 2 and 3 describe Reverberation Time T20 (s), figure 4 shows Speech Transmission Index (STI) and tables 1, 2 and 3 describe Sound Pressure Levels in different microphone positions. The stairway’s background noise level during measurements varied between L.Aeq = 30 – 35 dB.

![Figure 2. Reverberation Time T20 (s), (63 Hz – 8000 Hz) before and after each stage.](image-url)
Figure 3. Reverberation Time T20 (s), (250 Hz – 2000 Hz) before and after.

Figure 4. STI - values before and after.

Table 1. Sound pressure levels of the reference noise (LwA = 92 dB). Loudspeaker is on the 2nd floor.
Table 2. Sound pressure levels of the reference noise ($L_{wA} = 92$ dB) at the top floor, when loudspeaker was on the ground floor.

<table>
<thead>
<tr>
<th>Microphone position</th>
<th>Sound pressure level, $L_{A,eq}$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
</tr>
<tr>
<td>Floor 4</td>
<td>80</td>
</tr>
</tbody>
</table>

Table 3. Sound pressure levels of the reference noise ($L_{wA} = 92$ dB). Loudspeaker is on the 3.5 floor.

<table>
<thead>
<tr>
<th>Microphone position</th>
<th>Sound pressure level, $L_{A,eq}$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor 3</td>
<td>91</td>
</tr>
<tr>
<td>Floor 4</td>
<td>93</td>
</tr>
<tr>
<td>Inside an apartment (2nd floor), outer door closed, inner door open</td>
<td>61</td>
</tr>
</tbody>
</table>

Table 4. The measured reverberation times are compared to the requirements of the National Building Code of Finland, part C1:1998 [5].

<table>
<thead>
<tr>
<th>Space</th>
<th>Reverberation time, see tables 1-3 and 5-7</th>
<th>The National Building Code of Finland, part C1:1998 requirement (500Hz - 4000Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stairway, before</td>
<td>Does not fulfill the requirements</td>
<td>$\leq 1.3$ s</td>
</tr>
<tr>
<td>Stairway, phase 1</td>
<td>Fulfills the requirements</td>
<td>$\leq 1.3$ s</td>
</tr>
<tr>
<td>Stairway, phase 2</td>
<td>Fulfills the requirements</td>
<td>$\leq 1.3$ s</td>
</tr>
</tbody>
</table>

4. Discussion

In figures 3 and 4 we can see the biggest change occurred in phase 1. Before changes the Reverberation time was 3.6 seconds, after Phase 1 it was 0.8 s. and after Phase 2 it was 0.6 s. Owing to dramatically shortened Reverberation Time, whenever noise comes up in the stairway, it will almost immediately fade out as well.

Figure 4 diagram proves out that adding absorption enhances also the STI-value. This means improved speech clarity. Thanks to that, whenever people meet in the stairway, they start to talk with a lower sound level than they did earlier. And as a consequence, talking in the stairway is hardly audible anymore inside the apartment.
Table 1 demonstrates that after phase 1 the sound pressure level decreased 7 dB and after phase 2 it dropped 3 dB more, altogether 10 dB. This is such a big reduction, that people experience the sound strength only as half what it was earlier.

From Table 2 we can see that after phase 1 the sound pressure level from ground floor to floor 4 decreased 17 dB, which is really huge reduction. After phase 2 the sound pressure level dropped still 6 dB more, so the total reduction was as much as 23 dB.

Table 3 shows clearly, that absorption material decreases effectively the sounds coming from the stairway inside the apartment. After phase 2 the sound pressure level dropped even 16 dB.

In table 4 we can see that the reverberation time meets the requirements of the National Building Code of Finland already after phase 1.

5. Conclusions

From these results we can conclude, that this acoustical treatment was really worth doing and meets the requirements of Finnish National Building Code, C1:1998 even after stage 1. The sound absorption, which was installed on the ceilings of each landing, already gave the residents good protection from noise coming from stairways. But undoubtedly, adding the sound absorption tiles also under the staircases decreased the noise disturbance even more, thus making living in the apartment flats even more peaceful.

The stairway is now more comfortable, harmonious and makes the residents` lives feel a bit more luxurious in this noisy world we are living in.

References

The Development of a Generic Design for Primary Healthcare Facilities in South Africa

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Abstract

Primary healthcare (PHC) service delivery is severely hampered by lack of, and poor quality infrastructure. In many cases the physical infrastructure at clinics is old, inadequate and in some cases not suitable for use. The provision of services (water, sanitation and electricity) is in many cases not adequate, especially in rural areas. This study developed a generic design for modular conventional clinics and for rapid deployment clinics. Researched, patient-centric service delivery and workflow have been used as major drivers for design configuration. Clinics have been organised to accommodate three patient streams: namely chronic services, acute services, preventive and promotive services. An optimal patient flow pattern was determined and the infrastructure norms and standard guidelines developed by the South African National Department of Health were considered. The space requirements were derived from the design terms of reference and the PHC norms and standards. Two methods of construction were assumed, i.e. traditional brick and mortar, and Innovative Building Technology (IBT) system with the latter being an insulated panelised system. A conceptual design for a generic, basic clinic for use in South Africa is developed. The conceptual design is modular based and allows for additional functions to be added as and when required. The design is both flexible and adaptable. It is highly likely that the clinic may function off-grid under certain circumstances.

Keywords: health infrastructure, basic clinic, building services

1. Introduction

Recognising that historical funding models have entrenched inequity and undermined affordability of healthcare services in South Africa, the South African National Department of Health has introduced the National Health Insurance (NHI) scheme to integrate healthcare services. This requires a “re-engineered approach to providing primary health care (PHC) using a population based approach for the delivery of PHC outreach service to the uninsured population of South Africa” (NDoH 2011:2). Major implications, such as shifting to increased community outreach services (as opposed to facility-based services), and emerging requirements for information networks (for NHI management) are foreseen. As infrastructure is integral to the delivery of healthcare services, these organisational transformations provide an extraordinary opportunity for science, engineering and technology input across the life cycle of primary healthcare facilities.
Primary healthcare (PHC) service delivery is severely hampered by lack of, and poor quality infrastructure. In many cases the physical infrastructure at clinics is old, inadequate and in some cases not suitable for use. The provision of services (water, sanitation and electricity) is in many cases not adequate, especially in rural areas. In addition to this, no standardised clinic design and lifecycle management tools currently exist. This results in poor infrastructural investment decision making, problematic procurement processes and practices and poor maintenance of existing facilities. Re-engineering of primary healthcare as the main mechanism of healthcare service delivery requires urgent intervention at the infrastructure level.

This study developed a generic design for modular conventional clinics and for rapid deployment clinics. The study does not evaluate materials that could be used or undertake a comparative analysis between materials. This study focuses on the components underlined in Chapter 3.

2. Research approach and methodology

Designers of buildings are often unable to explain how they arrived at a design solution beyond “that his or her reason for making a particular design decision is based on a ‘feeling’ or ‘intuition’” (Wiggins 1989:1). However, increasing building complexity and sustainability imperatives require a “new decision model” (Mendler and Odell 2000:19; CIB 2009:4). Mendler and Odell (2009:24) argue that this new approach “requires some focused research time” and that sustainable design “requires the design team to consider a larger number of issues in the decision-making process” with “supplemental research to understand the environmental impacts associated with design options and to identify preferred approaches”. It can be argued that what is being proposed is the use of grounded theory being “a set of rigorous research procedures leading to the emergence of conceptual categories” which may make use of both quantitative and qualitative data (GTI 2015).

The research approach to the study was based on the South African Institute of Architects (SAIA) Plan of Work as proposed in their Practice Manual (SAIA 1.1211:3). The Plan of Work consists of five work stages namely:

Stage 0 – Inception briefing and appointment of consultants
Stage 1 – Appraisal and definition of the project
Stage 2 – Design concept
Stage 3 – Design development
Stage 4 – Technical documentation and approvals
Stage 5 – Contract and administration and inspections

This study includes only Stages 1 and 2.

A reading of the practice manual Plan of Work may suggest that the two work stages actually imply a research-based approach to design: however the text is biased towards meeting the programmatic goals of the client rather than researching the full range of performance requirements of the building project.

The research method used by the study is Ernst Neufert: Architects’ Data (ed. Herz, 1970) as it suggests a methodology closer to research-based design and uses qualitative and quantitative research data. In the section appropriately titled ‘Design Method’ (Herz, 1970:30) it is recommended that the
“work starts with the preparation of an exhaustive brief” and lists information that must be known before planning begins. The required information includes site (location, environment, size, levels, services, fixtures); space requirements (areas, heights, positioning and relationship); dimensions of existing furniture; finance (site acquisition, legal fees, mortgages, etc.); proposed method of construction (brick, frame construction, sloping roof, flat roof); and all the legal facts. A questionnaire is included in this approach which includes questions relating to the client, fees and agreements, persons and firms connected with the project, general, project, basic design factors, technical fact finding, records and preliminary investigations, preliminaries, and activities and events. The question is a combination of quantitative data (e.g., type of topsoil) and qualitative (e.g., what is the attitude of the town planning officer towards architecture).

It then recommends that the individual units are analysed, drawn to scale and put provisionally into groups. The relationships of rooms to each other and to the sun are analysed (Herz 1970:30). What follows is critical: ‘at this stage an “idea” in 3-dimensions will emerge’ and ‘instead of starting to design at this stage, explore the various means of access, the prevailing wind, tree growth, contours, aspect, neighbourhood, then finalise the positioning of your building, relating it to tentative landscaping, etc.’ Finally, it recommends that one ‘try out several solutions to explore all possibilities and use their pros and cons for searching examination.’ Based on the foregoing it argues that the ‘idea now becomes clearer and the real picture of the building emerges’.

What is described in Neufert’s text is grounded theory, a research method that aims to allow the theory (in this case the idea) to emerge from the research. In fact, an early attempt to ‘design’ is discouraged to allow theory testing to be done from which a ‘design’ emerges. Further evidence to support this theory is found later: Neufert recommends that after the completion of the preliminary design a pause is taken to ‘help get rid of preconceived ideas and undigested brain-waves, and to allow time for other short-comings of the design to be revealed not least in discussions with staff and client’ (Herz 1970:30).

To further aid this research method Barry’s Introduction to Construction of Buildings (Emmitt and Gorse, 2005) is used to construct a useful methodology for considering the construction of buildings by breaking the construction process down into five basic components, namely; sub-structure, super-structure, roof assembly, services, and finishes. Each of these components can be further sub-divided into sub-components such as windows and doors for super-structure. This approach has been used with some success in previous experimental studies undertaken by the CSIR at its Innovation Site in Pretoria (van Wyk, 2009; de Villiers 2011).

3. Research question and sub-questions

The primary research question is the following:

How and in what way can Science, Engineering and Technology (SET) give input into the development of a standardised design terms of reference, based on a modular approach, for a basic clinic that will comply with primary healthcare (PHC) norms and standards while delivering improvements in indoor environmental quality, reductions in non-renewable resource use, improved construction quality, reduced construction time, reduced construction cost, and support resilient human settlements in a sustainable and economical manner?
In order to answer the primary research question, a number of sub-questions must be answered. Not all of these sub-questions are addressed in this paper: the sub-questions addressed in this paper are underlined in the primary research question.

4. Standardised design terms of reference

Research, patient-centric service delivery and workflow have been used as major drivers for design configuration. Clinics have been organised to accommodate three patient streams: namely chronic services, acute services, preventive and promotive services. Care is taken to provide general zoning which allows for future expansion, particularly for specialised services, community outreach services, and the patient streams, where greatest future growth is anticipated.

Figure 1: General zoning

4.1 General ambulant patients

Patients enter the clinic site through a controlled entrance at the security guardhouse. From here they proceed to the front entrance of the clinic building. Upon entering, patients are triaged and except for emergency cases, register at the front reception desk. Thereafter they remain in the main waiting area until called by the nurse who, where necessary, takes the patients’ details, blood pressure and possibly their weight. Patients required to give a urine sample for testing will use the universally accessible ablution facility adjacent to the sample room. Having been attended to by the nurse, patients are directed to wait in the sub waiting area before proceeding to the relevant room. After consultation or counselling, patients either go to the treatment room for further assistance, collect medication from the dispensary or leave the building.
4.2 Emergency patients

Patients requiring urgent care are triaged on arrival and are immediately directed to the emergency room where they are attended to by the nurse who may arrange to transfer the patient to a referral hospital.

5. Norms and Standards

The development of guidelines, norms and standards formed part of a National Department of Health project called Infrastructure Unit Systems Support (IUSS Project). IUSS was a structured collaboration between the National Department of Health (NDoH), the Development Bank of Southern Africa (DBSA), the Council for Scientific and Industrial Research (CSIR), and other stakeholders with the shared objective of optimizing the acquisition and management of South Africa’s public healthcare infrastructure throughout the infrastructure’s lifecycle.

The development of guidelines, norms and standards has been structured into work package sets and 45 work packages including facilities and departments, regulations, engineering services, infection prevention and control, equipment, sustainability and environment, tomorrow’s healthcare environments, have been identified. A development programme has been initiated providing for input focused workshops and output focused task groups developing new draft documents.

The draft norms and standards developed for the IUSS Project have been used to prepare the concept design.

6. Modular requirements

The intention is to develop a generic basic clinic design that can be constructed using either conventional building technology (brick and mortar) or innovative building technologies (IBTs).
In both instances use has been made of a modular approach based on a modular dimension (modules of 300 mm) creating a standardised unit capable of being fitted out to serve the specific function, and have interchangeable components (doors, windows, etc.). This approach was taken to ensure that the clinic was flexible enough to adapt to local conditions and could be scaled-up to meet local needs over time. The modular approach was also applied to the design and selection of off-grid utility services, especially electricity generation (solar and wind) and sanitation.

Having regard for the patient flow and norms and standards a modular dimension of 4.2m x 3.0m created the most flexibility. In the conventional building technology application the foundations will be conventional concrete foundations and slab: for the IBT application a steel chassis will be constructed with steel supporting super-structure and roof. The IBT module will be manufactured in the factory and transported to the site where it will be placed on supporting stub columns (brick or concrete).

In both IBT cases the interior can be equipped according to its intended use either off-site, or on-site, depending on the circumstances of the specific project.

7. Non-renewable resource reduction

Buildings and their operations depend on the continued supply of services such as water, sanitation and electricity. However, service delivery failures do occur whether due to design and operational factors such as regular maintenance or system failure. An assessment of infrastructure in South Africa in 2011 noted that “the quality and reliability of basic infrastructure serving the majority of our citizens is poor and, in many places, getting worse” (SAICE 2011:5). Of the three services targeted in the study namely, electricity, water and sanitation, the infrastructure report card finds that there has been “further deterioration in the ageing bulk water infrastructure portfolio as a result of insufficient maintenance and neglect of ongoing capital renewal” with water quality identified as “a serious problem, especially outside metros” (SAICE 2011:6), “serious problems with management of many waste water (sewage) treatment works” including “waste water leakage and spillage, especially into major rivers” and that the backlog in sanitation “increasing owing to unsustainable infrastructure”, and with regard to electricity that “in many areas infrastructure is ageing and/or overloaded” with municipal infrastructure in particular described as “below standard and poorly maintained (SAICE 2011:8).

Critical services such as primary healthcare rely on a stable service provision especially with regard to water, sanitation, electricity and the proper storage of drugs. Innovative infrastructure service technologies are technologies that can be implemented to provide alternative methods for securing a stable infrastructure service.

One of the strategies that can be employed to ensure an uninterrupted service is to reduce the building’s exposure to municipal services through the use of innovative infrastructure technologies. This has a number of benefits: first, it assists the building to adapt to major perturbations and events without a disruption in service delivery; second, reducing the building’s dependence on municipal services also reduces the operational costs of the building; and third, innovative infrastructure technologies are less resource intensive, especially with regard to the water/energy nexus, as they operate at the site of use, thereby reducing the requirement to move bulk services around.
7.1 Energy

It is intended that all the power required to operate the building should be generated on site allowing the building to function off-grid. As the building is to be used primarily as a clinic facility, the design demand should be calculated on maximum demand when the building is being fully utilised. Based on an analysis of the expected demand for electricity, a load profile was generated using the expected utilisation of appliances. The daily average power consumption of the clinic was calculated as 19.8kWh/day, i.e., an electricity generation system that is sized to produce 20kWh/day is required. The cost of a 20 kWh/day PV system for a sunny but wind poor location such as CSIR Pretoria campus ranges from R291,718.00 to R319,000.00 inclusive of VAT and requires 48m² of PV panels. The cost of a 20 kWh/day wind system for a windy location such as the East London Industrial Development Zone is R287,854.56 inclusive of VAT and requires 2 x 3kW wind turbines. Preliminary investigations indicate that a wind system is slightly cheaper than a PV only system, but is site dependent on the availability of wind and solar resources.

The following three options were recommended, each one capable of being up-scaled using the modular approach, for the clinic to function off-grid:

- Photovoltaic (PV) based system for the generation of electricity for sunny but wind free sites such as CSIR Pretoria campus.
- Wind based system for the generation of electricity for windy sites such as the East London Industrial Development Zone.
- Liquid Petroleum Gas (LPG) for heating and cooking.

7.2 Water

Standard setting for water and sanitation at clinics takes place within specific dimensions of quality - acceptability, accessibility, appropriateness, continuity, effectiveness, efficiency, equity, interpersonal relations, technical competence and safety. Different kinds of facilities will be required to provide the same services in different situations, for example services to clinics in remote rural areas will be provided through different facilities compared to polyclinics in high-density urban areas. Therefore national standards about facilities and staffing norms for clinics are not set. The National Department of Health defines what services and facilities are required to best meet the health needs of the nation, i.e. a clinic must have a supply of electricity, running potable water and proper sanitation, which means adequate number of toilets for staff and users in working order and accessible to wheelchairs, but do not specify how the services are to be provided and at what level the standards should be met.

Clinics, especially in rural areas, tend to become a social gathering point for the communities, mainly because of the general lack of infrastructure (electricity, water sanitation, roads, transport, etc) compared to clinics in urban areas. The person-load per day of rural clinics is therefore generally higher than that of urban clinics, as patients normally have the responsibility of caring for a number of children/family, or are too old, or disabled, to visit the clinic by themselves and need assistance, and as transport services are infrequent, long waiting periods.

Water conservation includes rainwater harvesting and treatment, and waste water recycling systems. Rainwater harvesting, in its essence, is the collection, conveyance and storage of rainwater. The scope, method, technologies, system complexity, purpose and end use vary from rain barrels for garden irrigation in urban areas, to large-scale collection of rainwater for all domestic uses.
In the case of this clinic design, rainwater is collected and stored in rainwater tanks: the tank or tanks can either be positioned on the ground close to the downpipes or in a single more ideally situated location, or buried in the ground as a subterranean tank. The number of people being served at the proposed clinic estimated at 1400 per month. The recommended water allowance per person per day use as recommended in the World Health Organization guidelines is 2 to 6l/d (WHO 2011:9.2). The water demand per month will range between a lower limit (1400 x 2 x 22 = 61600) and the upper limit (1400 x 6 x 22 = 184800). No provision is made for urinals and the water closets (wc’s) are based on closed-system units described more fully under sanitation. Using Pretoria as the location of the clinic, and given the area of the building (300 m²) and the annual rainfall (732mm) (Climatemps 2015) the expected maximum annual harvested water supply will be 219600 liters which is insufficient to meet the needs of the clinic. Additional water sources will be required including sustainable urban drainage systems (SUDS) which will be very site-specific.

7.3 Sanitation

Lack of sanitation in healthcare facilities appears to be a more serious matter than lack of water supply. Many factors influence the choice of sanitation technology that meets the requirements for adequate sanitation at clinics, and these include:

- Cost effective provision of services and accessible to maintenance and servicing of the toilet by local community members.
- Management - The choice of system that is sustainable over the years.
- Use of the local contractors targeting youth and women.
- Sustainability of employment for the operation and maintenance.
- Improvements to health.

If a water supply is available, a conventional water-borne system can be selected, but many rural clinics have an erratic water supply that is inappropriate for the provision of water-borne sewage systems. In the case of insufficient water supply the choice of sanitation facility is usually limited to a dry on-site system, whether a VIP or waterless system, or a closed-loop recycling system. On-site, close-loop system, flush toilet waterborne sanitation systems are available from a number of companies and manufacturers in South Africa. They are ideal sanitation solutions in cases where only dry sanitation was an option. Generally in these systems naturally-occurring micro-organisms (bacteria) are selected as a biological additive to the digester tank. The biological process occurring in the digester tank converts raw sewage into re-usable filtered water, ready for re-use to the toilet cistern for flushing. A solar panel is installed to power the recycle pump in the digester unit. The product can be supplied as a pre-assembled unit or it can be supplied in a kit form to be assembled on site. This makes the transport of the unit much easier and no heavy equipment is needed for installation. The parts can easily be handled and carried by hand.

8. Concept design

From the above data a concept design was generated. Using the design approach advocated by Neufert (Herz 1970:30), the design commenced by the preparation of an “exhaustive brief”. This was obtained from the patient flows and the PHC norms and standards. No specific site was identified so the assumption was made that the site is accessible on all sides, is flat, and is north orientated. It was assumed that no services are available. The space requirements were derived from the design terms of reference and the PHC norms and standards. It was assumed that finance would be made available.
from Government. Two methods of construction were assumed, i.e. traditional brick and mortar, and Innovative Building Technology (IBT) system with the latter being an insulated panelised system.

The second phase of the concept design analysed all the individual units, drew these to scale, and arranged them in groups (see the plan sketch in Figure 3). From the 2-dimensional floor plan a section was generated (see section in Figure 2). This was the outcome of a number of “solutions to explore all possibilities and use their pros and cons for searching examination” (Herz 1970:30). A number of assumptions were used to generate the section. First, the building is raised to enable displacement ventilation to occur. An overarching roof was generated to provide additional shade to the rooms below, and to enable the extraction of air from the rooms. Preliminary ideas around the fitting of photovoltaic panels and solar water heaters are explored, as well the fitting of a rainwater harvesting system. The potential to open and shut the rooms is also explored to aid ventilation and security after hours. The section was the first attempt of a “real picture of the building emerging”. From the plan and the section a 3-dimensional sketch could be generated (see Figure 3).

![Figure 3: Design sketch](image)

As already indicated above, this sketch was the outcome of a number of iterations. Further to Neufert, “a pause is taken to help rid of preconceived ideas and undigested brain-waves, and to allow time for other short-comings of the design to be revealed not least in discussions with staff and client (Hertz 1970:30).

The outcome of this period of reflection was the further development of the design as shown in Figure 4.
9. Conclusion

The study developed the basis for a generic basic clinic for application in South Africa. The conceptual design is modular based and could be constructed using either conventional building technologies (brick and mortar) or Innovative Building Technologies (IBTs). The conceptual design also allows for additional functions and its supporting infrastructure to be added as and when required. The design is therefore both flexible (the modularity allows rooms to be used for different functions should the requirements and needs change) and adaptable (may be extended in a number of ways).
The research finds that it is highly likely that the clinic may function off-grid under certain circumstances with the exception of water where approximately half of the required demand can be met off-grid. These circumstances relate to climatic conditions, topography of the site, location of the site, ground conditions, and the extent of the site.

References


Modelling the Process of Innovation in Construction: Framework and Research Agenda

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Abstract

Increasing demand and expectations from clients coupled with the need to compete necessitate that Construction firms innovate to gain competitive advantage. Despite the labelling of the construction industry as less innovative by a number of reviews and comparative studies, innovation in the industry occurs at a high rate often hidden on projects. A better understanding of such innovation processes could be crucial for the management and implementation of innovations. However, current innovation literature in construction is focused on adoption and diffusion of innovations sourced from manufacturers and leading suppliers. Attempts at innovation processes have often come from generic models of how innovation occurs in construction based on theoretical speculation rather than empirical observation of the processes of specific innovations. This has resulted in a lack of understanding of the dynamics and processes by which innovation occurs in construction and an inadequate process theory for construction innovation. This paper presents a framework and agenda for exploring the trajectory of innovations in construction adapting concepts from the Minnesota innovation studies framework (MISF). The MISF suggests that the process of innovation involve five concepts: ideas, people, transactions, context, process and outcomes. The paper also draws on organizational ambidexterity theory and the intellectual capital based view, proposing a framework that is an adaptation of MISF. The proposed framework focuses on innovative ideas as being explorative or exploitative; people in terms of human capital; transactions shaped by social capital and context as organizational capital; the process as the sequence or stages of innovation generation or adoption for implementation and outcomes as the consequences of the innovation process for projects and firms. The paper draws on an ongoing research that aims to develop process theory for construction innovation, which can potentially provide a model of the innovation process in construction based on real examples of how processes of specific innovations unfold.

Keywords: Innovation Process, Construction Innovation, exploration, exploitation

1. Introduction

The construction industry has been described as an important sector contributing significantly to the socio-economic development of nations. However, the industry has been criticized for its poor performance (Harty, 2008; Winch, 1998). The answer to the industry’s challenges is considered to lie in the development of a stronger innovative culture to improve the rate and quality of innovation across the industry (Harty, 2008; Manley, 2008). The unique nature of projects necessitates that construction firms explore new innovative solutions or exploit existing capabilities to solve problems. However, knowledge of the processes of exploration and
exploitation of innovative ideas in construction is limited. Most studies on exploration and exploitation have been conducted in high technology intensive industries (e.g. He & Wong, 2004; Katila & Ahuja, 2002) with a few exceptions (e.g. Liu et al., 2012) that have investigated project based firms or project settings.

Mainstream innovation researchers have proposed numerous stage-based models to represent the innovation process as a sequence of discrete steps or stages (e.g. Rogers, 1983; Zaltman et al., 1973). These models, however, lack an empirical basis and there have been a few attempts to test the ability of such models to reflect how innovations develop in real situations. The innovation process has been described to be very much fluid than such stage models suggests, and in the project based environment can be very interactive and dynamic with feedback loops (Manley, 2008). Similarly, current literature on construction innovation processes is mostly generic models (e.g. Gann & Salter, 2000; Slaughter, 2000; Winch, 1998) of how innovation occurs in construction. These are based on theoretical speculation rather than empirical observation of the processes of specific innovations. This has resulted in a lack of understanding of the dynamics and processes by which innovations occur in construction and an inadequate process theory to help better manage the innovation process.

Among the central problems in the management of innovation according to Van de Ven (1986) is the process involved in the management of ideas into good currency to ensure implementation. Innovation efforts in the industry are considered to be disproportionately oriented towards enhancing products rather than process improvements. This is exacerbated by the poor state of knowledge in research into innovation processes (c.f. Winch, 1998). Harty (2008) points out the dearth of studies that investigate the processes of innovation implementation in construction. In a recent review of the state of the science in innovation, Anderson et al., (2014) observed a move away from process research which has led to a limited understanding of the processes of innovation. They call for more process research, to make the notion of process and interaction the point of departure. An innovation process study will help gain a deeper understanding of how and why innovation unfolds over time in construction and increase understanding of the processes and behaviours that are necessary for effective development and implementation of innovations. A process theory will not only provide an insight into the transformation of an idea but will also produce a model of innovation process for construction which can serve as a roadmap to managers of innovation, depicting paths that result in success or failure of an innovative idea.

2. Innovation defined

Various attempts have been made to define innovation. According to West and Farr (1990), innovation as a term has been used in many ways and the variance appears systematic with the level of analysis used, and is often very much varied and vague the more macro the approach becomes. Sexton and Lu (2012) suggests the need to adopt a view of innovation that is suited for particular contexts. Zaltman et al., (1973, p. 10) consider innovation as “any idea, practice or material artefact perceived to be new to the unit of adoption” whilst Van de Ven (1986, p. 604) emphasized the transactional nature of innovation and defined innovation as “the development and implementation of new ideas by people who over time engage in transactions with others within an institutional context”. In the construction management literature, Slaughter (1998) defines innovation as “the actual use of a nontrivial change and improvement in the process, product or system that is novel to the institution developing the change”. This paper adopts a more comprehensive definition of innovation proposed by the OSLO manual (OECD, 2005) that consider an innovation as “the implementation of a new or significantly improved product (good or
service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations”

3. The nature of construction innovation

Construction innovation can take a number of different forms regardless of the type of innovation involved. Tatum (1987) proffers four ways by which technological innovation occurs in construction: adoption of new approaches from external sources; modification and adaptation of existing technologies; incremental improvement of existing technologies; and the development of new technologies. The source of these ideas may be from research and development processes, leaders in the industry, leading suppliers and product manufacturers from other industries, competitors adopted or developed technologies or from experienced clients. Various typologies of innovation have been put forward. A popular typology is that of Slaughter (1998) who categorize construction innovation into incremental, modular, architectural, system and radical. Much of the innovations in construction according to Koskela and Vrijhoef (2001) fall into the incremental and modular categories of Slaughter’s classification.

Construction innovation occurs at the sector, business and project levels (Abbott et al., 2007). Innovation on construction projects include process, product and organizational innovations which can be established innovations in the industry or custom developed for specific projects with opportunities to be diffused on future projects. Construction innovation is described as hidden on projects occurring within teams and often developmental through interaction between stakeholders on site. NESTA (2007) in its report on hidden innovations presents four categories of hidden innovations that include locally-developed, small-scale incremental innovations that take place ‘under the radar’. At the business level innovation is much more about developing resources and capabilities: research and development (R&D) and organizational development. Whilst R&D focusses on the development of new materials or improvement on existing ones, organizational innovation involves the generation of new or enhancement of existing supply chain arrangements, strategies relating to human resource management, business processes and practices (Abbott et al., 2007; NESTA, 2007) or health and safety policy (Sexton & Barrett, 2003). Innovation at the sector level also takes two forms: through regulations and standards that prescribe new material attributes or behaviours which forces innovation, and the drive of innovation by client’s that are dominant enough to drive innovation in the sector or rather for their specific needs (Abbott et al., 2007).

4. Theoretical framework

A number of models and frameworks have been proposed for the study of the process of innovation in organizations. Such models, often from product development perspective propose frameworks or models that are linear and generic (e.g. Zaltman et al., 1973). Some construction management researchers have also proposed similar generic models of the innovation process in construction organizations (e.g. Gann & Salter, 2000; Winch, 1998). Researchers in the Minnesota innovation study programme proposed a comprehensive but succinct framework for the study of the innovation process that doesn’t only look at the process itself but concepts that feed into, drive or result from the innovation process. Van de Venn and Angle,(2000) rather summarize these concepts in the framework that: “from a managerial perspective, the process of innovation consists of motivating and coordinating people to develop and implement new ideas by engaging in transactions (or relationships) with others and making the adaptations needed to achieve desired outcomes within changing institutional and organizational contexts”. The framework for their study of innovation process involves six concepts: ideas, people, transactions, process, context and
outcomes. Changes in these concepts constitute an event which is mapped over the period of development and implementation of the innovation.

4.1 Innovation Ideas

Innovative ideas can be of different forms and from a myriad of sources. Ideas might be a recombination of old or existing ideas, something new that challenges the status quo or something new to the people involved (Van de Ven & Angle, 2000). Innovations are often a combination of emergent processes, adopted and adapted procedures often in use elsewhere and ideas that become refined over time through realistic organizational limitations (West, 2002). Therefore, the newness characteristics tell whether the innovation is new to the world or to a given context. Rogers (1983, p11) put forward that innovation involves products or services that are considered new to a social system with little emphasis on whether the newness of the idea is objectively assessed as by the time lapse since the first use of the product or service. Gopalakrishnan and Damanpour (1997) for instance consider newness as a function of the field’s unit of analysis which goes to determine whether the innovation is new to an individual, group or team, an organization, industry or society in general. This degree of newness separates, or can be used as the basis to distinguish innovation generation from its adoption, and newness has often been considered as an empirical question for experts or executives of firms to address (Damanpour and Wischnevsy, 2006).

4.2 Individual engagement in innovation process

The role of individuals in the innovation process in organizations has been reiterated by researchers in the creativity and organizational behaviour literature. Early attempts to study the role of individuals in the innovation process in organizations focused on creativity, considered the first stage of the innovation process (e.g. Amabile, 1988). Winch (1998) made the point that operational personnel are the sources of ideas in many work environments, often captured through suggestion systems and quality circles. This can be through their own experiences and knowledge or through what can be referred to as practitioner research. Yuan and Woodman (2010) give examples of such behaviours to include the search for new technologies, exploring and suggesting new ways to achieve objectives, adoption of new and improved methods of working as well as the investigation and securing the needed resources to implement new ideas. Individual engagement in innovative behaviours has been described in relation to idea generation, idea promotion (championing or coalition building) and idea implementation (Holman et al., 2012).

4.3 Transactions

Transactions are necessary is examining how relationships develop in the management of innovation. Such transactions according to Van de Ven and Angle (2000) could be in relationships among peers (team-member exchange) or hierarchical relationships between superiors and their subordinates (leader-member exchange) regarding their engagement in the development of innovations. It could also be about proposals and commitments regarding the search and allocation of resources or any arrangement with parties to undertake tasks needed for the innovation development. Transactions are deemed to be a dynamic process that consists of three stages: negotiations, agreements and administration (Commons, 1950; cited in Van de Ven & Angle, 2000). How transactions go can be contingent on the novelty of the innovative idea. Much more novel and radical ideas require more trial and error with repeated or renewed cycles of negotiation, commitment and administration (Fernandez, 2001; Ring and Van de Ven, 2000). Transactions in
construction could be with clients, consultants or other units or teams in the firm that play a role in the development and implementation of the innovation.

### 4.4 Context for innovation

Innovation has often been described as context specific. Context has been described by Andriopoulos and Lewis (2009) as a set of pressures and stimuli that shape the behaviour of individuals and groups. Van de Ven and Angle (2000) consider context as the setting or institutional environment within which an idea is developed and implemented through transactions among people. Thus, context can be described as the environment within which innovation occurs and can be within a team, project, firm, network, industry or even a nation. The structures, practices and procedures of an organization can be crucial to creating the necessary infrastructure for the successful development/adopter and implementation of innovations. Van de Ven and Angle (2000) suggest that for technological innovation such context variables include institutional norms, basic scientific knowledge, financing and human resources.

### 4.5 Innovation outcomes

The outcomes of innovation are realized after their development/adopter and implementation. Scholars have often drawn attention to the positive bias that anything innovation is good. Innovation is considered to be new to the unit of adoption and with the anticipation to reap benefits from its usage or the changes that it brings to the organization (West & Anderson, 1996). As Van de Ven and Angle (2000) point out innovation is often seen as good as a new idea must be useful; being possibly profitable or to solve problems and often ideas that are not successful characterized as mistakes. The process through which teams or organizations achieve innovation, however, results in either positive or negative consequences. Janssen et al., (2004) put forward both benefits (e.g. successful innovation, cohesion, effectiveness and efficiency) and downside (e.g. failure of the innovation, less cohesion, ineffectiveness and resistance to future innovations) to innovation in teams. Effectiveness judgements can also be made during the process of innovation development and implementation and can change during the process of implementation depending on the judgement of stakeholders or their perception of how well the innovation is meeting their expectations (Van de Ven & Angle, 2000). These changes result from changes in targets and expectations often coinciding with some unanticipated problems and setbacks or shifts in organizational priorities. Perceived in process judgement of innovation outcomes according to Van de Ven and Angle (2000) is a consequence of actions as well as a predictor of future actions but rather often incomplete explanations of actions.

### 4.6 The process of innovation in organizations

The innovation process is considered to be much more complex than the decision to adopt/develop and implement change. For instance, King and Anderson (2002) opine that a lot of activities are required before the decision to adopt is taken which can include fact finding, politics and manoeuvres, negotiations as well as formal and informal discussions. Process models can be deemed to belong to either the rational or behavioural schools of thought. The rational school is considered to be the most dominant view that underpins construction literature as far as innovation process is concerned (c.f. Barrett & Sexton, 2006). King and Anderson (2002) suggests that existing rational models are based on theoretical speculation, are normative, and give descriptions of the process as a sequence of stages. These models often prescribe linear and often predictable stages of innovation which Sexton and Barrett (2003) regard as depicting the innovation process as
rigid, multistage and linear in nature. The stages, however, could be dependent on the nature of innovation, source and context within which the innovation is implemented. For instance, innovations that are adopted for implementation are often considered to be much simple and linear whilst innovations that are developed or originate from the implementing organization can follow much more complex, iterative, and non-sequential trajectories (Wolfe, 1994), consistent with the description of the innovation process by Quinn (1985) as a controlled chaos.

5. Proposed framework and research agenda

Despite the comprehensive nature of the concepts in the Minnesota innovation studies framework, it is generic and lacks a strong theoretical grounding and focus. To address this is to introduce a new adapted framework that is rooted in theories that will give the findings much more focus. Therefore, a framework that adapts the Minnesota innovation studies framework is proposed (fig.1) which is rooted in the theories of ambidexterity and intellectual capital. In presenting an input-process-output model of ambidexterity, Simsek (2009) conceptualize exploration and exploitation as the components of the process with inputs that drive such processes existing at different levels of an organization. This input-process-output model can be adapted to investigate the process of explorative and exploitative innovations and their inputs at different levels of organizations that underlie the process of such explorative and or exploitative endeavours. Such inputs occurring at different levels of the firm can be intellectual capital: human capital, individual characteristics and individual engagement in the process; social capital and transactions between stakeholders; organizational capital that reflects the context within which the innovation occurs can be explored in terms of its facilitative ability or otherwise in explorative and exploitative innovative processes which are either adopted or generated. The output following Simsek’s model would be the possible consequences of innovation processes at different levels which could at the individual, team, project or firm depending on whether the innovation is bottom up or top down. In the context of construction, the output of innovation could mainly be the consequences for the project as well as for the firm involved. Again the Minnesota framework is silent on the incentive or motivation as all innovations require that before they are initiated and is required before any innovation process commences.

5.1 Motivation or trigger for specific innovations

This is what Van de Ven (1991) describe as shocks that trigger innovation which can be opportunities for improvement, identified problems or competition from the environment. Individuals often go through the cognitive process to come up with novel solutions to problems or as opportunities for improvement (Holman et al., 2012) often with the identification of a problem that needs solving, a threat requiring urgent attention, an opportunity to improve current or existing conditions. Drucker (1985) identified sources of innovation opportunity to include: new knowledge, industrial changes as well as unexpected success or failure. Motivation or the trigger from sources both within and outside the organization sets the stage for concrete actions to pursue or undertake specific innovations regardless of the availability of the appropriate organizational climate (Van de Ven, 1991).

5.2 Explorative and exploitative innovative ideas

Part of the definition of an innovative idea is its characterization into different typologies and one such classification is whether the innovation idea constitutes an explorative or exploitative innovation (He & Wong, 2004; Jansen et al., 2006). Exploratory innovations offer new designs and
create new markets requiring new knowledge (Benner & Tushman, 2003; Jansen et al., 2006). Exploitative innovations rather tend to improve and expand on existing knowledge and skills, brings improvement in efficiency and builds on existing structures and processes (Benner & Tushman, 2003). Whilst some researchers equate exploration and exploitation respectively to incremental and radical innovation, others have moved away from such classification for less technology intensive firms where there are less research and development activity (e.g. He and Wong, 2004) and firms undertake problem-solving activity using new knowledge, methods and techniques or refine and reuse existing knowledge, technologies and methods. Both forms of innovations entail knowledge combinations where one utilizes the existing and well-understood ways with the other leveraging knowledge that is varied and dispersed. Exploitative innovation demands efficiency and convergent thinking to be able to harness existing capabilities to improve products and services on a continual basis whilst explorative innovation involves efforts to generate novel recombination of knowledge, technologies and methods through search and experimentation (Andriopoulos & Lewis, 2009).

5.3 Human capital and individual role in innovation

The ability of an individual to actively be involved in the innovation process in organizations could be attributed to their innovation competency. Innovation competency according to Cerinsek and Dolinsek (2009) is to “act and react in an innovative manner in order to deal with different critical incidents, problems or tasks that demand innovative thinking and reactions, and which can occur in a certain context”. This competency might also be underlain by factors as creative ability, education, training and experience which constitute human capital and is a source of knowledge and a resource for firms. Individuals association with the innovation unit according to Van de Ven and Angle (2000) is dependent on their skills, background, the frame of reference, experiences and activities that occupy their attention. Amabile (1988) suggests that the individual’s creative behaviour is shaped by expertise, creative thinking skills and intrinsic task motivation. As Van de Venn and Angle caution, people as creators or facilitators of innovation must be balanced with people as inhibitors. This is against the backdrop of the fact that human beings have limited capacity in dealing with complexity and tend to adapt unconsciously to incremental changes often conforming to the group and organizational norms. This raises the question of how individuals can become invested in the development of new ideas given the tendency to focus on and protect existing practices (Van de Venn and Angle, 2000).

5.4 Social capital and transactions

Transactions and relationships might require internal and external social capital to be successful. Social capital is considered to be the network of interrelationships that aids knowledge exchange and integration within a firm. Adler and Kwon (2002) propose three dimensions of social capital: structural, cognitive and affective social capital. These complement each other in creating opportunity, motivation and ability to exchange knowledge. Social capital facilitates the exchange of knowledge, insights and mental models, improving the richness of exchange of information and iteration (Subramaniam & Youndt, 2005) which is relevant in transactions among parties involved in the innovation process. Social capital can be described as either cooperative or entrepreneurial. According to Kang et al., (2007) these two configurations of social capital can be identified especially in their alignment with exploration and exploitation. Cooperative social capital represents a social system that is tightly coupled with strong and dense networks of inter-connections. Entrepreneurial social capital, on the other hand, is characterized by weak redundant relational networks where members share a common component knowledge which is a reflection
of their shared technical and professional knowledge (Kang and Snell, 2009). In effect cooperative social capital involves the existence of strong ties for the efficient sharing of knowledge whilst entrepreneurial social capital is about having access to a myriad of contacts from whom knowledge and expertise can be accessed when needed without necessarily having a close social relationship.

5.5 Organizational capital

Innovation in firms is developed in a context that can be reflected in the organizational capital. Organizational capital depicts the knowledge in processes, systems, structures as well as behaviour, norms, mental maps, core competencies and culture and is often context specific relating to the internal structure and organization of a firm. Organizational capital also consists of codified experiences and institutionalized knowledge that remain in the firm and used through databases, to preserve knowledge and to create routines, processes, structures and systems for continuous usage (Youndt et al., 2004). Organizational capital has been identified in two forms; mechanistic and organic (Kang & Snell, 2009). Whilst the mechanistic archetype involves detailing routines the organic type of organizational capital is about flexible or simple routines, priorities, vision and boundaries within which individuals and teams must work. This is more of a culture of conformity versus the encouragement of proactivity and creative thinking that can be associated with the empowerment or autonomy to be able to shape or challenge established norms (Kang & Snell, 2009). Thus, mechanistic archetype is where there are structures in place for coordination and control of activities and processes whilst the organic provides the flexibility to accommodate unexpected events and allow problem-solving through innovative thinking. The context can also relate to what Amabile (1988) refers to as an organization’s motivation for innovation manifest in a number of ways either positive or negative to encourage or discourage innovative efforts in the organization.

5.6 Innovation generation and adoption processes

Damanpour and Wischnevsky (2006) argue that the process of innovation differ for innovation generation and innovation adoption and therefore how such innovations occur in organizations cannot be explained by the same theories of innovation. Generation is more of a creative process involving exploration of ideas, emergent and inherently characterized by variation and experimentation (March, 1991). Adoption, on the other hand, involves the adaptation of existing ideas and is more exploitative, planned and characterized by selection, refinement and implementation (Damanpour & Wischnevsky, 2006; March, 1991). Damanpour and Wischnevsky (2006) argue that such distinction between generation and adoption has often been overlooked by innovation researchers often referring to both as the innovation process. The requirement for success in innovation may, however, vary from one case to another or between innovations in different industries. Construction, for instance, provides a different context within which innovations are often adopted for implementation as compared to other high technology industries like manufacturing. This warrants a differentiation of innovation processes depending on whether innovations are adopted or generated for implementation and more so for contexts such as construction where the incidence of innovation might include both adoption and or generation.

5.7 Project and organizational outcomes

Outcomes of innovation in construction could be cost and time reduction in the execution of an operation, improvement of safety on site, reduction in environmental impact or improvement in the performance of the completed facility (Slaughter, 2000). Such effects ultimately impact the
success of not only operations but projects and among a portfolio of projects affects the firm’s performance and competitiveness. This reinforces the fact that innovation in construction not only benefits projects they are implemented on but also the parent organizations of the teams involved. Innovations developed on-site can help increase the capability of firms for innovation through learning and diffusion on future projects (Gann & Salter, 2000; Winch, 1998). Not all innovations are however successful, and failed innovations can have cost, time and quality implications. Failed innovations can as well impact relationships between parties or the image of the organization involved.

Figure 1: Conceptual framework for process of specific innovations

The forgoing discussion proposes a theory-driven framework and provides an agenda for exploring the process of innovations in the context of project-based firms where innovation is considered hidden and where the unique characteristics of the context and organizing have consequences for the innovation process. Therefore, it will be worth exploring or finding answers to the following questions: How are innovations adopted/developed and implemented by construction firms? How does the process of specific innovations differ depending on the innovation’s attributes? What is the motivation for construction innovations and what roles do individual stakeholders play in the process? How does intellectual capital facilitate the process of innovation development/adoption and implementation by construction firms? And what are the consequences of the innovation processes for projects and organizations involved?

The above forms part of an ongoing research aimed at creating a process theory of innovation in construction. Data is to be collected through case studies using mixed methods: retrospective interviews, ethnographic interviews and observation. The critical incident technique is to be adopted in the interviews to focus on critical or significant moments and events that define the innovation process. Case study firms and innovations are to be carefully selected to consist of firms of different sizes as well as innovations of varied attributes. Cluster analysis could be used to distinguish innovation processes by type or attributes in an attempt at creating a differentiation theory by identifying patterns within and across clusters.

6. Conclusion

The framework presented here departs from the Minnesota innovation studies framework and existing process studies by including intellectual capital and ambidexterity theory. The nature of construction being a project based industry suggests that the nature of innovative ideas, multifunctional personnel and contexts differ from that of permanent organizations that have been the contexts for many innovation process studies. A study of innovation process as proposed in the advanced framework will be one of the first few attempts to provide an innovation process theory for construction and project based firms based on empirical studies of specific innovations. This
The proposed study will also help create a differentiation theory on innovation process not only for explorative or exploitative innovations but also whether innovations are bottom up or top down, product or process etc. Finally, the paper presents how intellectual capital can facilitate innovation through individuals (human capital), social capital in transactions and organizational capital in providing the appropriate context for innovation. Such a study will help point out the criticality of human, social and organizational capital in facilitating the innovation process of specific innovations adopted/developed and implemented by construction firms. It will also potentially provide a model for innovation process in construction that can help managers better manage intellectual capital to enhance the innovation process and its outcomes.

7. References


Design and Prototyping of a Curtain Wall System With Wooden Load-bearing Structure and Glass Infill Panels

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Abstract

The sector of architectural envelope is at the moment one of the most developed, both in terms of technological innovation and design experimentation. The whole construction industry knows that the curtain wall performances are essential to reduce the impact of buildings in the environment, in terms of greenhouse gases emissions and energy consumption. At the same time, a positive trend for the buildings with wooden load-bearing structure has developed and it is proved by a growing number of projects in geographic areas where historically no-one used this material. The wood is highly appreciated in the field of construction industry because of its good mechanical resistance, its good thermal insulation and sound-proof, the ease it can be worked, the tactile heat that transmits and the message of environmental eco-friendly improvements it can be associated with. After a meticulous observation of these trends, the Università Iuav di Venezia has decided to develop a specific research project: it has prefigured that a work in synergy between the two sectors can offer a fertile ground to develop technical and planning know-how. The aim is to develop prototypes of innovative curtain walls with wooden load-bearing structure and glass infill panels. A market survey has shown that wood curtain walls are almost absent, that’s the reason why it has been chosen to analyse and develop this kind of product with the partnership of Simco Tecnocovering (nowadays Simeon S.r.l.), an Italian company specialized in aluminium curtain wall systems. It has been decided to set aluminium systems with wooden envelopes and a mixture of aluminium and wooden structures made by the most important competitors against a façade system only made of wood. The paper presents the final results of the research, underlining the problems observed and the solutions that have been found.

Keywords: Architectural envelopes, curtain wall, wooden structure, glass infills, sustainability
1. Introduction

The development of a curtain wall system with wooden load-bearing structure and glass infill panels was the goal of this experience. The project included also activities evaluation, as well as the technical and technological aspects, about the “patentability” of the system.

A curtain wall (according to EN 13830:2015 “Curtain walling – Product standard”) consists of “a part of the building envelope made of a framework usually consisting of horizontal and vertical profiles, connected together and anchored to the supporting structure of the building, and containing fixed and/or openable infills, which provides all the required functions of an internal or external wall or part thereof, but does not contribute to the load bearing or the stability of the structure of the building. Curtain walling is designed as a self-supporting construction which transmits dead-loads, imposed loads, environmental load (wind, snow, etc.) and seismic load to the main building structure”, and it is normally made with an aluminium structure.

Despite the excellent technical and performance characteristics of the aluminium, using wood as a structural material brings undoubted positive effects in terms of environment preservation, in addition to satisfying a market sector that requires aesthetic standards related to the use of natural materials. Instead of aluminium, in fact, the use of wood would mean fewer problems of thermal bridge, the use of a material with a lower embodied energy (the amount of energy required to produce a unit of material starting from the raw material), in addition the obvious advantages of static (it is lighter). In a territory, also, as we have been seen, particularly receptive for the development and production of envelope systems.

Goal of the project was therefore the development of a patent system of bloc curtain wall made in wood/glass, based on the know-how of the producer in a first and recent application “pilot” of this system on a building in France.

2. Description of the research project

The research project was born from the participation of Veneto Region, during the period 2007-2013, to the European Social Fund program that is part of the European Community strategic guidelines focused to strength economic and social cohesion of the European Union by reducing economic, social and territorial disparities among Member States and the regions of the Union. This was achieved through the European “Regional Competitiveness and Employment Objective” which established the strategy, the priorities and objectives of the European Social Fund (ESF) in every specific regional area. In this context, in 2013 the Veneto Region has supported and funded a program called “ESF – Axis Human Capital – Research Grants” for the presentation of postgraduate research projects that include cooperation between a university and a company based in Veneto Region (called “operating partner”), with the target to train and employee young researchers. In this context, 127 research grants – 49 assigned to the Università Iuav di Venezia – started, with a total funding of more than 6 million euro.
The Università Iuav di Venezia in collaboration with Simco Tecnoovering S.r.l. (company specialized in curtain wall systems) as operating partners developed a research project. The role played by Simco Tecnoovering was a technical support during the design phase of a new curtain wall system in wood and glass. The level of involvement of the operating partner was comprehensive, because it took place during most of the period of research project. The operating partner was the main promoter of the research project, having identified the market potential and, thanks to the experience developed in this industrial sector, having the specific technical skills to develop the prototype. The position of the operating partner in the regional, national and international market also allows to directly focus in the dissemination of results.

The research project takes place in the building envelope and curtain wall area, particularly in wooden doors and windows sector, of great importance both nationally and regionally. According to the available data at the time of the research project, the Italian market of windows and architectural envelope was about 5 billion Euros worth (2011, Studies and Research Service of the Chamber of Commerce of Verona, data InfoCamere), where the curtain walls sub-sector amounted to nearly 500 million euro (2012, Uncsaal/ISTAT data). Particularly, concerning wooden window frames, the market reached the billion and a half total turnover (2011 data, Studies and Research Service of the Chamber of Commerce of Verona, data InfoCamere).

The Veneto Region is particularly important concerning energy saving measures: almost all – about 95% – of works carried out on buildings in 2011 was the replacement of windows. Concerning the replacement of windows, 10.2% of the total amount of work in Italy took place in Veneto, ranked fourth after Lombardia, Piemonte and Emilia Romagna. Veneto is in fourth position in Italy also as total surface installed, with over 250,000 square meters. (2011 data, Enea Annual Report – Tax deductions of 55% for the energy upgrading of existing buildings).

All across Europe the awareness that the wood can become a key material for the construction industry, not only for small private buildings but also for large structures, is constantly growing. In Berlin new residential houses will totally made of wood; in Sweden skyscrapers are designed also in wood, while in France the government announced that the construction will be stimulated by new tall buildings with wooden frame, together with a policy development of forests supported by the Ministry of Agriculture.

Architectural envelope prefabrication allows to reduce waste, to control the quality of the product, to test its real performance, to inspect the equipment on site and to speed up the assembly stages. Systems of mixed wood-aluminium façade are present on the market, but no system is completely made of wood; moreover, they are usable for several types of buildings (residential, office, school, etc.). This was the main focus of the research, being also a development opportunity for the Veneto Region.
3. Organization and methodology

The research, which took place from March 2014 to March 2015, was divided into four phases. The first phase was focused on the collection and analysis of information related to the research project, with particular reference to the technical aspects of the building envelope and windows. It covered a period of about two months and was carried out mainly in the Università Iuav di Venezia. The first phase included five additional sub-phases:

2. The analysis of the main systems of building envelopes, in particular those related to the UNI EN 13830: 2005 Curtain walling. Product standard (still current at the time of the research project, now substituted by EN 13830:2015 Curtain walling. Product standard);
3. The analysis of the physical/technical (thermal, light, sound, fire safety, etc.) factors involved and of the performance levels of the main types of architectural envelopes currently available;
4. The analysis of the main types of wood species currently used for architectural envelopes;
5. The analysis of the physical/technical (thermal, light, sound, fire safety, etc.) factors involved and of the performance levels of the main types of the glazing systems currently available on the market.

The first phase allowed to get a comprehensive state-of-the-art of curtain wall and architectural envelopes sector, updated to the most recent technical solutions. This phase prepared a solid background for the research, before starting the true design process.

The second phase focused the methodology of design and production of curtain walls. It covered a period of about three months and was carried out between the Università Iuav di Venezia and the corporate headquarters. It included four additional sub-phases:

1. The analysis the dynamics of the curtain wall industrial sector and of the operating partner organization, of its technical/economic departments and business function, of its production facilities, of the commercial network, of systems and products already on the market;
2. The analysis of the UNI norms concerning curtain walls systems;
3. The analysis of laboratory tests and tests aimed to design and produce a curtain wall;
4. The collection of information about similar existing wooden structure systems, with glazed infill panels, and the analysis of their characteristic.

The second phase allowed to better understand the operational partner and its industrial organization; moreover, the second phase allowed to collect information about similar products already on the market, in order to focus the design process in a better way.
The third phase included the design and prototyping of the curtain wall system in wood/glass. It covered a period of about six months and was carried out between the Università Iuav di Venezia and the corporate headquarters. It included two further sub-phases:

1. Study of a curtain wall system with wooden frame and glazed infill panels;
2. Mock-up of the system itself.

The third phase was the true design phase, when all the information collected during the previous phases were put together in order to prepare a mock-up to be later verified in its formal and technical aspects.

The fourth and final phase, which lasts about a month, took place between the Università Iuav di Venezia and the corporate headquarters, included the making of a video of the whole process and the preparation of a book with the technical/performance characteristics of the system.

4. Phases of analysis, design and prototyping

Based on the information gathered during the analysis phase, we found that in the market there aren’t systems of wooden facade entirely of wood, but there are always metal elements especially for the connection between the carrier and plugging.

We considered the multiple needs related to marketing, to engineering, production, installation and maintenance of the same during the design phase of the system. For this reason we developed a process of continual review, but at the same time the result is a product more in line with actual needs of future customers.

The system is a curtain wall, female-female typology: this solution allows to optimize the number of profiles, to facilitates the industrialized production of the modules and to do a faster assembly of the element. It is available in two versions:

- With external caps: the fixing of the glass takes place with a mechanical system;
- Full glass structural version: the fixing of the glass takes place using particular adhesives.

_System with external caps_
A great potential of the system is linked to the possibility to product particular forms, customized shape for the structure of the façade (mullion and transom) and the outer cover. Contrary to the extruded aluminium, which features production must maintain a constant shape, wood is malleable and can be modelled.

_Full glass structural version_
This version of the system is studied to obtain a full-glass aspect. The bonding of the glass to the structure was made with a particular adhesive. The supplier of the adhesive tested this fixing system and the process of certification of the product is just started. This product is applied in
wooden support after that it is cleaned and treated with the primer. The tightness is immediate so that the block can be immediately moved with glass suckers. The maximum tightness is achieved after 60 hours after the application. This system minimizes the strips that we should normally have with the use of structural silicone, speeds up the production process and guarantees high performance.

One of the crucial problems to be solved was the system of engagement and disengagement of the elements of connection between the main frame and the glass panel. We thought about maintenance methodology.

In the course of the useful life of the building in fact it is possible that some glasses break due to accident, breakage due to nickel sulphide in tempered glass (also with HST) and the replacement of these collisions is often not a simple operation. In Francophone countries, the main market for the company, if the structural glazed infill breaks, it can not be replaced directly on the jobsite, but, as opposed, it is necessary to remove the sub-frame and proceed with the replacement in the factory or in a protected and dedicated area. These solutions are already been broadly applied for aluminium facades or for mullions and transoms curtain wall, but there aren’t many application in wooden façade. The main difficulties concerning the needs to ensure adequate mechanical strength, to contain the width of the profile and to minimize the use of metallic materials, both for thermal reasons, both for evaluations on the life cycle of the product. We overcome these aspects proposing a punctual anchor that allows the replacement of vision modules from the inside and the replacement of shadow box part from the outside. The method of replacement is safe and easy: we can also keep some replacement element already glazed in the building, ready for use. During the study of the system we considered various types of openings (bottom hung, top hung, pantograph) and we studied accessories of hardware ad hoc, due to the size and of the loads involved. We can integrate the bloc with different types of internal and external solar screening: screening curtains, brisesoleil, blinds, architectural louvers, mobile systems. Also claddings can be different: glass (monolithic, double glazing, triple glazing) or opaque (enamelled glass, wood, plastic or metal sheet). The basic system is in laminated wood. We can also use microlamellar to increase performance static. Wood species can be chosen by the architect. You can also choose the wood finish. You can use the natural wood (accepting the uncontrolled maturation and reaction to weather), treated with paint (that make it stable over time but it will reduce the natural variability) or earlier aged (the change is more controlled and the material is more stable).
5. Discussion

One of the most important point of discussion is the introduction of a wooden frame as substitute of aluminium as structural material for curtain wall. Since aluminium is largely considered as the main structural material in curtain wall industry, one of the targets in the following steps will probably be spreading the results to convince potential architects, clients and users of the possible applications of this façade system. Actually, considering the characteristics of the system, we can state that:

- Static performance are satisfactory: the system is dimensioned to respond to a wind pressure of 1250Pa (a pressure which is normally used for mid-rise towers, about 14 floors). We can review this performance according to different needs by changing the size of the profile or type of wood;
- The thermal and acoustic performance are very good being the wood a naturally insulating material;
- The embodied energy is less than traditional aluminium systems;
- It’s possible to disposal the envelope after its phase of life. It is disposable and recyclable since the system is composed by a single material or different materials easily divided into the various elements and it will not become hardly disposed.

The following picture can, at a glance, summarise and compare the different characteristics of an aluminium and a wooden frame curtain wall.

Figure 2: comparison between aluminium and wooden frame curtain wall.

Wooden frame can represent a valid alternative to aluminium façades, especially considering its lower embodied energy and the thermal performances. We can also consider wood like a
sustainable material if we develop correct reforestation policies with the aim of increasing our forest resources. In this way we can obtain more natural resources, a reduction of emission, an increment of the use of recyclable materials.

Moreover, since one the most important targets of the Veneto Region “ESF – Axis Human Capital – Research Grants” program was to supported the occupation, the introduction into the construction building materials and products market of a brand new façade system, potentially usable in several different building typologies, can have the impact to push other companies to develop similar systems, with the consequent impact of new possible work assumptions. In fact, the design, prototyping, engineering, production and installation of a new façade system by a specialist company, able to carry out research applied, is in fact one of the motors which allows, subsequently, other operators to propose their own solution, triggering a virtuous circle that can bring, as well as a new market and a benefit in terms of employment.

6. Conclusions

The industrial nature of the Veneto region and of the whole Italy is particular fruitful for closures and the window frame sector. This research that aimed at the development of an innovative system of closure with wooden frame and glass curtain, virtually absent from the market certainly brought advantages to operating partner, but also to their suppliers and to the business world linked in similar activities. The design of a new system involved the use of resources and an initial investment that will to return in economic, commercial, image, etc. positive effects.

Architectural envelope, and especially façades and curtain wall, that represent one of the most important sectors in construction industry, both from formal and technical point of view, are highly important in the energy balance of a building, since thermal performances of the envelope deeply influence the internal comfort and energy consumptions. Also, the use of wood as structural material can be a valid alternative to more common aluminium structures, that can be used various building typologies (residential, directional, commercial, etc.). Moreover, this type of curtain wall can be largely used both in new and refurbishment projects.

Considering the objectives of the research and the prototype characteristics, the final results can be considered largely satisfying. The prototype represents a good example of a new system that is quite absent from the façade market and has some peculiarities that can satisfy designers’ and users’ needs.

References

Lean Project Management during the Construction Phase of South African Public Sector Projects

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Abstract

In construction, the progress of the project is driven primarily by the construction project programme or schedule and the Construction Project Manager (CPM). The project programme sets out the bases for monitoring and controlling the project by the CPM. Many construction projects in the public sector are subject to late completion, cost overruns and poor quality arguably as a result of inadequate programme management. During the construction phase of projects, there are many opportunities for the CPM to implement lean tools and techniques that will have a positive impact on the project from a programming perspective. This study investigated the impacts of implementing lean project management (LPM) tools and techniques during the construction phase of public sector projects on the successful delivery of the programme. A sample of 234 registered CPM’s were surveyed to determine whether they were aware of LPM and identify how often they used LPM tools and techniques under the nine project management areas of expertise to achieve the successful delivery of the programme. Seventy two responded to the survey questionnaire. It was found that CPM’s are aware of LPM and are utilising these principles under the nine project management areas as an initiative towards improving the delivery of the programme during the construction phase of public sector projects. It is evident that there is consensus between LPM principles used often to always under the nine project management areas. The data did however, identify that not all of the LPM principles are equally implemented under each area of expertise. This study was limited to professionally registered CPM’s involved in the public sector based within the KwaZulu-Natal province of South Africa.

Keywords: Construction Phase, Construction Project Managers, Lean Project Management, Project Programme, Public Sector.
1. Introduction

A key stimulator of economic growth is the construction industry (National Treasury, 2015). This stimulation is accomplished by increasing the productive capacity of the economy through the provision of infrastructure to both private and public sectors. One of the fundamental challenges of the South African government is service delivery in the construction sector. Some of these challenges are highlighted by the South African Government New Agency Report (2015) as, delays and disruptions during construction, poor site management, time and cost variations, skills and competence issues, lack of quality improvement processes and lack of worker participation.

There are numerous performance indicators regarding service delivery in the construction industry (Chan and Ada, 2004). Time is one of the most important factors taken into consideration regarding the successful delivery of construction projects in the industry. Time is monitored and measured against the construction programme on public sector construction projects during the construction phase. The construction programme as defined by the Project Management Book of Knowledge (PMBOK) (2004) includes the processes required to accomplish timely completion of the project.

Construction usually involves the interpretation of the Client’s brief into a design and then translation into reality. This translation requires a design or consultant team selected by the Client/Employer. Construction Project Management is defined by the South African Council for the Project and Construction Management Profession (SACPCMP) in terms of the Project and Construction Management Professions Act (2000) as the management of projects within the built environment from conception to completion, including the management of related professional services. The CPM is the single point of responsibility in this regard. More specifically this study makes reference to CPM’s appointed by the Public Sector to manage and deliver successful construction programmes during the construction phase of projects in the industry.

Truman and King (2013) note that the successful delivery of construction projects in the public sector are hindered by poor programme management. These are failure to adequately programme the work and properly execute the programme, failure to provide adequate qualified human resources to manage the programme, failure to develop an efficient programme and to effectively maintain the programme throughout the project execution and failure to control cost changes that impact the programme throughout the execution of the project.

Lean project management as defined by Pfeiffer and Weiβ (1994) is a system for organising and managing all aspects of a project function by creating principles, practices and tools in order to develop goods and services with higher quality and fewer defects. The general outcome is to do this by using less effort, space, capital and time. In construction, lean project management is delivering more value with less waste in a project context.

A study conducted by Rust and Koen (2011) revealed that the South African construction industry is renowned for low levels of innovation towards stimulating technological solutions to provide and maintain future growth of the industry. As a result, the research conducted in this study aims
to identify and highlight lean project management and its implementation as an innovative initiative towards the successful delivery of the project programme. The study aims to achieve the following objectives, to determine whether CPM’s are aware of LPM and to identify how often CPM’s use LPM tools and techniques under the nine project management areas of expertise towards the successful delivery of the programme.

2. Literature Review

2.1 Lean Project Management

Lean thinking is a philosophy based on the concepts of lean production (Koskela, 1992; Koskela, 2000). Alternatively, the first consideration of the ideas of lean production for use within construction is attributed to Koskela (1992) (Garnett, et al., 1998; Mossman, 2009). Lean construction is a different project management approach because it has a clear set of objectives for the delivery process, is aimed at maximising performance for the customer at the project level, designs concurrently product and process, and applies production control throughout the life of the product from design to delivery (Howell, 1999).

Lean project management builds on the understanding that no other project has been or will be exactly the same as the one you are currently working or preparing to work on. It takes a practical approach with simple steps to demonstrate how to complete projects in half the time, all the time. LPM assists project managers taking on more projects, wanting to complete them faster with less team stress (Leach, 2006). LPM is the inclusive adoption of other lean concepts such as lean construction, lean manufacturing and lean thinking into the project management context. LPM has numerous ideas in common with other lean concepts. However, the fundamental principle of LPM is delivering more value with less waste in the project context. LPM has many techniques for implementation to projects and one of the main methods is standardisation (Leach, 2006).

2.2 The Public Sector

One of the fundamental challenges of the South African government is service delivery in the construction sector. In recent report presented by Public Enterprises Minister in 2015, it was highlighted that although the government considers the public sector to be part of the country’s economic fibre, the sector is confronted with major delivery challenges. Some of these challenges faced during the course of executing construction projects include: delays and disruptions, poor site management, time and cost variations, skills and competence issues, lack of quality improvement processes and a lack of worker participation. As a result, there is no doubt that substantial improvements in quality and efficiency are needed and are possible (South African Government News Agency, 2015).

Project risks further highlighted by the Price Waterhouse Coopers (PWC) report: SA Construction (2014) includes project execution, noting the challenges as: the competitive nature of the market as well as skill shortages which places pressure on companies to deliver projects. This then poses a risk to companies’ ability to start projects efficiently, manage changes in projects, manage
limited resources and complete and handover projects. The report further identifies the proposed actions required by the industry as: Implementation and monitoring of project management procedures and policies over the life cycle of a project; and assignment of accountability is imperative in mitigating the risk posed to project execution. This reinforced the initiative proposed by the research regarding the implementation of LPM during the construction phase of public sector projects as an initiative towards the successful delivery of the programme.

2.3 The CPM Profession

Construction project management is project management applicable to the construction industry which is aimed at meeting the client’s requirements in order to produce a functional, feasible and financially viable project. The CPM’s roles involve overall planning, co-ordination and control of a construction project from initiation to completion (Burke, 2003). More specifically this research makes reference to CPM’s appointed by the Public Sector to manage and deliver successful construction programmes during the construction phase of projects in the industry. In construction, the selection of the CPM is a key appointment which can influence the success or failure of the project. As the single point of responsibility, it is the CPM who integrates and co-ordinates all the contributions and guides them to successfully complete the project (Burke, 2003).

2.4 The Construction Phase and Project Programme

The progress and success rate of the project is driven primarily by the programme and the CPM. The project programme sets out the grounding upon which the project is monitored and controlled by the CPM (Truman and King, 2013). Determining what work must be done, what resources including human resources are to be used, together with the identification of equipment, facilities and funds needed for projects reinforces the need and importance of having a sound project programme to manage these deliverables. The aim of the programme is to provide a plan that is well thought out and realistic which can be achieved.

Many construction projects in the public sector are subject to late completion, cost overruns and poor quality as a result of inadequate/poor programme management (Truman and King, 2013). During the construction phase of projects, there are many opportunities for the CPM to implement lean tools and techniques that will have a positive impact on the project from a programming perspective. Watt (2014) further notes that during the construction or implementation phase, the project plan is put into motion and the work of the project is performed. Progress is continuously monitored and appropriate adjustments are made and recorded as variances from the original plan. The programme is updated and communicated on a regular basis. In any project, a project manager spends most of the time in this phase.

2.5 The Relationship between LPM, the Public Sector, the CPM Profession, the Construction Phase and the Project Programme

Evidence of the use of lean thinking has shown that there are many benefits to be made from applying lean principles to construction. These benefits claimed include, improved productivity,
increased reliability, improved quality, more client satisfaction, increased predictability, shortened schedules, less waste, reduced cost, enhanced buildability improvements to design and improved safety (Lehman & Reister, 2004; Mossman, 2009).

Government, industry and clients are all seeking to bring about a change in the construction industry to improve quality, competitiveness and profitability, and to increase value to clients. Where the emphasis has traditionally been on the need to manage the interface between the project and the client’s organisation, it is now shifting towards the need to manage the flow of activities through the whole life cycle of the project, concentrating on those activities that actually add value (Matheu, 2005). The South African construction industry plays a major role in contributing towards the gross domestic product (GDP), highlighting its major role of adding towards the growth and development of the country. It has been identified that the construction management profession in the industry is one of the key roles and is the single point of contact between other consultant professionals on a project and the client. As a result, the success of the project ultimately rides on the unique management skills of the CPM.

The successful completion of construction projects are achieved when they are completed within budgeted cost, specified quality, stipulated time and delivered safely. One of the key tools identified in order to aid CPM’s towards achieving this goal is the project programme. The application of sound project management principles on a project is not only the means to the project ends, but aids in guiding and managing the project towards its successful completion while meeting the client’s needs within the defined budget (Truman and King, 2013). This highlights the ability of CPM’s to provide the public sector with the unique management skills they require such as LPM to assist in improving the delivery of the project programme. One of the key management areas highlighted that can be implemented by CPM’s is LPM. CPM’s need to implement LPM tools and techniques during the construction phase of public sector projects as an initiative towards improving the delivery of the project programme.

3. Research Methodology

In order to achieve these research aims, the research approaches adopted involved, conducting a comprehensive literature review which investigated the concepts of LPM, the public sector, the CPM profession, the construction phase and the project programme and the relationship between these areas of concern.

The study involved targeting all CPM’s professionally registered with the SACPCMP in the province of KwaZulu-Natal (KZN). These registered CPM’s were identified from the Professions and Projects Register (2015). This register lists 234 registered CPM’s in KZN. Out of the 234 registered CPM’s, 72 responded to the survey questionnaire. This represents a 31 per cent response rate.

The sample was surveyed to determine whether they were aware of LPM and to identify how often they used LPM tools and techniques under the nine project management areas of expertise to achieve the successful delivery of the programme. The data was analysed using SPSS version
23. Finally, conclusions were drawn from the research findings and recommendations for implementation are presented.

4. Findings and Discussion

CPM’s were presented with the fifteen principles underpinning LPM and asked on a scale of 1 to 5, where 1 = never and 5 = always, to confirm how often they used these principles under the nine project management areas of expertise during the construction phase of public sector projects towards improving the management and delivery of the programme. The CPM’s responses were ranked according to the mean scores presented in Table 1.

Table 1: LPM comparison with the Nine Project Management Areas of Expertise

<table>
<thead>
<tr>
<th>Lean Principles and Techniques</th>
<th>Nine Project Management Areas of Expertise</th>
<th>Mean and Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communication Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integration Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Procurement Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Human Resource Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Risk Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scope Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quality Management</td>
<td></td>
</tr>
<tr>
<td>1. Improving planning and communication</td>
<td>4.29</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4.16</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4.12</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4.12</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4.08</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>4.08</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>4.04</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>3.95</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>3.93</td>
<td>9</td>
</tr>
<tr>
<td>2. Eliminating waste and errors</td>
<td>3.97</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>3.98</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>3.54</td>
<td>8</td>
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<tr>
<td></td>
<td>3.48</td>
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<tr>
<td></td>
<td>4.08</td>
<td>4</td>
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<tr>
<td></td>
<td>4.09</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4.25</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4.18</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4.01</td>
<td>5</td>
</tr>
<tr>
<td>3. Direct intervention to drive immediate and apparent change</td>
<td>3.95</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3.86</td>
<td>(8)</td>
</tr>
<tr>
<td></td>
<td>4.26</td>
<td>(11)</td>
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<tr>
<td></td>
<td>3.75</td>
<td>2</td>
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<tr>
<td></td>
<td>3.90</td>
<td>7</td>
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<td></td>
<td>3.75</td>
<td>9</td>
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<td></td>
<td>4.54</td>
<td>(10)</td>
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<tr>
<td></td>
<td>3.66</td>
<td>(15)</td>
</tr>
<tr>
<td></td>
<td>3.95</td>
<td>(8)</td>
</tr>
<tr>
<td>4. Improving work planning and forward scheduling</td>
<td>3.56</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>3.70</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>3.79</td>
<td>7</td>
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<tr>
<td></td>
<td>3.84</td>
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<td>4.18</td>
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<td></td>
<td>3.97</td>
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<tr>
<td></td>
<td>4.27</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 1: LPM comparison with the Nine Project Management Areas of Expertise (Continued)

<table>
<thead>
<tr>
<th>Lean Principles and Techniques</th>
<th>Mean and Rank</th>
<th>Nine Project Management Areas of Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Direct intervention to drive immediate and apparent change</td>
<td>Mean 3.95 Rank 3</td>
<td>3.86 2</td>
</tr>
<tr>
<td>6. Improving work planning and forward scheduling</td>
<td>Mean 3.56 Rank 9</td>
<td>3.70 15</td>
</tr>
<tr>
<td>7. Specifying value from the perspective of the customer/client</td>
<td>Mean 4.06 Rank 5</td>
<td>3.83 4</td>
</tr>
<tr>
<td>8. Eliminating activities that do not add value</td>
<td>Mean 4.22 Rank 1</td>
<td>4.16 2</td>
</tr>
<tr>
<td>9. Ensuring the work environment is clean, safe and efficient</td>
<td>Mean 3.93 Rank 6</td>
<td>4.01 9</td>
</tr>
<tr>
<td>10. Implementing critical path analysis and programme management</td>
<td>Mean 3.90 Rank 5</td>
<td>3.70 11</td>
</tr>
<tr>
<td>11. Reduce lead time</td>
<td>Mean 3.93 Rank 7</td>
<td>4.09 4</td>
</tr>
<tr>
<td>12. Reduce total costs</td>
<td>Mean 3.84 Rank 6</td>
<td>3.73 12</td>
</tr>
</tbody>
</table>

356
Table 1: LPM comparison with the Nine Project Management Areas of Expertise (Continued)

<table>
<thead>
<tr>
<th>Lean Principles and Techniques</th>
<th>Nine Project Management Areas of Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>4.04</td>
</tr>
<tr>
<td>Rank</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>(5)</td>
</tr>
<tr>
<td>13. Maximising workflow, minimising the performance variation rather than focusing on speed only</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Rank</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Value management techniques</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Rank</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Benchmarking techniques including the use of key performance indicators</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Rank</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Risk management techniques</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Rank</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Note: Ranking in brackets refers to the LPM principles as used within each project management area).

Table 1 presented the means of responses to the frequency of the use of 15 LPM principles in each of the nine project management areas of expertise, highlighting where each principle was most frequently used. The following was noted regarding the principles critical to the successful delivery of the programme:

- Improving planning and communication was most often to always used under cost management, suggesting that planning and communication important towards ensuring the cost management is adhered to;

- Eliminating waste and errors was used often to always under scope management, indicating that it was important for CPM’s not to deviate from the scope, as the primary objective towards completing the programme is to achieve the planned scope;

- Improving work planning and forward scheduling was used often to always under quality (1st) and human resource (2nd) management. This suggests that competent human resource
selection including the quality of the works being executed was key towards ensuring that planning and scheduling is implemented efficiently;

• CPM’s highlighted that eliminating activities that do not add value were most often to always used under cost management, indicating that by not deviating from the scope and adhering to the approved budget the primary objective of completing the programme timeously can be achieved;

• CPM’s felt that implementing critical path analysis and programme management was used most often to always under Time (1st), scope (2nd) management, suggesting that completing the project on time and as per the approved scope was important to the successful delivery of the programme;

• Reduce lead time was used often to always under procurement management, suggesting that the procurement and delivery of materials in relation to the programmed deliverables were key towards the successful completion of the programme;

• Maximising workflow, minimising the performance variation rather than focusing on speed only, was used often to always under time management, indicating that completing as many work activities as possible, the right way, the first time around timeously was important towards achieving the target milestones governed by the programmed;

• Risk management techniques was ranked 1st under both risk and procurement management suggesting that CPM’s find procurement a critical area that has to be managed towards ensuring that the procurement and delivery of materials coincide with the milestones highlighted in the programme;

• Implementing continuous improvement from one project to another was used often to always under human resource management (1st) suggesting that CPM’s see the need to ensure that implementing continuous improvement from one project to another is carried out through human resource team on the project.

In comparison, Table 1 then presented the means of responses to the frequency of use of the nine project management areas of expertise in each of the 15 LPM principles highlighting were each area of expertise was most frequently used. The following was noted:

1. Cost management was used often to always under improving planning and communication, suggesting that improper planning and communication will have a negative impact on cost management for the project.

2. Communication management was used often to always under improving planning and communication suggesting that there is consensus with improving communication under communication management as highlighted by CPM’s.
3. Integration management ranked 1st under benchmarking techniques including the use of key performance indicators, highlighting that CPM’s are tracking their performance by integrating benchmarking techniques and key performance indicators during the construction phase of the project.

4. Procurement management was used often to always under reduce lead time, suggesting that reducing the lead time under procurement management plays a vital role towards ensuring that delays in the programme are avoided as long lead items must be ordered timeously so that they are delivered and installed in alignment with the programme.

5. Human resource management ranked 1st under improving work planning and forward scheduling, indicating that CPM’s prioritise improving the team’s work planning and forward scheduling so that any anticipated delays or hold points can be identified prior towards eliminating possible delays so that the programme is delivered on time.

6. Risk management ranked 1st under risk management techniques highlighting that there is consensus between the application of the principle under the respective area of expertise.

7. Scope management was used often to always under direct intervention to drive immediate and apparent change, suggesting that CPM’s ensure any changes to the scope that may impact the programme is driven immediately towards understanding the nature of the change, its impact on the programme and then determining the way forward.

8. Time management ranked 1st under implementing critical path analysis and programme management and maximising work flow, minimising the performance variation rather than focusing on speed only. This suggests CPM’s ensure the management of the programme including the execution of the critical path is monitored closely during the delivery of the programme so that the project is delivered on time. In addition, it is also indicative that CPM’s focus on maximising the workflow towards ensuring more work is executed and completed rather than increasing speed and minimising performance. As a result, progress of the works is capitalised on towards ensuring the successful and timeous delivery of the programme.

9. Quality management was used often to always under improving work planning and forward scheduling including risk management. This indicates that detailed planning of the programme including execution of same was seen as critical by CPM’s towards ensuring that risks are mitigated and controlled so that quality is not compromised by abortive work being redone due to poor quality workmanship. This ensures that the programme is delivered on time but at a quality level that is acceptable and satisfactory.

The mean scores and rankings presented in Table 1 bring to light that CPM’s are aware of LPM and are utilising these principles under the nine project management areas as an initiative towards improving the delivery of the programme during the construction phase of public sector projects. It is evident that there is consensus between LPM principles used often to always under the nine
project management areas. The data did however, identify that not all of the LPM principles are equally implemented under each area of expertise.

5. Conclusions and Recommendations

Having reviewed the concepts of LPM, the public sector, the CPM profession, the construction phase and project programme including the relationship between these areas of concern and taking into consideration the results of the survey, this study comes to the following conclusions: It is evident that CPM’s were implementing most of the LPM principles under the nine project management areas of expertise as an initiative towards improving the delivery of the programme during the construction phase of public sector projects. While other principles were only used seldom to sometimes, suggesting that there is room for improvement regarding the equal implementation of all principles under the nine project management areas. It was therefore concluded that CPM’s are aware of LPM and are using these principles and techniques during construction projects towards improving the delivery of the project programme.

As a key role player on construction projects, CPMs were identified to be in an opportune position to drive the implementation of LPM on public sector projects. CPM’s may consider partnering with the public sector to eliminate/ minimise challenges with implementing LPM principles under the nine project management areas during the construction phase towards improving the management and delivery of the programme. This could be facilitated through regular workshops and programming meetings being held with the public sector and CPM’s during the projects life cycle, whereby the problems/drawbacks are identified and listed, so that control measures are put in place such as risk management plans in order to monitor and avoid identified problems/drawbacks including dealing with them immediately as they occur.

It was also found that CPM’s were using LPM on an ad-hoc basis. LPM was being implemented where CPM’s felt it needed to be applied and not as a requirement under all areas of expertise. Hence, it is suggested that the public sector promotes the implementation of LPM though the development of a policy for LPM implementation on their construction projects which will make room for LPM to be applied in a structured manner throughout the construction phase of public sector projects.

References


3 Step Site Layout Planning

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Abstract

This paper proposes a method named "3 Step Site Layout Planning" in order to define construction site organization. The designer is supposed to go, one after another, through three activities, that are: construction sequencing definition; transportation system choice; and site layout definition. The method is the nowadays version of an attempt of the authors to propose a useful tool to help construction managers to design their sites. A first approach was proposed, some years ago, based on the literature about the theme. After several uses in real construction cases, it was improved until the present status that is considered to fill manager needs. This method was used, by the authors, for as much as 50 real construction projects. In order to better explain the commented 3 steps, this paper describes one example of each step.

Keywords: Site layout, construction planning, construction design.
1. Introduction

Any industrial production description demands three types of design that are related to: the product being produced; the adopted process; and the factory that hold all the activities.

Building construction industry should proceed the same way. But it is very common, in Brazil and in several parts of the world, to face very poor representations of production sites. One can point out several reasons to justify this situation: product stays in, and factory moves out; each workday is different from the others; etc. But the variability of the construction products and processes, leading to a very large range of production efficiency, safety, and quality indexes, can be pointed out as stronger reasons to justify spending technical efforts in deeper discussing construction sites. In this context, the authors have been working in both developing and implementing a method to be used for such a purpose.

Building construction sites usually hold a very large amount of workers and materials. One square meter of construction can demand from for about 5 to 100 work hours; such a construction labour productivity, associated to tight schedules, can lead to a very large crew (many times hundreds of workers) to be hosted in the site. Bathrooms, dressing rooms etc. should be available; and also organized work areas should be there to provide good work conditions to guarantee work efficiency and safety. One square meter of a building weights for about one thousand kg; then, the amount of materials to be stocked and moved along the site, and the ways to do that, are special topics to be addressed by construction managers.

The authors, concerned with the necessity of improving labor productivity, material transportation logistics and workers safety in the site, and based on their personal experience and literature about the
theme available at that time, proposed a method to deal with site layout planning. During several years a textbook presenting the method was adopted in several construction management disciplines in Brazil as the basic approach to discuss site layout. The author’s professional experience, along the last years and more than 50 construction sites studied, lead them to propose the application of such a method stressing three main discussions: construction phases; transportation systems; and site layout. The improved approach has been used in several construction cases and it is been useful to help discussions about improvement of labor productivity, logistics and safety construction (Figure 2).

Figure 2: Author’s experience and new approach

2. Theory about site layout

Table 1 presents the authors understanding about how to deal with site layout planning. Unfortunately, to deeply discuss building construction conception, differently from other design subjects, is still new for the contractors in Brazil.

Table 1: Site layout planning approaches (adapted from Souza 2000)

<table>
<thead>
<tr>
<th>Questions about the design process</th>
<th>Incorrect posture</th>
<th>Correct posture</th>
</tr>
</thead>
<tbody>
<tr>
<td>How to design?</td>
<td>From personal criteria</td>
<td>From pre-set criteria</td>
</tr>
<tr>
<td>When to do it?</td>
<td>When you need</td>
<td>Preferably, before the work start</td>
</tr>
<tr>
<td>Who designs?</td>
<td>Who is around when the decision has to be made</td>
<td>Set of people that reflects the ideas of both the management and the workers</td>
</tr>
</tbody>
</table>
Authors first experience in trying to establish directions to design construction sites was based on the ideas proposed by Muther (1973) in his book. Muther proposes several tools to help conceive a factory layout. For example, Figure 3 presents a diagram to define the factory areas to be closer to each other.

**Figure 3: Defining area relative proximity importance (Muther 1973)**

The steps related to the project process, such as, preliminary information and definitions regarding the process technology and demands for physical resources and spaces inside the construction site, have already been exploited enough by other authors, such as Parker & Oglesby (1978), Peurifoy & Ledbetter (1985), Souza (1993), and more recently, Andayesh & Sadeghpour (2014) who did comparative study of different approaches for finding the shortest Path on construction sites.

During his academic work, the main author of this article also contributed to the studies on construction site guiding some thesis dealing with site layout planning. Birbojn (2001), for example, listed all the site “elements” (parts) one site design should address presenting criteria to orient designers to choose among several alternatives they have to define each element. Table 2 shows the site elements classified according to Birbojn.

**Table 2: Site elements types (adapted from Birbojn 2001)**

<table>
<thead>
<tr>
<th>Site elements</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related with production</td>
<td>Central procession unit, production site...</td>
</tr>
<tr>
<td>Support of production</td>
<td>stocks, warehouse...</td>
</tr>
<tr>
<td>Transportation system</td>
<td>lifts, tower cranes...</td>
</tr>
<tr>
<td>Administrative support</td>
<td>offices, reception...</td>
</tr>
<tr>
<td>Living space</td>
<td>sanitary facilities, canteen, ambulatory...</td>
</tr>
</tbody>
</table>
In such a context, authors like Handa & Lang (1988) described sampling elements considered necessary for the operation on construction sites and, through observation of these elements, developed a checklist for the projects evaluation containing weights for each item to be evaluated.

Another research advised by Souza, Maia (2003) considers a site designer goes through different phases in the conception processes and indicates that some of them demand more a mathematical work than a creative effort. He also proposes some directions to help the creative phase of the site layout planning. Figure 4 summarizes some of his directions.

The compatibility between the phases of construction can be done with adjustments to positioning of elements, or changes of schedules, as Zouein & Tommelein (1992) did, aiming at reducing changes in the physical arrangement.

In order to help improving site layout planning implementation, Souza (2000) proposed a step by step method for new site designers. Figure 5 shows a flowchart discussed by Souza in his book.
Ideas proposed by Souza (2000) were used in several courses dealing with Construction Management, both for undergraduates and graduates. Some Brazilian researchers, as De Freitas & Santos (2009), tried to facilitate the use of these (and other) ideas leading to the site layout designing “by offering computer resources to help in their decisions making process and to visualize the spatial distribution of the elements in the construction site”. Other countries researchers also tried to help establishing a routine to design site layout in a similar way. Tam & Leug (2002) uses TI to import data to be used in the decisions and believes 3D visualization is very useful in discussing layout. The same authors and also Khalafallah & El-Rayes (2006) also presents algorithms to help some decisions, as for example to evaluate materials transportation cost.

The authors believe TI can help a lot not only with site layout planning but also in several others areas of construction management. But they also believe all these tools just can really be implemented if the process as a whole in defining site layout is understood. Based on the ideas one can see in Figure 5, the authors participate in real site layout planning activities during several years. In their professional experience, they have success whenever a representative group of the construction managers of the site being designed were able to participate in a process where 3 main issues (named “steps”) were discussed and decisions were taken about them. These three needed decisions are described in the next item. But the authors believe that: 1) sequence of activities to produce one building extremely influences site layout best solution; 2) materials transportation is an issue to be addressed but there is more than one good solution to provide transportation, and to find the best choice demands interactions with the other 2 steps; 3) locating the several elements (working and nonworking areas) is something that demands more than architectural skills, for example to take into account manager can even change technology or supply politics to help finding better solutions for layout.

3. Proposed method

3.1. General description

The method was created based in a long term research and implementation effort, in a “back and forth” experience type. The academic studies and the opportunity to implement them in several real cases molded the nowadays method. In a very simple description, the new method uses the old ideas (see Figure 5) with an emphasis on the 3 commented aspects steps: construction phases understanding in terms of site demands; using mathematical models to determine the best transportation system for each case; and approaching architectural prescriptions both for working areas and temporary facilities to be built. Although a strong interaction among them occurs, the 3 aspects can be seen as 3 steps to reach the main goal, that is, discuss site layout before the construction activities begin.

Then, the main steps (Figure 6) to face a new project production conception are named: a) construction phases definition; b) macro logistics; c) site layout.
3.2. Examples of the steps

3.2.1. Step “a” – Production Macro Planning

Considering the construction of a single building, Figure 7 exemplifies different plans of production that can be followed. One can plan to produce the tower as a whole before dealing with periphery; the opposite can also be planned; and a mix of the two approaches may constitute the plan to be chosen.

Figure 7: Example of distinct production macro plans for the same building to be built: a) tower before; b) periphery before; c) tower and periphery simultaneously.

Figure 8 presents a real example where plan “b” was adopted instead of plan “a” (to excavate from the back to the front portion of the site; and the same in order to latter produce foundation, steel reinforced concrete structure etc.) which is usually adopted by construction planners. The project holds three
towers located in a relatively narrow site with just an only access (a very crowed by cars avenue near tower 1). Plan “b” allows the area of tower 2 to temporarily host the rebar working area avoiding material stocking crash.

![Figure 8: Project with three fifteen-story apartment buildings in Rio de Janeiro state- Brazil](image)

### 3.2.2. Step “b” – Transportation System Definition

Material moving usually evolves several repetitions of a cycle, described as showed in Figure 9, with 4 parts: beginning, going, finishing, and return. The total time to completely move an amount of materials is defined once one knows the total amount to be moved, the quantity it is moved each cycle and the time of one cycle. More than this simple model, delays should be considered to calculate the capacity of a certain transportation system.

![Figure 9: Cycle of materials transportation.](image)
Once one knows the quantity and type of transportation equipment to face calculated demands, it is necessary to provide an appropriated location for them in the site. Figure 10 shows tower cranes (fixed and mobile) location in a multiuse (shopping mall and corporative office building) project in São Paulo – Brazil.

![Location of the demanded tower cranes in a multiuse project site in São Paulo state.](image)

**3.2.3. Step “c” – Site Layout Drawing**

Once site layout varies almost continuously (accordingly to the construction phases), some drawings are necessary to represent it. The drawings should both represent the working areas and temporary facilities for the workers. Each area can be represented as a “piece in the whole design” (“overview” of the site elements) but also it can be showed in detail.

Figure 11 presents an overview, in the beginning phase, for a residential two tower project where one can see the representation of several working areas, but also the access for trucks and even the place used to sell apartments.
4. Conclusions

This paper summarized a method that has been used in several Brazilian projects. The ideas here described were firstly defined in some academic researches; later, these ideas were used in real cases and there was a kind of improvement, both simplifying and fulfilling the directions to help designing the sites. Simplifying the steps to discuss site layout planning allowed more site managers participation what, in the authors opinion, increase de number of construction projects working with site layout designing. The method has being successfully used in a varied type of projects; from an unique house construction to a very huge multiuse group of high rise buildings. In terms of demanded research, the authors believe TI can help, but they recommend an emphasis in improving methods tools that gather together decision related to the 3 described steps.

References


De Freitas M R; Santos E T (2009), Validation of a system for planning and design of construction site layouts, 5th CIB W102 Conference: Deconstructing Babel: Sharing Global Construction Knowledge


Khalafallah A; El-Rayes K (2006), Decision support system for optimizing construction site layouts, CIB W078 23nd Joint International Conference on Computing and Decision Making in Civil and Building Engineering


Muther R (1973) Systematic layout planning, Boston, Boston Cahners Books

Parker H W; Oglesby C H (1972) Methods improvement for construction managers, New York, MacGraw-Hill


Zouein P P, Tommelein I D (1992), MovePlan: allocating space during scheduling, CIB 92 WORLD BUILDING CONGRESS, Montreal

Abstract

The need to manage and coordinate design has been recognized in different industries, including construction. However, teams need to have a shared language, which requires a design framework or in other words ontology, providing a terminology, principles and methods. Systems thinking approaches have been used in variety of design ontologies, here we have focused on the Domain Theory (DT). The purpose of this work is to understand how a common design framework aids the design inquiry and management. For that the DT is outlined, its implications to construction are reviewed and a case study as a main method is carried out to illustrate the effectiveness of this design theory for practice. The DT provided the common framework for studying end users, their needs and requirements based on their business operations. Also, the DT supported the design team in understanding the purpose of verification and validation. Results indicate that the common theory reinforced focusing on key parameters, issues and design requirements. However, outcomes also illustrate that system approaches tend to be resource intensive, requiring a more thorough analysis up-front.

Keywords: Domain Theory, design domains, technical activities, organs, structure

1. Introduction

The need to manage and coordinate design has been recognized for some time in industrial product (artefact) development (Farr, 1966), mechanical engineering (Andreasen, 1980), architecture (Emmitt, 2010) and also in engineering design for construction (Ballard and Koskela, 1998). The main reason for these developments is the division/disintegration of master builder into dedicated disciplines as the body of engineering design knowledge and expectations to efficacy have rapidly increased throughout the last three centuries (Kranakis, 1997, Reed, 2009). This has increased the complexity of construction projects and thus, the need for more thorough cooperation, coordination and management of engineering design processes thorough effective communication (Kleinsmann, 2006).

For the latter, design teams need a common language, such as a Domain Theory (DT) (Andreasen et al., 2014). Andreasen (2011) defined ‘domains’ as a set of dedicated views onto a product:
activities, organs and parts. These are used as the skeleton of a procedure for the product development/design. Domains consist of entities; e.g. the activity domain is determined by the user’s application of the product, which together with the user experience and usability, to satisfy the initially unsatisfied need. Thus, the DT is an ontology, a common modelling framework, providing the viewpoints and vocabulary to represent the knowledge needed in product development.

An explicit and common modelling language allows transforming mental models into explicit models that can be shared among designers (Erden et al., 2008). Defining the domains, entities and the types of relationships can serve the purpose of developing a theoretical and conceptual model for engineering design coordination and management. Moreover, a consistent ontology supports the development of computing technologies and helps avoiding mistakes due to the neglect of some domains (Gielingh, 1990).

The aim of this research is to understand how formal design framework aids the design inquiry and management. More particularly, here we review the Domain Theory and its implications into practice (Andreasen et al., 2014, Howard and Andreasen, 2013). In the first part of this paper, a theoretical framework of DT is outlined; in the second part, the implications to construction industry are summarized; and finally, a case study, informed by the DT, is compiled to illustrate the importance of design theories.

2. Methods

The purpose of this study is to understand the implications of a common design framework (Domain Theory) to design practice. Thus, this research aims to answer to the following questions: How does the common design framework aid the conceptualization of design solution from users’ perspective? What implications does the framework have on design team and process? For that a qualitative case study method is used to acquire context-dependent knowledge (Fellows and Liu, 2009). The lead author of this article participated in the development of new warehouse concept for small and medium sized businesses dealing with wholesale, retail sales, services or combination of these. This work focuses on the early stages of design and processes for developing a new concept for warehousing.

3. Engineering Design Terms and Frameworks

Across industries, several design researchers have tried to propose a unified definition for engineering design. Here, we start with the definition proposed by Evbuomwan et al. (1996):

“The process of establishing requirements based on human needs, transforming them into performance specification and functions, which are then mapped and converted (subject to constraints) into design solutions (using creativity, scientific principles and technical knowledge) that can be economically manufactured and produced.”

This definition succinctly illustrates the subject and the content of engineering design and three aspects are clearly visible. First, designers work on a variety of aspects during design process:
needs (voice of the customer), performance requirements (required, expected and actual behavior), functional descriptions, structural descriptions, and production/manufacturing processes. Secondly, engineering design can be viewed as a process, using different modes of reasoning, including regressive vs. deductive (backward and forward), decomposition vs. composition (breaking down and putting together) and transformation (transferring problems between abstract and particular) (Koskela et al., 2014). Thirdly, design is between thought and object (Bucciarelli, 2002), aligning three aspects of facilities, including user needs and requirements, design solutions and production processes.

### 3.1 Domain Theory

Several engineering design frameworks have been developed based on the systems thinking approach, such as the DT by Andreasen et al. (2014). DT consists of several models and concepts for understanding and researching design practices. The basic domains in DT include: technical activity, organ and part (structure). Andreasen et al. (2015) define the technical activity as the user’s application of the product (use functions) for fulfilling the unsatisfied need. A use function is an activity of the user to utilize the product for performing certain action. Chen et al. (2015) define a need as a subjective desire of a person to change a problematic conceptual environment into a desirable one. The organ domain is the set of functions, the means of a product, displaying a mode of action (realization of function) and its behavior (properties). Part domain consists of components as an elementary material system, making-up an organ, realizing the organ’s mode of action by the part’s physical states and interactions. Thus, an artefact is defined by its structure, describing the anatomy of components, properties and relationships.

Properties of the systems and components are divided into two categories, describing the product structural characteristics (form, material, dimensions and surfaces) and behavior (derived from structural characteristics) (Andreasen et al., 2014). Characteristics are a class of properties of an object that define the means by which the object’s behavioral properties are realized (Albers and Wintergerst, 2014). The behavior reveals when product is deployed by the user(s) in its context for use purpose and processes. In engineering design literature, behavior is characterized by successive states, including manifestations and value of the properties of the system in response to its environment and the received stimuli (Albers and Wintergerst, 2014).

When a product is deployed it contributes to the transformation of operands such as material, energy, information and/or biological objects. The properties of use functions in relation to the operands are described by their input and output states; the necessary effects from the operators, their nature, their state and how they lead into contact with the operands; and the active environment (Andreasen et al., 2014). The organs are based upon physical, chemical or biological phenomena. When stimuli act on the organ in its context, it delivers an effect. In other words, organs are also called *wirk* functions (Hubka and Eder, 1996, Albers and Wintergerst, 2014), which is a statement about what the product does when in operation (Howard and Andreasen, 2013).
Also the structure and its components are active and interact with each other through their assembly interfaces (Howard and Andreasen, 2013). Components are related to the wirk functions, which are based on natural (physical, chemical and biological) phenomena. A part interfaces with other parts and its surroundings, creating the effects of the part. Therefore, the DT defines the domains, its entities and relationships to describe the practice of engineering design.

Andreasen et al. (2015) have also described the engineering design process as a progression throughout the domains in DT. They define the engineering design process as a causal chain: user need > use activity result > determination of use activity > determination of the product’s effects and functions > determination of organs and organ structure > determination of parts and part structure. However, in practice, design is not a linear process from needs to structure, it is rather a top-down and bottom-up approach simultaneously (March, 1984), meaning that problem and solution are coevolving throughout the design process.

### 3.2 Summary of the Domain Theory

The DT, initially developed based on the Hubka’s Theory of Technical Systems, distinguishes between use functions (e.g. write text) and wirk functions (e.g. deposition of graphite onto the paper by means of pressure and friction) (Howard and Andreasen, 2013). This shows that designers do not only designate a product’s behavior or mode of action but also the use activity of the end user. Secondly, the DT differentiates two types of properties, static structural characteristics as means for realizing the objectives and behavior (state variables) corresponding to the stimuli and changes in the environment. Thirdly, design is a process, moving from the need to the description of a structure (part domain) for delivering the expected effects (behaviors). Thus, design is a modelling process for establishing the network of connections between entities in different domains through the expected behaviors to be actualized.

### 4. Conceptualization of an Engineering Design Framework for Construction

Essentially, buildings are designed to facilitate users’ personal or business operations. Space as the functional unit facilitates the satisfaction of user needs. In this work we consider the activity, organ and part domains of DT as a common denominator for design processes and disciplines. In following sections, the content of these domains are discussed in detail.

#### 4.1 Activity Domain: Deployment of Facilities for Value Creation

As in the theory of domains (Andreasen et al., 2015) or proposed by Pennanen (2004), the first domain to be considered is the user process domain. This is an activity-based approach for decomposing client processes (personal or business) into user activities/sub-activities and their properties that realize the client’s goals and thus are value-adding. For example, in office building the activity ‘meetings’ can have these properties: type of an meeting, types of participants, number of participants and usage of equipment (projectors, tables, chairs etc.). Currently, this tends to be
considered only informally in the design process (Pikas et al., 2015). Thus, in the activity domain, use functions are defined as interaction with the artefact.

4.2 Organ Domain: Space as a Functional Unit

The user activities, their nature and resource requirements become the basis for defining the environment and its facility centric functional organs to be decomposed into sub-functions. This is typically articulated in the project brief, including information about the area (unit of area per room/person), dimensions (e.g. ceiling height), indoor climate (e.g. temperature, air exchange type and volume, air movement speed, cooling, heating and control of indoor climate), acoustics, lighting, electricity, water supply, sewage and use of equipment. It describes the facility consisting of functional spaces and its sub-functions, some required as resource for activity and others determined by the design decisions (Pennanen et al., 2005).

However, the articulation of spaces in the project brief is a complex activity, where form and use function of the building play the main role in determining how spaces should function, laid out and utilized. Required spaces affect many different aspects of the building, including its form, layout, utilization and spatial planning (Mayouf et al., 2014). Moreover, in a building program, expected behaviors of functions and structures are determined (e.g. air exchange rate). Thus, the completed building program, even though still subject to changes in later stages, is the basis for engineering design process. Koga (2010) defined functional decomposition as value engineering in Integrated Project Delivery, or in other words functional analysis.

4.3 Part Domain: Linking Functional Requirements to Structural Description

Design theoreticians have considered this as the kernel of the design process (Andreasen et al., 2015, Suh, 1998, Kroes, 2002). In schematic design, architect analyses the user needs and translates these into functional requirements (spaces and its sub-functions) and expected behaviors (temperature level to be maintained) as a basis for design conceptualization, and syntheses of the form based on selected technologies and materials required for meeting the client needs. The form defines the internal and external spaces, a composition plan for the totality and the details (relationships), social and economic issues, and a framework for human interactions (Andreasen et al., 2014). According to Hubka and Eder (1996), form can be interpreted and modelled as geometry. Other main structural characteristics include the materials, technologies and dimensions, determined to meet the expected behaviors of the structure. The outcome is the design concept describing the system architecture and its division (structure, HVAC, MEP etc.). Each system consists of a number of components designated during the embodiment of functions and expected behaviors, and its configurations and connections (Ullman, 2009). Particularly, it is the selection of components and their physical characteristics that determine the actual behavior of a system and the best fit with the requirements of the project brief. For example, the architect can link a ventilation unit to the requirement of minimum air exchange rate in a space.
5. Case Study for Illustrating the Implications of Domain Theory

In this section, a case study is compiled to illustrate the importance of domains and their entities; particularly, how the design ontology informs the design process. One of the largest Estonian companies, in the field of logistics parks and warehousing services, is looking for new opportunities for expanding their business services. Until now they have focused on large logistics parks, but they are planning to start providing warehousing services to small and medium sized vendors, service providers and trade companies. They were interested in developing a new warehouse concept that can be detailed for a specific parcel. In this sense, it can be compared to product development in industrial engineering. In the following, a short summary of the results and key findings are given.

5.1 Design Development Process

Largely, the design development process was divided into three steps: I observation of existing solutions and user needs; II design conceptualization; and III product concept development. In the first step all similar existing facilities were mapped in and around Tallinn, Estonia, and ten existing facilities were selected by the project team for closer study. Then the team, including client representatives, the architect, the design project manager and the lead author of this article, paid a visit to these ten facilities during a period of two and a half days. The result of this was a 20 page report, summarizing the problems, existing solutions, main users, use activities and user needs/requirements. In the second stage, the report developed in the first stage, became the basis for conceptualizing the product and articulating the design task. The team avoided compiling heavy documentation, instead through several iterations a two page design concept paper was compiled as a basis for schematic design. The third step, product concept development took place over many weeks in an iterative manner. The architect proposed concepts, which were discussed within the project team. The final outcome was the concept for modular and flexible combined warehouse, office and service spaces.

5.2 Observation of Existing Solutions and User Needs – Activity Domain

As a part of a activity domain, ten sites were visited and users were questioned regarding solutions and their satisfaction. The following are the main observations:

- Complex nature of the client: All observed companies were importing goods and depending on the type of a product, these companies were either doing wholesale, retail and/or provided product related services (e.g. a tire shop), determining which kind of functional spaces were needed. Overall the following target client categories were identified: wholesale, retail sales, product related services or combination of these.

  - Typical spatial layout:
    - Average space area per company was 317 m², including either storage, office and show rooms or combination of these. However, the distribution of spatial area
varied remarkably, and excluding one very small company from the sample, the average area increased to 568 m².

- There was no correlation between the number of people working in the company and storage and/or show room area.
- The average office area per person was 14 m². However, most of the tenants indicated that it was too much and more storage space was required. It was concluded that around 10m² of space per person in the office would be around the optimal solution.
- Show rooms must be flexible and situated on the first floor, meaning companies who want can use it as a show room and others as an office space or service space.

- **Limitations of building form, layout and solutions:**
  - Offices spaces were designed throughout the whole building depth on different floors. The problem was that companies who had storage spaces on both sides of office spaces had difficulty moving goods between these two, they had to either transport the goods through office space or from outside. The latter is a problem in winter.
  - Several solutions had storage space through three floors, resulting in heights around 9-10 m. For workers responsible for storing goods this was a bad solution as it complicated the process of stowing goods.
  - Poor layout of office spaces as people working in these indicated that they did not have space for resting, eating or meetings.
  - Thresholds between show rooms and storage spaces hindered transporting goods.
  - The shelves were too long hindering the entrance and exiting through the transportation doors.
  - Also, several companies indicated that the transportation doors for transporting goods in and out from storage space were disproportional, either too high or wide.
  - Lights and ventilation ducts were crisscrossed with roof trusses.

- **Technical solutions:**
  - Observed buildings were made of precast concrete or steel structures, including sandwich panels, steel or concrete structural frames.
  - For heating and cooling mainly electricity based systems were used, e.g. air to air heat pumps.
  - Five buildings out of ten had skylights either in office or storage sections as the storage buildings can be relatively deep.

**5.3 Design Conceptualization – Organ Domain**

The observations within activity domain became the basis for articulating the goal and requirements. The main goal was to develop: “Modular, flexible, spatially optimal, cost and energy efficient combined production, service, storage and office building for small and medium sized wholesale, retail or service companies.” Table 1 defines the value structure for the project, defining the category, expected performance and constraints.
Table 1. Summary of concept categories and expected performance.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Category</th>
<th>Expected Performance</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Suitability</strong></td>
</tr>
<tr>
<td>1</td>
<td>Modular spaces</td>
<td>Space range per module: 200-600 m²</td>
</tr>
<tr>
<td>2</td>
<td>Flexible storage and show room spaces for</td>
<td>Movable internal walls and flexible building services</td>
</tr>
<tr>
<td></td>
<td>expansion</td>
<td></td>
</tr>
</tbody>
</table>
| 3  | Effective form, spatial layout and stowing   | • Office spaces shall be along the front exterior wall of building  
• Storage spaces shall have optimal paths for the movement of equipment and transportation of goods  
• Office spaces must have small kitchenette and toilet on first and second floors  
• The width of the corridor shall be designed based on maneuvering radius of forklifts with lifting capacity of ≤ 1.5 tons. Expected width between shelves ≥ 3.2 m  
• For the maximization of storage spaces the optimal spacing of shelves shall have two or three corridors  
• Office space ≈ 10 m² per person  
• Size of the transportation doors: ≥ 2.8m height and ≥3 m width  
• Clean height of storage space under trusses: 6m (clean height for stowing is 4.5 m) |
|    | of goods                                     |                                                                                                                                                                                                                       |
| 4  | Comfortable working conditions               | Well-lit working spaces and aesthetical materials                                                                                                                                                                     |
| 6  | Energy efficient                             | Cost effective energy efficiency solutions: minimum requirement is B-class (consider renewable energy)                                                                                                                                 |
| 7  | Indoor climate control                       | Users have possibility to control indoor climate, heating, cooling, ventilation and lighting                                                                                                                                 |
| 8  | Optimized structures and details             | Cost optimized solutions of structures and details                                                                                                                                                                     |
| 9  | Optimal maintenance costs                    | Highly enduring materials and maximum lifespan (50 years for structures)                                                                                                                                              |
| 10 | Construction cost                            | ≤ 400 €/m² (target cost)                                                                                                                                                                                                |

The overall preferred layout for the business activities is that goods are transported from behind and clients enter from front. The functional decomposition depends on the business function or main activities, which here were divided into four categories: **wholesale, retail sales, product related services** or combination of these. These categories became the basis for spatial decomposition as follows:

- **Office spaces**: must be aesthetical, comfortable, functional and well lit. Companies want to provide good working conditions to workers. The office spaces must have good layout, providing enough workspaces, kitchenette and toilet. Typically, companies with total space around 400 – 600 m² also need small meeting room.

- **Show rooms**: Not all companies need this type of space, those who need have varying requirements in terms of size. Thus, first floor offices spaces must be flexible, either be used as a show room, reception space for clients or as an office space.

- **Service areas**: Companies, who need service spaces, must have rooms two floors high. Some companies who provide services also provide shower and dressing room for workers.

- **Storage spaces**: In general goods can be divided into two groups: small and large by size. Thus, larger goods are moved with forklifts and smaller ones by hand. Companies need enough space between shelves to manoeuvre with forklifts. Regarding the indoor climate, few companies had products that required controlled indoor temperature and humidity levels.
5.4 Product Concept Development – Part Domain

In this stage, architect prepared the first draft based on the selected concept, linking functional requirements to physical characteristics. The overall concept was a modular warehouse for different user needs. Modules were defined as rectangles in varying sizes, which were combined in different ways to form a whole building. However, the whole size of the building will depend on a specific site, zoning requirements and design requirements by the local government. The driving concept for the architect was “organized chaos”. A model was prepared in Graphisoft ArchiCAD to facilitate the conversation between the architect and the client. The starting point for the architect was the storage space with two or three corridors between shelves and with the size of the columns, initially 300 x 350 mm.

The second aspect that the architect had in mind was modularity, the proposed main module being 6 m x 6 m. However, the first module, including office spaces and show rooms, was 7.5m deep. The architect also had to consider the other constraints, such as transportation door width and height. For example, based on the size of transportation doors, the first floor windows were chosen to be of the same size. During this iterative process several layouts were proposed and in each iteration, the architect focused on a specific aspect. After a few iterations, the structural, HVAC and electrical engineers were involved, performing the basic calculations to verify the architect’s assumptions and proposed conceptual solutions for different systems. For example, the columns were changed to 400 x 400 mm due to the fire safety considerations.

The biggest challenge was to find appropriate solutions for flexible spaces, which was considered as an important innovation and a primary goal of the project. As shown in Figure 1, the end walls of each section are movable. The same is with the office and show rooms, however, these can be expanded only to right and left in respect to the front and back of building. Flexibility was required considering how to build lighting systems and building services in the way that these would accommodate the changes in the layout of the building. Therefore, the meters for measuring the energy consumption were designed to be placed to the beginning of every rentable section of the facility. Lighting systems were connected through outlets, in case of moving walls the connections can be moved as well from one outlet to the other. For same reason of flexibility, the floors for second floor were planned to be built of standardized prefabricated wooden frame panels and the interior walls of sandwich panels that can be easily assembled or disassembled.
At the end of the product development stage, one Estonian contractor was involved to validate the solutions from the perspective of buildability, and to make an early cost estimation. The model was used for quantity take-off and making buildability assessments. The target cost was set to 400 €/m², the contractor estimated 413 €/m². However, the team also figured that cost can be reduced by more detailed design and elaboration of technical solutions.

Furthermore, the client used the produced concept to validate the business model on the market. They used layouts and BIM based renderings to compile a fictive advertisement. Altogether, project got around 20 views on the website and three persons called and asked for more details. Although the interest could be considered low, it was also understood that organizations who are looking for new spaces are interested in facilities, which are already existing. The client confirmed the proposed product concept, and now the first project has been initiated.

6. Discussion

The case study, guided by the application of the DT, indicated the importance of a common design framework as a means for effective communication. Case study clearly indicates the content of the different stages: I stage as a part of activity domain was focused on observing existing solutions and user needs; II stage as a part of organ domain was for design conceptualization; and III stage as a part domain focused on the materialization of product concept. All involved parties agreed on the usefulness of common domains, entities and relationships. Furthermore, a clear articulation of project value structure, in terms of targets and constraints, facilitated the iterative design process. However, as the design team was busy with understanding the DT, the focus was not on design management, thus, causing the concept development to take three months more than was initially planned. Thus, this can also be considered as the main limitation of this research.

In the future projects, design management aspects must be considered, including the implementation of Last Planner System and/or Scrum (from Agile Management) to plan, execute and control the design process by defining the information flows through pull mechanism.

Figure 1. Combined storage, office, service and show rooms building: a) flexibility of spaces enabled by movable walls; and b) two examples of modules and composition.
other reason why this is particularly important is that currently the architect still tended to make many assumptions, instead of involving downstream engineers immediately to concept development. Thus, in the near future, the plan is to implement the cell layout for project design team, to facilitate real time communication and reduce the response time for request for information. The team also noticed that systematic approaches tend to be resource intensive, which currently is not a typical practice for the early stages of design. Thus, approaches such as Axiomatic Design theory, could be used to stage the design process by focusing on a key functional requirements and design parameters in each stage.

7. Conclusions

In this article, the DT and its implications for construction were studied through a case study. Answers for two questions were sought: How does the common design framework aid the conceptualization of a design solution from users’ perspective? What implications does the framework have on design team and process? As for the first question, the DT provided the common language for the design team, a mental model for the design concept development. This means that the DT provided the common framework and reinforced focusing on key parameters, issues and design requirements. For the second question, the DT supported the design team in understanding the purpose of verification and validation. An example of verification was the involvement of structural and building services’ engineers in the early stages of design, doing design review. However, the limitation of this case study was that the design focused solely on familiarizing with the DT, but not on the design management. The result was that the concept development took several months longer than was initially planned. Thus, in the future research, control methods must be implemented to maintain the schedule and avoid the architect’s assumptions by using a pull mechanism.

References


KOGA, J. E. Function analysis in integrated project development. 50th Annual Conference of SAVE International, 2010 Queen Mary, Long Beach, California. CVS-Life, AIA, 256-296.


Multi-criteria Analysis of Service Life Prediction Methods Applied to Natural Stone Claddings

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Abstract

Depending on the user's perspective, a given reality can be represented in different ways and by different mathematical models. Service life prediction is a challenging task, due to the variability related with the degradation processes and the large number of variables that affect the buildings' life cycle. There are different possible approaches to the service life prediction of natural stone claddings. In this study, different models for service life prediction are proposed, grouped in four methodological families: i) deterministic models; ii) factorial models; iii) stochastic models; and iv) artificial intelligence-based models. These different approaches are established based on an expert survey of 203 stone claddings (directly adhered to the substrate), in-use conditions. This survey is performed by the authors on natural stone claddings in current buildings (housing and commerce) located in the Lisbon area, in Portugal. A comparative analysis is performed, through the comparison between the results obtained by each model and the data collected during field work, corresponding to the real degradation condition of the stone claddings analysed, in order to evaluate the sensitivity, specificity and accuracy of the models. Once the prediction capability of the proposed models is evaluated, a multi-criteria decision analysis is performed in order to compare the different models applied to service life prediction of stone claddings. This analysis intends to guide the choice of a particular model for a given application based on a set of decision criteria. Also, the main motivations and goals of the stakeholders are analysed, leading to different weights in the decision criteria. In real world, a rational process of decision-making incorporates subjective criteria and different "points of view". In this study, the multi-criteria decision analysis comprises two perspectives: the planner’s point of view (who defines the model, e.g. the designer); and the user’s perspective (who uses the model, e.g. a real estate manager). The essential parameters that may influence the selection of a given model are analysed. Based on the comparative analysis of different service life prediction models, some recommendations are made, concerning the advantages and limitations of the models proposed.

Keywords: Service life prediction; natural stone claddings; comparative analysis.
1. Introduction

Currently, there are different possible approaches to the service life prediction of natural stone claddings (directly adhered to the substrate). Naturally, different methods lead to different results, with (Lourenço et al., 2007): i) different levels of complexity; ii) different levels of availability; iii) different processing times, ranging from the instantaneous output of results to models that may require hours of computer processing; and iv) different costs. This study presents a review of different methodologies for service life prediction applied to natural stone claddings, grouping these approaches into four methodological families: i) deterministic models; ii) factorial models; iii) stochastic models; and iv) artificial intelligence-based models. All the proposed models lead to accurate results and are able to describe the degradation phenomena of stone claddings. Therefore, a comparative analysis is performed in order to evaluate the applicability of each model. The comparison between predictive models must take into account some basic principles: i) the model should be adjusted to the data, with a significant explanatory power, and must cover all the relevant aspects in the description of the phenomena under analysis; ii) it should respect the parsimony principle, i.e. in the presence of two models equally accurate, the model with lowest number of parameters should be chosen; iii) the model parameters should be easily interpretable; iv) the model should be able to describe the behaviour of the entire population, i.e. should not be over-adjusted to the sample, and must be able to predict the behaviour of new case studies, which have not been previous analysed by the model; v) it should be easy to apply, considering the ease with which the user understands how to use the model, the quantity and complexity of the data required for the model to work properly, and the software required and its processing time. Based on a set of different criteria, a multi-criteria decision analysis is performed, comprising two perspectives: the planner’s point of view (who defines the model); and the user’s perspective (who uses the model). Assuming that different stakeholders have different points of view, a sensitivity analysis is also performed in order to analyse the best model for different decision-making profiles. Based on the comparative and the multi-criteria analysis, some recommendations are provided, referring the advantages and limitations of the models analysed and thus allowing a more rational and informed selection of a service life prediction model concerning the purpose of the model and the planner’s profile and the user’s perspective.

2. Service life prediction models

In this study, 203 natural stone claddings (directly adhered to substrate) are analysed, in service conditions, surveyed through visual inspections. The overall degradation of stone claddings is evaluated through a numerical index, initially proposed by Gaspar and de Brito (2008), given by the ratio between the degraded area - weighted as a function of its state of repair - and a reference area, equivalent to the whole area of the façade with the maximum degree of degradation - expression (1).

\[ S_w = \frac{\sum (A_n \times k_n \times k_{a,n})}{A \times k} \]  

(1)

Where \( S_w \) represents the severity of degradation, expressed as a percentage, \( k_n \) the multiplying factor of defects \( n \), as a function of their degradation level, within the range \( K = \{0, 1, 2, 3, 4\} \), \( k_{a,n} \) the weighting factor corresponding to the relative weight of the defect detected (\( k_{a,n} \in \mathbb{R}^+ \)) according to the cost of repair (Silva et al., 2011), \( A_n \) the area of coating affected by a defect \( n \), in m\(^2\), \( A \) the façade area, in m\(^2\) and \( k \) the multiplying factor corresponding to the highest degradation
level of a cladding, as defined in \( K \) above, of area \( A \).

To predict the service life of stone claddings it is necessary to define the instant in time in which they reach the end of its service life. However, this theoretical limit is not easy to define since it depends on a set of subjective criteria, varying according to time, place, user’s needs and the building’s context (economic, social, aesthetics, environmental or political). In this study, it is considered that a cladding with a severity of degradation higher than 20% has reached the end of its service life. This value was adopted based on the sample analysed and on a survey answered by the owner and users of the buildings analysed.

The different models described in the next sections include as explanatory variables the variables with higher statistical significance in the description of the degradation phenomena of stone claddings. The variables were selected using a sensitivity analysis and based on a stepwise technique described in Silva et al. (2012). All the proposed models include as explanatory variables age, distance from the sea and size of the stone plates, thus revealing a high relevance of these variables in the description of the degradation phenomena of stone claddings.

### 2.1 Deterministic models

Deterministic models use mathematical formulations and/or statistics, aiming to describe the relationship between the degradation mechanisms and the façades’ degradation condition. These models, although being extremely effective in large and representative population samples, generally ignore the random nature of the phenomena under analysis. In this study, deterministic models comprise different types of regression analysis: i) simple regression analysis (degradation curves); ii) multiple linear regression; iii) multiple nonlinear regression. Simple regression expresses the loss of performance of façade claddings through a continuous function called “degradation curve”. This curve can be graphically represented, where the \( x \)-axis represents the age of the stone claddings (assuming that age is the period of time between the date of the last intervention on the cladding and the inspection date) and the ordinate axis the index that expresses their global degradation \( (S_w) \). Equation (2) shows the result of the simple regression analysis performed.

\[
S_w = 6E - 05 \cdot A^3 - 0.0013 \cdot A^2 + 0.065 \cdot A + 1.538
\]  

Where \( S_w \) represents the severity of degradation of the façade (%) and \( A \) the age of the façade.

The second model, multiple linear regression analysis, can be seen as an extension of the simple regression analysis that comprises more than one explanatory variable. Equation (3) presents the model applied to stone claddings with four explanatory variables. In the model’s definition, a stepwise regression technique is applied, ensuring that all the assumptions concerning the statistical significance of the model are fulfilled.

\[
S_w = 0.003 \cdot A - 0.429 \cdot S - 0.195 \cdot SS - 0.174 \cdot D + 0.772
\]  

Where \( S_w \) represent the severity of degradation of the façade (%), \( A \) the age of stone claddings, \( S \) the distance from the sea, \( SS \) the size of stone plates and \( D \) the exposure to damp.
The third methodology is the multiple nonlinear regression analysis, which is similar to the multiple linear regression but uses a nonlinear function in the approximation between the model and the data. In this study, nine nonlinear models are applied: polynomial regression; Gompertz curve; Von Bertalanffy curve; Richards curve; Morgan-Mercer-Flodin curve; Weibull curve; Brody curve; exponential regression; potential regression - equations (4) to (12), respectively.

\[ S_w = 4.033E-05 \cdot A^2 - 0.080 \cdot S^2 - 0.083 \cdot SS^2 - 0.075 \cdot D^2 + 4.659 \cdot WR^2 - 0.069 \cdot O^2 - 4.213 \]  
\[ S_w = e^{-0.097e^{-0.017A+1.440S+0.504D+1.058SS+0.553O+0.447TS}} \]  
\[ S_w = \left(1 - e^{-0.05e^{-0.014A+0.145S+0.035D+0.745SS+0.299TS+0.366O}}\right)^3 \]  
\[ S_w = \left(1 - e^{-1.896e^{-0.04e^{-0.018A+1.120S+0.938D+0.8845}}}\right)^{606351} \]  
\[ S_w = \frac{-76.557 + 1.756 \cdot (A^{2.49} + S^{-1.7441} + D^{-3.2849} + SS^{-49.303} + TS^{-53.132})}{1594.935 + A^{2.49} + S^{-1.7441} + D^{-3.2849} + SS^{-49.303} + TS^{-53.132}} \]  
\[ S_w = 588.913 - 588.911e^{-1.660e^{-0.09(A^{2.46} + S^{-1.8567} + D^{-1.87606} + SS^{-1.64604} + TS^{-2.16057})}} \]  
\[ S_w = 1064.756\left(1 - 0.999e^{-2.599e^{-0.06A+0.148S+0.121D+0.044S+0.206O+0.04SS+0.0130D-0.05TS}\right) \]  
\[ S_w = 7.478e^{0.035A-1.501S-1.756D-1.777SS-1.062TS} \]  
\[ S_w = 1.907e^{-0.06(A^{2.718} + S^{-1.67949} + D^{-1.02858} + SS^{-1.52310} + TS^{-2.2006})} \]  

Where \( S_w \) represent the severity of degradation of the façade (%), \( A \) the age of the stone claddings, \( S \) the distance from the sea, \( SS \) the size of stone plates, \( D \) the exposure to damp, \( WR \) the exposure to wind-rain action, \( O \) the façades orientation and \( TP \) the type of stone. For the application of the deterministic models, the variables included in the models must be replaced by the numerical values presented in Table 1.

### 2.2 Factorial model

The factorial method is one of the main methodologies for service life prediction and is proposed in the international standard for durability (ISO 15686: 2000). In this method, the service life is obtained by multiplying a reference service life by the durability factors that influence the degradation process of the element under analysis. Equation (13) shows the application of this method to the service life prediction of stone claddings.
\[ ESL = RSL \times A1 \times B1 \times B2 \times B3 \times B4 \times B5 \times E1 \times E2 \times E3 \times E4 \times F1 \times G1 \]  

(13)

Where ESL represents the estimated service life, RSL the reference service life (68 years), A the type of stone, B1 the façade colour, B2 the type of finishing, B3 the size of stone plates, B4 the thickness of the stone plates, B5 the location of cladding, E1 the façades orientation, E2 the distance from the sea, E3 the exposure to wind-rain action, E4 the exposure to damp, F1 in-use conditions, and G1 ease of inspection of the façade. The quantification of the durability factors is presented in Table 1.

**Table 1: Quantification of the variables included in the deterministic and factorial models**

<table>
<thead>
<tr>
<th>Durability factors</th>
<th>Numeric value - deterministic models</th>
<th>Weighting value - factor method</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 Type of stone</td>
<td>Limestone</td>
<td>1.040</td>
</tr>
<tr>
<td></td>
<td>Marble</td>
<td>0.960</td>
</tr>
<tr>
<td></td>
<td>Granite</td>
<td>1.390</td>
</tr>
<tr>
<td>B1 Colour</td>
<td>Light colours</td>
<td>1.010</td>
</tr>
<tr>
<td></td>
<td>Dark colours</td>
<td>0.880</td>
</tr>
<tr>
<td>B2 Type of finishing</td>
<td>Smooth</td>
<td>0.993</td>
</tr>
<tr>
<td></td>
<td>Rough</td>
<td>0.991</td>
</tr>
<tr>
<td>B3 Size of the stone plates</td>
<td>Medium size</td>
<td>1.040</td>
</tr>
<tr>
<td></td>
<td>Large size</td>
<td>0.940</td>
</tr>
<tr>
<td>B4 Thickness of the stone plates</td>
<td>Less than 2.5 cm</td>
<td>0.970</td>
</tr>
<tr>
<td></td>
<td>More than 2.5 cm</td>
<td>1.000</td>
</tr>
<tr>
<td>B5 Location of the cladding</td>
<td>Integral or partial elevated cladding</td>
<td>0.960</td>
</tr>
<tr>
<td></td>
<td>Bottom wall cladding</td>
<td>1.000</td>
</tr>
<tr>
<td>E1 Façade orientation</td>
<td>East/SE/NE</td>
<td>1.010</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>0.960</td>
</tr>
<tr>
<td></td>
<td>West/NW</td>
<td>0.930</td>
</tr>
<tr>
<td></td>
<td>South/SW</td>
<td>1.040</td>
</tr>
<tr>
<td>E2 Distance from the sea</td>
<td>Less than 5 km</td>
<td>0.960</td>
</tr>
<tr>
<td></td>
<td>More than 5 km</td>
<td>1.030</td>
</tr>
<tr>
<td>E3 Exposure to wind-rain action</td>
<td>Moderate</td>
<td>0.986</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
<td>0.984</td>
</tr>
<tr>
<td>E4 Exposure to damp</td>
<td>Low</td>
<td>1.030</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>0.910</td>
</tr>
<tr>
<td>F1 Type of property</td>
<td>Private/Housing</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Commerce and services</td>
<td>0.990</td>
</tr>
<tr>
<td>G1 Ease of inspection</td>
<td>Normal</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Unfavourable</td>
<td>0.870</td>
</tr>
</tbody>
</table>

2.3 Stochastic models

These methods allow analysing the probabilistic distribution of the degradation condition of stone claddings over time and according to their characteristics. With logistic regression it is possible to establish the probability that each case study has of reaching the end of its service life according to its age or characteristics - equation (14).

\[
P(Y = "End of service life") = 1 - \frac{1}{1 + e^{-12.743 + 0.1884r}}
\]  

(14)

2.4 Artificial intelligence based models

Artificial neural networks (ANNs) can be seen as emulations of biological neural systems, gathering information through a learning process. ANNs “learn” from a set of input and output patterns concerning the degradation of stone claddings, and are able to predict the behaviour of new
case studies. Using this model, the severity of degradation of stone claddings is obtained depending on the values of the explanatory variables and a set of coefficients defined according to the proposed formulation - equations (16) and (17).

\[ S_i = h_0 + \sum_{i=1}^{4} h_i H_i \]  
\[ H_i = \tanh \left( c_{i0} + c_{i1} F + c_{i2} S + c_{i3} SS + c_{i4} A \right) \]  

Where variables \( F, S, SS \) and \( A \) are respectively the type of finishing, distance from the sea, size of the stone plates, and age of the stone cladding, and coefficients \( h_0 \) to \( h_4 \) and \( c_{i0} \) to \( c_{i4} \) are listed in Table 2.

<table>
<thead>
<tr>
<th>( i )</th>
<th>( h_i (\cdot) )</th>
<th>( c_{i0} (\cdot) )</th>
<th>( c_{i1} (\cdot) )</th>
<th>( c_{i2} (\cdot) )</th>
<th>( c_{i3} (m^2) )</th>
<th>( c_{i4} (\text{year}^{-1}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.368E-01</td>
<td>-7.461E-02</td>
<td>1.040E+00</td>
<td>2.079E-01</td>
<td>-2.551E-01</td>
<td>-1.675E-01</td>
</tr>
<tr>
<td>1</td>
<td>-6.571E-02</td>
<td>5.434E-02</td>
<td>-1.016E+01</td>
<td>-1.838E-01</td>
<td>-3.709E-01</td>
<td>-6.621E-03</td>
</tr>
<tr>
<td>2</td>
<td>8.618E-02</td>
<td>7.720E-01</td>
<td>5.671E-02</td>
<td>-2.963E-01</td>
<td>-1.034E+00</td>
<td>4.278E-03</td>
</tr>
<tr>
<td>3</td>
<td>-1.190E-01</td>
<td>2.495E+00</td>
<td>1.620E-01</td>
<td>-2.387E-01</td>
<td>-1.596E+00</td>
<td>-2.333E-02</td>
</tr>
</tbody>
</table>

Fuzzy models are especially interesting when the problem modelled is subject to uncertainties, and are capable of describing systems and realities naturally vague. Fuzzy models combine numerical precision to transparency in the form of linguistic rules, dealing with complex phenomena with better performance than conventional linear models. In this study, a fuzzy model is used to estimate the severity of degradation of stone claddings - equation (18).

\[ S_n(x) = \frac{\sum_{i=1}^{C} \beta_i f_i(x)}{\sum_{i=1}^{C} \beta_i} \]  

Where \( f_i(x) \) denotes the function assigned to each of the rules and \( \beta_i \) the value of the membership function associated with the set of conditions that describe the case analysed (Vieira et al., 2015). The fuzzy rules describing the local input-output relation are presented in equations (19) and (20).

**Rule 1:** If \( u_1 \) is \( A_{11} \) and \( u_2 \) is \( A_{12} \) and \( u_3 \) is \( A_{13} \) and \( u_4 \) is \( A_{14} \) then:

\[ y_1(k) = 4.25 \cdot 10^{-4} u_1 + 6.00 \cdot 10^{-4} u_2 - 2.78 \cdot 10^{-2} u_3 + 1.38 \cdot 10^{-3} u_4 + 1.56 \cdot 10^{-2} \]  

**Rule 2:** If \( u_1 \) is \( A_{21} \) and \( u_2 \) is \( A_{22} \) and \( u_3 \) is \( A_{23} \) and \( u_4 \) is \( A_{24} \) then:

\[ y_2(k) = 1.04 \cdot 10^{-2} u_1 + 1.29 \cdot 10^{-2} u_2 + 1.09 \cdot 10^{-4} u_3 + 5.24 \cdot 10^{-3} u_4 - 1.96 \cdot 10^{-1} \]  

Where \( u_1 \) represent the type of finishing, \( u_2 \) the distance from the sea, \( u_3 \) the size of the stone plates and \( u_4 \) the age of the stone cladding. The membership functions for each of the four input variables are shown in Figure 1.
3. Comparative analysis of service life prediction models

All the proposed methods allow estimating the service life of stone claddings, leading to different results. The models present different characteristics; i) regression analysis and artificial intelligence based models are defined to obtain the estimated severity of degradation ($S_w$); in these models, to estimate the service life of stone claddings it is necessary to calculate the age of the façades corresponding to a $S_w$ of 20%, corresponding to the end of service life of stone claddings; ii) stochastic and factorial methods are not intended to predict the severity of degradation of stone claddings - the first allows estimating the probability of each case study reaching the end of its service life and the second allows calculating directly the estimated service life of façade claddings. Table 3 shows the estimated service life obtained using each model, with the associated standard deviation. Furthermore, some statistical indicators are used to evaluate the performance of each model, namely: the Pearson correlation coefficient ($r$); the determination coefficient ($R^2$), the mean absolute percentage error (MAPE). Lewis (1997) refers that the MAPE can be used to measure the average relative size of the absolute prediction deviation as a percentage of the corresponding demand value; the author suggests that a value of MAPE less than 10% reveals a model with a potentially very good predictions. Besides these parameters, other indicators can be used to analyse the accuracy of the proposed models. In this study, ROC (Receiver Operating Characteristics) curves are used to evaluate the sensitivity, specificity and accuracy of the service life prediction methods. ROC curves are normally used to measure the performance of a diagnosis system; in this study, ROC curves are used to evaluate the accuracy of the models in classifying correctly the case studies that “reached the end of their service life” and the case studies that “not reached the end of their service life”. This test produces three relevant indicators: i) accuracy of the model - measure of the overall percentage of cases correctly classified by the model; ii) sensitivity - measures the ability of the model to correctly predict the cases that have reached the end of their service life; iii) specificity - measures the probability of the model assuming that a cladding has not reached the end of their service life, when it has really not reached that stage; iv) area under the ROC curve - varies between 0 and 1 and measures the classification capability of the model (models with an area under the ROC curve below 0.5 show no discriminating power). Concerning the fuzzy logic model, it is not possible to estimate the model’s sensitivity, since in the sample test (randomly selected) none of the case studies has reached the end of its service life.
Table 3: Estimated service life and the statistical indicators used in the analysis of the predictive ability of the proposed models

<table>
<thead>
<tr>
<th>Model</th>
<th>Average ESL (years)</th>
<th>Standard deviation (years)</th>
<th>r</th>
<th>R²</th>
<th>MAPE</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Accuracy</th>
<th>Area under the ROC curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple nonlinear regression</td>
<td>68.182</td>
<td>-</td>
<td>0.880</td>
<td>0.775</td>
<td>6.347</td>
<td>43.48%</td>
<td>95.00%</td>
<td>89.16%</td>
<td>0.692</td>
</tr>
<tr>
<td>Multiple linear regression</td>
<td>77.213</td>
<td>7.650</td>
<td>0.843</td>
<td>0.711</td>
<td>7.128</td>
<td>52.17%</td>
<td>98.89%</td>
<td>93.60%</td>
<td>0.755</td>
</tr>
<tr>
<td>Polynomial regression</td>
<td>69.110</td>
<td>2.873</td>
<td>0.886</td>
<td>0.785</td>
<td>6.388</td>
<td>56.52%</td>
<td>98.33%</td>
<td>93.60%</td>
<td>0.774</td>
</tr>
<tr>
<td>Gompertz curve</td>
<td>72.775</td>
<td>7.489</td>
<td>0.904</td>
<td>0.818</td>
<td>6.101</td>
<td>69.57%</td>
<td>98.33%</td>
<td>95.07%</td>
<td>0.839</td>
</tr>
<tr>
<td>Von Bertalanffy curve</td>
<td>73.585</td>
<td>8.114</td>
<td>0.895</td>
<td>0.801</td>
<td>6.502</td>
<td>73.91%</td>
<td>98.33%</td>
<td>95.57%</td>
<td>0.861</td>
</tr>
<tr>
<td>Richards curve</td>
<td>69.380</td>
<td>4.642</td>
<td>0.897</td>
<td>0.805</td>
<td>6.295</td>
<td>69.57%</td>
<td>98.33%</td>
<td>95.07%</td>
<td>0.839</td>
</tr>
<tr>
<td>Morgan-Mercer-Flodin curve</td>
<td>76.219</td>
<td>5.610</td>
<td>0.845</td>
<td>0.714</td>
<td>7.117</td>
<td>39.13%</td>
<td>100%</td>
<td>93.10%</td>
<td>0.696</td>
</tr>
<tr>
<td>Weibull curve</td>
<td>68.563</td>
<td>1.980</td>
<td>0.880</td>
<td>0.775</td>
<td>6.443</td>
<td>52.17%</td>
<td>95.00%</td>
<td>90.15%</td>
<td>0.736</td>
</tr>
<tr>
<td>Brody curve</td>
<td>79.370</td>
<td>8.358</td>
<td>0.799</td>
<td>0.639</td>
<td>8.198</td>
<td>21.74%</td>
<td>100%</td>
<td>91.13%</td>
<td>0.609</td>
</tr>
<tr>
<td>Exponential regression</td>
<td>73.193</td>
<td>7.422</td>
<td>0.879</td>
<td>0.772</td>
<td>6.353</td>
<td>43.48%</td>
<td>95.00%</td>
<td>89.16%</td>
<td>0.692</td>
</tr>
<tr>
<td>Potential regression</td>
<td>68.008</td>
<td>1.828</td>
<td>0.875</td>
<td>0.766</td>
<td>7.213</td>
<td>52.17%</td>
<td>95.00%</td>
<td>90.15%</td>
<td>0.736</td>
</tr>
<tr>
<td>ANNs</td>
<td>70.256</td>
<td>5.802</td>
<td>0.839</td>
<td>0.704</td>
<td>7.717</td>
<td>80.00%</td>
<td>93.48%</td>
<td>94.00%</td>
<td>0.867</td>
</tr>
<tr>
<td>Fuzzy systems model</td>
<td>90.275</td>
<td>31.230</td>
<td>0.882</td>
<td>0.778</td>
<td>7.635</td>
<td>-</td>
<td>78.43%</td>
<td>80.00%</td>
<td>-</td>
</tr>
<tr>
<td>Factor method</td>
<td>66.905</td>
<td>10.236</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Graphical method</td>
<td>70.545</td>
<td>17.097</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

4. Multi-criteria analysis of service life prediction models

Table 4 shows the description of the criteria applied in the multi-criteria analysis performed.

Table 4: Description of the criteria adopted

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
<th>Analysis of the proposed models</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>The learning process includes: i) a comprehensive survey of the state of the art about the statistical tool underlying the prediction model; ii) an analysis of the potential and applicability of the model to service life prediction; iii) an evaluation of the results that may be obtained and the best way to achieve those results; iv) the model experimentation and statistical software necessary for its implementation; v) the ability to deduce the results.</td>
<td>The simpler method is simple nonlinear regression, which is based on fitting a mathematical equation to a data set. Fuzzy logic is the most complex method, with a time-consuming learning process and whose theoretical assumptions are more intricate.</td>
</tr>
<tr>
<td>P2</td>
<td>In this criterion the time necessary for the creation and processing of the model is considered. It is assumed that the researcher knows exactly what is to be achieved with and how to proceed to model each approach.</td>
<td>Simple and multiple linear regression are the models whose results are obtained immediately. Artificial intelligence-based models are the most time-consuming approaches.</td>
</tr>
<tr>
<td>P3</td>
<td>In this criterion, two parameters are analysed: i) availability and prominence of the software; ii) cost of software’s acquisition.</td>
<td>Models that use available online software (such as Excel) occupy the most favourable position. Models that require the application of expensive software adopted in this study appear in the bottom of the hierarchical scale adopted.</td>
</tr>
<tr>
<td>P4</td>
<td>Concerning the interpretability of results and usefulness of the information produced, two parameters are considered: i) readability of the output and ease of use provided by the mathematical equation models for a user unfamiliar with statistical models; ii) richness of the information obtained by the models and its usefulness for service life prediction.</td>
<td>Deterministic and artificial intelligence-based methods lead to an average estimated value. On the other hand, stochastic models provide probabilistic information, with data concerning the risks associated to the degradation process (producing a richer information).</td>
</tr>
<tr>
<td>U1</td>
<td>The number and subjectivity of the variables included in the models are analysed in this criterion. Concerning the subjectivity associated with the variables, the following criteria are adopted: i) age is a parameter that is easily quantifiable; ii) variables such as distance from the sea are objective parameters (easy to quantify); iii) variables such as exposure to damp are more subjective and are more difficult to quantify.</td>
<td>The simple nonlinear regression and logistic regression are the most favourable models based on this criterion, since they use only one variable. The factor method is the model in the worst position, since it includes eleven variables in its definition.</td>
</tr>
<tr>
<td>U2</td>
<td>In this criterion, three factors are applied: i) the ratio between the average service life predicted by the model and the average service life obtained by the graphical method; ii) the deviation between the values of the estimated service life with a probability higher than 5% to be exceeded predicted by the model and observed; iii) the difference between the probability distribution that characterizes the observed values and the probability distribution associated with the observed values, assuming a normal distribution for all models.</td>
<td>Based on this criterion, logistic regression is the most accurate model, followed by the factorial method and nonlinear multiple regression using a Gompertz curve. The fuzzy logic model is the least accurate, resulting in an estimated average service life much higher than the values obtained through other methods, with the highest deviation between the predicted and the observed values.</td>
</tr>
</tbody>
</table>
The methodologies described in the previous sections are conceptually distinct and naturally lead to different results, but all of them are capable of accurately describe the degradation process of the stone claddings. The different actors in the construction sector need to decide which model to use. However, Basel and Brühl (2013) refer that a rational process of decision-making can be complex, vague and of a controversial nature, as it incorporates subjective criteria and different "points of view". In this study, a multi-criteria analysis is therefore performed taking into account the factors that should be considered by stakeholders, evaluating two points of view: the planner’s point of view (who defines the model); and the user’s perspective (who uses the model). From the planner’s point of view, four criteria are considered: P1) difficulty in learning the model; P2) time consumed in the model’s definition; P3) software used; P4) number and subjectivity of the variables included in the model. Regarding the user’s perspective, two criteria are adopted: U1) interpretability and utility of the information obtained using the models; U2) model’s accuracy.

Table 5 shows the impact profiles of the six criteria analysed for stone claddings. There are different approaches to multi-criteria models; in this study, an additive aggregation approach with compensatory rationality is adopted (Cochran and Chen, 2005). In an overall analysis, fuzzy systems are those with worst results, being the most complex model.

<table>
<thead>
<tr>
<th>Model</th>
<th>P.1 Ease of learning</th>
<th>P.2 Time required to build the model</th>
<th>P.3 Necessary software</th>
<th>P.4 Variables included in the model</th>
<th>U.1 Utility of the results</th>
<th>U.2 Model’s accuracy</th>
<th>Overall scale</th>
<th>Overall standardized scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterministic models</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple nonlinear regression</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.343</td>
<td>5.343</td>
<td>0.969</td>
<td></td>
</tr>
<tr>
<td>Multiple linear regression</td>
<td>0.75</td>
<td>0.998</td>
<td>1</td>
<td>0.857</td>
<td>1</td>
<td>0.878</td>
<td>5.483</td>
<td>1.000</td>
</tr>
<tr>
<td>Polynomial model</td>
<td>0.625</td>
<td>0.877</td>
<td>0.108</td>
<td>1</td>
<td>0.576</td>
<td>3.329</td>
<td>0.520</td>
<td></td>
</tr>
<tr>
<td>Gompertz curve</td>
<td>0.625</td>
<td>0.877</td>
<td>0.108</td>
<td>0.286</td>
<td>1</td>
<td>0.957</td>
<td>3.853</td>
<td>0.636</td>
</tr>
<tr>
<td>Von Bertalanffy curve</td>
<td>0.625</td>
<td>0.877</td>
<td>0.108</td>
<td>0.286</td>
<td>1</td>
<td>0.983</td>
<td>3.879</td>
<td>0.642</td>
</tr>
<tr>
<td>Richards curve</td>
<td>0.625</td>
<td>0.877</td>
<td>0.108</td>
<td>0.857</td>
<td>1</td>
<td>0.736</td>
<td>4.203</td>
<td>0.714</td>
</tr>
<tr>
<td>Morgan-Mercer-Flodin curve</td>
<td>0.625</td>
<td>0.877</td>
<td>0.108</td>
<td>0.286</td>
<td>1</td>
<td>0.763</td>
<td>4.087</td>
<td>0.689</td>
</tr>
<tr>
<td>Weibull curve</td>
<td>0.625</td>
<td>0.877</td>
<td>0.108</td>
<td>0.714</td>
<td>1</td>
<td>0.469</td>
<td>3.793</td>
<td>0.623</td>
</tr>
<tr>
<td>Brody model</td>
<td>0.625</td>
<td>0.877</td>
<td>0.108</td>
<td>0.714</td>
<td>1</td>
<td>0.868</td>
<td>4.192</td>
<td>0.712</td>
</tr>
<tr>
<td>Exponential model</td>
<td>0.625</td>
<td>0.877</td>
<td>0.108</td>
<td>0.714</td>
<td>1</td>
<td>0.945</td>
<td>4.269</td>
<td>0.729</td>
</tr>
<tr>
<td>Potential model</td>
<td>0.625</td>
<td>0.877</td>
<td>0.108</td>
<td>0.714</td>
<td>1</td>
<td>0.429</td>
<td>3.753</td>
<td>0.614</td>
</tr>
<tr>
<td>Computational methods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Artificial neural networks</td>
<td>0.125</td>
<td>0</td>
<td>0.893</td>
<td>1</td>
<td>0.5</td>
<td>0.863</td>
<td>3.381</td>
<td>0.531</td>
</tr>
<tr>
<td>Fuzzy logic model</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.000</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Factorial methods</td>
<td>0.875</td>
<td>0.752</td>
<td>1</td>
<td>0.857</td>
<td>1</td>
<td>0.991</td>
<td>5.475</td>
<td>0.998</td>
</tr>
<tr>
<td>Stochastic models</td>
<td>0.375</td>
<td>0.939</td>
<td>0.108</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4.422</td>
<td>0.763</td>
</tr>
</tbody>
</table>

The multiple linear regression is the model that globally presents the best results, combining an average degree of complexity with a high level of efficiency. Once the criteria to be used in a multi-criteria analysis are defined, it is possible to perform a new analysis considering the relative importance of each criterion for stakeholders. In fact, some criteria are more relevant than others.
sometimes even decisive. For this, three hypothetical scenarios for the preferences of decision-makers are considered: i) scenario 1 - the decision-maker prefers the ease of the model’s application, neglecting other criteria, i.e. a higher weight is assigned to the criteria related with the ease of learning, the time required to build the model and the number and subjectivity of the variables included in the model (Table 6); ii) scenario 2 - the decision-maker is essentially interested in the model’s accuracy and the utility of the results (Table 7); iii) scenario 3 - the decision-maker needs to get most accurate model, in the shortest possible time (Table 8).

Table 6: Sensitivity analysis of weights assigned to scenario 1

<table>
<thead>
<tr>
<th>Criteria’s weight</th>
<th>Overall assessment of the models</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda P.1 = 2; \lambda P.2 = 2; \lambda P.3 = 1; \lambda P.4 = 2; \lambda U.1 = 1; \lambda U.2 = 1 )</td>
<td>1st Simple nonlinear regression; 2nd Multiple linear regression Worst performance - Fuzzy logic model</td>
</tr>
<tr>
<td>( \lambda P.1 = 8^*; \lambda P.2 = 2; \lambda P.3 = 1; \lambda P.4 = 2; \lambda U.1 = 1; \lambda U.2 = 1 )</td>
<td>1st Simple nonlinear regression; 2nd Factor method Worst performance - Fuzzy logic model</td>
</tr>
</tbody>
</table>

* Above this value, even increasing significantly the weight value \( \lambda P.1 \), maintaining the remaining weights unchanged, the hierarchical scale of models remains the same.

Table 7: Sensitivity analysis of weights assigned to scenario 2

<table>
<thead>
<tr>
<th>Criteria’s weight</th>
<th>Overall assessment of the models</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda P.1 = 1; \lambda P.2 = 1; \lambda P.3 = 1; \lambda P.4 = 1; \lambda U.1 = 2; \lambda U.2 = 2 )</td>
<td>1st Factor method; 2nd Multiple linear regression Worst performance - Fuzzy logic model</td>
</tr>
<tr>
<td>( \lambda P.1 = 1; \lambda P.2 = 1; \lambda P.3 = 1; \lambda P.4 = 1; \lambda U.1 = 5; \lambda U.2 = 20^* )</td>
<td>1st Factor method; 2nd Logistic regression Worst performance - Fuzzy logic model</td>
</tr>
<tr>
<td>( \lambda P.1 = 1; \lambda P.2 = 1; \lambda P.3 = 1; \lambda P.4 = 1; \lambda U.1 = 20^*; \lambda U.2 = 5 )</td>
<td>1st Factor method; 2nd Multiple linear regression Worst performance - Fuzzy logic model</td>
</tr>
</tbody>
</table>

* Above this value, even increasing significantly the weight value \( \lambda U.1 \), maintaining the remaining weights unchanged, the hierarchical scale of models remains the same.

** Above this value, even increasing significantly the weight value \( \lambda U.2 \), maintaining the remaining weights unchanged, the hierarchical scale of models remains the same.

Table 8: Sensitivity analysis of weights assigned to scenario 3

<table>
<thead>
<tr>
<th>Criteria’s weight</th>
<th>Overall assessment of the models</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda P.1 = 2; \lambda P.2 = 2; \lambda P.3 = 1; \lambda P.4 = 1; \lambda U.1 = 1; \lambda U.2 = 2 )</td>
<td>1st Multiple linear regression; 2nd Factor method Worst performance - Fuzzy logic model</td>
</tr>
<tr>
<td>( \lambda P.1 = 5^<em>; \lambda P.2 = 5^</em>; \lambda P.3 = 1; \lambda P.4 = 1; \lambda U.1 = 1; \lambda U.2 = 2 )</td>
<td>1st Simple nonlinear regression; 2nd Multiple linear regression Worst performance - Fuzzy logic model</td>
</tr>
<tr>
<td>( \lambda P.1 = 2; \lambda P.2 = 2; \lambda P.3 = 1; \lambda P.4 = 1; \lambda U.1 = 1; \lambda U.2 = 3^** )</td>
<td>1st Factor method; 2nd Multiple linear regression Worst performance - Fuzzy logic model</td>
</tr>
</tbody>
</table>

* Above this value, even increasing significantly the weights values \( \lambda P.1 \) and \( \lambda P.2 \), maintaining the remaining weights unchanged, the hierarchical scale of models remains the same.

** Above this value, even increasing significantly the weight value \( \lambda U.2 \), maintaining the remaining weights unchanged, the hierarchical scale of models remains the same.

5. Discussion

The proposed service life prediction models analysed in this study present high levels of accuracy in the description of the degradation phenomena of stone claddings, according to the statistical parameters considered. In fact, all the proposed models show a MAPE lower than 10%, revealing a potentially very good predictive capacity. Additionally, the coefficients of determination (\( R^2 \)) and correlation (\( r \)) are always greater than 0.6 and 0.8, respectively, indicating that there is a strong
correlation between the observed data and the values predicted by the models. Regarding the capability of correctly classify the cases that have reached the end of its service life, it can be seen that all the models present accuracy higher than 80%, revealing a good discriminant power. The proposed models lead to an average estimated service life ranging from 66 to 90 years, for factor method and fuzzy systems, respectively. The results obtained seem realistic from a physical point of view, due to the high durability of stone claddings, and are coherent with the values present in the literature related to the service life of this type of cladding (Silva et al., 2011). When the service life of stone claddings is reached, they should be subjected to generalised rehabilitation actions in order to ensure that they are able to fulfil all the performance requirements. In fact, the knowledge of the ESL allows optimising the maintenance actions, in a rational and technically informed way, avoiding unnecessary costs (in an economic and environmental level).

For stakeholders to whom the simplicity of the model is the most relevant parameter (scenario 1), it is suggested to use an intermediate model, for example the multiple linear regression, whose modelling is extremely simple and allows encompassing the significant variables in the degradation process (unlike simple regression that only encompasses age) and factorial method (which includes more variables, although these may not be relevant to the phenomenon under analysis). In some situations, if the stakeholders want to define warranty periods and manage a large built park, it is important to obtain information regarding the degradation of the claddings in the form of a probability distribution, thereby evaluating the risk of a given decision regarding the rehabilitation of the façade; in this case, it is proposed to choose stochastic models. These methods are essential when the stakeholders intend to define with a known risk the instant after which they cannot ensure that the claddings will be able to conveniently comply with the function for which they were designed. Artificial intelligence-based models are definitely the most complex ones, whose definition is more intricate and whose results are more difficult to be interpreted. However, these models are obtained through a validation process that ensures the ability of generalization of the models. For an unfamiliar user, the accuracy of these models is not sufficiently compensatory, and it is advisable to opt for less complex models. However, in the case of a manager of a very large building stock, the high economic burden associated with the maintenance and rehabilitation of this heritage can justify the use of such tools.

6. Conclusions

Based on this study, it is not possible to unquestionably define the best model. In a global analysis, it can be concluded that simpler models consume less time and can be equally effective but analyse the problem only in one dimension, i.e. they only relate loss of performance of the stone cladding with its age. More complex models consume more time, are more complex and require software that may not be available to all and whose use may be more difficult; however, usually they are more robust and analyse various parameters that influence the degradation of stone claddings, allowing obtaining more interesting findings regarding the choice of a particular type of cladding over another depending on given environmental exposure conditions. Finally, stochastic models produce more relevant information, since they provide the probability of occurrence in order to evaluate the risk associated with the end of service life of stone claddings. Multi-criteria analysis allows a multidimensional analysis of the choice of a particular model for service life prediction. This analysis allows evaluating and comparing the different models, establishing hierarchical scales of preference. Regardless of the criteria adopted, there is always subjectivity
associated with the decision-making process, since this process is conditioned by individual perceptions and actual preferences of the decision-makers. In fact, the decision-maker may not be able to define precisely the level of importance of each criterion (criteria weights), and even when he/she refers to the opinion of experts, they can assign different values to the weights of the criteria. Ultimately, it will be up to the decision-maker to choose the best model depending on the expected result, using the recommendations of this study. The selection of the best service life prediction model for a given application is extremely relevant for practical applications, such as the definition of maintenance policies for real estate managers, or the definition of warranty periods for insurance companies.

References


Ageing and Living Environment: A Review of the Need for Smart Home Technologies (SHT) In Hong Kong

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Abstract

Smart home technology (SMT) has been identified as a promising means of meeting the desire of older people to remain independent, maintaining their quality of life (QoL) while containing spiralling elderly care costs. SHT development in Hong Kong, however, as well as in many other countries, lacks sufficient reliable information on such as the needs and requirements of older people concerning technical design needs and appropriate technological solutions to address these needs. Without a clear and accurate understanding of the needs of older adults, the value of the use and implementation of SHT in support of the living of old people in Hong Kong is questionable. The aim of this paper is to present the results of an investigation into the perceptions and expectations of home-based smart technology amongst the elderly in Hong Kong. Factors influencing the decisions of elderly people to use SHT have been identified. A focus group meeting (and snowball sampling) provided the data for this study. A total of 98 participants aged between 55 and 76 participated in the study. The participants were divided into fourteen interview groups. Twelve factors influencing the use of SHT were identified from focus group discussions, which were categorised into the four groups, operational design of devices, functions provided by devices, personal considerations, and external influence. By gaining an understanding of their needs and a QoL-oriented smart home devices design model, this study provides a preliminary insight into the way SHT should be designed, adopted and implemented so as to provide a better living environment for older people in Hong Kong living independently.

Keywords: Smart home technology, Ageing-in-place, Motivating factors, Hong Kong
1. Introduction

Hong Kong is facing a sharp increase in the proportion of older people in the overall population and an increasing number of independent-living older adults. This generates significant economic and social costs, and stress placed on family, carers and the community in general. With the age-associated decline in health and functional ability, supporting older adults in line with the ‘ageing-in-place’ concept may require modification of their existing home settings. Smart home technology (SHT) is regarded as a potential means of meeting the desire of the elderly to remain independent, maintaining their quality of life (QoL), while containing spiralling care costs. Despite the recent Government’s pilot scheme (i.e. Hong Kong Housing Society) to promote SHT in housing for the elderly, there is limited understanding of the appropriate form such SHT interventions should take. In this regard, this study aims to fill this understanding gap by identifying the factors motivating the elderly to adopt SHT. The ‘third age’ is the targeted potential group of ageing people in this study, because they have an out-going attitude, a relatively open mind, and better financial status for the funding of SHT. The ‘third age’ is that group of post-retirement people who have fewer family responsibilities, adequate resources, and good health providing freedom to seek self-fulfilment and purposeful engagement (Rubinstein, 2002; Weiss & Bass, 2002). The perception of the ‘third age’ group, as prospective SHT users, provides preliminary and valuable insights into SHT development planning for aging people in Hong Kong.

2. Ageing-in-place: an opportunity of SHT development in Hong Kong

The Thematic Household Survey revealed that approximately 97% of elderly respondents in Hong Kong had no intention of moving to a residential care home, and 82% prefer to remain living in their own home when the choice is available to them and their physical health and financial situation allows (Census and Statistics Department, 2009). The growing desire of older adults for ‘ageing-in-place’, remaining in their familiar home environment or an environment of their choice for as long as possible, reflects an optimum strategy that can reduce stress, improve their QoL, allowing continuity and self-control over important aspects of daily life. ‘Ageing-in-place as the core’ has been recently launched as a strategic and holistic planning policy objective for the care of elderly in Hong Kong (Labour and Welfare Bureau, 2014).

A home living environment is considered to have a strong linkage with the physical and psychological well-being of older people (Oswald et al., 2007). Past research shows that older people are likely to spend 80% of their time at home, more than other age groups (Baltes et al., 1999; Iwarsson et al., 2007). The person-environment fit model (Lawton & Nahemow, 1973) posits that older adults become increasingly reliant on their surroundings, such as their physical living environment, to offset functional decline as they continue to age (Brawley, 2001). The home environment should function to accommodate losses of physical function, enhancing the independence of older adults in daily activities and autonomy (Lawton et al., 1973). The
significant advances in microprocessor-based technologies over the last decade has led to the emergence of home automation and intelligent control technologies which provide convenience, comfort, energy efficiency, security, and a better quality of home living (van Hoof & Kort, 2009; Wong, Hang, & Wang, 2005). SHT have been proposed as a possible solution assisting older people to maintain independent and safe living at home in performing the activities of daily living, predicting normal and abnormal behaviour, and alerting carers of potentially dangerous behaviour (Blaschke, Freddolino, & Mullen, 2009; World Health Organization, 2012). SHT includes a range of emergency assistance systems, security and safety features, falls prevention, sensors, and timers that aim to reduce falls, disability, stress, fear, and social isolation, and monitor the daily functioning of the elderly at home (Barlow & Venables, 2004). For example, real-time monitoring and detection of accidental falls or slipping amongst elderly people from standing, chairs, or beds (Yu, 2008) would enable first-aid by carers, families, and paramedics as soon as possible (Abbate et al., 2012). Detection of unauthorised intrusion will maintain home security (Gaßner & Conrad, 2010; Lehmann, Giacini, & Davis, 2013). Arguably, a home setting equipped with SHT should reduce stress and optimise QoL: for example, by improving functional capacity; monitoring health status, enhancing psychological well-being, increasing social support, improving morale, enhancing independence, and allowing for coping and adjustment. SHT can also help relieve the burden on carers and social support services (Blaschke et al., 2009; Demiris & Hense, 2008).

3. Research Method

A focus group was used to gather collective thoughts and insights into the use of SHT by the senior citizens in Hong Kong. Those collective views of the research participants emerged from evaluation of their informal conversations and debates (Kitzinger, 1994; Liamputtong, 2011). Those collective views of SHT consolidate the factors identified during the conservations of this study. This research study adopted snowball sampling to expand the recruitment of the participants. Subject recruitment information was sent in two ways. Firstly, the project information and subject recruitment details were sent to members of The Institute of Active Ageing (IAA) of the Hong Kong Polytechnic University with the institute’s support. The Institute of Active Ageing is a non-profit university-driven organisation that promotes active ageing to third age people by organising a wide range of programmes and activities. Secondly, subject recruitment posters were placed around a university campus, which is located at the city centre with high accessibility. The snowball effect started from these two spreads. Most of the participants were referred by the attending participants. A total of 98 participants aged between 55 and 76 recruits and took part in the group interviews. The participants expressed their interests in the SHT topic when they signed up for the group interviews. The participants were arranged into 14 groups of size between 6 to 9 participants. Ten SHT devices were presented to the participants by short video clips. These ten SHT devices and applications were classified into living environment control, safety, health monitoring, and social communication categories (Table 1). Semi-structured questions were asked to encourage discussions on their reasons, preference, acceptance, motivation, and suggestions for using SHT.
Table 1: Categories of Demonstrated SHT Devices and Applications

<table>
<thead>
<tr>
<th>Categories</th>
<th>SHT Devices and (Source of Video Clips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living Environment Control</td>
<td>Environmental Control System (LSCM R&amp;D Centre, 2015)</td>
</tr>
<tr>
<td></td>
<td>Energy Management System – Smart Meters (Hkbnnewson, 2012)</td>
</tr>
<tr>
<td>Safety</td>
<td>Cooking Safety Control (Amano Connect, 2015)</td>
</tr>
<tr>
<td></td>
<td>Infrared Environment Monitoring System (LSCM R&amp;D Centre, 2015)</td>
</tr>
<tr>
<td></td>
<td>Home-stay Wellness Sensing System (LSCM R&amp;D Centre, 2015)</td>
</tr>
<tr>
<td></td>
<td>Emergency Alarm ( Senior Citizen Home Safety Association, 2000)</td>
</tr>
<tr>
<td>Health Monitoring</td>
<td>Cardiovascular Monitoring Device (LSCM R&amp;D Centre, 2015)</td>
</tr>
<tr>
<td></td>
<td>Non-Contract Electro-Cardiogram Monitoring Bedsheet (Centre for Innovation and Technology, 2010)</td>
</tr>
<tr>
<td>Social Communication</td>
<td>Smart Communication Board (LSCM R&amp;D Centre, 2015)</td>
</tr>
<tr>
<td></td>
<td>Video Conferencing (CFSC, 2014)</td>
</tr>
</tbody>
</table>

4. Findings: Factors influencing the adoption of SHT

System support and management of devices is considered an important factor underlying the successful adoption of SHT. SHT devices and applications are usually composed of electronic components, computer programmes, and communications networks. The elderly frequently express concern about the possibility of instability or malfunctioning of SHT devices and applications due to poor system performance and electricity supply. A number of participants asked ‘What I can do if the device is out of order?’ after most of the video demonstrations and ‘What will happen if the electricity supply is cut?’ after demonstration of a home environment control system. The respondents further explained that they did care about support for those SHT devices and the quality of support provided by the management when there are problems. The type of supports of concern included provision of instruction, on-site service, and the response rate and time to each inquiry. Apart from system support, management of the system connecting SHT devices to the off-site systems, such as the emergency alarm and the infrared environmental monitoring system, have been considered. For example, participants are worried about whether there is a response from the operator if they press the emergency button. Regarding some monitoring systems, the participants worry whether the staff in the off-site centres, actually notice the emergency condition even though the system has alerted them. A group of participants who care about personal privacy when their living environment is connected to an off-site system and personal data is stored. This implies there are issues of trust to consider and overcome.

The maintenance of devices is another concern raised frequently by elderly participants in group discussions. Corresponding to the last factor, this concern also emerges from their perceptions of using electronic devices. Most of the participants were concerned about the need to spend a lot on the maintenance, repair, and warranty of installed SHT devices. For example, two of the most raised questions after demonstrations, are ‘Is it difficult to maintain the device in daily use?’ and
‘Is it difficult to find someone to repair the device if it is damaged?’ Those questions indicate that participants are concerned about the robustness and reliability of SHT systems. Therefore, an all-round warranty service is preferred by the respondents to maintain the devices.

In line with the concerns mentioned above, operational design of devices is another crucial factor if SHT is to be used by the third age participants. In term of design, the participants prefer SHT devices to be safe, effective for ageing people’s daily activities and safety, and suitable for the Hong Kong home environment. The participants also expressed their concern for contingency design. For example, a number of participants asked ‘Can I operate the home appliances manually without electronic supply?’ after a video demonstration of a home environmental control system. This implies that the basic operations and functions of home appliances should not be affected when SHT devices have problems. It was agreed that these requirements related to the design of devices were applicable for all SHT devices in general. For those SHT devices that interact with ageing people, such as the smart communication board, the participants are concerned that the devices must be user-friendly and easy to learn how to use.

The increasing popularity and level of usage and penetration of smart devices in society is another factor that influences the decision of whether to adopt individual SHT devices. Obviously, this factor is influenced by the reputation of particular devices. The participants expressed the view that if a SHT device has high usage and penetration rates into ageing people networks and society, they would be more willing to use it. They believe that high rates of usage and penetration of a particular device are correlated with a better support and reasonable device costs. Most participants have a good understanding of the emergency alarm services (EAS) provided in Hong Kong, which reflects its high penetration rate in society. Correspondingly, emergency alarms and associate services were found as the most well-known devices during group interviews. This indicates that higher usage and penetration rates of a particular SHT device influence the willingness of people to use them.

The participants were aware that their health and physical functions would get worse as they age. The participants expressed their willingness to use SHT devices if the devices would make housework easier. The third age people worried about heavy daily activities/tasks in the future, such as cleaning windows and hanging out clothes. As Hong Kong is a Chinese culture society, 63% of elderly citizens live with family members (Census and Statistics Department, 2009). Elderly people usually take over the family housework. Some participants stated that they would rather keep on helping their families with housework instead of receiving help.

Individual needs on SHT was another issue highlighted by the third age participants to show their willingness to use SHT. The participants argued that this important factor influence final decisions on the use of a particular SHT device. As the living space per person in Hong Kong is tight and the living cost is high (Economist Intelligence Unit, 2015; Ho, 2015), the third age people are likely to install handy SHT devices which suits their individual needs, such as health and physical conditions. Participants were concerned as to whether the particular device could reduce body disorders and help to perform some daily tasks due to body limitations. In the group discussions,
the participants were frequently asked in what circumstances would they use a particular SHT device.

*Enhancing home safety* is considered a constituent of QoL for elderly people (Cardea & Tynan, 1987; Lin et al., 2007). The participants stated that home safety is a fundamental and essential purpose of a SHT installation. The participants stated that they would consider installing and using i) infrared environment monitoring systems, ii) home-stay wellness sensing systems, and iii) emergency alarms when health and physical condition were deteriorating. Despite the fact that many participants do not intent to install these SHT devices now, they are highly likely to install them when there is a need to enhance home safety. In terms of home safety, the significance of a cooking safety control system was highlighted in some group discussions. A number of participants had experienced the case of stove left on in their home. Avoiding fire incidents in the kitchen is one of their priorities in terms of home safety.

*Health* is a dimension of QoL for elderly people (Bowling et al., 2013; Farquhar, 1995; Gabriel & Bowling, 2004). The home safety function provided by SHT devices helps in emergency. SHT devices designed for health monitoring, aim at recording and analysing the health conditions of ageing people in order to reduce the number of emergency situations. The discussions of health monitoring devices is now seen as an issue of public health. A number of participants argued that a long-term health-monitoring programme assisted by SHT devices is a solution, also strengthening the awareness of health by the public. They stated that the installation of health monitoring devices at home should not only be beneficial to themselves, but also to their family. They agreed that health monitoring SHT devices were important, especially for long-term health issues of the society.

*The cost of SHT devices* is considered another factor of significance in determining the willingness to adopt SHT devices by third age participants. The participants expressed concern about spending due to a low or zero income after retirement. They tend to save money for medical expenses, manage their budget well during life after retirement. Their consideration includes the costs of devices, costs of maintenance, and costs of management, which aligns with their concerns about the maintenance of devices, (Point 4.2) above. In addition, *the level of support from Government* on SHT adoption was raised in group discussions. The participants agreed that SHT is a good idea to encourage ageing-in-place in Hong Kong. In this regard, the participants thought that initiatives by government would be an ideal way to promote the SHT concept. According to participants’ comments, potential governmental efforts could be classified into three types. First, direct financial support from the government, such as subsidies, is suggested and highlighted by the participants as necessary for promoting the SHT concept among the elderly in Hong Kong. The participants would be happy to try SHT if there is a supporting government scheme. Second, support offered to groups and organisations concerned with SHT, including research and development, manufacturers, and contractors, is a way to strengthen the functions of SHT devices. Third, the participants suggested adoption of a wider pilot scheme for SHT devices in new senior housing, to help speed up promotion of SHT to the public.
In group discussions, the importance of communication with different parties and maintaining social life were discussed and highlighted after a video of a smart communication board and video conferencing devices had been demonstrated. Sustaining communication with different parties was raised by participants in connection with QoL in social relationships (Bowling et al., 2013; Farquhar, 1995; Gabriel et al., 2004). The participants commented that communication devices and applications, such as the smart phone and desktop computer equipped for instant chatting and video call applications, are commonly used by the third age elderly nowadays. They agreed that technology helps them to maintain social connections with family members, friends, and neighbours and is crucial to their lives. They also expect SHT devices to help maintain communication with the external environment using advanced and SHT high-tech devices, for example, video conferencing video functions integrated with other home appliances.

The factors identified in this study can be categorised into four types (Table 2). The findings indicate that ageing people take operational issues into account when thinking of using SHT devices. The identified factors relate to operational issues of SHT include system support and management of devices, maintenance of devices, and operational design of devices. The participants particularly raised some functional SHT considerations. Those include support of housework, enhancing home safety, health monitoring, and maintaining communication with the external environment. Ageing people expect SHT to provide housework support, home safety, health monitoring, and communications. In addition, the individual needs and financial considerations indicate the individual concern when thinking of using and installing SHT. The identified factors indicate that external issues also affect the use of SHT by ageing people. These factors include levels of usage and penetration of devices, government support, and family support. These four types of factor encompass a wide range of considerations by ageing people when using SHT.

Table 2: Four categories of found factors

<table>
<thead>
<tr>
<th>Categories</th>
<th>Found Factors</th>
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<tbody>
<tr>
<td>Operational Issues of SHT</td>
<td>System support and management of devices</td>
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<td></td>
<td>Maintenance of devices</td>
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<tr>
<td></td>
<td>Operational design of devices</td>
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<tr>
<td>Functional Consideration on SHT</td>
<td>Support to housework</td>
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<tr>
<td></td>
<td>Enhancing home safety</td>
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<tr>
<td></td>
<td>Health monitoring</td>
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<tr>
<td></td>
<td>Maintaining communication with external environment</td>
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<tr>
<td>Individual Concern</td>
<td>Individual’s needs</td>
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<tr>
<td></td>
<td>Financial considerations</td>
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<tr>
<td>External Issues</td>
<td>Level of usage and penetration of devices</td>
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<td></td>
<td>Government support</td>
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<td></td>
<td>Family support</td>
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5. Conclusions and Further Study

This study has identified factors that motivate the adoption of SHT, which meets the ageing-in-place desires of the local older adults. This paper provides preliminary insights into the potential for SHT in Hong Kong, and makes four proposals for promoting aging-in-place through SHT, as follows: i) enhance the operational design of SHT devices; ii) match the needs of the elderly with the functionality of SHT; iii) improve support for SHT adoption, and iv) understand the needs of ageing people in relation to SHT. In the next phase, the data collected will be further analysed so as to understand the interrelationships between these factors using the interpretive structural modelling (ISM) approach. With the appropriate technological intervention, this generates a ‘win-win’ situation for the elderly, carers, the community and the government in the long run, by enhancing the independence of older people and reducing the burden and distress of the carers, releasing government institutional healthcare funds and older person’s time for more productive activities in support of the national economy, leading to a more cost-effective and less-dependent need for public-sector service provision.

Acknowledgements

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References


Economist Intelligence Unit. (2015). *Worldwide cost of living 2015: Which city is the most expensive to live in? Which city is the cheapest?: A summary from The Economist Intelligence Unit*.


Kitzinger, J. (1994). The methodology of focus groups: The importance of interaction between research participants. *Sociology of Health & Illness, 16*(1), 103-121.


Offsite Manufacturing in Nigeria: Feasibility Research and Future Directions

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Abstract

Nigeria is facing a deficit of 17 million houses due to a myriad of issues. This paper reports on the findings of a feasibility study which investigated Nigerian stakeholders’ perceptions on the needs, promises and barriers of adopting Offsite Manufactured Construction (OSM) in Nigeria, in order to address this challenge. In-depth interviews were conducted with domain experts directly involved in housing delivery, the data of which was analysed using thematic analysis, powered by Nvivo software. Results showed that although OSM could improve housing delivery efforts in Nigeria, any such initiatives to support this were perceived to be considerably low. As such, this study concluded that there is a need for high-level awareness, greater collaboration, investment in training and education, and endorsement/encouragement from the Government. This study presents additional understanding of OSM in Nigeria based on expert opinion, the results of which were used in the development of a framework for the effective adoption of OSM in Nigeria. It is proffered that adopting OSM can help support housing delivery efforts in Nigeria, and may also leverage wider benefits to the construction industry and associated supply chain.

Keywords: Offsite Manufacturing, Housing Delivery, Stakeholders, Nigeria

1. Introduction

Nigeria is currently facing a significant and progressive housing deficit. Whilst it could be argued that this is similar to many other rapidly developing countries, there are some unique contextual facts that need to be noted. For example, it has a population of 177 million, with an annual growth rate of about 2.5% (PRB, 2014). It also needs about 17 million new houses in the short term (Okonjo-Iweala, 2014). Thus, in order to address these issues, several mitigation efforts have been deployed by the local industry, including: promoting locally manufactured building materials as a means of improving housing delivery (Olayiwola & Adedokun, 2014); directing the industry towards better implementation of the Nigeria National Housing Policy (Makinde, 2014); and seeking possibilities of introducing better mortgage systems in Nigeria
(Olayiwola & Adedokun, 2014). Despite the success of some of these innovative attempts to address the problems affecting housing delivery in Nigeria, a wide margin still exists between housing demand and supply (Ibimilua & Ibitoye, 2015). Acknowledging this, it has been argued in seminal literature that this is mainly due to the inherent problems of the exiting conventional housing delivery systems in Nigeria and concomitant challenges, such as time and cost overruns, skills shortage, inadequate quality, and labour intensive activities (Femi & Khan, 2014; Makinde, 2014). As such, Dada (2013) suggested that a paradigm shift from the conventional construction approach to a more innovative housing production processes was vital in the context of Nigeria.

This kind of radical change in housing delivery methods was also advocated in several other countries, e.g. in the UK, USA, Australia and South Africa. Several Government reports have also noted that collaborative working and integrated project delivery must be promoted in order to make a ‘revolution’ in construction projects. To leverage these, literature has proffered the adoption of Modern Methods of Construction (MMC) and Offsite Manufactured Construction (OSM) as viable delivery mechanisms for both developed and developing countries (Gibb & Pendlebury, 2006; Goulding et al., 2014; Mullens & Arif, 2006; Nadim & Goulding, 2010; Taylor, 2009). In this respect, the primary role of OSM here is to move some of the effort and risk prone construction site activities into a ‘controlled environment’ typically associated with a manufacturing or factory facility (Arif et al., 2012). This controlled environment and application of OSM offers several benefits, particularly: a higher speed of construction, improved quality of the finished product, lower costs, and lower labour requirements on-site (Mullens & Arif, 2006). These achievements are sustained and significant; and it is therefore proffered here, that such offerings may act as a platform for addressing the specific housing problems of Nigeria (discussed above).

Despite these potential benefits, OSM only has a negligible share of the housing market in Nigeria (Kolo et al., 2014). Taylor (2009) asserted that this failure in many countries could be due to inaccurate public assumptions regarding offsite. This study therefore posits that, if offsite production and manufacturing are to make a positive contribution to the Nigerian construction industry, there is a need to identify the causal issues associated with its uptake and adoption. This undertaking would need to encompass several areas, not least, market drivers and dynamics, culture, societal issues, and existing economic business model

2. Background of the Study

Statistics are not promising at all about housing delivery in Nigeria, where only 10% of Nigerians can currently afford to either purchase or build their desired quality houses, compared to those for other countries 72% in USA, 78% in UK, 60% in China, 54% in Korea and 92% in Singapore (Ayedun & Oluwatobi, 2011). Olayiwola and Adedokun (2014) complained that the housing situation in Nigeria is far from being satisfactory, taking into account the high rates of urbanisation and population growth in this country. Makinde (2014) asserted that there was no perspective of improvement in near future; if the country decides to continue to rely on its conventional housing delivery systems, which are deficient in terms of quantity and quality of
housing units delivered. These problems tend to have a cascading effect that results in the other housing problems, such as unstable businesses, shortage of skills and materials, inadequate infrastructure, lack of innovation and unfair distribution of resources.

3. Offsite Manufacturing and the Opportunity for Its Adoption in Nigeria

Offsite manufacturing falls under the broad umbrella of Modern Methods of Construction (MMC) (Nadim & Goulding, 2010) and, there are several acronyms associated with OSM. OSM can be defined as set of processes that incorporates prefabrication and pre-assembly to produce units and or modules that are then transported to site and positioned to form a permanent work (Gibb, 1999). From a system point of view, Gibb and Pendlebury (2006) defined OSM as a range of applications which involve moving operations that are traditionally completed onsite to a manufacturing environment. This transformation improves the quality, customer satisfaction, efficiency, predictability of delivery timescale and sustainability of a project (Nadim & Goulding, 2010). It has been widely advocated that several benefits are obtainable from the use/adopton of OSM. The following paragraphs provide a categorised summary of these benefits in accordance to main themes of housing challenges in Nigeria, which were discussed in the previous section.

Ajayi et al. (2008) presented shocking statistics about waste generation in Nigerian construction projects where more than one-ton per day waste is generated in more than 75 per cent of conventional building sites. They also argued that most wastes are generated from demolition works on site and material handling. According to a report by Waste and Resources Action Programme (WRAP, 2007) within the context of UK, 40 per cent of all council waste come from construction projects. OSM has been successful in reducing waste generation of typical construction projects by 70% to 90%. It has also been advocated that it is much easier to gather and recycle waste generated from OSM than those for conventional construction projects (WRAP, 2007).

Gibb and Pendlebury (2006) asserted that “time is a big-plus for offsite”. Similar to other countries, construction projects in Nigeria often delay due to some regular issues, such as material shortage, skills shortage and bad weather conditions (Mansfield et al., 1994). With OSM, these issues are inherently addressed, since most of the building components are manufactured in factories and transported to site for speedy assembly at very predicted times with limited workforce (as per discussed with very much detail in: Arif et al., 2012; Gibb & Isack, 2003; Taylor, 2009). (See Figure 1).

Despite the higher initial cost of OSM projects (NAO, 2005), savings from OSM can be achieved in the areas of cost certainty and reduced risk, reduced running and maintenance costs, reduced preliminaries and site overhead, and reduced construction time (Gibb & Pendlebury, 2006). WRAP (2007) also identified that, savings can be achieved by using OSM as a result of reduction in waste of building materials especially bricks. In Nigeria were sandcrete blocks are
predominantly used, incorporating OSM will go a long way in reducing waste on site and this will in turn augment for the high cost of construction when using OSM.

Figure 1: Comparison between OSM Schedule and Conventional Construction Schedule; Adapted from *MBI* (2010)

NAO (2005) advocated that OSM meets the three quality requirements of durability, whole life cost and performance. It was ascertained that achieving greater quality was a major benefit and a key driver to the adoption of OSM in various contexts of different countries such as India (Arif et al., 2012) and UK (Gibb & Isack, 2003). Gibb and Isack (2003) linked this superiority in the production quality and output consistency to the controlled factory environment in OSM as opposed to the uncertain conditions of a conventional construction site.

Despite all benefits, seminal literature highlights myriad of barriers hindering the uptake of OSM (e.g., Arif et al., 2012; Goulding et al., 2014). It was crucial for this research to identify these barriers through reviewing literature and investigate their likelihood within the context of Nigeria based on evidence from primary data.

Initial cost of products has often been considered as the main barrier to the uptake of OSM in many countries including Nigeria. Scofield et al. (2009) also identified manufacturing capacity as another barrier to the uptake of OSM. Countries in which OSM usage has already been established, (e.g. UK, US, Japan and Nordic countries) have a robust supply chain including good number of factories to support OSM market. In a country like Nigeria, there are only few factories involved in the manufacturing of OSM components. This can certainly hinder update of this industry in the future. Another barrier hindering the uptake of OSM is the negative public and stakeholders’ perceptions towards OSM. Arif et al. (2012) argued that one reason for this is that prefabricated housing was used during periods of high demand (e.g. post-world wars), resulting in mostly low quality shelters. Although this has changed in many countries, Opara (2011) confirmed that similar negative perception still is a real barrier in Nigeria.

Another major barrier for adopting OSM in many countries is lack of suitable building codes and standards (Goulding et al., 2014). This is a problem in Nigeria also where there are no official codes and standards to guide the use of OSM. Shortage of skilled workers and labour
specific for OSM has also been a regular issue for OSM adoption (Goulding et al., 2014). This problem is even magnified in countries like Nigeria where the OSM industry is too small, so that there is too much reliance on expatriate skills (Opara, 2011).

4. Research Methodology

This study focuses explicitly on the barriers of adoption of OSM in Nigeria. As such, a narrow-bounded literature review lens was used to identify the main problems affecting housing delivery in Nigeria, cognisant of the globally recognised capabilities of OSM in addressing these issues, barriers and subsequent transformation from conventional construction to OSM. The results of the conducted literature developed the theoretical framework and identified main constructs, factors and variables of this study. It was also essential to get affirmation for the developed theories through checking them against tacit knowledge of stakeholders involved in the Nigerian housing industry. Since not much research have been conducted in the past to investigate issues related to OSM adoption in the context of Nigeria, a qualitative research approach was adopted, using in-depth interviews as the instrument for data collection, to engage profoundly with actual stakeholders, get their views and opinions, and capture deeper knowledge about the nature of these issues. Due to the nature of qualitative study, very high-level experts from various sectors of the Nigerian housing industry were selected and invited as the participants for the in-depth interviews.

The study followed Gu and London (2010) in shaping the main constructs of the study and interview questions around the three main dimensions of OSM, i.e. people, process and technology. Cost was also included as the fourth construct, since it has been identified as a major player in housing delivery by various studies. The interview questions were divided into three main categories in accordance with the main aim of this study, specifically: 1) The main problems of housing in Nigeria, 2) The potential capabilities of OSM, which can leverage housing delivery in Nigeria, and 3) The probable barriers to OSM adoption in Nigeria.

In order to engagement effectively with the respondents, face-to-face interview was selected as the method of conducting the interviews and about 30 minutes was allocated for each interview. Interview questions were also tailored to the expertise of each participant to assure maximum productivity of meetings. Reaching theoretical saturation (Kumar & Phrommathed, 2005) was the main strategy for determining sample size of each set of interviews; i.e., the study continued the interviews with new participants from each group, until the point whereby no new data was received from the new respondents. Data gathered for the interviews were audio recorded with the permission of the interviewees to ensure all necessary information were captured for proper analysis of the data.

Total of 26 experts were approached for interview based on the roles they play in the housing delivery value chain of Nigeria. All data gathered from 26 interviews was transcribed and analysed using the QSR - NVivo Data Analysis Software (V10.0.638). In order to systematically investigate the core issues of housing delivery in Nigeria and the potentials of OSM to address these issues, this study adopted thematic content analysis.
5. Results and Discussions

5.1. The Problems of Housing Delivery in Nigeria

From an exploratory analysis of the interview results, it was obvious that despite the various mitigation attempts, the problem of housing deficit in Nigeria continues to remain. It was reaffirmed by results of this study that a large housing deficit still exists in Nigeria and currently, there is no promising prospect for improvement. It was strongly pointed by many interviewees that this problem is likely to be even more serious than what has been officially reported, and nothing significant is being done to tackle this issue. The following paragraphs present the details of the problems of effective housing delivery in Nigeria.

Respondents of this study identified financial issues as a major hindrance to effective housing delivery in Nigeria. High cost of construction in Nigeria was brought into conversation by many of interviewees and this concurs with results of a previous research conducted by Odunjo (2013) highlighting this issue. The results of the interviews point out several factors which account for the high cost of housing in Nigeria. One of the most crucial issues highlighted here was overheads imposed due to lack of proper infrastructure. Another subset of cost is the cost of getting title documents in Nigeria which is usually very high and this also impacts on the overall building cost. Other sub categories indicted as major factors contributing to high cost of construction in Nigeria included importation of building materials and poor earning power.

In terms of construction sector related issues, this study identified various factors which have negative impact on housing delivery in Nigeria. Lack of construction standards and poor professional ethics were identified as two main codes under construction sector related issues. One of the interviewees argued that “so many people tend to cut corners with regards to building materials...”. This concurs with the findings of an earlier study by Solaja (2015) which complained about poor ethics within the Nigerian construction industry at every level. Similarly, it also reaffirms the findings of Oseghale et al. (2015) who argued that use of unqualified professionals, lack of maintenance culture, poor quality materials and inadequate fund are some of the major causes of building failure in Nigeria. Similar to every other context (Kamara et al., 2004), the issue of the fragmented nature of the construction industry was also identified as a major contributor to hindrance of housing delivery in Nigeria. Other sub categories identified under this theme by the interviewees were reluctance to innovate and lack of investment and research.

The last theme identified in this section was Government related issues. This theme referred to issues concerning the Government role in supporting or hindering housing delivery at all levels. Importance of the Government to assure that everyone has access to at least a quality shelter as basic need of mankind (Olayiwola et al., 2005) was highlighted by many of respondents. The respondents complained that the Government has not been successful in providing this in Nigeria. Other codes highlighted under this theme were inflation of contract prices, poor Government policies and lack of control on corrupt practices. The results of the interviews conducted revealed that these three areas tend to significantly affect housing delivery in Nigeria.
It was also argued by the interviewees that Nigeria needs a robust mortgage system to assure continuity of supply and demand within the construction industry. It was also brought to attention through the interviews that the issue of poverty affects the acquisition of housing in Nigeria and this is further compounded by the poor Government policies concerning housing and mortgage.

5.2. Barriers to the Use of Offsite Manufacturing in Nigeria

With regards to contribution of OSM to the Nigerian construction industry, many interviewees that participated in this study argued that OSM is almost of non-existence in the context of Nigeria. Similarly, they also asserted that OSM has not been accepted formally or even informally in this country. However, some interviewees mentioned that OSM had an acceptable share of the construction market of Nigeria during the 1970s and 1980s, and then it gradually disappeared due to the minor demand for housing at that time, and the fact that it was only the Government demanding for prefabricated houses during that period. Nevertheless, the stakeholders interviewed in this study admitted that prefabrication is vastly used in some civil engineering projects carried out by large construction firms in Nigeria, but this has nothing to do with the housing sector, which heavily relies on the conventional bricks and blocks construction methods. Despite its missing role, this study argues that due to the typical challenges that the Nigerian housing industry currently faces, it would be paramount for this industry to adopt OSM, which is already capable of addressing many of these issues (Arif, 2012; PrefabNZ Incorporated, 2013). In the meantime, for OSM to be adopted in Nigeria there was a need to identify the barriers that can hinder its adoption. This study identified three core themes (Pan et al., 2004) with respect to barriers to OSM adoption, namely “human barriers”, “technical barriers” and “industrial barriers”.

**Human barriers** covers barriers that are concerned with the stakeholders involved in the delivery of housing in Nigeria as well as the end-users. Several studies identified negative perception about OSM as a major barrier for its adoption (e.g. Arif et al., 2012; Pan et al., 2004; PrefabNZ Incorporated, 2013). This was also echoed by the respondents of this study who argued that people in Nigeria have a negative perception about OSM components and think they are not so strong. Based on the results of this study, other major codes identified under the category of human barriers to OSM adoption in Nigeria include: maintenance difficulties, client’s resistance, cultural issues and design flexibility.

**Technical barriers** refer to the barriers that hinder the construction process and the procedure that end up with the final product, i.e. a house. The main categories identified under this theme were lack of necessary infrastructure, lack of machinery, logistics and technical expertise. In terms of Infrastructure development, it was discussed by many respondents that Nigeria needs much better roads, transportation system, and power grid in order to be able to adopt OSM. These results resonate with the results of a similar study by Arif et al. (2012), which identified infrastructure as a major challenge to OSM adoption in a similar context such as India.
This study identified the industrial barriers as high cost of establishing factories, importation of materials, need for expatriate workers and limitation of existing OSM factories as major barriers to OSM adoption in Nigeria. Although cost has been identified as a major barrier, many of the interviewees argued that some of the initial costs could be offset through the areas such as cost certainty and reduced risk, less overall life cycle costs due to better quality of products, reduced preliminaries and site overhead, reduced construction time. This is very aligned with the findings of Gibb and Pendlebury (2006). Some interviewees also advocated that despite being capital intensive, investment in OSM could be very beneficial for Nigeria anyway, since the country would reap the benefits of OSM in the long-term.

6 Conclusion

Research findings indicate that whilst there is still a very large housing deficit in Nigeria, there are currently no significant measures implemented to address this challenge. However, OSM has been proffered as a potential solution, particularly though its ability to meet volumetric delivery patterns with reduced costs and improved quality thresholds. That being said, contextual conditions need to be assessed before this can be considered a viable solution. In doing so, several barriers to OSM adoption were presented and discussed. Based on this, low-impact construction methods (such as OSM) were considered viable methods for improving sustainability and particularly, feasible solutions for improving the housing deficit. This study presented a series of underpinning steps based on the view of various stakeholders on the issues regarding these housing challenges, and the possibility of OSM adoption. Whilst these context-specific OSM barriers highlighted the barriers, this is just a start. There is an exigent need to investigate these issues further, as it is important to proffer bespoke solutions to this environment e.g. infrastructure and local suitable materials for OSM. For this to be achieved, the experience garnered in other contexts need to evaluated regarding their suitability.

In pursuance of this, the ultimate goal of this research will be to develop a roadmap that will facilitate the effective adoption of OSM in Nigeria. This paper presented a series of underpinning steps based on the views of various stakeholders on the barriers to OSM adoption in Nigeria. Whilst OSM barriers have been highlighted within the Nigerian context, there is an exigent need to investigate these issues further, as it is important to proffer solutions to this environment e.g. infrastructure and local suitable materials for OSM. For this to be achieved, it is imperative that these issues are studied further, cognisant of experience garnered in other contexts and this will be useful in developing a suitable roadmap for the successful adoption of OSM in Nigeria.

References


Abstract

Hong Kong is an international metropolis, which is suffering from a chronic lack of land resources, housing supply, and the effects of high density urban development. Although a number of studies have been conducted to explore the feasibility of increasing development intensity by assessing environmental impacts, infrastructure capacity and public consultation, these reviews and assessments were implemented using 2D Geographical Information System. However, most people cannot visualize the impact of relaxed plot ratio/building height (PR/BH) restrictions from a 2D drawing, as the spatial distribution of land unit in the real world is 3D. This study aimed to measure the effects of minor relaxation of maximum PR/BH restrictions of 21 sites in Kai Tak Development Area from a sustainability perspective using 3D modelling and spatial analyses, including urban skyline, visual effect of mountain ridgeline, shadow and solar exposure, wind ventilation, and air temperature. Different scenarios with various PR/BH restrictions for the 21 target sites were generated and compared. With Hong Kong as the case study area, results indicated that people could obtain a more holistic view and be able to make more effective and informed decisions based on 3D modelling and spatial analysis. Considering the minor effects or slight changes during the various analyses, Scenario 4 is the recommended reasonable scale to relax the maximum PR/BH restriction for the 21 target sites. The proposed method can also be applied in urban renewal for other densely populated cities.

Keywords: 3D modelling, 3D spatial analysis, Micro-climate simulation, Planning decision, High-density city

Introduction

Similar to many global cities, Hong Kong (HK) is suffering from a chronic lack of land resources, housing supply, and the effects of high-density urban development. Over 7,000,000 people live in this tiny place with an area of only 1104 km². Even worse, almost 75% of this land is covered with mountains and country parks, which are unsuitable for urban development/redevelopment. Shen et al. (2009) explained that land use is crucial for both current and future sustainable urban development. To achieve sustainable development in HK, the Government has made every effort to increase land supply by adopting a multi-pronged approach in the short, medium, and long term. To increase land supply within a short time...
frame, increasing development intensity of built-up area by minor relaxation of the PR/BH height restrictions is commonly employed.

In HK, development intensity is mainly controlled based on lease conditions, statutory outline zoning plan (OZP), and the Building Planning Regulations, which aim to impose restrictions on site coverage and PR/BH of individual land lots. As a statutory organization, the Town Planning Board (TPB) is responsible for the approval of OZP and any subsequent amendments. There have been rising concerns in recent years that possible undesirable effects of high-density development may be caused by further relaxation of density control in urban areas. Therefore, TPB needs to consider these applications while ensuring that the proposed changes not only have the satisfactory and acceptable environmental impacts on surrounding areas but also will be in line with the HK Planning Standards Guidelines. The employment of 3D modelling and Geographical Information System (GIS) analysis technology meets this demand, which can facilitate a more interactive debate on urban density and informed planning decisions toward better provision of urban space.

As part of the Government’s effort to increase housing and office supply, the Civil Engineering and Development Department (CEDD) proposed a minor relaxation of the maximum PR/BH restrictions for three study areas marked in Fig. 3, including 21 sites zoned as Residential, Commercial, Mixed Use, as well as Government, Institution, or Community, on the approved Kai Tak OZP (CEDD, 2015). Although previous research findings can provide fundamental and valued resources for this study, they were conducted using 2D GIS. Given that the spatial distribution of the land unit in the real world is three-dimensional, 3D GIS can help us examine the world in true perspective and make effective decisions. Therefore, this study aimed to measure the effects of minor relaxation of the maximum PR/BH restrictions of 21 sites in the Kai Tak Development Area (KTDA) from a sustainability perspective through 3D modelling and spatial analysis technology, including urban skyline, visual impact of mountain ridgeline, shadow and solar exposure, wind ventilation, and air temperature. The results of this study can be used to develop informed strategies for other global cities facing similar issues on urban development/redevelopment.

2 Literature Review

With the rapid development of 3D GIS technology, an increasing number of researchers are using 3D GIS to assist in various decision-making processes for urban development.

Zhang et al. (2004) conducted 3D spatial analyses for urban development using 3D models, including visibility, solar panel, flood, and air pollution. Similarly, to obtain more vivid effects, Mak et al. (2005) conducted an urban skyline analysis covering HK using 3D GIS technology. Their findings indicated that 3D GIS plays an important role in implementing the urban design guidelines (UDGs) of HK, including the quantitative measurement of mountain ridgeline, the height of buildings, and urban skylines. Stevens et al. (2007) employed a novel tool named iCity, which runs in a 3D environment to assist in spatial decision making during urban planning. Alternatively, Li et al. (2005) used ArcGIS spatial analysis functions to analyse the sky view factor, which is one of the important factors affecting climate during the urban design process. Wong et al. (2011) described an original methodology applied 3D GIS to investigate the “wall effect” caused by proliferation of high-rise buildings along the coast in Kowloon, HK.

Although the abovementioned studies focused on using 3D spatial analysis technology to address certain issues encountered during urban development, few researchers have emphasized development control, such as the effect of minor relaxation of the maximum PR/BH restrictions on surrounding environments. Therefore, the present study, investigated the viability of minor relaxation of the maximum PR/BH restrictions using 3D modelling and simulation technology to provide sufficient evidence to the decision maker.
3 Research methodology

3.1 Overview of the Research

Fig. 1 presents the overall framework of this study. First, based on the available 3D spatial data and approved Kai Tak OZP, a model of the whole KTDA was generated. A number of spatial analyses from various scenarios on urban skyline, visual effect of mountain ridgeline, shadow and solar exposure, wind ventilation, and air temperature were then conducted. Besides, Digital Elevation Model (DEM) was integrated with the 3D models to conduct the spatial analysis of mountain ridgeline. The findings of the above spatial analyses were compared under four different PR/BH scenarios. Furthermore, a previous study on the Environmental Impact Assessment and carrying capacity of infrastructure was used as a reference before a conclusion was drawn.

3.2 Data Collection and 3D Modelling

A case study was chosen in HK, which is an international metropolis with a high population density. The study areas were finally defined with assistance from DEM, the ridgeline of mountain, visual environment, and other related factors. Fig. 2 shows that the inner area boundary in red is the Kai Tak rebuilt planning area, whereas the outer area boundary in green represents the potential boundary of the affected adjacent region.

To date, only part of the 3D data for the KTDA is available from Lands Department of Hong Kong. However, for areas without existing 3D data, the 3D models were generated by
commercial software CityEngine according to the planning scheme. Fig. 4 shows the 3D spatial data covering the highlighted area (in pink). The creation of new buildings should refer to a number of planning regulations, including TPB (2012 & 2015) and Building Department (2012).

Four various scenarios with different PR/BH restrictions were established for our study. Scenario 1 (S1) represents the original plan, which follows the maximum PR/BH defined by KTOZP or BPRs. Scenario 2 (S2) is the approved plan proposed by CEDD. Scenarios 3 (S3) and 4 (S4) are the further increased PR/BH based on S2, which was assumed intensively in this study. In the site of 1kl in Area 1, the plot ratio was increased by 22% (from 4.5 to 5.5) between S1 (the original plan) and S2 (already approved plan) after comparison. Similarly, the plot ratio of S3 increased by half of this growth rate (11%) to 6.1, whereas the plot ratio of S4 increased by the same growth rate of 22% to 6.7. A similar formula was applied to the calculation of building height for each scenario. Simultaneously, the same area was assumed with the height of 2.9 m for each floor. Finally, the Gross Floor Area per floor and site coverage in each scenario could be achieved. In the same way, rules for establishing scenarios of other sites were acquired.

ArcGIS and CityEngine were employed to model 3D buildings for the three study areas. ArcGIS was applied to model the footprints of buildings. Footprints were modelled in/around the three study areas according to the layout map. CityEngine helped transform 2D footprints to 3D models. Finally, all the generated 3D building models, surrounding building models, and terrain data were integrated (Fig. 5) for further 3D spatial analyses.

![Figure 4: Example of the visualization of 3D spatial data](image1)
![Figure 5: 3D models of the KTDA](image2)

### 3.3 Three-dimentional Spatial Analyses

#### 1) Urban Skyline

Urban skyline serves as a kind of fingerprint as no two skylines are alike. For this reason, skylines are always presented to establish a city location, as well as used for city renewal (Skyline, 2015). As Fig. 8 shows, two skylines were drawn to show the profile of this study area. In particular, Skyline 1 crosses Study Areas 1 and 2, whereas Skyline 2 passes through Study Area 3. A comparison of the four different scenarios will reveal the extent in which the increased building height affects the profiles.

![Figure 8: Two skylines](image3)
![Figure 9: Ridgelines on Kowloon and HK Island](image4)
2) Visual Effect of Mountain Ridgeline

Ridgelines and peaks are valuable assets for HK according to UDGs, especially those located close to the city center in Kowloon and HK Island, shown in red in Fig. 9 (Planning Department and RMUM Hong Kong Limited, 2002). Therefore, protection of ridgelines is an important step and worth special attention during urban development. The long-term objective is to promote HK’s image as a world-class city by enhancing the quality of our built environment from both functional and aesthetic perspectives.

There are seven vantage points around Victoria Harbour (VH) as start reference points for consideration of views to ridgelines/peaks (Fig. 10). Considering the study area location and visual factors, only three vantage points along VH in HK Island were chosen, namely, Quarry Bay Park, HK Convention and Exhibition Center, and Sun Yat Sen Memorial Park.

![Figure 10: Popular vantage points](image1)

To conserve the precious ridgelines and peaks, a 20% building free zone (Fig. 11) is recommended to be maintained according to Metroplan (Hong Kong Planning Department, 1991) guidelines. Following this suggestion, a number of sampling points with 1° interval were identified along the limit of roofline for the mountain in Kowloon Island. View corridors from the three abovementioned vantage points to the limit of roofline were established to determine the effects of visibility.

![Figure 11: Building free zone](image2)

3) Shadow and Solar Exposure

Sunlight is visible during the day when the sun is above the horizon of the Earth, which is a part of electromagnetic radiation emitted by the sun (Sunlight, 2015). A shadow is a region where sunlight is obstructed by an opaque object (Shadow, 2015). Generally, sun exposure hours are normally used to measure solar exposure.

In this analysis, the effects of sunlight hours and the distribution of solar exposure with the minor relaxation of PR/BH through comparison of S2 versus S3 and S2 versus S4 were investigated. With careful consideration, three analysis areas shown in Fig. 13 were determined based on solar altitude (20°) and sunlight shadow. Considering sunlight intensity and illumination time, summer was the most suitable season out of the four seasons. Finally, the average sunlight hours per day and related locations were calculated.
4) Wind Ventilation and Air Temperature

(i) Introduction of ENVI-met

ENVI-met is a 3D model that can simulate the microclimate of an appointed area. The simulation is based on fluid dynamics and thermodynamics, and the results consider the interaction among soil, vegetation, and the atmosphere. To simulate the microclimate using ENVI-met, a few assumptions should be considered, such as a steady temperature inside buildings and no heat storage in buildings. Therefore, the simulated result only relies on physical influence instead of anthropogenic effect. Moreover, the soil temperature and humidity in the modelling areas follow the default setting during the simulation.

(ii) 3D Modelling Regulations in ENVI-met

The model size in ENVI-met in the early stage should be determined using building footprints. To avoid the jet effect of the wind above the top of the models during the simulation, some regulations must be followed. The building height \( Z \) of the models in the three study areas should be twice the height of the highest building for each study area. The resolutions of all the models were the same to prevent the simulation results from being affected by different modelling settings.

(iii) Modelling of the Study Areas and Surroundings

After determining the model size, the study areas and surroundings were modelled in ENVI-met. With the aid of ArcGIS and CityEngine, the same building location, shape, and building height used in the former analyses were extracted. The building model was developed in ENVI-met by allocating height values to the grids forming the shape of the buildings. In the modelling process, only buildings were considered, and the wall properties and the roof materials of the buildings were assumed to be hollow block and concrete slab. The equidistance method was chosen for the generation of vertical grid; thus the vertical grids were of the same size apart from the bottom one. Similarly, the same four scenarios were developed for future simulation and comparison of wind ventilation and air temperature.

(iv) Configuration Setting and Simulation

To implement a simulation, configuration settings should be provided beforehand. This software requires initial weather information, including wind speed, wind direction, air temperature, relative humidity, and special humidity in 2500 m, for a particular date and time (Table 1). All the past raw weather data records were kept by the Hong Kong Observatory. Considering that significant changes in wind ventilation and air temperature appear in winter, 4 February 2014 was chosen as the testing date. The air temperature on this selected date was close to the average temperature that February.

After completing the configuration setting, the models were run for different scenario simulations. During the simulation, the calculated meteorological data, including wind speed, air temperature, humidity, and some other data such as surface temperature and soil humidity,
were allocated to each grid in the ENVI-met model. The data formed an output file in the designed time interval for further analysis.

Table 1: Configuration setting in ENVI-met

<table>
<thead>
<tr>
<th>Figures</th>
<th>Values</th>
<th>4 Feb 2014 (Winter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start time of simulation</td>
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<tr>
<td>Total simulation time (hour)</td>
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<tr>
<td>Model state saving interval (min)</td>
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<td>Receptors state saving interval (min)</td>
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<td>Wind speed in 10 m above ground (m/s)</td>
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<tr>
<td>Wind direction</td>
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<td></td>
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<tr>
<td>Roughness length at reference point</td>
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<tr>
<td>Initial atmosphere temperature (K)</td>
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</tr>
<tr>
<td>Specific humidity in 2500 m (g Water/kg air)</td>
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</tr>
<tr>
<td>Relative Humidity in 2m (%)</td>
<td>88</td>
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</tr>
</tbody>
</table>

4 Experimental Results and Comparison

1) Urban Skyline

Fig. 14 shows Skyline 1 of the three study areas in different scenarios. The building heights in Areas 1 and 2 gradually increased from Scenario 1 to Scenario 4. However, the effect of increasing PR/BH on the scene of Skyline 1 was not significant. Compared with the traditional baseline photographs for landscape assessment, 3D GIS provides a more vivid and convenient way to show the city profile using skyline.

2) Visual Effect of Mountain Ridgeline

With continuous increases in heights for four different scenarios, three blocked sightlines only existed in S4 at the vantage point of Quarry Bay Park (Fig. 15). Besides, a further step was conducted based on the three blocked sightlines. A maximum area was designed to calculate the blocked sightline in red from the leftmost to the rightmost side with a much smaller interval of 0.01°, which means that the sightlines within this angle area should always be blocked. Following a number of new blocked sightlines, the summation block angle of all angles between adjacent sightlines within this block area was calculated. Finally, a block percentage was calculated for each sightline bundle (left is 1.36%, middle is 1.4%, and right is 1.58%). This result indicated that the visual effect on conservation of ridgelines was relatively small after the increasing PR/BH.
3) Shadow and Solar Exposure

The average sunlight hours per day were calculated for the three study areas. The findings are presented in 3D environment within the chosen analysis regions in summer (Fig. 16). Specifically, ten classes of sunlight hours ranging from (0, 1] to (9, 10] are shown in different hues. These findings revealed that the differences between S2 versus S3, S2 versus S4 were not evident.

To further analyse the variation trend of sunlight hours for different scenarios, the differences in area range and related percentage between S2 versus S3 and S2 versus S4 were calculated and described in blue and red curves in Fig. 17, respectively. However, a consistent trend was observed. The two curves illustrate the difference in long sunlight categories; for example, (9, 10], (8, 9], and (7, 8] decreased because of the increased PR/BH. For short sunlight categories, such as (3, 4] and (2, 3], the difference increased accordingly. The fluctuations in the vibration rate were almost 0% for the shortest sunlight category. Moreover, the vibration rate of hours in middle categories such as (6, 7], (5, 6], and (4, 5] may not be fixed for different study areas because of the various distributions and directions of buildings. During this middle category, Sunlight hours increased in Areas 1 and 3, but decreased in Area 2, possibly because the spacing between the buildings in Area 2 was relatively larger than that in Areas 1 and 3. In general, all changes were insignificant, which demonstrated that the effect of increased PR/BH on shadow and solar exposure in summer was relatively small.
4) Wind Ventilation and Air Temperature

To understand the extent of changes in different scenarios, various simulations were carried out in winter night as an example. The temperature range (−0.20 °C to 0.020 °C) presented in the legend in white is defined as an insignificant change. Air temperatures outside that range (below −0.20 °C in green or above 0.20 °C in red) were deemed significant changes. Fig. 18 shows an insignificant change in air temperature for most areas between S3 versus S2 and S4 versus S2. A small part of the red area is presented only for the upper left corner of Area 2, which indicated a slight change in air temperature between 0.2 °C and 0.3 °C in this area after increasing building height.

Similar to air temperature, the difference in wind speed was also classified into different intervals. According to the subjective response to air motion (Bradshaw, 2006), the minimum wind speed that can be detected by human beings is 0.25 m/s, and the speed between 0.25 and 0.51 m/s that can be sensed by people is considered comfortable. Except for wind speed, wind direction in the study areas was also simulated and symbolized by the arrows, where a long arrow represents a fast wind speed.
As shown in Fig. 19, Areas 2 and 3 both showed some changes in wind speed. The extent of increase/decrease became more obvious in S4 versus S2 in the winter night. The decreased wind speed was due to the increase in building height, which blocked the wind. Meanwhile, increased wind speed was possibly due to the enlarged height difference between tall buildings and adjacent low buildings after the increase in PR/BH. According to wind direction, a southeast wind was defined for initialization during this simulation. The changes in wind direction depend on the site conditions, including position and layout of the buildings. As shown in Fig. 19, wind direction slightly shifted to allow wind to pass through the buildings. Finally, the findings indicated only small changes both in wind speed and wind direction for the three study areas, but more obvious changes were observed in Areas 2 and 3.

<table>
<thead>
<tr>
<th></th>
<th>Area 1</th>
<th>Area 2</th>
<th>Area 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3 vs S2</td>
<td><img src="image1" alt="Map" /></td>
<td><img src="image2" alt="Map" /></td>
<td><img src="image3" alt="Map" /></td>
</tr>
<tr>
<td>S4 vs S2</td>
<td><img src="image4" alt="Map" /></td>
<td><img src="image5" alt="Map" /></td>
<td><img src="image6" alt="Map" /></td>
</tr>
</tbody>
</table>

Legend:
- below -0.40 m/s
- -0.40 to -0.30 m/s
- -0.30 to -0.20 m/s
- -0.20 to -0.10 m/s
- -0.10 to 0.00 m/s
- 0.00 to 0.10 m/s
- 0.10 to 0.20 m/s
- 0.20 to 0.30 m/s
- 0.30 to 0.40 m/s
- above 0.40 m/s

*Figure 19: Wind speed comparison in different scenarios in winter night*

5 Discussion

For wind speed analysis, more obvious changes were presented in our findings. Both increased and decreased wind speed appeared in Areas 2 and 3. The difference in wind speed was around 0.4 m/s, which was within the comfortable range sensed by humans (0.25–0.51 m/s), so the results were still identified as slight changes.

To prove the effects of minor relaxation of the maximum PR/BH restrictions of 21 target sites, 3D modelling and simulation technology were employed. However, only primary and simple 3D models were generated in this study. Therefore, more complicated and realistic 3D models should be produced and designed in terms of different building structures, materials, suitable layout and directions, and podium and car park employment for further studies. Besides, the simulation of thermal properties of buildings, types of gas sources, and energy source in water bodies was limited, which resulted in a less accurate simulation compared with the real case. Furthermore, more ideas about the formation of numerical model and microclimate can also be investigated in the future.

6 Conclusions

3D modelling and spatial analysis technology were introduced in this study to conduct simulations based on 3D models, which could aid in people’s understanding and provide more vivid visualizations than 2D GIS. The effects of increasing PR/BH toward urban skyline, visual effect of mountain ridgeline, shadow and solar exposure, air temperature, and wind ventilation for the three target study areas in four scenarios were successfully observed. Based on the findings of various spatial analyses, minor relaxation of the maximum PR/BH led to the following conclusions.
(1) Urban skylines were drawn to check the city profiles of the three study areas in four scenarios. The effect of increasing PR/BH on urban skylines was not significant, which was reasonable and acceptable.

(2) Sightlines were generated by connecting the selected vantage points and sampling points on the mountain to check the visual effect of mountain ridgeline. With continuous increasing height for the four scenarios, the blocked sightlines only existed in S4 at the Quarry Bay Park. Three bundles of sightlines were blocked. Based on the figures, a very slight visual effect was noted on the conservation of ridgelines.

(3) During shadow and solar exposure analysis, the conditions in summer were considered for the whole study areas. The average sunlight hours per day, sunlight area size, and corresponding percentages for different categories of sunlight hours were calculated and presented by figures. The findings showed that the changes were insignificant, which indicated that the effect of shadow and solar exposure to the surrounding environment in summer was relatively small when we increased PR/BH.

(4) For air temperature, only a slight change appeared in Area 2 in summer night. The changes were between 0.2 °C and 0.3 °C.

(5) For wind ventilation, more obvious changes were shown in wind speed and direction for Areas 2 and 3. However, the magnitude of change in wind speed was only that sensed by humans and deemed as a comfortable change. Therefore, only slight changes were observed when increasing PR/BH for the study areas.

(6) The findings of 3D spatial analyses revealed that S4 was the recommended reasonable scale for relaxation of the maximum PR/BH restriction for the 21 target sites in the KTDA.

The use of 3D modelling and spatial analysis technology provides people with a more holistic view and allows them to make more effective and informed decisions. The method proposed in this paper can also be applied in urban renewal studies or new development areas in other densely populated cities similar to HK.

References


Introduction of sustainable low-cost housing. Experiences from a demonstration project viewed from an innovation diffusion perspective

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Abstract

The purpose of the study is to describe and analyse, from an innovation diffusion perspective, factors important when using demonstration projects as a tool for introduction of sustainable low cost housing. The study is focused on Ethiopia, a country with big challenges as regards population increase, lack of resources, deforestation, land erosion and a general need for better and sustainable housing, especially in rural areas. The study is furthermore focused on the adobe technology as a more sustainable alternative to the traditional building technology which is very timber consuming. Many attempts have been made to introduce this technology with the use of demonstration buildings. A great part of these attempts have failed, some have been successful. In order to study and discuss important factors in connection with the use of demonstration buildings, a project executed some years ago in southern Ethiopia has been analysed. The study is based on findings collected during and after the erection of these buildings mainly through practical tests, interviews and observations. From a technical point of view this demonstration project was successful. It was possible to develop an appropriate production technology and the result was buildings with a good standard and good function. Experiences up to now indicate a good durability. From an innovation diffusion perspective however the demonstration buildings have not fulfilled their purpose. The impact in the region seems to be very small. The conclusion in the paper is that the reasons behind this failure mainly are: (1) Lack of clear and visible relative advantage in comparison to the traditional building technology. The supply of construction timber in the area in question is still good. (2) Lack of a champion advocating the technology by using the demonstration buildings and thereby giving the message to the society that the technology is valuable and trustworthy. (3) Lack of continuity in the demonstration efforts, as a result of the lack of a champion.

Keywords: innovation diffusion, adobe, demonstration project, sustainability, low-cost

1. Introduction

Ethiopia is currently ranked as number 174 of 187 countries in the world by the Human Development Report (2015). The ranking is based on a Human Development Index which is a composite index measuring among other things the standard of living. The low ranking indicates difficult living conditions for the vast majority of the inhabitants of Ethiopia. This is caused by current serious
problems such as a very large population with a high population growth rate putting a high pressure on already inadequate resources causing e.g. high rate of deforestation, (Barton and Dlouhá, 2014). The deforestation in its turn causes other problems and difficulties, e.g. land erosion and lack of suitable timber for construction, (Barton and Dlouhá, 2014).

In 2011 the Ethiopian Government issued the document “Ethiopia’s Climate-Resilient - Green Economy. Green economy strategy” (2011). In this publication it is stated that Ethiopia aims to achieve middle-income status by 2025. The aim is to develop a climate-resilient green economy by avoiding sharp increases in greenhouse gases (GHG emissions) and unsustainable use of natural resources.

A vast majority of the Ethiopians, about 80%, are living in rural areas. This means that a majority of the Ethiopians have rather bad housing conditions. A study by Kumie and Berhane (2002) indicated poor living conditions for many persons living in rural areas, with overcrowded houses with poor sanitation conditions. The authors stress that this fact predisposes to adverse health conditions and that appropriate interventions are needed.

As regards the Ethiopians living in urban areas the average situation seems to be better with a much bigger variation in living standard from case to case; (Abelti et al, 2001) and (Bihon, 2007). Anyhow, the need of improvement is great also for urban areas.

From what is written above it is obvious that there is a great need to improve the housing conditions for many Ethiopians. New methods for erecting dwelling houses must be introduced. These methods must be sustainable and take into account the present situation in the country and the Ethiopian Governments aims regarding GHG emissions and the sustainable use of natural resources. In addition to this, the methods must result in durable and safe dwelling houses that have a healthy indoor climate. A technology that is interesting in this context for erection of walls is the adobe-technology.

During the years several attempts have been made to introduce this technology in Ethiopia. Many times demonstration buildings have been erected in connection with the introduction. Some of the attempts have been and are successful, many have been failures.

The aim of this paper is to present and discuss from the innovation diffusion perspective factors of importance for the introduction of adobe-technology technology in Ethiopia. The discussion is based on findings and experiences from a demonstration project executed during the years 2009 – 2012. The aim of the demonstration project was to introduce this technology in a region in southern Ethiopia. The data from this demonstration project presented in this paper was collected mainly thorough practical tests, interviews and observations.
2. Innovation diffusion

Innovation has been defined in many ways, in different contexts, but all are more or less pointing in the same direction, with slight differences. One definition that has gained a wide acceptance is “the implementation/ adoption of new or significantly improved production or delivery methods” (OECD, 1997). It is useful as it links innovation to value creation and recognize this in a broader sense than short-term economic perspectives, as well as move away from the linear process best measured by R&D spending (Loosemore, 2014). That makes it also useful in this context. Innovations evolve in an economic, social, cultural and political context and are highly influenced by this (Weisenfeld, 2003). This explains why innovation vary between different contexts such as industry, political, national etc. This suggests that different national contexts when transferring an approach or technology between contexts, for example when transferring between countries, need to be addressed (Abdul-Azis, 2002). Developed and developing countries have to address different problems in relation to innovation (Bröchner, 2011). Differences in education, communication, business maturity etc all affect innovation. As learning is a central to innovation, and it is a social activity, which involves interaction between people (Lundvall, 1992) it is important to have a supporting framework around the innovation project or innovation diffusion project suited to the context enabling people to learn about the innovation.

Undertaking construction innovation outside of projects appears to be a very unusual process (Tatum, 1987). This result in that innovation in construction, from a process perspective, is complex and involves different stakeholders and components (Manseau, 2005). From a technical perspective the innovation in the current context is not as complex as in most western countries, but the process may be as complex, but in other ways. The development of a collective understanding of the innovation and building trust at the operational level where individuals are more likely to encounter it is important. A critical success factor is involvement, from the early stages of development, of those who will be responsible for implementation, possibly requiring mediation between new development and existing routines and duties within the organizations affected (Barlow et al., 2006).

In an earlier study where common areas of importance for the diffusion process, compare with Stoneman (2001), have been applied on non-commercial innovation diffusion in developing countries, it was found that the factors, apart for commercial factors, are applicable (Hjort and Widén, 2015). Those cases where there was a champion, where there was a “market”, a need, where the cultural context allowed for the innovation, the diffusion succeeded. In the cases where a majority of the factors were missing the diffusion failed. Other factors that may be of importance for diffusion, not specifically studied in the earlier work, are relative advantage, compatibility, complexity, trialability and observability (Rogers, 2003). Relative advantage is how much better the innovation is perceived to be than the technology it is supposed to replace. Compatibility is the extent an innovation fit within the existing values, past experience and needs of the adopters. Complexity addresses how difficult the adopter finds the technology to use. Trialability deals with the adopters’ potential to experiment with the technology. Observability is about how the results are visible to others. Some of these factors are to some extent overlapping the factors tried earlier,
for example relative advantage share much with if there is a market. The market will be there if there is a relative advantage of the innovation. Compatibility has some parts in common with the cultural dimension. Does the innovation fit into the contextual setting where it is to be diffused? Whereas complexity, trialability and observability are not dealt with to the same extent explicitly in the earlier study, compare with Hjort and Widén (2015).

3. Alternative building technologies

The traditional way of erecting a dwelling-house in Ethiopia is to use a framework of timber in the walls. Timber-poles with an appropriate length are put into the soil. The timber-specie mainly used varies from region to region according to availability. In the highlands the timber-specie mainly used, has been and still is fast growing Eucalyptus. However, in order to enhance the durability of the walls, some poles of more durable timber species, have been used in the walls with a spacing of approximately 1000 mm. The framework is provided with a roof structure which is covered with grass or corrugated iron sheets. This framework is later on covered with mud mixed with straw. Sometimes one of the last steps in the process is to provide the walls with a “foundation”. This is done by arranging a stone masonry around the outer walls. It is clear that this masonry actually is not a real foundation but protection of the lowest part of the walls. The timber core of the walls are in contact with the soil and can thereby be exposed to termite attack and decay caused by high moisture content. With regard to this the use of more durable timber in the walls is crucial.

Dwelling houses that give a good indoor climate and that are reasonably durable can be erected if these houses are provided with a proper foundation and sufficiently long roof overhangs. Despite this it is very doubtful if this technology can be used on a broader scale in the future. There are important reasons for this standpoint. Firstly, the traditional technology is very “timber-consuming”. With regard to the current deforestation in Ethiopia and resulting timber shortage, it seems clear that an alternative technology must be used. Secondly, the possibility to obtain durable timber species, traditionally used in connection with construction of walls, e.g. Thid (Juniperus Procera Hochst) and Kosso (Hagenia Abyssinica), will be very limited in the future, (Bekele et al, 1997). Because of the ongoing deforestation such species are very difficult to obtain, at least to a reasonable price. This has had, and will have, a serious impact on the possibility for ordinary people to erect dwelling houses with framework that could resist termite-attack and decay.

The termite problem, which is underlined in Berhane (1984), seems to have be a growing problem in Ethiopia a rather long time. A rather recent study on termite damage on rural housing in the Central Rift Valley in Ethiopia, (Debelo and Degaga, 2014), confirms this. According to this source the wood/straw thatch buildings characteristics of farming communities in Ethiopia, are susceptible to termite damage, particularly in the tropical savanna areas. They forward a source, (Abduraman, 1990) which reports that in western Ethiopia, where the termite problem is accentuated, thatched roof huts are destroyed in less than five years and corrugated iron roof houses in less than eight years.

A realistic alternative to this traditional building technology is to use adobe blocks for the walls, i.e. to build walls in dwelling houses with sun-dried blocks made of mud; with or without straw included.
The technology is not a traditional technology in Ethiopia as a whole, although there are some areas where the technology has been in use for a rather long time, e.g. in the eastern Ethiopia.

In a recent study, (Petersson and Ström, 2015) the spread and diffusion of this technology in some locations in the eastern, the central, south-central and western parts of Ethiopia has been analyzed. As regards the diffusion, adoption and spread of the adobe technology the main of the study result can be presented as follows:

- In some parts of the country, mainly rural, there is a development which can be described as a spontaneous spread of the technology. The technology is commonly adopted and the driving force behind this development is clearly the present effect of deforestation – lack of construction timber at reasonable prices. This is the case in some parts in Eastern Ethiopia and in the Central Rift Valley.

- During the years a number of initiatives have been taken in order to introduce the adobe technology in Ethiopia, both in rural areas and in urban centers. The erection of demonstration buildings has been an important part of these initiatives. Most of these initiatives seem however to have failed, as they have not resulted in a sustainable diffusion of the technology. The reasons behind this are many and interdependent. Petersson and Ström (2015) mention, among other things the following: lack of continuous efforts, neglecting of training and education, market forces, negative attitudes from authorities and absence of advantages that are easily and clearly identified.

- In some cases the adobe technology has been used in a way that is not recommendable from a technical point of view. The reason behind this seems to be a lack of understanding of the limitations of adobe and a lack of experience. It can be anticipated that cases like these creates negative demonstration that limits further diffusion of the technology instead of promoting it. These observations underline the importance of proper demonstration and education.

Several cases in Ethiopia, see e.g. Hjort and Sendabo (2007), show that durable houses with a good indoor climate can be built by a proper use of adobe technology. The technology has many advantages: it is real low-cost, local material can be used to a very great extent and the “timber content” is very low. In addition to this it is rather simple with no need of special equipment with the exception of some simple forms for block-making. The technology has really the potential to become “the property of everybody”.

As regards durability however a special concern must be given in some regions to termite-attack also for adobe-houses. This is clearly demonstrated by Debelo and Degaga (2014). In connection with site-visits in Central Rift Valley in Ethiopia they have noted that more than 85 % of 35 houses built by mud blocks where prone to termite infestation. The corresponding figures for 23 houses built according to the traditional technology was 100%. It can be noted that the great majority of the houses, both adobe and traditional, were rather young, i.e. less than six years old.
Debelo and Degaga (2014) argue that it is more likely that infested wooden wall houses have a shorter life than adobe houses as they attack the load bearing structure, the wooden wall. However, also in adobe houses, the termite can cause serious problems. In adobe walls they can simply move through the walls without affecting these and the roof structure and cause heavy damages.

4. The demonstration project

At Halmstad University studies concerning low-cost housing with a special focus on the Kambaata Region in South Central Ethiopia have been conducted for several years; (Hjort and Sendabo, 2004). The overall aim has been to introduce low cost housing technologies and at the same time study and analyse the attitudes of ordinary people towards these technologies. From the beginning the importance and necessity of erecting demonstration buildings have been underlined.

In accordance with this a project aiming at erection of four demonstration buildings in the town of Durame in the Kambata Region was initiated. The aim was to study and demonstrate two low-cost housing technologies; adobe technology and a technology based on cement stabilised soil blocks. The purpose was to get a basis for technical studies as well as studies concerning attitudes. The technology based on cement stabilised soil blocks will not be commented further in this paper.

When the project started the adobe technology was by and large unknown in the Kambaata Region. Although this region was and still is densely populated, the access to timber for construction purpose was and still is rather good, at least as concerns eucalyptus. This means that an important driving force for a spontaneous development of the adobe technology was and still is lacking.

The project was planned and conducted in cooperation with a local development organisation. The plan was that this organisation should own and use the erected demonstration buildings in the future. The work at the site started in the beginning of 2009. Due to different difficulties the project was delayed and the demonstration buildings were not finalized until the beginning of 2012.

The studies related to these demonstration buildings can be divided into two groups: studies which focuses on technical issues and studies related to attitudes towards the new technologies. They have been executed before, during and after the erection of the demonstration buildings, see Table 1.

Table 1. Studies within the project – overview.

<table>
<thead>
<tr>
<th>Type of study</th>
<th>Before erection</th>
<th>During erection</th>
<th>After completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical studies</td>
<td>Trial tests of soil reported in Andersson and Berglund (2002)</td>
<td>General observations with focus on methods for weather protection during manufacturing of blocks and masonry work of walls.</td>
<td>Follow-up studies that will focus on durability and function.</td>
</tr>
<tr>
<td></td>
<td>Laboratory and field tests regarding adobe blocks; reported in Hjort (2009).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Studies regarding attitudes</td>
<td></td>
<td>Observations</td>
<td>Observations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inquiry form</td>
<td>Interviews.</td>
</tr>
</tbody>
</table>

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The detailed design of the demonstration buildings was executed by two BS.C students. It is described in Johansson and Wartainen (2008). These two students based their design from findings obtained during a field study in Ethiopia. An essential part of their field study was a visit to Challia in Western Ethiopia, where they studied a successful low cost housing project. Interviews with people living in houses erected by adobe technology were an essential part of their study.

Three buildings were designed according to the following:

- Buildings: Dwelling House, Kitchen and Toilet:
- Sizes: Dwelling House: 5.5 x 5.8 m², Kitchen: 3.4 x 3.4 m², Toilet: 2.5 x 2.5 m²
- Foundation: Stone masonry for all buildings
- Walls: Adobe;
- Roofing: Trusses of eucalyptus. Corrugated iron sheets for all buildings
- Flooring: Concrete slab on natural stone for all buildings
- Ceiling: Dwelling House Of cloth
- Doors and Windows: Wooden. Locally fabricated for all buildings

This is a description of the main features of the design. However, many important details are discussed and appropriate solutions are proposed by Johansson and Wartainen (2008). The following can be mentioned: foundation details, roof overhang, securing of roofing against wind-forces, fastening of door and windows.

The soil available at the spot was used for the production at the site of adobe blocks with the size 150 mm x 200 mm x 400 mm. The soil, taken at a depth of about 500 mm after the topsoil had been removed was mixed with water and straw. The straw, consisting of” teff-straw” was purchased locally. Simple forms made of ply-wood were used. These forms were open in the bottom and in the top. The manufactured blocks were stored and cured, at a first stage inside a store and at a second stage under a weather protection roof, see below. The expected and intended curing time was 28 days. However, for some of the manufactured blocks this time was prolonged considerably due to rainy and thereby humid air conditions. As mortar in the adobe walls soil mixed with water and straw was used.

The weather in Durame and its surroundings seems to have become unpredictable. Because of this the erection of a temporary roof structure was necessary as adobe blocks are very sensitive against water and wetting up. Because of this, and because of difficulties in planning the project work in relation to rainy periods, a temporary roof structure acting as weather protection was erected for the Dwelling House. This temporary roof structure consisted of the final roof structure (eucalyptus trusses, eucalyptus purlins and corrugated iron-sheets) for the building in question resting on temporary eucalyptus poles. The manufactured blocks were in a first stage stored below this temporary structure. In a second stage the walls were erected below it. At a final stage the roof structure was made to rest upon the walls and the eucalyptus poles were removed.

The general impression and experience from the use of this technology in Durame is that it is very suitable for the region and that it is easily understood and easily adopted by workers involved. The
manufacture of adobe blocks and the erection of the buildings arouse a great interest among the inhabitants of Durame and most people expressed a positive attitude towards the technology.

In Table 2 the result from a questionnaire regarding the attitude towards the adobe technology is presented. The questionnaire was written in the official national language amharinja and in the local language kambatinja. It was made with the erection of the demonstration buildings as a reference. The questionnaire was distributed to 40 persons whose answers were analysed.

Table 2. Studies of attitudes towards adobe technology

<table>
<thead>
<tr>
<th>Part</th>
<th>Statement</th>
<th>(% responding positively)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regarding the acceptance of adobe technology</td>
<td>I don’t support the idea</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>I support the idea</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>I support the idea but I don’t think it will be accepted</td>
<td>2</td>
</tr>
<tr>
<td>Regarding training in adobe technology</td>
<td>I am willing to participate</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>I am not willing to participate</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Before I answer – let me see the training</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>No answer</td>
<td>2</td>
</tr>
</tbody>
</table>

5. Follow-up studies

During a visit in the beginning of 2015 to Durame observations and semi-structured interviews in the region were made. The observations showed that from a technical point of view the demonstration buildings were in good condition. Some defects were however noted, e.g. has the cement-lime plaster on the walls, which is intended to protect the walls from rain, come loose. It was also noted that the demonstration buildings were not used; neither by the local development organisation in its daily business, nor as demonstration objects related to ongoing education regarding adobe technology.

At an interview with a person representing the local development organisation it was mentioned that this organisation, due to lack of resources, had not been able to utilise the demonstration buildings as intended from the beginning. One of the intentions had been to continue with educational activities within adobe technology with the use of the demonstration buildings as reference objects.

The observations indicated further that the impact of the project and the demonstration buildings with regard to introducing the adobe technology in Durame and its surroundings was very small, if any. This impression was confirmed by interviews. At the interview with the person representing the local development organisation it was stressed that the adobe technology would have big advantages as a building material in the Durame region but that it has not been adopted by the local population mainly due to lack of knowledge.
6. Concluding discussion

The project showed that it is possible to erect durable and functional adobe buildings in the Durame area. Appropriate material is available and the technology can easily be understood and adopted by local workers. Furthermore, it showed that it is possible to handle the somewhat unpredictable weather conditions in the area by erection of a temporary roof structure that later on can be transferred into the permanent one.

The outcome of the project with regard to introducing a new technology can be discussed and analysed from an innovation diffusion perspective based on the attributes defined by (Rogers, 2003):

“Relative advantage”. The relative advantage of the adobe technology, in relation to the traditional technology, might be underestimated or even denied by ordinary people in Durame. In this region there is no shortage of timber for construction; one of the main driving forces behind the spontaneous spread of the technology in other regions in Ethiopia. Other advantages, such as a better indoor climate and a better resistance against termite attack can only be perceived by the use of the building and after a longer period respectively.

“Compatibility”. The adobe technology can be regarded as a compatible technology as mud mixed with straw is a very important part of the traditional building technology. In accordance with this working with mud has a long tradition in Ethiopia. However, working with clay has low status in Ethiopia; (Hjort and Sendabo, 2005). This might deter potential users from building their dwelling house almost entirely of mud.

“Complexity”. Adobe is a simple technology; it is easy to understand and it is easy to adopt as clearly demonstrated during the erection of the buildings. However, the use of a temporary roof structure as a shelter and as a storage area and later on using this as permanent roof structure might have been regarded as complicated and difficult. It is possible that this part of the process has deterred potential users from adopting the technology.

“Trialability”. The adobe technology offers a good trialability as such. It is thus possible for a potential adopter to try the technology in small scale, for instance by using it for a minor building, e.g. for a store or similar. In this case this has only been done when executing the demonstration project. The reason for that is that the organisation championing the diffusion had to withdraw earlier than planned.

“Observability” The adobe technology offers a good observability of its buildability which was used in connection with the demonstration buildings erected in Durame. But, the observability of the finished product, its durability, indoor climate etc has to be observed for some time, years. As the building has not been used and the organisation championing the diffusion withdrew this has not been done in this case.

From a comparison between this study and the study presented in Hjort and Widén (2015) it is clear that the role of a champion is very important as is the perceived relative advantage and the cultural
In this case several of the factors pointed out by Rogers (2003) was not fulfilled, but could, or would, have been if a champion had been present over time, also after the demonstration project finished.

This study, together with the earlier study, forms an interesting base for future studies of non-commercial innovation diffusion in developing countries. In future studies the focus will be on the role of the champion of the innovation over time, the role of relative advantage and the cultural context and how these influence the success of diffusion, as well as how these influence the other factors said to be important for innovation diffusion.

References


Ethiopian Government (2011) *Ethiopia’s Climate-Resilient Green Economy Green economy strategy*


Advanced Intelligent Agents for Optimised Dynamic Process Monitoring and Defect Inspection in Construction Projects

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Abstract

Defects and errors in new or recently completed work continually pervade the Architecture, Engineering and Construction (AEC) sector. Whilst inspection and monitoring processes are established vehicles for 'control', the procedures involved are often process-driven, time consuming, and resource intensive. Paradoxically therefore, they can negatively impinge upon the broader aspects of project time, cost, and quality outcomes (the three central tenets). Acknowledging this means appreciating concatenation effects such as the potential for litigation, impact on other processes and influence on stakeholders’ perceptions – which in turn, can impede progress and stifle opportunities for process optimisation and innovation. This also deleteriously affects opportunities for improving: logistics, carbon reduction, health and safety, asset underutilisation, and labour distribution. This study evaluates these challenges from a time, cost, and quality perspective, focusing on identifying opportunities for process innovation and optimisation. It reviews the state of the art technologies that support optimal use of artificial intelligence, cybernetics, and complex adaptive systems within the AEC sector. From this, a conceptual framework for the development of a real-time intelligent observational platform supported by advanced intelligent agents (RtIOP), is presented as a solution to these challenges. RtIOP actively, autonomously, and seamlessly manages intelligent agents (e.g. cameras, RFID scanners, remote sensors, etc.) in order to identify, report, and document 'high risk' defects. Findings underpin a new ontological model that supports ongoing development of a dynamic, self-organised sensor (agent) network, for capturing and reporting real-time construction site data. The RtIOP model is a 'stepping stone' towards the advancement of independent intelligent agents, embracing sensory and computational support, which are able to perform complicated (previously manual) tasks to optimise dynamic processes seamlessly and autonomously.

Keywords: Intelligent agent, process, innovation, ICT, sensors, optimisation
1. Introduction

Defects and errors within the AEC sector still continually pervade the industry. Whilst detailed inspection and monitoring processes are established vehicles for their 'control', the procedures involved are often process-driven, time consuming, and resource intensive. These checking and monitoring processes can negatively impinge upon the broader ambitions of project time, cost, and quality outcomes as they are very resource-intensive. In recent years, the trade-off between an increasing need for non-stop inspections during construction work and their negative ramifications have focused on the ‘value’ of systematic, innovative monitoring of construction operations (vis-à-vis conventional ‘inspector-based’ methods). Research in this area has attempted to address this through various proffered systems, typically embracing the ability to automate, capture, process and share project data among relevant stakeholders.

These systems have provided additional project benefits, for example improved: logistics, carbon reduction, health and safety performance, project efficiency savings, increased asset utilisation, and smoother labour distribution. However, unlike other industries, the AEC sector has not been quite as successful in adopting such automated monitoring systems; especially, for small and medium scale projects (Navon and Sacks, 2007). This is mainly due to the: nature of construction products (Howell, 1999); unsuitable nature of construction sites for high-tech monitoring solutions (Cheng and Chen, 2002); disaggregated nature of construction project teams (Davidson and Skibniewski, 1995); and slow, error prone existing project data collection systems (Saidi et al., 2003).

Given these challenges and associated conditions, the majority of construction projects retain their protracted and inaccurate traditional (inspector reliant) control mechanisms. Among other things, this leads to a lack of ‘as-built’ construction project information (Saidi et al., 2003) – which results in a general disorganisation of projects in relation to schedule, cost, and workforce control (Howell and Koskela, 2000). Acknowledging these issues, this study evaluates these challenges associated with current technologies from a time, cost, and quality perspective. The overall focus is to identify opportunities for the introduction of hybrid low cost systems which are specifically able to optimise the monitoring and control process; thereby allowing significant innovation opportunities to occur.

2. Related Works

This section overviews the state of the art technologies for facilitating systematic onsite monitoring of construction projects. In pursuance of this, it should be noted that regardless of the core functions and associated technologies, the majority of thinking on monitoring and control systems can be categorised into two groups: 1) Tracking or Scanning Equipment based technologies; and 2) Still Image based technologies. The challenges and opportunities of these two categories are presented as a prelude to making recommendations for the development of a hybrid, intelligent monitoring system (RtIOP).
2.1 Tracking or Scanning Equipment Based Technologies

There are a myriad tracking or scanning technologies available to facilitate systematic and automated construction project monitoring. One popular example is the Global Positioning System (GPS) which can be widely used to determine the geometric properties of a constructional element e.g. equipment within a construction site. Others include for instance, augmented reality (AR) (Chi et al., 2013). These systems are now being used for tracking and managing the workforce (Hammad et al., 2009), as well as monitoring and helping control the implementation of constructional elements (Behzadan et al., 2008). Additional similar functions are supported by technologies such as Radio Frequency Identification (RFID) (Kelm et al., 2013), Ultra-Wide Band (Zhang and Hammad, 2012), and Barcoding (Chen et al., 2002). Hybrid systems use a combination of these options; such as when GPS is merged to work alongside RFIDs (Kelm et al., 2013). Despite their merits, the reliability of such systems has always been something of a challenge, since they can be affected by unexpected interfering fields (Chi et al., 2013). Another downside is the comparatively high capital investment needed for such equipment, which in many cases ultimately becomes ‘buried’ in the completed construction facility – which can add significantly to the overall project cost.

An alternative system relies on laser-scanned point clouds. Laser scanning is not a new technology, but due to the increasing take up of Building Information Modelling (BIM), as-built BIMs scanned by these tools are gaining popularity, with increased use being acknowledged within the AEC sector. This is mainly because they are capable of measuring geometric characteristics of environments, with high accuracy and within short timescales (Tang et al., 2010). The as-built BIM generation – which is also known as ‘scan to BIM’ – is described by Tang et al. (2010) as a process comprising the following: 1) data collection through dense measurement of points about the building using laser scanners; 2) data pre-processing, which includes filtration of point clouds and the integration of coordination systems; and 3) modelling the BIM, which is a process of transforming the point clouds to semantically rich BIM objects. The downside of as-built BIM technology is that whilst data pre-processing is a fairly straightforward process, the data collection and modelling tasks are often very costly, time consuming and error prone (Bosché et al., 2015; Brilakis et al., 2010). These challenges have made many scholars to suggest Still Image based technologies as a viable alternative.

2.2 Still Image Based Technologies

Advancements in technology and the declining prices of mobile and fixed cameras have encouraged the increased use and uptake of photography to record daily activities and progress of construction projects. This also includes monitoring, logistics, documentation, and control purposes (e.g. resource management, Health and Safety etc.). This has also underpinned the emergence of new photographic documentation and distribution services, to provide ‘visual’ progress records for efficient distribution among stakeholders (Han and Golparvar-Fard, 2014). With the aid of multi-view geometry methods, image processing, and computer graphics, these ‘as-is’ images can either be compared with one another throughout the construction process or
against an ideal ‘to be’ 4D BIM, which represents the assumed flow of processes. These options help flag up possible deviations (e.g. errors) in construction works (Yang et al., 2015).

Due to their distinctive benefits, for example cost efficiency, accuracy, and reliability – such systems are increasingly popular. This popularity includes: detection and recognition of building elements (Chi and Caldas, 2011; Gong and Caldas, 2011); tracking 2D and 3D positions of objects (Hu et al., 2004); controlling and monitoring site activities (Rezazadeh Azar et al., 2012); and managing productivity (Gong and Caldas, 2009). Their downside is however, that they are fully dependent on the quality and supply of the images – which can yield challenges due to volume regarding the need to continuously capture photographs with site data. These solutions can also be highly labour-dependent for systematic image capture when ‘high-tech’ equipment is not available. Another challenge can be access, especially to all parts of construction site; as in some cases this is not practically feasible.

3. Research Methodology

The research methodological approach adopted in the research includes a reflection on extant literature within the field of reference to evaluate the state of the art technologies employed within the AEC sector in order to capture the salient challenges facing researchers examining automated project appraisal. This process involved the selection of cognate discipline fields (see keywords) and text from seminal journals and core reports to not only identifying the challenges associated with each technology, but also the current thinking and future trajectories proffered. From these results, a theoretical propositions is presented for discussion. This was based on the scientific foundations required to support such systems, including the optimal use of artificial intelligence, cybernetics, and complex adaptive systems. The resulting conceptual framework (RtIOP) presents a typology, which includes software agents to access and address multiple data analysis tasks, including vision-based object recognition and tracking for construction monitoring.

4. Future Perspectives

Extant literature confirms significant achievements and emerging advancements, especially in computer graphics, 4D modelling, BIM, AR, big data processing, aerial robotics, cybernetics, and smart agents. These are now starting to pervade the market, and are starting to revolutionise construction project monitoring. However, whilst it could be argued that collaborative multi-agent systems for real-time monitoring and planning on construction sites is not particularly new (Zhang et al, 2009); there are still many challenges associated with seamless integration. In terms of computer graphics, Karsch et al. (2014) developed an interface based on the Structure-from-Motion (SfM) technique to automatically compute alignment of photos taken from a selected model. This engages automatic reasoning on both real-world construction data and established multi-view datasets.

Modern photogrammetry and remote sensing have a strong heritage (Thompson, 1977; Richards, 2013). However, new technological advancements and the declining costs of
equipment - especially computer processing and visualisation, robotics and geomatics engineering has resulted in an increase in the use of low cost accurate aerial systems for collecting and analysing geometric and geographic data (Colomina and Molina, 2014). Similarly, Siebert and Teizer (2014) developed an innovative programme for photogrammetric flight planning and control to generate 3D point clouds from digital mobile images. They evaluated the performance of a purposively developed Unmanned Aerial Vehicle (UAV) system, which was able to rapidly and autonomously collect 3D data.

With the aim of capturing large amounts of data with minimum manual input Zollmann et al. (2014) used a UAV system controlled by an automatic flight path planning programme. Larger UAVs were able to capture the whole geometry quickly; while smaller, less expensive vehicles were employed to capture more detailed, localised data from parts of the target boundary. Due to limitations in battery life for such vehicles, an optimisation algorithm for programming flight paths and task objectives was also designed (ibid.). Despite these kinds of valuable advancements for systematic use of UAVs on projects, issues of capital cost and the requirement for in-house expertise, puts their use beyond the capabilities of many construction projects.

Given these issues, it is postulated that these kinds of challenges can be overcome by employing a mix of artificial intelligence, cybernetics, and complex adaptive systems. Intelligently combined, these could support novel arrangements of independent equipment solutions (as smart agents), with sensory and computational resources to perform complicated tasks of dynamic data collection and analysis of construction projects. Within such a network, agents could take the form of any device capable of collating and communicating site data, such as still time-lapse or video cameras, RFID tags, GPS receivers, range sensors, and other type of sensors capable of localised sensing.

A set of optimisation agents for managing project resources would need to complement project targets, including delivery of just-in-time logistics; distribution and management of materials; and labour optimisation, across the entire works. The system would actively embrace the model of the ‘invisible hand theory’ (Minowitz, 2004), whilst also taking account of concomitant human factors typically engaged in site-related activities. A conceptual model of this RtIOP architecture is shown in Figure 1.
5. Discussion

In developing the conceptual model, specific consideration should be given to the optimisation of inter-agent communication and collaboration schemas, possibly in the form of a dynamic autonomous management tool. The system could have wide scope of application including identification, reporting, and documentation of defects and errors within a construction environment; monitoring of the construction progress; creation, maintenance and updating of the construction site materials repository; and optimisation and monitoring of workforce deployment.

The architecture of this system is envisaged to rely on a network of dynamic, self-organised sensors (agents) for capturing and reporting construction site data in semi or real-time. The network could consist of a set of multiple, autonomous ‘clip on’ sensing agents (including intelligent cameras) that are easily attached to different structures – typically engaging a ‘pick and reposition’ sensor concept. A particular feature of the proposed system would be the availability of relatively low cost of individual sensing devices; to a level at which they can, if desired, be treated as disposable units. One of the most expensive and least reliable subsystems of the robotic agent is its propulsion mechanism. The mobility of the RiOP device would depend on its acceptance by and cooperation with, the construction workforce. This is
important, as pick and reposition requests will need to ‘be moved’ in relation to data capture mechanisms, which would be signalled audio-visualy (e.g. by flashing LED). A key requirement here would therefore be for a worker to physically reposition the (signalling) unit. For instance, by clipping it to an appropriate safe structural component. Worker input would also extend to include simple repositioning tasks as required. The RtIOP system would therefore require operatives to be trained accordingly in order facilitate this interchange.

From a sensor perspective, each sensor unit is able to estimate its own position with respect to the construction site topology and the target work activity; thereby being able to plan the optimal trajectories needed reach its final destination in a finite number of ‘pick and reposition’ steps. Given this, the key enabler here is the low cost technology needed to making this a possibility, using for example a combination of existing proprietary (‘off the shelf’) GPS systems and SiM [Tao and Matuszewski, 2013; Tao et al., 2013]; combined with Simultaneous Localisation and Mapping (SLAM) (Davidson et al., 2007) computer vision algorithms.

Another but more expensive option would be to manage sensors’ positional arrangements with the help of autonomous UAVs. This will engage pick and repositioning agents – to send out signals, indicating when a change of position is required. UAVs could then reposition sensors as and when prompted by the system. A set of software agents would address multiple data analysis tasks, including: vision based object recognition for non-obtrusive inventory; tracking and action recognition for onsite personnel management; and site map building (using an intelligent SLAM algorithm) for construction progress monitoring.

6. Conclusion

This study was motivated by the need for automated project monitoring and control systems for optimisation of day-to-day activities within AEC projects. This paper presented a review of the state of the art technologies that typically facilitate systematic project monitoring within the AEC domains. In order to address the issues (challenges) identified with existing systems, a proposed conceptual model was presented for discussion. This relies on the optimal use of artificial intelligence, cybernetics, and complex adaptive systems. The RtIOP model is supported by advanced intelligent agents; where the proposed platform can actively, autonomously and seamlessly manage intelligent agents (cameras, RFID scanners, remote sensors, etc.) in order to identify, report and document ‘high risk’ defect areas or activities.

The findings underpin a new ontological model that complements ongoing development of a dynamic, self-organised sensor (agent) network, for capturing and reporting real-time site data. As such, RtIOP is a ‘stepping stone’ for the advancement of automated project monitoring and control systems – using independent intelligent agents and sensory and computational support to perform complicated (previously manual) tasks. It is proffered that this solution can help deliver the three central tenets of project time, cost and quality.
References


Tao, L., Mein, S. J., Quan, W., and Matuszewski, B. J. (2013). Recursive non-rigid structure from motion with online learned shape prior. Computer Vision and Image Understanding, 117(10), 1287-1298.


Investigation of Relined Rehabilitated Piping in Residential Buildings

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Abstract

In this paper rehabilitation methods for piping systems by relining in Sweden are reviewed. The paper also includes analyzing relined pipes which have been in the field between one to ten years to evaluate the quality and performance of the relining as well as typical problems which can occur. The investigated samples were sent to the laboratory for investigation and since they were not randomly taken out, the notations in this study should not be an indication of relining performance in general. However it can be said with certainty that improvement in technology is needed which is the reason of our study.

Keywords- Building, Pipe, Rehabilitation, Relining, Sewer

1. Introduction

Aging of water and waste water pipelines is a growing problem. Replacing of pipes in the traditional way is costly, disturbs local environment and is time consuming. These challenges have led to finding other types of renovation solutions such as rehabilitation with relining. In the relining technique, a new polymer pipe forms inside the old pipe without the need for taking the old pipe out. The use of relining methods and materials is increasing in Nordic countries, also in Sweden, due to the fact that water piping systems are getting old. Renovation by relining is faster and considerably cheaper compared to replacement of the old pipes. Flow chart 1 describes the three most common relining methods in Sweden.

**Flow Chart 1**

*Rehabilitation methods for relining in domestic waste water piping in Sweden*

*Spray-on method*
- A polyester composite reinforced by glass flake
- The most common material in Sweden is known as Baltoflake (Jotun, 2015)
- Approximately 3 layers of 900-1100 µ
- Application is with airless and air spray

*Brush-on method*
- Rubber-filled epoxy composite
- Usually 2 layers of 1000 µ (in some cases 3 layers)
- Application with different sizes and types of brushes

*Flexible sleeve method*
- Resin–saturated fabric
- The resin is commonly epoxy
- Inversion of the saturated fabric into the sewer system
- Thickness depends on the material and diameter of the old pipe
One relining company, has introduced another technique with is called hybrid where both flexible sleeve and brush-on method are used to reline the host pipe. Different types of relining which are used in Sweden can be also classified and known as non-structural, semi-structural or fully-structural (AWWA, 2014), (Kharazmi, Björk, 2016).

**Figure 1 – Distribution of the three main relining application methods between relining companies in Sweden (2013)**

*Table 1- Pictures of pipe inspection by closed-circuit television*

<table>
<thead>
<tr>
<th>Figure 2</th>
<th>Figure 3</th>
<th>Figure 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed-circuit television (CCTV) for inspection of the interior side of the water pipe and to evaluate condition of the host pipe (Proline, 2013)</td>
<td>Application of the epoxy relining by brush-on method and controlling the procedure by camera (known as Dakki method in Sweden)</td>
<td>Closed-circuit television (CCTV) inspecting the interior of the pipe after application of the relining to evaluate condition of applied relining (Proline, 2013)</td>
</tr>
</tbody>
</table>

Closed-circuit television (CCTV) is usually the method to inspect the interior of the water pipe and to evaluate quality of the installed pipe. The main reasons of inspecting the pipe are first, to evaluate the degree of cleaning and the required preparation for the existing pipe before starting the lining application, to detect any structural problems such as cracks, holes, leakage and also to check the pipe bends that can affect cleaning. The basic principle of CCTV inspection is that a television camera, together with a light source, is mounted on a tractor or skid which is pulled or propelled through the sewer from one manhole to the next. The camera transmits pictures by cable to a monitor (Ian G,
To remove corrosion and standing water before application or installation of the relining, cleaning is required. The cleaning method is usually mechanical using a steel rod, which is called Drag Scrapers (Najafi, 2010). Based on recommendation by a manufacturer for the polyester composite (Jotun, 2016) all surfaces should be clean, dry and free from contamination. The surface should be assessed and treated in accordance with ISO 8504. Adequate drying time is related to the substrate temperature and the air circulation. For example based on the manufacturer’s (Jotun) specification data, for the polyester Baltoflake, the temperature of the substrate should be at least 3°C above the dew point of the air to reach a good curing degree.

Although relining has been used in Sweden around 30 years, studying of the old relined pipes which have been taken out from the field, show improvement is needed, particularly regarding monitoring the quality of final products. Critical investigation of the quality level and studying the performance of different relining materials will create a basis for well-founded advices and recommendations. Moreover more investigation such as this ongoing study will provide better understanding regarding advantages and limitations of relining in comparison to a traditional replacement of the piping in residential buildings.

2. Performance of relined pipe with polyester and epoxy composites

Relining as a renovation technique is expected to perform well during a longer time. Therefore, it is promising to investigate the quality of common materials and techniques over time. To study the performance of relining, a study has been carried out on 11 relined pipes (as listed in Table 2) which have been in the field in different parts of Sweden. Different analyses were used to evaluate the quality of the installation and materials performance and in this paper the visual inspection, thickness measurement and material comparison with FTIR spectroscopy will be discussed. Samples numbered from 1 to 6 were relined with rubber modified epoxy material applied by brushing method and samples 7 to 11 had relining material based on reinforced polyester with glass flake and applied with spray-on technique. Table 3 shows a cutted piece of each sample and provides a short summary of notification from visual inspection. The names of the relining companies for each sample will not be mentioned but the related information about each sample such as the applied material and technique, the time that they have been installed in practice and defects seen in visual inspection will be discussed.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Type of relining material</th>
<th>Application method</th>
<th>Approximate time in service after relining</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Epoxy based composite (Rubber filled)</td>
<td>Brush-on</td>
<td>6 years (2005-2011)</td>
</tr>
<tr>
<td>2</td>
<td>Epoxy based composite (Rubber filled)</td>
<td>Brush-on</td>
<td>6 years (2005-2011)</td>
</tr>
<tr>
<td>3</td>
<td>Epoxy composite (Rubber filled)</td>
<td>Brush-on</td>
<td>10 years (2001-2011)</td>
</tr>
<tr>
<td>4</td>
<td>Epoxy composite (Rubber filled)</td>
<td>Brush-on</td>
<td>14 days (2009)</td>
</tr>
<tr>
<td>5</td>
<td>Epoxy composite (Rubber filled)</td>
<td>Brush-on</td>
<td>3 years (2008-2011)</td>
</tr>
<tr>
<td>6</td>
<td>Epoxy composite (Rubber filled)</td>
<td>Brush-on</td>
<td>4 years (2007-2011)</td>
</tr>
<tr>
<td>7</td>
<td>Polyester based composite (reinforced with glass flake, known as baltoflake)</td>
<td>Spray-on</td>
<td>3 years (2008-2011)</td>
</tr>
<tr>
<td>8</td>
<td>Polyester glass flake (reinforced with glass flake, known as baltoflake)</td>
<td>Spray-on</td>
<td>7 days (2010)</td>
</tr>
<tr>
<td>9</td>
<td>Polyester glass flake (reinforced with glass flake, known as baltoflake)</td>
<td>Spray-on</td>
<td>3 years (2008-2011)</td>
</tr>
<tr>
<td>10</td>
<td>Polyester glass flake (reinforced with glass flake, known as baltoflake)</td>
<td>Spray-on</td>
<td>2 years (2009-2011)</td>
</tr>
<tr>
<td>11</td>
<td>Polyester glass flake (reinforced with glass flake, known as baltoflake)</td>
<td>Spray-on</td>
<td>3 years (2008-2011)</td>
</tr>
</tbody>
</table>

Table 3- Relined pipe which have been installed in the field
Sample 1 - A relined pipe with rubber modified epoxy composite applied with brush-on method. The approximate time in service after relining has been 6 years. As can be seen, relining has been unevenly applied. Cracks could be seen and corrosion between lining and the host pipe can easily be detected.

Sample 2 - A relined pipe with rubber modified epoxy composite applied with brush-on method. The approximate time in service after relining has been 6 years. Corrosion and naked spots without any coverage with epoxy layer can be seen.

Sample 3 - A relined pipe with rubber modified epoxy and applied with brush-on method. The approximate time in service after relining has been 10 years. Uneven application of relining can easily be seen. Lining film was loose which could easily be separated in the edge of cutted pipe and heavy corrosion was spread through the relined pipe.

Sample 4 - A relined pipe with rubber modified epoxy and applied with brush-on method. Approximate time in service after relining has been 14 days. The relined pipe was taken out only after 2 weeks because of the fail in application.
Sample 5 - A relined pipe with rubber modified epoxy and applied with brush-on method. Approximate time in service after relining has been 3 years.

Besides air bubble which could be seen randomly on the outside of the film, no major defect can be detected.

Sample 6 - A relined pipe with rubber modified epoxy applied with brush-on method. Approximate time in service after relining has been 4 years.

Sample had uniform film application without any major defect.

Sample 7 - A relined pipe with polyester baltoflake applied with spray method. Approximate time in service after relining has been 3 years.

The lining was not applied in totally uniform layer. After cutting the piece of the relined pipe, the lining layer came off totally showing heavily corroded substrate surface of the original pipe.

Sample 8 - A relined pipe with polyester baltoflake applied with spray method. Approximate time in service after relining has been 7 days.

Pipeline was taken out shortly after relining due to fail in rehabilitation. Uneven film and thickness variation can easily be seen.
2.1. Thickness evaluation

According to the manufacturer of the relining materials (Jotun, 2015), also information provided by relining companies (e.g. proline, Dakki), lining with rubber modified epoxy (brushing method) and polyester based material (spray-on technique) shall be produced to have nominal thickness of 2 and 3mm respectively. Circumferential thickness measurements were carried out using a digital caliper with 10 measurements with 5 measurements from each edge of relined sample pipes. The results are shown in Figure 5 for the pipes relined with epoxy based relining applied with brushing and in Figure 6 for the pipes relined with polyester based relining material and spray technique.
Figure 5: Circumferential thickness measurements for sample 1 to 6

In relining application, a uniform thickness application of the lining material should be applied all around the pipe for the material to be able to perform as expected; too much or too little material, causing very thin or very thick layers, remaining uncoated spots or forming sag, all are defects leading to poor performance of the relining. As it can be seen in Figure 5, sample 3 (which is the oldest sample) showed the highest variation in thickness. This is also possible to see in visual inspection and in the picture in table 2.

Figure 6: Circumferential thickness measurements for sample 7-11

Figure 5 shows that sample number 4 has the lowest thickness average and it can be seen from figure 6 that sample number 8 has a very uneven film thickness. These two samples have been taken out due to failure of the system and poor relining application.
2.2. Fourier transform infrared spectroscopy (FTIR)

FTIR spectroscopy was used to see if there is significant difference between the materials that have been used by different relining companies in each technique. The spectra were recorded from 400 to 6000 cm\(^{-1}\) using a Perkin Elmer FTIR instrument with scan number and resolution of 4 and 4 cm\(^{-1}\) in order. Figure 7 shows the FTIR spectra for the samples relined with epoxy based relining materials and Figure 8 shows FTIR spectra of relined samples with polyester based relining material.

*Figure 7- Normalized FTIR spectra for samples 1, 2, 3, 4, 5, and 6 (Epoxy based relining material)*

Comparison of FTIR spectra shows that molecular structures of the materials which have been used in different projects are not the same. As it can be seen in the changes in spectra at 1100 cm\(^{-1}\), sample 1 and 2 are not similar to 3, 4, 5 and 6. This indicates that installation companies do not use the exact same material in brush-on method.
FTIR spectra showed that molecular structures of the materials which have been used for sample 7 to 11 are similar indicating the same formulation/material that have been used in the different projects (more likely all have provided material so called Baltoflake).

3. Discussion

The uneven relining layer in Sample 1 can be due to a wrong viscosity of the composite in liquid state and before application. This can cause sagging, as can be seen in picture of sample 1, especially in gravity sewers which are majority of sewers in residential buildings. The existence of corrosion between liner and host pipe can be because of improper cleaning. In sample 2, relining was applied in a thinner layer than normal and this was the reason for inadequate coverage of the film, leaving some spots uncoated and consequently causing corrosion. Sample 3 shows uneven film formation of relining which was a cause of fail after application.

The reason for getting a loose lining layer can be mainly due to insufficient cleaning before application of relining. Sample 4 was taken out only two weeks after application due to poor application of relining. The layer of the applied film was very thin and the other problem was the material of the host pipe. A PVC pipe, as the original pipe, needs more consideration regarding preparation of the host pipe and before application of relining to secure adequate adhesion between lining layer and the host pipe. The air bubbles which can be seen in sample 5 can be due to inadequate mixture of the resin and hardener. Loose lining and corroded surface of the pipe in sample 7 can be again because of insufficient cleaning and poor preparation of the host pipe before relining application. The uneven film application in sample 8 can be due to the fail in proper preparation of the coating composite in liquid phase and before application. Uniform film application and good adhesion in sample 10 and 11 is mainly due to proper cleaning of the host pipe.

The investigation is highlighting the importance of proper cleaning and preparation before relining application. The other repeated result was a fail in applying a uniform and adequate film using lining
material. Both of these defects are possible to prevent with enough attention to the quality of application.

Thickness measurements indicated that circumferential lining thickness for spray-on technique was more consistent compared to the brushing method in those samples which were studied here.

The FTIR analysis showed that materials used in Swedish market differ from some companies compare to others. This difference more likely will not cause any problem as long as the quality of the provided material is high enough. However it must be checked, for example with comparison of the purchased new batch of material with an accepted high quality sample as the reference.

It is worth mentioning that these samples were not randomly taken out from different relining projects, therefore cannot be an indication of the quality performance of the relining techniques in general.

4. Conclusion

The investigation on the old relining samples taken from the field showed that developing a detailed quality control plan for each relining technique would provide more consistent quality between installation companies and manufacturers which are active in the field. The provision of the quality control requirements should be higher in different steps, such as inspection of the host pipe, cleaning, application and curing. Moreover choosing and applying the right material and giving adequate curing time and conditions can lead to a higher quality of the final result. Thickness measurements in this study indicated that circumferential lining thickness for both spray-on technique and brushing technique can be improved. It should be noted that samples discussed in this paper were not randomly taken out from different relining projects, therefore cannot be an indication of the quality performance of the relining techniques in general.

Studying the old relined pipes which have been in the field and in real conditions contributes greatly to a better understanding of the materials and techniques, limitations and advantages of this type of rehabilitation compare to the replacement of the pipelines and will help towards providing practical recommendation in close future.

Acknowledgement

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References

Manual M 28 Rehabilitation of Water Main, American Water Works Association (AWWA).

Dakki, *Hybrid method* (available online: http://www.dakki.se/metoder-inom-relining, [accessed on 20/03/2016])


Research on the Air Quality in the Classroom with Fresh Air Systems

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Abstract

Natural ventilation is generally used in classrooms in China, though such ventilation strategy could not ensure good indoor air quality all the time. In order to establish healthy and comfortable air environment in the classroom, this study installed fresh air system (FAS) and analyzed the relationships between the fresh air rate and PM$_{2.5}$ and CO$_2$ distributions. On-site measurement shows that after turning on the FAS, the fresh air rate raised from 2.4 m$^3$/h per person to 6.1 m$^3$/h per person, and the indoor PM$_{2.5}$ concentration decreased from 40 μg/m$^3$ to 18 μg/m$^3$. However, the CO$_2$ concentration still exceeded 2000 ppm, as the actual airflow rate of the FAS was 43.6% of its' rated airflow rate. Through calculation, this study recommended the minimum fresh air rate in the classroom should be 24.0 m$^3$/h per person to ensure the CO$_2$ concentration less the 1000 ppm. Furthermore, the economic analysis indicated that the FAS we chosen had both low initial invest and operating cost.

Keywords: Fresh air rate, Carbon-dioxide, PM$_{2.5}$

1. INTRODUCTION

Indoor air quality (IAQ) is highly related to student's health, comfort and study efficiency in the classroom. With the increase of the ventilation rate from 2.5 m$^3$/h per person to 19 m$^3$/h per person, the study performance would increase 10% (Kaneko, et al., 2007). A 1000 ppm increase in ΔCO$_2$(indoor minus outdoor CO$_2$ concentration) was associated with 10~20% increase in student absence (Shendell et al., 2004).

However, the IAQ is not so satisfy in Chinese classrooms nowadays. The CO$_2$ concentration was over 1000 ppm in 89.7% of the measured classrooms (Liu et al., 2005), In Deng's (2007) study, the CO$_2$ concentration in the classroom was 3800 ppm, with the fresh air rate of 0.29 ACH. Zhu et al. (2012) monitored PM$_{2.5}$ concentration of 114 classrooms in Shenzhen, China, and found the average PM$_{2.5}$ concentration was 71 μg/m$^3$, which was much higher than the limited level in Ambient Air Quality Standards (GB3095-2012, Chinese standard, 35 μg/m$^3$).

Natural ventilation is generally adopted in the classroom in China. Such method highly depends on the outdoor air quality. Due to the heavy haze resent years in China, it is recommended to close the
window to prevent the outdoor contaminant spreading to indoor space. On the other hand, closed window leads insufficient fresh air, causing high CO₂ concentration and odors. In order to establish healthy and comfortable indoor air environment in the classroom, this study installed fresh air system and analyzed the relationship between the fresh air rate and PM₂.₅ and CO₂ distributions.

2. METHODOLOGIES

2.1 Experimental method

This study installed the fresh air system (FAS) in a computer classroom of a middle school located in Shanghai, China. The classroom was 11.74 m in length, 7.97 m in width and 3.24 m in height (Figure 1). Ventilation rate, PM₂.₅ and CO₂ concentration were measured in both cases of FAS on and off. There were 40 students in the classroom during the measurement.

![Figure 1: The classroom configuration (a) used in the measurement (b) used in the model](image)

Tracer gas decay method (Zhu, 2005) was adopted to measure the air change rate, and the tracer gas was Sulfur hexafluoride (SF₆). INNOVA 1303 and 1312 were used to test the SF₆ concentration. Dusttrak8530 aerosol monitor was used for PM₂.₅ concentration measurement, with the sampling
frequency of 1 min. AZ7798 CO₂ datalogger was used for CO₂ concentration measurement, with the sampling frequency of 2 min. As shown in Figure 1 (b), The sampling points for CO₂ concentration were placed on the desk, which were close to the breathing zone of students. The sampling point for PM₂.₅ concentration was in the middle of the classroom.

2.2 Calculational method

The indoor PM₂.₅ concentration was calculated via the following mass conservation equation:

\[ V \frac{dC}{dt} = G + C_{\text{out},Q}\sigma + C_{\text{out},Q}(1 - \eta)Q_{\tau} - C_{Q} - C \times \text{CADR} \quad (1) \]

where \( C \) is the indoor PM₂.₅ concentration at \( \tau \) time (µg/m³), \( C_{\text{out}} \) the outdoor concentration (µg/m³), \( G \) the indoor PM₂.₅ emission rate (µg/h), \( \sigma \) the penetration coefficient, \( \eta \) the primary filtration efficiency of the fresh air system, \( Q_{\tau} \) the air leakage rate (m³/h), \( Q_{l} \) the supply air rate (m³/h), \( Q_{o} \) the exhaust air rate (m³/h), \( \text{CADR} \) the clean air delivery rate (m³/h), \( V \) the room volume (m³), \( \tau \) the time (h).

Considering steady condition, this study set \( \frac{dC}{dt} = 0 \). Via measurement, the PM₂.₅ concentration at inlet was zero and there was no air cleaner in the room. Then Equation (1) was simplified as:

\[ G + C_{\text{out},Q}\sigma \tau - C_{Q} = 0 \quad (2) \]

Moreover, this study also simulated the indoor CO₂ concentration distribution by Computational Fluid Dynamics (CFD). We discretized the classroom space into 1.08 million cells via Ansys Workbench 2014. Hexahedral mesh was used, with the skewness less than 0.97. All the boundary conditions were measured and input into Ansys Fluent 14.0. Re-Normalization Group k-ε (RNG k-ε) model was selected to approximate the Navier-Stokes equations. As for numerical schemes, this study used the SIMPLE algorithm to couple the pressure and velocity. The PRESTO! scheme was used for pressure discretization and the second-order upwind scheme for all the other variables. The solutions were considered to be converged when the sum of the normalized residuals for all the cells became less than \( 10^{-6} \) for energy and \( 10^{-3} \) for all other variables (Fluent, 2011)

3. Results

3.1 Ventilation rate

Figure 2 depicts the designed and measured fresh air rate with the fresh air system (FAS). When the windows and FAS were both closed, the fresh air rate in the classroom was 96.4 m³/h, namely 2.4 m³/h per person. After using the FAS, the fresh air rate increased to 244.0 m³/h, namely 6.1 m³/h per person. According to Code for Design of School (GB50099 - 2011, Chinese standard), the minimum fresh air rate in the middle school should be 14 m³/h per person, so that the designed ventilation rate should be 560 m³/h (as for 40 person). However, the actual airflow rate of the FAS was 43.6% of its rated value. The reason for such deviation between the rated and actual airflow rate was that the FAS was rated at laboratory condition, which was quite different with the actual operating condition. Under the operating condition, the fresh air unit external static pressure was not the same as the value when it
was tested in laboratory, so the actual supply air rate was not its rated airflow rate. Therefore, this study suggested the FAS rating test condition should be more close to its actual operating condition.

![Graph showing fresh air rate](image)

**Figure 2: The designed and measured fresh air rate with the fresh air system (FAS)**

### 3.2 CO₂ concentration

Figure 3 compares the CO₂ concentration in the classroom during the school day and weekend with natural ventilation. When the windows and FAS were both closed, the CO₂ concentration was approximately 3200 ppm during the class, while it was around 400 ppm at weekend. According to *Indoor Air Quality Standard (GB/T 18883, Chinese standard)*, the indoor CO₂ concentration should be less than 1000 ppm. However, the CO₂ concentration in the classroom was much higher than the standard limit with natural ventilation.

![Graph showing CO₂ concentration](image)

**Figure 3: Indoor CO₂ concentration with natural ventilation**

Figure 4 shows the CO₂ concentration from 9:45 to 14:00 at sampling point a. The CO₂ concentration at sampling point b was also monitored and similar results could be found. At stage 1, the FAS was off, so the CO₂ concentration rose from 848 ppm to 1927 ppm at sampling point a, and from 802 ppm to 2063 ppm at sample b. During the break (stage 2), the CO₂ concentration reached the peak at first, and then it started to decrease as the doors were opened and some students went out of the classroom, which lead more fresh air rate and fewer CO₂ sources. At stage 3, the FAS was turned on at the beginning of the second class. Comparing with stage 1, the CO₂ concentration growth rate declined. However, the CO₂ concentration still exceeded 2000 ppm at the end of stage 3. As mentioned in
section 3.1, the actual supply air rate was much less than the designed value, causing the indoor CO\(_2\) concentration exceeded the required value in the standard.

![Figure 4: CO\(_2\) concentration at sampling point a (stage 1: the class time with closed FAS; stage 2: the break; stage 3: the class time with opened FAS)](image)

In addition, CFD was employed to simulate the indoor air and CO\(_2\) distributions. As seen in Figure 5, when the fresh air rate increased from 244.0 m\(^3\)/h (6.1 m\(^3\)/h per person) to 960.0 m\(^3\)/h (24 m\(^3\)/h per person), the CO\(_2\) concentration decreased from 2024 ppm and 2191 ppm to 908 ppm and 762 ppm at sampling point a and b respectively.

![Figure 5: The CFD simulated CO\(_2\) concentration at sampling point a, b and the volume-averaged concentration with different fresh air rate](image)

Figure 6 displays the CO\(_2\) distribution at Z=1.1 m in the classroom. When the fresh air rate was 244 m\(^3\)/h, the CO\(_2\) concentration around students was higher than 1300 ppm. When the fresh air rate was 960 m\(^3\)/h, the CO\(_2\) concentration in most space was lower than 900 ppm. With the increase of fresh air rate, the volume-average CO\(_2\) concentration decreased from 1409 ppm to 750 ppm, which could meet the requirement of the Indoor Air Quality Standard (GB/T 18883, Chinese standard).
3.3 PM$_{2.5}$ concentration

This study also analyzed the PM$_{2.5}$ concentration in the classroom. We monitored the indoor and outdoor PM$_{2.5}$ concentration simultaneously. As shown in Figure 7, when using natural ventilation, the PM$_{2.5}$ indoor/outdoor (I/O) ratio was 0.50–0.70 with the closed windows, while it rose to 0.89 in 30 min after opening the windows. Thus, natural ventilation could not prevent outdoor PM$_{2.5}$ spreading to indoor spaces.
When using the FAS, the indoor PM$_{2.5}$ concentration decreased from 40 μg/m$^3$ to 18 μg/m$^3$ and the I/O ratio decreased from 0.75 to 0.32, as shown in Figure 8.

Moreover, this study calculated the indoor PM$_{2.5}$ concentration via mass conservation equation. The main indoor PM$_{2.5}$ source was occupants. As Xu (1998) studied, the particles emission rate from occupants ranged from 2.2μg/m$^3$ (sit) to 3.0 μg/m$^3$ (wrist movement) for 40 persons. The outdoor PM$_{2.5}$ concentration was set as 54.1 μg/m$^3$ and the air leakage rate was 96.4 m$^3$/h based on measurement data. The calculated indoor PM$_{2.5}$ concentration was 19.4 μg/m$^3$ ~ 20.2 μg/m$^3$ via Equation (2) and the deviation between the calculated and measured results was -7.8% ~ -12.1%.

### 3.4 Economic analysis

The initial investment on the FAS was 8000 RMB. The operating cost depended on the operating time. This study set the operating time as 128 days (school days) per year and 8 h per day, whose daily-average outdoor PM$_{2.5}$ concentration exceeded 35 μg/m$^3$ (the requirement of Ambient Air Quality Standard GB/T 3095). The outdoor PM$_{2.5}$ concentration data was acquired from Shanghai Environmental Monitoring Station. The rated power of the fresh air unit was 92 W and the electricity price was 1 RMB/kWh. Through calculation, the energy charge of the FAS was 94 RMB per year. Thus, the FAS had both acceptable initial investment and operating cost.
4. Conclusion

This study installed fresh air system (FAS) in the classroom to ensure healthy and comfortable indoor air environment. Both measurement and calculation were used to analyze the relationship between the fresh air rate and PM$_{2.5}$ and CO$_2$ distributions. The following conclusions can be drawn:

1) The fresh air rate was 2.4 m$^3$/h per person in the classroom with closed windows. After using the FAS, it rose to 6.1 m$^3$/h per person. However, the actual airflow rate of the FAS was 43.6% of its' rated value, due to the deviation between the FAS rating test condition and the operating condition.

2) The indoor CO$_2$ concentration was approximately 3200 ppm during the class with closed windows. After using the FAS, the growth rate of the CO$_2$ concentration declined. However, the indoor CO$_2$ concentration still exceeded 2000 ppm, due to the insufficient supply air rate of the FAS. Through calculation, this study recommended the minimum fresh air rate in the classroom should be 24.0 m$^3$/h per person to ensure the CO$_2$ concentration less than 1000 ppm.

3) Natural ventilation could not prevent the outdoor contaminant spreading to indoor spaces. When using the FAS, the indoor PM$_{2.5}$ concentration decreased from 40 μg/m$^3$ to 18 μg/m$^3$ and the I/O ratio decreased from 0.75 to 0.32

4) The initial invest on the FAS was 8000 RMB and the energy charge was 94 RMB per year, which was economical acceptable.

5. Acknowledgement

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References


SECTION 4
Risk mitigation, resilience and health and safety
An Investigation on Fire Hazard and Smoke Toxicity of Epoxy FRP Composites

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Abstract

The fire performance of two types of fibre reinforced epoxy composites (GFRP and CFRP) was studied in bench-scale using cone calorimeter test method in two incident heat fluxes of 35kW/m² and 50kW/m². Ignitability, time to ignition, heat release rate, total heat release, smoke release parameters and Carbon monoxide production were measured and discussed. Both thermal and smoke toxicity hazard of the material was studied. The time to flashover in an assumed room lined with the tested FRP was predicted with using Conetools software. The obtained results showed that the tested FRP products had a dangerous behaviour in case of fire, so it could show a high contribution to fire growth due to the combustible nature of epoxy resin. The tests also showed that these kinds of resins have a low glass transition temperature, around (50-60) °C. Therefore, the mechanical strength (and strengthening potential) of the product might be critically reduced at first stages of a fire incident. This shows that a regular thermal barrier, which is typically used for protection of plastic foams against fire, may be not sufficient for this purpose for FRP composites and a higher level of fire protection may be needed for prevention of failure of the strengthened system. The performance of protected FRP composites with a type of mineral spray applied coatings is discussed in another article.

Keywords: FRP, fire hazard, reaction to fire, ignitability, smoke.

1. Introduction

One of the main concerns with using polymer composites is their performance in the case of fire. The reason is that the FRP materials are inherently flammable due to nature of its polymeric resin. Furthermore, typical polymer resins for FRPs for civil engineering applications typically have glass transition temperatures between 60°C to 80°C [1, 2]. Hence, it is necessary to assess their fire behaviour due to widespread structural applications including strengthening and retrofitting. For assessment of fire hazard of a material, measurement of its reaction to fire properties are needed, including ignitability, peak and average values of heat release rate (PHRR and Av.HRR), total heat release (THR), etc. Other important properties include smoke and yield of toxic gases especially carbon monoxide, which in turn affect on visibility and ability of people to escape from the building engaged in fire, i.e. on life safety aspects [3]. In
this paper fire performance of the two types epoxy CFRP and GFRP composites is discussed. Reaction-to-fire properties of specimens including thermal, smoke and toxic gases were measured with ignitability and cone calorimeter tests. Then the fire hazard of the specimens were assessed, based on Petrella method, in which the flashover propensity (x parameter) is defined and used for this purpose, as is outlined in continue. Time to flashover (t_{fo}) was predicted based on cone calorimeter results by Conetools software.

2. Experimental

2.1 Materials

The samples were two kinds of epoxy/glass (GFRP) and epoxy/carbon composites (CFRP). The specimens were provided by the commercial sources. The reason for choosing these two FRP composites is that they are common for external reinforcement of concrete structures in Iran. The matrices of both FRP composites were epoxy resin and only their reinforcing fibres were different (glass and carbon fibres). The thicknesses of all samples were approximately 3 mm.

2.2 Test procedure

Ignitability fire test

The ignitability test was carried out according to ISO 11925-2, which specifies a method of test for determining the ignitability of vertically oriented test specimens when exposed to a small flame, either at the edge or the surface of the specimens. Flame spread and occurrence of burning particles and droplets are observed during the specified flame exposure. The six flat specimens shall be used with dimensions: 250mm × 90mm and maximum thickness 60mm. The flame is applied for 15s (test duration 20s) and 30s (test duration 60s). The test results can be used for assessing a classification according to EN 13501-1.

Cone calorimeter fire test

The bench-scale fire test was performed with cone calorimeter according to ISO 5660-1. The specimens were cut as 100 by 100 mm square samples. Two incident heat fluxes of 35kW/m² and 50kW/m² were set for evaluations. Three tests were carried out for each incident heat flux.

3. Discussion

3.1 Thermal aspects

At first a simple ignitability test were done on both samples. For both set of specimens, the flame tip did not reach the distance of 150mm during the test at 15s flame exposure. However, in contrary, when the tests were carried out at 30s flame exposure, the flame tip reached to a distance of 150mm before the end of the test duration. Thus, according to the test results and
classification method of EN 13501-1, the tested FRP specimens met the reaction to fire class of E. Figure 1 shows the CFRP and GFRP specimens during the ignitability fire test.

![Figure 1: GFRP and CFRP epoxy composites during ignitability fire test](image)

Cone calorimeter tests were carried out at two radiation heat fluxes of 35kW/m² and 50kW/m². All of the specimens were ignited under these radiation heat fluxes in less than 1 min. The results showed a high flammability of tested materials. The PHRR values were high at both radiation levels (figure 2). In addition, TTI of the specimens were about 20s at 50kW/m² (table 1). The definitions of abbreviations are as following:

<table>
<thead>
<tr>
<th>abbreviations</th>
<th>Comment</th>
<th>abbreviations</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ (kg/m³)</td>
<td>Volumetric density</td>
<td>Av. SEA (m²/kg)</td>
<td>Average of specific extinction area</td>
</tr>
<tr>
<td>TTI (s)</td>
<td>Time to ignition</td>
<td>TSR(-)</td>
<td>Total smoke released</td>
</tr>
<tr>
<td>Parameters</td>
<td>GFRP</td>
<td>CFRP</td>
<td>GFRP</td>
</tr>
<tr>
<td>-----------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>( \rho )</td>
<td>1230</td>
<td>872.5</td>
<td>1071</td>
</tr>
<tr>
<td>Heat flux</td>
<td>35 kW/m(^2)</td>
<td>50 kW/m(^2)</td>
<td></td>
</tr>
<tr>
<td>TTI</td>
<td>56</td>
<td>38</td>
<td>22</td>
</tr>
<tr>
<td>( Mi (g) )</td>
<td>41.0</td>
<td>26.4</td>
<td>34.7</td>
</tr>
<tr>
<td>( ML (g) )</td>
<td>16.9</td>
<td>18.7</td>
<td>18.5</td>
</tr>
<tr>
<td>PHRR</td>
<td>636.1</td>
<td>551.0</td>
<td>693.4</td>
</tr>
<tr>
<td>THR</td>
<td>59.1</td>
<td>52.7</td>
<td>49.3</td>
</tr>
<tr>
<td>( x=\frac{PHRR}{TTI} )</td>
<td>11.4</td>
<td>14.5</td>
<td>31.5</td>
</tr>
<tr>
<td>Av. SEA</td>
<td>-</td>
<td>811.7</td>
<td>734.0</td>
</tr>
<tr>
<td>TSR</td>
<td>-</td>
<td>1723</td>
<td>1528</td>
</tr>
<tr>
<td>Predicted time to flashover-conetools</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( t_{fo} )</td>
<td>-</td>
<td>-</td>
<td>81</td>
</tr>
</tbody>
</table>

Table 1: Reaction to fire thermal/smoke parameters in heat radiation levels 35kW/m\(^2\) and 50kW/m\(^2\).
The results shown in table 1 are the average values. Therefore, based on these results, these FRP materials would have a high contribution in growth of fire, if used without a protection layer. This shows that use of a protective layer for prevention of premature ignition and high contribution of materials in fire growth is necessary. Figure 3 shows the GFRP and CFRP specimens during cone calorimeter test in heat flux of 50kW/m².

**Figure 2:** Heat release rates from GFRP and CFRP epoxy composites in heat flux 50kW/m²

**Figure 3:** GFRP and CFRP epoxy composites during cone calorimeter fire test
The fire hazard of tested materials was analyzed with different methods. According to Petrella [4], the flashover propensity or x parameter is defined as ratio of PHR to TTI (in kWm$^{-2}$s$^{-1}$) and can be used for fire hazard classification of materials. In addition, he proposed a two-fold system consisting of the x parameter and total heat release (THR) for fire hazard evaluation, an attributed x parameter and THR to different fire hazard classes as following: x: 0.1-1.0 (low risk); 1.0-10 (intermediate risk); 10-100 (high risk) and THR: 0.1-1.0 (very low risk); 1.0-10 (low risk); 10-100 (intermediate risk); 100-1000 (high risk). Some researchers used this method for fire hazard assessment [5-6]. The x parameter of tested GFRP and CFRP specimens was calculated and compared with the method proposed by Petrella. The results are given in table 1 and as it can be seen both GFRP and CFRP showed high flashover propensities. An intermediate risk was acquired based on THR figures, which were in the range of 49-59 MJ.m$^{-2}$. Using test data from cone calorimeter, a time to flashover of 80s was acquired with conetools software for tested materials.

### 3.2 Smoke and toxic gases

The average specific extinction area (Av.SEA) and total smoke release (TSR) are reported. Attenuation of light (reducing incident intensity from I0 to I) by soot particles is proportional to the projection area (in m$^2$) of particles blocking the distance L (in m) between the light source and the receiver. SEA is a measure of this value normalized by the fuel mass [4]. Based on the values shown in table 1 this smoke parameter is relatively high.

The yields of toxic gases including carbon monoxide and carbon dioxide (COY and CO2Y) and the peak concentration of CO (pk[CO]) are given in table 2. CO concentration versus time is given in figure 4.

<table>
<thead>
<tr>
<th>Specimen Parameters</th>
<th>GFRP</th>
<th>CFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>1071</td>
<td>877.6</td>
</tr>
<tr>
<td>Peak CO</td>
<td>1153.4</td>
<td>888.3</td>
</tr>
<tr>
<td>pk.COY $\times$ 100</td>
<td>130</td>
<td>110</td>
</tr>
<tr>
<td>pk.CO2Y $\times$ 100</td>
<td>2440</td>
<td>2260</td>
</tr>
<tr>
<td>$F_{ED}=pkCO/5000$</td>
<td>0.23</td>
<td>0.18</td>
</tr>
</tbody>
</table>
It was observed that the value of $p_{k[CO]}$ was very high. It should be noted that the cone calorimeter is an open laboratory test and during the test about 24 lit/s fresh air is ventilated in the hood system. So the CO concentration is continuously diluted with the fresh air and it is not directly the CO concentration that can be expected in a real fire incident. In the other side, the integral of the area under curve of CO concentration might be a better index of the produced CO. As it can be seen from the figure 4, the CO concentrations of the tested materials were high.

A method of assessing toxic hazard in fire is fractional effective dose (FED). FED can be obtained from the ratio of the average concentration of a gaseous toxicant to its LC50 value [7]. Since CO and CO2 are measured in cone calorimeter and toxic potency LC50 for CO2 is much greater than LC50 for CO [8], FED was calculated [5] from $p_{k[CO]}$ in the cone calorimeter by:

$$FED = \frac{p_{k[CO]}}{5000}$$

The resulted FED was about 0.2 for tested specimens (table 2). Comparing with literature values for different materials [5] this can be taken as a relative high value. In the other side, as it was discussed in the above, the test is an open type with continues suction of fresh air. This is something again here that should be taken into account for interpretation of the results; and regarding this matter it can be said that the studied materials showed a high potential for producing toxic gases in case of fire, which is very important for life safety and evacuation of people from the building. Two factors including oxygen depletion and increasing of CO (and the other toxic gaseous) seriously affects survivability.
4. Conclusions

Fire behaviour of two types of fibre reinforced epoxy composites (CFRP and GFRP) was evaluated by reaction to fire tests including ignitability and cone calorimeter. Cone calorimeter tests were carried out in two different incidental heat fluxes of 35kW/m² and 50kW/m². Both FRPs Products showed relative dangerous behaviours in case of fire. They were highly flammable and their peak heat release rates were higher than 600kW/m², which is a very high value.

Fire hazard assessments were done according to the method proposed by Petrella and also with use of Conetools software. The smoke and CO production of the materials were measured with cone calorimeter and then assessed using the related theories and methods. The results revealed that such FRP materials, used for external strengthening of concrete structures, are dangerous in case of fire, if they are used without a protective coating. In addition, the resin matrix would be rapidly molten, paralyzed and involved in combustion, if exposed to fire or high temperatures. So the mechanical strength of the system would be rapidly decreased and the system might be prematurely falls to a structural failure. Hence it is needed to protect the FRP system, due to both reaction-to-fire and fire resistance requirements. The results showed that high smoke and CO values from burning the FRPs. Furthermore, the obtained data revealed that there is a serious need for regulating the use of the FRP composite materials in building and other applications. Moreover, the study clearly shows the limitations of FRP composites applications should be determined based on the fire safety requirements in buildings especially widespread application for strengthening and rehabilitation of structures.

References


Risk Assessment Impact on Landfill Structures Design

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Abstract

The purpose of this research was to investigate environmental permits of landfills with respect to the appropriateness of risk assessments focusing on contaminant migration, structures capable to protect the environment, waste and leachate management and existing environmental impacts of landfills. The objective of the environmental permit procedure is to ensure that the landfill owner has prepared a plan to protect the landfill environment using the Best Available Technique (BAT) and specialists with sufficient expertise. The plan includes structures for the protection of the environment with the help of which the environment, groundwater, surface water and the climate can be protected on a sufficient protection level during the whole life-cycle of the landfill according to the laws and regulations in force.

The directive admits of possible exceptions to the structural requirements if the protection capability of the deviations can be demonstrated to be corresponding with the help of risk assessment. Landfills risk assessing methods typically focuses on structural dimensions and harmful substances flux instead of focusing on local circumstances in Finland.

Several development needs were found in the risk assessments of the environmental permit decisions. The risk analysis equations used in the decisions did not adequately take into account all the determining factors like waste prospects, total risk quantification or human delineated factors. Instead of focusing on crucial factors, the landfill environmental protection capability is simply expressed via technical factors like hydraulic conductivity.

In this paper, it could be shown, that using adequate risk assessment approaches the most essential environmental impacts can be taken into account by consideration of contaminant transport mechanisms, leachate effects, and artificial landfill structures. The developed structural risk analysing (SRA) method shows, that landfills structures could be designed in a more cost-efficient way taking advantage of recycled or by-products. Additionally, the research results demonstrate that the environmental protection requirements of landfills should be updated to correspond to the capability to protect the environment instead of the current simplified requirements related to advective transport only.

Keywords: landfill, contaminant transport, geological barrier, environmental protection, Structural Risk Analysing method (SRA).
1. Introduction

The Landfill Directive defines explicit and unambiguous requirements for the structures that can be realized without a need for separate risk assessment. In the case of deviations, the risk assessment is obligatory. However, the directive does not define unambiguous requirements or procedures for it. Based on the literature, the risk factors affecting the landfill bottom structure can be divided into factors related to the landfill operational environment and to the waste content (Guyonnet et al. 2009; Cossu et al. 2003; Katsumi et al. 2001; Giroud et al. 2000; Korkka-Niemi & Salonen 1996; Christensen et al. 1994; Othman et al. 1994; Shackelford & Daniel 1991). Figure 1 presents the division of the most common identifiable factors related to the landfill operational environment and waste content, which affect the environmental protection crucially.

Based on the inadequate results of landfill risk assessment, it can be stated necessary to introduce further developed landfill risk assessment methods (Pollard et al. 2006). Risk assessing helps to define the risk factors, which have been identified in the designing phase and how their impact has been taken into account. The Structural Risk Assessment (SRA) method is introduced in this paper and is a tool for a sustainable landfill designing process. The SRA method gives substantially more information for landfill management, risk management and risk identification compared to the risk assessments conducted in the environmental permit processes.

The SRA method has been verified in the environmental permit processes of two landfills. The first verified case was an innovative surface structure and the second one a hazardous waste bottom structure. These verified structures used local products, by-products or recycled materials as much as possible to supplant natural materials and offer a substitute to expensive materials, such as sand bentonite. Also, these materials have to fulfil environmental regulations; otherwise authorities may not issue an environmental permit.

<table>
<thead>
<tr>
<th>Operational environment</th>
<th>Waste content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base ground</td>
<td>Leachate</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Contaminant migration</td>
</tr>
<tr>
<td>Hydrogeological properties</td>
<td>Phenomenon in bottom layer</td>
</tr>
<tr>
<td>Environment and structures</td>
<td>Gas emission to air</td>
</tr>
<tr>
<td>Surface structures</td>
<td>Gas collection</td>
</tr>
</tbody>
</table>

Landfill mining

*Figure 1. Effects of the most common identifiable factors related to the landfill operational environment and waste content on the landfill life-cycle information management and environmental protection (Ortner et al., 2014; Laner et al., 2012).*
2. Materials and methods

2.1 Landfill surface structure

The risk assessment process was to find a solution for a lightweight structure that fulfils the environmental protection demands and is cost-effective. The incinerator has been activated recently and the surface structure should be possible to open for landfill mining purposes. The life expectancy exceeded 50 years because of the incinerator, landfill mining and the separation of waste (Pivato & Morris 2005). Landfill gases generate undesired odours in the vicinity of the landfill, and this could be avoided after the surface structures have been installed. Near the landfill site is a moraine area that has been tested during the landfill site construction, and the material could be used in the sealing structures. According to measurements by the Finnish Meteorological institute, the average drainage capacity is 548 mm/year. The temperature is below 0 degrees Celsius for 158 days a year.

The study was initiated with laboratory tests, calculations of gas emissions and water migration through porous media in a partly saturated situation. The risk quantification for uncertain assessment calculations had to be at least 1.5. The exposure assessment demands were set to control the water migration and electrical conductivity measurement results outside the landfill site in real time. The significance of electrical conductivity measurements is to control and secure that surface structures do not affect the surrounding environment. Electrical conductivity was chosen because the measurements easily indicate if harmful substances increase in the landfill areas, and comprehensive advance material is available as a reference (Grellier et al., 2006).

The hydrogeological properties, drying and shrinkage factors, insulation properties, frost resistance and mechanical properties of till were tested in laboratory conditions. The calculations of mineral layer hydraulic properties were simulated according to the Van Genuchten equation for partially saturated soils, the drainage system capacity according to unit gradient method and the bearing capacity with the general shear failure method. A drainage core was included in the gas collection layer. Table 1 illustrates the laboratory tests.

<table>
<thead>
<tr>
<th>Property, [unit]</th>
<th>test 1</th>
<th>test 2</th>
<th>test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic conductivity [m/s]</td>
<td>2.2 E-8</td>
<td>1.7 E-8</td>
<td>6.6E-9</td>
</tr>
<tr>
<td>Effective stress [kPa]</td>
<td>26</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Water content [w %]</td>
<td>5.2*</td>
<td>5.0*</td>
<td>9.5*</td>
</tr>
<tr>
<td>Dry unit weight [kN/m³]</td>
<td>20.11</td>
<td>20.49</td>
<td>21.26</td>
</tr>
<tr>
<td>Volume shrinkage [%]</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Compression strength [kPa]</td>
<td>73</td>
<td>75</td>
<td>72</td>
</tr>
<tr>
<td>Shearing strength [kPa]</td>
<td>36.5</td>
<td>34</td>
<td>37.2</td>
</tr>
</tbody>
</table>
2.2 The bottom structure of a hazardous landfill

The risk assessment process was to find a solution for a sustainable structure that fulfils the environmental protection demands and the life-cycle expectancy exceeded 50 years. The structural dimensioning was partly based on meteorological background information. Also, the result of the absorption tests was essential.

The average drainage capacity, founded on the precipitation statistics of the Finnish Meteorological Institute, is 513 mm/year. By 2012, the maximum precipitation during the preceding 40 years was 900.5 mm/year. The air temperature was below 0 degrees Celsius for 108 days and the soil temperature 217 days.

The background research included laboratory tests, a site investigation by boring drill holes into the solid base rock, taking samples from the drill holes, and absorption tests of water sludge made from existing landfill leachate. The objective of the absorption experiments was to examine the absorption capacity of water sludge and leachate, the impact of leachate on electrical conductivity, pH, and the chromium, molybdenum and nickel liquid-solid content. The risk quantification for uncertain assessment calculation had to be a minimum of 1.5 or at the same level as the frame of reference values. The exposure assessment demands were to control the electrical conductivity measurement results outside the landfill site in real time.

One of the primary principles was to make sure that the HDPE membrane does not include any holes after installation. There are several methods to confirm the integrity of the membrane. In this case, the electrical tension difference method has been used. The integrity of the membrane was crucial for structural dimensioning.

2.3 The Structural Risk Assessment method

The SRA method is useful to all landfill stakeholders: owners, designers, authorities and residents in the vicinity of the landfill. However, its most essential task involves design. The SRA method a tool for landfills risk assessment, which can be divided into three main categories (Fig. 2):

* Human factors
* Environmental factors
* Technical factors.

In the first phase, the identification of the current operational environment begins by evaluating source information, i.e. by comparing monitoring information, which can be called reference data, and test results. The second phase concentrates on the impact of various mechanisms, local conditions and phenomena in the design phase in relation to the required environmental protection level. In addition, during the design process, the initial conditions in the current operational environment and their impact on the environmental protection requirements will be
taken into account. In the third phase, the achieved total result of the design phase will be compared to the minimum environmental protection requirements that are based on laws and decrees. In the last phase, the planned landfill life-cycle length will be examined in relation to the monitoring system with the help of which the changes or damages in the structures can be predicted, along with their environmental impacts. Also the risk quantification safety factors and the ranking between the risk assessment factors have to be defined.

Each category item has been further divided into sub-categories. The risk quantification can be identified more easily in the design phase with the help of the classification. In the risk analysis, the selected factors are examined based on the hypothesis that unidentified risk management does not exist but only identified risks could be accepted. The method emphasises the observation of every single factor, but examines analytically whether the factor is identified as a risk or not. Based on the reference data, it can be analysed whether the important factors have been identified in the design phase. Also, the identified factors impact the life-cycle information from the management perspective. In addition, the classification would have indicated how much and what type of essential additional information would have to be produced with the help of the evaluation procedure.

Figure 2. Risk assessment according to the SRA method.
Typically, the source data would be more reliable if statistics could be calculated or the frequency of the data could be evaluated.

Unidentified risk factors will not necessarily cause risks during the whole landfill life-cycle, but the risk assessment is challenging if a risk has not been identified and its impacts have not been acknowledged in the design phase. The method does not guarantee risk-free environmental protection at the chosen risk level, because it is mainly a tool for the design phase. Errors during the construction phase may result in deviations in the selected life-cycle information management risk level and cause problems to the environment. For this reason, monitoring information should be utilised in the life-cycle information management after the design and construction phases.

Risk factors have to be ranked ($P_x$) after identifying them from the source data. $P_x$ is the ranking value of an identified risk factor. Also, the landfill management or the designer has to determine the acceptable total risk level ($R_{total}$). The total risk level includes identified risk factors ($R_{id}$) and unidentified risk factors ($R_{ud}$). The risk factor ranking depends on the structure protection demands, regulations, protection environment and human factors. This will lead to the situation that every risk assessment process has to be determined case by case. In addition, all the dominant risk factors are not included in regulations and environmental permits. Landfill management must identify the risk level ($R_{ud}$) of these unidentified risk factors.

The total risk level calculation is shown in Equation 1:

$$R_{total} = \sum_{x=1}^{n} R_{id} + \sum_{x=1}^{n} R_{ud}$$

(1)

The identified risk level ($R_{id}$) can be determined by using Equation 2:

$$R_{id} = \sum_{x=1}^{n} P_x * Q_x$$

(2)

$Q_x$ is the probability coefficient of the identified risk.

The unidentified risk level ($R_{ud}$) can be determined by using Equation 3:

$$R_{ud} = \sum_{x=1}^{n} P_x * \beta_x$$

(3)

$\beta_x$ is the probability coefficient of the unidentified risk.

The probability coefficient $Q_x$ of identified risk factors is always higher than demanded in regulations or environmental permits. The probability coefficient of unidentified risk factors could vary because increasing the reliability of the other risk factors could compensate for it. For example, the drainage layer risk probability is due to the fact that the soil is not being able
to protect environment by increasing contaminant migration. Furthermore, the total risk level has to fulfil the demanded risk level. Figure 3 presents an example of a landfill risk assessment with the SRA method.

![Figure 3. An example of landfill risk assessment with the SRA method.](image)

### 3. Result and discussion

#### 3.1 Landfill surface structure risk assessment with the SRA method

According to calculations, the surface structure environmental protection capacity of a mineral layer with a thickness of 0.09 meters could meet Government recommendation if fully saturated. Laboratory tests substantiate that the mineral layer could not reach full saturation in any meteorology condition (Henken-Mellies & Schweizer 2011). Consequently, partial saturation is a relevant calculation principal. Tammirinne et al. (2004) have made a model for surface structure drainage, but this model assumes that the temperature above 0 degrees Celsius throughout the year. The assumption is meteorologically irrelevant, but the model has been modified to be more realistic and relate to weather conditions in the landfill area. Tables 2 and 3 include mineral layer calculation results of dimensioning and safety factors. The dimensioning is calculated including and excluding safety factors.
Table 2. Dimensioning and risk factor calculation results for a surface structure mineral layer.

<table>
<thead>
<tr>
<th>Property, [unit]</th>
<th>Including safety factor</th>
<th>Excluding safety factor</th>
<th>Risk factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic conductivity [m/s], (partly saturated conductivity)</td>
<td>4.6 (10^{-11})</td>
<td>1.3(\cdot10^{-11})</td>
<td>3.5</td>
</tr>
<tr>
<td>Effective stress [kPa]</td>
<td>26</td>
<td>13.7</td>
<td>1.9</td>
</tr>
<tr>
<td>Saturation degree [%]</td>
<td>40</td>
<td>30...50</td>
<td>---</td>
</tr>
<tr>
<td>Mineral layer thickness [m]</td>
<td>0.2</td>
<td>0.09</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 3. Dimensioning, risk factors and total risk factor for the structural dimensioning of the surface structure drainage layer.

<table>
<thead>
<tr>
<th>Property, [unit]</th>
<th>Including risk factor</th>
<th>Excluding risk factor</th>
<th>Risk factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate [l/m²s]</td>
<td>2.38 (10^{-1})</td>
<td>7.26(\cdot10^{-2})</td>
<td>3.3</td>
</tr>
<tr>
<td>Effective stress [kPa]</td>
<td>20</td>
<td>13.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Gradient [-]</td>
<td>0.25</td>
<td>0.14</td>
<td>1.8</td>
</tr>
<tr>
<td>Structural dimensioning and total risk factor</td>
<td>2.05</td>
<td>1.5</td>
<td>(2.4^*)</td>
</tr>
</tbody>
</table>

Note: * Total risk factor of the SRA method.

The layer thickness has been increased from 0.09 meters to 0.2 meters because of construction and dimensioning problems. A very thin-layer construction over the angle slope would be challenging to excavate. Under Finnish regulations, the maximum fraction size of soil material, such as till, has to be at least five times smaller than the constructed structure thickness. The maximum fraction size of till is 32 mm. Based on these factors, the 32 mm fraction size is a good reason for the thickness of the layer. According to frost resistant tests, water sources could not determine the freezing-thawing phenomenon for the mineral layer structure. The calculated total risk factor value was 2.4. The total risk factor value is the sum of the identified risk factors, and the ranking of the risk factors of this structure is the same (1).

The cost-efficiency of the structure compared with Government recommendations is 14% more affordability per hectare. The cost-efficiency will increase if the structure is opened in the future, because the structures are thinner and easier to excavate.

The limit conditions stated in the EC Landfill Directive should be developed further by means of structure life expectancy calculations, which can be implemented using various methods, such as the conversion factor method, statistical measuring and limit state of fatigue measurements, and the risk assessment safety factor.
### 3.2 Risk assessment of the bottom structure of a hazardous landfill with the SRA method

The structural dimensions of the geological barrier, water sludge, are shown in Table 4. The barrier is 1.2 meters thick, and the calculated risk level is 1.78. Hydraulic conductivity determined by 100 kPa effective stress, which is 1/6 of the final situation when the landfilling is finished. The porosity could be much lower in the last few years of landfilling because the effective stress increases and causes loading. The hydraulic conductivity will decrease impact on porosity and also affect the transport equation.

**Table 4.** Geological barrier’s structural dimensions, calculation coefficients, porosity and contaminant transport times for three layer thicknesses.

<table>
<thead>
<tr>
<th>C/C₀</th>
<th>Layer thickness [m]</th>
<th>Hydraulic conductivity [m/s]</th>
<th>Hydraulic gradient [-]</th>
<th>Diffusion coefficient [m²/s]</th>
<th>R [-]</th>
<th>Porosity [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>63</td>
<td>1.0</td>
<td>4.5·10⁻¹⁰</td>
<td>1.5</td>
<td>2.0·10⁻¹⁰</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>1.2</td>
<td>4.5·10⁻¹⁰</td>
<td>1.42</td>
<td>2.0·10⁻¹⁰</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>118</td>
<td>1.4</td>
<td>4.5·10⁻¹⁰</td>
<td>1.33</td>
<td>2.0·10⁻¹⁰</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: * The hydraulic conductivity value was determined by 100 kPa effective stress that is 1/6 of the final situation when the landfilling is finished. ** The diffusion coefficient is based on calculations by Katsumi et al. (2001).

The HDPE geomembrane will be installed above and under the water sludge layer, also called the geological barrier. A double layer geomembrane could secure the migration of harmful substances of water sludge to the soil. The drainage layer and the leachate will be collected separately when the HDPE geomembrane is installed. This enables the control of the leachate source and content in both layers. Leachate is conducted to the reservoir and further to water treatment.

The uncertainty of the risk assessment has been estimated by determining the content of the drilled ground samples. The sample test results have been compared with the Government decree limit values and natural values (VNa 214/2007). Table 5 shows the reference values for soil.

The total risk value is the sum of the identified and unidentified risk factors and the ranking of the risk factors of this structure is the same (1). The total risk factor (Rₜₒₜₐ₅) was 1.79. The cost-efficiency of the structure compared with the Government decision is 43% more affordable per hectare. The total cost-efficiency is influenced most by the possibility to use by-products as a part of the structure.
Table 5. The examples test results compared with Government decree limit values and natural values.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Unit</th>
<th>Frame of reference</th>
<th>Limit value</th>
<th>Natural content</th>
<th>Lower reference value</th>
<th>Upper reference value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium (Cr)</td>
<td>mg/kg</td>
<td>30*(25-48)</td>
<td>100</td>
<td>31(6-170)</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Molybdenum Mo)</td>
<td>mg/kg</td>
<td>&lt;1*</td>
<td>-</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>mg/kg</td>
<td>10*(8-13)</td>
<td>50</td>
<td>17(3-100)</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>7*(6.2-7.8)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: * Outside of the bracket is the mean value of 12 measurements and inside of the bracket are the lowest and the highest determined values.

Typically in environmental protection structures, attention is paid mainly to the hydraulic conductivity of the mineral layer. The landfill structure analysis should take into account the leachate management, and in leakage situations the leachate content, human-related factors and waste prospects in the risk assessment. Essential factors for the securing of the landfill barrier structures’ operation are the functionality of the drainage layer and the intactness and life-expectancy of the artificial barrier. If it is possible to conduct the leachate from the bottom structure through the drainage layer into treatment during the whole life-cycle, the hydraulic gradient to the bottom structure is not significant. This reduces the leachate stress on the mineral layer including all transport mechanisms. From this example, the effect of the hydraulic gradient is eliminated because the artificial layer will be controlled to avoid damage after installation. Therefore, during the active phase the artificial and drainage structure will eliminate the effect of the hydraulic gradient.

Factors related to material transport and retention and contaminant migration have been discussed above. Based on them, it can be concluded that an unambiguous correspondence between the materials and structures is not easy to determine. The definition of reference materials or structures is also difficult because some materials may be better than others in some respect. Instead, materials and structures can be compared in relation to functional requirements. Dominant factors may in some applications be the amount of penetrating water and in some applications the penetrating contaminants or their concentrations or the time needed for their accomplishment. In structural analysis, the identification of the dominant factors and the setting of boundary conditions are essential and significant. According to the results of this thesis, the boundary condition setting has to be based on landfill-specific requirements, which may vary significantly depending on e.g. the location of the landfill, hydrogeology, meteorology and topography.

The SRA method is the most suitable for materials like these, that is, industrially by-produced materials for which the manufacturer can provide a serviceable life estimate for comparison. Statistical measurements support the SRA method for measuring structure dimensions, since the measuring equations are presented as a fatigue parameter and a response parameter so that the parameters are time-dependent. One example of this is the contaminant migration equation in
which a concentration differential forms as a function of time due to the effects of fatigue caused by different loads.

### 4. Conclusion

The overall aim of this research was to provide further information on how the landfill risk assessment process has to be focused according to human-related, environmental and technical factors while evaluating the possible risk assessment to the environment. The technical requirements of the present landfill protection structures cannot achieve sustainable protection by focusing on the landfill life-cycle risk assessment information. The most essential problems in the design period are the unidentified and unrecognised risk factors and their effects on the landfill’s environmental protection capability. The most significant factors are the inadequacies in the contaminant transport modelling and in the identification of the factors affecting it. Another essential factor is the identification of the factors affecting the environmental protection structures’ capability and their life-cycle. In addition, the impacts of the existing structures or infrastructure on landfills have not been identified.

The directive should be developed to include complete guiding principles for the risk assessment scenario. The inconsistency in risk assessment leads to overly optimistic solutions and does not observe crucial requirements such as the local climate and weather. Unfortunately, it seems that numeric goals are missing in the directive. The directive only defines hydraulic conductivity and layer thickness, enabling different interpretations.

The results of this study emphasise the importance of utilising risk assessment like the SRA method for designing landfill structures. The design parameters should be based on true technical and environmental factors, human influence, waste prospects and risk quantifications for the final result to acknowledge the existing hydro-geological environment. In the future, demands concerning landfills will change because of reuse, recycling and using landfills as a material source. In consequence, landfills will be used as temporary storage in the future. Therefore, tools such as the SRA method will be needed to evaluate the life-cycle of landfill structures from different angles.

### References


Minimizing Risk through Performance Rather Than Warranties

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Abstract

Many problems are caused by owners specifying project technical requirements to expert vendors, then picking the low price vendor, assuming that all the vendors are providing the same quality of product. Research in the last 20 years has identified that when working with highly technical areas, this practice brings high risk to the owner because the vendors do not have the expertise to understand the requirements. The Alpha sprayed polyurethane (SPF) roof system has brought the Dallas Independent School District (DISD) high value but also occasional risk caused by the low price vendor. The authors are proposing that DISD’s effort to buy the Alpha SPF roof system through the low price competition will cause DISD risk. A new approach is proposed to DISD, that the Alpha SPF roof system only be used as an alternate value added option. This approach assumes that the only way the Alpha SPF system can be procured is if it is in the best interest of the owner due to dominant value. This approach minimizes the risk that DISD has encountered from low price contractors who have not been able to minimize risk through the use of expertise and experience because their low price was directly related to a lack of experience and expertise.

Keywords: roofing, Alpha Program, Sprayed polyurethane, Best Value, performance

1. Introduction

Sprayed polyurethane foam (SPF) roof systems have been installed since the early 1970s. SPF roof systems have the following characteristics:
1. Have the highest insulating factor of any roof insulation systems.
2. Have the lowest weight of any roofing system [0.50 PSF (3 PCF)].
3. Monolithic.
4. Has a very technical application utilizing an exothermic reaction that transforms two liquid components into a rigid three pound density SPF.
5. The industry has changed the insulating refrigerant material numerous times to meet EPA standards, causing applicators to change their temperatures and process details.
6. It is a sustainable and green roof system [renewable, minimizes the need to remove the existing roofing system and lightweight].
7. The SPF industry has had difficulty regulating itself, resulting in many SPF roof failures.
8. Properly installed SPF roof systems have performed very well. The industry has always remained less than 3% of the roofing industry due to their inability to regulate the performance of their contractors.
9. SPF roof systems require a coating system to protect it from UV degradation.
10. Confusion on the performance of different coating and SPF roof systems [hail resistance, UV degradation and ability to sustain roof traffic].
11. Warranties are used by sales/marketing personnel to attempt to identify performance.
12. Warranties are used as marketing and are not related to performance.
13. In 2001, when coated SPF systems failed at DISD, and the manufacturers did not honor the warranty, DISD stopped using coated SPF roof systems.

An example of illogical warranty and marketing information was provided by Factory Mutual, [one of the two largest building insurance groups], who put out a report that all coated SPF systems, offer hail protection against 1-3/4 inch size hail based on their hail testing. PBSRG testing in 1996 could not verify their results. There published results identified silicone coating as the most hail resistant, and urethane coatings as offering the worst protection. PBSRG tests found it was the exact opposite [Kashiwagi & Pandey 1996]. FM testing was done only on new coatings and coating systems that were weathered using artificial weathering. When actual aged systems in the field were tested, the results verified that the Alpha urethane coating was the only coated SPF roof system that offered protection against 1-3/4 inch size hail. [Kashiwagi & Savicky 2003]

Only one SPF coating system has documented high performance in heavy hail areas. The Alpha system, made by Neogard, is the only coated SPF system with documented protection against hail. Other urethane coatings have not documented the same protection after being exposed to the elements.

DISD used the design-bid-build procurement approach to award contractors to install SPF roof systems. The resulting poor performance of SPF roof systems led to a DISD policy of “no SPF” roof systems on DISD roofs. It has not been proven that the price based approach can be used to utilize the value of the hail resistant Alpha SPF roof system.

2. Dallas Independent School District

From 1987-2001, DISD had a few high performance Alpha SPF roof systems, but the majority of the SPF systems failed. It was common for the coating and SPF manufacturers to offer warranties but not honor those warranties. Since DISD could not utilize their warranties and due to poor performing SPF roof systems, in 2002, DISD banned the installation of SPF roof systems.

DISD is in a heavy hail area, and is self-insured against hail damage. DISD identified that the Alpha roof system [with sufficient urethane coating] on the Casa View School roof showed 16 year performance with no maintenance. In 2002 DISD allowed the installation of the Alpha SPF roof system in a best value procurement test to identify if the same high performance could be
duplicated. The results showed that the Alpha SPF roof systems were installed with high performance [Kashiwagi & Savicky 2003]. Due to the dominant performance results, DISD changed their policy and allowed the installation of the Alpha SPF roof systems.

In addition to the test results, the Neogard Corporation supported the Alpha roof system with a joint and several warranty, covering the performance of the SPF and the Alpha coating system. These warranties held the insured parties [Alpha coating manufacturer, SPF manufacturer, and the Alpha contractor] joint and severally, liable for any defects of the system. Defects included blistering and delamination. Defects that were not covered by the SPF industry were covered by the warranty [leaking was the only recognizable defect covered by warranties]. The joint and several warranty, along with the proven performance of the Alpha roof system in hail areas, differentiated the Alpha SPF roof system and help convince the DISD to continue to install the Alpha roof system.

In 2005 DISD had bond program to renovate their school buildings. The bond program eventually ran short of funding. Due to the shortage of funding, DISD did not utilize the Alpha SPF roof system and its warranty, but utilized a ten year SPF system, with a more traditional 10 year warranty. The ten year urethane coated SPF system [no joint and several warranty] was still at a much lower cost compared to the traditional built up and modified roof systems. The contractors bids were shopped, and one of the contractors used a SPF system that was not utilized in the Alpha program.

Table 1 shows the SPF roof performance of the Alpha roof systems at DISD based on the physical inspections of 98 roofs. Evaluating roof coverings using physical inspection and reporting the repair or replacement conditions to the owner have been used for other roofing systems [Coffelt et. al. 2010, Sharara et. al. 2009]. Table 2 compares the blisters and repairs at DISD for the last 4 years.

Table 1 – Overall DISD SPF Roof Performance

<table>
<thead>
<tr>
<th>No</th>
<th>Criteria</th>
<th>Unit</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oldest job surveyed</td>
<td>Years</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>Average age of jobs surveyed</td>
<td>Years</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Age sum of all projects inspected</td>
<td>Years</td>
<td>675</td>
</tr>
<tr>
<td>4</td>
<td>Average total repairs on each roof</td>
<td>SF</td>
<td>348</td>
</tr>
<tr>
<td>5</td>
<td>% of roof repaired</td>
<td>%</td>
<td>0.79%</td>
</tr>
<tr>
<td>6</td>
<td>Average total existing blisters on each roof</td>
<td>SF</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>% of roof blistered</td>
<td>%</td>
<td>0.035%</td>
</tr>
<tr>
<td>8</td>
<td>Average blister size</td>
<td>In.</td>
<td>4”</td>
</tr>
<tr>
<td>9</td>
<td>Average job area (of jobs surveyed and inspected)</td>
<td>SF</td>
<td>43,128</td>
</tr>
<tr>
<td>10</td>
<td>Total job area (of job surveyed and inspected)</td>
<td>SF</td>
<td>4.3 M</td>
</tr>
<tr>
<td>11</td>
<td>Total number of jobs inspected</td>
<td>#</td>
<td>98</td>
</tr>
</tbody>
</table>

498
Table 2: Blister and Repair Comparison at DISD

<table>
<thead>
<tr>
<th>No</th>
<th>Criteria</th>
<th>Unit</th>
<th>Year 4</th>
<th>Year 3</th>
<th>Year 2</th>
<th>Year 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>% of total roof area blistered</td>
<td>%</td>
<td>0.035%</td>
<td>0.038%</td>
<td>0.098%</td>
<td>0.131%</td>
</tr>
<tr>
<td>2</td>
<td>Total blisters</td>
<td>SF</td>
<td>1,525</td>
<td>1,599</td>
<td>3,915</td>
<td>4,117</td>
</tr>
<tr>
<td>3</td>
<td>% of total roof area repaired</td>
<td>%</td>
<td>0.79%</td>
<td>0.62%</td>
<td>0.38%</td>
<td>0.27%</td>
</tr>
<tr>
<td>4</td>
<td>Total repairs</td>
<td>SF</td>
<td>34,137</td>
<td>26,046</td>
<td>14,946</td>
<td>8,721</td>
</tr>
<tr>
<td>5</td>
<td>Total job area</td>
<td>SF</td>
<td>4.3 M</td>
<td>4.2 M</td>
<td>4.0 M</td>
<td>3.2 M</td>
</tr>
</tbody>
</table>

Despite the low bidding and shopping of the Alpha roof contractors bids, DISD has received performance from the roofs that were installed. One of the reasons for using the Alpha roof system was the Alpha program required their contractors to maintain 98% customer satisfaction and roofs not leaking on an annual basis to continue to be allowed to install the Alpha roof system. This included all roofs that were installed by the roofing contractor. If they had issues that resulted in customer dissatisfaction, they were required to fix the roof. This resulted in many of the DISD roofs being maintained by the contractors, not as a warranty requirement, but as a requirement to get further work at DISD.

However, the following factors led to a degradation of the some of the contractor’s roof system performance:
1. The Alpha roofing contractors are shopped for price through general contractors and traditional roofing contractors.
2. A relatively new contractor, who needed work, took the majority of the work due to their very low prices.
3. The low price contractor used substandard SPF due to a shortage of SPF material.
4. The low price contractor had an excessive amount of work and ended up cutting corners, such as installing SPF in marginal conditions.

In studying the defects of the Alpha system, it is clear that the majority of the problems were contractor generated. Requiring the manufacturers to pay for the repair of the defects under a ten year warranty, cannot be enforced. Once the contractor is paid, there has not been a way to force the contractor to fix the defects. If the defects are large, the contractor will go out of business. If the roofing system did not have a joint and several warranty, the roof owner has no recourse but to install another roof.

The low price contractor installed 62 out of the 98 roofs and there were 16 roofs which had defects that required maintenance. The contractor did not charge enough to maintain their roofs through the ten year warranty period [DISD expectation]. The roofing manufacturers [alpha coating and SPF manufacturer] continued to sell their materials to the contractor. DISD continued to hire and utilize the contractor. The contractor began to have issues with their roofs, and was not doing their maintenance work to keep the roofs performing. They ended up going bankrupt in
2015. DISD requested Neogard to cover the warranties, but with the ten year warranty, Neogard and their SPF manufacturing partner BASF, did not cover the SPF roof defects.

Another analysis of the roofs show that the majority of the problem roofs were installed in 2014 and 2015 during the beginning of the 2004/2005 bond program (Table 3). Ten years later the roofs show the problems which could have been avoided with more careful installation, and better materials. Despite a number of poor performing roofs, the number of performing roofs outnumber the poor performing roofs (Table 4). To identify the performance of a few nonperforming roofs due to extenuating circumstances in the bond program, with the performance capability shown on other roofs that are installed correctly would minimize the value that the DISD could receive from the Alpha SPF roof system.

### Table 3: # of Roofs Installed Yearly

<table>
<thead>
<tr>
<th>Year</th>
<th># of roofs installed</th>
<th>Year</th>
<th># of roofs installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>1</td>
<td>2007</td>
<td>1</td>
</tr>
<tr>
<td>1992</td>
<td>1</td>
<td>2008</td>
<td>5</td>
</tr>
<tr>
<td>2002</td>
<td>3</td>
<td>2010</td>
<td>12</td>
</tr>
<tr>
<td>2003</td>
<td>1</td>
<td>2011</td>
<td>9</td>
</tr>
<tr>
<td>2004</td>
<td>15</td>
<td>2012</td>
<td>6</td>
</tr>
<tr>
<td>2005</td>
<td>28</td>
<td>2013</td>
<td>1</td>
</tr>
<tr>
<td>2006</td>
<td>11</td>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4: Roof Yearly Analysis
3. Problem

The warranties accompanying the coated SPF roof systems could not be enforced. The warranty is provided by the manufacturer to the buyer as a protection [Agrawal et. al. 1996]. Since the manufacturer provides the warranty it is written by their legal representatives [Murthy & Djamaludin, 2002] and contains exclusion that will void the warranty if encountered [Christozov et. al. 2009]. Hence warranties have no proven correlation to the actual performance of the product, however, contractors still use them for marketing purposes [Kashiwagi 2012]. Similar to the history of the SPF roof industry, where warranties were used as marketing tools to convince building owners that a longer warranty meant that they had a longer performing roof system with protection against defects, DISD found themselves with a few SPF roofs with problems which were not protected by the warranty.

DISD is aware of the value of the SPF roof systems when they are installed correctly. They are also aware of the impact of the “low bid” delivery system on the value and performance of the roof system. There were additional problems that DISD and the Alpha coating manufacturer (Neogard) encountered:

1. Neogard did not get the needed support from the SPF manufacturer that they had partnered with. The SPF manufacturer charged a higher price for the Alpha SPF, but offered no added support for the needed maintenance repairs.
2. Neogard no longer wanted to cover the liability for the correct installation of the SPF.
3. The contractors did not have the sufficient business acumen to take needed steps to minimize the risk of SPF roof defects.
4. The bonding companies were charging unaffordable rates to cover joint and several warranties. Due to this the contractors were not willing to sign the joint and several warranty.
5. DISD had 4M SF of the Alpha system installed and had seen it was a good value proposition. However, DISD wanted a joint and several warranty, and none of the vendor parties were interested in taking on the liability.

The challenge to the Alpha coating manufacturer and DISD is:
1. To create a system that self-motivates the contractors to install a quality roof system.
2. Motivate the SPF manufacturer to take accountability of the SPF performance.
3. Minimize the risk of a non-performance at key points in the installation process, therefore minimizing and not transferring risk of non-performance to non-responsible parties.

Table 5: Roofs with High Damage (Over 1% Blistered)

<table>
<thead>
<tr>
<th>School</th>
<th>Roof Area in SF</th>
<th>Date Installed</th>
<th>Contractor</th>
<th>Total SF of Blisters</th>
<th>% of Total Roof Area Blistered</th>
<th># of Blisters over 1 SF</th>
<th># of open blisters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russell ES</td>
<td>27,295</td>
<td>May-04</td>
<td>Alpha Contracting</td>
<td>1,050</td>
<td>3.85%</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Samuel HS</td>
<td>147,500</td>
<td>Aug-05</td>
<td>Alpha Contracting</td>
<td>4,000</td>
<td>2.71%</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>Spruce HS</td>
<td>85,000</td>
<td>Aug-05</td>
<td>Alpha Contracting</td>
<td>2,150</td>
<td>2.53%</td>
<td>25</td>
<td>7</td>
</tr>
</tbody>
</table>
4. Approach and solution to the Problem

The steps to the solution of this opportunity must include the following:
1. Identify the DISD delivery system of construction and construction systems.
2. Identify the value of the Alpha roof system.
3. Identification of the source of risk caused by non-performance and create a new system that minimizes risk due to the structure of the approach and does not depend on a warranty to minimize non-performance [has not worked at DISD in the past ten years].
4. Create a best value structure that minimizes the risk of non-performance.
5. Create a transparent environment that clearly identifies expertise and the source of risk.

5. Description of the DISD Procurement/Delivery System

The DISD delivery system of construction is a design-bid-build (DBB) delivery system. The designers in the system do not have accurate information of the performance of different roofing systems and therefore do not have the expertise to select or design highly technical roof systems. They also do not have the legal liability or accountability of the roof system performance over the duration of the roofing system’s lifespan. Due to the lack of information, the designer’s decision making increases risk. The only party that does have the responsibility of roof system performance is the DISD roofing maintenance expert. He has the responsibility to resolve all roofing issues. Any change in roof system policy requires the DISD roofing expert’s support.

The SPF roofing contractors and manufacturers in the DISD environment have shown the following characteristics:
1. There are vendors who cannot accurately price roof systems to accept the accountability of the performance of the roof for the duration of ten or more years. The Alpha SPF roof system should never be competed based on price.
2. Manufacturers of both the Alpha coating system and the SPF have not consistently exhibited leadership or control over the vendors pricing, installation and maintenance activities. Neither
have they consistently understood or supported the vendors at key times in the beginning of a project and at the end of the project to ensure the minimization of risk.

3. The Alpha SPF roof system has not consistently and successfully been competed among the SPF contractors. Rather than assume the cause of this lack of success, the Alpha SPF roof system should only be an alternate to the traditional modified or built up roof system, and should only be installed when the value to DISD shows tremendous value [cost savings of 30% or higher].

4. Warranties have shown minimal value in protecting the client against SPF defects and should not be used to protect the building owner. The more DISD depends on the warranties, the greater is DISD’s risk.

6. Value of the Alpha SPF Roof System to the DISD

The DISD is in a heavy hail geographical area and is a self-ensured organization/entity. The Alpha SPF roof system has the following characteristics:

1. When installed correctly, proven 20 year history of performance in hail areas with the ability to withstand 1-3/4 inch size hail, it has been documented to resist larger hail, but due to the uniqueness of the hail shape and hail storm characteristics, expectations of hail resistance for larger hailstones must be tempered.

2. DISD documentation showing that the Alpha SPF roof system at DISD has exceeded 25 years [Foster Elementary and Casa View] and has the capability to be recoated for an additional 15 years [total of 40 years]. The aged Alpha SPF system’s ability to withstand hail damage shows no degradation over time.

3. The Alpha SPF system does not require the removal of the existing Built-up Roof (BUR). Together with the BUR it forms a better waterproofing system. It does not require the throwing away of the existing roofing system which is environmentally friendly [Knowles 2005].

4. The Alpha SPF system is renewable through recoating.

5. The SPF is the highest known insulating material, and is monolithic which increases the insulation value.

6. The documented and observable value of the Alpha SPF system is 40 – 50% less that the price of the traditional BUR of modified roof system. This is established from the DISD base price of $16/SF for BUR vs the SPF pricing of Wattle & Daub [Tisthammer, identified as the best SPF performing vendor in the United States, 2015].

7. Risk of Defects in the Alpha SPF Roof System

Due to inconsistency in performance of the same roofing system, it has been observed that the craftspeople installing the SPF roof system, commit easily avoidable errors that lead to SPF defects. The industry expert [has been doing research for the longest duration, has help create the Alpha program for SPF roof systems, and has the most dominant performance in the SPF industry in the U.S.] stated that “the SPF system may exceed the planning and technical capabilities of the average SPF roofing manpower force.” [Tisthammer, 2015] The defects observed over the past twenty years in the SPF industry are attributed mainly to applicator error [Bailey & Bradford 2005]. The number of occurrences that are due to material problems have been rare. The sensitivity of the chemistry of the SPF system when installed [temperature, ratio of the two
components, not stepping on the cured system before it is cured, sensitivity to moisture, and not installing on a substrate with moisture], increases the need for expertise to follow specific installation instructions.

The defects require a system to assist installers to identify and mitigate risk that the installers may not instinctively do. This issue is not unique to the SPF industry, but is observable in the construction industry in general. Oftentimes, if the SPF installers have a discussion with the manufacturers’ representatives, DISD roofing expert and other DISD involved stakeholders, many of the issues that cause risk can be eliminated. By observing the DISD Alpha SPF roof performance history, an on-site clarification meeting where the vendor’s experts clearly articulate their concerns and challenges and then get input from the DISD and other stakeholders would have minimized most of the risks and defects encountered over the last 13 years at DISD.

The second observation of the DISD Alpha SPF roof history performance is that lab testing of the installed Alpha roof system must be performed, and the results analysed not only for the newly installed roof, but compared with the physical characteristics of all other installed SPF roofs at DISD. The results of the tests and analysis should be accessible to all stakeholders and to the industry. The current DISD environment has a lack of transparency of the technical metrics.

The third observation of the history of DISD Alpha SPF roof system performance is that any warranty documentation must be simple and the responsibility of the SPF and coating defects must be clearly stated. Once the Alpha coating and SPF physical metrics are checked and approved, the Alpha coating manufacturer is responsible for the coating defects, and the SPF manufacturer is responsible for the SPF defects. Another option is for the contractor to be responsible for all SPF defects. However, if the contractor is responsible, the risk is greater and the owner may require a performance bond due to the financial instability of roofing contractors.

**8. Creation of a Best Value Structure for the Alpha Program**

A best value structure is required for the DISD use of the Alpha SPF roof system. As previously identified, the Alpha program must have transparency, show responsibility and accountability and show expertise of the vendor to successfully install and maintain their Alpha SPF roof systems. This structure includes:

1. The inspection of a minimum of 50 performing SPF roof systems.
2. Have a 98% roofs not leaking and customer satisfaction of all SPF roof systems installed.
3. Annual surveys of all SPF roofs installed.
4. Every other year inspection of 25 or more roofs being installed.
5. Respond to a leak or customer dissatisfaction within a week, and fixing the defect with two weeks unless given more time by the owner’s representative.

Any vendor who fails to meet any of these requirements at any time shall be suspended from the Alpha program. Re-entry into the program will require the above five steps to be redone.
9. Transparent Environment Built by the Manufacturers, Contractors and DISD

The best value environment is transparent. When an environment is transparent, the following characteristics are observable:
1. Consensus. All stakeholders will know the performance of any building system or vendor or system.
2. Metrics. All performance will be delivered in terms of relative number of years the roofs have been performing, initial and repair costs, number of leaks, was the leak fixed, the duration of time it took to be fixed and customer satisfaction.

The Alpha SPF roof system cannot be consistently and successfully specified and installed. The Alpha SPF system can only be selected and installed if the following is observed:
1. The budget for the traditional roof system is exceeded, and the Alpha SPF system can be installed within the constraints.
2. The Alpha SPF roof system is a dominant value [30% or more in cost savings of the specified system].
3. The alternative option which warrants all coating and SPF defects [with verifiable information that the manufacturer’s system has been operational in covering defects]. The options that identify that the manufacturer will cover defects caused by their material has no value. It must state that the SPF manufacturer covers all SPF defects. This forces SPF manufacturers to cover the risk of applicators who do not respond to installation problems.

10. Conclusion

The Alpha SPF roof system has shown tremendous value for the Dallas Independent School District (DISD). However, the following are observations of the last 13 years of DISD attempting to deliver the Alpha SPF roof system using the low bid environment:
1. A few of the Alpha SPF roofing contractors have not been able to escape the low bid pressures that have led to occasional non-performance issues.
2. A high performance Alpha SPF roof system cannot be consistently delivered in the DISD low bid environment as lower performing contractors win jobs with low prices.
3. The Alpha coating and SPF manufacturers and DISD have not been able to regulate the contractor performance by proper quality control and the use of performance information.
4. There are Alpha SPF contractors who do not have the management and planning expertise and discipline to identify and minimize sources of SPF performance risk at the beginning of the project.
5. The Alpha SPF manufacturers have not provided the transparency that would have minimized DISD risk by testing for performance metrics at the end of the project, and continually comparing the project metrics to existing DISD Alpha SPF roof metrics.

Instead of using the traditional warranties which are difficult to enforce, the Alpha SPF manufacturers [Alpha coating and SPF] must create a new risk mitigation environment. The risk shall be minimized by identifying the sources of risk, and eliminating the sources of risk before
the project begins instead of passing the risk to another party [traditional warranty system]. The DISD will also participate in the program by following simple rules of best value. The new environment will minimize risk sources regardless of who causes the risk.

The following are the risk mitigation mechanisms:
1. The SPF Alpha system should only act as an alternative to the traditional modified BUR system and can only be selected if it shows tremendous value for DISD [a minimum of 30% cost savings]. The Alpha roof system is already identified as an alternate roof system in the DISD approved specifications.
2. The SPF alternative proposal will be selected if the SPF manufacturer covers all SPF defects regardless of cause [and shows an operational process that has been in place] and still shows dominant value over the traditional specified system [minimum of 30% cost savings].
3. A clarification period will be held on every Alpha SPF project that is approved that requires the manufacturers’ representatives and DISD stakeholders to attend. The Alpha contractor should clarify how they will install the Alpha system, present a list of risks and risk mitigation and have a schedule that will be tracked throughout the project.
4. The contractor will have third party inspection of the roof of coating thicknesses and SPF density, compressive strength and material stability. The testing metrics will be in a system that is accessible to all and easy to understand, creating transparency in the event that there are performance issues during the service period of the Alpha SPF roof system.
5. The contractors will show their level of expertise by belonging to an Alpha performance program that monitors the performance of all their SPF roof applications.
6. This Alpha program suspends the contractor if they do not follow any of the requirements of a high performance contractor [maintains their roof systems, maintains customer satisfaction and roofs not leaking to a 98% level of performance, and fixes any deficiencies within two weeks of notification].

References


Improving the Resilience of Roofs: Lessons from Wind Damage Reports

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Abstract

As wind strengths increase in the future there will be requirements to assess the roof attachment strength of existing buildings. Improving the resilience of roofs to wind damage follows from an understanding of load transfer paths through the multi-layer roof systems.

Several case studies of wind damaged roof investigations in the UK and Ireland are presented, exploring alternative causation theories and identifying the weakest links in the roof attachment.

It is hoped that by sharing feedback from wind damage reports in an independent and constructive way we can improve our common understanding of failure mechanisms, enabling us to design and build more resilient building envelopes that are better able to withstand the extremes of changing weather patterns.

Keywords: roof resilience, roof reliability, wind damage

1. Introduction

Technical investigation reports on wind damage to roofing and cladding can provide a wealth of useful information relevant to designers, researchers, manufacturers, contractors and building owners. It is common to find multiple failures within roof systems and often the challenge is to identify which link in the assembly broke first. The forensic investigations demand a methodical approach, piecing together the available evidence of the initial point of failure, which is often hidden from view.

Several case studies of wind damaged roof investigations in the UK and Ireland are presented, exploring alternative causation theories and developing options for strengthening and repair.

This paper describes the method used for determining the attachment strength of a profiled metal roof construction under wind suction loading. Improving the resilience of an existing roof is dependent upon the identification of the weakest links and strengthening them.
2. Background

2.1 Extreme wind events

Situated on the edge of the North Atlantic Ocean, the islands of the United Kingdom experience storm force winds with gust speeds of $30 – 40$ m/s occurring several times each season. Major storms can result in personal injuries and significant financial losses. In an average year 200,000 buildings are damaged by high winds, although the majority of insurance claims are for minor losses of ridge tiles on older properties. This was described by Blackmore (2003). The prevailing wind direction in the UK and Ireland is from the south west as frontal depressions track across the North Atlantic. Winds blowing from the north and east tend to be less severe and cause less building damage.

In recent years there have been several significant wind events where recorded wind speeds in isolated locations have been greater than could be expected to occur once in fifty years. If these events were to recur then our basic wind speed maps may need to be revised. However, at present no plans have been published to update the relevant standards.

It is understood that the increase in extreme wind events is related to changes in the paths of the jet stream, with broader meander patterns and increased velocities. Various explanations for these changes have been offered, although at present there does not appear to be a broad consensus. There is uncertainty in the longer term forecasting of weather patterns and predicting maximum wind speed data for future building design. What is predicted with a high degree of confidence is that more extreme weather events will occur.

2.2 Roof attachment strength

Wind suction forces acting on the outer weathering skin of a roof are transferred from layer to layer down through the roof construction into the structural framework. Each connection transfers the upward load to the next layer down. A useful analogy is that of a chain anchoring the upper weathering skin down to the support structure. If one link in the chain were to break, then potentially the outer sheets can become detached from the roof. As part of routine design calculations should be prepared to estimate the design wind suction loads acting on the different links in the chain and then compared with the characteristic strength of the fasteners to determine their factors of safety.
A protocol for the assessment of wind damaged roofs in North America is described by Smith (2013). Within the UK a permissible stress approach is still used for checking the attachment strength of a profiled metal roof, as described in BS 5427 (1996). The design wind pressures acting on the roof are calculated in accordance with BS EN 1991 Part 1.4 (2004). The permissible strength of the roof assembly needs to be greater than the applied pressure.

\[
w < \frac{f}{\gamma}
\]

where:
- \(w\) = design wind load
- \(f\) = characteristic strength
- \(\gamma\) = factor of safety

The minimum factors of safety used in the UK for checking the attachment strength of profiled metal and single ply membrane roof fasteners, are 2.0 for pull-out from steel or aluminium, 3.0 for pull-out from timber and 4.0 for pull-out from masonry or concrete.

From the calculations for the roof assembly the greater the factor of safety, the greater the resilience of the roof.
3. Wind damage investigations

3.1 Case study A: standing seam roof

On New Year’s Day 2005 a strong gale blew across southern Ireland resulting in an extensive area of lightweight aluminium standing seam roofing becoming detached from the windward verge and causing significant consequential impact damage to roof cladding and rooflights downwind. The aquatic centre and adjacent gym were evacuated safely without injury to members of the public or staff.

<table>
<thead>
<tr>
<th>Location</th>
<th>Dublin, Ireland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building use</td>
<td>Aquatic centre</td>
</tr>
<tr>
<td>Altitude, site exposure, topography</td>
<td>+74 m severe, rural</td>
</tr>
<tr>
<td>Roof area</td>
<td>5,700 m²</td>
</tr>
<tr>
<td>Roof slope</td>
<td>Barrel vault 62 m wide, slope up to 20°</td>
</tr>
<tr>
<td>Roof type</td>
<td>Aluminium standing seam</td>
</tr>
<tr>
<td>Roof substructure</td>
<td>Halters fixed to top hat rails, to saddles, through liner into purlins</td>
</tr>
<tr>
<td>Basic wind speed (hourly mean)</td>
<td>23 m/s</td>
</tr>
<tr>
<td>Recorded peak speed (hourly mean)</td>
<td>14 m/s</td>
</tr>
<tr>
<td>Design wind suction pressure in damage zone</td>
<td>-2.0 kN/m² ↑</td>
</tr>
<tr>
<td>Extent of detachment</td>
<td>300 m² of standing seam</td>
</tr>
<tr>
<td></td>
<td>60 m of parapet capping</td>
</tr>
<tr>
<td>Estimated financial loss</td>
<td>£10 million</td>
</tr>
</tbody>
</table>

Table 2: Basic data for Case A

An investigation was commissioned to examine the evidence relating to the wind damage and to identify probable causation. The instructions were received three months after the wind event such that on arrival on site much of the original roof construction and initial damage had been disturbed. Consequently the colour photographs taken immediately after the storm became a vital record. The site inspection confirmed the as-built arrangement of the roof assembly and the details of the fasteners used.

Figure 2: Detachment of aluminium standing seam roofing from windward verge
The wind damage photographs showed that there had been a detachment between the steel top hat rail and the aluminium saddle at 900 mm centres. In addition there was upward distortion in the wide top plate of the saddle. Calculations were prepared to check the strength at each of the connections and the conclusions are summarized in Table 2 below.

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>Design wind pressure kN/m²</th>
<th>Area loaded m²</th>
<th>Number fasteners no.</th>
<th>Load / fastener f kN</th>
<th>Fastener strength f kN</th>
<th>Factor of safety γ</th>
<th>Satisfactory?</th>
</tr>
</thead>
<tbody>
<tr>
<td>standing seam</td>
<td>0.9 mm aluminium</td>
<td>-2.0 ↑</td>
<td>-</td>
<td>-</td>
<td>-5.0 kN/m</td>
<td>2.5</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>halter</td>
<td>aluminium</td>
<td>-2.0 ↑</td>
<td>0.64</td>
<td>2</td>
<td>0.64</td>
<td>3.35</td>
<td>5.2</td>
<td>✓</td>
</tr>
<tr>
<td>top hat rail</td>
<td>1.25 mm galvanised steel</td>
<td>-2.0 ↑</td>
<td>1.89</td>
<td>2</td>
<td>1.89</td>
<td>2.1</td>
<td>1.1</td>
<td>X</td>
</tr>
<tr>
<td>saddle</td>
<td>2.0 mm aluminium</td>
<td>-2.0 ↑</td>
<td>1.89</td>
<td>2</td>
<td>1.89</td>
<td>18</td>
<td>19</td>
<td>✓</td>
</tr>
<tr>
<td>purlin</td>
<td>10 mm steel flange</td>
<td>-2.0 ↑</td>
<td>1.89</td>
<td>4</td>
<td>0.95</td>
<td>18</td>
<td>19</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 2: Summary of factors of safety for the Competition Pool roof assembly

The calculations found that the local bending stress in the crown of the aluminium saddle was excessive and that the factor of safety against the top hat rail to saddle fixing pulling out was 1.1, significantly less than the recommended minimum of 2.0. This is the same weakest link as observed in the photos of wind damage.

The adjacent verge cappings also became detached in the storm and their means of attachment was closely examined. The aluminium capping had been held in place with rivets which had
pulled through. The spacing of the rivet holes through the supporting cladding rail was measured and the distances found to be greater than the recommended 450 mm. This was a further weakness in the roof assembly.

The original roofing contractor undertook to replace the area of detached roofing, to make good the downwind isolated impact damage, and to strengthen the top hat rail to saddle and purlin connection by installing additional long screw fixings through the top hat rail directly into the steel purlin below. This repair scheme had a number of disadvantages, including puncturing the vapour control layer, although those advising the building owners considered the future condensation risks to be acceptable.

### 3.2 Case study B: single ply membrane roof

On 28th September 2013, St Jude’s Day, a fast moving vigorous Atlantic depression brought very strong winds and heavy rain to south east England with winds gusting up to 36 m/s. One modern building that suffered wind damage was a hotel in Chelmsford, to the north east of London. Lengths of roof edging and single ply membrane roofing became detached from the western side of the second floor roof and peeled back, resulting in debris falling to ground level. This led to the closure of the public highway immediately to the east of the building for a period of several days.

<table>
<thead>
<tr>
<th>Location</th>
<th>Chelmsford, England</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building use</td>
<td>Hotel</td>
</tr>
<tr>
<td>Altitude, site exposure, topography</td>
<td>+25 m, sheltered, urban</td>
</tr>
<tr>
<td>Roof area</td>
<td>2,000 m²</td>
</tr>
<tr>
<td>Roof slope</td>
<td>Flat</td>
</tr>
<tr>
<td>Roof type</td>
<td>Single ply membrane, adhered</td>
</tr>
<tr>
<td>Roof sub structure</td>
<td>Mineral wool thermal insulation, screw fixed through vapour control layer into steel deck</td>
</tr>
<tr>
<td>Basic wind speed (hourly mean)</td>
<td>22 m/s</td>
</tr>
<tr>
<td>Recorded peak speed (hourly mean)</td>
<td>18 m/s</td>
</tr>
<tr>
<td>Design wind suction pressure in damage zone</td>
<td>-1.8 kN/m² ↑</td>
</tr>
<tr>
<td>Extent of detachment</td>
<td>200 m² of single ply membrane roofing and roof edges</td>
</tr>
<tr>
<td>Estimated financial loss</td>
<td>£1 million</td>
</tr>
</tbody>
</table>

Table 3: Basic data for Case B

An independent investigation of the roof was commissioned two months after the storm to inspect the evidence of damage, to identify causation and to advise on remedial works to remaining roofs. The roof system comprised of a single ply membrane that was adhered to a tissue faced mineral fibre insulation board, which in turn was screw fixed through the vapour control layer into a galvanized steel deck.
At the time of the inspection temporary remedial works had been completed to enable the hotel to re-open. Much of the debris had been removed from site by the repair contractor and fortunately had been kept for examination in his local yard. The samples were closely examined to reveal an inadequate thickness and spacing of the adhesive bonding. Samples of the mineral wool insulation showed that the top tissue facing readily detached from the fibrous core and was not the specified insulation board with a ‘single ply adhered facing’. The wrong product had been supplied which had not been identified by the roofing contractor, the supplier or the other surveyors initially inspecting the wind damage.

The wind damage photos also showed that the roof edge became detached. A short parapet had been constructed using two channel sections with an internal metal stud and no fixings joining the channels together. Under wind uplift pressure the capping and support could lift upwards. From this it was possible to determine the probable sequence of detachment along the western edge of the central roof in which a zed section flashing rotated upwards, increasing the wind uplift pressure acting on the underside of the flashing and entering the upstand detail. This in turn caused the perimeter channel and studs to lift upwards, causing the single ply membrane to peel back readily with the lack of adhesive restraint.
Within a month of the initial inspection the second floor roof was fully replaced with a new mechanically attached single ply membrane system. The third and fourth floor roofs were investigated and found to be of a similar construction, with areas of de-bonded single ply membrane adjacent to the western edge. It was recommended that a new mechanically fixed single ply membrane should be laid over the existing with a new secure perimeter detail developed. There were delays in carrying out this work during which the extent of the delaminated zone increased over a six month period, ultimately resulting in extensive ruckling. This evidence of further progressive damage persuaded the parties to mechanically fasten and overlay the third and fourth floor roofs, with works satisfactorily completed in the summer of 2014.

4. Conclusions

Identifying probable causation is rarely straightforward, often with multiple failures requiring an answer to the question ‘what failed first?’ A methodical approach is needed in gathering and recording the evidence of wind damage, in undertaking the desk study and then producing the factual report.

There is a need to learn from experience and to avoid repeating mistakes. In February 2014 the roof of another aquatic centre in southern Ireland blew off, suffering the same mode of failure as the aquatic centre in Dublin a decade before. The lessons from previous investigations had not been shared within the roofing community.

In the UK the Standing Committee on Structural Safety has established a scheme to improve structural safety and reduce failures by using confidential reports to highlight lessons that have been learnt, to generate feedback and to influence change.

It is hoped that by sharing feedback from wind damage reports in an independent and constructive way we can improve our common understanding of failure mechanisms, enabling us to design and build more reliable building envelopes that are better able to withstand the extremes of changing weather patterns in whichever country we practice.

References


A New Demountable Seismic-Resistant Joint to Improve Industrial Building Reparability

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Abstract

In seismic-prone areas, post-event operability for steel warehouses can be considered an important issue for economic and social continuity during the recovery phase. Structures surviving strong earthquakes - even if designed with minimal probability of collapse - might suffer so much damage, that their repair costs would be prohibitive. Strategies for limiting the building's damaged zones to specific parts (or "fuses") can significantly reduce repair costs. However, the replaceable part is limited to a small portion of the structure, whereas the rest cannot be disassembled in a non-destructive way. This is an issue for steel warehouses, as their life span is more likely dependent on economics and technology rather than on their actual structural performance. From a sustainable design standpoint, making steel warehouses easily disassembled would be cognizant of their environmental footprint, not only in seismic areas but also in any industrialized area. The aim of this paper is to explore the Design for Disassembly (DfD) approach to complement seismic design and to find a compromise between these two rather opposite approaches. Due to the complexity of this problem, one single type of structures was analysed (the moment resisting frame), focusing on the design of a seismic-resistant steel connection, capable of being deconstructed in a reversible way. The design process involved several design iterations until an “optimum” compromise between seismic design and DfD was met. It is worth noting that the assessment criteria for seismic design and DfD were different: the former required the compliance with building codes for each connection components; the latter implied to create new criteria, which had to be as accountable as possible. The results of this study show that a compromise between seismic design and DfD is possible. In this specific case, the compromise was achieved at the expenses of more complex design calculations and a number of components larger than that used in standard connections. However, this would be compensated for by a higher residual value for the entire structure. Moreover, this study has proved that a metric for assessing DfD steel connections is possible, but further structural analyses are needed to validate it.

Keywords: design for disassembly, sustainable structural design, reuse of steel structures
1. Introduction

Sustainable design as a research topic involves a wide range of disciplines. Since the development of one of its most commonly accepted definitions - in the “Brundtland Report” in 1987 – research on sustainable has increased significantly and expanded from general areas (i.e. construction sector) to specific fields (i.e. structural design). Studies aimed at investigating the impact of structural systems independently from the rest of the building (Cole and Kernan, 1996) stimulated research on sustainable design of structural systems – the so-called “Sustainable Structural Design” or “SSD.” Research papers pointing out the importance of teaching sustainability in Engineering Schools (Maydl, 2004 and Ochsendorf, 2005) raised attention on the responsibilities of civil engineers towards the environment, economy, and society.

Most of the discussions on SSD involve proper selection and usage of structural materials, as their extraction, manufacturing process and erection can be very carbon and energy intensive. Moreover, growing concerns about the depletion of raw materials (e.g. stone, iron, and bauxite), as well as construction and demolition waste management issues, encouraged researchers to develop SSD strategies. Some of them include “Minimizing Material Use, Minimizing Material Production Energy, Minimizing Embodied Energy, Life-Cycle Analysis/Inventory/ Assessment, and Maximizing Structural Systems Reuse” (Danatzko and Sezen, 2011).

Research projects carried out in countries using large quantities of structural steel (e.g. the United Kingdom) attempted to develop strategies for making the use of steel “greener.” The “Wellmet2050” project, carried out at the Cambridge University, identified four main themes to reduce the steel carbon footprint: “Reuse without melting”, “Less metal, same service”, “Longer, more intense metal use”, and “Supply chain compression” (Allwood et al, 2012). All these strategies aim allow reducing the use of new steel or the energy required to produce it. This translates into structural engineering design practices including the reuse of existing steel (without re-melting it), the optimization of steel profiles in order to use less steel, and the extension of steel structures’ design life by designing structures for future reuse. This paper focuses on this last strategy – also called “Design for Disassembly” or “DfD” – whose main benefit is to overcome the limits of traditional demolition, by obtaining valuable salvaged structural materials instead of scrap or debris (Crowther, 1999). This can be possible by considering a building structure as a kit of components and planning upfront all its assembly and disassembly steps.

Through a set of reversible operations, DfD can also facilitate the substitution or repair of damaged structural profiles. This feature simplifies not only regular retrofit operations but also a structure’s repair after hazardous events. In fact, if structural components are designed properly, those being damaged can be easily disconnected and repaired or substituted. This is a relevant benefit especially for buildings of “normal importance” such as steel warehouses. Yet, even if these structures are designed to withstand strong earthquakes with minimal probability of collapse, they usually suffer a high level of damage and, far too often, repair costs are so prohibitive that demolition is preferred. By reducing repair costs and facilitating the substitution of damaged components, DfD can provide a faster recovery from hazardous events.
Despite its great potential in achieving sustainable and resilient structures, DfD tends to be in conflict with current seismic-design practices, especially as far as concerns the design of connections. In fact, seismic-resistant connections can be barely disconnected in a reversible way, as they usually employ a large amount of connectors to provide adequate strength and stiffness. This practice is at odds with any reuse strategy.

The goal of this work is find a compromise between current seismic design practises and DfD, in order to ensure both post-earthquake reparability and ordinary deconstruction for industrial building. This work will focus on the critical aspect of connections design, with the following goals: a) to design a connection fulfilling both requisites for seismic resistance and deconstruction; b) to develop DfD criteria to assess if the goal is met.

2. Methodology

The design of a DfD seismic-resistant connection is a complex task, as it involves two quite distinct processes: a) the design of a steel connection for disassembly and b) the design of a seismic-resistant steel connection. Process a) is not supported by building codes but its achievement is rather predictable. In fact, construction experience shows what practices should be avoided and which ones should be reduced as much as possible. Conversely, process b) is regulated by codes, but its achievement needs to be proved by numeric analyses and testing. Besides being rather different, processes a) and b) tend to be in conflict, as mentioned in the Introduction.

In order to find a compromise between them, the connection design has been split into two phases. The first phase consisted in the conceptual design of a connection meeting both seismic and DfD goals and in the definition of criteria for a DfD steel connection. The second phase entailed the engineering design and the connection characterization, in order to provide the moment-rotation curves associated with the connection connecting a specific range of profiles. The first phase was carried out at The Catholic University of America and is the object of this paper, while the second phase is still on going.

More in detail, Phase 1) comprised a review of existing steel connection (paragraph 3), a selection of a structural layout in order to define the size of the profiles to connect (paragraph 4), and the actual design. This last phase consisted into two iterative processes, which started in parallel: on the one hand, the definition of criteria for DfD steel connections, and, on the other hand, the design of a connection meeting both these criteria and structural requirements.

Criteria for DfD were initially drafted based on the literature on DfD; these criteria were then refined through a survey (paragraph 5) to a group of “experts” (structural engineers with an expertise on DfD), where they were asked to evaluate some design concepts with these criteria. Eventually, experts were asked to grade and rank those criteria. The outcome of this process led to the definition of general criteria to guide the following design iterations and of quantitative criteria for a final design evaluation. After many design-feedback iterations (paragraph 6), a final version of the “pre-design” roughly meeting structural requirements and DfD criteria was developed (paragraph 7) and eventually compared to existing seismic-resisting steel connections on the basis of such those quantitative criteria (paragraph 8).
3. Review of existing steel connections

A review of several steel connections (both traditional and innovative) helped identify the main features of DfD steel connections and seismic-resistant steel connections. The following sub-paragraphs will summarize this review, focusing on beam-to-column connections.

3.1 Traditional steel connections

Generally speaking, steel connections can be located either at the nodes of a structure or along structural members; depending on their structural behaviour, they can be simple, rigid, or semi-rigid; lastly, they can use welds and/or bolts. These very basic features do affect the disassembly potential of connections. In fact, connections placed at structural nodes can make the disassembly process complex, as their removal might compromise the structural stability. Simple connections are usually easier to disconnect than rigid or semi-rigid connections because they employ fewer connectors. Last, but not least, bolted connections can be removed in a reversible way, that is, without destructive operations. On the contrary, welded connections need to be destroyed, for instance by torch cutting. Figure 1 shows some of the most common types of beam-to-column steel connections.

Figure 1: Traditional beam-to-column steel connections: a) extended end plate; b) double angle; c) flange plate; and d) seat connections).

Depending on their assets, steel connections require different degrees of accuracy for their assembly and disassembly processes. For example, being a field-bolted connection, the end plate connection needs that pre-drilled holes on the end plate match perfectly those on the column flange. Other connections, i.e. a double angle connection, may determine assembly issues such as the “knifing” of a beam, that is, the beam coping is needed to lower a beam into place. Eventually, connections, such as a flange plate connection, require tolerances, as a beam needs to fit the distance between the two plates that are shop-welded to a column flange. From a structural standpoint, both an end plate connection (in their extended version only) and a flange plate connection are moment resisting, while double angle and seat connections are can resist shear only.

3.2 DfD steel connections

DfD steel connections employ innovative technologies to facilitate both the assembly and the disassembly processes, in order to increase structural members’ reusability. Figure 2 shows three...
examples of DfD steel connections. Information on them has been taken from Cooper (2010) and relevant websites (see References).

Figure 2: DfD steel connections: a) ATLSS; b) LINDAPTER; and c) QUICON connections.

The ATLSS Connection (Lehigh University) comprises two cast pieces shaped to match each other: a tenon – both bolted and welded to the end of a beam - and a mortise welded to a column. In the erection process, the tenon is lowered into place and bolted with one bolt only. A limitation of this connection consists in the fact that shaped cast pieces are barely detachable from structural members and too non-standard to be reused in other structures.

Lindapter (Lindapter GmbH) beam-to-column connection employs “High Slip Resistance Clamps” to keep elements connected. Relying on friction only, this system avoids drilling holes in structural members, thereby maximizing their reusability. However, its moment-resisting application requires welding an endplate and a stiffener to a beam, so that the reuse benefits are limited to columns.

Quicon (Steel Construction Institute) comprises T-stub shop-bolted to a column’s flange with k-holes slots on their other free terminal. Shoulders bolts pre-attached to a beam’s web are lowered easily in the holes and tightened. This system allow speeding up the assembly process. Boltholes in structural members are the main barrier to reuse. Because of their structural weaknesses, all these connections are currently unsuitable for seismic applications.

3.3 Seismic-resistant steel connections

Seismic-resistant connections are designed to guarantee adequate strength and ductility in the case of seismic events. Some of them dissipate energy through specific components - called “fuses” - that are replaceable. Figure 3 shows three examples of seismic resistant steel connections. Information them has been taken from Cordova (2011) and relevant websites (see References).

Figure 3: Seismic-resistant steel connections: a) ConXL; b) Strong Frame Yield-Link; and c) SidePlate connections.
ConXtech’s ConXL moment connection (ConXtech Space Frame Systems of Hayward) comprises a column’s and a beam’s “collar” with tapered terminals that should facilitate the erection process. Both the collars are shop-welded to structural members and mutually field bolted. Collars are expected to exhibit minimal yielding, while the Reduced Beam Sections (RBS) to lead to the formation of flexural hinging. From a DfD standpoint, this system presents some disadvantages, including a large number of bolts, which makes the disassembly operations long, the tapered terminals that limit structural members’ reusability, and the possibility of using a single type of columns (HSS columns). Moreover, in the case of a fuse replacement, the entire beam should be removed.

Strong Frame Yield-Link™ (Simpson Strong-Tie Company Inc.) is entirely field-bolted. Its reduced-section plate, placed on a beam’s top flange, is expected to dissipate energy during an earthquake and is designed to be replaceable. Despite its flexibility, this system uses a large number of bolts, which make it less reusable.

Sideplate (SidePlate) comprises a welded connection, with horizontal shear plates shop-welded to column flanges. The beam is lowered between the plates and welded to them. This solution avoids the formation of a plastic hinge at the beam-to-column interface by physically separating a beam end from a column face; however, its fuse is barely replaceable and its welds are almost impossible to detach.

4. **Structural layout selection**

Structural pre-requisites for a connection depend on the structural layout and structural elements connected. The moment resisting frame (MRF) was selected among those suggested by the Eurocode 8 because it has an inherent DfD potential. In fact, its lack of vertical bracings confers a great floor plan flexibility. This allows focusing on the connection issue.

Some important issues to consider in MRF connections design are: a) columns shall be stronger than their adjacent beams, so that the beam fails before the column; b) beam-to-column connections shall be moment-resting to guarantee structural stability; c) the connection must not fail, therefore the connection’s shear and moment capacities shall be higher than the beam’s shear and moment capacities; d) the seismic “fuse” shall be located as far as possible from the column, so that the risk of column failure is avoided.

The steel profiles to be connected were sized on the basis of common spans and widths for one-story one-bay steel industrial buildings (determined from previous research works): an IPE 300 section for the beam and a HEA 400 section for the column.

5. **Surveys**

In order to find a trade-off between structural prerequisites and DfD, a priority among DfD criteria should be determined. Criteria for DfD were initially listed based on the review of steel connections; then, these criteria underwent an examination from a group of “experts” (civil engineers/architects.
with an expertise on DfD), in the form of a semi-structured survey. This survey consisted in three sections: 1) an introduction; 2) a presentation of three connections designs, which the group of experts should evaluate on the basis of the listed DfD criteria; and 3) a section in which experts were asked to rank the importance of these criteria, by means of a “Likert Scale” (from Strongly Agree to Strongly Disagree).

Since the survey was an online-survey expected to take a limited amount of time, criteria for DfD were kept under the limit of seven criteria: 1) “Reduce the number of bolts” (with respect of traditional connections): the smaller the number of bolts to unbolt, the faster the disassembly process is; 2) “Use the same type of bolts”: the fewer the disassembly tools, the faster the disassembly process is; 3) “Adaptability of different structural members”: the more adaptable, the more reusable the connection is; 4) “Reduce the holes in the structural members”, increasing their reusability (too many holes require patching the holes – when not cutting off the bolted part); 5) “Ease of access for the disassembly operation” (a non-accessible connection cannot be disconnected at all); 6) “Reversibility”, so that the disassembly produces no or limited damage; 7) “Ease of assembly” (so that DfD and assembly are not in conflict). These criteria served to evaluate three design concepts (Figure 4) in terms of reusability and disassembly potential with respect to common beam-to-column moment resisting connection. It is worth noting that one inherent limit of this evaluation is the fact that there is no unique understanding of what a common moment resisting beam-to-column connection is; yet, the evaluation was deemed reliable purely on the basis of an the experts’ personal judgement.

![Preliminary design concepts](image)

Figure 4: Preliminary design concepts (design idea #1: diagonals; design idea #2: many shear plates few bolts; design idea #3: two long bolts)

In about one month, six experts took the survey providing an evaluation of both the design and of the DfD criteria. These surveys had two main outcomes: design idea #1 (Figure 4, on the left) turned out to be the best one under all the criteria; a general agreement on the criteria raking was not found, and this led to the conclusion that criteria should be refined so that they could be used as transparent tool.

6. Design iterations

Surprisingly, the most useful part of the survey was the section in which experts were asked to give an open feedback on the design. This helped identify design ideas strengths and weaknesses and guided following design iterations. Some of the interviewed experts offered to keep on providing feedbacks on new design ideas. Interestingly, DfD goals for the connection emerged naturally from this iterative
process and can be summarized as follows: to avoid welds, to reduce bolts, and to be adaptable to different steel profiles.

7. Final design

The design process stopped when, in proximity of the end of the time available, the overall goal of avoiding welds and holes in structural members was met. Even if this paragraph is called “final” design, the design process did not stop there. During the second phase of this work, the design changed, even if these changes are not addressed in this paper. At the end of first phase, the connection incorporated some of the ideas developed at the very beginning of the conceptual design process: a) the use of clamps to avoid bolts and welds in structural members; b) the use of external connectors; and c) the increase of the number of section planes to reduce the amount of bolts. Among the three design concepts, the connection layout resembles design idea #1 the most: two diagonals deliver bending moment to a column, while a “shear tab” bears the gravity loads.

![Figure 5: Final design](image)

All the connection components were sized according to Eurocode 3 and 8. More in detail, these components are: a) two diagonals; b) slip-critical clamps; c) pins; d) a shear tab; and e) continuity plates. The diagonals serve to increase the moment arm, in order to reduce the entity of the horizontal forces applied to structural elements. The diagonals are also conceived as replaceable “fuses”. Therefore, they are designed with a lower steel grade (S235) than the rest of the structure (S275) so that they reach their yielding point before. The diagonals’ cross section is a tubular with a great thickness in order to impede buckling phenomena. The clamps serve to avoid boltholes and welds on structural members. High strength slip-critical bolts are used for this purpose. The condition upon which the clamps work properly is that the steel plates do not bend. To ensure it, steel plates are thick and stiffened by the steel plates forming the pins. The pins connect the clamps to the diagonals; they consist in a row of shaped plates that increase the number of shear planes, thus reducing the overall number of bolts. The “shear tab” is clamped to the column and bolted to the beam. These two boltholes at the beam end were considered an acceptable compromise, considering the fact that the beam web might have to accommodate another shear tab in future re-uses. The continuity plates are welded to the clamping plates and are secured through slotted holes. They are used instead of
stiffeners - which are usually welded to the beam’s and column’s webs - and are meant to receive a portion of the vertical load off the beam’s web.

8. Discussions

The main challenge for this design was to keep all the bolts and the welds of connection outside the structural members (with the exception of two bolt-holes on the beam web). This translates into two major benefits: the acceleration of both the assembly and the disassembly processes and a high degree of reparability/flexibility/reusability. Figure 6 synthetizes the first advantage: since most of the construction processes are carried out off-site, the erection can be faster and more accurate.

![Figure 6: Construction operations](image)

Figure 6: Construction operations

Figure 7 shows the second advantage. The substitution of damaged diagonals requires unbolting four bolts only. A minor change in the configuration requires unbolting more bolts but should be a very reversible process. If the entire system were disconnected, steel profiles would be easily reusable. Two other interesting advantages for this connection are its applicability to a variety of building structures (not only the industrial ones) and its potential for being a retrofit measure: the diagonals and the clamp system can be inserted in any existing connection to improve its moment capacity in a reversible way.

![Figure 7: Reuse scenarios](image)

Figure 7: Reuse scenarios
Despite these relevant benefits, this design presents some issues. First, this connection is overall more complex than most of the other existing connections and employs more material. Secondly, this connection is likely a semi-rigid connection rather than a rigid connection, which puts some restriction to its use. However, all these drawbacks can be compensated for by a high residual value for steel profiles at a structure’s end-of-life.

In order to evaluate if the goal of designing a seismic-resistant connection with a higher disassembly potentials than the existing ones, a new set of DfD criteria was developed. These criteria are an improvement of those used in the surveys, are accountable and fewer (four criteria), making the evaluation simple. Figure 8 shows a comparison between the design and two existing seismic-resistant steel connections, based on new DfD criteria: number of bolts to be assembled or disassembled on-site; number of holes in the structural members; length of welds in the structural members; ability of replacing the seismic fuses.

![Figure 8: Comparison with a traditional and an innovative seismic-resisting connection](image)

The existing connections were assumed to have the same capacity of the design connection and their capacity values were taken from the following literature: Ardeshir and Ashraf (2004) provided values for the end plate connection, while Dessouki et al (2013) for the side plate connection. It is worth noting, though, that the real capacity for the design connection was not determined yet and its design value was taken as the value of the connection capacity. As one can see from Figure 8, the design and the end plate connection have a similar number of bolts to be bolted (or unbolted on-site). However, the design entails a higher degree of reusability for the structural members because it is weld-free, has two bolts only and a replaceable fuse. Conversely, both the end plate and the side plate connections turn to be not as easily reparable (their “fuses” cannot not be easily replaced), reusable (either too many bolt holes or too many welds) and reversible (the welds cannot be removed in a reversible way).

9. Conclusions

The results of this investigation show that, despite their evident conflict, seismic design and DfD can be combined to reach innovative solution. In this case, the compromise of having a DfD seismic-resistant connection implied complex design calculations and many connection components. However, this would be compensated for by a high residual value for the steel members, a potential waste reduction, and energy savings. This study has also demonstrated that it is possible to develop a
metric for assessing DfD steel connections, but further structural analyses are needed to validate it. In fact, in order to compare the DfD potential of two connections it is necessary to know their real structural performances. This part is currently on going will be presented in future research papers.

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References


Webster M and Costello D (2005) “Designing structural systems for deconstruction: How to extend a new building’s useful life and prevent it from going to waste when the end finally comes.” In Green build Conference, Atlanta, GA.


The Experimental Behavior of CFRP-Strengthened Reinforced Concrete Slabs with Fire Protection Systems Subjected to Standard Fire Exposure

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Abstract

Fire resistance of CFRP (carbon fiber reinforced polymer) strengthened concrete slab systems were evaluated in two forms of unprotected and protected against fire. In order to achieve this objective, an unstrengthened and two CFRP strengthened concrete slab (totally 3 specimens) were firstly subjected to increasing gravity loading until failure. The test results revealed that CFRP strips bonded to concrete slabs increased the load-bearing capacity considerably. So, this method can be suitable for flexural strengthening of concrete slabs. Subsequently, the unstrengthened concrete slab was placed on a furnace and was subjected to a constant service gravity load and then, the temperature of the furnace was increased according to a standard temperature-time curve until the failure of the slab occurred. This concrete slab was strengthened by CFRP with two different amounts and then, in two cases of unprotected and protected against fire (two different thicknesses) were tested with aforementioned method (totally 4 specimens). The results showed that because of more load-bearing capacity and subsequently increase in service gravity load, the strengthened concrete slab failed in a short time due to the lack of CFRP resistance against the fire. By contrast, the protected specimens resisted the fire in a considerable time. In addition, it was revealed that details of fire protective coating had an important effect on fire resistance duration and in flat large surfaces with thick fire insulation, the use of reinforcing mesh must be considered.

Keywords: reinforced concrete slab, strengthening, FRP, fire protective coating, fire resistance

1. Introduction

Fiber reinforced polymers (FRPs) are mainly used in civil engineering because of their advantages such as high resistance, light weight, and resistance against corrosion compared to available materials. Carbon fiber reinforced polymer (CFRP) strips are composite materials that currently used as external strengthening bonded to reinforced concrete members with epoxy resins (Hollaway 2010). Although CFRP system has considerable advantages in concrete buildings, there are concerns about its behavior in high temperatures. In fact, the stiffness and resistance of FRP greatly
decrease in relatively low temperatures (Dodds et al. 2000; Correia et al. 2013), i.e. when temperature reaches glass transition temperature ($T_g$) of polymer matrix that usually lies between 55 to 120 °C. Also, the bond strength between CFRP and concrete which is necessary for the effectiveness of the strengthening system is severely reduced in temperatures higher than $T_g$. Some researchers have showed that the bond strength between CFRP and concrete rapidly decreases, if the temperature of the epoxy resin increases to more than about 60-70 °C (Gamage et al. 2006; Leone et al. 2009; Ahmed and Kodur 2011a).

Fire resistance tests performed on CFRP strengthened reinforced concrete beams (Williams et al. 2008; Ahmed and Kodur 2011b; Palmieri et al. 2012), slabs (Williams et al. 2006; Lopez et al. 2013), and columns (Bisby et al. 2005; Chowdhury et al. 2007) revealed that when temperature of epoxy resin reaches $T_g$, composite action between CFRP and concrete will be weakened.

External strengthening using FRP composites are performed in various structural reinforced concrete members. Generally, external strengthening system with FRP sheets is used for three main objectives of flexural strengthening, shear strengthening, and confinement and increase in ductility of compressive members. Considering the subject of this study, flexural strengthening of reinforced concrete slabs using CFRP strips was only investigated here. When CFRPs are used in buildings for the retrofitting of reinforced concrete (RC) slabs, FRP-strengthened RC slabs have to satisfy fire resistance requirements specified in building codes. Thus, conducting fire tests on FRP-strengthened RC slabs is necessary to generate fire endurance ratings and study the response of them under fire conditions. In addition, there was a lack of data on FRP-strengthened slabs protected with domestic fire insulation system used in this research project. First of all, a reinforced concrete slab is designed and then it is strengthened by CFRP strips. Subsequently, the fire resistance of reference concrete slab, CFRP strengthened concrete slabs as well as CFRP strengthened concrete slabs and protected by fire protective coating will be evaluated in a furnace according to the standard test method.

It should be noted that in the present study, only external strengthening of concrete slabs by CFRP materials has been investigated and internal strengthening by elements such as FRP bars has not been taken into account. Selection of carbon fibers in strengthening of concrete slabs was due to their high ratio of resistance to weight and widespread use of them in strengthening of different concrete structures. On the other hand, it should be considered that the amount of creep in carbon fibers is very low in comparison with glass fibers and so, they are more suitable for strengthening of concrete slabs against gravity loads (Hollaway 2010).

Also in this research, mechanical properties of materials used in the concrete slabs such as compressive strength of concrete and tensile strength of steel bars were determined according to the standard test methods.

2. Experimental Program

2.1 Design of test Specimens

In order to examine the fire resistance of CFRP strengthened concrete slabs as well as the performance of fire protective coatings, a total of 8 concrete slabs were fabricated as shown in
Table 1 at Road, Housing & Urban Development Research Center (BHRC). Test specimens were designed and made by considering the following parameters:
1. The effect of strengthening with CFRP; 2. Test temperature (room temperature as reference and exposure to furnace conditions for evaluation of fire resistance); 3. Width of strengthening strips; 4. Thickness of fire protective coatings.

Table 1: Specifications of test specimens

<table>
<thead>
<tr>
<th>Row</th>
<th>Slab designation</th>
<th>Without strengthening</th>
<th>Strengthening with two one layer longitudinal CFRP strips</th>
<th>Without fire protective coating</th>
<th>With fire protective coating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>30 cm width</td>
<td>15 cm width</td>
<td>2.6 cm thickness</td>
</tr>
<tr>
<td>1</td>
<td>CS-25</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>FR1-25</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>FR2-25</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>CS-Fire</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>FR1-Fire</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>FR1-Fire-P1</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>FR1-Fire-P2</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>FR2-Fire</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Because of existing dimensional limitations, the test specimens were scaled by scaling factor of one-quarter and fire resistance tests were performed in a one cube meter (1 m³) furnace. Thickness, width, and length of these small-scale specimens were 5, 98, and 146 centimeters, respectively. Reinforced concrete slabs in two cases of unstrengthened and strengthened with GFRP, were designed as per ACI 318 (2011) and ACI 440 (2008) provisions. Test details including specimens dimensions, load places, and supports in two cases of unstrengthened and strengthened, are illustrated in Figures 1 and 2, respectively.
As it is shown in these figures, the free length of flexural slabs is equal to 130 centimeters. As the specimens were scaled, tensile steel of the slabs was formed of a welded reinforcing bar mesh with a diameter of 4.95 millimeters and a distance of 8 centimeters from each other in both directions. For the case of unstrengthened concrete slabs, the section was low steel and so, the mode of flexural failure was ductile. In this case, firstly steel begins to yield and then, crushing of concrete in compression zone occurs. Also, for the case of CFRP strengthened concrete slabs, the amount of CFRP was selected in a manner to achieve tensile yielding of steel in flexure which is desirable and ductile. Namely, the tensile steel is yielded at the first time and then, crushing of concrete in compression zone happens before the rupture of CFRP strips.

2.2 Materials

2.2.1 Concrete
In order to make concrete for slabs, Portland cement type 1 and standard sands and gravels were utilized. Compressive strength of cylindrical concrete samples at 28 days age and on the day of the fire resistance test (6 months age) was 16 and 20 MPa, respectively. The mentioned data are the average of compressive strength of three samples for each time of test. The compressive strength of cylindrical samples was determined according to ASTM C 140 (2011).

2.2.2 Steel
With respect to scaling test specimens, welded wire mesh was used instead of reinforcing bars in concrete slabs. In order to determine mechanical characteristics of steel reinforcement used in construction of concrete slabs, one direction simple tensile test was performed on raw and welded steel wire samples according to ASTM A 370 (2011) and obtained results are given in Table 2. It is obvious that welding causes strain hardening, decrease in fracture strain, and increase in tensile and yield strength of the steel. Also, at the end of the tensile test of welded steel wires, it was observed that the fracture of samples did not occur at the welded locations.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Wire type</th>
<th>Diameter (mm)</th>
<th>Yield strength (kg/cm²)</th>
<th>Tensile strength (kg/cm²)</th>
<th>Fracture strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>raw</td>
<td>4.95</td>
<td>4158</td>
<td>5719</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>raw</td>
<td>4.95</td>
<td>4211</td>
<td>5823</td>
<td>18</td>
</tr>
<tr>
<td>1</td>
<td>welded</td>
<td>4.95</td>
<td>5700</td>
<td>6400</td>
<td>13.6</td>
</tr>
<tr>
<td>2</td>
<td>welded</td>
<td>4.95</td>
<td>5580</td>
<td>6800</td>
<td>12</td>
</tr>
</tbody>
</table>
2.2.3 CFRP
Carbon fibers together with epoxy resin were used to strengthen the concrete slabs. So, the composite material resulted from this mixture is a kind of CFRP composite which was applied for strengthening six reinforced concrete slabs. Geometrical and mechanical characteristics of this type of carbon fiber with commercial name of PANEX are presented in Table 3 based on specifications announced by the producer.

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Thickness (mm)</th>
<th>Elastic modulus (GPa)</th>
<th>Tensile strength (MPa)</th>
<th>Elongation at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.81</td>
<td>0.176</td>
<td>242</td>
<td>4127</td>
<td>1.5</td>
</tr>
</tbody>
</table>

2.2.4 Fire protective coating
The surface exposed to fire (bottom surface) of two slabs was protected by sprayed fire protective coating from type of gypsum-vermiculite (Vermifire-G) with two nominal thicknesses of 15 and 25 mm. After spray and when coating became dry, thickness in different locations were measured and actual values were 16±2 mm and 26±2 mm for two cases. Also, measured average density was 600 (kg/m³). These measurements were carried out in accordance with ASTM E 605 (2011). For higher bond strength and according to the producer's instruction, a thin layer of primer was firstly applied on the slab surface. Also, a keying steel mesh was fixed between primer and coating layers when the primer layer was still wet.

2.3 Test setup and instrumentation
In this study, the fire resistance experiments were performed by an intermediate scale furnace (1 m³) at Road, Housing and Urban Development Research Center (BHRC). In all the tests, the furnace temperature was increased according to the temperature-time curve of BS EN 1363-1 (2012). The mean temperature of furnace was measured by thermocouples installed inside the furnace. During testing, the mean temperature of furnace had been accurately maintained in the standard limit. In all the tests, vertical loading on the specimen was applied by a hydraulic jack statically. Considering the performance type of a concrete slab, fire resistance tests were continued until the failure of load bearing capacity criteria and the comparisons were fulfilled on this basis.

Flexural loading test on eight slab specimens were carried out according to ASTM E 72 (2010). Vertical displacements of each slab were measured by four LVDTs at midspan and support locations. Also, strain at tensile steel of the slab, extreme concrete compression fiber and outside surface of FRP were measured and recorded in each step by installed strain gauges.

For the fire test, the slab specimens were placed on the furnace. Quarter-point loading configuration was selected and two equal loads were applied on the slab specimens, each at a distance of one quarter of the span from the supports, toward the middle of the span. The total load for each specimen was equal to its calculated service load. After loading, when a steady condition (almost zero increase in deflection with time) was reached, the slabs were exposed to fire in accordance with the standard fire curve, with no additional load. The slabs were simply supported at the ends with a total length of 1.46 m, of which 1.3 m was exposed to the standard
fire by the furnace. Each slab specimen was supported on an insulated edge along four sides of the furnace which did not make any restraint to the movement of the slab in its free edges. For this purpose, a ceramic fiber blanket insulation was placed between the slab and its supports and the edges of the furnace for the prevention of flame and heat exit (Figure 3). Also, for specimens FR1-Fire and FR2-Fire that CFRP layer did not have any fire resistant material, for protecting the strain gauges installed on the CFRP against the fire, they were covered by a ceramic fiber blanket insulation which was fastened to the concrete slab by means of a steel mesh.

![Figure 3: Test setup for the fire resistance tests](image)

In these fire resistance experiments, two thermocouples were mounted inside each specimen to measure the temperature of the steel mesh (No. 2) and the specimen center (mid-thickness, thermocouple No. 1) at mid-span. In specimens FR1-Fire-P1 and FR1-Fire-P2, two additional thermocouples (No. 3 & No. 4) were places between the CFRP layer and the fire protective layer in order to measure the temperature of the CFRP layer.

### 3. Results and discussion

#### 3.1 Gravity loading tests

Three slab specimens were tested under gravity loading in room conditions (almost 25 °C). One specimen (CS-25) was unstrengthened and two other specimens (FR1-25 and FR2-25) were strengthened with CFRP. In these tests, the applied vertical load was incrementally increased until the failure of the specimen was reached, i.e. reduction in the specimen strength after experiencing the maximum strength was at least 20%. Obtained load-deformation curve for these specimens is shown in Figure 4.
In Figure 4, load-displacement curves of specimens CS-25, FR1-25, and FR2-25 are compared. According to this figure, the maximum flexural load-bearing capacity of strengthened specimens FR1-25 and FR2-25 is more than that of unstrengthened specimen CS-25 by a factor of 3.47 and 3.28, respectively, which shows the high efficiency of CFRPs in the flexural retrofitting of concrete slabs. On the other hand, as can be seen in this figure, the strengthening with CFRPs causes a reduction in the assembly ductility; since the stress-strain curve of CFRPs is linear up to failure (CFRPs have brittle behavior).

3.2 Fire resistance tests

A total of five slab specimens in accordance with Table 1 were subjected to fire resistance tests including one unstrengthened specimen (CS-Fire), two strengthened specimens without fire resistant material (FR1-Fire and FR2-Fire) and two fire protected strengthened specimens (FR1-Fire-P1, FR1-Fire-P2). In these tests, firstly the applied vertical load to each specimen was incrementally increased to reach the specimen service load. After loading, the furnace temperature was increased according to the selected standard temperature-time curve until the failure of the specimen occurred, namely the specimen was no longer able to resist the applied constant vertical load.

3.2.1 Specimen CS-Fire

A service load of 9.5 kN was obtained in accordance with ACI 440.2R-08 for the unstrengthened slab, which is corresponding to a stress of 0.8F_y in the slab tensile reinforcement, where F_y is the yield stress of the reinforcement. The mid-span displacement-temperature curve for this specimen is plotted in Figure 5. In this test, firstly, the load was gradually increased up to 9.5 kN which the corresponding displacement was equal to 13.5 mm. After mechanical loading, the specimen was exposed to the standard fire. During the testing, the mid-span displacement of the specimen increased continuously. With the increase in the temperature during the test, a progressive cracking in the slab top surface developed. After the steel mesh temperature reached 550 °C, the slab mid-span displacement became suddenly 123.4
mm and the specimen failure happened. At that moment, the slab residual strength became lower than the applied constant load due to elevated temperatures. The test was stopped at approximately 79 min of fire exposure time because of the failure of the strength criteria. Figure 6 shows the temperature-time curve of the installed thermocouples in the specimen. For analyzing the slab failure at 79 min, the following explanation can be mentioned:

This unstrengthened concrete slab was under a constant load of 9.5 kN during the fire resistance test. Since the maximum load carrying capacity of this slab was 16.15 kN, thus the ratio of load to strength was around 0.6. At the failure time of the slab (79 min), the steel temperature was recorded as 550 °C by means of the installed thermocouple. In this temperature, the yield strength of the steel reaches 0.6 of its initial value in accordance with ANSI/AISC 360 (2010). Therefore, the slab flexural strength decreases about 40% and reaches from 16.15 kN to lower than the applied load of 9.5 kN that causes the slab to fail which agrees with experimental results. It should be noted that since the compression depth of this slab is small, the slab flexural strength is approximately related to the steel yield strength with a linear equation.

Figure 5: Measured mid-span displacement as a function of fire exposure time for slab CS-Fire

Figure 6: Temperature-time curve of installed thermocouples in slab CS-Fire

3.2.2 Specimens FR1-Fire & FR2-Fire

The service load of the strengthened specimens was computed based on the conditions that the service stress in CFRP sheets reaches 0.33C_EC_Df_u according to ACI 440.2R-08. C_E (environmental reduction factor), C_D (durability factor), and f_u (tensile strength of fibers) were considered as 0.65, 1, and 4127 MPa, respectively. Finally, these service loads for specimens FR1-Fire and FR2-Fire were determined as 33 and 24 kN, respectively.

Variations of mid-span deflection versus time for specimens FR1-Fire and FR2-Fire are plotted in Figure 7. In specimen FR1-Fire, the load was incrementally increased until the calculated service load of 33 kN was obtained and the corresponding mid-span deflection was equal to 31.6 mm. Then, after the start of the fire test, this load was kept constant. With the increase in furnace temperature, the specimen mid-span deflection increased and when its value reached 43.3 mm, the debonding of CFRP sheets from the concrete surface in the fire-exposed span of the slab occurred. Then, anchorage failure and spalling of the concrete under a CFRP sheet in one slab end occurred (Figure 8) that resulted in a rapid reduction in the slab strength and so, the slab failed.
This test was stopped at 7 min due to the torsion of the transverse beams which the load was being applied to the slab by them. After the modification of the loading system, the fire test was performed again. After 4 min, the test was terminated because the slab was not able to carry the applied load any more. In other words, the strength of the slab at this time was lower than the applied load due to high temperatures. The fire endurance of this specimen was totally 11 min (Figure 7).

Visual observations were made for this specimen after the test. As can be seen in Figure 8, the epoxy resin of the CFRP strips in the fire-exposed span of the slab has burned. However, we can conclude that during the testing, in the absence of any debonding of CFRP within anchorage zones located outside the fire zone, the unbonded continuous carbon fibers at the slab bottom continued to contribute towards the tensile strength of the beam through the cable mechanism. Due to this cable mechanism, the collapse of the slab was delayed until the anchorage failure was reached and thus, the slab fire resistance increased. In practice, the use of mechanical anchors at both ends of FRP can aid the cable mechanism. It should be noted that in the literature, there is a lack of data on the contribution of this cable mechanism to fire endurance of FRP-strengthened slabs without any fire protection system.

It can be seen according to the temperature-time curve of the installed thermocouples in specimen FR1-Fire that the temperature of the steel was low and before reaching 100 °C, the test terminated. This is because the applied load to this strengthened slab was higher than that of the unstrengthened slab, due to the contribution of the CFRP sheets to the slab load bearing.
capacity. On the other hand, the epoxy resin in the CFRP is very vulnerable to high temperatures and after exposing to the fire, the strength of the CFRP-strengthened slab suddenly diminishes. Thus, FRP-strengthened concrete slabs that the FRP has not any fire protection coating, have very lower fire endurance as compared to that of the unstrengthened case in a fire event.

Similarly, in specimen FR2-Fire, the load was incrementally increased up to the calculated service load of 24 kN and in this situation, the corresponding mid-span deflection was equal to 28.6 mm. Then, after the start of the fire test, this load was kept constant. With the increase in the furnace temperature, the specimen mid-span deflection increased and when its value reached 53.6 mm, the debonding of the CFRP sheets from the concrete surface in the fire-exposed span of the slab occurred that leaded to a significant reduction in the slab strength. Then at mid-span deflection of 85.2 mm, the collapse of the slab occurred.

The fire test of specimen FR2-Fire terminated at 22 min because of the strength criteria failure. In other words, at this time the slab was not able to tolerate the applied load. Overall, the above explanation about the fire behavior of specimen FR1-Fire can be mentioned for this specimen again. However, due to the lower mechanical load in this case, the fire resistance rating and thermocouples temperature for specimen FR2-Fire are higher than those of the previous specimen.

Visual observations were made for this specimen after the test. Similar to specimen FR1-Fire, the epoxy resin of the CFRP strips in the fire-exposed span of the slab has disappeared and the continuous carbon fibers have separated from each other and debonded from the concrete surface in this region.

### 3.2.3 Specimens FR1-Fire-P1 & FR1-Fire-P2

The mid-span deflection as a function of time for specimen FR1-Fire in two cases of protected and unprotected against the fire is shown in Figure 9.

For the purpose of comparing the results of protected and unprotected slabs against the standard fire, the loading conditions was considered the same and the service load of specimen FR1-Fire (i.e. 33 kN) was applied to fire-protected specimens FR1-Fire-P1 and FR1-Fire-P2 similarly. The loading method for these specimens was similar to specimen FR1-Fire. That is the applied load was incrementally increased up to 33 kN and then, was kept constant during the fire test.

According to Figure 9, the fire test of specimen FR1-Fire-P1 terminated at 47 min due to the failure of the load bearing capacity criteria, that is the strength of the specimen reached lower than the applied constant load of 33 kN. However, the strength criteria failure for specimen FR1-Fire took place at 11 min that indicates the significant positive effect of the fire protective material. The temperature-time curve of the installed thermocouples in specimen FR1-Fire-P1 is plotted in Figure 10.
During the fire test, cracking and spalling of the fire resistant coating of slab FR1-Fire-P1 occurred that led to faster transfer of the heat flow to the strengthened concrete slab (Figure 11a). In spite of the higher thickness of the fire insulation in specimen FR1-Fire-P1, the fire resistance of this specimen was lower than that of specimen FR1-Fire-P2 (Figure 9). This was due to the high thickness of the external thermal insulation and unsuitable details. In specimen FR1-Fire-P1, about 2 cm of the insulation was located outside the keying mesh. During the fire test, falling off some portions of the unreinforced protective coating happened as a result of high temperatures and slab deformations (Figure 11a). This phenomenon started at around 28 min and at 47 min reached its peak. Due to this phenomenon, the CFRP was exposed to high temperatures and subsequently, the CFRP failed and it caused the specimen to collapse rapidly. This event demonstrates that the details of fire protective coatings have important role on their performance and an increase in the insulation thickness without appropriate details can accelerate the spalling of the insulation and weaken the fire protection effectiveness. According to BS 8202-1 (1995), for high thickness insulations and or large flat substrates, the use of reinforcing mesh into the insulation may be required for providing integrity. However, where the insulation is locked in position by virtue of the shape of the element, for example I shape columns, the reinforcing mesh is not usually needed because of the encapsulation by the insulation.

The fire resistance test of specimen FR1-Fire-P2 terminated at 74 min because of the strength criteria failure; that is the specimen did not have sufficient strength to carry the applied load.
This fire endurance reveals the satisfactory performance of the fire protective coating as compared to that of specimen FR1-Fire-P1. According to Figure 11b, at the end of the test, the fire resistant coating in specimen FR1-Fire-P2 suffered many cracks; however, because of the presence of the keying mesh and its low thickness, any spalling of it did not occur. During the fire test of specimen FR1-Fire-P2, first, the debonding of the CFRP in the fire-exposed zone happened and the continuous carbon fibers transferred the load to the end anchorage zones. After the anchorage zones failure, the strength of the specimen decreased suddenly and subsequently, the slab collapsed.

At the end, the test results of all the tested specimens are summarized in Table 4.

### Table 4: Fire endurance rating of experimental slabs based on strength criteria failure

<table>
<thead>
<tr>
<th>Row</th>
<th>Slab designation</th>
<th>Slab properties Width of CFRP strips (cm)</th>
<th>Thickness of Fire protection layer (cm)</th>
<th>Applied load (kN)</th>
<th>Fire resistance period (min)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>CS-Fire</td>
<td>—</td>
<td>—</td>
<td>9.5</td>
<td>79</td>
</tr>
<tr>
<td>2</td>
<td>FR1-Fire</td>
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<td>—</td>
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<td>2.6</td>
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<td>47</td>
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<tr>
<td>4</td>
<td>FR1-Fire-P2</td>
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<td>1.6</td>
<td>33</td>
<td>74</td>
</tr>
<tr>
<td>5</td>
<td>FR2-Fire</td>
<td>15</td>
<td>—</td>
<td>24</td>
<td>22</td>
</tr>
</tbody>
</table>

**4. Conclusions**

Based on this experimental research, the following conclusions can be drawn:

1. It was proved that the CFRP reinforcement is capable to increase the flexural strength of concrete slabs significantly. For the specimens tested in this experimental program, this increase in the load bearing capacity of the slabs was between 228% and 247%. However, the stress-strain curve of the CFRP up to the rupture is linear. As a result, the overall ductility and failure deformation of concrete slabs are reduced by the presence of the CFRP.

2. Strengthening a reinforced concrete slab with CFRP will increase the slab load carrying capacity and so, the applied service load to the slab can be increased. On the other hand, the CFRP is very vulnerable to high temperatures that the mechanical properties of its epoxy resin degrade at temperatures close to and above its glass transition temperature (usually is below 100 °C) which leads to the separation of the continuous carbon fibers. Because of these two factors, the fire resistance rating of a CFRP-strengthened reinforced concrete slab is much lower than that of the corresponding reference reinforced concrete slab. In this study, the fire endurance of the reference reinforced concrete slab was 79 min that reduced to 11 and 22 min for the strengthened slabs with different amounts of the CFRP. This issue reveals the intense need of fire insulation systems to protect the CFRP used in gravity retrofitting of reinforced concrete slabs.

3. The fire protection of the CFRP-strengthened reinforced concrete slabs with the gypsum-vermiculite material used in the study demonstrated that this type of materials is able to improve the fire resistance of the strengthened slabs significantly. In these experiments, a fire protection coating with 1.6 cm thickness could increase the fire endurance of the CFRP-strengthened
concrete slab from 11 min to 74 min. The reasonable thickness for the fire protection layer must be calculated to satisfy the mandatory fire resistance in accordance with building codes.

4. The installation method and details of a fire protection layer have a significant effect on its fire performance. In this study, in spite of an increase in the thickness of the spray-applied insulation from 1.6 to 2.6 cm, the fire endurance became lower contrary to our expectation. This result exhibits that for a large flat surface with a thick fire protection coating, a reinforcing mesh inside the fire protection coating is necessary to prevent it from detachment and maintain its integrity in high temperatures and large deformations.

5. In external strengthening of a reinforced concrete slab with CFRP strips, if a suitable external fire insulation or mechanical anchor can be provided at the ends of the CFRP strips, in a fire event, the continuous carbon fibers will separate from each other except the protected or strengthened ends. The bond of these fibers to the substrate at the ends will form a cable mechanism which will increase the slab strength and the slab fire endurance accordingly. This cable mechanism will fail at the time of the concrete cover detachment at the ends due to the high CFRP-induced tensile stresses.

Acknowledgement
Road, housing and urban development research center (BHRC) provided financial and laboratory supports for this research. The authors would like to appreciate Composite Sazeh Moghavem Company for supplying the needed FRP materials and their implementation. In this regard, the authors would also like to appreciate valuable cooperation of Dr. Sarafraz and staff of the fire department of BHRC; Mr. Koosha, Mr. Jamali Ashtiani, Mrs. Doroodiani, and Mrs. Askari moghadam.

References
American Concrete Institute Committee 318 (2011) Building Code Requirements for Structural Concrete and Commentary, ACI 318-11.


Knowledge Gaps in the Construction Industry to Increase Societal Resilience: A Local and National Government Perspective

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Abstract

Over the last decade, a series of increasingly devastated natural disasters have been witnessed across the world. The disaster threats were further aggravated due to various social, economic and environmental trends, such as, growing population, urbanisation, inequality and global environmental change. This demanded a more proactive approach to reduce the vulnerability and exposure, and to increase resilience. For proper implementation of resilience measures, various efforts are required from construction practitioners. Accordingly, construction practitioners are expected to play a key role at each stage of the disaster management cycle. However, recent literature concerning disasters has highlighted the inadequate engagement of the construction industry in reducing the risk of disasters. This emphasises the need to engage the construction professionals adequately, in achieving a resilient built environment. Therefore, it is of paramount importance to provide construction industries with the necessary capacity and capability to plan, design, build and operate in such a way that will reduce vulnerability and exposure, and increase resilience. In order to address this challenge, CADRE (Collaborative Action towards Disaster Resilience Education), which is an EU funded research project, intends to develop an innovative professional doctoral programme that addresses the career needs, and upgrade the knowledge and skills, of practising professionals working to make communities more resilient to disasters. Accordingly, the first phase of the research involved, capturing the needs of 5 stakeholder groups associated in disaster resilience and management as well as current and emerging skills and ultimately knowledge gaps, applicable to construction practitioners towards enhancing societal resilience to disasters. In this context, the paper aims to analyse the current and emerging knowledge gaps of construction practitioners as highlighted by the national and local government stakeholders. Accordingly, the paper provides an extensive analysis of knowledge gaps, which were captured via 20 semi-structured interviews with national and local government stakeholders. Knowledge gaps were analysed in relation to social, technological, environmental, economic and institutional factors and property life-cycle stages. Some of the key knowledge gaps identified in the study are, business continuation management; damage assessments and claims; financing, budgeting and estimating; building codes, regulations and planning; resilient buildings and infrastructure; community empowerment; stakeholder management; legal frameworks and compliance; disaster risk assessment; environmental impact assessment and management; and knowledge management.
1. Introduction

There is a growing recognition that those responsible for the built environment have a vital role to play in developing societal resilience to disasters. If construction researchers and practitioners are to be able to contribute to reduce risks through resilient buildings, spaces and places, it is important that capacity is developed for modern design, planning, construction and maintenance that are inclusive, inter-disciplinary, and integrative. In order to address this challenge, EU funded research project, CADRE (Collaborative Action towards Disaster Resilience Education) will identify knowledge gaps, and develop an innovative professional doctoral programme (DProf) that integrates professional and academic knowledge in the construction industry to develop societal resilience to disasters. Through the development of an innovative and timely curricular and learning material, the project seeks to update the knowledge and skills of construction professionals in the industry.

Before developing the proposed DProf programme, it was important to identify the knowledge gaps in the construction industry to develop societal resilience to disasters. Accordingly, the paper aims to present the knowledge gaps that have emerged as part of this research. Capturing knowledge gaps involved, capturing the needs of various stakeholder groups associated in disaster resilience and management, as well as current and emerging skills, applicable to construction practitioners towards enhancing societal resilience to disasters. The primary and secondary data generated a long list of needs and skills. Finally, the identified needs and skills were combined ‘like-for-like’ to produce broader knowledge gaps. The paper provides an extensive analysis on the knowledge gaps identified through this process.

The paper begins with a literature synthesis on disaster resilience knowledge and skills. The paper then presents the analytical framework of the study. The scope of the paper is limited to findings gathered from one stakeholder group, national and local governments and therefore the paper investigates the role of the government in developing societal resilience to disasters. The paper continues with an analysis of the data gathered through semi-structured interviews based on five resilience dimensions, economic, environmental, institutional, social and technological and concludes with a list of key classifications derived from government stakeholders in enhancing the knowledge and skills of construction practitioners serving them to increase societal resilience to disasters.

2. Disaster resilience knowledge and skills

Hazards cause various disruptions to the built environment. The damage to the built environment accounts for most of the economic losses of disasters and its failure often determine the amount of fatalities (Witt et al., 2014). As such, professionals related to construction sector are expected to play a major role in mitigating such impacts of disasters. At the same time, it is the duty of the professionals attached to the construction sector, to plan, design, construct and operate necessary risk reduction infrastructure and other services to
protect the communities exposed to hazards (Malalgoda et al, 2015). As such built environment should be planned, designed, built and operated in such a way that it can withstand at a time of a disaster. Therefore it is clear that the construction industry and the built environment professions play an important role in contributing to society’s improved resilience (Haigh and Amaratunga, 2010). Max Lock Centre (2009) developed a guide to demonstrate the value of using construction professionals in disaster risk reduction and response. This guide shows how the relevant professional skills and expertise can be applied at all stages of disaster management. Some of the key activities highlighted in this guide are, risk and vulnerability assessment; disaster risk reduction (DRR) and mitigation; emergency water supply and sanitation; logistical planning; relief and transitional shelters; project planning and management; design, construction and monitoring; physical condition surveys and audits; compensation packages; resource mapping; housing need assessment; land survey and acquisitions; physical planning; infrastructure planning and implementation; property rights and claims; financial planning and management; and advice on regulations and codes. Especially, poor urban planning and poorly regulated building codes have aggravated exposure to hazards (Bosher, 2014; Malalgoda et al, 2014) and as such utilising construction practices, building codes and technology that can withstand the exposure is of paramount importance (Ireni-Saban, 2012). As such it is clear that construction practitioners have a key role in DRR and management and their professional skills and expertise need to be deployed in disaster risk reduction and management. In addition to these, Norman and Binka (2015) highlighted the importance of soft skills such as leadership in building disaster resilience and response. A study conducted in Sub-Saharan Africa revealed that leadership capacities need to be strengthened through continual professional developments and formal education in order to build resilience and to improve response. It is important to understand that the disaster resilience requires efforts of various stakeholders and would require a multi-sectoral and inter-disciplinary approach (Haigh and Amaratunga, 2010). As such collaborative actions are required for a better resilience outcome (Ireni-Saban, 2012), which highlights the importance of knowledge and skills, related to collaborative working and community interactions.

Indigenous knowledge is another important aspect when it comes to DRR and resilience. According to Ireni-Saban (2012) local knowledge places a greater importance, including understanding communities at risk, including their practices, traditions, customs and beliefs. By understanding the indigenous knowledge, such as local skills and materials and how it can be successfully used and its success in coping with disasters over time (UNISDR, 2008) would undoubtedly benefit in the preparation for future disasters. However, according to Gaillard and Mercer (2012) there is a gap in integrating local and scientific knowledge because of the lack of trust between stakeholders operating at different level. As a result, contributions of local communities are often disregarded which lead to gaps between policy development at the national level and the practice at the local level. This emphasises the need of multi stakeholder approach, inclusion and empowerment.

As discussed above, various knowledge and skills are required to better perform the tasks associated with risk reduction. As such, knowledge plays a major role in disaster risk reduction and resilience (Weichselgartner and Pigeon, 2015). As a result of prominent gaps in knowledge,
Sendai Framework for Disaster Risk Reduction (2015-2030) has identified the need of enhancing the capacities of relevant stakeholders and industries. The Framework provides recommendations regarding the creation and dissemination of knowledge (Weichselgartner and Pigeon, 2015). Accordingly, the framework suggest to “build the knowledge of government officials at all levels, civil society, communities and volunteers, as well as the private sector, through sharing experiences, lessons learned, good practices and training and education on disaster risk reduction, including the use of existing training and education mechanisms and peer learning” (UNISDR, 2015). Professionals attached to construction sector play an important role in disaster resilience and management. As such, construction professionals require continuous update of knowledge and education in order to effectively contribute to disaster management (Thayaparan et al, 2014). It is therefore important to design educational and training courses to enable them to successfully fulfil this role (Witt et al., 2014). Therefore as argued by Bosher et al. (2007), risk and hazard awareness training needs to be integrated systematically into the professional training of architects, planners, engineers, developers, etc. The next section presents the analytical framework and methodology of the study.

3. Analytical Framework and methodology

The initial framework of the study is a three dimensional framework consisting of the following parameters:

Built environment stakeholders: National and local government organisations; Community; NGOs, INGOs and other international agencies; Academia and research organisations; and Private sector.

Dimensions of resilience: Economic Resilience; Environmental Resilience; Institutional Resilience; Social Resilience and Technological Resilience

Stages of property lifecycle: Preparation Stage (PS); Design Stage (DS); Pre-Construction Stage (PCS); Construction Stage (CS) and Use Stage (US)

The framework was developed through an extensive consultation process with project partners and was refined throughout the first year of the project with the emerging literature findings and the opinion of stakeholders who has been interviewed to capture the labour market demands in construction industry to increase societal resilience to disasters.

The research discussed in this paper is focussed on analysing the market demands of one of the stakeholders, national and local governments. Accordingly, the paper analyses the semi-structured interviews conducted with national and local government organisations. Semi-structured interviews were conducted with a total of twenty respondents from the “national and local government” stakeholder group across different countries and continents. The respondents identified and interviewed in this category were individuals that were attached to national and local government institutions, involved in various activities related to disaster resilience and management. The interviews were aimed at capturing the needs as well as skills, applicable to
construction professionals towards enhancing societal resilience to disasters. During the interviews, special interest and focus was given on the needs of national and local government organisations engaged in disaster resilience and management and the skills required from construction industry professionals serving them. Accordingly, the interviews were more of a discourse structured around the stages of disaster management cycle. The analysis was done using NVivo (version 10). The themes were presented under two main headings i.e. Needs and Skills. The category “Needs” covers the stakeholder requirements that emerged from the interviews as well as the demands specifically made by interviewees. Also, what the interviewees believe should be in place while professionals relate with them to enhance societal resilience were categorized under the heading “Needs” in the analysis. During the interviews, some set of skills were emerged; some were displayed by professionals while serving to reduce the threats posed by natural and human induced hazards and some that are desired by interviewees. These set of skills were categorized under the heading “Skills”. All needs as well as skills were categorized into five dimensions of resilience (Social, Economic, Institutional, Environmental, Technological) and each of the dimensions of resilience is sub-headed with the five stages of property lifecycle, Preparation, Design, Pre-construction, Construction and Use stage. The interviews generated a long list of needs and skills with respect to the property lifecycle stages under the respective dimensions of resilience. Finally, the identified needs and skills were combined ‘like-for-like’ to produce broader level of knowledge gaps (themes).

3.1 Government as a stakeholder

A number of parties are involved in the process of increasing societal resilience to disasters, including community and citizens’ groups, local governments, the private/corporate sector, the national government, civil society organisations, external actors, professional groups and the media. There should be adequate coordination among the interested parties in order to overcome the challenges posed by a disaster, successfully. Between these stakeholders, a government of a country plays a predominant role. All activities related to disaster management are usually centred at governmental level, and hence, governments can be identified as the principal stakeholder in disaster management (Moe and Pathranarakul, 2006). Usually the government assigns the responsibility for each task to different ministries or may form new authorities or committees and assign the responsibility for different tasks to these authorities or committees (Wolensky and Wolensky, 1991). To be successful, proper partnerships and cooperation are essential between local and national governments and civil society in order to reduce the costs of risk reduction, ensure local acceptance and build social capital (UN-ISDR, 2010). Recent literature highlight administrative shortcomings that prevent affected communities recovering from disasters (Ireni-Saban, 2012). In overcoming these challenges, government require professional services from the construction professionals to prevent, mitigate, prepare and recover from disasters. According to Bosher (2014) number of structural and operational obstacles does exist in making the built environment resilient to disasters and lack of knowledge and skills were key among others especially in developing country context (Malalgoda et al, 2014). Thus, it is very important to identify the knowledge gaps and develop educational programmes to cater the identified knowledge gaps. The next section analyses the data gathered through semi-structured interviews.
4. Data analysis and discussion

4.1 Economic Resilience

According to Seneviratne et al (2010) economic factors are two-fold, economic planning measures and financial measures. Aspects relating to production, distribution and consumption of goods and services are considered as economic planning measures and aspects relating to money and management of monetary assets are considered under financial measures. In terms of economic resilience, most of the interviewees identified the gaps in business continuity management. Some of the key highlights within this theme were business continuation strategies and business continuation plans. Having a business continuation strategy/plan is of paramount importance in order to make sure that business is up and running after a disaster. Local authorities have a responsibility to promote business continuity to businesses and the interviewees considered this as a key knowledge area within the domain of disaster resilience.

Financing, budgeting and estimating was another key theme identified under economic resilience. This covers number of sub-themes such as, sourcing of funds, investment appraisals, construction budgets, cost control, contingency management, financial management relation to disaster resilience and, transparency and accountability. Damage assessments and claims is another important theme highlighted by the interviewees. Under this theme, interviewees highlighted the importance of knowledge and skills related to, property insurance, damage assessments, valuation, and compensation for damages. This include, assessing what damage has the disaster caused and what works need to be done to get back to pre-disaster condition and what further work could be done to prevent or reduce the risk of happening it again. Process and quality management was also categorised under economic resilience as it highlighted the importance of resource management and prioritising work. In particular, prioritisation of work is very much relevant in the context of disaster resilience due to the restricted budgets. Thus, identifying the most critical activities and prioritising projects is very important in implementing DRR projects. Resource management and prioritisation also has a link to the next theme, which is social and cultural awareness. Interviewees highlighted the importance of the use of local knowledge, skills and materials and emphasised the necessity of deploying economically feasible and socially acceptable solutions that would enhance societal resilience to disasters.

Another theme was the contracts and procurement. Interviewees argued the importance of knowledge and skills with regard to different procurement strategies which facilitate rapid restoration; different forms of contracts such as nec3 option G which allows instructing task orders during incidents; framework contracts for incident management works; and rapid response of supply chain. All these are formed under the theme, contracts and procurement. Table 1 highlights all themes derived in relation to economic resilience and their relevance to different stages of property life cycle.

<table>
<thead>
<tr>
<th>No.</th>
<th>Classifications</th>
<th>Property lifecycle stages</th>
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<tr>
<td>1</td>
<td>Business continuation management</td>
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<td>2</td>
<td>Financing, budgeting and estimating</td>
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</table>
4.2 Environmental Resilience

Factors relating to environment, ecology and sustainability were considered under environmental resilience. Similarly, analysis of semi-structured interviews facilitated deriving number of themes for environmental resilience. Each of these themes was derived from various needs and skills identified by the interviewees. One of the key themes identified under this category was the risk and need assessment. This theme was identified as a result of sub themes such as, preventive structures, identifying vulnerable population and properties, hazard and risk mapping, identifying suitable places for relocation and, forecasting and warning. In doing so, it is very important that community know that they are at risk, so that they will be more engaged and will be willing to take action. For an instance, they can equip with property level protection, for an example, in the case of floods, they can install floodgates for their doors and windows and flaps for inlets and vents into their houses. The theme, knowledge management arise based on interviewees arguments on the need for, access to related data and information and access to required software and technology such as GIS. Lack of data and information is a prevailing issue especially for more remote areas. These include, lack of hazard and risk maps, water tables, soil types, rainfall data, geological data etc. Under environmental management, interviewees highlighted the need of understanding and managing the environmental impacts, which trigger disasters, forecasting, early warning, weather and climate change, use of resilient designs, materials and construction techniques, environmental impact assessments and local topography. Materials and resource management also plays a role in environmental resilience. Accordingly, interviewees highlighted the importance of having the knowledge of resilient and environmentally friendly materials and other resources in order to enhance the environmental resilience. For an example, one interviewee highlighted the importance of selecting materials to match the location, climate, and soil types while another highlighted the importance of resource management to reduce the wastage. Sustainability and resilience is yet another important theme identified under environmental resilience. It covers number of sub themes such as, sustainable design solutions, selection and use of sustainable materials and technologies and ensuring sustainability of resilient solutions. Table 2 highlights all themes derived in relation to environmental resilience and their relevance to different stages of property life cycle.
Table 2: Themes for environmental resilience

<table>
<thead>
<tr>
<th>No.</th>
<th>Classifications</th>
<th>Property lifecycle stages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PS</td>
</tr>
<tr>
<td>1</td>
<td>Disaster risk and need assessment</td>
<td>x</td>
</tr>
<tr>
<td>2</td>
<td>Knowledge management</td>
<td>x</td>
</tr>
<tr>
<td>3</td>
<td>Environmental impact assessment and management</td>
<td>x</td>
</tr>
<tr>
<td>4</td>
<td>Materials and resource management</td>
<td>x</td>
</tr>
<tr>
<td>5</td>
<td>Sustainability and resilience</td>
<td>x</td>
</tr>
<tr>
<td>6</td>
<td>Building codes, regulations and planning</td>
<td>x</td>
</tr>
<tr>
<td>7</td>
<td>Resilient buildings and infrastructure</td>
<td>x</td>
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<tr>
<td>8</td>
<td>Disaster management and planning</td>
<td>x</td>
</tr>
<tr>
<td>9</td>
<td>Health and safety</td>
<td>x</td>
</tr>
<tr>
<td>10</td>
<td>Process and quality management</td>
<td>x</td>
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<tr>
<td>11</td>
<td>Social and cultural awareness</td>
<td>x</td>
</tr>
<tr>
<td>12</td>
<td>Teaching and research on disaster resilience and management</td>
<td>x</td>
</tr>
<tr>
<td>13</td>
<td>Time management</td>
<td>x</td>
</tr>
<tr>
<td>14</td>
<td>Town and country planning</td>
<td>x</td>
</tr>
</tbody>
</table>

4.3 Institutional resilience

Institutional resilience, as defined in this paper refers to the political, legal and institutional factors. Aspects relating to government and policies are considered as political factors; aspects relating to law, accepted rules and regulations in managing disasters are considered under legal factors; aspects relating to an organisation linked to disaster management are considered under institutional factors (Seneviratne et al, 2010). As shown in Table 3, various themes were identified in relation to enhancing institutional resilience. One of the key themes identified was stakeholder management. Stakeholder management was derived from a combination of responses given by the interviewees. Some of these include, multi stakeholder engagement, appropriate institutional arrangements, clear definitions of roles and responsibilities, coordination between different organisations, collaborative working, relationship with other stakeholders and communities, commitment to disaster management and resilience. This theme further incorporated the interviewees’ responses such as communication skills, team working and management and leadership skills. Legal frameworks and compliance is another key theme under institutional resilience. This theme incorporated sub themes such as, policies, plans and legal frameworks for disaster resilience, disaster risk reduction strategies, knowledge on prevailing laws and implementation of laws and regulations. Leadership and people management has been identified as a separate theme as it was a concern for most of the respondents. However, this has a close link to the theme, stakeholder management, and include, sub themes such as multi stakeholder engagement, understanding community needs, engaging communities, collaborative working, conflict management, leadership skills, people management skills, commitment for disaster risk reduction and proactive thinking. Governance is yet another important theme classified under institutional resilience. The theme was derived from number of sub themes, such as, institutional arrangements for disaster resilience;
commitment to disaster risk reduction; coordination between stakeholders; and policies, plans and legal frameworks for disaster resilience.

Table 3: Themes for institutional resilience

<table>
<thead>
<tr>
<th>No.</th>
<th>Classifications</th>
<th>Property lifecycle stages</th>
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</thead>
<tbody>
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<td></td>
<td></td>
<td>PS</td>
</tr>
<tr>
<td>1</td>
<td>Stakeholder management</td>
<td>x</td>
</tr>
<tr>
<td>2</td>
<td>Legal frameworks and compliance</td>
<td>x</td>
</tr>
<tr>
<td>3</td>
<td>Leadership and people management</td>
<td>x</td>
</tr>
<tr>
<td>4</td>
<td>Governance</td>
<td>x</td>
</tr>
<tr>
<td>5</td>
<td>Building codes, regulations and planning</td>
<td>x</td>
</tr>
<tr>
<td>6</td>
<td>Business continuity management</td>
<td>x</td>
</tr>
<tr>
<td>7</td>
<td>Communication</td>
<td>x</td>
</tr>
<tr>
<td>8</td>
<td>Contracts and procurement</td>
<td>x</td>
</tr>
<tr>
<td>9</td>
<td>Damage assessment and claims</td>
<td>x</td>
</tr>
<tr>
<td>10</td>
<td>Knowledge management</td>
<td>x</td>
</tr>
<tr>
<td>11</td>
<td>Resilient buildings and infrastructure</td>
<td>x</td>
</tr>
<tr>
<td>12</td>
<td>Disaster management and planning</td>
<td>x</td>
</tr>
<tr>
<td>13</td>
<td>Disaster risk and need assessment</td>
<td>x</td>
</tr>
<tr>
<td>14</td>
<td>Environmental impact assessment and management</td>
<td>x</td>
</tr>
<tr>
<td>15</td>
<td>Human resource management</td>
<td>x</td>
</tr>
<tr>
<td>16</td>
<td>Process and quality management</td>
<td>x</td>
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<tr>
<td>17</td>
<td>Project and construction management</td>
<td>x</td>
</tr>
<tr>
<td>18</td>
<td>Teaching and research on disaster resilience and management</td>
<td>x</td>
</tr>
<tr>
<td>19</td>
<td>Team working</td>
<td>x</td>
</tr>
<tr>
<td>20</td>
<td>Time management</td>
<td>x</td>
</tr>
<tr>
<td>21</td>
<td>Town and country planning</td>
<td>x</td>
</tr>
<tr>
<td>22</td>
<td>Transparency and accountability</td>
<td>x</td>
</tr>
</tbody>
</table>

4.4 Social resilience

Social resilience was defined based on Cacioppo et al (2011) definition for social resilience, which is revealed by capacities of individuals, or groups, to foster, engage in, and sustain positive social relationships and to endure and recover from disasters. Similar to previously identified resilience dimensions, number of themes was also derived under social resilience dimension. Community empowerment is the most noted theme under social resilience. In terms of community empowerment, interviewees highlighted the importance of community engagement and participation, maintaining or re-establishment of community relationships, working with the community, understanding community needs, empowering community and social cohesion. Especially in multi-cultural societies, communities aren’t always engaged or integrated, however after an incident community relationship grow stronger and participate more willingly. Team working is also an important theme identified under social dimension which includes, collaborative working, working with the community, understanding community needs, effective involvement of the community and team working. Communication was classified as a separate theme due to the importance placed by the interviewees on communication. Communication skills are especially required when dealing with disaster-
affected communities, to understand their emotional and psychological conditions and to avoid any further harm. Sometimes it is difficult to convince the vulnerable population to take preventive action due to cost, time and other constraints. As such, good communication skills are of paramount importance to ensure that they understand the risk and act upon to reduce it. Another important theme derived under social dimension is the social and cultural awareness. This incorporated interviewees’ responses such as the importance of the use of local knowledge and skills, use of local businesses for repairs and reconstructions, and selection of approaches suitable to local context. Table 4 highlights all themes derived in relation to social resilience and their relevance to different stages of property life cycle.

Table 4: Themes for social resilience

<table>
<thead>
<tr>
<th>No.</th>
<th>Classifications</th>
<th>Property lifecycle stages</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td>PS</td>
</tr>
<tr>
<td>1</td>
<td>Community empowerment</td>
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</tr>
<tr>
<td>2</td>
<td>Team working</td>
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</tr>
<tr>
<td>3</td>
<td>Communication</td>
<td>x</td>
</tr>
<tr>
<td>4</td>
<td>Social and cultural awareness</td>
<td>x</td>
</tr>
<tr>
<td>5</td>
<td>Building codes, regulations and planning</td>
<td>x</td>
</tr>
<tr>
<td>6</td>
<td>Business continuation management</td>
<td>x</td>
</tr>
<tr>
<td>7</td>
<td>Consultancy services in relation to constructions</td>
<td>x</td>
</tr>
<tr>
<td>8</td>
<td>Damage assessment and claims</td>
<td>x</td>
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<td>9</td>
<td>Resilient buildings and infrastructure</td>
<td>x</td>
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<tr>
<td>10</td>
<td>Disaster management and planning</td>
<td>x</td>
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<td>11</td>
<td>Disaster risk and need assessment</td>
<td>x</td>
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<tr>
<td>12</td>
<td>Emergency shelter management</td>
<td>x</td>
</tr>
<tr>
<td>13</td>
<td>Environmental impact assessment and management</td>
<td>x</td>
</tr>
<tr>
<td>14</td>
<td>Financing, budgeting and estimating</td>
<td>x</td>
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<tr>
<td>15</td>
<td>Health and safety</td>
<td>x</td>
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<tr>
<td>16</td>
<td>Knowledge management</td>
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<tr>
<td>17</td>
<td>Leadership and people management</td>
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<tr>
<td>18</td>
<td>Legal frameworks and compliance</td>
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</tr>
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<td>19</td>
<td>Post project audits</td>
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<td>Process and quality management</td>
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</tr>
<tr>
<td>21</td>
<td>Stakeholder management</td>
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</tr>
<tr>
<td>22</td>
<td>Sustainability and resilience</td>
<td>x</td>
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<tr>
<td>23</td>
<td>Teaching and research on disaster resilience and management</td>
<td>x</td>
</tr>
<tr>
<td>24</td>
<td>Time management</td>
<td>x</td>
</tr>
</tbody>
</table>

4.5 Technological resilience

The final dimension of resilience was about technological resilience. This includes “application of scientific advances including any tool, technique, product, process and method to benefit disaster management” (Seneviratne et al, 2010). In terms of technological resilience, number of themes was identified and this section highlights the key themes identified under this dimension of resilience. The first theme identified was building codes, regulations and planning. This was derived from the sub themes, awareness of property related regulations and policy, knowledge
of construction codes for different properties, knowledge on planning and building regulations and knowledge of planning permissions. In supporting this, one of the interviewees stated, “one of the things that put people and businesses at more risk than anything is permitted developments within flood plains and close to rivers”. Land next to rivers and next to water causes or flood plains are relatively cheaper, however, it is important to influence planners and decision makers to not to allow any developments within flood plains. The next theme identified under this was the resilient buildings and infrastructure. This theme covered a variety of sub themes such as, resilience planning, designing and construction, advice and guidance on design and construction of resilient structures, monitoring and supervising the construction and operation of resilient structures, use of resilient construction processes and techniques, development of resilient transport networks, identifying vulnerable population and properties, understanding impacts of disasters on the built environment, addressing disaster resilience in preparation and design stages, proactive approaches to disaster risk reduction or pre-disaster management, build back better and development of preventive structures and methods. There are so much that can be done to prevent or mitigate disasters, for an example, to manage flood risk, some of the things that can be done are, flood walls, embankments, storage areas and flood gates and vent protection to protect individual properties. Project and construction management is a combination of sub themes such as knowledge and experience of construction technology, knowledge of construction codes for different properties, resource management and monitoring and supervising the construction and operation of resilient structures. Table 5 highlights all themes derived in relation to technological resilience and their relevance to different stages of property life cycle.

Table 5: Themes for technological resilience

<table>
<thead>
<tr>
<th>No.</th>
<th>Classifications</th>
<th>Property lifecycle stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Building codes, regulations and planning</td>
<td>PS</td>
</tr>
<tr>
<td>2</td>
<td>Resilient buildings and infrastructure</td>
<td>x</td>
</tr>
<tr>
<td>3</td>
<td>Project and construction management</td>
<td>x</td>
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<tr>
<td>4</td>
<td>Knowledge management</td>
<td>x</td>
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<tr>
<td>5</td>
<td>Disaster management and planning</td>
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<td>Disaster risk and need assessment</td>
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<td>7</td>
<td>Emergency shelter management</td>
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<td>8</td>
<td>Environmental impact assessment and management</td>
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<td>Materials and resource management</td>
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<tr>
<td>13</td>
<td>Teaching and research on disaster resilience and management</td>
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</tbody>
</table>

5. Conclusions

A number of needs and skills were identified in respect to various resilience factors and property life-cycle stages. Finally, labour market needs and skills with respect to resilience
dimensions across property life stages were filtered to generate a total list of 33 knowledge gaps. 13 (out of 33) gaps emanated from labour market needs and skills under economic resilience with their respective property lifecycle stage. 14 (out of 33) gaps originated from labour market needs and skills under environmental resilience. 22 (out of 33) gaps emanated under institutional resilience. 24 (out of 33) gaps derived under social resilience, and 13 (out of 33) gaps produced under technological resilience. It is evident that more gaps were derived from social resilience, followed by institutional resilience. The paper analysed the knowledge gaps in the construction industry to develop societal resilience to disasters from the perspective of national and local government stakeholders. The paper was based on an EU funded project, CADRE (Collaborative Action towards Disaster Resilience Education) and as part of the project similar studies were conducted to obtain the views of other stakeholders, such as community, private sector, academia and non governmental organisations. Finding of all stakeholders were collated to derive a comprehensive list of knowledge gaps and at the next phase of the research it is expected to validate these findings through stakeholder seminars. Finally, it is intend to develop a professional doctorate to cater the identified knowledge gaps.

6. Acknowledgements

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References


UNISDR (2008) Ingenious knowledge for disaster risk reduction: Good practices and lessons learned from Experience in the Asia Pacific Region, Bangkok, UNISDR.


Built Asset Management Climate Change Adaptation Model

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Abstract

Climate change continues to pose major challenges to those responsible for the management of built assets. Whilst mitigation is largely being driven by legislation and corporate social responsibility, adaptation has to compete alongside general built asset management needs. As such, adaptations to address longer-term building performance issues (such as those posed by climate change) rarely get prioritised above more immediate, short-term needs. However, failure to adapt a built asset to climate change could result in significant premature obsolescence if work is not programmed in a timely fashion. This paper will present the results of a case study of climate change adaptation of UK social housing.

The project reports the results of an in-depth participatory action research project with a London based social landlord to develop and test a 6 stage climate change adaptation framework and risk based model as part of its built asset management strategy. The project developed metrics to analyse the performance of the housing stock against climate change scenarios for current time and 2050. The project also examined the potential (options appraisals and cost/benefit analyses) for a range of adaptation solutions to close the performance gap and developed performance thresholds to prioritise adaptations into long-term built asset management plans. These plans were developed against a range of futures scenarios through interviews and workshops with senior decision-making stakeholders within the social landlord’s organisation. This paper will present the practical results from this study along with a new theoretical model that integrates resilience theory, risk framing and performance management into built asset management (maintenance and refurbishment) planning. The paper will conclude with a 10 step asset management framework that was developed as an aide memoir to guide other social landlords through the climate change adaptation planning process.

Keywords: Adaptation, Built Asset Management, Housing, Risk, Resilience.
1. Introduction

The world’s climate is changing in ways that will have a significant impact on both human society and the built environment (IPCC, 2014a). These changes affect not only average temperature but also results in changed temperature patterns and in particular the severity and frequency of extreme weather events (ibid). Whilst the impact of climate change is different across the world it is urban centres that are likely to be at greatest risk and where action needs to be taken to improve resilience to climate change threats (IPCC, 2014b). To this end actions that accelerate adaptation of the built environment are required (ibid). In particular actions are needed that reduce the vulnerability and improve the resilience of urban systems (e.g. housing, buildings and infrastructure etc.) and provide the governance, policies and incentives to realise adaptive capacity (ibid). This paper reports the development of a built asset climate change adaptation model for social housing in London. The paper supplements a previous publication by Jones et al (2013) where the climate risks to London were discussed and the theoretical base to the risk framework model was presented. This paper provides details of a participatory action research project that integrated the risk framework model with built asset management theory and tested the resulting model against approximately 4000 housing units in London. The paper concludes with a 10 step approach to adaptation planning that should allow Facilities Manager’s to develop built asset management plans to reduce the vulnerability and improve the resilience of their built assets.

2. Background

Whilst in the UK the impact of a changing climate on new buildings can be accommodated through new design standards and planning guidance (CLG, 2007; CLG, 2009; Environment Agency, 2009), the same instruments are not universally applied to existing buildings. As such many existing buildings could be vulnerable to the impacts of climate change, and particularly extreme weather events (EWEs), requiring adaptation if they are to remain viable (Saunders & Phillipson, 2003). Further, in the UK adaptation to climate change is not generally considered part of routine maintenance/refurbishment and it is unclear whether the approaches used by the climate change community (UK climate projections, risk frameworks) can be effectively integrated into built asset management models. These issues are particularly acute in London where it is already apparent that the changing climate could have a significant impact on the ability of existing social housing to provide the quality environment expected by residents (Jones et al, 2013). This poses a problem for many landlords; how do they prioritise adaptation for an uncertain future climate over solutions that improve the immediate quality of their housing stock today?

The EPSRC Community Resilience to Extreme Weather (CREW) project studied the potential impact that a range of extreme weather events could have on the vulnerability, resilience and adaptive capacity of buildings in the SE London Resilience zone (Hallet, 2013). The CREW project used the UKCP09 probabilistic weather files to predict weather patterns across SE London and then superimposed these onto topographical and drainage information to generate extreme weather impact scenarios for 2020 and 2050. The scenarios were then used to investigate the risks
to housing of overheating and flooding and to identify adaptation solutions that could reduce vulnerability and improve resilience. One of the key outputs from the CREW project was a risk based adaptation framework (Fig. 1) that sought to guide facilities managers through the climate change adaptation assessment process. In this framework future scenarios are used to predict the degree of change over current conditions that could occur to a building(s) as a consequence of climate change. For each potential impact a risk assessment is then performed to identify impacts and cost adaptations. These adaptations are then prioritised and integrated into contingency plans (Jones et al, 2013). The application of the adaptation framework forms the background to this project.

Figure 1: Adaptation Framework (Hallett, 2013)

In order to test the applicability of the adaptation framework to inform maintenance and refurbishment plans it needs to be integrated into a performance based built asset management model (Jones and Sharp, 2007) (Fig. 2). The performance model involves: identifying the critical success factors (CSF’s) against which maintenance and refurbishment (including climate change
adaptation) will be judged; establishing a series of performance toolkits that measure the performance-in-use of each property; establishing the underlying cause of any underperformance; developing action statements that describe the required improvements in performance; developing and evaluating adaptation solutions against the organisations CSF’s; and evaluating the success of the adaptations and provide feedback to the organisation’s climate change adaptation policy and strategies. This project developed the tools necessary to achieve this integration. This paper builds on work previously published (Jones et al, 2013) where the background to, and further details of, the factors that affect the vulnerability, resilience and adaptive capacity of UK social housing to climate change can be found.

Figure 2: Performance Based Built Asset Management Model (Jones and Sharp, 2007)

3. Methodology

The focus of the project was a UK Registered Social Landlord (RSL) that owns and manages approximately 4000 homes, located mainly in inner London. The RSL’s property portfolio was extremely diverse, ranging from large modern purpose built blocks, to Victorian street properties. Whilst the RSL owned few whole houses, more than 86% of its stock was made up of maisonettes and flats (the majority the result of the conversion of houses rather than purpose built blocks). Forty six percent of the stock were bedsits or one bedroom properties; 18% were three bedroom properties; and the remaining 3% were four and five bedroom properties. Forty nine percent of the stock was built before 1919; 8% between 1919 and 1944; 22% between 1945 and 1980; and 21% post 1980. A number of the RSL’s properties were Listed Buildings and others were in Conservation Areas. At the time of the project the majority of the stock was in a reasonable state of repair, with the RSL spending approximately £11m per year on maintenance/refurbishment and a further £25m on new build. The RSL had a comprehensive asset management database, including an up to date condition survey of their stock, and had maintenance/refurbishment plans in place for general improvements over a 5, 10 and 30 year period. The RSL also had detailed contingency plans to deal with flooding events. For logistical reasons the fieldwork was limited to a sample of the RSL’s housing, of 1255 properties or 31.46% of their total stock, located in a single London Borough.

A series of facilitated workshops, semi-structured interviews, building surveys of archetype housing units (undertaken by the RSLs consultants using standard UK guidelines), building
simulation models and life cycle costing analyses were used to develop and test a range of practical adaptation planning tools that could be used to integrate climate change adaptation into the built asset management process. The field work for this project took place in 2012/13. Although the project examined both flooding and overheating for the sake of brevity only the flooding results are presented here.

4. Results

The following section describes the process that the participatory action research team went through to integrate the adaptation framework (Fig 1) into the performance based built asset management model (Fig 2).

**Step 1 - Identify Policy/Strategy Drivers:** The first task was to establish the Critical Success Factors (CSFs) against which current and future performance would be judged. This was done through discussion with senior managers and by reference to the RSLs strategic plan and operational documents. The RSLs approach to the quality of their housing was governed by their ‘Performance Standard’ that described expectations for the quality of the stock. Although the Standard didn’t explicitly address the impact that climate change could have on a house it did establish the general principle that:

"Your home should be in good working order and fit for purpose - it should meet a certain set of standards, both inside and outside and in shared and private areas to make it a safe and healthy environment to live in."

The Standard also implied that the RSL would adopt a proactive approach to ensuring that its homes meet the Standard. To this end the ‘Standard’ provided the basis from which CSF’s were derived and against which the success of adaptation solutions would be measured. For flooding these were:

1) Reduce disruption to tenants from flooding events. Performance thresholds to relate to the degree of disruption that a flood event would cause to tenants.
2) To continue to maintain tenant confidence and trust in the RSLs ability to deal with climate change issues. Performance thresholds to be measured through the tenant satisfaction survey.

Once the CSFs had been established a set of performance toolkits were developed to help identify adaptation needs.

**Step 2 - Identify Need:** Toolkit 1 sought to identify those properties that were located in a potential (current and future) flood zone AND were vulnerable to water ingress. This toolkit involved superimposing the RSLs properties onto flood maps using geo-referenced data and a geographical information system to identify those properties that were at potential risk of flooding. Each property was then examined in more detail (using the RSLs asset management database, Google Street View, and external street surveys) to identify the potential for water ingress assuming a 0.5
m flood in the street immediately adjacent to the property. A combination of the potential flood risk and likelihood of water ingress into the property was used to determine the property’s level of vulnerability (Fig. 3).

Toolkit 2 sought to quantify the impact that exposure to a flood would have on the performance-in-use of those properties at risk of such an event. Assessments of the potential impact of flooding events on a sample of those properties identified as highly vulnerable to such an event was used to identify their coping capacity. A combination of the potential damage that a flood event would cause and the recovery time it would take to return the property to its pre-flood performance level was used to categorise the properties coping capacity threshold as Low, Medium or High.

| Likelihood of water ingress to the property / damage to critical infrastructure | Likelihood of a flood event |
|---|---|---|---|---|
| No likelihood | Low | Medium | High |
| No likelihood | Not vulnerable | Not vulnerable | Not vulnerable | Not vulnerable |
| Low | Not vulnerable | Low | Low | Low |
| Medium | Not vulnerable | Low | Medium | Medium |
| High | Not vulnerable | Low | Medium | High |

*Figure 3: Typical vulnerability threshold matrix for flooding*

The vulnerability and coping capacity for each property identified as ‘at risk’ of flooding was plotted onto a Resilience Matrix (Fig. 4). From this figure a number of properties were identified as highly vulnerable with a low coping capacity and these would be prioritized for early action in the asset management plan. Those properties that were highly vulnerable but had a Medium/Low coping capacity would be prioritized as short-medium term action in the asset management plan. Those properties that had a low vulnerability and high coping capacity would be reviewed at regular intervals as more climate change data became available.

**Step 3 - Establish Cause:** Internal surveys of 26 typical properties were undertaken to establish the root cause of flooding damage and to identify potential adaptation solutions. In all cases these solutions were affected by legacy design decisions made when the buildings were newly constructed or underwent major refurbishments.

Adaptation options in the form of resistance (preventing water entering the property) and resilience (increasing speed of recovery once the property has flooded) measures were considered for each surveyed property. From the surveys it was clear that it would be very difficult (if not impossible) to prevent water entering basement flats or basement floors of individual houses. Further, once water had entered the property it was likely to cause significant damage to both building components and fixtures & fittings that would require significant work in order to return the property to a habitable condition. Thus the best adaptation strategy for this type of property would be to let it flood but to improve the resilience of building components (non-structural) and
fixtures & fittings to shorten the time it would take to return the property to a habitable condition. Similar analyses were undertaken for ground floor flats, houses and communal areas and a set adaptation principles (Fig 5) were developed in the form of an Action Statement (Step 4).

![Resilience Matrix](image)

**Figure 4: Generic resilience matrix and specific resilience matrix for flood risk properties**

### Adaptation Guiding Principles

- If it is economically feasible to prevent flood water entering a property then this should be adopted.
- Water resilient components, fixtures and fittings should be installed when flood ingress is likely.
- Ensure all essential services are resistant to a flooding event.
- Work with residents to prepare personal flood action plans.

**Figure 5: Adaptation principles**

**Step 5- Develop Solutions:** The potential (technical and cost/benefit) for a wide range of flood resistance and resilience measures were assessed for each archetype property. A set of triggers and thresholds were developed to allow potential adaptations to be prioritised for inclusion into the built asset management plan. At the strategic level these triggers and thresholds tended to be statements of intent or desire, rather than quantified metrics to instigate an action. These statements of intent were related directly to the RSLs ‘Performance Standard’ and were expressed as commitments for each quadrant of the Impact/Priority Matrix shown in Fig. 4 and summarized in Table 1.

In addition to the generic triggers and thresholds outlined above, specific action should be taken in Year 1 of the adaptation plan to address known, current problems. Where the problems are
known, but the scale is unknown, action should be taken in the first 5 years of the adaptation plan to quantify the scale of the problem. Where there is uncertainty about the potential problem or a solution the situation should be regularly monitored. These thresholds and triggers are summarized in Table 2.

**Table 1: Action trigger/thresholds for flooding adaptations**

<table>
<thead>
<tr>
<th>Resilience Quadrant</th>
<th>Action Trigger/Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Vulnerability / Low Coping Capacity</td>
<td>Take action to improve resistance and/or resilience in the next 5 years.</td>
</tr>
<tr>
<td>High Vulnerability / High Coping Capacity</td>
<td>Take action to improve resistance and/or resilience in years 6 to 10.</td>
</tr>
<tr>
<td>Low Vulnerability / Low Coping Capacity</td>
<td>Take action to improve resistance and/or resilience in years 11 to 30.</td>
</tr>
<tr>
<td>Low Vulnerability / High Coping Capacity</td>
<td>Take no action.</td>
</tr>
</tbody>
</table>

**Step 7 - Adaptation Strategy:** Once all the previous described steps had been completed an adaptation strategy was developed to address the potential impact of flooding both today, and in the future. A typical part of the adaptation plan is shown in Table 3.

**Table 2: Thresholds and triggers for action in an adaptation plan.**

<table>
<thead>
<tr>
<th>Year to Action</th>
<th>Threshold</th>
<th>Trigger</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Know scale of problem and solution</td>
<td>Known level of risk is high</td>
</tr>
<tr>
<td>2-5</td>
<td>Know problem exists but don’t know scale or</td>
<td>Establish level of risk</td>
</tr>
<tr>
<td>6-30</td>
<td>Unsure if problem exists. Don’t have a solution</td>
<td>Continue to monitor risk</td>
</tr>
</tbody>
</table>

**Table 3: Example extracted from the adaptation strategy**

<table>
<thead>
<tr>
<th>Property Type</th>
<th>Vulnerability - FLOODING</th>
<th>Timescale for Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vulnerable Street Houses</td>
<td>Where ever possible floodwater should be prevented from entering the house. Depending on the depth of any water entering the house (will depend on floor level above the street, existence of a basement etc.) resilient fixtures and fittings should be used to ensure that the house can be returned to a habitable condition in the shortest period of time. Undertake detailed surveys of the vulnerable properties identified in this report to identify the flood resistant actions required to prevent water entering the property (including the sealing of air bricks, appropriateness of door dams, non-return valves on drainage and foul water systems etc.). Identify the impact that any floodwater entering the property would have on the post-flood recovery period. These plans should include a detailed assessment of post-flood recovery.</td>
<td>Year 2-5</td>
</tr>
</tbody>
</table>
building works and an estimate of the time to return the house to a habitable (or part habitable) condition.

Assess the potential of resilience measures to reduce the estimated time to return the house to a habitable (or part habitable) condition. In particular examine measures that improve the resilience of essential services, kitchen and bathroom areas. Undertake a more detailed cost/benefit analysis of these measures and implement those that are appropriate when next refurbishment is planned.

Ensure that the RSL is signed up to the environment agency early warning service and develop a communications strategy that informs its residents of an impending flood events and keeps them informed of progress through the clean-up and repair phase.

Engage with the residents living in these houses to ensure that they are as prepared as possible for potential flooding events. Consider providing labour to assist residents in the removal of personal and treasured items to the upper floors of the houses.

Ensure that arrangements are in place with alternative landlords to provide temporary accommodation for those residents displaced by a flood.

### 5. Discussion

This project sought to test the theoretical adaption framework developed through the CREW project by developing a set of tools that could be used to integrate it into a performance based built asset management planning model. Through this process a new 10 step model for adaption planning for future climate change was developed. This model is summarised in Table 4.

<table>
<thead>
<tr>
<th>Step</th>
<th>Actions</th>
</tr>
</thead>
</table>
| 1    | Identify current climate related threats to your stock  
Examine local histories for details of climate related impacts. This could involve reviewing national and local climate risk assessments (e.g. flood maps) and identifying previous extreme weather events that have affected the region where properties are based. |
| 2    | Develop future climate impacts scenarios that are relevant to your circumstances  
Identify future climate impact change predictions for your area. This could include reviewing national climate change assessments where they exist and undertaking absolute climate change assessments where possible. In most cases individual organisations will not have access to the resources necessary to undertake absolute assessments so relative (step-up or morphing) assessments can be used as an alternative to predict the scale of potential future extreme weather events. |

Table 4: Ten step adaption planning model
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Map current and future climate threats to your property portfolio</td>
</tr>
<tr>
<td>4</td>
<td>Identify the coping capacity of your properties to current and future climate threats</td>
</tr>
<tr>
<td>5</td>
<td>Identify possible adaptation solutions</td>
</tr>
</tbody>
</table>
| 6 | Articulate required improvements to the performance of your properties | Identify performance expectations for your properties against each climate change impact. For example,  
  - Let properties flood and ensure rapid recovery; or  
  - Prevent water ingress where ever possible; or  
  - Ensure at least one room in every property does not over heat; etc. |
| 7 | Identify priorities | Develop priority thresholds based on the performance expectations identified in step 6. Identify what types of adaptation should occur in years 1-5; 6-10; and years 11-30? |
| 8 | Develop adaptation strategy | Identify the actions to be taken for each vulnerable property archetype. This could include identifying known problems for immediate action in year 1; gathering missing data (surveys) for high risk properties in years 1-5; and monitor performance of medium risk properties in years 6-30. All other missing data should be collected as a part of the normal re-survey cycle. |
| 9 | Prepare adaptation plan | Identify individual properties requiring action in years 1-5 (steps 3, 4 and 8). This will involve detailed (property level) assessments of the potential for different adaptation solutions identified in step 5 to achieve the performance improvements identified in step 6. Use priority thresholds (step 7) to order adaptation actions. Cost each solution and select appropriate ones for inclusion in the adaptation plan. Develop an adaptation programme for the works over a 5 year period. |
Implement and test plan

Monitor effectiveness of interventions and close the feedback loop. If you experience a climate related event how well did your plans work? If you don’t experience an event then test your plans against a simulation. Review the effectiveness of your Disaster Management and Contingency Plans

Whilst the theories supporting the adaptation framework and the performance based built asset management complemented each other, and at the theoretical level integration was fairly easy to achieve, a number of issues were identified that limited its practical application.

Whist access to public data on past extreme weather events and potential impact of none climate change future events was generally available and suitable to inform step 1 of the adaptation planning model the data required for steps 2 and 3 wasn’t. Whilst UKCP09 climate change projections provided a means of generating future weather patterns the lack of future risk assessments (e.g. future flood risk maps, local heat islands etc.) made it difficult to assess the future vulnerability and resilience of the housing stock. As such the project scenarios were based on possible relative changes to weather impacts rather than absolute risk projections. Whilst these scenarios worked well when introducing the problem and examining the generic vulnerability and resilience of the housing stock (see Jones et al, 2013 for further details), the lack of probability risk factors associated with the different scenarios limited their credibility when trying to prioritise adaptation actions. The lack of projected climate risk data must be addressed if real advances in adaptation planning are to be made.

Whilst the toolkits developed to assess the impact of flooding (and overheating) on a range of archetypal properties worked well, allowing ‘potentially at risk’ properties to be clearly identified and generic adaptation solutions to be evaluated, the level of data required by the toolkits was significantly greater than that which existed within the RSLs built asset management database (step 4). As such re-survey work (internal and external) had to be undertaken to identify the potential impacts that flooding (and overheating) would have on the performance of a range of property archetypes before indicative adaptation solutions could be identified and evaluated (step 5). Going forward the additional data needed for adaptation to climate change should be gathered as part of the routine stock condition survey process.

Whilst the RSL had a clear understanding of its performance criteria through its ‘Performance Standard’ translating this into generic adaptation principles (step 6) and strategic level thresholds that trigger inclusion of an adaptation into their built asset management plans (step 7) was more complicated than had originally been considered. For example the RSL had a number of basement flats that were at risk from pluvial flooding. Whilst the initial approach to adaptation (from the performance standard) was to make these properties resistant to flooding, it became clear through the study that such adaptations would be uneconomical to achieve. As such a compromise threshold was agreed for these properties to allow them to flood but improve their resilience to speed up recovery. Initially the RSL were very concerned that this approach would be interpreted by tenants as a ‘don’t care’ attitude (contrary to the Performance Standard Principles) and as such they added a non-technical adaptation to work closely with tenants in the potentially ‘at risk’ properties to explain how they will support tenants through a flooding event. This included
working with tenants to help them develop personal flood plans; providing support to allow tenants to protect valuable items; and having robust relocation plans in place.

The other problem with setting meaningful priority thresholds (step 7) and developing adaptation plans (steps 8 and 9) was the lack of quantifiable (probabilistic) projected weather impact data and the numerous gaps in building data meant that only the most obvious adaptations were prioritised for action with the vast majority of adaptations being put ‘on hold’ until better information is available or until the future risk became obvious. As such, the adaptation strategy can best be described as cautious and reactionary. This approach is at odds with the need to accelerate adaptation of the existing built environment (IPCC, 2014b).

6. Conclusions

This project sought to integrate a theoretical adaptation framework with a performance based built asset management model to provide an approach by which Facilities Managers could develop short, medium and long term climate change adaptation plans. The project has described how a series of performance toolkits can be used to identify potential impacts of climate change on the performance of a house and how triggers and thresholds based on an organisation’s CSFs can be used to prioritise interventions as part of routine maintenance and refurbishment planning. Although developed for housing the 10 step model should be applicable to most property types.

Whilst the underlying theory and the assessment tools developed in the project worked well, some of the underlying data required to support the tools was lacking or incomplete. As such, working assumptions had to be made that reduced the level of detail and confidence that Facilities Managers had in the final adaptation plans. At the time of this project there was no consistent UK wide data on the future impact that climate change could have on physical performance of the building stock. Most flood maps that were available didn’t accommodate climate change scenarios and, in the case of pluvial flooding, didn’t map future rainfall predictions onto local drainage topology. As such the future flooding scenarios lack the currency associated with existing fluvial flood assessment. Where there are accepted climate change models, organisations asset management databases don’t generally contain the level of building detail required to develop adaptation solutions. Whilst these issues do not undermine the development of the adaptation strategy, they will influence attitudes towards adaptation planning, resulting in a wait and see approach which is at odds with the needs to plan for the implications of climate change. Better national and organisational data sets are needed to address this shortcoming.

Finally, whilst the technical approach described in this paper worked well, it was developed within a mature (in climate change adaptation and mitigation terms) organisation that had previously assessed its vulnerability, resilience and adaptive capacity to respond to potential climate change threats (see Jones et al, 2013). The approach may not be as easy to replicate for organisations who have not gone through this process. Also, it should always be remembered that it is people who are ultimately affected by the impacts of climate change and more work does need to be done to understand the factors that affect an individual’s vulnerability and resilience. In this study no account was taken of vulnerable people living in vulnerable houses.
7. Acknowledgements

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References


IPCC. (2014a) Synthesis Report Summary for Policy makers, (available online

IPCC. (2014b) Climate change 2014, impacts, adaptation and vulnerability, (available online


The Construction Project Manager’s OSH Responsibilities

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Abstract

The role of Project Manager is central to a successful safe and healthy execution of any construction project. While there are specific statutory obligations placed on various duty holders across the entire construction process, from the Client through to the worker, it is a core responsibility of the Project Manager to ensure that the hazards that exist in construction do not present harm to the workers and anyone else affected by the construction activity. There are ample sources of advice and guidance available. The Institution of Civil Engineers works closely with Health and Safety Executive in UK and in Northern Ireland to ensure that the highest possible standards of health and safety are developed, promoted and adhered to. This clearly should come within the ethics reasoning of any professional.

This paper introduces key aspects of safety, health and welfare in construction with particular emphasis on project management. The practice based paper examines how the project managers responsibilities developed under the previous (2007) CDM regulations and how these duties are impacted under the CDM 2015 and the proposed CDM (NI) regulations.

Keywords: Construction Design and Management (CDM), Operation Analysis and Control (OAC), Clients, Designers, Principal Contractors, CDM Coordinators, Health and Safety File

1. Introduction: Principles of Health and Safety

Robens (1972) in his report, presented to Parliament by the Secretary of State for Employment stated that “…the first and perhaps most fundamental defect of the statutory system is simply that there is too much law” and in an attempt to simplify the situation recommended a self-regulating system of safety and health provision, where industry and commerce are encouraged to address their own safety and health issues, supported by a single enabling act and a series of appropriate standards and voluntary codes of practice. Much has happened since then but Robens’ fundamental concept holds true. Self-regulation is crucial to good health and safety management and while the influence of Europe has resulted in the introduction of several regulations since the early 1990s the focus in the UK remains consistent.
The core legal requirement for employers is to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all their employees. The parent law is supplemented by regulations, approved codes of practice and guides that provide specific details on how that duty may be met in regard to particular work operations and industries. Across Europe the basic premise in construction safety legislation is that projects should be designed so that they can be built, used, maintained and demolished in a manner that does not cause harm to the workers or others who come in contact with them and that is the essence of the UK’s Construction (Design and Management) Regulations (CDM). For many years legislators have been intent upon creating the conditions whereby risk in the workplace would be eliminated. However despite the existence of our present laws, the introduction of new laws such as CDM 2015, and the continuing implementation of supplementary regulations and codes of practice, workplace accidents continue to occur unabated, albeit with a decreasing rate of incidence. However it is not the standard of the law that causes accidents in the workplace. The state aims to eliminate workplace accidents and ill health and many safety professionals understand that to be the intent behind risk management. Yet the mistaken notion has grown up around safety that risk management simply means reducing risks to ‘an acceptable level’. This is far from being the intent of legislation since the legal requirement is to secure the health safety and welfare of persons at work through the provision of safe working environments and products. Additional new laws are not needed to control the construction industry, but rather a reexamination of what exists with a view to managing things better. What is needed is a dynamic management model, focused on the elimination of or control of hazards that can produce significant improvements.

Failure to comply with statutory requirements is a criminal matter and the reverse burden of proof placed on a defendant (i.e. the need to prove your innocence), a peculiarity of H&S legislation, emphasises the importance of being able to identify and control hazards throughout the construction process and of being aware of and implementing guidance and good practice (Metherall 2015). This approach is broadly similar across European Union (EU) member states, since much of the present day H&S legislation is derived from EU Directives. A more detailed discussion of H&S law and how it relates to the construction industry is given in the ICE Manual of Health and Safety in Construction (McAleenan and Oloke, 2010).

2. Safer and Healthier Workplaces

It is not just the law that requires that employers and employees have due regard for the potential for harm, inherent in work activities. One of the three paradigms in the Seoul Declaration (ILO et al 2008) refers to the ‘prevention culture’ indicating that “...it needs to be supported and sustained by shaping and implementing OSH policies, strategies and programs fully reflecting preventive measures”. Furthermore the OECD Principles of Corporate Governance state “…boards are expected to take due regard of, and deal fairly with … stakeholder interests, including those of employees, creditors, customers, suppliers and local communities”. Therefore there is a moral, legal and principled obligation to manage construction projects in a manner that will not only prevent harm or injury but also protect others from it and this obligation extends to design quality; that combination of functionality impact and build quality that incorporates the key requirements of all the stakeholders, business and whole-life value in relation maintenance,
management, flexibility, health and safety, sustainability and environmental impact (Office of Government Commerce, 2004).

Many workplaces are safer and healthier today not simply because of legislation but as a result of the efforts of workers, engineers, safety professionals, legislators and philanthropists. However with 2.3 million dying each year because of workplace accidents and ill health (International Labour Organisation (ILO) 2008) it cannot be asserted that work in general has become safer. There is still a way to go. It is now common in safer workplaces for risk and hazard assessment to be part of good work practices. Metherall (2015) stated that what matters “…is that construction work is organised and done safely” and it is here where the role and the focus of the Project Manager needs to dominate. Knowledge and understanding of the safety legal framework is secondary but that knowledge can help identify what steps must be taken. Metherall (2015) further indicated that the legal framework based on self regulation rather than prescription, has a tiered approach moving from the general obligation in the Health and Safety at Work Act 1974 (Health and Safety at Work (Northern Ireland) Order 1978) to provide and maintain plant and systems of work that are (so far as is reasonably practicable) safe and without risks to health, through to regulations, then to Approved Codes of Practice (ACoPs) and Guidance and finally to the development of good practice.

It is true that construction sites are hazardous environments, with high consequences should control measures be omitted or fail. The Health and Safety Executive (HSE) recognise the main causes of harm in construction as; falls from heights (33% of construction industry injuries), struck by object (13%), and slip, trips and falls (27%), (HSE 2015a, 2015b). Additionally there are health issues such as exposure to harmful agents (such as asbestos and silica), vibration, noise and manual handling (HSE 2015a). Gibb (2015) describes occupational health (OH) as “the poor relation of occupational safety” and goes on to describe OH as “a slow accident”. Ill health continues to kill and disable significant numbers of construction workers and the delay in the outworking of the effects is one of the main reasons why the subject must be taken seriously. The major point of concern is that Project Managers are less clear in their understanding of their role regarding the prevention of ill health than they are about safety and this has got to be corrected. Gibb (2015) describes in great detail the various OH issues and the actions that designers and project planners can take to eliminate or reduce ill health effects from the construction process. But the existence of hazards does not make the industry dangerous. There needs to be a negative act or omission before the harm is realised. Every incident represents a loss of control of the work operation. Whether that loss of control can be attributed to the individual worker, or to a Project Manager, at the highest levels of the planning and design stage of the project is not so important as establishing how and why it happened and putting plans in motion to ensure that there isn’t a recurrence.

The normal understanding of the word accident is referring to something specific that was unforeseen, unpredictable and/ or an unusual occurrence with no apparent cause. In construction where a Project Manager has a sound and thorough knowledge of the site, the project and the construction processes involved and having analysed the range of operations, identified the hazards and established the necessary controls it is not acceptable to contemplate unusual
incidents with no apparent cause. At this point it is worth establishing that accidents don’t just happen, rather they are the result of failures in the control process and that should never happen in a well managed project. But Projects Managers cannot deliver a safe and healthy project in isolation, it requires a team effort where they, their site supervisors and the workers control and influence safe and healthy progress, each according to their level of competence and authority, (Maharaj et al 2012, Postman and McArthur 2015).

3. Health and Safety Roles and Responsibilities

3.1. Health and Safety Executive

Great Britain and Northern Ireland’s Health and Safety Executives are each “…an independent prosecuting authority who take action against those who put workers at risk of death, illness or injury” (HSE 2010). Among other things they:

- Advise on legislation,
- Produce approved codes of practice and guidance,
- Regulate and enforce compliance with health and safety legislation,
- Investigate workplace fatality, injury and illness incidents,
- Maintain workplace fatality, injury and illness statistics, and
- Carry out appropriate scientific research

3.2. Project Managers

Lingard and Rowlinson (2005) identified construction as a project-based industry and discussed the need for an appropriate structure to deal with the changing nature of the project. As it moves “…from design to construction to in-use phases, and as problems arise there is a need for rapid, decentralised decision-making, contingency planning and an appropriate, organic form of organisation”. This engenders a free, independent spirit among construction site personnel and here Lingard and Rowlinson (2005) caution that this freedom could lead to “a disregard for authority and regulations”. Such a warning is one that a Project Manager needs to be clear about since he gives both safety guidance and direction in the construction phase of any project. The lessons learned from safety failures in Nuclear Newbuild (e.g. Flamanville 3 NNB in Maharaj et al 2012) post to the need to establish project teams and high calibre managerial and engineering people … and led by a person with the authority to act, (Maharaj et al, 2012). The attitudes and behaviours displayed on construction sites are largely down to the drive and determination of the Project Manager to get the job done well and done safely. Project Managers are key to ensuring that corporate safety and health strategies are delivered at the site level and the culture is one of caring and support for the entire workforce. Therefore where accidents or incidents occur it is
crucial that the safety health and welfare of the workers are uppermost in the considerations of the entire management structure, with work progress coming in behind, at a judicious interval.

### 3.3. CDM Roles

The CDM regulations define the roles and responsibilities of some, not all of the players in construction projects. In the legislation Clients, Designers, Contractors, Workers (and in Northern Ireland, CDM Coordinators) are all given specific legal duties. A short synopsis follows;

### 3.4. Clients

Clients are required to assess the competence of those they engage to execute a construction project, provide designers and contractors with pre-construction health and safety information (the information that will assist in determining inherently safer design solutions and construction phase safe working methods and resources), ensure that appropriate project health and safety management arrangements are in place before projects commence and where projects are notifiable (longer than 30 days or more than 500 person days of construction work) appoint a Principal Contractor and a CDM Coordinator.

### 3.5. Principal Designers

A principal designer must plan, manage, monitor and coordinate the pre-construction phase of a project, taking into account the general principles of prevention to ensure that the project progresses without risks to health and safety. The PD must ensure that appropriate assistance is provided to the client in the preparation of pre-construction safety information that includes the identification and elimination or control of hazards likely to effect workers carrying out the construction phase. The PD has the additional duties to ensure the cooperation of all persons working on the project and to ensure that the designers are aware of and are complying with their duties under the regulations, this includes an on-going liaison with the Principal Contractor for the duration of the project.

### 3.6. Designers

Designers are required to check that project clients are aware of their CDM statutory obligations, be satisfied that they have the competence to undertake the design, consider the pre-construction information and design the project in a manner that it can be built, used maintained and eventually demolished without causing harm to workers or other affected by the structure or building.

### 3.7. Principal Contractor

The principal contractor is the Project Manager for the construction project and as such is required to plan, manage and monitor the construction phase to ensure that health and safety is appropriately delivered throughout. There can only be one principal contractor therefore ensuring that the other contractors and the workforce are engaging with and coordinating their project
health and safety activities are his responsibility. The Project Manager, on behalf of the principal contractor should ensure that the construction phase plan is followed and that any information required for the Health and Safety File is collected and made available before the project hand-over. HSE (2010) describes the Health and Safety File as follows;

“...the file will contain information necessary for future construction, maintenance, refurbishment or demolition to be carried out safely, and is retained by the client or any future owner of the property. (Where a client gets non-notifiable work done, and a health and safety file already exists for the premises, it should be updated if necessary). The file should be a useful and valuable document for the client”.

3.8.CDM Coordinator (NI only at the date of writing)

The CDM Coordinator is appointed where projects are notifiable. Their primary role is to give advice and assistance to Clients. Additionally they are to ensure that health and safety has been adequately addressed in the design phase, collect pre-construction information to be made available to the principal contractor and where there is more than one designer they are to check that they are cooperating and coordinating their design information. They do not have a role in site management and during the construction phase their involvement is limited to collection of information for the Health and Safety File and ensuring health and safety is considered, should any redesign take place.

Health and Safety Executive (2007) and Oloke (2010) describe the CDM roles in greater detail.

4.Effective Project Management

Effective project management is concerned with controlling the operation, the process and/or the system in order to achieve its objectives. The extent to which it succeeds is directly linked to the degree of management effectiveness, which must be focussed on the outcomes rather than simply the processes and methodologies. It must recognise and respond appropriately to factors that impinge upon the outcomes and ensure that the desired outcomes are attained and the principal that management is solely concerned with outcomes falls short if the outcomes are defined purely in terms of product. They must be defined in the wider quality assurance terms that include quality of product, cost effectiveness of production, health, safety and welfare of and appropriate remuneration for workers, safety of customers, sustainability and organisational profitability. The correct activities are those that control the operation properly to achieve the right outcomes. However, where risk exists, control is weakened because risk means that there is a possibility that harm may result; in essence risk exists where there is ignorance of (or choosing to ignore) some or all of the facts and it isn’t known with absolute certainty whether the operation will succeed or fail. Every action will therefore have an outcome that is either desired or undesired and a managed operation is one in which all of the hazards have been considered and the controls have been put in place so that the operation itself is free from risk. By effectively managing the operation,
Whereas ‘risk’ is a subjective measure of the possibility of danger being realised, management is the authoritative control of operations, a critical aspect of the Project Manager’s responsibilities. The purpose behind the Operation Analysis and Control (OAC) model (McAleenan and Oloke, 2015) is to ensure that work operations are carried out in strict accordance with all relevant ‘safe working’ procedures. In this way, with high quality planning and implementation you can make sure that people, plant and property are protected from harm prior to, during and after the work operation, regardless of the nature of the hazards faced. Planning any project without reference to the safety requirements means that the project will fail, certainly and, often, spectacularly. Effective management requires that safety is considered as an integral aspect of the project, central to and fully integrated with the project objectives. What a good planning process delivers is consideration of the objectives as well as the means and the methods of achieving them. All elements of the project and every eventuality are considered, in advance and appropriate actions developed and scheduled. Anything that is left out, by accident or by design exposes the project and the company to risk and consequently the likelihood of an undesirable outcome. It is here where the twin survival objectives come strongly to the fore, that is; where workers safety (survival of the individual) and company profitability (survival of the company) co-exists (McAleenan and McAleenan 2010).

In defining the outcomes, and all the relevant considerations the OAC approach requires the identification of the principal actors necessary for the establishment, development and successful achievement of the project. The competence and expertise of a wide range of personnel are needed to input to the various aspects of the project, to establish the parameters of what is achievable within the constraints of finance, engineering & technical capabilities, environmental management, and human interaction before, during and after the project. There will be contradictions between the demands of the various elements that will require expertise to not only resolve them effectively, but to identify and define them in the first instance. The health and safety input will not be derived solely from Health and Safety professionals, but must also come from experienced and competent managers and supervisors, engineers, specialist experts and of course the workers and their representatives. Effective management and operation analysis and control require that those involved in the project will have a contribution to make to the elimination or control of hazards and this applies equally where a client engages a contractor. The client needs to ensure that all relevant H&S information is made available to the contractor and that time and resources have been suitably budgeted for. Similarly the contractor must demonstrate competence to carry out the work; such competence extends to having adequate funds, time and other necessary resources.
5. Discussion, Risk assessment – Process or Product?

In 1997 a NI government agency began the process of implementing the OAC approach to safety management, the underpinning assumption being that every work operation that was not fully controlled was heading for failure, whether in reduced quality or output, plant failure or worker injury. Their approach re-integrated H&S into the process, into individual competence and also required co-operative effort between all the various departments in order to achieve successful production. Crucially OAC took into consideration worker competence, recognising that the competent worker is one who is fully aware of the hazards and the H&S issues within their own sphere of competence and who is capable of assessing and making appropriate decisions with regard to their work activities. This shifted decision-making and control of work operations back into the hands of the worker and the competent team. Superfluous decision makers were removed from the process and those who were left co-operated in the achievement of the objectives, e.g. the production department determined the outputs, engineering the competency requirements, human resources recruited and trained competent workers, finance ensured that the activities were adequately resourced and the operational team determined the requirements of and carried out the work operation, (McAleenan and Oloké, 2015).

The risk assessment approach is not without its critics and opponents. The pre-2010 UK Government established a parliamentary committee (WPC 2008) to look into the problems caused by the risk assessment approach, particularly that aspect that led to the profusion of paper based assessments that workers seldom read much less adhered to, and also the claim that ridiculous decisions were being made, (e.g. councils banning hanging flower baskets for fear that they will fall on the heads of pedestrians). In his submission to the Work and Pensions Parliamentary Committee McAleenan (2008) identified that the risk-averse culture prevalent in Great Britain, stemmed from a misinterpretation of the statutory requirements, which had never been corrected. Now the 2010-2015 government, following a review by Lord Young (2010) to see if the H&S legislation is the cause of such nonsensical decisions appointed Professor Lofstedt to consider what changes may be made to the legislation to reduce the burden on employers (Löffstedt 2011). It is worthy of note that the now defunct CDM ACoP was ahead of such reviews when it stated “…paperwork which adds little to the management of risk is a waste of effort, and can be a dangerous distraction from the real business of risk reduction and management” (HSE 2007).

Some employers see the safety component of work as an additional cost, which can be jettisoned when business is suffering as a result of local or global economic downturn. This unfortunate situation occurs when H&S is perceived as an adjunct to rather than an integral aspect of worker competence. The defunct CDM ACoP (HSE 2007) held that the integration of health and safety into the management of the project is the key aim of the regulations. At the launch of the Seoul Declaration (ILO et al 2008) a number of the platform speakers and signatories highlighted this very point, namely that globalisation and (at that time) the looming economic crisis has serious negative consequences for the health, safety and welfare of workers. The negative health effects of the economic climates since 2008 has impacted most severely on psychosocial risks with mental ill health increasing throughout that period, (van Stolk et al, 2012). (In discussing risk averse companies and the potential consequences McAleenan and McAleenan (2010) introduced
the concept of calculating a safe flight distance (Dawkins 2009) or the point at which it is safe to commence the work activity to health and safety, stating that:

“The risk-averse company faces extinction in the marketplace and for the company that ignores risk, their extinction comes at the hands of the courts. The successful company survives because it has evolved a balanced dynamic between productivity and hazard control in which the twin objectives of worker safety (survival of the individual) and profitability (survival of the company) co-exists ”.

Greenman, Fire Engineering instructor, Bates College, Tacoma, USA in a private correspondence with the authors (2010) commented that workers tend to think only in terms of food on the table, management on profits and so each forgets that their goals are dependent on each other’s. The calculation of the flight distance must aim to achieve both worker’s and manager’s objectives, recognising that an acceptable risk is one that does not conflict with either, (Figure 1).

Figure 1: Calculating your Flight Distance (McAleenan and McAleenan, 2010)
6. Conclusions

Orr (ICE Past President, 2007-08) issued one strong piece of advice (in: McAleenan and Oloke, 2010), which is echoed by all of the construction professionals who contribute to the ICE’s body of health and safety expertise and specifically the Expert Panel on Health and Safety. As construction professionals we all have core values and an ethical position that demands we have a sound knowledge of health and safety within our chosen field of construction and maintain a high regard for the consequences of our professional activities on the safety of workers and others affected by our work, which means;

- Working with integrity;
- Tackling only the work we are competent to do;
- Acting always in the public interest; and
- Continually developing our knowledge.

Project Managers following these principles can ensure that health, safety and welfare is at the heart of everything that is done on a construction project.

References


Health and Safety Executive (2015a) Health and Safety Statistics, Annual Report for Great Britain. HSE, UK,

Health and Safety Executive (2015b) Health and safety in construction sector in Great Britain, 2014/15, HSE, UK


Investigating the Electrical and Mechanical Safety in Construction

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Abstract

Electrical and Mechanical (E&M) installations are indispensable to any construction projects. In the light of number of workers and companies involved, E&M works play an important role in the construction industry. The objectives of this study are to reveal causes of accidents of E&M works and provide recommendations to improve safety and health of E&M practitioners. A systematic approach with multidisciplinary inputs will lead to the formulation of a series of holistic and practical measures. An investigation in “WiseNews”, a comprehensive newspaper search engine, shows that there were at least 60 E&M works related fatal cases between 1998 and 2014 in Hong Kong. Fatalities due to fall of person from height and contact with electricity account for over 70 % of all occupational fatalities in electrical and mechanical installations. The study also found that the proportion of occupational fatalities due to fall of person from height is occurred more frequently in air-conditioning installation trade. Focus group meetings with frontline workers and experts will identify the root causes of the E&M accidents. Structured interviews will solicit views of different stakeholders to formulate safety preventive measures. NVivo, which is a software package that supports qualitative and mixed methods research will be used to analyse the qualitative data obtained from the interviews. A questionnaire survey will validate and prioritize the causes of accidents and strategies for improving E&M safety. The proposed study will be useful in improving the safety performance of E&M practitioners in Hong Kong.

Keywords: Electrical and Mechanical, Safety, Electrocution, Fall of person from height

1. Introduction

Electrical and mechanical (E&M) installations are significant to most construction projects regardless of new construction works or repair, maintenance, alteration and addition (RMAA) works. E&M works consist of various specialist trades such as fire services installation, electrical wiring, plumbing and drainage, air-conditioning installation, and lift and escalator installation. With the presence of ageing buildings which lack of proper maintenance, the deterioration of fire services, water pipes and electrical wiring in old buildings commonly occurs. To uphold the ageing building stock properly and enhance public safety in a sustainable way, the Hong Kong SAR government has initiated the
Mandatory Building Inspection Scheme (MBIS) in 2012 to inspect and repair these ageing buildings on a regular basis. Around 2,000 target buildings would be selected by the government for inspection and for owners to carry out corresponding repair and maintenance works each year. The scope of inspection is not only limited to the structural elements of buildings, but also the fire safety elements and drainage system. Thus, it is expected that the volume of E&M RMAA works will continue to increase.

E&M installation involves a considerable number of workers. As shown in Table 1, the number of persons directly engaged in “building services installation and maintenance activities” in 2013 was 73,165, accounting for nearly 40% of the number of persons directly engaged in “all construction activities” (n=185,773) (Census and Statistics Department, 2014). The data are also plotted as illustrated in Figure 1. Statistics of number of persons directly engaged in building services installation from 2007 to 2013 also show that the employment of E&M workers has continued in an upward trend (Figure 1). The number of “building services installation and maintenance activities” establishments in 2013 was 7,075, accounting for 32% of the number of establishments of “all construction activities” (n=22,312) (Census and Statistics Department, 2014). The gross value of construction works performed (HK$'000) increased by 17% from 236,926 in 2012 to 278,175 in 2013 whereas the gross value of building services installation works (HK$'000) expanded by 25% from 50,567 in 2012 to 63,089 in 2013 (US$1=HK$7.8). The importance of E&M works to the construction industry of Hong Kong is expected to increase further.
Table 1. Statistics for building services installation activities in Hong Kong (Census and Statistics Department, 2014)

<table>
<thead>
<tr>
<th>Industry /Group</th>
<th>Year</th>
<th>Number of establishments</th>
<th>Number of persons directly engaged</th>
<th>Gross value of construction works performed (HK$'000) (US$ 1 = HK$ 7.8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building services installation (including New works and RMAA activities)</td>
<td>2013</td>
<td>7,075</td>
<td>73,165</td>
<td>63,089</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>7,282 (-10.1%)</td>
<td>73,828 (+1.9%)</td>
<td>50,567,303 (-6.2%)</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>8,096 (+16.1%)</td>
<td>72,434 (+37.5%)</td>
<td>53,916,770 (+36.2%)</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>6,976 (-13.7%)</td>
<td>52,664 (+10.1%)</td>
<td>39,595,569 (+11.9%)</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>8,082 (-8.0%)</td>
<td>47,839 (-14.7%)</td>
<td>35,395,071 (-14.7%)</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>8,788 (+25.8%)</td>
<td>56,107 (+40.0%)</td>
<td>41,489,497 (+31.4%)</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>6,985</td>
<td>40,079</td>
<td>31,577,350</td>
</tr>
<tr>
<td>All construction activities (including New works and RMAA activities)</td>
<td>2013</td>
<td>22,312</td>
<td>185,773</td>
<td>278,175</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>22,309 (-4.7%)</td>
<td>184,563 (+8.3%)</td>
<td>236,926,550 (+10.2%)</td>
</tr>
<tr>
<td></td>
<td>2011</td>
<td>23,417 (+14.2%)</td>
<td>170,345 (+15.9%)</td>
<td>214,976,995 (+19.5%)</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>20,506 (+1.4%)</td>
<td>146,958 (+8.7%)</td>
<td>179,836,843 (+15.2%)</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>20,216 (+0.6%)</td>
<td>135,254 (-0.5%)</td>
<td>156,068,485 (-5.1%)</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>20,100 (+3.6%)</td>
<td>135,990 (+19.0%)</td>
<td>164,376,972 (+15.7%)</td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>19,399</td>
<td>114,294</td>
<td>142,035,628</td>
</tr>
</tbody>
</table>

Figure 1. Number of persons directly engaged in construction activities and building services installation in Hong Kong (Census and Statistics Department, 2014)
2. Research Aim and Objectives
Safety issues of E&M works are critical in the construction industry because of the hazardous work nature, tight working schedule and complexity of work. Previous statistics have manifested that falls of person from height and electrocution are the top two killers on E&M works in Hong Kong. There are some detailed analyses of construction fatalities on fall accidents (Huang and Hinze, 2003; Chi et al., 2005; Chan et al., 2008; Hon and Chan, 2013), struck-by fatalities (Hinze et al., 2005), electrocution (Janicak, 2008; Chi et al., 2009) and crane related fatalities (Beavers et al., 2006; Tam and Fung, 2011) etc. Safety research focusing on E&M work installations has been scant. It has not received sufficient attention. The proposed research aims to reveal the causes of accidents on E&M works and provide recommendations to improve the safety and health of E&M practitioners, particularly for those two accident types. To achieve the research aim, four specific research objectives were set out as follows.

1. To understand the general practice and procedures in E&M installation.
2. To determine the causes of E&M accidents.
3. To identify effective measures to be implemented in order to reduce E&M accidents on construction sites.
4. To give recommendations to various stakeholders to enhance E&M installation safety.

3. Significance and Value of Research
The Hong Kong Federation of Electrical and Mechanical Contractors Limited (HKFEMC) which is a sizeable E&M works trade association, has long identified safety a key issue to address (Lam, 2006). HKFEMC has expressed serious concerns for safety of their member practitioners in different occasions. The safety of E&M works has not been given enough attention it deserves. Some hazards associated with E&M works are identified in activities that involve working at height, electricity, lifting, and lift or escalator machinery. Most of the maintenance activities for air-conditioning and plumbing & drainage need to be carried out at height outside the external wall of a building. This greatly increases the likelihood of fall of person from height. Moreover, there are some risks, like electrocution perhaps is significant at E&M works. The study will provide insights to root causes of both fatal and non-fatal accidents of E&M works. The overall aim is to investigate the major causes of E&M works related accidents and recommend a series of practical and holistic measures to reduce them. It is important to upkeep construction workers’ safety and health. Improvement in the safety of E&M works will benefit not only the practitioners themselves but the industry as a whole.
4. Research Methods

A mix of qualitative and quantitative research methodology has been employed in this project. The whole research process comprises seven key stages: (1) literature review, (2) focus group meetings, (3) case studies, (4) structured face-to-face interviews, (5) questionnaire survey, (6) data analysis and (7) validation of the results. The research framework for the proposed study is shown in Figure 2.

![Research Framework Diagram]

**Figure 2. Flow of the Overall Research Framework**

5. Research Progress and Preliminary Findings

*Literature review*

The research project began with a comprehensive review on general practice and safety procedures in E&M installation and common causes of E&M works related accident and safety research on E&M works from academic journals, industry report, research monographs, guidance notes, and newspaper, etc. An extensive review of related ordinance, code of practice, safety working guidelines from six government departments or organizations including the Construction Industry Council (CIC), Labour
Dep
artment, Occupational Safety and Health Council (OSHC), Buildings Department (BD), Hong Kong Housing Authority (HKHA) and Electrical and Mechanical Services Department (EMSD) has been launched to capture common types of E&M accidents, major causes of E&M accidents and recommendations on E&M works.

Accident statistical data in Hong Kong will be collected from government departments (including the Architectural Services Department, Census and Statistics Department and the Labour Department) and the volume, nature and the patterns of E&M works related accidents will be examined. The review will focus on safety problems and good practices of E&M installations which will form the foundation for the whole research.

**Focus Group Meetings**

Two focus group meetings were conducted with (1) trade unions’ representatives and frontline tradesmen, and (2) representatives from the Hong Kong Federation of Electrical and Mechanical Contractors Limited (FEMC) in October and December 2014 respectively. It aims to examine the safety problems and the major causes of accidents. Focus group meetings are considered a convenient and effective way of collecting a large amount of information supplementing the traditional one-to-one interview (Haslam, 2003) because it generates synergism and stimulation among attendants (Vaughn et al., 1996). Their expertise has been drawn upon to give comments on safety issues on E&M works, to indicate the root causes of E&M accidents from their practical experience and contribute to the formulation of preventive strategies and measures. Focus group meetings provided a general picture of the safety problems of E&M works and also helped in developing templates for structured interviews and questionnaire surveys.

**Case Studies**

Both fatal and non-fatal E&M accidents will be retrieved and reviewed. Information on fatal cases will be solicited from relevant government departments and further supplemented by the “WiseNews” newspaper archive which is an electronic search engine containing key local newspaper clippings (Hon and Chan, 2013). These cases will be categorized according to characteristics and features. Key categories may include (1) year and month of accidents; (2) location of accidents; (3) type of work involved; (4) trade of work involved; (5) type of accidents; and (6) any other special features. Fatal cases collected from various sources will be triangulated and cross-referenced to ensure accuracy and reliability of the raw data. The study requires support of the industry. Sources of non-fatal accident cases for analysis could be obtained from member contractors of the Hong Kong Federation of Electrical and Mechanical Contractors Limited (HKFEMC), the Electrical and Mechanical Services Department (EMSD), the Architectural Services Department (ArchSD), and the Hong Kong Housing Authority, etc. Root causes of E&M fatal and non-fatal accidents will be identified respectively.
As official accident statistics on E&M works are not readily available in the public domain, an extensive search in “WiseNews”, which is an electronic database of local newspapers in Hong Kong, was conducted. The results show that there were at least 60 E&M works related fatal cases between 1998 and 2014 in Hong Kong. Approximately two-thirds of the 60 fatal cases were related to RMAA works. There were 39 E&M works related accident cases occurred in RMAA works which far outweighed that of new construction works (n=21). Fatalities due to fall of person from height and contact with electricity account for over 75% of all occupational fatalities in the electrical and mechanical industry. Among various E&M trades, air-conditioning installation is the most common trades leading to fatality. This trade accounted for a total of 33% of all E&M works related fatal cases (Figure 3). This may be due to the fact that air-conditioning works extensively involve working at height outside the external wall. This greatly increases the likelihood of fall accidents.

With the consent of the Coroner's Court, 13 case files of E&M fatalities between January 2010 and July 2013 have been collected for detail analysis. Each case file include information on police investigation files, coroner's death investigation reports, fatal accident reports by the Labour Department, autopsy reports and medical reports. The advantages of referring to the coroner’s reports are that the data is highly reliable for revealing the real causes behind an accident.
Structured interviews

Ten structured interviews have been conducted with key trades of E&M installations, including air-conditioning, fire services, plumbing, and electrical works. Interviewees include representatives from the government, quasi-government organizations, professional institutes, contractors’ associations, and trade unions. Interview questions are compiled based on the literature review and also the results of the focus group meetings. It designed to identify the causes leading to common E&M accidents and strategies for improving safety of E&M work practitioners. The interviews results has been transcribed, coded and analysed in NVivo, a software system for analysing qualitative data. Mixed methods research qualitative data will similarly be collected, organized and analysed (Creswell, 2009). Basically, common interview narrative subjects and similar semantic meanings are first coded in individual category. After that, each identified category will then be compared with other categories and repeat this coding process for refinements to better arrive at distinct categorization.

Based on the ten structured interviews of E&M works practitioners, fall from height and electrocution have been identified as the top two killers in both new and repair, maintenance, alteration and addition (RMAA) E&M works in Hong Kong. The major causes of new E&M works and RMAA works are “Compressed working schedule & long working hours” and “Lack of facilities for safe access or improper design for maintenance” respectively.

Questionnaire survey

A questionnaire survey will be designed based on literature and findings from the case studies and
structured interviews. The previous qualitative interviews can be used as an exploratory step before designing the questionnaire survey form. Respondents will be requested to prioritize the causes of E&M accidents and importance of recommendations for enhancing E&M works safety. About 200 number of completed questionnaires will be targeted to facilitate quantitative statistical analyses. Questionnaires will be dispatched via industry forum and presentations. The advantages of conducting questionnaire survey in this way are that respondents can get immediate assistance from investigators of the proposed studies and thus improving quality of their responses. Also, respondents attending the industry forum have interests in E&M safety. They are more likely to give reliable and informed responses based on their working experience and expertise.

**Data analysis**

An Excel template with predetermined categories will be decided for the analysis of case studies (Hon and Chan, 2013). The cases will be coded in the EXCEL template and analysed with SPSS. Descriptive statistics will be utilized in analysing accident records pattern. Key coded variables include year of accident, month of accident, type of accident and trade of E&M works etc. Some fatal and non-fatal accident cases will be selected for detailed analysed. Cluster analysis will be employed to classify types of E&M fatal and non-fatal accidents respectively (SPSS, 2001; Hon and Chan, 2013).

Descriptive statistics and multivariate statistics will be used for analysing questionnaire data using Statistical Packages for Social Science (SPSS). Kendall’s coefficient of concordance (W) will be adopted to measure the levels of agreement of experts (Siegel and Castellan, 1988). Spearman’s rho correlation (Norušis, 2008) will be calculated to assess the degree of correlation among the opinions expressed by groups of experts. The Kruskal-Wallis Test, which is regarded as a non-parametric test will be conducted to decide whether three or more independent groups are from distinct populations.

6. **Conclusions**

Hong Kong is a populous city with a multitude of ageing and deteriorated buildings. It is crucial to inspect and repair these buildings on a regular basis. E&M installations involve a considerable proportion of all practitioners in the RMAA sector. Repair and maintenance of air conditioning systems and water pipes are highly related to working at height. Fall injuries frequently happen when using ladders and majority of the injured workers are unskilled labourers working on a temporary basis. Electrocution is also a major type of E&M related accident. A person who has been electrocuted may be severely injured or even die. This research project provides an overview of E&M works related accidents in Hong Kong, identify underlying causes of accidents and practical recommendations through a series of research tools including focus group meetings, cases studies, structured interviews and questionnaire survey. The project has begun for about a year and is still
ongoing. Case analysis, focus group meetings and interviews have largely been completed. The next step is to collect holistic opinions from E&M works practitioners by questionnaire for improving safety performance of the E&M industry.

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References


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Evaluating the Safety Awareness and Behaviour of Construction Practitioners in Hong Kong

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Abstract

In Hong Kong, safety performance of the construction industry has substantially improved since the late 90s. However, this improvement in terms of accident rate and fatality number has slowed down and reached a plateau after 2006. The purpose of this study is to evaluate the safety awareness and behaviour of construction practitioners at various levels. Construction practitioners were classified into five levels as CEO, project management team, supervisors/foremen, trade-specific foremen, and frontline workers based on their different roles in construction site safety. Semi-structured interviews were conducted to assess the safety awareness and behaviour of CEO, project management team, and supervisors/foremen. Questionnaire survey was conducted to assess the safety awareness and behaviour of trade-specific foremen and frontline workers. A total of 280 construction practitioners participated in this survey, including 6 CEOs, 6 project management team leaders, 8 supervisors/foremen, 28 trade-specific foremen, and 232 frontline workers. It was found that construction practitioners across different levels possessed a satisfactory level of awareness and behaviour on safety with those at the frontline level having a comparatively lower score for safety awareness and behaviour. It is recommended that training, instructions, and remarks should be given for safety improvement at various levels.

Keywords: construction industry, Hong Kong, safety awareness, safety behaviour, safety culture

1. Introduction

Construction is a large, complex, and dynamic sector that generates employment for millions of people worldwide. However, this sector has high number of fatalities and non-fatal occupational injuries and illnesses (Hoonakker et al. 2005). Improving site safety is a top priority for construction companies throughout the world (Choudhry et al., 2007). Having a mature and positive safety culture is becoming crucially important to facilitate safety improvement (Choudhry et al., 2007).

The construction industry is one of the economic pillars which contributes about 4.0% of Gross Domestic Product (Census and Statistics Department, 2015) and 8.2% of total working population in Hong Kong (Labour Department, 2015). According to the occupational safety and
health statistics of 2013, there were a total of 3,232 industrial accidents from the construction industry, 2.3 per cent up when compared to 3,160 in 2012 (Labour Department, 2014). Furthermore, the safety performance of the construction industry in Hong Kong lags behind as compared with nearby Asian cities, such as Singapore. The accident rate per 1,000 construction workers in Hong Kong was 41.9 in 2014 whereas the accident rate per 1,000 construction workers in Singapore for major injuries and minor injuries were 0.41 and 5.20 respectively (Legislative Council 2015). Although the Hong Kong SAR (Special Administrative Region, China) government has stipulated construction related safety and health legislation to reduce the accident and fatality rate, there are still a lot of rooms for improvement. Cultivating a good organizational safety culture is considered to be an effective way for further improvement (Zou 2011).

Safety culture is shaped by people working together in organizational structures and by social relationships in the workplace. It is recognized that leadership is important in the creation of a culture that supports and promotes a strong health and safety performance of an organization. Leaders play a key role in the creation of safety climate, which in turn influences workers to increase their safety behaviours, thereby decreasing their accidents and injuries (Hoffmeister et al., 2014). Managers and/or the team leaders are vital in inspiring employees to a higher level of safety and productivity, which means that they must apply good leadership attributes on a daily basis (Flynn and Shaw, 2010).

In Hong Kong, an annual Construction Safety Week (CSW) is organised by the Development Bureau (DevB) and the Construction Industry Council (CIC) to promote health and safety to all stakeholders of the construction industry. As one of the key initiatives of the CSW, the organizers commissioned the authors to undertake a research study to investigate and further enhance the safety awareness amongst the key stakeholders of the construction industry. The objectives of the study included: (a) classify the practitioners of the construction industry into a number of levels based on their different roles in construction site safety; (b) establish guidelines to enable the practitioners to become safety leaders in their corresponding levels; (c) monitor/gauge the enhancement of safety culture in the construction industry.

### 2. Five Levels of Construction Practitioners

Effective leadership can improve safety performance in hazardous and complex working environments (Flin and Yule 2004). An extensive literature review of construction practitioners’ values, attitudes, perceptions, and patterns of behaviour at various levels were conducted. Previous studies related to this research are consolidated, thereby enriching the understanding of current knowledge. The literature was sourced from government/industry reports, books, and top-tier journals (Biggs et al. 2008; Choudhry et al. 2007; Clarke 2013; Conchie et al. 2013; Cooper 2000; Fernández-Muñiz et al. 2007; Flynn and Shaw 2010; Flynn and Yule 2004; Hoffmeister et al. 2014; Kines et al. 2010; Krause and Weekley 205; Koch 2013; Lu and Yang 2010; Martinez-Corcoles et al. 2011, 2013; Martin and Lewis 2014; Mohamed 2003; O’Dea and Flin 2001, 2003; Ostrom et al. 1993; Wamuziri 2006, 2013; Wu et al. 2008, 2011; Zou 2011). As illustrated in Table 1, construction practitioners are classified into five levels according to
their roles in construction site safety. The roles of construction practitioners at each level are shown in Table 1:

Table 1 Five (5) levels of construction practitioners

<table>
<thead>
<tr>
<th>Level</th>
<th>Position</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CEO</td>
<td>drive strategic decision</td>
</tr>
<tr>
<td>2</td>
<td>Project Management Team</td>
<td>involve in all project related issues</td>
</tr>
<tr>
<td>3</td>
<td>Supervisors and Foremen</td>
<td>supervise and arrange the construction materials and the labors at project level</td>
</tr>
<tr>
<td>4</td>
<td>Trade-specific supervisors</td>
<td>supervise and arrange the construction materials and the labors at trade level</td>
</tr>
<tr>
<td>5</td>
<td>Frontline worker</td>
<td>operate specific task</td>
</tr>
</tbody>
</table>

3. Data Collection

Semi-structured interviews and questionnaire survey were conducted to assess the current level of safety culture in the Hong Kong construction industry. Construction practitioners at various levels (i.e., CEO, project management team, supervisors/foremen, trade-specific foremen, and frontline workers) were invited to participate in this study. Face-to-face interviews were conducted with construction practitioners from Level 1 to 3, including 6 CEOs, 6 Project Management Team Leaders, and 8 Supervisors/Foremen. Questionnaire survey was conducted with trade-specific supervisors and frontline workers. A total of 28 valid questionnaires from Level 4 and 232 valid questionnaires from Level 5 were collected respectively. The participants were asked to evaluate their safety awareness/consciousness and actions/behaviours in day-to-day operations. They were asked to rate the level of agreement on the awareness/consciousness based on a 5-point Likert scale (i.e., 1 represents “strongly disagree” and 5 indicates “strongly agree”), and the actions/behaviours based on a 5-point Likert scale (i.e., 1 represents “always don’t” and 5 indicates “always do”). The participants from Level 1 to 3 were also asked to rank the relative importance of factors contributing to positive safety culture. The factors contributing to positive safety culture were identified in the literature (Biggs et al. 2008; Feng et al. 2014; Wamuziri 2006, 2013; Chen et al., 2013; Choudhry et al. 2007; Zhang and Gao 2012; Zou 2011). All the data collected are treated in strict confidence by the research team. Both quantitative and qualitative analyses were employed to analyse the empirical data in this study.

4. Results and Discussion

4.1 Level 1 CEO

Ratings on safety awareness and safety behaviour in Level 1 are illustrated in Table 2. The respondents are strongly realize the importance of safety. Only the mean score on “all accidents can be prevented” is less than 4.5. Regarding the safety behaviour, the mean scores are between 4 and 5. It is found that “proactive action will bring about changes in safety behaviours and performance” is relative low with the score of 4.17.
Table 2 Ratings on the safety awareness and safety behaviour in level 1

<table>
<thead>
<tr>
<th>Safety awareness</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everyone shares a responsibility on safety</td>
<td>5</td>
</tr>
<tr>
<td>The company shoulders a social responsibility on safety</td>
<td>5</td>
</tr>
<tr>
<td>All accidents can be prevented</td>
<td>4</td>
</tr>
<tr>
<td>Safety is an integral part in business performance</td>
<td>5</td>
</tr>
</tbody>
</table>

Safety behaviour

| Establish a clear mission, safety responsibility system and goal in order to set standards of behaviour for employees | 4.83 |
| Work with subordinates to reinforce the corporate safety commitment                | 4.83 |
| Be clear and transparent when dealing with safety issues                           | 4.67 |
| Ensure statutory compliance with government health and safety regulations          | 4.67 |
| Share the beliefs of the project management team                                  | 4.33 |
| Proactive action will bring about changes in safety behaviours and performance     | 4.17 |

The participants were asked to rank the relative importance of factors contributing to positive safety culture. It is found that “provides resources to support safety”, and “formulates safety policies to reflect the beliefs” are the top two important factors contributing to positive safety culture at Level 1 CEO.

4.2 Level 2 Project Management Team

Ratings on safety awareness and safety behaviour in Level 2 are illustrated in Table 3. Regarding the safety awareness, the mean scores on both “Shares the CEO’s belief” and “worker safety is first priority” are 4.67. The mean score on “proactive action will bring about changes in safety behaviours and performance” is 4.33.

The mean score on “positive and proactive action will bring about changes in safety behaviours and performance” is 4.33. Regarding the safety behaviour, the mean scores on most items are between 4 and 5. It is found that the respondents performed worse in the “drive for the flexibility and adaptation of safety management” with the score at 3.67.

Table 3 Ratings on the safety awareness and safety behaviour in level 2

<table>
<thead>
<tr>
<th>Safety awareness</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shares the CEO’s belief</td>
<td>4.67</td>
</tr>
<tr>
<td>Safety is a core element of project management</td>
<td>4.67</td>
</tr>
<tr>
<td>Positive and proactive action will bring about changes in safety behaviours and performance</td>
<td>4.33</td>
</tr>
</tbody>
</table>

Safety behaviour

| Motivate the workforce to participate in safety activities in order to increase their awareness of safety and acceptance of safety responsibility | 4.5    |
| Allocate resources to safety management commitment                               | 4.67   |
| Reinforce/support subordinates’ safety activities                                | 4.5    |
| Organize safety training and promotion                                           | 4.83   |
The participants were asked to rank the relative importance of factors contributing to positive safety culture. It is found that “enhance safety knowledge”, and “instil respect and commands authority” are the top two important factors contributing to positive safety culture at Level 2 Project Management Team.

### 4.3 Level 3 Supervisors/Foremen

Ratings on safety awareness and safety behaviour in Level 3 are illustrated in Table 4. Regarding the safety awareness, the mean scores on both “shares the beliefs of the project management team” and “worker safety is first priority” are 4.67. The mean score on “proactive action will bring about changes in safety behaviours and performance” is 4.33. Regarding the safety behaviour, the mean scores on most items are between 4 and 5. It is found that “provide subordinates with a flow of challenging and innovative ideas for improving safety” is relatively low with the score at 3.67.

#### Table 4 Ratings on the safety awareness and safety behaviour in level 3

<table>
<thead>
<tr>
<th>Safety awareness</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shares the beliefs of the project management team</td>
<td>4.67</td>
</tr>
<tr>
<td>Worker safety is first priority</td>
<td>4.67</td>
</tr>
<tr>
<td>Proactive action will bring about changes in safety behaviours and performance</td>
<td>4.33</td>
</tr>
<tr>
<td>Consider the hazards and risks before and during the execution of any task</td>
<td>4.5</td>
</tr>
<tr>
<td>Take necessary precautions to mitigate these risks</td>
<td>4.5</td>
</tr>
<tr>
<td>Review safety process and take feedback seriously</td>
<td>4.5</td>
</tr>
<tr>
<td>Provide safety equipment to the workforce</td>
<td>5</td>
</tr>
<tr>
<td>Explain the concept of safety and good practices clearly</td>
<td>4.67</td>
</tr>
<tr>
<td>Stop any unsafe activity or operation</td>
<td>4.83</td>
</tr>
<tr>
<td>Be consistent and fair in dealing with workers against safety issues</td>
<td>4.67</td>
</tr>
</tbody>
</table>
Listen to workers’ concerns with regard to safety and act on them 4.50
Be willing to admit mistakes and correct them 4.67
Report all unsafe conditions, practices and all injuries and illness 4.67
Report the risk assessment regularly 4
Conduct safety site-walks and report and rectify any irregularities 4.33
Detect and correct errors based on monitoring subordinates’ safety behaviour or being reported by the subordinates 4.33
Coach, mentor, and provide feedback promptly 4.33
Build strong relationship with frontline workers 4.33
Provide subordinates with a flow of challenging and innovative ideas for improving safety 3.67
Deliver the established incentives and punishments as part of the daily routine 4
Lead investigations into injuries, accidents and high potential incidents 4
Provide feedback and follow up near-miss and post-accident reports 4.17

The participants were asked to rank the relative importance of factors contributing to positive safety culture. It is found that “carry out risk assessments before work”, and “give safety instructions and information along with work instructions” are the top two important factors contributing to positive safety culture at Level 3 Supervisors/Foremen.

**4.4 Level 4 Trade-specific Foremen**

Ratings on safety awareness and safety behaviour in Level 4 are illustrated in Table 5. Regarding the safety awareness, the mean scores on “worker safety is first priority” at 4.75, which is higher than that on “proactive action will bring about changes in safety behaviours and performance” and “shares the beliefs of the project management team” at 4.39 and 4.18 respectively. Regarding the safety behaviour, it is found that the respondents performed worse in “provide inputs for design for safety”, “report the risk assessment to superiors regularly”, “deliver the established incentives and punishments as part of the daily routine”, and “provide subordinates with a flow of challenging and innovative safety ideas”, with the score at 3.73, 3.90, 3.90, and 3.90 respectively.

<table>
<thead>
<tr>
<th>Safety awareness</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shares the beliefs of the project management team</td>
<td>4.18</td>
</tr>
<tr>
<td>Worker safety is first priority</td>
<td>4.75</td>
</tr>
<tr>
<td>Proactive action will bring about changes in safety behaviours and performance</td>
<td>4.39</td>
</tr>
<tr>
<td>Consider the hazards and risks before and during the execution of any task</td>
<td>4.20</td>
</tr>
<tr>
<td>Take necessary precautions to mitigate these risks</td>
<td>4.03</td>
</tr>
<tr>
<td>Provide safe equipment to workers</td>
<td>4.43</td>
</tr>
<tr>
<td>Detect and correct errors based on monitoring subordinates’ safety behaviour or</td>
<td>4.13</td>
</tr>
<tr>
<td>being reported by the subordinates</td>
<td></td>
</tr>
</tbody>
</table>
Stop any unsafe activity or operation 4.43
Coach, mentor, and provide feedback promptly 4.20
Carrying out safety induction/familiarization training 4.40
Ensure that plants and equipment are being licensed, registered, and maintained regularly 4.13
Report all unsafe conditions, practices, near-misses, injuries, and illness 4.33
Comply with all safety policies, procedures and rules 4.37
Ensure workforce to obey/enforce safety rules 4.20
Monitor worker’s awareness of safety instructions regularly 4
Trust and respect frontline workers 4.33
Be consistent and fair in dealing with workers against safety issues 4.30
Be willing to admit mistakes and correct them 4.3
Provide inputs for design for safety 3.73
Report the risk assessment to superiors regularly 3.90
Deliver the established incentives and punishments as part of the daily routine 3.90
Provide subordinates with a flow of challenging and innovative safety ideas 3.90

4.5 Level 5 Frontline Workers

Ratings on safety awareness and safety behaviour in Level 5 are illustrated in Table 6. Regarding the safety awareness, the mean scores on “safety is everybody’s responsibility and each one has a part to play” and “personal safety at work is utmost concerns to one’s family and friends” at 4.46 and 4.43 respectively, which are higher than that on “all accidents can be prevented” with the score at 4.20. Regarding the safety behaviour, it is found that the respondents performed worse in “make suggestions and initiate new ideas to supervisor proactively”, “participate in safety activities”, and “communicate with fellow-workers on health, wellbeing and safety issues regularly” with the score at 3.91, 3.94, and 3.97 respectively.

Table 6 Ratings on the safety awareness and safety behaviour in level 5

<table>
<thead>
<tr>
<th>Safety awareness</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety is everybody’s responsibility and each one has a part to play</td>
<td>4.46</td>
</tr>
<tr>
<td>Personal safety at work is utmost concerns to one’s family and friends</td>
<td>4.43</td>
</tr>
<tr>
<td>All accidents can be prevented</td>
<td>4.20</td>
</tr>
<tr>
<td>Safety behaviour</td>
<td></td>
</tr>
<tr>
<td>Commit to use safety equipment provided</td>
<td>4.23</td>
</tr>
<tr>
<td>Perform work in accordance with safety practices and safety procedures</td>
<td>4.25</td>
</tr>
<tr>
<td>Report all injuries, illnesses, near misses, equipment damage, unsafe conditions, and practices to the superiors promptly</td>
<td>4.16</td>
</tr>
<tr>
<td>Advise and remind fellow-workers who deviate from safe working practice or misbehaves in safety</td>
<td>4.11</td>
</tr>
<tr>
<td>Reinforce and influence safety behaviour in workplace constantly</td>
<td>4.26</td>
</tr>
<tr>
<td>Work with management to identify safety problems and find solutions</td>
<td>4.03</td>
</tr>
<tr>
<td>Keep abreast of new knowledge</td>
<td>4.07</td>
</tr>
</tbody>
</table>
5. Conclusions

In Hong Kong, the safety performance of the construction industry has substantially improved since the late 90s. However, this improvement slowed down and reached a plateau after 2006. Having a mature and positive safety culture is becoming crucially important to facilitate such an improvement. This study aims to evaluate the performance of safety leadership scheme in the Hong Kong construction industry. Construction practitioners were classified into five levels as CEO, project management team, supervisors/foremen, trade-specific foremen, and frontline workers based on their different roles in construction site safety. Beliefs, initiatives, guidelines on being a “Safety Pioneer” for each level of construction practitioners were established. Semi-structured interviews and questionnaire survey were conducted to assess the safety culture in the local construction industry. A total of 280 construction practitioners were participated in this survey, including 6 CEOs, 6 Project Management Team leaders, 8 Supervisors/Foremen, 28 Trade-specific Foremen, and 232 Frontline Workers.

Findings of the research study indicated that: (a) construction practitioners at all levels possessed a satisfactory level of awareness/consciousness and actions/behaviours on safety; (b) construction practitioners at lower level tended to have a comparatively lower score for safety awareness and behaviours; (c) areas for further improvement includes: (1) “drive for the flexibility and adaptation of safety management” at Level 2 Project Management Team, (2) “provide subordinates with a flow of challenging and innovative ideas for improving safety” at Level 3 Supervisors/Foremen; (3) “provide inputs for design for safety”, “report the risk assessment regularly”, “deliver the established incentives and punishments as part of the daily routine”, and “provide subordinates with a flow of challenging and innovative ideas for improving safety” at Level 4 Trade-specific Foremen; and (4) “participate in safety activities” “communicate with fellow-workers on health, wellbeing and safety issues regularly”, and “make suggestions and initiate new ideas to supervisor proactively” at Level 5 Frontline worker; (d) the main benefits of safety leadership scheme includes “minimize the work-related accidents on site”, “a powerful influence on promoting the safety culture because initiated by the government”, and “set clear expectation and can be measurable”. Based on the above findings, it is recommended that training, instructions, and remarks should be given for safety improvement at various levels.

A limitation of the study is the limited sample source and sample size. In this study, participants at Level 1 CEO, Level 2 Project Management Team, and Level 3 Supervisors/Foremen were mainly from large-sized enterprises. Further research work should be done to increase the sample size and to replicate the survey to small and medium-sized enterprises (SMEs). The present study examines the current status of safety awareness and behaviour at various levels of
construction practitioners. Similar studies should be carried out in regular basis to monitor the enhancement of safety culture in the construction industry.

6. Acknowledgements

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References


Census and Statistics Department, Hong Kong Special Administrative Region Government. 2015. National Income. (available online http://www.censtatd.gov.hk/hkstat/sub/sp250.jsp?tableID=036&ID=0&productType=8 [accessed on 21/03/2015])


Causes of Risk Misallocation in the Zambian Construction Industry

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Abstract

Risk misallocation has been a concern in the construction industry globally due to its resultant effects of quality shortfall, disputes, claims, cost and time overruns. Various studies have focused on the identification of misallocated risks and how a project team can rectify the problem. However, the current discourse does not address the causes of misallocation. This research is aimed at bridging that gap by establishing why risks are misallocated in the construction industry, with the Zambian building sector as a focus. The study used heterogeneous purposive sampling to select professionals in the Zambian construction industry for semi-structured interviews. The professionals selected had over ten years’ experience in the building sector and had worked on building projects with various peculiarities. Various causes for misallocation were identified, and these were divided into three main categories, namely, work environment related, worker related and work related. Work environment factors include available contract forms; data, information and feedback, and contract conditions; worker factors include lack of perception and knowledge, inadequate skills and training and poor understanding of the consequences of risk; work related factors include the rationale for risk allocation and available response mechanisms. The identification of causes of risk misallocation helps the client to better understand how risk allocation can be enhanced in the construction industry; this is a positive step toward reducing misallocation and improving project performance in the construction industry. The research highlights the need for the construction industry to have diverse contracts, favourable and enabling contract conditions and workers with the necessary skills and understanding of the consequences of unmitigated risk among the contracting parties. Contractor and client as the contracting parties also need clear knowledge and perception of risks in addition to adopting a rationale for risk allocation that is not only based on responsibility but also ability to manage.

Keywords: Risk misallocation, buildings, causal issues, Zambia
1. Introduction

A construction project of any magnitude or nature is normally faced with a variety of risks. These risks could be market related, environmental, economic, financial, social, legal, technological, political, technical or physical (Sharma & Bhatnagar, 2006). The generic understanding of risk is that it is an event or occurrence that negatively impacts project performance (Flanagan & Norman, 1993; Smith, Merna, & Jobling, 2006). However, risk can also be construed as an event or occurrence that can impact project performance positively or negatively (Hilson, 2002; PMI, 2004). Caño and Cruz (2002) define risk as “an uncertain event that, if it occurs, has a positive (opportunities) or negative (threats) effect on a project objective” (p. 473). The way in which risk is managed can result in either threats or opportunities. It is during the risk management process that liability for risk, commonly known as risk allocation, is assigned. This is normally done in the risk response stage. A risk response measure could be an alternative procurement method, a construction method or material, monitoring, the use of insurance or bonds, contingency (time or money), subcontracting or even collaboration (Bakr, Khaled, & Ayda, 2012; Loosmore and McCarthy, 2008; Serpella, Ferrada, & Rubio, 2014; Smith, Merna, & Jobling, 2006; Uff, 2010). In architectural and engineering projects the allocation of risk is done through the standard form of contracts. Contracts allocate risks by providing for future contingencies with varying degrees of specificity (Triantis, 2000). Nevertheless, it is not uncommon for the standard forms to have modifications (Mooney & Mooney, 2013) resulting in either unbalanced risk allocation or more equitable allocation, so when the occurrence of an unforeseeable event would cause a promisor to bear an unexpectedly large loss in performing their contractual obligation, the parties may perhaps renegotiate and modify the promisor’s contract (Triantis, 2000).

Various risks have been observed to negatively impact project delivery in the Zambian construction industry, leading to quality shortfalls, as well as cost and time overruns (See Kaliba, Muya, & Sichombo, 2013). In addition, claims in the industry are rampant, with such causes as poor risk sharing and incomplete and incomprehensive contract documentation (Sibanyama, Muya, & Kaliba, 2012). Mukumbwa and Muya (2013) find in their study of unethical practices in the Zambian construction Industry (ZCI) one-sided contracts, where risk is transferred to the contractor, and insertion of unfair clauses which are disadvantageous to the contractor.

This research is aimed at identifying the prevalent risks and the practices that lead to risk misallocation. This has been done cognizant of prior studies which have identified misallocated risks with a view to allocating risks appropriately between the client and contractor. It is important that the causes of misallocation be established if this problem is to be dealt with at the source in the future.

2. Risk Allocation in the Construction industry

Risk allocation is the assigning of management responsibility and accountability for risk(s) (Alsalm an and Sillars, 2013). Risk allocation practice in the construction industry has been described as poor, unbalanced, balanced, and from misallocated to inappropriate (Alsalm an &
Sillars, 2013; Baloi & Price, 2003; Khazaeni et al., 2012). For risk allocation to be carried out, risk identification, risk analysis and response should be undertaken. Poor risk allocation refers to any instance of misallocation, including incomprehensive allocation of risks (Meng, 2012; Mead, 2007); unbalanced risk allocation refers to allocation of most of the risks to one party without justification (Alsaman & Sillars, 2013; Bakr, Khaled, & Ayda, 2012; Lam et al., 2007); balanced risk allocation refers to liability associated with risk events, and thus possible loss or gain from the project, properly identified and distributed (Khazaeni, et al 2012); inappropriate risk allocation refers to contractual shifting of risk to the contracting party with the least amount of bargaining power (Hanna et al., 2013).

This research defines risk misallocation as the allocation of risks wrongly or inappropriately (Hanna, Thomas, & Swanson, 2013); that is, it refers to any wrong method of allocation and/or inappropriate response method and/or allocation to the wrong party between client and contractor and their representatives and/or allocation of inappropriate resources or lack of allocation. Alsalam and Sillars (2013), using a questionnaire survey, established that when risks are not allocated accordingly they result in disputes, tensions, claims, quality shortfalls and time and cost overruns.

3. Methodology

This study used a qualitative approach to appraise misallocation in the Zambian building sector using a heterogeneous purposive method to select various professionals (engineers, quantity surveyors, architects and procurement officers) in the Zambian construction industry for semi-structured interviews. Semi-structured interviews have been used in related studies (e.g., Goh and Abul-Rahman, 2013; Lehtiranta and Juunonen, 2014). A semi-structured interview is one which has a written set of open-ended or closed questions for use by the interviewer in a person-to-person interaction (Kumar, 2011). The professionals selected had at least ten years of experience in the building sector and had worked on a variety of building projects. The sample was selected from professionals in both public and private sectors; contractors were selected from the building category in grades 1–3. Grade 1–3 contractors are registered under the National Council for Construction (NCC); grade 1 represents the highest contractor grade, those contractors with unlimited capacity; grade 2 is for contractors with a capacity of carrying out projects of up to K25M (US$2M; exchange rate: US$1 = K12.5); grade 3 contractors carry out projects of up to K10M (US$0.8M). The grades go up to 6. Grades 1–3 were chosen because 90% of the work in the building sector is done by these contractors, and they are obligated to subcontract 20% of the value of the works to grades 4–6 for public works when necessary. However, maximum contract values of Grade 4 (K5M [US$400,000]), Grade 5 (K3.5M [US$280,000]) and Grade 6 (K1M [US$80,000]) should not be exceeded. The respondents were as follows: 2 quantity surveyors, 2 architects, 2 civil engineers, 2 clients, 2 project managers, 1 contractor grade 1, 1 contractor grade 2, 1 contractor grade 3 and 2 procurement officers, giving a total of 15 respondents (see Table 1 for details).

The interviews to gain insight into issues leading to risk misallocation ranged from about 45 minutes to 70 minutes. Before the interview, permission was sought to audio record, and where the permission was not given, permission was obtained to take notes. Interviews were chosen because they are the best tools for collecting in-depth information (Greener, 2008; Patton,
Semi-structured interviews were preferred because they normally provide uniform information (Gray, 2009). Apart from the ability to collect in-depth information, interviews aid in the generation of historical data (Cresswell, 2007) and provide an opportunity to probe. Other advantages to interviews include these: information can be supplemented, questions can be explained and they can be used in any type of population (Kumar, 2011). Conversely, interviews have the demerit of being time consuming and expensive (Bhattacherjee, 2012; Cresswell, 2007; Gray, 2009; Kumar, 2011). The seven-step procedure outlined by Cresswell (2007) was used as follows: (1) locating an individual, (2) gaining access and making rapport, (3) purposefully sampling, (4) collecting information, (5) recording information (audio recording and/or taking notes), (6) resolving field issues, and (7) storing data. Location of individuals and gaining access was mainly done through their professional bodies. Prior contact was made either by e-mail or phone call to ascertain whether an individual had at least 10 years’ experience in building projects. Table 1 shows respondents’ years of experience, sector of engagement and nature of building projects worked on. The average in years for the respondents was 17 years. It is quite clear that the years of experience are vast and the nature of building projects provides a good mix for the study.

Table 1: Respondents’ characteristics

<table>
<thead>
<tr>
<th>I.D</th>
<th>Sector</th>
<th>Experience in Years</th>
<th>Role in construction</th>
<th>Scope of building projects in years of experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Public</td>
<td>15</td>
<td>QS</td>
<td>Offices, houses, schools</td>
</tr>
<tr>
<td>2</td>
<td>Public</td>
<td>12</td>
<td>Civil Eng.</td>
<td>Offices, hospitals, schools</td>
</tr>
<tr>
<td>3</td>
<td>Public</td>
<td>10</td>
<td>Procurement officers</td>
<td>Offices, houses</td>
</tr>
<tr>
<td>4</td>
<td>Public</td>
<td>20</td>
<td>QS</td>
<td>Housing units, offices, health facilities, hospitals</td>
</tr>
<tr>
<td>5</td>
<td>Public</td>
<td>19</td>
<td>Architect</td>
<td>Schools, offices, border infrastructure, houses</td>
</tr>
<tr>
<td>6</td>
<td>Private</td>
<td>10</td>
<td>Contractor</td>
<td>Houses, student hostels, high rise buildings</td>
</tr>
<tr>
<td>7</td>
<td>Private</td>
<td>32</td>
<td>QS/PM</td>
<td>Offices, hospitals, residential, banks, filling stations, stadia, factories</td>
</tr>
<tr>
<td>8</td>
<td>Public</td>
<td>21</td>
<td>Client org</td>
<td>Primary schools, secondary schools, colleges, houses</td>
</tr>
<tr>
<td>9</td>
<td>Public</td>
<td>23</td>
<td>PM</td>
<td>Prisons, military installations, houses, rural health centers, flight terminal, border facilities, offices</td>
</tr>
<tr>
<td>10</td>
<td>Private</td>
<td>30</td>
<td>Eng. Consultant</td>
<td>Showrooms, schools, filling station, hospitals hotels, office buildings</td>
</tr>
<tr>
<td>11</td>
<td>Private</td>
<td>29</td>
<td>Contractor</td>
<td>Housing, offices, banks, schools, hostels</td>
</tr>
<tr>
<td>12</td>
<td>Private</td>
<td>10</td>
<td>Contractor</td>
<td>High schools, maternity wards, student hostels, offices</td>
</tr>
<tr>
<td>13</td>
<td>Private</td>
<td>10</td>
<td>Client Org</td>
<td>Markets, fire stations, bus shelters, houses,</td>
</tr>
<tr>
<td>14</td>
<td>Private</td>
<td>15</td>
<td>Procurement Officer</td>
<td>Office blocks, houses, farm layouts and different buildings, lodges, banks</td>
</tr>
<tr>
<td>15</td>
<td>Private</td>
<td>10</td>
<td>Architect</td>
<td>Houses, offices, shops, farm buildings, banks</td>
</tr>
</tbody>
</table>

The analysis was done mainly through content and interpretive analysis. Interpretive analysis aims to capture hidden meaning and ambiguity (Gray, 2009), looking at how messages are encoded, latent or hidden. Content analysis is a research tool used to determine the presence of
certain words or concepts within text or sets of texts (Robson, 2011). In some instances, there was a link in the analysis between the current practice and existing theory in risk allocation, namely, transaction cost theory, expectancy theory, principal-agent theory and structuration.

4. Discussion

4.1 Prevalent Risks to Building Projects

Various risks impact building projects, and the following were indicated by respondents as prevalent: late payment (80%); lack of inspection, supervision and monitoring by consultants (73%); poor supervision by contractors (73%); contractor’s cash flow problems (73%); lack of adherence to contractual provisions by client (67%); slow decision making by client (60%); bureaucratic processes (60%); frequent changes in material prices (60%); unstable exchange rate (60%); poor workmanship (52%); frequent change in scope (52%). These risks are diverse due to the nature of building projects. Late payment is mainly attributed to poor financial standing of the client, poor budget planning or poor bureaucratic processes. This could be contributing to contractors’ poor cash flow.

4.2 Nature of Risk Misallocation in the Building Sector

All respondents, as shown in Table 2, asserted that the allocation of risk is not balanced because contractors are compelled to carry more risks than the client. Additionally, in certain instances, risks which are better shared between the client and the contractor, such as escalation in the cost of materials and unstable exchange rates, are shifted to the contractor. The underlying reason for this practice, as explained by the consultants, was to minimize the cost to the client. It was also clear that certain methods of allocation preferred by the client contributed to misallocation, such as the practice of obtaining bonds from banks only and the allowable level of subcontracting. This was indicated by 60% of the respondents. Some risks were not allocated despite the fact that these are present in the original standard forms of contract which were modified using waiver clauses, leading to some clauses becoming non-applicable. The respondents (60%) suggested that sometimes either the client or the contractor is wrongly allocated a risk resulting from modification of a standard contractual clause, such as the omission of fluctuation and escalation clauses. Lastly, it was also common to allocate resources wrongly due to the underestimation of the scope or nature of the work. This form of misallocation would be mainly in terms of inappropriate finance allocation, as illustrated by 100% of the respondents; insufficient personnel to supervise and monitor the works, as pointed out by 80% of the respondents and insufficient or wrong plant and equipment revealed by 60% of the respondents. This is usually occasioned by incomplete design and a lack of investigation of the site conditions.
Table 2: Nature of risk misallocation in the construction industry

<table>
<thead>
<tr>
<th>Nature of misallocation</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unbalanced risk allocation</td>
<td>15</td>
</tr>
<tr>
<td>Wrong method of allocation</td>
<td>9</td>
</tr>
<tr>
<td>Risk allocation to wrong party</td>
<td>9</td>
</tr>
<tr>
<td>Lack of allocation in signed documents</td>
<td>3</td>
</tr>
<tr>
<td>Inadequate or wrong resources used in allocation (personnel)</td>
<td>12</td>
</tr>
<tr>
<td>Inadequate or wrong resources used in allocation (plant or equipment)</td>
<td>6</td>
</tr>
<tr>
<td>Inadequate resources used in allocation (finance)</td>
<td>15</td>
</tr>
</tbody>
</table>

4.3 Causes of Misallocation: Work Environment Related

The environment relates to the surrounding conditions in which an employee or organisation operates. It can be composed of physical conditions, such as office temperature, or equipment such as personal computers. However, for this study the environment was used to refer to work processes or procedures as they relate to risk in a project environment. Process and procedures followed on projects that were particularly related to risk allocation were considered. The following were identified as factors contributing to misallocation.

4.3.1 Contract Forms Used

The main contracts in use in the Zambian construction industry are the Zambian Public Procurement Agency (ZPPA) contracts (2013), which include open national bidding, international bidding (FIDIC red book, harmonised 2005 version) and small works contracts, and the Joint Liaison Contract (JLC), commonly known as the ZIA (Zambia Institute of Architects) contract. All the respondents claim that these are almost always modified to accommodate the requirements of the clients or financiers of projects. Occasionally, this leads to allocating most of the risks to contractors. Of the respondents, 60% also indicated that current contracts do not reflect what is needed because they are based on traditional procurement, and in recent times professionals in the industry have had contracts that are design-and-build in nature and feel the current contracts do not seem to address the risks that come with such arrangements. It is important to point out that contracts in use based on traditional procurement do not reflect the risk liability in an integrated system of procurement. The respondents (60%) indicated that there is a need to have a flexible contract or new contract showing the actual risk liability in such an arrangement.

4.3.2 Data, Information and Feedback

Data and information were cited as some of the initial causes of risk misallocation. Designers (architects and engineers) and cost estimators (quantity surveyors) interviewed (60% of respondents), especially those in the public sector, suggest that most of the time they design or estimate projects without going to the site or conducting necessary investigations; this results in
inaccurate assumptions of site conditions. Contractors indicated that most of the data they base their tender price on lack detail, especially drawings which had either missing or insufficient detail. Contractors claim they would sometimes tender for projects, especially for public sector projects, without going to the site, making it difficult to quote properly and allocate resources accordingly. There seems to be lack of information and project data for decisions to be made on risk where site conditions are concerned.

Feedback on risks between the contractor and the client once projects have commenced was described as generally poor by 80% of the respondents. When steps were taken to get feedback, the feedback was not given in a timely manner. However, among consultants there seemed to be various methods of feedback on issues to do with risk, such as reports and meetings. It was also noted that contractors who have been in operation for 3 years or more appeared to have the knowledge to query on certain issues which they felt would affect their performance, such as verification of variations and specification, and demand for detailed drawings. Contractors (100%) indicated that the lack of design details and late feedback lead to risk misallocation on their part, especially in the allocation of resources and pricing. Consequently, consultants and procurement officers (73%) from the private and public sectors pointed out that when there was no clarity in a drawing the contractor tends to over-price the work to cover risk. This is expected even more when escalation and fluctuation clauses are omitted in a contract. The latter could be understood as an act by the client or employer to keep transaction cost to a minimum at the peril of the contractor. Nevertheless, in the final analysis, costs are hardly reduced, as alluded to by the consultants, because contractors give fairly high bids, reacting from an expectancy theory viewpoint. Fair bids and contract sums could therefore be attained through the preparation of clear and detailed contract documents.

4.3.3 Contract Conditions

Various contractual conditions which form part of the procedure for practice in the Zambian construction industry could be said to be inhibiting appropriate risk allocation and result at times in either misallocation of resources or formulation of one-sided contracts. The following are practices that seem to be contributing to misallocation.

Sub-contracting. Most contracts carried out in the Zambian construction industry have a level of subcontracting of 20% of the value of the work. For large projects contractors have a mandate to subcontract 20% of the work to medium- and small-scale contractors when necessary. The respondents, especially consultants, indicated that this level of subcontracting is too low, and that those awarded the 80% in most cases do not themselves have the capacity or need to subcontract much more than 20%, and failure to subcontract more than 20% invariably leads to late completion. On the other hand, such specialised works as electrical, plumbing and air-conditioning exceed the 20% threshold and result in works being carried out by the main contracted, who may not be specialised. Using inappropriate subcontracting levels may lead to wrong resource allocation, leading in turn to late project delivery.

Omission of escalation and fluctuation clauses: Contracts over a twelve-month period normally require the use of escalation and fluctuation clauses, mainly to protect the contractor from increased prices. However, in the Zambian construction industry these clauses are omitted or
waived most of the time, even for contracts whose duration is over 12 months, resulting in the contractor carrying this risk when it should be covered or shared with the client. This was reported by 93% of the respondents. This, if illustrated from a principal agent point of view, could be said to be spawning opportunistic behaviour by the client (principal), who will be trying to lower costs. However, the contractors proactively mitigate this risk by putting a high mark-up on their bids (expectancy theory). This was alluded to by 73% of the respondents. Nevertheless, this demonstrates that the client has not fully analysed the consequence of this act, which may result in higher costs.

**Preferred sources of bonds and guarantees:** The Zambian construction industry has traditionally demanded the securing of bonds and guarantees from banks only. However, in the last year all respondents indicated that insurance firms have become acceptable as sources of bonds and guarantees. This is a positive move, ensuring that performance bonds and advance payment bonds are obtained on projects. However, despite this, most clients still insist on bonds or guarantees from banks. Banks need collateral in the form of fixed assets. This in turn reduces the sources of finance for contractors, which normally results in poor cash flow during project execution. This is so because obtaining guarantees or bonds initially from banks lessens the opportunity of this avenue being utilised in the future, as the collateral held by the bank will render a contractor less liquid. This could be minimised if bonds or guarantees are obtained from insurance houses, which usually require payment of premiums, rather than collateral in the form of fixed assets. The majority of the respondents (87%) were of the view that bonds and guarantees obtained from insurance houses afford contractors the opportunity to source additional finance if needed from the bank, unlike when they are initially obtained from the bank. This helps the contractor’s financial management and cash flow and could help cushion the risk of late payment by the client, thereby ensuring that resource misallocation in the form of finance is minimised.

**Safety Provisions:** One project manager and 1 architect, and 2 of 3 contractors, comprising only 33% of respondents, stated that there seems to be a wrong method of risk allocation associated with safety because the clause is not punitive towards non-compliance. Though the respondents may not be in the majority, they give insight into why accidents are a common feature on construction sites. Consequently, contractors do not comply in terms of providing a safe working environment and provision of proper safety gear for workers on site. The respondents were of the view that if the safety clause were punitive in nature it would reduce the risk of contractors not complying.

### 4.4 Causes of Misallocation: Worker Related

The *Oxford Learner’s Dictionary* defines a *worker* as “a person that performs a specific or necessary task or who completes tasks in a certain way.” For tasks to be completed successfully workers need to have the necessary skill and capacity to perform the task. For risk allocation or management to be done effectively the skills and capacity of those involved should be adequate (Mu, Chen, Chohr, & Peng, 2014).
4.4.1 Perception and Knowledge

Perception of risks is significant in the consideration of the allocation of any risk. One rarely allocates risk(s) that are perceived to be less important or thought to have a low possibility of occurrence. Most of the respondents (67%) asserted that sometimes risks are not allocated due to lack of perception. In some cases, the resources allocated are not appropriate due to lack of perception or knowledge of an event as being a risk. There was nevertheless unanimity among the respondents that risks that are poorly managed lead to project failure. Giddens (1978) notes in his seminal work that in the duality of structure only a knowledgeable agent can influence structure or perhaps the way risks are allocated. From a structuration theory point of view, lack of perception in the Zambian construction industry of certain risks is leading to misallocation. Agents cannot allocate or monitor what they do not perceive to be a risk.

4.4.2 Skill and Training

Effective carrying out of risk allocation requires that risks be identified, analysed and treated. The majority of respondents (67%) indicated that they have had some training in risk management: some aspects of risk allocation were covered during their tertiary education, during their professional membership registration process or during a workshop or a seminar; the other 33% appear to have had no training at all. When asked the methods they used for risk identification, the majority indicated experience on past projects (62%); others indicated local knowledge (27%) and 33% use checklists. Other methods captured for risk identification included document review, meetings, works task analysis and cash flow analysis. Risk analysis is not actively done in the Zambian construction industry. Experience was indicated by 47% of the respondents as the method utilised for risk analysis, though it is rarely done; others indicated that they do not use any method for risk analysis (53%). For risk response, all the respondents indicated that this is done in the contract documents used. However, given that most contracts are modified and some clauses omitted or waived, risk response and analysis should be undertaken when conducting contract modifications.

4.4.3 Poor Understanding of Consequences of Risk

The majority of respondents (80%) were of the view that most clients as they modify contractual clauses or fail to honour contractual obligations do not fully understand that they allow other risks to occur. Figure 1 shows the risks that were mentioned by various respondents as being unanticipated by clients.

![Figure 1. Risks consequential to late payment (respondents’ views)](image-url)
That is, late payment either by public or private clients results in other risks. As many respondents noticed, clients normally foresee paying interest on late payments but not the other risks.

4.5 Causes of Misallocation: Work Related

4.5.1 Rationale for Allocation

The *Oxford Learner’s Dictionary* defines *work* as “a task or tasks to be undertaken.” In the construction sector various tasks are undertaken by various professionals. Risk allocation on contracts used in the Zambian construction industry is understood to be based on responsibility or role by 67% of the respondents. Other rationales used to allocate risk identified by respondents (20% each) include risk avoidance and management ability. Basing risk allocation on responsibility or role is good for establishing liability, basing on a principal agent reasoning, but it may neglect or lead to misallocation of external risks which are not a direct responsibility of either party. In addition, it may result in risk being allocated to the party least able to manage risk. Moreover, the one whose role includes being responsible for risk is not necessarily the one best suited to manage the risk.

4.5.2 Available Response Mechanism

All types of construction projects have risks, building projects included; uncertainties sometimes lead to risks not being foreseeable. The majority of respondents, especially those in the public sector, are reactive when it comes to risks, and they respond to risk mainly to avoid audit queries and budget overruns (indicated by 60% of the professionals). This leads to misallocation by unfairly allocating risks to contractors. Contractors (100%) in their defence rarely query such allocations for fear of losing work opportunities.

5. Conclusion

Different construction industries in different jurisdictions have peculiar risks impacting on their performance and their own challenges in achieving appropriate risk allocation. Late payment is the most prevalent risk in the Zambian construction industry. Various risk misallocation practices have been found to exist in the Zambian construction industry, such as unbalanced or one-sided allocation, wrong or inappropriate methods of allocation in terms of response strategy used, and use of wrong or inappropriate resources (plant and equipment). Causes of this misallocation have been found to be environmental factors (contract used; data, information and feedback; contract conditions), worker related factors (perception and knowledge, skill and training and poor understanding of the consequences of risk) and work related factors (rationale for allocation and response mechanism). The clients in their preparation of contract documents and conduct of contract administration have been seen to take measures that seemingly reduce costs without considering how the reaction from contractors would impact cost. From an expectancy theory perspective, contractors tend to over-price bids as a response to client omission of clauses and neglect of adherence to contract conditions, such as costs awarded with an extension of time.
It could therefore be concluded that risk misallocation is contributing to poor project delivery in the building sector. The research highlights the need to have diverse contracts, timely exchange of information and data between contracting parties, favourable and enabling contract conditions, necessary skill and understanding of the consequences of unmitigated risk among the contracting parties, clear knowledge and perception of risks and the adoption of a rationale for risk allocation that is based not only on responsibility but also on ability to manage. In addition, flexibility by clients on sources of guarantees and bonds such as insurance companies could help the contractors’ cash flow, thereby reducing the risk of late payment. Furthermore, varying the percentages for subcontracting according to project requirements could lead to favourable project delivery. The future focus of this research is to validate these findings through a questionnaire survey and document analysis of contract documents used in the Zambian construction industry.

References


Causation Model for Psychological Injuries in the Construction Industry

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Abstract

A plethora of studies is found, which investigates physical injuries and health problems in construction. Similarly, numerous models have been developed to date to explain their causes. However, an equally important work health and safety issue, the psychological wellbeing of construction workers, is an under explored area. This research empirically analysed 376 cases of psychological injuries occurred to construction workers and developed a causation model. The study found seven causes that are responsible for psychological injuries amongst construction workers, viz.: (1) workplace harassment and bullying, (2) work pressure, (3) work-life conflict, (4) discrimination, (5) poor physical work environment, (6) job uncertainty and (7) poor workplace relationships. Among these, long sustained workplace harassment and bullying, often accompanied by violence, produces critical psychological injuries that require time-off-work for longer than a year. Similarly, constant work pressure leads to severe psychological injuries that require time-off-work for 100 to 365 days. The study highlights the urgent need to curb workplace harassment and bullying in order to make the construction industry free from critical psychological injuries.

Keywords: Work health and safety, psychological injury, construction operatives, causation model.

1. Introduction

Construction accidents have been explored extensively to date, resulting in several accident causation models. These various models focus on physical injuries and health issues because these are visible to the outer world and loud when occur. Most of the existing safety management strategies and systems too are heavily focused on curbing physical injuries and health problems. An equally important work health and safety (WHS) issue is the psychological wellbeing of construction workers. Because psychological injuries suffered by workers are invisible and silent, unlike physical injuries, they go unnoticed for extended periods, causing serious damages to workers. Hohnen and Hasle (2011) asserted that most employers fail to see the psychosocial injuries endured by workers and current WHS management practices too are heavily focused on technical aspects and neglect psychosocial hazards.

Some previous studies are noted within the broader topic of psychological health of construction workers. Golderhar et al. (1998) examined the impact of sexual harassment, gender discrimination, job uncertainty and over compensation at work on female construction workers’ physiological well-being. Golderhar et al. (2003) modelled the relationships between job stressors and accident outcomes.
in construction projects. Likewise, Siu et al. (2004) investigated relations among safety climate, psychological strains and safety performance in construction projects. Larsson et al. (2008) studied the significance of good psychological climate in construction projects for improved safety outcomes. Leung et al. (2010) identified workplace factors affecting job stress of construction workers and further explored the impact of it on injury incidents. Melia and Becerril (2007) explored how factors such as leadership, role conflict and mobbing behaviours influence workers’ psychological health. Most of these studies still placed the focus on accident outcomes and treated psychological symptoms as mediators of physical injuries and health problems. The other studies were narrow in scope, suggesting further explorations are needed to understand and model the realm of psychological injuries of construction workers. To this end, this research aimed at identifying the factors that affect the psychological health of construction workers and mapping them in a causation model.

2. Literature review

Psychological health is defined as a state of mental well-being that influences one’s ability to realise his/her potentials and work productively to contribute to the advancement of self and society while successfully managing the stressors of work and life (CSA 2013). Poor psychological health lead to several undesirable behaviour patterns and symptoms in employees, viz.: difficulty to focus on work and to make rational decisions; finding it hard to meet reasonable goals and deadlines; being absent from or late to work frequently; excessive tiredness and fatigue; getting overwhelmed or irritated easily with people or work tasks; displaying negative thoughts and loss of self-confidence; avoiding workplace gatherings such as staff meetings, socialisations, etc.; appearing atypically worried, apprehensive, emotional or tearful; and resorting to alcohol or drugs to cope (Beyondblue 2014).

Unfavourable conditions and/or stressors encountered at workplaces can trigger poor psychological health in employees. Eight such themes were elicited in a critical review of literatures, as discussed below. The literature review provided valuable insights and a solid foundation for the empirical study.

2.1 Work pressure

The inherent nature of construction could exert pressure on site management team and workers as they try to accomplish several tasks concurrently within a limited time and space. Choudhry and Fang (2008) reported that construction workers were constantly instructed by their supervisors to perform the task quickly, which often led to compromising safety for productivity and thereby higher injury rates. This situation causes worker to be under constant job stress. Leung et al. (2010) added that work overload also increases job stress within workers.

2.2 Workplace relationships

Poor support or relationships at workplaces can put a psychological strain on workers (Walen and Lachman 2000). Having a sense of team spirit and developing good relationships with workmates are of significant socio-psychological influencers for workers (Kazaz and Ulubeyli 2007). This creates a harmonious and positive workplace where workers tend to be morally supportive to each other. However, social relationships among co-workers can be a challenging issue for migrant workers. Language barrier is an impediment. Fang and Goldner (2011) argued that local language competency is a determining factor for migrant workers’ successful transition into work culture. Moreover, it is directly linked to their economic success, which also influences the psychological well-being.
2.3 Poor physical work environment

Arboleda and Abraham (2004) postulated that being constantly exposed to extreme outdoor temperatures, poor air quality, excessive noise, dirty drinking water, odour, chemicals and hazardous working conditions can induce stress in workers.

2.4 Work-life conflict

Tennant (2001) observed that most adults attain satisfaction in life from work and family; however, these could also be sources of stress if not balanced effectively. Van Amelsvoort et al. (2004) postulated that work-family conflicts often result in inadequate time and energy to fulfil both family and work duties; one of them is likely to be compromised. Bust and Gibb (2006), for example, found that shift work among construction workers created family problems and stress. Moreover, workers with family issues had their work performance affected, which in turn showed repercussions on their economic situations. These factors collectively affect their psychological state (Glasscock et al. 2006).

Overtime work is commonly practised by organisations when a project is behind schedule or faces labour shortages. Overtime can be in the form of extending the daily work hours or rostering weekend work. In construction projects, workers generally cannot opt out overtime work. Long work shifts exceeding 13 hours or continuously working throughout weekends could lead to both physical and mental exhaustion, particularly in difficult conditions like extreme heat or cold (SocialistWorker 2011).

2.5 Workplace harassment and bullying

Mikkelsen & Einarsen (2002) found that exposure to harassment and bullying at work was associated with an increased number of psychological and psychometric complaints. Likewise, Law et al. (2011) found in Australia that 24% of compensation claims in 2007 and 2008 were linked to workplace harassment and bullying. Moreover, gender-based and sexual harassments were identified by Goldenhar et al. (2003) as strong stressors that cause poor psychological wellbeing for women in the construction industry. Severe forms of harassment and bullying are regarded as violence, which are extreme social stressors (Zapf et al. 1996). Leymann (1996) enlisted behaviours that constitute violence at work, which include: social isolation, assigning a person too little or too simple tasks, slander, intimidating or criticising, physical violence and threat of violence, and rumours about one.

2.6 Discrimination

Literature suggests that migrant workers may face discriminatory treatments by employers, local workers and/or unions. Discrimination by employers include unequal wages for the same jobs, offering jobs un-matching their qualifications/skills and limited work hours. Wong et al. (2007) claimed that migrant workers are perceived to be increasing competition in the market, thereby threaten job opportunities for local workers. As such, migrant workers face hostility from locals and at times are linked to increased crime rates in the city. Harcourt et al. (2008) argued that discrimination against migrant workers is not limited to employers or local workforce and pointed out that unions that lobby for restrictions on immigration to satisfy the majority group are hesitant to help ethno-cultural groups to acquire decent work conditions. Depending on the country of origin and economic backgrounds, migrant workers would initially tolerate discrimination. However, over time they experience frustration, feelings of shame, bitterness, strain and loss of sleep (Simich et al. 2006).
2.7 Job uncertainty

Dekker and Schaufeli (1995) found that job uncertainty faced by employees of a transport organisation in Australia was strongly associated with psychological distress. They further argued that the negative psychological effect of job uncertainty extends beyond the potentially redundant employees and affects their families too. Among the organisational practices that pose a sense of job uncertainty are: casual/contract employment, redundancy, gender/ethnic/nationality preferences, etc. Job uncertainty for construction workers is placed in a delicate position. The continuity of construction jobs is heavily dependent on the availability of new projects for the employer. Many external factors influence this; i.e., changes to government policies on infrastructure development and other economic issues can impact on construction demand, which may make job insecurity a constant issue in construction.

3. Research method

Figure 1 illustrates the methods deployed in this empirical research, which utilised a large database of construction accidents for developing the causation model. Accident data for the research were obtained from Safe Work South Australia, which is a state government agency responsible for work health and safety. They maintain a database of workplace accidents across all industries in South Australia. The database encompassed 29,205 construction accidents, reported during 2002-13. Filtering the database, a subset of 444 records was extracted, which described incidents related to psychological injuries to construction workers.

Pre-processing was undertaken to prepare the filtered data for statistical analysis. A typical case was characterised by variables such as: mechanism of incident, occupation, age, gender, language, nationality origin, experience, timing of incident, date of incident, employer size, description of incident, lost days and worker’s compensation paid. First, records that are not related to construction, but had been incorrectly recorded were removed (21 cases). Further checking was conducted to identify cases that are not significant for analysis. Forty-seven cases with both zero lost days and zero compensation were identified and removed, resulting in 376 usable cases for further analysis. Then, entries and descriptions across records were made consistent. Finally, nominal scales were introduced for variables that had numerical entries to facilitate non-parametric statistical analyses.
After the data pre-processing, an exploratory analysis using descriptive statistics was performed to gain a broader understanding of the psychological injuries in the South Australian construction industry. Subsequently, associations between the independent variables and the severity of psychological injuries were investigated using chi-square tests. While chi-square statistics are helpful for revealing associations they cannot be interpreted as causations. Thus, incident descriptions were qualitatively analysed to corroborate how the associations exhibit causation. Finally, findings from the quantitative and qualitative analyses and the literature review were consolidated, enabling the development of a new causation model for psychological injuries in the construction industry.

4. Quantitative data analysis and findings

The data set was redefined by 10 independent variables and one dependent variable (severity of psychological injury) in the pre-processing stage. In the original database, some of these variables were defined by different measurement scales, such as: occupation of victim had 67 job titles; age was in years; language background had 7 entries; nationality origin consisted of 9 countries; time of incident was 30-minute class intervals; and month of incident had 12 entries. Table 1 shows how these variables were re-categorised using nominal scales. Some of the categories, such as gender, mechanism of injury and employer size, were directly taken from the original dataset.

Table 1: Variable measurements

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measurement (nominal)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Independent variables:</strong></td>
<td></td>
</tr>
<tr>
<td>1. Mechanism of injury</td>
<td>Assault; exposure to a traumatic event; exposure to workplace or occupational violence; work pressure; workplace harassment and/or bullying; suicide or attempted suicide; other mental stress factor</td>
</tr>
<tr>
<td>2. Season of injury</td>
<td>Summer (Dec, Jan &amp; Feb.); autumn (Mar, Apr &amp; May); winter (Jun, Jul &amp; Aug); spring (Sep, Oct &amp; Nov)</td>
</tr>
<tr>
<td>3. Work shift of injury</td>
<td>Morning shift; afternoon shift; evening shift; night shift</td>
</tr>
<tr>
<td>4. Age range of victim</td>
<td>Under 20; 20 to 29; 30 to 39; 40 to 49; 50 to 59; over 60</td>
</tr>
<tr>
<td>5. Gender of victim</td>
<td>Male; female</td>
</tr>
<tr>
<td>6. Occupation category of victim</td>
<td>Office staff; site staff; trades personnel; machinery operator; apprentice; general worker</td>
</tr>
<tr>
<td>7. Experience of victim</td>
<td>Experienced worker; new worker</td>
</tr>
<tr>
<td>8. Native language of victim</td>
<td>English; non-English</td>
</tr>
<tr>
<td>9. Nationality origin of victim</td>
<td>Australian; non-Australian</td>
</tr>
<tr>
<td>10. Employer size</td>
<td>Small (1 to 20 employees); medium (21 to 200 employees); large (more than 200 employees)</td>
</tr>
<tr>
<td><strong>Dependent variable:</strong></td>
<td></td>
</tr>
<tr>
<td>11. Severity of psychological injury</td>
<td>Minor; moderate; major; severe; critical</td>
</tr>
</tbody>
</table>

The dependent variable, severity of psychological injury, was derived based on the number of lost days reported for the cases. The utilisation of lost days to categorise injuries in to different severity levels has commonly been used by previous researchers who investigated physical injuries in construction; for example, Dumrak et al. (2013) and Arquillos et al. (2012). Nonetheless, varied severity levels and groupings of lost days were implemented by different researchers. This research adopted five levels of severity such as: minor, moderate, major, severe and critical, and the definitions for these categories are given below, which were derived from the risk matrix recommended by the National Patient Safety Agency (NPSA) (2008):
- **Minor** – psychological injuries requiring time off work (lost days) for shorter than 3 days.
- **Moderate** – psychological injuries requiring time off work (lost days) for 4 to 14 days.
- **Major** – psychological injuries requiring time off work (lost days) for 15 to 99 days.
- **Severe** – psychological injuries requiring time off work (lost days) for 100 to 365 days.
- **Critical** – psychological injuries requiring time off work (lost days) for longer than 365 days.

In interpreting the results, findings of both exploratory and chi-square analyses were looked at in a combined manner. The below sections expound the findings. In general, an upward trend in psychological injuries to construction workers in the South Australia is discernible. Whilst the severity level of psychological injuries are more on the minor category, the combination of major, severe and critical injuries constitutes one-third of all incidents. Given the psychological injuries are on constant increase, the ratio is likely to result in negative social outcomes and sufferings. It is therefore crucial that lessons are learnt from past incidents and measures are put in place to curtail them in the future. Table 2 elucidates chi-square analysis results. Interpretations of these results are provided below under appropriate subheadings.

**Table 2: psychological injury severity pattern**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Category (% of total accident)</th>
<th>% of accident within severity level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minor</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanism of psychological injury</td>
<td>Being assaulted by a person or persons (12%)</td>
<td>80</td>
</tr>
<tr>
<td>(x2 = 50.909, df = 24, p = 0.001)</td>
<td>Exposure to a traumatic event (12.5%)</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Exposure to workplace or occupational violence (8%)</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Work pressure (33.2%)</td>
<td>54.4</td>
</tr>
<tr>
<td></td>
<td>Work related harassment and/or workplace bullying (27.9%)</td>
<td>51.4</td>
</tr>
<tr>
<td></td>
<td>Suicide or attempted suicide (0.8%)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Other mental stress factors (5.8%)</td>
<td>76.2</td>
</tr>
<tr>
<td>Occupation</td>
<td>Apprentice (6.6%)</td>
<td>72</td>
</tr>
<tr>
<td>(x2 = 28.047, df = 20, p = 0.108)</td>
<td>General worker (7.7%)</td>
<td>62.1</td>
</tr>
<tr>
<td></td>
<td>Machinery operator (17.3%)</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Office staff (19.4%)</td>
<td>54.8</td>
</tr>
<tr>
<td></td>
<td>Site staff (11.7%)</td>
<td>54.5</td>
</tr>
<tr>
<td></td>
<td>Trade personnel (37.2%)</td>
<td>70</td>
</tr>
<tr>
<td>Work shift</td>
<td>Morning shift (32.4%)</td>
<td>66.4</td>
</tr>
<tr>
<td>(x2 = 13.257, df = 12, p = 0.351)</td>
<td>Afternoon shift (21.5%)</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Evening shift (2.7%)</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Night shift (43.4%)</td>
<td>62</td>
</tr>
<tr>
<td>Employer size</td>
<td>Large (34%)</td>
<td>56.3</td>
</tr>
<tr>
<td>(x2 = 29.209, df = 12, p = 0.004)</td>
<td>Medium (36.7%)</td>
<td>62.3</td>
</tr>
<tr>
<td></td>
<td>Small (29%)</td>
<td>71.6</td>
</tr>
<tr>
<td></td>
<td>Unknown (0.3%)</td>
<td>100</td>
</tr>
<tr>
<td>Season</td>
<td>Autumn (25.4%)</td>
<td>66.3</td>
</tr>
<tr>
<td>(x2 = 27.245, df = 12, p = 0.007)</td>
<td>Spring (25.3%)</td>
<td>60.0</td>
</tr>
<tr>
<td></td>
<td>Summer (22.9%)</td>
<td>73.3</td>
</tr>
<tr>
<td></td>
<td>Winter (27.4%)</td>
<td>54.3</td>
</tr>
<tr>
<td>Gender</td>
<td>Female (19.1%)</td>
<td>50.0</td>
</tr>
<tr>
<td>(x2 = 8.890, df = 4, p = 0.064)</td>
<td>Male (80.9%)</td>
<td>66.1</td>
</tr>
<tr>
<td>Age</td>
<td>Under 20 (1.9%)</td>
<td>71.4</td>
</tr>
<tr>
<td>(x2 = 15.266, df = 20, p = 0.761)</td>
<td>20 to 29 (14.9%)</td>
<td>69.6</td>
</tr>
<tr>
<td></td>
<td>30 to 39 (26.1%)</td>
<td>61.2</td>
</tr>
<tr>
<td></td>
<td>40 to 49 (27.4%)</td>
<td>64.1</td>
</tr>
<tr>
<td></td>
<td>50 to 59 (25.8%)</td>
<td>58.8</td>
</tr>
<tr>
<td></td>
<td>Over 60 (4%)</td>
<td>66.7</td>
</tr>
<tr>
<td>Experience</td>
<td>Experienced (84.3%)</td>
<td>61.2</td>
</tr>
<tr>
<td>(x2 = 9.949, df = 4, p = 0.041)</td>
<td>New Worker (15.7%)</td>
<td>72.9</td>
</tr>
<tr>
<td>Nationality origin</td>
<td>Australian (75.8%)</td>
<td>67.4</td>
</tr>
<tr>
<td>(x2 = 18.553, df = 8, p = 0.017)</td>
<td>Non-Australian (13.6%)</td>
<td>58.8</td>
</tr>
<tr>
<td></td>
<td>Unknown (10.5%)</td>
<td>37.5</td>
</tr>
<tr>
<td>Native language</td>
<td>English (96.3%)</td>
<td>63.3</td>
</tr>
<tr>
<td>(x2 = 7.955, df = 8, p = 0.438)</td>
<td>Non-English (2.1%)</td>
<td>62.5</td>
</tr>
<tr>
<td></td>
<td>Unknown (1.6%)</td>
<td>50.0</td>
</tr>
</tbody>
</table>
4.1 Mechanism of incident

Data analysis revealed that work pressure and workplace harassment and bullying are the major causes of psychological injuries among construction workers with almost one-third of incidents are attributable to each. Moreover, these mechanisms are represented heavily in the major, sever and critical categories of injury severity. That is, work pressure recorded a total of 43.20% incidents in these categories whilst workplace harassment and bullying represented a total of 45.7%. Chi-square test results ($\chi^2 = 50.909, \text{df} = 24, p = 0.001$) reveal that there is a statistically significant association between injury severity levels and incident mechanisms.

4.2 Occupation

In terms of occupation, trades personnel were heavily represented in psychological incidents, followed by office-based employees of construction organisations and then machinery operators. Even though no statistically significant association between the occupations and the psychological injury severity levels was observed ($\chi^2 = 28.047, \text{df} = 20, p = 0.108$), a quarter of office-based employees in construction suffered severe injuries, which resulted in time-off-work between 100 days and a year.

4.3 Work shift

No statistically significant association was observed between work shifts and psychological injury severities ($\chi^2 = 13.257, \text{df} = 12, p = 0.351$). This finding contradicts with literature on severities in physical injuries, which confirms that a large proportion of fatalities occur in afternoon shifts (known as ‘after lunch effect’), and more injuries occur in morning shifts. However, night shift workers represent psychological injury statistics heavily, across severity categories of major, sever or critical.

4.4 Worker’s gender

Females accounts for only 13% of the South Australian construction workforce (Australian Bureau of Statistics 2013); but, they are represented doubled the rate for male workers in severe psychological injuries, as revealed in this study. In other categories of severities, females and males seem to represent almost similarly, leading to weak chi-square statistics ($\chi^2 = 8.890, \text{df} = 4, p = 0.064$) to conclude that there is no significant association between gender and psychological injury severity.

4.5 Worker’s age

Past studies on physical injuries have concluded that the severity of physical injury increases with the age of workers (Arquillos et al. 2012). However, this study has found that there is no significant association between the age and the severity of psychological injury ($\chi^2 = 15.266, \text{df} = 20, p = 0.761$). Age groups such as 30 - 39, 40 - 49 and 50 - 59 are nearly equally represented in the overall records.

4.6 Worker’s experience

This study indicated a weak association between experience and psychological injury severity ($\chi^2 = 9.949, \text{df} = 4, p = 0.041$). In contrary to psychical injuries reported in literature, new workers represented double the rate of experienced workers in the severity category of ‘critical’ psychological injuries that lead to time-off-work for longer than a year.
4.7 Worker's nationality origin and native language

Australian-born workers represented more in psychological injury statistics than overseas-born workers and an association is noted between the nationality origin and the injury severity ($x^2 = 18.553$, df = 8, $p = 0.017$). However, language background of the worker did not show any association. Australian workforce comprises 26% persons born overseas (Australian Bureau of Statistics 2010), but their representation in psychological injury statistics (13.6%) is lesser. Nevertheless, they are disproportionately represented (37.2%) in injury categories of major, severe and critical.

4.8 Employer size

Only minor differences in the number of psychological incidents was observed across employer sizes though a significant association between the employer size and injury severity levels was apparent ($x^2 = 29.209$, df = 12, $p = 0.004$). Small organisations represent more in minor incidents whilst nearly 25% of incidents occurred in medium-sized organisations resulted in severe or critical injury outcomes. A similar proportion of incidents in large organisations caused major psychological injuries. No significant differences in the percentage of critical incidents arose in small and medium organisations.

4.9 Season

The climatic season of winter recorded slightly a higher number of incidents (27.4%) of psychological injuries than spring (25.3%) and autumn (24.5%). Similarly, winter accounted for the largest proportion of major, sever and critical incidents than the other seasons, with a total of 41.8% of all the incidents occurred in that season. Chi-square test results also prove that there is a strong association between the season and injury severity ($x^2 = 27.245$, df = 12, $p = .0007$).

5. Qualitative data analysis and findings

The quantitative analysis displayed the aforementioned patterns within the incident cases. However, they did not explain the underlying issues that yield them. Hence, the qualitative analysis probed into the incident descriptions reported by victims and the following trends were discovered.

- One of the major causes of work pressure was excessive workload along with working long hours, sometimes continuously working without breaks, and trying to achieve unrealistic goals set by the management. Most of the workers were unable to cope with such excessive workloads, found the job to be very stressful and ended up having anxiety and depression. As reported by one of the victims “I was standing in the yard, shaking in tears, unable to achieve...... build up of pressure due to worrying about getting the job done on time........ unbearable work load”.

- Under workplace harassment, bullying was reported to be the major issue followed by verbal abuse and sexual harassment. Interestingly these were mainly committed by co-workers rather than the management or employer. In most cases victims reported an ongoing harassment for a long time; for example, a worker indicated “I was going about my normal duties and could no longer handle the harassment and bullying that I was suffering. I find harassment about on that I had nothing to do with”. Few cases of threatening behaviours either by a co-worker or employer were also reported. For example, a worker reported “I was victimised by the directors of the company and made to feel threatened and bullied. I feared for my life and felt
very unsafe at work. I had to call the police” and another worker alleged “I received threatening phone calls at night. Caller said he would kill or damage me and my family”.

- Few workers reported stress and anxiety due to repetitive tasks over a long period of time. Others reported work environment to be the major cause of work pressure. They have experienced intolerable conditions and unsafe work practices that led to work stress.
- Confrontations with the employer or management were reported as causes of work stress. Arguments, aggressive and violent actions at meetings, false accusations, allegations of misconduct were the major reasons behind these confrontations.
- Job uncertainty, non-payment, underpayment or delayed payments of wages were also found to have caused depression. In few cases, unfair dismissals have caused stress.
- Work situation (isolation) and workload were cited as main reasons for anxiety and depression that led to very long absenteeism.

The qualitative analysis was extended to scrutinise the level of injury severity against incident descriptions and discovered the below patterns in the incident cases.

- Critical incidents were predominantly caused by multiple sources of harassment over a period; for example, “work and work environment causing anxiety, panic attacks and depression due to harassment, bullying and victimization”; and “workplace bullying, verbal and behavioural threats, sexual harassment, undermining authority, defamation”.
- Unlike the above, severe incidents were equally caused by harassment and work pressure. Seventy-five percent of major incidents were caused by work pressure while only 25% were due to harassment; for example, a worker reported “work related stress and anxiety due to staff shortages and performing work of two”, and another worker’s account “work pressure, working long hours, work overload, and overseeing too many projects”.

6. Discussion

The empirical analysis investigated the influence of personal factors (age, gender, experience, nationality and language background), work factors (occupation, work shift, work conditions, and employer) and environmental factors (season) on the psychological injury outcomes in the construction industry. It has been found that work factors have predominant influence in psychological injuries than other factors. Hence, the seven themes discovered in the literature research are confirmed to be relevant to the construction industry. However, the degree of influence varies in the construction industry setting in the descending order of: (1) workplace harassment and bullying, (2) work pressure, (3) work-life conflict, (4) discrimination, (5) poor physical work environment, (6) job uncertainty, and (7) poor workplace relationships. Similarly, the above order is also a reflection of the severity of these incidents, where harassment and bullying resulting mainly in critical to severe outcomes while work pressure and work-life conflict lead to severe to major outcomes. Other causes are not generally associated with higher order severities. It is interesting to observe that all critical incidents, except four cases, were caused by harassment and bullying. Thus, the study clearly highlights the need for curbing harassments and bullying to make construction workplaces free from critical psychological incidents.
7. Formulation of a causation model for psychological injuries

The findings of the two distinct research methods were consolidated and corroborated towards formulating a causation model for psychological injuries in the construction industry. Figure 2 demonstrates the model by mapping out the factors and their influence paths. The far left end of the diagram encompasses seven umbrella stressors with their originating sources. Being a victim of one or a combination of these stressors causes emotional distress with feelings such as tension, anxiety, insecurity, frustration and/or trauma in workers. Enduring these distress symptoms for an extended period can lead to excessive mental stress. When the excessive stress is not controlled, it can result in psychological depression, which often impacts on the physical health, behavioural and social patterns/habits, work performance and family relationships. These negative consequences in turn reinforce the emotional distress and mental stress.

![Figure 2: Causation model for psychological injuries](image)

8. Conclusion

While numerous models have been developed by researcher to explain the causation of workplace accidents and health damages that occur to construction workers, silently suffered psychological injuries have not gained attention. This study proposes a causation model, which maps out seven factors along a stress influence path. The factors include: workplace harassment and bullying, work
pressure, work-life conflict, discrimination, poor physical work environment, job uncertainty, and poor workplace relationships. The degree of distress exerted by workplace harassment and bullying, and work pressure is found to be more significant in the construction industry context than that of caused by other stressors. Workplace harassment and bullying have the potential to cause psychological damages that can lead to lost days in excess of a year and excessive work pressure could result in lost days due to psychological injuries longer than 100 days. Hence, these factors warrant special attention and scrutiny from organisational management as well as WHS authorities in order to maintain a construction industry that is free from serious or critical psychological incidents.

References


CSA (2013) Psychological health and safety in the workplace —Prevention, promotion, and guidance to staged implementation, Canada, Canadian Standards Association.


SECTION

5

Sustainable construction
Global Real Estate Sustainability Benchmark (GRESB Survey): Improving Sustainability Performance in the Commercial Real Estate Sector in the Nordics

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Abstract

Considering the globe and the built environment, commercial real estate sector is one of the largest consumers of natural resources and greatest polluter with reference to GHG emissions and solid waste production. Among initiatives to reduce environmental impact of commercial real estate industry, Global Real Estate Sustainability Benchmark or as since December 2015 GRESB Real Estate Assessment (GRESB Survey) focuses on collecting information regarding sustainability performance of property companies and funds.

The purpose of this paper is to analyse GRESB Survey as a tool to improve the sustainability performance of commercial real estate industry. Drivers to participate, benefits, best practices and challenges with GRESB Survey among Nordic real estate companies and funds were analysed in the recent research conducted by the author.

This research on GRESB Survey and commercial real estate sustainability is a practical investigative research conducted during October 2014 – April 2015. Research data was collected by interviews and web surveys. Interviews and web survey addressed four different target groups; real estate investment companies and funds, real estate user owners, GRESB investor members and institutional investors aligned with principles of responsible investment.

Benchmark data with peer organizations provided by GRESB Survey directs participants’ sustainability efforts, helps in allocation of resources, brings sustainability on the top management agenda and connects companies with investors on sustainability issues. GRESB Survey participation requires dedication, time, resources and willingness to meet challenges. GRESB Survey develops in agile way and it is expected to “raise the bar” over the years and become more analytical and detailed. Together with development of GRESB Survey itself and growing number of users, also other actors within real estate industry are developing new services and aligning existing services to better support real estate companies and funds with sustainability performance improvement through the GRESB Survey.

Keywords: Sustainability, ESG, GRESB Survey, GRESB Assessment, sustainability services
1. Introduction

Sustainable development is about integrating the needs of society while maintaining earth’s ecological capacity and not endangering the possibility of future generations to meet their needs. Three dimensions of sustainable development; economical, environmental and social dimension, are interdependent and mutually reinforcing.\(^1\) Built environment and buildings are responsible annually on global level for more than 40% of energy consumption, 30% of energy-related greenhouse gases (GHG) emissions and considering the whole building sector 30% of resource consumption, 12% of fresh-water use and 40% of total solid waste generation. On average building sector employs more than 10 % of global workforce. Construction and real estate sector play a significant role in the response to climate change and have substantial potential for sustainable reduction of emissions with minimum investments or even with net savings.\(^2\) Considering the globe and the built environment, commercial real estate sector is one of the largest consumers of natural resources and greatest polluter with reference to GHG emissions and solid waste production.\(^3\)

Along growing global awareness of the environmental impact of buildings and commercial real estate, sustainability has gained more important role in the real estate sector with environmental sustainability focus. However, the adaptation of sustainable principles has been hindered by the lack of evidence of concrete financial benefits and common agreements how to share the cost burden and benefits between investors, owners, fund managers and tenants regarding investments improving sustainability in real estate sector.\(^4\)

Among initiatives to reduce environmental impact of commercial real estate industry, GRESB Survey focuses on collecting information regarding sustainability performance of property companies and funds. Benchmark information serves institutional investors and participants themselves to monitor, benchmark and improve sustainability performance further. GRESB Survey is aligned with international sustainability reporting schemes as Global Reporting Initiative G4 (GRI G4), UN Principles for responsible investment (PRI), Dow Jones Sustainability Index (DJSI) and Carbon Disclosure Project (CDP). GRESB Survey is not limited on environmental aspects only while it covers broader sustainability issues in terms of ESG criteria, such as sustainability management, assessment of sustainability risks, sustainability improvement programs and stakeholder engagement.\(^5\)

GRESB Survey participation requires dedication, time, resources and willingness to meet challenges. GRESB Survey develops in agile way and it is expected to “raise the bar” over the years and become more analytical and detailed. Together with development of GRESB Survey

\(^{2}\) UNEP (n.d.) online.
\(^{3}\) Bauer et al. (2010) p.17.
itself and growing number of users, also other actors within real estate industry are developing new services and aligning existing services to better support real estate companies and funds with sustainability performance improvement through the GRESB Survey. The purpose of this paper is to analyse GRESB Survey as a tool to improve the sustainability performance of commercial real estate industry and to discuss the range of services Ramboll can provide to real estate companies and funds to support both GRESB Survey participation and consequent development processes to improve sustainability performance further.

Two following chapters describe GRESB Survey and applied research methodology. The chapter four focuses on benefits and challenges related to GRESB Survey as well as on identified best practices and GRESB Survey’s potential to improve sustainability performance of real estate investment funds and companies. Furthermore available tools and external services supporting GRESB Survey participation are discussed. Last chapters focus on business opportunities around GRESB Survey and its significance to different actors among commercial real estate industry.

2. About GRESB Survey

GRESB –survey was started in 2009 through a survey project of Maastricht University aiming to develop “Environmental real estate index”. In five years GRESB Survey has developed into a global standard to assess the sustainability of real estate portfolios.

GRESB Survey contains 42 basic questions and 14 questions covering new construction and major renovation activities. The survey collects information on performance data as energy, GHG emissions, water and waste. In addition GRESB Survey covers also sustainability risk assessment, performance improvement programs and engagement with employees, tenants, suppliers and community. Reported sustainability aspects are divided into following sections:

- Management e.g. strategy, objectives, resources, decision-making.
- Policy and disclosure e.g. guidelines, policies, reporting and third party reviews.
- Risks and opportunities e.g. governance and sustainability.
- Monitoring and environmental management systems and certifications.
- Performance indicators e.g. energy, GHG and water data, waste management.
- Building certifications e.g. green building certificates and energy ratings.
- Stakeholder engagement e.g. employees, tenants, suppliers and local communities.
- New construction and major renovations:
  - Sustainability requirements of projects and sites
  - Community engagement and socio-economic impact
  - Materials and certifications
  - Energy efficiency
  - Requirements for occupant wellbeing, energy and water efficiency
  - Supply chain requirements
  - Health and safety on-site
GRESB allocates an overall GRESB score to each participating real estate company or fund. Due to complexity of the sustainability and real estate sector as well as variations between countries and regulatory environments, companies and funds are analysed through peer group benchmark instead of absolute sustainability performance. Peer group comparison takes into account country, regional, sector and investment type of variations.

Participation to GRESB Survey is free of charge. GRESB on-line survey reporting period is between 1st of April and 1st of July. Survey submissions are validated during the months of July and August. GRESB Survey results are published in September. Participants receive their GRESB Scorecard with headline results as overall score, strengths and weaknesses and the score on reported sustainability aspects. For extra charge, survey participants can purchase complete and more detailed benchmark report covering single answers of the GRESB Survey. Key figures describing the scope of GRESB Survey are illustrated in the table below.

Table 1: GRESB Survey highlights 2014-2015.

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GRESB participants</strong></td>
<td>637</td>
<td>707</td>
</tr>
<tr>
<td><strong>GRESB investor members</strong></td>
<td>46</td>
<td>51</td>
</tr>
<tr>
<td><strong>Company and fund manager members</strong></td>
<td>56</td>
<td>87</td>
</tr>
<tr>
<td><strong>Associate members</strong></td>
<td>21</td>
<td>28</td>
</tr>
<tr>
<td><strong>Partners</strong></td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td><strong>Institutional capital</strong></td>
<td>$5.5 trillion</td>
<td>$6.1 trillion</td>
</tr>
<tr>
<td><strong>Property value</strong></td>
<td>$2.1 trillion</td>
<td>$2.3 trillion</td>
</tr>
<tr>
<td><strong>Assets covered</strong></td>
<td>56000</td>
<td>61000</td>
</tr>
<tr>
<td><strong>New construction and major renovation assets</strong></td>
<td>3329</td>
<td>4127</td>
</tr>
</tbody>
</table>

3. Research methodology

This research on GRESB Survey 2014 and commercial real estate sustainability is an investigative field study. Collection of research data was conducted between October 2014 and March 2015. Data was collected by interviews and with web-surveys. Nine interviews were conducted in November 2014 with a sustainable investment consultant and five real estate companies and funds in Finland and in Sweden.

Web-surveys were conducted with Webropol on-line survey and analysis software. Altogether four web-surveys were conducted for different commercial real estate actors. Web-surveys for real estate companies, funds and user-owners were conducted between December 2014 and March 2015. Target group was divided in two groups; companies already participating into GRESB Survey (GRESB - pioneers) and companies potentially interested in participation into GRESB Survey (GRESB - potentials). Web-surveys for investors were conducted between January and March 2015. Also investor target group was divided into two; GRESB investor
members (GRESB – investors) and investors not being members of GRESB (Non-GRESB-investors).

Web-surveys included both multiple choice and open-ended questions. Survey was sent as an email link to targeted respondents and survey was also promoted in social media, LinkedIn. The survey had total 41 respondents (including the interviews) and the distribution of respondents is illustrated in following table. Sample size is approximate due the promotion of the survey in social media, but illustrates the number of emails sent to target groups with the survey link. Web survey participation was voluntary and respondents could skip any question and discontinue at any point. All responses are anonymous and kept confidential.

<table>
<thead>
<tr>
<th>Target group</th>
<th>Responses</th>
<th>Sample size</th>
<th>Response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRESB – pioneers</td>
<td>14</td>
<td>15</td>
<td>93 %</td>
</tr>
<tr>
<td>GRESB – potentials</td>
<td>17</td>
<td>70</td>
<td>24 %</td>
</tr>
<tr>
<td>GRESB – investors</td>
<td>7</td>
<td>33</td>
<td>21 %</td>
</tr>
<tr>
<td>Non–GRESB-investors</td>
<td>3</td>
<td>50</td>
<td>6%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>41</td>
<td>168</td>
<td>24 %</td>
</tr>
</tbody>
</table>

At the time of the research a total of 15 real estate investment companies and funds were identified as GRESB Survey participants in the Nordics. Later it was revealed that altogether 21 real estate companies and funds in the Nordics participated into GRESB Survey in 2014 and the number of participants grew into 41 participants in GRESB Survey 2015.6

The aim of the research was to understand:

- Benefits of GRESB Survey?
- Best practices and challenges with GRESB Survey?
- If GRESB Survey does help companies and investors to improve the overall sustainability performance? And how eventually?
- On what matters are external partners used in sustainability reporting process and GRESB Survey participation?
- What kind of tools, programs and software is used to facilitate data collection in connection to sustainability performance indicators?

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4. Impressions about GRESB Survey

Real estate companies and funds, especially listed ones, are faced by the burden of "multiple sustainability reporting". Some of the sustainability reporting frameworks such as GRI, CDP, DJSI and EPRA are well established and "institutionalized" among commercial real estate companies and funds in their efforts to communicate to their owners, investors, creditors and other stakeholders about their sustainability efforts and commitment. What are the perceptions towards GRESB Survey, an additional sustainability reporting framework among many others?

Real estate companies and funds participating into GRESB Survey consider it the most important sustainability reporting scheme backed by GRI sustainability reporting. GRESB Survey is seen to have focus on industry-related, material aspects and as a valuable tool for improving the sustainability performance of real estate companies, funds and commercial real estate portfolios. Benchmark data with peer organizations directs sustainability efforts, helps in allocation of resources, brings sustainability on the top management agenda and connects companies with investors on sustainability issues. It should not be seen as “judgement” of existing practices, but as a starting point of a continuous improvement process.

4.1 Benefits of GRESB Survey

While asking the importance of different sustainability reporting and assessment schemes, there is no doubt of how strong position GRESB Survey has when compared with sustainability reporting frameworks as illustrated in Figure 1. GRESB pioneers as reporting companies consider also the importance of other schemes as GRI reporting and EPRA Sustainability BPR. Sustainability reporting according GRI guidelines is considered by one interviewee as something that “Once you start, you can’t give it up...” It is very improbable that GRESB – survey would replace GRI sustainability reporting as GRI serves all stakeholder groups and is an “open access system” once published on-line.

According to GRESB – potentials open-ended responses, sustainability reporting pushes companies to set indicators in the first hand. Monitoring and reporting on environmental e.g. energy indicators leads to setting more precise targets for improvement and follow-up of the performance. Setting up reasonable targets enables reaching them with natural consequence of
positive results that motivates companies to set more challenging targets, widening the scope of environmental targets or investing in sustainability efforts.

Figure 2 illustrates benefits GRESB Survey provides both for GRESB – investors and GRESB – pioneers. Among benefits provided by GRESB Survey, the GRESB – investors emphasized increased transparency towards investors themselves as the key benefit provided by GRESB Survey. According to open-ended answers GRESB Survey gives investors pieces of information they have not thought about before and this information can be used as a catalyst for new sustainability initiatives. One respondent highlights the idea of implementing a “robust” Green Lease as new standard for all office and retail asset. When not all companies and funds within the investment portfolio are participating into GRESB Survey, investors tend to engage with them with issues and ideas from GRESB Survey, resulting in improvement the overall sustainability performance of the portfolio.

Communication and branding benefits as well as improved credibility of sustainability disclosure rank high among benefits of GRESB – pioneers. Furthermore the survey gives new ideas from peer group and from the survey itself. GRESB Survey directs sustainability efforts by evidencing aspects that may not be considered earlier and showing where the industry is heading to regarding sustainability. Several interviewees see GRESB Survey as a development tool for sustainability, showing what is material and important in the real estate industry. GRESB Survey encourages self-evaluation which leads to self-reflection and works as natural, in-born catalyst for sustainability improvements.

Figure 2: Benefits provided by GRESB Survey.

One interviewee emphasizes the global focus and approach to sustainability innovations of GRESB Survey as feeding the real estate industry over the time with new ideas as innovations become everyday work and are found as a part of the GRESB Survey questions.
After completing GRESB Survey, as revealed by open-ended responses participants got to know what they have to actually work with e.g. focus more on water consumption of to develop external communication about sustainability on their website. GRESB Survey reveals strengths and weaknesses of companies and helps to prioritize and allocate resources correctly in actual and relevant sustainability aspects.

Improved transparency and connectivity with investors is naturally important for GRESB – pioneers. Furthermore GRESB Survey is described in open-ended responses of GRESB - pioneers also as a tool for putting sustainability on the agenda of top management in concrete and appetizing way. First it pushes for more structured management of sustainability aspects and making sustainability more concrete and simpler to deal with. Second as a consequence, GRESB Survey facilitates target setting, measurement and communication about sustainability efforts with management, investors and own personnel. As one interviewee describes: “GRESB Survey visualizes connection between sustainability work and progress to all employees. It gives a new meaning to sustainability work.”

4.2 Challenges and best practices with GRESB Survey participation

Challenges experienced with GRESB Survey participation are dependent on knowledge and experience of sustainability reporting and sustainability data collection practices of participating organizations. Many of private real estate investment companies and funds are small and medium sized companies (SME), often with less than 30 employees. Private SMEs have also different governance and reporting obligations as listed, public real estate investment companies and funds.

Data collection and processing existing data into GRESB Survey – format, where the aim is to collect data by property types and separate consumption and waste data between landlord and tenants. When portfolio includes many multi-purpose properties, division of energy consumption data between different property types leads to excessive manual calculation and aggregation of performance indicators. Generally the amount of data; performance indicators, process descriptions and evidencing documents may be challenging for SMEs and portfolios with large number of properties.

Survey is perceived as rigid and data to be submitted must be very precise. As GRESB Survey has global reach and it develops over the time, some questions remain generic, difficult to understand and without common clarification.

Respondents were asked to share best practices applied in connection of GRESB Survey participation. First timers should consider GRESB Survey as a starting point in a process of continuous improvement, not as judgement of existing policies and performance. When there is no clarification for a problem participant is dealing with, it is important to make own conclusions and assumptions, explain them thoroughly and be consistent with methodology over the time. Time and resources can be saved by getting familiarized with GRESB Survey guidance, committing top management and other people and functions needed in reporting
process properly and well in advance. Sharing and publishing information about sustainability commitment, efforts and activities facilitates GRESB Survey submission. One respondent describes: “Don’t overdo. Use what you have and build on that.”

4.3 Does GRESB Survey help to improve sustainability performance?

One central question of this survey is, whether GRESB Survey actually helps companies to improve sustainability performance. To start the analysis it is feasible first to understand what kind of benefits improved sustainability performance may offer to real estate companies and funds according all respondent groups. Improved sustainability is first associated with reduced operating costs and environmental impact of properties. Secondly it is associated with health, comfort and higher quality of buildings, which consequently may result in improved tenant satisfaction and commitment. Furthermore branding, marketing and sales related benefits are emphasized together with meeting investors’ and shareholders’ sustainability criteria (Figure 3).

![Figure 3: Benefits of improved sustainability performance.](image3.png)

Both GRESB – pioneers and GRESB – investors were asked whether GRESB Survey helps to improve overall sustainability performance, on company or on the real estate investment portfolio level. All except one of GRESB – investors witnesses GRESB Survey role in this improvement process Within GRESB – pioneers majority sees GRESB Survey as a tool for improving overall sustainability performance, but the difference is not so clear (Figure 4).

![Figure 4: Does GRESB Survey help in improving sustainability performance?](image4.png)
Still interviews and open ended comments emphasize clearly the practicality, benchmarking function and real estate industry focus of GRESB Survey in improving sustainability performance of companies and funds.

4.4 GRESB Survey and external partners, tools, programs and software

External partners are used in connection to sustainability reporting and GRESB Survey by two thirds of respondents in both GRESB pioneers and GRESB potential group. One group of external partners are marketing and communication agencies providing services for design, repro, printing and composing texts. Consumption data collection, calculation of emissions and environmental performance indicators as well validation of data to be reported is other group of tasks that are commonly outsourced to external partners. As already mentioned GRESB Survey indicators require asset level data, division between landlord and tenant as well as aggregation of data by property types, which may make the GRESB Survey more challenging in comparison to GRI sustainability reporting.

![Figure 5: Does GRESB Survey help in improving sustainability performance?](image)

According to the open-ended responses, almost half of the respondents both in GRESB – pioneers and GRESB – potential groups use a variety of tools, programs and software to facilitate sustainability reporting and actual sustainability performance at the end. Data management systems are getting more sophisticated and more commonly used by real estate companies. Furthermore data management systems are also adapted to meet the criteria and requirements of different sustainability reporting frameworks. Good example of this is Nuuka Solutions’s DMS elaborating data into GRESB Survey format, developed together with Genesta Property Nordic AB. This is a good example how sustainable innovations and practices are spread and shared for the benefit of whole industry and society.
Respondents use both internally and externally developed software and tools for data collection, monitoring and reporting. In some cases existing applications as electronic maintenance manual is customized and developed further to provide information for sustainability monitoring and reporting. In some cases the overall responsibility on data collection, monitoring and reporting is given to service providers. Most commonly used external tools are: Vitec Energy / WebEss, Credit 360°, Nuuka DMS and RESPECT Europe Svante. Widening the focus from energy, water, waste and GHG data collection and monitoring into overall sustainability data collection, some respondents view this comprehensively summing up different stakeholder, employee and customer satisfaction surveys with data management as well as financial reporting and consolidation tools.

5. Discussion

External partners as consultants should be recognizing the growing importance of GRESB Survey in improving the sustainability performance of real estate investment companies and funds. Sustainability communication and reporting is not requested only from listed, public real estate investment companies and funds, smaller organizations should follow and adopt new practices to meet growing demand for sustainability data by tenants, investors, financers and employees. Ramboll has recognized this opportunity and actively aligns existing services and develops new services to facilitate GRESB Survey participation to any size of real estate investment companies and funds. It is not only organizations participating into GRESB Survey, but also institutional investors and financing institutions which can be helped by Ramboll to develop further their sustainability assessment process of commercial real estate portfolios within the GRESB Survey framework.

Ramboll has gained a wide knowledge and experience around GRESB Survey and works actively with real estate companies and funds by providing various services to facilitate GRESB Survey participation of first timers and more experienced participants. Ramboll GRESB Survey services cover the whole GRESB Survey process from assessing the actual state of sustainability management, monitoring and reporting capabilities into analysing GRESB Benchmark Report with identification of respective short-, medium- and long-term development issues. Most successful project resulting in GRESB Green Star award and comprehensive development of sustainability performance has been carried out as in-house consulting.

6. Conclusions

GRESB Survey is considered very important sustainability ranking scheme by respondents, backed up by GRI reporting. GRESB Survey offers new ideas and insight both for the improvement of sustainability performance of real estate investment companies and funds as well for sustainability assessment process of institutional investors. GRESB Survey is material and practical framework which improves sustainability performance of real estate investment companies and funds and investor members’ commercial real estate portfolios.
Benchmark data with peer organizations directs sustainability efforts, helps in allocation of resources, brings sustainability on the top management agenda and connects companies with investors on sustainability issues.

GRESB – survey participation requires dedication, time, resources and willingness to meet challenges. Pioneering real estate consultants as Ramboll are aware of the growing role of sustainability in improving overall profitability of real estate investment companies and funds and securing long-term value of properties. GRESB Survey has proven to be a material, concrete tool in improving sustainability performance of commercial real estate industry by pushing participants to improve sustainability management and communication processes.

External partners as consultants have been recognizing the growing importance of GRESB Survey in improving the sustainability performance of real estate investment companies and funds. Wide range of skills and capabilities are developed to support listed, public real estate investment companies and funds, as well as private real estate investment companies and funds in their sustainability work to meet requirements of institutional investors covering commercial real estate investment universe. GRESB Survey will develop and “raise the bar” until sustainability will be managed with same regime and accuracy as company financials.

References


UNEP (2009) Sustainable buildings and climate initiative, (available online http://www.unep.org/sbci/AboutSBCI/Background.asp [accessed on 15/5/2015])
A Study on the Expansion of Database for Establishing Low Energy Building Materials Information Portal

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Abstract

The purpose of this study is to provide reliable service of materials information portal through the establishment of public big data by collecting and integrating scattered low energy building materials and equipment data. In the establishment of low energy building materials database in the country, there was almost no case of integrating scattered data based on the standardized data classification system and code. Therefore, data attribute items were extracted based on information highly used in the building market in this study in order to establish building materials database, and data standardization was carried out through the definition of attribute of such entities.

Keywords: Materials information portal, building materials database, entity definition, data standardization

1. Introduction

Price comparison web sites in Korea mainly target consumer goods used in everyday life such as clothing and home appliances, but a website providing real estate information has appeared recently so that the object of service is becoming more diversified. The service provided by those web sites is mostly price comparison, product and consumer review information, allowing users to obtain information regarding a desired product and product manufacturers to have price competitiveness. When consumers purchase a product, the product, product quality and diversity are emphasized for decision making, and they can receive information regarding the product promptly through a price comparison web site and purchase the same product at a low price. Due to such advantage, 51% of consumers who purchased a product actually purchased a product after price comparison through a price comparison web site, and 45.4% among them...
considered product reviews when deciding whether or not to purchase the product (Ma, Mi-Yeong (2008)). The Public Procurement Service, the central procurement agency of Korean government, opened Korea On-line E-procurement system in 2002 and currently 47,000 public agencies and 270,000 procurement companies use this system in all procurement stages including the registration of company, bidding, contract, inspection and payment (Public Procurement Service (2015-1)). Korea On-line E-procurement system plays a role of single window for public e-procurement by integrating bidding information of all public agencies, but since publicness of purchase should be considered in addition to economic rationality, so this system has the relevant limitation unlike private procurement. The purpose of this study is to establish low-energy building materials information database in order to provide low-energy building materials information portal service by applying the concept of price comparison web site explained above into building materials & equipment field.

The low energy building materials information portal (hereinafter referred to as 'materials information portal') in this study is established at national level with quasi-governmental agencies including Korea Energy Agency and Korea Appraisal Board, and as the concept of general-purpose service targeting whole nation, this portal integrates scattered database and provide reliable contents related to government systems and policies in order to allow portal service users to select a desired product rationally. Also, this portal leads healthy competitions between companies through the product price and quality comparison so that reasonable prices can be established in the market. Besides building materials and equipment data, for service provision, data related to laws, excellent cases of low energy buildings and economic evaluation should be added and supplemented to complete the integrated information database, and building materials database among the integrated information database includes core information for the whole construction tasks including design, construction, purchase and estimate. Therefore, efficient data collection, classification and continuous update regarding building materials are required, so the purpose of this study is to examine the establishment and expansion of materials database for establishing materials information portal.

2. Status of materials database establishment in Korea

2.1 Korea Prices information

Korea Price Information, Corp. is a price investigation and cost accounting service agency registered on the Ministry of Strategy and Finance and it has establish database by integrating price and survey information and provides information through Korean prices information sheet through on- and off-line. The price information shown in the prices information sheet can be used in studies and practical fields regarding the calculation of equipment cost and initial investment amount, and basic information such as the model name and specifications is uploaded by companies and the detailed information including product catalogue can be checked through the link of company's website. Information based on the unit price of product is provided except for construction or installation cost.
2.2 Efficiency management machinery, equipment or materials and high-efficiency energy machinery, equipment or materials

Korea Energy Agency operates the energy consumption efficiency rating indication system and high-efficiency energy using appliance certification system, and the energy consumption efficiency rating indication system is the obligatory report system to lead manufacturing companies that produce applicable products for energy consumption efficiency rating indication system to produce and sell energy-saving products (efficiency management machinery, equipment or materials) from the production step in order to allow consumers to check and purchase highly efficient energy-saving products easily. In this system, products are indicated separately into 5 grades according to energy consumption efficiency or energy usage, and the minimum energy efficiency applies to Minimum Energy Performance Standard (MEPS). Target items are 28 items including electric cooling apparatus and an energy consumption efficiency rating label cannot be attached to any product not announced in the Ministry of Trade, Industry and Energy's efficiency management machinery, equipment or materials operating procedure.

High-efficiency energy using appliance certification system is voluntary system to certify a product of which energy efficiency and quality test results satisfies a certain standard announced by the government as high-efficiency energy machinery, equipment or materials. This certification system is to revitalize distribution of high-efficiency energy products and certificate is issued by Korea Energy Agency upon a voluntary request of manufacturing company. The target items are 47 items and any product not included in the application range announced in the Ministry of Trade, Industry and Energy's regulation on the distribution and promotion of high-efficiency energy machinery, equipment or materials is not subject to high-efficiency certification. The materials information database in this study is established with only items related to the building energy usage for two systems above. The characteristics of information included in the prices information sheet in Korea, efficiency management machinery, equipment or materials, and high-efficiency energy machinery, equipment or materials are as shown in Table 1 below and systematic construction of the materials information database is showed in Figure 1.
Table 1: Properties of the materials database in Korea

<table>
<thead>
<tr>
<th>Classification source</th>
<th>Characteristics of available information</th>
<th>Depth of information (e.g.: boiler)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Procurement Service</td>
<td>Building, machine &amp; equipment, electricity, materials and construction cost (Based on price)</td>
<td>Boiler Model name, capacity, unit price</td>
</tr>
<tr>
<td>Prices information sheet</td>
<td>Price information such as building, facility, electricity, lighting and survey information, etc (Based on price)</td>
<td>Gas boiler Model name, company name, specification, unit price</td>
</tr>
<tr>
<td>Efficiency management machinery, equipment or materials</td>
<td>Applicable product for energy consumption efficiency rating indication system (Based on performance)</td>
<td>Gas boiler for home Model name, company name, heating thermal efficiency %, efficiency level</td>
</tr>
<tr>
<td>High-efficiency energy machinery, equipment or materials</td>
<td>Applicable product for high-efficiency test (Based on performance)</td>
<td>Gas boiler for industry-building Model name, company name, rated capacity, efficiency % (total calorific value, net calorific value), air flow rate of air blower, CMM, etc</td>
</tr>
</tbody>
</table>
2.3 Korea On-line E-procurement System of Public Procurement Service

Korea On-line E-procurement System (www.g2b.go.kr) established as one of 11th projects for e-government in 2002 is the comprehensive e-procurement system to enable digitization of transactions between the government, public agencies and companies from purchase decision to payment (Seo, Jin-Wan (2009)), and the size of the public procurement market is 110 trillion KRW as of 2014 (Public Procurement Service (2015-2)) and it plays a role of saving national finance and improving technology competitiveness of companies by making procurement companies to provide quality service at a proper price. However, complicated procedures and unnecessary regulations of public procurement market have brought difficulties to startup companies to enter the procurement market, and excessive authentication requirements regarding products have become a burden to companies (Public Procurement Service (2015-2)). Also, the government procurement has public aspects such as the management of supply market considering the supply aspects, influence on the economy and industry due to public agency's consumption, professional support of procurement activities (Kidd (2007)) besides economic rationality, so the same product can be searched from Internet shopping web site at a lower price than the procurement price and procurement products are posted on Korea On-line E-procurement system for 1 year to 1 and a half year, there is a possibility that the price information may not be updated for a number of months rather than real-time update of price information, and it is the difference of government procurement from the private procurement based on economic rationality.

The materials information portal has no purpose of promoting public system targeting the whole nation or publicness aspect of purchase so that purchase behavior will be carried out according to economic rationality considering quality and price, and when materials production companies post the characteristics, performance and price information of products according to the standardized formats for data upload, consumers will be able to access the product information posted by companies by searching a desired condition.

3. Low energy Building Materials database

3.1 Range of Low energy Building Materials database Establishment

Low energy building materials database is established targeting materials and equipment systems such as insulation materials, windows, air conditioning equipment and boilers that influence the energy consumption of buildings, and the production information such as efficiency management machinery, equipment or materials, high-efficiency energy machinery, equipment or materials managed by Korea Energy Agency are also included. The following table shows the target and range of materials database establishment.
Table 2: Range of materials database establishment

<table>
<thead>
<tr>
<th>Classification source</th>
<th>Classification of establishment items</th>
<th>Number of items</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Public Procurement Service</strong></td>
<td>Insulation material, window, glass, interior finishing materials, exterior finishing materials, blind and shade, etc</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td>refrigerator, air conditioner, ventilator, heat exchanger, heat pump, boiler, duct, etc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lighting fixture, lamp</td>
<td></td>
</tr>
<tr>
<td><strong>Prices information sheet</strong></td>
<td>Insulation materials, glass, window materials, block, roof materials, etc</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>boiler, air conditioner, refrigerator, heater, cooling and heating equipment, etc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lighting fixture, lamp</td>
<td></td>
</tr>
<tr>
<td><strong>Efficiency management machinery, equipment or materials</strong></td>
<td>Windows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electric cooler, electric cold and hot water dispenser, household gas boiler, electric cooler and heater, gas water heater, electric heating fan, multi electric heat pump system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incandescent lamp, fluorescent lamp, lamp with built-in ballast stabilizer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Metals, equipment or materials</td>
<td></td>
</tr>
<tr>
<td><strong>High-efficiency energy machinery, equipment or materials</strong></td>
<td>heat recovery type ventilating system, gas/oil boiler for industry and buildings, pump, centrifugal type &amp; screw type chiller, direct fired and absorptive cold and hot water dispenser, ventilator, centrifugal type air blower, etc</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>metalhalide lamp, embedded and fixed LED light fixture, light fixture for electrodeless fluorescent lamp</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Code system of low energy building materials database

In order to consider operation and management of materials database in future and enable linkage and operation with domestic building materials database later, the product list system and classification code of Public Procurement Service were introduced. The classification code was same with Public Procurement Service's code until sub-class, and the code for sub sub-class was recomposed according to the range of data to be established in this study. The established database for low energy building materials and equipment related insulation material, window, glass, refrigerator, boiler and lighting fixture was classified into 5 levels and 165 cases were coded. Table 3 shows a part of building material items.
<table>
<thead>
<tr>
<th>Major Class</th>
<th>Middle Class</th>
<th>Minor Class</th>
<th>Sub-class</th>
<th>Sub Sub-class</th>
<th>Code name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building materials</td>
<td>Insulation material</td>
<td>Heat insulation material</td>
<td>03</td>
<td>Bubble insulation material</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>08</td>
<td>Fiber insulation material</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>Foam polystyrene insulation material</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td>Extruded foam polystyrene insulation material</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Special insulation material</td>
<td>01</td>
<td>Soundproof insulation material</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>04</td>
<td>Spray coating insulation material</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>04</td>
<td>Spray coating insulation material</td>
<td>02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>99</td>
<td>Fire resistive covering material</td>
<td>01</td>
</tr>
<tr>
<td></td>
<td>Door</td>
<td>01</td>
<td>Glass door</td>
<td>01</td>
<td>Glass door</td>
</tr>
<tr>
<td></td>
<td></td>
<td>04</td>
<td>Timber door</td>
<td>01</td>
<td>Timber door</td>
</tr>
<tr>
<td></td>
<td></td>
<td>05</td>
<td>Metallic door</td>
<td>01</td>
<td>Metallic door</td>
</tr>
<tr>
<td></td>
<td></td>
<td>88</td>
<td>Synthetic resin door</td>
<td>01</td>
<td>Synthetic resin door</td>
</tr>
<tr>
<td></td>
<td>Window</td>
<td>95</td>
<td>Synthetic resin window</td>
<td>01</td>
<td>Synthetic resin window</td>
</tr>
<tr>
<td></td>
<td></td>
<td>96</td>
<td>Timber window</td>
<td>01</td>
<td>Timber window</td>
</tr>
<tr>
<td></td>
<td></td>
<td>98</td>
<td>Metallic window</td>
<td>01</td>
<td>Metallic window</td>
</tr>
<tr>
<td></td>
<td>Glass &amp; glass products</td>
<td>05</td>
<td>Laminated glass</td>
<td>01</td>
<td>Laminated glass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>06</td>
<td>Tempered glass</td>
<td>01</td>
<td>Tempered glass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>08</td>
<td>Plate glass</td>
<td>01</td>
<td>Colored glass</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>02</td>
<td>Clear glass</td>
<td>3017170802</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>03</td>
<td>Flat glass</td>
<td>3017170803</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>04</td>
<td>Embossed</td>
<td>3017170804</td>
</tr>
</tbody>
</table>
3.3 Establishment of low energy building materials database

Data modeling work is necessary for database establishment, and for this, the list and specification of entities are prepared and database is established according to the list and specification of entities. At first, an entity is tangible (eg: person, automobile, etc) and intangible (eg: hobby, trip, etc) information and it is defined as several related attributes which could explain and characterize the relevant information. The list of entities contains information regarding source of data, change period and number of materials for each data item to be established, so it is prepared to determine data area and capacity, and the specification of entities is prepared to define attributes related to data to be established and establish the relevant attribute information. Figure 2 shows the list and specification of entities in materials database.

Attribute information of materials database can be classified into general item and detailed information item for each product. Data was established with information that could include the product performance and characteristics information by collecting basic information such as product model name, image, company name, price and specifications in general item and collecting advisory opinions from employees of materials production and sales companies for the detailed information. The materials information data for materials information portal should be established to draw materials information search function as well as service result in economics section such as energy consumption reduction effect and cost recovery period according to the application of materials selected by consumers to buildings, so attribute information which influenced the building energy consumption was also included in the detailed information in addition to detailed information items generally used in the market, and the relevant detailed information items were composed based on input items of ECO2, which is building energy performance evaluation program used in domestic building energy efficiency rating system for calculating the rating. In case of detailed information items, the attribute of insulation material was defined with heat conductivity (W/m²K), density (kg/m³) and combustibility (burning time, burn length), and in case of boiler, it was defined with thermal efficiency (%), rated heat quantity (kW) and heating area(m²).
4. Discussion

For the establishment of low energy building materials database in this study, information is established under the cooperation with quasi-governmental agencies including prices information sheet, Public Procurement Service and efficiency management machinery, equipment or materials, but from the time of providing the service after materials information portal is completed, materials production and sales companies will upload product information. At this time, the information uploaded by companies show the price and quality of products in actual market, so it is the newest information, but companies will be responsible for the reliability of uploaded information. The verification and confirmation of information uploaded by companies are excluded from the concept of this study, but these elements are important items with regarding the usage frequency and satisfaction level of portal service from the viewpoint of consumers.

5. Conclusions

The purpose of this study is to provide reliable service of materials information portal through the establishment of public big data by collecting and integrating scattered low energy building materials and equipment data.

In the establishment of low energy building materials database in the country, there was almost no case of integrating scattered data based on the standardized data classification system and code. Therefore, data attribute items were extracted based on information highly used in the building market in this study in order to establish building materials database, and data
standardization was carried out through the definition of attribute of such entities. It is possible to maintain accurate communication and data easily and improve operation efficiency in the portal development through the standardization of attribute definition by applying consistent input method (text or number), use of word and unit for materials of the same category.

The materials information portal can provide one stop service to users based on materials database under establishment in this study and real-time price information through voluntary upload of price information for establishing reasonable prices between materials production companies and allowing companies to register their products on the portal in future, so important verification process of standard system for portal data will be carried out continuously for searching, sharing and managing information from the position of portal users and developers and a study to improve users' satisfaction level such as GR certification (Good recycled), certification information such as environmental mark, review of legal obligations and recommendations before using materials and equipment and addition of user's review function will be carried out.

Acknowledgements

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References

Public Procurement Service (2015-1) http://www.pps.go.kr/kor/jsp/introduce/organization/org_function.pps [accessed on 02/12/2015]

Ma, Mi-Yeong (2008) Survey on the information provided by price comparison web sites, policy research report of Korea Consumer Agency


How Will Green Property Services Change the Game? A Futures Studies View

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Abstract

As the environmental impacts of buildings have become more and more eminent, so too has the demand and need for specialized green property services. Green property services refer to operative real estate management services, including both property and facility management, which promote environmental, or green, aspect of the services. This study sets out to identify the possible future development paths associated with the expected rise in the demand of green property services in the future facilities market. The research uniquely utilizes a futures studies method in the context of facilities management. The futures wheel is a qualitative method based on expert opinions, and resembles structural brainstorming. With the futures wheel, different future elements and their possible influences can be identified, clarified and organized. The study finds that several outcomes, both beneficial and unfavourable, are possible in a future where green property services have become more common. The outcomes are classified based on the power to impact, namely, whether they are reached through the actions of the property service provider, or the client organisation. The identified first tier influences include surprisingly complex issues such as lack of expertise in the client organization, or poor occupant comfort resulting from effective energy management. On the other hand, highly positive influences, including intelligent buildings and saved natural resources are also identified as potential influences. The study is the first to employ the futures wheel method to facility services research, and provides a good foundation for further testing of the methods. Furthermore, the findings are a welcomed reminder to both researchers and practitioners of the intertwined and complex nature of sustainability issues within the built environment.

Keywords: commercial real estate, facilities management, futures wheel, green property services, sustainability
1. Introduction

The built environment is a significant cause of environmental impacts (UNEP 2007), and consequently, is often seen key in solving the environmental challenges set to our society. As the environmental impacts related to buildings have become eminent, the need and demand for specialized green property services are also growing. Green property services refer to operative real estate management services, including both property and facility management, which promote environmental, or green, aspect of the services. The role of facility management in building environmental performance is known to be crucial (e.g. Aaltonen et al. 2013, Kyrö et al. 2012, Määttänen et al. 2014a). Green property services can be defined as services that aim at reducing the negative impacts to the environment and human health, while simultaneously fulfilling the needs of occupant’s and maintaining the property’s condition and characteristics (Määttänen 2014a). In other words, green property services aim at both enhancing the environmental performance of the building and creating value to the end-customer. Määttänen (2014a) concludes that green property services are particularly useful when the end-user company lacks the appropriate resources for in-house environmental management. The increased demand for green property services has also been noted in market-based research, including a recent Green Market Study (Ramboll 2014), which estimates that green commercial facilities will become more common in the future. It has also been assessed that during the next few years property and user service companies will invest more in sustainable practices (KTI 2015). Interestingly, while the clients’ green requirements are expected to increase, the willingness to pay premium for green services remains low (KTI 2014).

While it is clear that buildings affect the surrounding society, it should be noted that the surrounding society and different forces of change emerging in the real estate market environment have their own influence on the built environment and associated businesses. Regardless, property management practitioners are not generally aware of the future forces of change and their possible influences on the future development. In other words, practitioners may have to make decisions that will have far-reaching consequences for their business, without sufficient awareness and needed analysis of the possible future development in the field. This study sets out to identify possible future development paths associated with the expected rise in the demand of green property services in the future facilities market. The research uniquely utilizes futures studies methods in the context of facilities management. Futures studies have only recently been introduced in the context of real estate markets (Toivonen 2011; Toivonen and Viitanen 2015; Toivonen and Viitanen 2016). Moreover, previous futures studies based research from the property management field does not yet exist, to the best of the authors’ knowledge.

According to previous studies environment pressure has been identified as a significant force shaping the future development of the commercial real estate market (Toivonen 2011; Toivonen and Viitanen 2015). Toivonen (2011) recognized the demand for green property services as a part of the environmental pressure set to the commercial real estate market and also as a phenomenon affecting the future market environment. For the purpose of this specific study, the increased demand in green property services is selected for further research through a method called the futures wheel. Based on Glenn (2009a) the futures wheel is a qualitative method based on expert
opinions, and resembles structural brainstorming. With futures wheel different future elements and their possible influences can be identified, clarified and organized (Glenn 2009a). Through a better understanding of the potential future elements, practitioners would be more conscious and they would have better prospects of doing far-reaching and sustainable decisions about their business.

The study finds that several outcomes, both beneficial and unfavourable, are possible in a future where green property services have become more common. The first tier influences include surprisingly complex issues such as lack of expertise in the client organization, or poor indoor comfort resulting from effective energy management. On the other hand, highly positive influences, including intelligent buildings and saved natural resources are also potential. The first tier effects produce a number of second and third tier influences, resulting in possible development paths for the future of green property services. Each of these development paths is presented with a discussion on the positive and negative effects to ecological, social and economic sustainability. The outcomes are also classified based on the target of impact, namely, whether they affect the property service as a business, or the client organisation. The study is the first to employ the futures wheel method to facility services research, and provides good foundation for further testing of the methods. Furthermore, the findings are a welcomed reminder to both researchers and practitioners of the intertwined and complex nature of sustainability issues within the built environment.

The remainder of the paper is structured, as follows. The research methods are introduced in detail in the next section, due to the novelty of the application. The third section presents the findings of the research, and the fourth section discusses implications and limitation of the findings. Finally, the fourth chapter concludes the paper with suggestions for further research.

2. Research methodology

Property services are in a nascent state as a research field, and therefore the explorative, qualitative research methods offer a best methodological fit (Edmundson and McManus 2007). This study takes a novel approach and utilises futures studies methods for the property services research. Future studies methods have been found well-suited for investigating the future development of the commercial real estate market, which is continuously affected by several different external and internal forces (Toivonen 2011). According to Mannermaa (1999), the future is formed based on both conscious and unconscious thinking, planning, decision making and actions taking place in different parts of the society. The future is present in the current situation through several different possibilities that have not yet been realized (Malaska 1993; Seppälä & Kuusi 1993). These different possible development paths can be identified and analysed with the help of the futures wheel method. The following sub-section describes the futures wheel method in detail.
2.1 Futures Wheel

This study utilizes a method called the futures wheel to study the possible future influences caused of the expected increase in green property services. The futures wheel is a qualitative method based on expert opinions, and resembles structural brainstorming. With the futures wheel method, the possible future influences of a studied phenomenon can be identified and clarified. The possible influences are organized into the different circles of the wheel to present primary, secondary and tertiary influences of the phenomenon in question. These influences can be connected to an actor, or to an object (Glenn 2009a; Rubin 2002). The wheels presenting the possible influences can be formed via a joint session with external participants (Benckendorff 2007; Boujaoude 2000; Shakweer and Youssef 2007), or by an internal research team that collects data and organizes it into the wheels (Toivonen 2011; Rantasila 2015). According to previous experiences, the joint sessions allow the participants to interact and develop the presented ideas further together as a team (Benckendorff 2007). This was seen as a significant advantage, and thought to best serve the purpose of the study. Consequently, a joint session among experts was organized to investigate the possible future impacts of the green property services. The experts were chosen to represent built environment researchers, consultants, and green building professionals. Altogether 5 participants took part in the wheel formation session.

The researcher acted as facilitators for the session. In the beginning of the session, the facilitator briefly presented the investigated phenomenon as well as the futures wheel method to ensure that all participants understood what was going to happen during the session. After this preparatory phase, the name of the phenomenon under examination, namely, “Increasing the demand of green property services”, was placed in the middle of the wheel into the centre circle. Next, the facilitator asked the participants “What would happen if the demand for green property services would increase?”. After that, the participants started to discuss the possible influences and the facilitator simultaneously draw the wheel presenting their views. The facilitator encouraged the participants to think further by asking the possible secondary and tertiary influences caused by the influences described in the earlier stage. The primary influences were located on the first ring surrounding the centre circle, the secondary influences derived from the secondary influences were placed on the second ring and the tertiary influences caused by the secondary influences on the third ring. The influences were also connected to each other with lines to demonstrate connections between them. The participants discussed different potential influences and only the influences that were seen possible by all of the participants were chosen to the wheel (see Glenn 2009a). This procedure is seen to increase the reliability of the results. Finally the different rings surrounding the centre circle presented the possible primary, secondary and tertiary future influences of the increasing demand of green property services and their possible future development paths. An example of a future wheel is depicted in Figure 1.
After the formation of the futures wheel, the influences on the outer rings are analysed and categorised into themes based on their context and power to impact, namely whether the influences concerned the service provider or the end-user. After this, the analysis process continued forward and the formed future themes divided as positive or negative. With the future studies it is possible to combine different value bases with different forecasts. This means that the desirability of different development paths can be evaluated (Bell 2003; Glenn 2009b; Mannermaa 1993). The desirability is derived from the values of every actor estimating the possible development. Futures researchers have presented some values that are universally seen desirable (Bell 2003; 2004; Malaska 1993) but in reality the desirability of different development paths might be viewed very differently among different stakeholders due to their individual position and characteristics (Heinonen 1993). However the desirability of different development paths is an essential part of the future studies while it determines the significance of the forecasts. If some development path is seen either very negative or very positive, it is considered more significant, than a development path that is seen indifferent (Linturi et al. 1998; Meristö 1993). This study analyzed the positivity and negativity of the influences from the service providers and the end-users point of view.

Bell (2003) argues that one of the aims of futures studies is the actualization of the development paths that are seen desirable. According to Bell, the results gained from futures studies should be exploited in practice, and the actors should try to steer the future development towards the desired direction. To be able to do that it is relevant to identify actors that are involved in different development paths. A development path that is seen very desirable will more likely be promoted.
than a development path that is irrelevant to the actor in question. Similarly, the involved actors will be more willing to try to prevent development paths that are seen very negative (Toivonen 2011). Due to this an analysis concerning the relevant stakeholders that will be affected by the development path and who possess the power of promoting or hindering the development, should be provided. As mentioned above, in this study the investigated stakeholders possessing this power are the service providers and the end-users. Next, the findings of the futures wheel on green property services are introduced.

3. Findings

This futures wheel on green property services identified influences up to the third-tier, and in one case also up to the fourth-tier. Altogether, the futures wheel generated 11 first-tier, 23 second-tier, four third-tier and one fourth-tier influences. The futures wheel on Green Property Services, as originally transcribed and translated from the Finnish research notes is presented as Figure 2.

![Figure 2: The Futures Wheel on Green Property Services](image)

The first tier impacts were noted to be somewhat neutral, i.e. the influences do not have a clear negative of positive connotation. The identified first-tier influences comprise:

1. **Lack of expertise in end-user organisations**
2. **Changes in service agreement scope**
3. Increased demand for quality of property services
4. The service provider’s role is highlighted
5. The demand for green property professionals increases
6. Green property services become self-evident
7. Green brand for property management companies
8. Technical solutions
9. Recycling
10. Smart materials
11. Occupant discomfort: too hot, too cold, dirty

During the second-tier however, even surprising negative potential influences were identified, along with the many positive potential impacts. However, this is considered to present an interesting contradiction that is truly beneficial for the analysis and identification of the future scenarios. Therefore the second-tier impacts were first categorised as either positive or negative. Furthermore, the direction of their impact was included in the analysis and divided into either end-user of service provider related impacts (See Table 1).

### Table 1: The identified future themes

<table>
<thead>
<tr>
<th>Power</th>
<th>End-user</th>
<th>Service Provider</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>Lower space demand</td>
<td>Wider scope: Total FM</td>
</tr>
<tr>
<td></td>
<td>Occupant comfort and higher workplace productivity</td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td>Cost and risk of outsourcing services</td>
<td>No more demand for specialized services and no price premium for green services (\Rightarrow) green FM becomes obsolete</td>
</tr>
<tr>
<td></td>
<td>Occupant discomfort and lower workplace productivity</td>
<td></td>
</tr>
</tbody>
</table>

Based on the findings, it may be argued that the key future scenarios of increased demand of green property services are related to the scope of services, i.e. are connected to the business logic of property services companies. Ultimately, this comes back to the discussion about integrated or total FM (Atkin and Brooks 2000), which was also included in the futures wheel as the final, fourth-tier outcome. Another related key finding is that green property services were thought to become the new norm. Määttänen et al (2014b) found that for example green cleaning could be on its way to becoming a standard service that the tenants expect to have, rather than a specialized green service. This is in line with a previous research. Määttänen et al. (2012) found that service providers should utilize their full potential and expertise better.

For the end-user or client organization, the major influences relate to the workplace productivity of the client organization, which is thought have both positive and negative outcomes. Low level
of expertise in-house and outsourcing services were thought to carry some risks, and is therefore categorized as negative. On the other hand, lower space demand was also a result of the wheel, and this possible outcome is viewed as positive.

4. Discussion

This paper set out to identify the different future influences of green property services, which had previously been identified as one force of change in the current facility service field, with the help of an environmental scanning method (Toivonen 2011; Toivonen & Viitanen 2015). The potential influences of the green property services were then analyzed with the futures wheel method. Through analysis of the possible first, second and third tier influences identified with the wheel, the following potential future development paths for green property services were formed: 1) wider scope for service providers, 2) green property services becoming obsolete 3) increased workplace productivity 4) decreased workplace productivity 5) cost and risk of outsourcing services 6) lower cost from outsourced energy and space.

The results of the wheels were found to be partly contradictory with each other. While this contradiction complicates the interpretation of the possible future influences, it gives valuable information concerning the inner conflicts that the phenomenon may possess. Glenn (2009) has seen this as a special advantage of the futures wheel method as it reveals the potential internal and external conflicts that could remain unnoticed. Likewise, Toivonen (2011) recognized this challenge to be an opportunity to increase a holistic awareness of the possible development paths of the phenomenon under study. This in turn allows the actors to prepare themselves for the needed actions to be able to cope with and steer the development of the future conditions. This study divided into either end-user of service provider related influences and analysed the desirability of the influences. This may help the relevant stakeholders to take actions to steer the development towards the desired future development.

This research contributes to the scientific body of knowledge in facilities management by introducing a novel research method. The future wheel as a research method is especially useful when structuring the relationships between different phenomena and influences due to the illustrative nature of the wheels. The method was rather easily applied and enabled structuring the future development paths and possible influences. The findings are in line with previous experiences concerning the method (Benckendorff 2007; Boujaoude 2000; Glenn 2009a; Toivonen 2011; Toivonen & Viitanen 2016). Outside the research field, the wheels could allow practitioners to foresee the potential influences proactively. Furthermore, by recognizing the wide range of different influences, it is possible to analyse who will be affected by the different development directions, and who are the actors possessing the power to steer the development direction. Furthermore, the results allow practitioners to estimate the wanted and unwanted development paths from their own point of view, and possibly form coalitions with other likeminded practitioners to enhance the desired development path. With the connection between forces and influences, practitioners can estimate which development paths are wanted or unwanted, and direct their actions towards the wanted development paths or trying to prevent the
unwanted ones, or altogether examine if their future targets are against or in favour of the possible future development and future theme.

4.1 Evaluation of research

According to Mannermaa (1993), it is not possible to analyse the success of a futures study by investigating the fulfilment of presented predictions, as the future does not exist as such in the current situation, and the presented predictions might affect the actualization of the unforeseen prediction. For example market actors may change their behaviour after acknowledging the ongoing development thanks to the predictions and consequently change the development path. Due to these reasons the success of futures studies should be analyzed by evaluating the possibility of the presented development paths (Gordon 1989; Mannermaa 1993; Pantzar 1993). Therefore, when evaluating this study, it has to be analysed whether the presented influences could actually occur when taking into account the current knowledge of the present situation.

This study selected only the influences that were jointly agreed by the participants to be analysed in the final wheels, in order to ensure that the results would comprehensively present the possible future influences of the green property services. However, as previously stated by many researchers (Gordon 1992; Mannermaa 2004; Naisbit 1984; Niiniluoto 1993), the presented predictions cannot be perfect and include all the possible development paths. Something will always remain unrevealed. For example some of the influences may have falsely been seen impossible according to current knowledge, and therefore left out from the wheels. On the other hand, the wheels may contain influences that turn out to not be possible in the future. For example technological advancement or legal restrictions might have this kind of effect. Most importantly, it should be noted that the futures wheel method is highly dependent on the participants forming the wheels, as well as on the facilitators guiding the participants to exercise future thinking. This study pursued to include specialists representing the field of sustainable built environment, roles ranging from researcher, consultants, architect and advisor. However, it can be stated that the variety of participants could have been wider and the number of participants could have been higher to better ensure the coverage of the possible future influences. Similarly, the analysis over the desirability of the influences could be developed further. For the purpose of this study, this task was conducted by the researchers but it can be argued if the positivity and negativity should be analysed by the stakeholders i.e. the service providers and the end-users themselves.

Regardless of the aforementioned uncertainties inherent to the futures studies methods, it may be argued that the future wheel method is a suitable tool for investigating unknown future development paths, such as the future development of facility services.

5. Conclusions

The study is the first to employ the futures wheel method to facility services research, and provides a good foundation for further testing of the methods. The findings, which identify a number of contradictory positive and negative potential influences, are a welcomed reminder to both researchers and practitioners of the intertwined and complex nature of sustainability issues.
within the built environment. A very good example is occupant comfort, which is seen to be affected both positively and negatively by Green FM. Further research could focus on finding more potential forces of change to be analysed with the future wheel, or analysing the now identified potential influences on a more detailed level. As the study identified a number of conflicting and even detrimental potential influences of green property services, both to the environment and FM as a profession, the potential negative influences in particular should receive more research attention in the future.

References


tulevaisuutta? Helsinki, Painatuskeskus Oy: Tulevaisuuden tutkimuksen seura. Acta Futura Fennica NO 5. (available in Finnish only)

KTI (2015) ”Vastuullinen kiinteistöliiketoiminta 2015” (Sustainable real estate business 2015)

KTI (2014) ”Vastuullinen kiinteistöliiketoiminta 2014″ (Sustainable real estate business 2014)


Mannermaa M (1999) Tulevaisuuden hallinta - skenaariot strategiatöskentelyssä. WSOY, Porvoo (available in Finnish only)

Mannermaa M (2004) Heikoista signaaleista vahva tulevaisuus. WSOY, Helsinki (available in Finnish only)


Toivonen S (2011) “*Tulevaisuuden toimitilamarkkinat – muutosvoimat, niiden vaikutukset ja toimitilatavoiteet pääkaupunkiseudulla*”, Doctoral Dissertation, Aalto University (available in Finnish only)


Toivonen S and Viitanen K (2016) “*Environmental scanning and futures wheels as tools to analyze the possible future themes of the commercial real estate market*”, *Land Use Policy* 52: 51-61

State of the Art of Demolition and Reuse and Recycling of Construction Materials

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Abstract

Nowadays, due to globally increasing building densities in cities, demolition works are an inherent part of construction. And they are focal activities related to life-cycle-oriented management of construction materials, which aims at drastically reduce the deployment and consumption of primary non-renewable construction materials. To give an overview on related worldwide existing activities, the state of the art of demolition and of reuse and recycling of construction materials is summarized in a report of selected countries based on reports of these countries. Within this report, first typical structures of the demolition and recycling industry in different countries, typical phases of demolition and recycling processes and involved stakeholders with their characteristic competencies are described. Secondly, leading companies, associations and research institutions in selected countries are outlined. Leading processes are identified by distinguishing between design processes for deconstruction, deconstruction processes on-site and innovative on-site and off-site recycling processes. Thirdly, challenges related to demolition and reuse and recycling of construction materials are identified and analysed in terms of technical, economic, ecologic, organizational and educational and political/legal challenges. Finally, single, country specific, already existing approaches to meet these challenges are identified.

Keywords: State of the art, deconstruction, life-cycle-oriented management, construction materials, reuse and recycling

1. Introduction

Nowadays, due to globally increasing building densities in cities, demolition works are an inherent part of construction. Furthermore, demolition works are focal activities related to life-cycle-oriented management of construction materials, which aims at drastically reduce the deployment and consumption of primary non-renewable construction materials. To give an overview on related worldwide existing activities, the state of the art of demolition and of reuse and recycling of construction materials is summarized in the following report. For this overview, the state of the art in selected countries is analysed based on reports of these countries, firstly by describing typical structures, processes and stakeholders of the demolition
and recycling industry. Secondly, by outlining leading companies, associations and research institutions as well as leading processes. Thirdly, by identifying and examining technical, economic, ecologic, organizational and educational and political/legal challenges. Finally, by identifying single, country specific and already existing approaches to meet these challenges.

1.1 Description of the demolition sector

The demolition sector\(^1\) is by no means homogenous and currently displays a wide diversity of sophistication levels, varying within and between regions and countries. Diverse stakeholders, such as clients, planning engineers, emission and contamination experts, decontamination companies, demolition companies, authorities and neighbours, are involved in and/or effected by the demolition process. These stakeholders have different interests and influences on the demolition project. Related to building types, surrounding conditions and sometimes hazardous substances of the building usage phase, the fields of activities are diverse and therefore, a variety of different usually small- and medium-sized enterprises dominate the demolition sector. The demolition sector is assigned to code F43.1 (demolition and site preparation) within the industry branch classification scheme NACE (EC – NACE (2010)). In 2012 nearly 170,000 enterprises of this sector represent 5% of all construction activities in the EU. 95% of these enterprises employ less than 10 persons and only 3.5% have more than 50 employees (EC – Eurostat (2015)).

1.2 Processes of construction materials management

The demolition process of buildings and infrastructures is at least as complex and sophisticated as the construction process. Figure 1 (own representation based on DA (2015)) shows the classical process steps, starting with building auditing to plan preliminary decontamination and site clearance followed by demolition, crushing, sorting, reprocessing and recycling processes. Furthermore, involved stakeholders are assigned to each project stage.

In the auditing and planning stage, the client, planning engineers and depending on the type of structure also authorities formulate the tender specifications. The decontamination and demolition companies audit the structure themselves and bid for the project. During auditing and planning, national guidelines are applied depending on the gross volume and characteristics of the building/infrastructure to be deconstructed.

In the preparation and demolition stages, the accepted company plans the previous steps. Depending on the type of structure and available space onsite, different demolition, crushing and sorting techniques are applied to disassemble building elements and break the material into transportable or reusable pieces. During preparation and demolition, legal regulations regarding occupational health and safety, including impact limits, protection measures, etc. have to be applied. Furthermore, national guidelines are applied regarding best practices in demolition,

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\(^1\) In parts of the world, where resource recovery is the standard, the term “demolition” is used synonymously with the terms deconstruction, dismantling and disassembly. But for most of the world, demolition with no thought to materials recovery is the standard and deconstruction is the best practice exception related to the careful disassembly/dismantling of buildings to recover materials for reuse. Hence, in the following, the term demolition is used in general terms.
namely deconstruction, processing and sorting such as in the German standard DIN 18007:2000-05. Especially, the prevalent type of construction, the prevalent materials, space availability, available (state-of-the-art) resources and entrepreneurial calculus determine the choice of technologies and applied resources in deconstruction, crashing, sorting and recycling processes. Within this context, waste fraction types and recycling paths/quotas of deconstruction materials are usually not predefined. Hence, the definition is left to the demolition companies, which face the challenge to constantly produce recycling material of good quality under changing and often not influenceable conditions.

In the reuse, recycling and disposal stages, materials are reprocessed, crushed, sorted, etc. to gain recycling materials of defined quality (e.g. defined in the German standard DIN 4226-100 for recycled aggregates) or to be classified into waste fractions of different qualities and prices. During reuse/recycling a plethora of legal, often regionally differing regulations have to be applied. These regulations address material quality and waste classifications, contamination limits regarding soil and health protection, allowed reuse/recycling options as well as transportation allowances. Major potential customers of recycling materials are authorities (for instance, regarding road works) and individual consumers with resource-saving attitudes.

1.3 Level of professional competency and business processes

Depending on the diversity of involved stakeholders, education in the demolition sector encompasses very different professions and degrees. Table 1 (own representation based on DA (2015)) gives an overview of the most common professional educations related to the type of stakeholders involved in the demolition process.

Table 1: Overview on educational degrees in the demolition and recycling industry (own representation based on DA (2015))

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Profession/degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning engineer</td>
<td>Architect, civil engineer</td>
</tr>
<tr>
<td>Demolition site manager</td>
<td>Civil engineer</td>
</tr>
<tr>
<td>Health and safety coordinator</td>
<td>Architect, civil engineer</td>
</tr>
<tr>
<td>Foreman</td>
<td>Master craftsmen</td>
</tr>
<tr>
<td>Equipment operator</td>
<td>Operator</td>
</tr>
</tbody>
</table>

Figure 1: Classical demolition and reuse/recycling process (own representation based on DA (2015))
Skilled worker | General training related to construction work (brick layer, concrete worker) and special training related to demolition work
(Unskilled) worker | -

In organizational terms, the demolition process (especially the deconstruction process) has project character, similarly to the “normal” construction process. A client, who is usually consulted by a planning engineer, calls for tenders and then accepts an offer of one demolition company. This company either performs the actual demolition process on site itself or acts as a main contractor and assigns single tasks to subcontractors and experts. Usually, for each demolition project new project teams are created. The engagement of subcontractors often follows long-term cooperation/alliances. In general, at least the removal of hazardous materials is done by a subcontractor. Following demolition on site, deconstruction material is landfilled or recycled, either by the demolition company itself or a special recycling company (DA (2015)).

Demolition works are one of the most dangerous jobs in the construction sector, due to confined space on site, parallel work, time pressure, hazardous materials, harmful impacts, such as noise and dust, as well as regularly unpredictable building statics and working conditions (Gabriel et al. (2010)). Hence, for instance in Germany a coordinator for safety and health matters has to be employed by the client by law, according to the construction site ordinance (BaustellV (2004)), when more than one contractor (including subcontractors) work on site. This coordinator consults the client, the planning engineer, the demolition company and subcontractors during planning and execution of the demolition process (§3, BaustellV (2004)).

Furthermore, often a waste concept has to be designed beforehand, where created debris/recycling material has to be quantified and their disposing has to be clarified. For instance, in Germany demolition companies can receive a quality label for deconstruction works by fulfilling defined and regularly controlled quality criteria, for example related to education and skills of employees and subcontractors as well as quality of equipment (RAL (2015)). In Germany, Denmark and Netherlands, paper-based documentation of buildings is dominating (Brewer and Mooney (2008)). Project progress and performance is almost daily reported to the project planner and controller via tablet or cell phone.

2. Leading Edge

2.1 Leading construction materials management industries

To identify leading companies in the demolition industry, it is suitable to look at major demolition tasks and respective leading companies performing these tasks. Tasks can be roughly divided into two main tasks levels: On the one hand, demolition is performed on different structure types, including complex bridges and viaducts, high-rise buildings, and industrial and chemical plants. On the other hand, demolition works are carried out in different sectors, such as the energy, petrochemical, infrastructure, education, industrial, residential and commercial sector. Related to demolition works in different sectors, there are some synergies with residential recycling, waste-to-energy and landfill gas-to-energy facilities. The tasks within these levels can overlap. As, the industry is scattered into small and medium sized enterprises, an overview of leading companies in the industry according to the outlined tasks is difficult.
Nevertheless, Table 2 (own representation based on the scope of this report) shows a selection of leading companies and associations of different countries based on the scope of this report.

**Table 2: Selection of leading demolition and material recycling companies and associations based on the scope of this report**

<table>
<thead>
<tr>
<th>Country of origin</th>
<th>Company/institutions name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Instant Waste Management; Liberty Industrial (Deconstruction, Remediation &amp; Civil); National Federation of Demolition Contractors</td>
</tr>
<tr>
<td>Canada</td>
<td>Milestone Project Management, Winnipeg; 3R Demolition</td>
</tr>
<tr>
<td>Germany</td>
<td>German Demolition Association (Deutscher Abbruchverband e.V., DA); RAL Community of Goods for Demolition Works (RAL Gütegemeinschaft Abbrucharbeiten); Gesamtverband Schadstoffsanierung e.V.</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Nihot air recycling technology</td>
</tr>
<tr>
<td>UK</td>
<td>Absolute Demolition Ltd</td>
</tr>
<tr>
<td>US and Canada</td>
<td>National Demolition Association; Building Materials Reuse Association; Construction Materials Recycling Association</td>
</tr>
</tbody>
</table>

### 2.2 Leading life-cycle-oriented management of construction processes

Common practices of deconstruction\(^2\) of the demolition industry are (DA (2015), VDI/GVSS 6202 (2012)): Identification of hazardous materials, such as asbestos; inventory listing of materials to determine, where each item will be sent; structural deconstruction starting from the roof down to the foundations and non-structural deconstruction, such as the removal of appliances, windows, doors and other finishing materials, which can be marketable components. Further practices are: cleaning and/or refinishing of materials after separation from the structure to increase the material value; secure and dry storage of dismantled building components; location of material salvage, encompassing non-profit reclamation yards and dismantling contractors and on-site or off-site recycling of materials that cannot be salvaged or taken to landfills. Additional aspects, which are considered especially by leading stakeholders of the demolition industry, are: Bespoke risk assessments and method statements, compliance with standards (such as BS6187:2011) - safe systems of work, state-of-the-art, high-tech demolition specific equipment, experienced and trained personnel and best practice and innovation.

Diverse processes of deconstruction and recycling related to these practices and additional aspects and up-to-date leading deconstruction and recycling processes based on the scope of this report are outlined in Table 3 (own representation based on the scope of this report).

**Table 3: Overview on life-cycle-oriented construction material management processes based on the scope of this report**

<table>
<thead>
<tr>
<th>Main process</th>
<th>Description/content/application</th>
</tr>
</thead>
</table>
| Integrated design & Design for deconstruction processes | - Upstream approach considering deconstruction during their design process.  
- Combination of simple construction methods with high-grade, durable materials with visible separation layers and mechanical fasteners such as bolts.  
- Deconstruction, Separation and disassembly of components / building elements.  
- Standardized materials, inventory systems for reclaimed materials (via bar codes), |

\(^2\) The careful disassembly/dismantling of buildings to recover materials for reuse.
RFID, GIS) and their consistent application throughout the project.
- Avoidance of difficult construction methods and materials in deconstruction such as nails and adhesives.
- Avoidance of hazardous materials altogether.
- Avoidance of mixed material grades to improve material quality.
- Saving/ Adaptation of existing structures to new needs.
- Modular building elements, that can be reconfigured as desired.

<table>
<thead>
<tr>
<th>Deconstruction processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 3D Demolition Simulation software for Extreme Loading for Structures (ELS) (Roaf et. al (2004)): used to model the collapse of a building. ELS software is based on structural-analysis using the applied element method (AEM) for tracking of cracks, separation of elements, and collapse of structures under extreme loads. ELS provides demolition scenarios and predictions for structural defects resulting from seismic activity as well as visualisation of forecasted structural responses.</td>
</tr>
<tr>
<td>- Smartwaste software tool developed by Building Research Establishment (BRE): assists in preparing and implementing Site Waste Management Plans and waste monitoring reporting. It includes a calculator for costs of embodied energy of waste and labor for waste disposal as well as an interactive map to find for instance waste management facilities, recycling sites, transfer stations and landfill sites as well as local reclaimed and recycled products and equipment for recycling and reprocessing.</td>
</tr>
<tr>
<td>- ERO Concrete Recycling robot: conceptual robotic concrete demolition machine that also bags the crushed aggregate in the same process.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Innovative on-site and off-site recycling processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Full site assessment: identifying decommissioning requirements and other separate assets to maximizing material value and recovery. Maintaining the building stability during structural separation and alterations.</td>
</tr>
<tr>
<td>- Soft Stripping: non-structural deconstruction of internal fixtures and fittings.</td>
</tr>
<tr>
<td>- Single stream recycling plants (off-site): sort waste materials.</td>
</tr>
<tr>
<td>- Diversion and Recycling Tracking (DART): online tool used to process waste materials from building construction and demolition sites.</td>
</tr>
<tr>
<td>- Separate handling of building plastic and electronic waste.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Separation processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Vacuum systems for separating film plastics.</td>
</tr>
<tr>
<td>- Magnets for recovering ferrous metal.</td>
</tr>
<tr>
<td>- Optical-sorting technologies for separating wood and aluminium. For instance, cameras and laser technologies to identify and sort objects and materials.</td>
</tr>
<tr>
<td>- Vibratory Screens for separating small stones and rocks, for reuse in construction.</td>
</tr>
<tr>
<td>- Gypsum plasterboards and blocks “closed-loop” recycling: recycling process separates gypsum from paper and both materials return in their original products.</td>
</tr>
<tr>
<td>- MRF (Material Recovery Facility): can recycle between 80 to 90 % of construction demolition waste in a single skip bin system. The facility extracts a variety of materials, including sand, wood, metals, brick, light materials and concrete by a rotating electro magnet, a flotation tank, a sand oscillation screen and a shredder.</td>
</tr>
<tr>
<td>- Bulk Handling Systems (BHS): automated process for sorting significant percentages of the C&amp;D material which is made up of small pieces. Eliminates inefficient hand sorting and keeps these materials out of the landfill.</td>
</tr>
<tr>
<td>- Air Separation Technology (AST): accurately separates rock, wood and light material by using air pressure, wind shifters and drum separators.</td>
</tr>
<tr>
<td>- Pneumatic vacuum systems for small rubble removal (intended for post disaster demolition process) and commercial machinery used currently only for loose stone such as roof ballast.</td>
</tr>
<tr>
<td>- Brick mortar removing power tools that plane or grind off the mortar.</td>
</tr>
<tr>
<td>- De-nailing guns for nail removal.</td>
</tr>
</tbody>
</table>

### 3. Perceived Problems and Challenges and Potential Solution Approaches

Aim of deconstruction and recycling of construction materials and buildings is to drastically reduce the deployment and consumption of primary non-renewable construction materials. Actual barriers in this industry can be found in Nakajima and Russell (2014). Furthermore, challenges faced to design for deconstruction make it difficult for architects to incorporate material recovery procedures into the initial building design (Hobbs & Adams (2012)). In the following different challenges are further described and analysed.
3.1 Technical challenges

Technical challenges of the deconstruction and recycling industry are often caused by unknown material qualities in existing buildings that are deconstructed. Establishing the structural performance of reused components can be perceived to be difficult by engineers who will be hesitant to use salvaged structural components unless they have been tested in accordance with current standards. This hampers reuse and recycling options. Hence, relevant technical developments to enhance reuse, recycling and waste tracking are economical material sampling methods for decontaminations and material quality measurements and documentation. These would enable fast determination of material quality and subsequent options of recycling material usage based on regional material demands. Within this context, actual knowledge on regional demands is required to locally reuse materials, which leads to one issue of organizational challenges (see section 3.4).

Furthermore, the use of non-reversible joints can make the deconstruction of building components difficult or impossible and therefore state technical challenges of design for deconstruction. For instance, in North America wood frame dominates residential low-rise building, which are often difficult to dismantle due to a large number of fasteners (Falk and Guy (2007); Davis (2012)). Framing members such as stick framing or trusses for roofs can be dangerous to remove and may require special equipment or bracing during the deconstruction process. The use of mechanical and easier to loosen joints might reduce this technical challenge. Also, innovative approaches for automated separation and decontamination of building elements e.g. via robots or self-controlling machines are required. They seem promising for instance, in the context of separation of outer walls thermal insulation composite systems, separation of layer composites as well as decontamination in contaminated sites and in decommissioning and deconstruction of nuclear power plants, such as the system MAFRO (Baulinks (2015)).

Furthermore, technical development of cost effective methods of raw materials sorting and of material processing plants are required to produce secondary raw-materials of constant quality. This also includes optimization of existing processing plants.

Further technical challenges exist in the automation of deconstruction processes, such as the acquisition of building information, processing of analogue and digital building information, operative project planning, emission management or site surveillance and control, e.g. via sensors. The application of digital building models and sensors onsite would enable planners and deconstruction companies to automatically plan, track and document project performance and related impacts on employee’s health or the local environment, such as adjacent neighbours or buildings. However, the demolition industry seldom adapts digital building models and planning methods, yet. At the moment the digitalization is limited to digital building documentation via Word/Excel on tablets.

Moreover, good examples demonstrating effectiveness of design for deconstruction, of selective deconstruction, material recycling and reuse are required to overcome technical challenges.

3.2 Economic challenges

Major economic challenge is the lack of economic incentives to use recycling materials in new constructions in most countries. Reasons are comparably cheap raw materials and low costs of
construction units, expensive material sampling methods, differing material qualities of recycling materials and temporal and spatial divergence of demand and supply. In many countries the main structural building components are often not salvaged due to a perceived lack of demand. Only single, high value, quick sale items are usually collected by selective deconstruction and often sold to a heritage market. This problem is one of both, supply and demand. Retailers do not carry products that are not demanded and consumers do not buy products they do not know. This is closely related to the awareness of the value of reclaimed building components. Sampling of built-in materials or building elements and tests of reclaimed components for structural integrity are costly and impede material quality determination and material reuse/recycling options. Although there are some national and regional online marketplaces and platforms for recycling materials and used building elements (in Germany on national\(^3\) and regional\(^4\) level; in Austria\(^5\); Canada\(^6\); Netherlands\(^7\)), the comparability and quality assurance of the offered materials/elements are not always given. Some clients even specify that they want all “new” materials. Here the liability of designers or recyclers can be a significant concern. “Without legislative action to create an artificial economic driver, the current market for deconstructed material is […] to remain economically feasible” (Nakajima and Russell (2013)). Widely spread recommendations among countries are to “encourage financial burdens on the landfill process through tipping fees or taxes” to force reuse/recycling or “provide financial incentives for efficient designs that facilitated end of life deconstruction” and recycling (Nakajima and Russell (2013)).

Furthermore, the demand is low, as reused building components are currently not available. More work is required by the design team to anticipate material requirements and identify potential sources. The question is, if there is enough of a single used component type to meet the demands of a new construction project. Then, design would need to be adaptable. Furthermore, production costs of recycled concrete aggregate vary depending on its use. Concrete components of existing buildings may need to be stored, moved and transported between sites and locations that might result in higher costs for new construction projects. Moreover, recycled aggregates might contain contaminant residuals, which reduce the compressive strength of the aggregate by up to 18% (Chini, et al (2001)). If the quality of recycled aggregate is lower than the virgin aggregate materials, the price should also be lower. However, the cleaning, processing, inspection, storage, and sale of recycled aggregate can result in higher costs than virgin aggregate. Other materials such as timber are extremely cheap to buy new and clean (e.g. in North America). Also, they are difficult to separate from other building components. Hence, there is very little economic perspective in recycling these materials.

In general, many industry professionals state that deconstruction result in higher overall costs for a project than traditional demolition and landfilling. Without a clear market and value for salvaged products little attention is paid to maintaining quality of demolition products.

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\(^5\) http://recycling.or.at/rbb/cake_rbb/
\(^7\) http://www.oogstkaart.nl/oogstkaart/
Moreover, according design for deconstruction additional time is often required for architects and engineers to include the added features to facilitate building deconstruction.

**3.3 Ecologic challenges**

Major ecologic challenges are that information on the life cycle of products as well as planning for end of service life are rarely considered and not yet mandatory at the building design stage (design for deconstruction). Values for use of reclaimed materials are mainly aesthetic and there are health concerns regarding the use of recycled material, which might contain hazardous substances. Environmental benefits are secondary.

Environmental product declarations (EPDs) (ISO (2006)) quantify ecologic information on the life cycle of products, based on Life Cycle Assessment (LCA) studies of independent institutions. EPDs represent a complete, robust and scientifically validated source of information of the environmental impacts of products along their life cycle. Even though they are not yet mandatory, EPDs are defined as a source of quantitative information on product life cycles in a standard way by the European Commission (EC, 2003). When available, EPDs can be used to assess the use of resources and the impact of construction works on the environment, according to the Construction Products Regulation (CPR) (EP (2011)). EPDs of construction products based on recent European standards (CEN (2011), (2013)), with the environmental assessment of construction waste flows, can be an important source of data for decision-making at the end-of-life of building materials and to ‘close the loop’ in their life cycle. Nevertheless, most EPDs are cradle to gate, including recycled content but no waste management processes or “recyclability” except in uses of steel and other metals, where recycling is more or less guaranteed. Hence, these gaps in reused/recycled materials for standards of life cycle stages, inventory data and allocation rules are major issues in the adoption of LCA.

Furthermore, if design for deconstruction would become a requirement or common practice, the likelihood of major portions of the building being salvaged can be greatly improved and the environmental impacts of that stage can decrease.

**3.4 Organizational and educational challenges**

A major organizational and educational challenge is a lack of knowledge by designers and builders on issues of component reuse. Designers are often not aware of supply sources and of actual materials. Although this issue has been highlighted by many green building rating programs, it is not highlighted in education programs, which tend to focus on waste reduction on site. The producer responsibility in the construction industry is not well established, and return of materials/components to their source only occurs if they have economic value. Many residential constructions are not big enough to fall under the regulations that do exist. Therefore, the client is not forced to provide a waste management plan and any demolition waste is most often sent to landfill, but may implement material reuse where gains can be created.

Furthermore, this lack of awareness makes demolition crews more likely to work recklessly and simply remove components as quickly as possible. Deconstruction and reuse still tend to be a niche activity. Although there are various resources available including scattered retailers and deconstruction practitioners, the mainstream industry seems unaware of the possibilities of reuse.
and the value of the existing materials. Within this context there is also a lack of consistent standards that include deconstruction. Hence, it is difficult to provide specifications for carrying out deconstruction and/or supervising the deconstruction process. Besides, there are other organizational challenges due to logistics and scheduling. Demolition is usually on the critical path and contractors are under time pressure. Ironically a building may have sat derelict for years but as soon as a new project is planned for the site there is very little time to carefully deconstruct the building. Hence, deconstruction as a slower process to remove the building is not performed. Additionally, often space and cost constraints prohibit the use of sorting bins for different materials on site. Furthermore, infrastructure is needed to collect, transport, store, and prepare salvaged components. But this infrastructure is rarely available. Moreover, there is often a lack of cooperation among all parties, including owner, designers, contractors, subcontractors, and waste haulers about resource stewardship. If any of the interested parties do not fully grasp the purpose of deconstruction, it can hinder the entire process. A thorough understanding of the project’s plan and goals are often not shared with all parties are not monitored.

### 3.5 Political/legal challenges

At present there are no legal requirements in any country for clients or contractors to consider deconstruction at the design stage. Furthermore, the obligatory use of recycling materials in the construction sector is not implemented in many countries yet except for concrete in Switzerland and the monetary incentives against landfilling are not high enough. Although many central and local governments are supportive of reducing waste, the issue of reuse is not in the focus of decision makers, such as politicians and clients. Sometimes it is even a threat to existing resource supply industries.

### 4. Leading national and global initiatives on deconstruction and construction materials management

Finishing the research in state of the art of demolition and reuse and recycling of construction materials, on-going national and global initiatives in the area of deconstruction and reuse/recycling of construction materials are summarized. The entities and stakeholders in charge of these initiatives and developments are associations, research centres and countries. The first type of initiatives is legal actions - such as specific regulations developed worldwide and related to construction material stewardship. Most of them are promoted by national governments. A summary of these initiatives based on the scope of this research is presented in Table 4 (own representation) for raw material extraction, material recycling process and use of recycled C&D material, respectively. The second type are global initiatives with a broader impact, for instance at the European level, such as the European Demolition Association (EDA (2015)). The promotion of European standards on demolition techniques and on recycling of demolition waste are major objectives of this institution.
Table 4: Regulatory initiatives at a national level related to material recycling processes, raw material extraction and the use of recycled C&D material based on the scope of this report

<table>
<thead>
<tr>
<th>Country</th>
<th>Specific regulation and content</th>
</tr>
</thead>
</table>
| Canada    | - Canadian Standards Association CSA Z782-06:2012. guide for deconstruction, disassembly and adaptability of buildings  
- Construction and Demolition Debris Deposit Program of San Jose: regulation on deposits of construction and demolition debris  
- Provincial aggregates royalty fees: royalty fees per tonne of aggregate extracted for instance in Ontario, British Columbia, Alberta and Quebec  
- Environmental Protection Act (EPA) Regulation 102/94. Requirements for waste audit before demolition, source separation (recycling) program |
| Denmark   | Tax on extracted raw materials (sand, gravel, stones, peat, clay and limestone) and on waste. |
| Germany   | - Closed Substance Cycle Waste Management Act (KrW-/AbfG (2000)): basic principles for waste management and closed loop recycling strategies. Waste management hierarchy - the first goal is waste prevention and avoidance  
- Ordinance about waste treatment (NachwV (2006)): way and scope to proof waste disposal and recycling  
- General technical specifications in construction contracts - demolition and dismantling work (ATV DIN 18459(2012)): extraction, storage and transportation of deconstruction materials/components based on the European Waste Catalogue (EWC)  
- Planned "substitute building materials ordinance". Actual draft as at October 31st 2012: nationwide regulations on mineral alternative construction materials produced out of/ resulting from recycled construction materials  
- Standard of "aggregates for concrete and mortar - part 100: recycled aggregates (DIN 4226-100 (2002)): quality of recycled aggregates and the composition of construction materials with portions of recycled aggregates (concrete and masonry) |
| Israel    | - Green Building Standard: voluntary principles for on-site waste management and closed loop recycling strategies  
- EPA: Municipal Solid Waste Landfill Regulations. operation and management of municipal solid waste landfills  
- Mining and Quarrying laws and regulations: planning and operation of quarries, increase efficiency of raw material extraction, such as aggregates, sand and cement  
- Requests for proposals and promoting obligatory use of recycled C&D waste: promotion of policy aiming at obligating contractors to use recycled C&D waste in buildings projects and public infrastructure |
| Netherlands | The Dutch building materials decree: quality criteria for the application and re-use of stony materials and earth used as building materials (Eikelboom et al. (2001)). Reduction of waste material disposal and raw material extraction (Hendriks and Raad (1997)). |
- Law-decree Nr.73/2011, July 17th: mandatory use of recycled materials in public construction |
| Sweden    | - Tax on natural gravel: substitution of natural gravel use (Söderholm (2011a), (2011b)).  
- Regional material inventories of natural gravel and alternative materials (Söderholm (2011b)).  
- Quality standards for road construction materials and tender bonus: to tender construction firms to use crushed rock instead of gravel (Söderholm (2011b)). |
| Switzerland | Recycling of aggregates (SN 640740, SN 640743 (1993)): obligatory recycling and use of RC concrete in new construction |
| United Kingdom | Taxes on aggregates: taxes on all extracted aggregates and imports (with the exception of recycled aggregates: sand, gravel and crushed rock used in construction)(Söderholm (2011b)). |
| USA       | - Municipal C&D recycling rate requirements in Chicago and Washington  
- Municipal mandatory C&D recycling, materials separation and deconstruction and reuse requirements in Seattle, Portland and Chicago  
- C&D materials landfill ban in Massachusetts |

5. Conclusion

The analysis of the state of the art of demolition and reuse and recycling of construction materials shows that the leading institutions are very fragmented and leading processes are diverse. This reflects the actual structure of the construction and demolition industry, which is
dominated by small and medium sized enterprises and includes diverse stakeholders and processes. Consequently, especially international activities are difficult to implement, as shown by the analysis of leading national and global initiatives. The major aim of deconstruction and recycling of construction materials is, to drastically reduce the deployment and consumption of primary non-renewable construction materials. The identified challenges related to this aim show that current activities are highly driven by costs. Particularly, country specific regulatory initiatives are identified to meet these challenges.

**Acknowledgement**

The paper is based on chapter 2 “State of the Art: Demolition and Reuse/Recycling of Construction Materials” of the Research Roadmap of the CIB Working Commission W115 Construction Materials Stewardship. Within this context, we thank Jorge de Brito, Mark Gorgolewski, Gil Peled and José Dinis Silvestre for their contributions.

**References**


FLEX 3.0: an Instrument to Formulate the Demand for and Assessing the Supply of the Adaptive Capacity of Buildings

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Abstract

Market developments show increased demands for flexibility and sustainability by users and owners of buildings. A direct connection can be made between adaptive building and sustainability. The longer a building can keep its functional life cycle instead of becoming vacant or being demolished, the more sustainable a building will be. One way of looking into this phenomenon is the more a building is flexible and able to adapt to changing user demands, the longer it will keep its functional life cycle. In 2014 a paper was presented at the International Union of Architects World Congress UIA2014 in Durban SA, titled Adaptive Capacity of Buildings. A report was given of an extensive international literature survey and the development of a method to determine the adaptive capacity of buildings. In total 147 flexibility indicators were described with accompanying assessment values. The most important recommendation for the next step was the development of an easy to use assessment method in practice with a limited number of important adaptability performance indicators. Further research led in 2015 to a renewed assessment method with 83 indicators, clustered in five layers with different life cycles. This method was called FLEX 2.0 and a derived version was called FLEX 2.0 LIGHT with only 17 of the most important indicators. This was presented in 2015 at the CIB Conference - Going North for sustainability in London. At the same time this method was used in two separate research projects for an evaluation with experts in practice. One research project concerned the development of school buildings; the other project was related to the development of office buildings. The main conclusions and recommendations of both research projects to evaluate the FLEX 2.0 method in practice with two different types of real estate will be described in this paper. Questions will be answered about the differences and similarities between the two different categories of real estate when using this flexibility assessment method. This will lead to some important conclusions for the next version of the method: FLEX 3.0. Finally a renewed framework for this next version will be presented.

Keywords: assessment instrument, adaptive capacity, building, flexible, sustainable
1. Introduction

Market developments show increased demands for flexibility and sustainability by users and owners of buildings. A direct connection can be made between adaptive building and sustainability. The longer a building can keep its functional life cycle instead of becoming vacant or being demolished, the more sustainable a building will be. One way of looking into this phenomenon is the more a building is flexible and able to adapt to changing user demands, the longer it will keep its functional life cycle. In 2014 a paper was presented at the International Union of Architects World Congress UIA2014 in Durban SA, titled Adaptive Capacity of Buildings (Geraedts 2014). A report was given of an extensive international literature survey and the development of a method to determine the adaptive capacity of buildings (Geraedts 2013). In total 147 flexibility indicators were described with accompanying assessment values (Hermans 2014). The most important recommendation for the next step was the development of an easy to use assessment method in practice with a limited number of important adaptability performance indicators. Further research lead in 2015 to a renewed assessment method with 83 indicators. They were clustered in five layers with different life cycles. This method was called FLEX 2.0 and a derived FLEX 2.0 LIGHT version with only 17 of the most important indicators. This was presented in 2015 at the CIB Conference - Going North for sustainability in London (Geraedts 2015).

At the same time in two separate research projects the method FLEX 2.0 was used for an evaluation with experts in practice. One research project concerned the development of school buildings (Carlebur 2015); the other project was related to the development of office buildings (Stoop 2015). The main conclusions and recommendations of both research projects to evaluate the FLEX 2.0 method in practice will be shortly described in this paper. Questions will be answered about the differences and similarities between the two different categories of real estate when using this flexibility assessment method. This will lead to some important conclusions to develop the next version of the method: FLEX 3.0. Finally a renewed framework for this next version will be presented.

2. Previous Developments

2.1 Determination Method for Adaptive Building

Definition of Adaptive Capacity
The adaptive capacity of a building includes all characteristics that enable the building to keep its functionality through changing requirements and circumstances, during its entire technical life cycle and in a sustainable and economic profitable way. The adaptive capacity is being considered as a crucial component when looking into the sustainability of the real estate stock (Hermans 2014).

Adaptive Capacity Determination Method
In 2014 a method for determining the adaptive capacity of buildings has been developed after an extensive survey of international literature on the characteristics, definitions and assessment instruments of adaptive building and on boundaries of adaptive capacity, sustainability and
financial business cases for real estate. The literature survey has resulted in a number of basic schemes with relevant flexibility indicators and their mutual relationships. Next to the literature survey, a substantial number of experts from practice have been consulted. The basic schemes formed the input for discussions in two different expert panels: one with representatives of the clients (demand side) and one panel with representatives of construction companies and suppliers (supply side) in the construction process (Geraedts 2013, Hermans 2014). The adaptive capacity method consists of three different modules:
1. The determination of the adaptive capacity.
2. The determination of the financial-economic viability.
3. The determination of the sustainability impact of the measures chosen.

**FLEX 1.0: 147 Indicators to determine the adaptive capacity**

In the further research only the first module was elaborated: the adaptive capacity of buildings (the AC Method). This method delivered a clear insight in and an overview of aspects that needed to be taken into account when assessing the adaptive capacity of buildings. The method combined existing knowledge on flexibility and sustainability (Berg 1981, Houtsma 1982, Geraedts 1989, REN 1992, Geraedts 1998, Geraedts 2001, Geraedts 2007, Schneider 2007), Beadle 2008, Geraedts 2009, Wilkinson 2009, DGBC 2013) amongst others into one overview of important aspects to determine the adaptive capacity.

For the owner of a building in total 36 different indicators were formulated with associated values for assessing the spatial/functional flexibility characteristics, and 49 different indicators to assess the construction/technical flexibility characteristics of a building. For the user of a building in total 29 different indicators were formulated with associated values for assessing spatial/functional flexibility characteristics, and 33 different indicators for assessing construction/technical flexibility characteristics. The total addition finally led to 147 indicators to determine the adaptive capacity of a building from an owners and a users point of view. It was the first step in the development of instruments to assess specific projects. Although it was not mentioned as such, one can identify this first version with the 147 flexibility indicators as FLEX 1.0.

The steering group behind this research project and the two already engaged expert panels played an important role for addressing the next research aim: the translation of this first developed instrument into a more accessible and easy to use instrument in the daily construction practice, with less indicators to deal with. This resulted in a renewed condensed method called FLEX 2.0 that will be briefly described in the next paragraph.

### 2.2 FLEX 2.0 and FLEX 2.0 LIGHT

**Combining and clustering in five layers**

First of all the double flexibility indicators described for the owner and the user of the building as well, were combined together. To structure and cluster the remaining large number of possible indicators any further, use has been made of the distinction in five layers with a different life cycle of the building and its environment (Brand 1994). As a consequence the number of flexibility indicators in FLEX 2.0 was reduced from 147 to 83 indicators, spread over five layers: Site, Structure, Skin, Facilities and Space plan/Finishing (Geraedts 2015).
Structure of FLEX 2.0: General requirements
To be able to actually use the adaptive capacity of a building or to change the use of a building is it necessary to recognize a number of common important preconditions. Especially some legal, organizational and common constructional preconditions have to be mapped before further actions can take place. Is it possible to change the function of the building or to extend the building according to the actual development plan of the local government? What is the general technical condition of the building, what is the age, when was the last renovation of the building, what type of user utilized the building?

Assessment level, weighting and scores
In this method values are given for each assessment aspect of flexibility performance indicators. Next to the indicator, the related assessment values and remarks, a column is shown to give a personal weight to the various indicators (varies from 1 = not important to 3 = very important) and finally a column to mark the score or level of the specific indicator concerned. There are four possible values for the score: 1 = Bad, 2 = Normal, 3 = Better, 4 = Best. Figure 1 shows an example of the four assessment values of indicator nr.11: Surplus of free floor height. The final score is calculated by multiplying the assessment value and the weighting factor for that indicator (see example in figure 2).

<table>
<thead>
<tr>
<th>Surplus of free floor height</th>
<th>Assessment values of the free floor height</th>
<th>Remark</th>
<th>Weighting</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much is the net free floor height?</td>
<td>1. &lt; 2.50 m (Bad)</td>
<td>The higher the free floor height, the better a building can be rearranged or transformed to other functions, the better a building can meet to changing demands of facilities and the quality of the building or units.</td>
<td>1 = less important</td>
<td>assessment x weighting</td>
</tr>
<tr>
<td></td>
<td>2. 2.60 - 3.00 m (Normal)</td>
<td></td>
<td>2 = important</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. 3.00 - 3.40 m (Better)</td>
<td></td>
<td>3 = very important</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. &gt; 3.40 m (Best)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Figure 1: Example of the four assessment values of flexibility indicator nr. 11: Surplus of free floor height, the assessment values, remarks, weighting and score (Geraedts 2015)

FLEX 2.0 LIGHT: The 17 most important indicators
After the clustering of 143 indicators to 83 indicators, in the next step a second clustering was carried out to find a limited number of the most crucial indicators. This lead to FLEX 2.0 LIGHT with 17 indicators in total, a very easy and fast to use instrument to assess the adaptive capacity of a building. Figure 2 shows an example of a fictive assessment of a certain building with FLEX 2.0 LIGHT. Each of the 17 indicators has been given a weight relative to the other indicators (weighting 1 - 3). Also each indicator is assessed (assessment level 1 - 4). This leads to a score per indicator and summed up to a total Adaptivity Score. At the same way a theoretical minimum score can be found of 17 and a maximum score of 204. With these two borders a class table can be made with five different classes of adaptivity with the total range from 17 to 204.
In the example of figure 2 the total Adaptivity Score is 95. When looking up this score in the class table, the related Class = 3: the building is Limited Adaptive.

2.3 Matching Demand and Supply: Gap Analysis

With the instrument FLEX 2.0 LIGHT as described in paragraph 2.2 four assessment levels of the different flexibility indicators are possible from 1 = Bad to 4 = Best (see figure 3).
A very important aspect of this method is that owners and users of buildings can formulate a flexibility demand profile based on the chosen assessment flexibility indicators and compare this with the supplied building flexibility profile (see figure 4).

![Figure 4: The comparison (gap analysis) between the demand for flexibility and the supplied flexibility in a building; in this example based on 8 flexibility indicators (Geraedts 2014)](image)

3. Evaluation by Research in Practice

At the same time when FLEX 2.0 LIGHT was developed, the more extensive method FLEX 2.0 with 83 flexibility indicators was used in two separate research projects for an evaluation with specific experts in practice. One research project concerned the development of (high) school buildings (Carlebur 2015); the other project was related to the development of office buildings (Stoop 2015). The results of these research projects are briefly presented in the next paragraphs.

3.1 Adaptive School Buildings Determination Method

**Methodology**

The main research question in this school buildings project was as follows: which indicators determine the adaptive ability of educational real estate and how can these be implemented to create an assessment method which can review the current real estate, and can also be used as a standard for formulating the program of requirements? In order to answer these research questions three research methods were used: a literature review, a panel survey and a Delphi research. A panel of 30 professionals working in the educational sector contributed in this survey. The panel consisted of both users and owners and also experts from the developmental sector. The survey used 83 adaptivity indicators from FLEX 2.0 and the experts reviewed the indicators on their importance for adaptive building in the educational sector (Carlebur 2015).

**Results**

The experts of the educational sector selected 21 of the most important flexibility performance indicators. They also ranked the indicators based on their importance for increasing the adaptivity of the educational real estate (high school level). Figure 5 shows an example of a
fictive assessment of a certain high school building. Each of the 21 indicators has been given a weight relative to the other indicators (weighting 4 - 1). Also each indicator is assessed (assessment value 1 - 4). This leads to a score per indicator and summed up to a total Adaptivity Score (121 in the example). At the same way a theoretical minimum score can be found of 55 and a maximum score of 220. Within these two borders a class table can be made with four different classes of adaptivity (see figure 5). When looking up this score in the class table, the related Class = 2: the school building is Hardly Adaptive.

![Figure 5: Example of the fictive assessment of a certain school building, the total Adaptivity Score (121) and the Adaptability Class (2) of the school concerned (Carlebur 2015)](image)

### 3.2 Adaptive Office Buildings Determination Method

**Methodology**

This research by Stoop was founded on two perspectives: on the one hand the current context of the office market (vacancy) and on the other hand the absence of a practical and manageable measuring instrument to assess the adaptive capacity of office buildings. The goal of this research project was to elaborate the method from FLEX 2.0 into a manageable version for the office sector with the focus on two research questions: which indicators of the FLEX 2.0 method characterise the adaptive capacity of office buildings? What does an instrument that measures the future value of office buildings based on these indicators look like? To answer
these questions, different research methods have been used: a literature study, interviews with experts from practice and a test in two pilot cases.

<table>
<thead>
<tr>
<th>LAYER/Locations</th>
<th>OFFICE BUILDINGS</th>
<th>SPECIFIC PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FLEXIBILITY PERFORMANCE INDICATOR</td>
<td>TRANS        USE</td>
</tr>
<tr>
<td>SITE/LOCATION</td>
<td>1 Multifunctional location</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>2 Expandable location</td>
<td>x</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>3 Building entrance, location of elevators, stairs, cores</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>4 Positioning pipes and shafts</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>5 Storey height</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>6 Insulation between stories and units</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>7 Bearing capacity of floors</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>8 Column layout</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>9 Positioning obstacles supporting structure</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>10 Availability of stairs and elevators</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>11 Expanding / reusing stairs and elevators</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>12 Division support - infil</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>13 Fire resistance supporing structure</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>14 Oversized building space/surface</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>15 Available floor area</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>16 Size of storey</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>17 Horizontal grid size</td>
<td>x</td>
</tr>
<tr>
<td>SKIN</td>
<td>18 Daylight entry</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>19 Openable windows</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>20 Insulation facade</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>21 Dismountable facade</td>
<td>x x</td>
</tr>
<tr>
<td>SERVICES</td>
<td>22 Overdimensioning capacity installations</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>23 Measurement and control technology</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>24 Overdimensioning pipes and shafts</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>25 Location of the supplying installations (heating, cooling)</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>26 Independence user units</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>27 Adjustable and controlable installations</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>28 Distribution / modularity installations</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>29 Distribution heating and cooling installations</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>30 Dismountable facility components</td>
<td>x x</td>
</tr>
<tr>
<td>SPACE PLAN</td>
<td>31 Accessible facility components</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>32 Horizontal routing, corridors, units</td>
<td>x x</td>
</tr>
<tr>
<td></td>
<td>33 Detailing joints inner walls - horizontal/vertical</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>34 Possibility suspended ceiling</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>35 Possibility elevated floor</td>
<td>x</td>
</tr>
</tbody>
</table>

Figure 6: The 35 most important flexibility indicators for office buildings (Stoop 2015)

Results
In figure 6 the presented indicators characterise the adaptive capacity of office buildings. The first column represents the layers that cluster the indicators. According to Brand these layers distinguish themselves by different life spans (Brand 1994). The second column shows the 35 most important indicators of the adaptive capacity of office buildings. The next two columns address the specific priority of that indicator: Transformation Dynamics (the capacity of a building to react to a change demand of the building function) or Use Dynamics (the capacity to react to a change in user demands). In contrast to FLEX 2.0 LIGHT and a similar instrument for educational real estate as described in paragraph 3.1, the instrument for office buildings does not use a weighting factor between the different flexibility indicators, nor calculates a final flexibility score.

At this moment three different instruments are more or less derived from FLEX 2.0 (the one with the original 83 flexibility performance indicators). In figure 7 these three instruments are presented and combined with each other:
1. FLEX 2.0 LIGHT with 17 indicators and generally applicable (Geraedts 2015),
2. An Assessment instrument for school buildings with 21 indicators (Carlebur 2015),
3. An Assessment instrument for office buildings with 35 indicators (Stoop 2015).

<table>
<thead>
<tr>
<th>LAYER</th>
<th>Sub-layer</th>
<th>Nr</th>
<th>Flexibility Performance Indicator</th>
<th>Light</th>
<th>Schools</th>
<th>Offices</th>
<th>T</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SITE</td>
<td>1</td>
<td>Surplus of site space</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Expandable site / location</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Multifunctional site / location</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. STRUCTURE</td>
<td>Measurements</td>
<td>4</td>
<td>Surplus of building space / floor space</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>1</td>
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<td></td>
<td></td>
<td>5</td>
<td>Available floor space of building</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>6</td>
<td>Size of building floors</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>Surplus free of floor height</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>Measurement system; modular coordination</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>9</td>
<td>Horizontal zone division / layout</td>
<td>x</td>
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<td>Access</td>
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<td>Access to building; location of stairs, elevators, core building</td>
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<td>x</td>
<td>x</td>
<td>x</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Presence of stairs and/or elevators</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Extension / reuse of stairs and elevators</td>
<td>x</td>
<td>x</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>13</td>
<td>Surplus of load bearing capacity of floors</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Shape of columns</td>
<td>x</td>
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<td></td>
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<td></td>
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<tr>
<td></td>
<td>15</td>
<td>Positioning obstacles / columns in load bearing structure</td>
<td>x</td>
<td>x</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>16</td>
<td>Positioning of facilities zones and shafts</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>Fire resistance of main load bearing construction</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Extensible building / unit horizontal</td>
<td>x</td>
<td>x</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Extensible building / unit vertical</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>Rejectable part of building / unit horizontal</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>21</td>
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<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. SKIN</td>
<td>Facade</td>
<td>22</td>
<td>Dismountable facade</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>23</td>
<td>Facade windows to be opened</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>Location and shape of day light facilities</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>Insulation of facade</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. FACILITIES</td>
<td>Measure &amp; Control</td>
<td>27</td>
<td>Measure and control techniques</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>Customisability and controllability of facilities</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Dimensions</td>
<td>29</td>
<td>Surplus of facilities shafts and ducts</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>Surplus capacity of facilities</td>
<td>x</td>
<td>x</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>Modularity of facilities</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>32</td>
<td>Distribution of facilities (heating, cooling, electricity)</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>Location sources of facilities (heating, cooling)</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>Disconnection of facilities components</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>Accessibility of facilities components</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>Independence of user units</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. SPACE PLAN</td>
<td>Functional</td>
<td>37</td>
<td>Multifunctional building</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>Distinction between support - infill (fit-out)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Access</td>
<td>39</td>
<td>Access to building; horizontal routing, corridors, gallery</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Technical</td>
<td>40</td>
<td>Disconnectable, removable, relocatable units in building</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>Disconnectable, removable, relocatable interior walls</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>Disconnecting/detached connection interior walls; hor/vert.</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>Possibility of suspended ceilings</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>44</td>
<td>Possibility of raised floors</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7: FLEX 3.0, the integral combination of the three developed instruments to assess the adaptive capacity of buildings with 44 flexibility performance indicators in total
Next to the ‘Instrument’ column the ‘Dynamics’ column is shown. The ‘T’ stands for Transformation Dynamics, the capacity of a building to react to a changed market demand of the building function from an owner’s point of view. The ‘U’ stands for Use Dynamics, the capacity of a building to react to a changed user demands from a users point of view.

This new FLEX 3.0 framework has in total 44 flexibility performance indicators that are all applicable for assessing the transformation dynamics while 32 of them are also suited for assessing the user dynamics of a building. Figure 7 also shows the seven general applicable flexibility performance indicators (most right column). They can be used for each type of real estate. The other 37 more specific indicators can be used for the assessment of specific real estate like schools or office buildings.

4.1 Support - Infill theory for a generic assessment instrument

This paragraph formulates an additional point of view on the gained results so far for explaining the potential future development. Habraken developed in the sixties a theory to distinguish construction components by different life spans (long and short life cycles), by different decision levels (community or individual), by different building levels (urban tissue, support, infill), or by differences in dealing with components (fixed or variable components). This is also known as the so-called Support-Infill theory (Habraken 1972). Similar to this theory it could be possible to distinguish flexibility performance indicators that are general applicable (on ‘support’ level for each building type (the seven indicators in the most right column of figure 7) and the other 37 indicators (on ‘infill’ level) that are more specific for a special type of real estate; in this case school buildings or office buildings. Further research in the near future will be necessary to elaborate this theory further and to develop the next version of this flexibility assessment instrument to be very useful in practice (FLEX 3.0).

5. Conclusions

In 2014 report was given of an extensive international literature survey and the development of a method to determine the adaptive capacity of buildings (Geraedts 2014). In total 147 flexibility indicators were described with accompanying assessment values. The most important recommendation for the next step was the development of an easy to use assessment method in practice with a limited number of important adaptability performance indicators. Further research led in 2015 to a renewed assessment method with 83 indicators, clustered in five layers with different life cycles. This method was called FLEX 2.0 and a so-called FLEX 2.0 LIGHT derived version with only 17 of the most important indicators (Geraedts 2015). At the same time in two separate research projects this method was used for an evaluation with experts in practice. One research project concerns the development of school buildings (Carlebur 2015), the other project relates to the development of office buildings (Stoop 2015).

In this paper the three different instruments derived from FLEX 2.0 are described and combined with each other to model the frame for the next version of a general and easy to use instrument to formulate the demand for adaptability on the one hand and assess the supply of the adaptability of buildings on the other hand: FLEX 3.0.
One of the main conclusions of this research project is that real estate experts from practice found the developed methods very useful. Furthermore, more additional research is required to improve the concept. One very good applicable development will be based on Habrakens support and infill theory as explained in the conclusions before (Habraken 1972).

Also financial effects of the costs and benefits of flexibility measures will have to be subject of further research, especially to convince owners and developers of buildings. Some indicators probably require lower initial investments than others. The relation between the investments and the extent of adaptive capacity will have to be studied, with a better judgement about the financial consideration to invest in adaptive capacity as a result.

Finally the assessment values of the indicators were not taken into account in this research. It would be interesting to evaluate if the assessment values are still valid, or if they should be strengthened or expanded. Weighting factors could be linked to the assessment values. Then it would be possible to work towards a certification of adaptive capacity.

References


Abstract

The awareness of, and need for sustainable construction (SC) is relatively well acknowledged in the construction industry. However, like the concept of sustainable development, it is open to different definitions; the way it is implemented can also vary depending on the perspective adopted. In this paper, the term is used to refer to all decisions and actions during the design and construction of buildings, which are designed to ensure that both the process and outcomes of construction over the lifecycle of a building are sustainable. This paper reports on the preliminary findings of a survey that was conducted to investigate the nature and characteristics of SC with a view to developing an understanding of the potential risks and likely impacts of SC practices on building projects in the UK. The survey was targeted at clients and AEC professionals with information being collected on SC goals, strategies, tools, techniques, risks and benefits for particular projects respondents had worked on. Preliminary findings suggest that the key motivation for SC is to minimise lifecycle operational costs; key goals include the minimization of waste, and ensuring that energy costs are below average. High capital cost was seen as the key risk; the reduction of operations costs, improved marketing and health and productivity gains are perceived benefits. The findings also raise questions for further research, about the impact of project related factors on SC practices and the awareness of professionals of strategies used in a phase of a project that they’re not involved in.

Keywords: AEC professionals, building projects, clients, sustainable construction

1. Introduction

The importance of sustainable development for the ongoing sustenance of life and the transformation of our world into a liveable place for all, is now widely acknowledged (WCED, 1987, UN, 2015). The attainment of “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987:43) requires concerted efforts to devise policies and strategies, which have been the subject of many
international initiatives. For example, the most recent Agenda for Sustainable Development, which supersedes the Millennium Development Goals has 17 Sustainable Development Goals (SDGs) and 169 targets in relation to people, planet, prosperity, peace, and partnership (UN, 2015). The achievement of these goals and targets requires the cooperation of many stakeholders and sectors to ensure that economic and social development are not achieved at the expense of the environment (Ofori, 2015).

In the construction industry, the consideration of sustainable development is usually within the context of sustainable construction, as the industry can be seen as both a contributor to sustainable development as well as a process that incorporates sustainability principles into its practices (Ding, 2005; Shelbourn et al. 2006; HMG, 2008; Halliday, 2008; Atkinson et al. 2009; Goh and Rowlinson, 2013). This paper reports on the findings of a scoping study, which was aimed at investigating the nature and characteristics of sustainable construction (SC) with a view to developing an understanding of the potential risks and likely impacts of SC practices on building projects. The concept of sustainable construction is explored in the next section, and thereafter the research undertaken and the findings from the survey are presented and discussed. The paper concludes with recommendations for further research.

2. Sustainable Construction

The construction industry has a direct impact on the built environment and plays a central role in promoting sustainability. Through its activities and outputs, it contributes to the economy, enhances the quality of life of society, and impacts the environment (HMG, 2008). In this paper, we define sustainable construction (SC) as: all decisions and actions during the design and construction of buildings, which are designed to ensure that both the process and outcomes of construction over the lifecycle of a building (or other built asset) are sustainable (economically, socially and environmentally). This is in recognition that the construction industry (otherwise referred to as the Architecture, Engineering and Construction (AEC) sector) is essentially project based, and mainly deals with the creation phase of built assets. But there is an acknowledgement that design and construction has lifecycle implications and are influenced by various stakeholders such as clients, governments and regulatory bodies and AEC professionals who use their knowledge, skills and expertise in translating client requirements into completed built assets.

Sustainable construction involves two interrelated dimensions: outcomes and process. These are reflected in the UK government strategy on SC as “ends” (with respect to mitigating environmental impacts and resource consumption) and “means” (with respect to innovative and improved practices and regulation that will ensure the desired outcomes) (HMG, 2008). Goh and Rowlinson (2013) identify nine principles of SC, which incorporate both process (e.g. design process, lifecycle costing) and outcomes (e.g. environmental impact, lifespan), although some principles (e.g. resources and materials consumption) can apply to both process and outcome. The sustainability issues identified by Atkinson et al (2009) also reflect a range of environmental impacts such as climate change, water resources, land take and remediation, etc.
Within the context of the short-term nature of construction projects (in comparison to the lifespan of assets), it is not easy to assess (long-term) outcomes at the immediate conclusion of a project, given rise to the traditional approach of considering time, cost and quality as key measures of project success (De Wit, 1998, Yu et al, 2005). It does suggest that while a good understanding of outcomes is necessary, there should be emphasis on the process to ensure that desired outcomes are achieved.

Against this background (e.g. of different stakeholder involvement in construction), and assuming that the concept of sustainable construction is now fairly well established, the research reported in this paper sought to gain insights into the realities of sustainable construction on building projects; drivers for, and strategies for its implementation in practice (e.g. what lifecycle issues/intended outcomes are incorporated in the design/construction stage); what, if any, are its risks and benefits; and whether there were any project related factors (e.g. type, contract value, duration, etc.) that influenced sustainable construction practices.

3. Research Methodology and Process

The research approach was exploratory in nature, aimed at soliciting views from various stakeholders that will later form the basis of more in-depth studies. It was therefore decided that a questionnaire survey was the most appropriate approach to collect such varied views.

The focus of the survey was on Building Projects in the UK, and it was administered through an online questionnaire developed with Survey Monkey. A pilot survey to test the construct validity of questions was run from October – November, 2012 and was circulated to architects, client representatives, project managers and facility managers (a total of 10 people). The responses to this pilot (70% response rate) was used to refine the final questionnaire. The link to the online questionnaire was circulated to a list of clients and AEC organisations compiled from the Association of Consultancy and Engineering (ACE) in the UK, Architectural firms and Construction Organisations (total of 200). It was also circulated to members of the Co-operative Network for Building Researchers (CNBR), an international email “list for those who have an interest in building research and related fields [academics and practitioners]” with 3858 members (https://groups.yahoo.com/neo/groups/cnbr-l/info), between December 2012 and February 2013.

The 23 questions in the questionnaire were divided into five (5) sections: Respondent Details and Experience (questions on professional background and number of years of experience of construction projects) Specific Project Information on a recent (within 5yrs) building project (e.g. type, sector, contract value; procurement, duration, location and main structural system); Project Sustainable Construction (SC) Goals and Strategies (ranking of SC goals, motivation, key driver(s) for SC project goals., key strategies adopted during design and construction, techniques and tools used to assess project sustainability); Risks and Benefits of SC (risks associated with SC, causes of risks, how risks were addressed during design and construction phases, expected benefits of SC); and Free text comments on SC strategies and implementation on reported project, SC policies and practices in the UK. Respondents were given the option to provide their contact
details if they wanted to receive an electronic copy of the survey summary. All those who provided this information were sent a summary of the findings.

4. Survey Results and Data Analysis

The data was analysed using IBM SPSS Statistics version 22 (IBM, 2013). There were 48 responses (on 48 projects) representing a response rate of 24% (using the list of 200, as it was not possible to determine the proportion of CNBR members who could have completed the questionnaire). However, not all respondents completed every question in the questionnaire, and the findings for each question presented below are for actual responses to each question.

4.1 Respondent Profile and Experience

Figure 1 shows the profile and experience of the respondents (43 and 42, respectively) who answered these questions. The majority of respondents were project/construction managers [25.6% (11)], architects [23.3% (10)] and civil/structural engineers [18.6% (8)]. The rest were: building services (mechanical and electrical) engineers, quantity surveyors/cost consultants, client representatives and a building surveyor. Regarding experience of the construction industry, 40.5% (17) had worked in the construction industry for more than 15 years; 9.5% (4) for between 11 -15 years, 16.7% (7) for between 6 and 10 years, and 33.3% (14) for 5 years or less.

![Figure 1: Respondent profile and experience](image)

4.2 Project specific information

Responses for project specific information are summarised in Table 1 and includes information on: project type [majority, 81.2% being new build]; client sector [mostly commercial (37.5%), public sector (37.5%) and residential (21.9%)]; contract value [fairly spread across all categories, with the majority being under £500k (27.3%) and between £5-£10m (21.2%)]; procurement type [majority being procured through traditional contracts (53.3%), followed by design and build (23.3%)]; project duration (construction phase) [majority between 12-36 months, followed by
Table 1: Project specific information

<table>
<thead>
<tr>
<th>Question</th>
<th>Project specific information</th>
<th>Frequency</th>
<th>Percent (%)</th>
<th>N (%)</th>
<th>Missing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Build</td>
<td></td>
<td>26</td>
<td>81.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refurbishment</td>
<td></td>
<td>6</td>
<td>18.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Client Sector</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td>12</td>
<td>37.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td>7</td>
<td>21.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public Sector</td>
<td></td>
<td>12</td>
<td>37.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (Education)</td>
<td></td>
<td>1</td>
<td>3.1</td>
<td></td>
<td></td>
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<tr>
<td>Contract value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-£500k</td>
<td></td>
<td>9</td>
<td>27.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>£500k-£1m</td>
<td></td>
<td>5</td>
<td>15.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>£1m-£5m</td>
<td></td>
<td>6</td>
<td>18.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>£5m-£10m</td>
<td></td>
<td>7</td>
<td>21.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over £10m</td>
<td></td>
<td>6</td>
<td>18.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procurement Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional Contracting</td>
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<td>16</td>
<td>53.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design and Build</td>
<td></td>
<td>7</td>
<td>23.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction Management</td>
<td></td>
<td>2</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management Contracting</td>
<td></td>
<td>2</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private Finance Initiative</td>
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<td>3</td>
<td>10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (construction phase)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-12months</td>
<td></td>
<td>7</td>
<td>23.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12-36months</td>
<td></td>
<td>20</td>
<td>66.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36-60months</td>
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<td>1</td>
<td>3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 60months</td>
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<td>2</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Structural System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Framed</td>
<td></td>
<td>9</td>
<td>33.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reinforced Concrete Framed</td>
<td></td>
<td>12</td>
<td>44.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timber Framed</td>
<td></td>
<td>1</td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load Bearing Bricks/Blocks</td>
<td></td>
<td>4</td>
<td>14.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (precast)</td>
<td></td>
<td>1</td>
<td>3.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.3 Project sustainable construction goals

The sustainable construction goals that were adopted for the projects reported on were: *minimising waste* (e.g. of water, materials, etc.) *during construction* (10/11 projects – 90.9%); *ensuring that energy costs are below average for that type of building* where (9/11 projects – 81.8%); *achieving economic regeneration of the area* (11/14 projects – 78.6%); *achieving above-average BREEAM rating* (9/12 projects – 75%). Regarding the motivation behind the sustainability goals, those that were relevant to the reported projects were: *to minimise lifecycle operational costs* (90.9% of
responses); to comply with organisational policy (e.g. corporate social responsibility) (81.8% of responses); to comply with government policy (obtaining statutory approval) (72.7%); to create an exciting building (72.7%); and to comply with government policy to obtain project funding (63.6%). Of these reasons, the top two (minimising lifecycle costs and complying with organisational policy) were rated as of high or medium importance by 100% and 88.9% of respondents, respectively. The desire to create an exciting building was rated as of high or medium importance by 90% of respondents to the question. With regards to the drivers for sustainability, the responses showed that clients were the main drivers (10 out of 11, 90.9%) followed by designers and contractors (5 out of 11, 45.5% each), government (4 out of 11, 36.4%), and engineers (3 out of 11, 27.3%). An analysis of sustainable construction goals and project specific factors (Table 2) to see if there was any correlation between the two, showed that there was no association between SC goals and project specific factors.

Table 2: Comparison between SC goals and project specific information

<table>
<thead>
<tr>
<th>SC Goals and Strategies</th>
<th>Project Specific Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achieving economic regeneration of the area</td>
<td>Chi-Square</td>
</tr>
<tr>
<td></td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>3.42</td>
</tr>
<tr>
<td></td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>1.73</td>
</tr>
<tr>
<td></td>
<td>4.55</td>
</tr>
<tr>
<td></td>
<td>P value</td>
</tr>
<tr>
<td></td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
</tr>
<tr>
<td>Achieving above-average BREEAM rating</td>
<td>Chi-Square</td>
</tr>
<tr>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>0.44</td>
</tr>
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<td>2.26</td>
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<td>4.28</td>
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<td>0.54</td>
</tr>
<tr>
<td></td>
<td>5.40</td>
</tr>
<tr>
<td></td>
<td>P value</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>0.51</td>
</tr>
<tr>
<td>Achieving between 0 and 10% carbon emissions</td>
<td>Chi-Square</td>
</tr>
<tr>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>0.07</td>
</tr>
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<td></td>
<td>4.53</td>
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<td></td>
<td>6.80</td>
</tr>
<tr>
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<td>3.11</td>
</tr>
<tr>
<td></td>
<td>3.33</td>
</tr>
<tr>
<td></td>
<td>P value</td>
</tr>
<tr>
<td></td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>0.80</td>
</tr>
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<tr>
<td></td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Ensuring that up to 20% of energy used in the building is</td>
<td>Chi-Square</td>
</tr>
<tr>
<td>from a renewable source (e.g. wind, solar)</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>1.45</td>
</tr>
<tr>
<td></td>
<td>2.73</td>
</tr>
<tr>
<td></td>
<td>2.04</td>
</tr>
<tr>
<td></td>
<td>4.95</td>
</tr>
<tr>
<td></td>
<td>P value</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
</tr>
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<td>0.69</td>
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<td>0.44</td>
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<td>1.00</td>
</tr>
<tr>
<td></td>
<td>0.48</td>
</tr>
<tr>
<td>Ensuring that energy costs are below average for that type</td>
<td>Chi-Square</td>
</tr>
<tr>
<td>of building</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>2.93</td>
</tr>
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<td>0.58</td>
</tr>
<tr>
<td></td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>2.04</td>
</tr>
<tr>
<td></td>
<td>P value</td>
</tr>
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<td>0.43</td>
</tr>
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<td></td>
<td>0.99</td>
</tr>
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<td></td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Minimising waste (e.g. of water, materials, etc.) during</td>
<td>Chi-Square</td>
</tr>
<tr>
<td>construction</td>
<td>3.93</td>
</tr>
<tr>
<td></td>
<td>1.52</td>
</tr>
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<td>0.92</td>
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</tr>
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<tr>
<td>There were no clear goals</td>
<td>Chi-Square</td>
</tr>
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<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>
4.4 Sustainable construction strategies in design and construction

Key strategies for SC during design are shown in Table 3. Those adopted on the majority of the 11 projects reported were: specifying A-rated materials (as per the Green Guide to Specification – (Anderson et al. 2009)) (90.9%); building envelope insulation technology (90.9%); use of heat recovery systems (72.7%) and rainwater harvesting (54.5%). The relative importance of these strategies (on 10 projects) showed that: building envelope insulation technology was of high importance in 7 (70%) projects and of medium importance in 3 (30%) projects; specifying A-rated materials was of high importance in 5 projects (50%) and of medium importance in 5 (50%) of projects. This suggests that building envelope insulation technology was the top strategy adopted at the design stage to achieve SC goals.

During construction the strategies that were adopted on the majority of the 11 projects for which information was provided were: applying water saving methods to construction (90.9%); off-site prefabrication (81.8%); delivery of waste materials to recycling sites for re-manufacture (81.8%); and reuse of construction waste (or demolition) materials on the construction site (80%). The relative importance of these strategies on 10 projects showed a mixed picture: applying water saving methods to construction was of high importance in 20% of projects, and of medium importance in 80%. For off-site prefabrication it was of high importance in 60%, medium importance in (20%) and low importance in 20%). For delivery of waste materials to recycling sites the corresponding figures were 30% (high importance), 60%, (medium importance) and 10% (low importance). For reuse of construction waste (9 responses), the relative importance was 22% (high), 56% (medium) and 22% (low). This suggests that while various strategies were adopted during construction, these were not necessarily of high importance in achieving SC goals.

Table 3: Key strategies adopted during design to achieve sustainability goals

<table>
<thead>
<tr>
<th>Key Strategies adopted during Design to achieve Sustainable Goal for this Project</th>
<th>Relevant to this project</th>
<th>Frequency (Count)</th>
<th>Percent (%)</th>
<th>N (%)</th>
<th>Missing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainwater or Greywater harvesting</td>
<td>Yes</td>
<td>6</td>
<td>54.5</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>5</td>
<td>45.5</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td>Heat recovery systems (e.g. CHP systems)</td>
<td>Yes</td>
<td>8</td>
<td>72.7</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>3</td>
<td>27.3</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td>Specifying A-rated materials (as per the Green Guide to Specification)</td>
<td>Yes</td>
<td>10</td>
<td>90.9</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1</td>
<td>9.1</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td>Passive Solar heating</td>
<td>Yes</td>
<td>3</td>
<td>27.3</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>8</td>
<td>72.7</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td>Use of Photovoltaic panels</td>
<td>Yes</td>
<td>4</td>
<td>36.4</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>7</td>
<td>63.6</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td>Building envelope insulation technology</td>
<td>Yes</td>
<td>10</td>
<td>90.9</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1</td>
<td>9.1</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
</tbody>
</table>
4.5 Techniques and tools for sustainable construction

The techniques/tools used to assess SC issues are shown on Table 4. Those used on the projects reported (between 8 and 11) were: BREEAM - BRE Environmental Assessment Method (9/11 projects); WLCC - Whole Lifecycle Costing (8/10 projects); Green Guide to Specification (7/9 projects); RSM Responsible Sourcing of Construction Materials (5/8 projects); DQI – Design Quality Indicator (5/9 projects) and CSH - Code for Sustainable Homes (1/9 projects). Regarding the relative importance of these techniques, BREEAM was of high importance in 8 (72.7%) projects, of medium importance in 2 (18.2%) projects and low importance in 1 (9.1%) project. For WLCC, it was of high importance in 7 (77.8%) projects, medium importance in 1 (11.1%) project and no importance in 1 (11.1) project. For Green Guide, it was of high importance in 6 out 8 projects (75%), medium importance in 1 (12.5%) project and of no importance in 1 (12.5%) project. The rating for RSM was, 42.9% (high), 28.6% (medium), 14.3% (low) and 14.3% (no importance); for DQI it was: 42.9% (high), 28.6% (medium) and 28.6% (no importance); and for CSH, it was: 14.3% (high), 14.3% (medium); and 71.4% (no importance).

Table 4: Techniques or tools used to assess sustainable issues for projects

<table>
<thead>
<tr>
<th>Techniques or Tools used to assess Sustainable issues for this Project</th>
<th>Relevant to this project</th>
<th>Frequency (Count)</th>
<th>Percent (%)</th>
<th>N (%)</th>
<th>Missing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BREEAM - BRE Environmental Assessment Method</td>
<td>Yes</td>
<td>9</td>
<td>81.8</td>
<td>11 (22.9)</td>
<td>37 (77.1)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2</td>
<td>18.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSH - Code for Sustainable Homes</td>
<td>Yes</td>
<td>1</td>
<td>11.1</td>
<td>9 (18.8)</td>
<td>39 (81.2)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>8</td>
<td>88.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DQI - Design Quality Indicator</td>
<td>Yes</td>
<td>5</td>
<td>55.6</td>
<td>9 (18.8)</td>
<td>39 (81.2)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>4</td>
<td>44.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Green Guide to Specification</td>
<td>Yes</td>
<td>7</td>
<td>77.8</td>
<td>9 (18.8)</td>
<td>39 (81.2)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2</td>
<td>22.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSM - Responsible Sourcing of Construction Materials</td>
<td>Yes</td>
<td>5</td>
<td>62.5</td>
<td>8 (16.7)</td>
<td>40 (83.3)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>3</td>
<td>37.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WLCC - Whole Lifecycle Costing</td>
<td>Yes</td>
<td>8</td>
<td>80.0</td>
<td>10 (20.8)</td>
<td>38 (79.2)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2</td>
<td>20.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.6 Risks and benefits in adopting SC strategies

The risks associated with the adoption of sustainable construction strategies on the 8 projects reported on were: financial risk (87.5%), delays to design schedule (62.5%), complexity of construction (50%), delays to construction schedule (50%). Regarding the relative importance of these risks, financial risk was of high importance on 6/7 projects (85.7%) and medium importance on 1/7 (14.3%) project. For delays to design schedule, it was of high importance on 3/7 (42.9%) projects, medium importance on 2/7 (28.6%) projects and low importance on 2/7 (28.6%)
projects. For delays to construction schedule (although not a risk on half of projects reported), it was of high importance on 4/6 (66.7%) projects and low importance on 2/6 (33.3%) of projects. The relative importance of complexity of construction was: 3/6 (50%) high importance, 1/6 (16.7%) medium importance, and 2/6 (33.3%) low importance. The biggest cause of risks associated with the adoption of SC strategies was: high initial cost (7/8 projects – 85%). The other options to this question (immature technology, lack of skilled staff, and immature market) did not receive meaningful responses.

The top expected benefits from the adoption of SC on the reported projects were: reduce operational costs (8/8 projects – 100%); marketing benefit (6/7 projects – 85.7%), health and productivity gains (6/7 projects – 85.7%); and new business opportunities (5/6 projects – 83.3%) All 8 projects indicated that reduce operational costs was of high importance. For marketing benefit and health and productivity gains, only 66.7% and 60% respectively said they were of high importance. For new business opportunity, only 40% said it was of high importance.

5. Discussion

The objective of the study reported in this paper was to gain insights into the actual implementation of SC (with respect to goals, strategies, techniques and risks/benefits) on building projects in the UK. Given that almost half of the respondents (48.9% - Fig 1) were professionals (architects and project/construction managers) who normally have an overview of the entire project process (especially for traditionally procured projects), and that two-thirds of them (66.7%) had over 5 years of experience of the construction industry, it is expected that their responses reflected a good knowledge of the industry and of project activities. The predominance of traditional procurement in the projects reported on (Table 1) is also fairly comparable with the findings of a national (UK) survey of construction contracts around the time of the survey (NBS, 2012), which suggest that the findings are based on projects that are fairly representative of projects nationally (at least in procurement type). It is however disappointing that there were poor responses to key questions on sustainable construction goals, strategies, etc. This might have been due to a lack of time to complete all questions, or that respondents simply didn’t know the answers, or indeed that there were no clear SC goals or strategies for those projects. If it was due to ignorance on the part of respondents, it raises questions about the awareness of SC goals and strategies by all participants on a project, or whether indeed these are made clear in project documentation. It might also suggest (as commented by a respondent in the free-text section of the questionnaire) that SC practices are “generally fragmented.” If the missing information was because there were no SC goals for those projects then it raises questions on the extent to which SC is being considered on projects.

The poor responses to key questions undermined any detailed analysis of the relationships between project-related factors and the goals, strategies, techniques, risks and benefits of sustainable construction (as was attempted in Table 2). But there are some interesting insights from the findings. For example, the SC goals that were relevant to reported projects (section 4.3) reflect both the ‘process’ (e.g. minimising waste during construction) and the ‘outcomes’ (e.g. relatively low energy costs) aspects of SC (HMG, 2008), and largely the economic (achieving
economic regeneration) and environmental (energy use, high BREEAM rating) aspects of sustainability (economic regeneration can also have social benefits). The motivation behind these goals (e.g. to minimise lifecycle operational costs) suggest an appreciation of lifecycle issues. It is also encouraging that the SC agendas on these projects were mostly driven by clients and their policy for corporate social responsibility (section 4.3). This suggests a more positive view of SC and not just a desire to comply with regulatory requirements for statutory approvals or project funding. It would also appear from the free-text comments of one respondent, that some organisations have developed (and are developing) pioneering policies, “which provide stringent requirements on regeneration, environmental sustainability, health and [wellbeing]”

The relevant strategies for SC during design and construction are to be expected (respondents did not provide additional options to the coded answers given in the questionnaire) but it is interesting to see that during design, the emphasis appears to be more with “outcomes” aspects of SC (lifecycle performance of materials, insulation, energy efficiency), whilst construction appears to focus on waste minimisation, mainly a “process” issue, but with economic and long-term environmental impact considerations. Reported SC design strategies did not appear to be explicitly geared towards the facilitation of SC strategies at the construction stage (probably because of how the questionnaire was framed), but this can be explored in future research.

Regarding risks and benefits, it is not surprising that financial risk (e.g. high initial cost, which is also mentioned in the free text comments of one respondent) and reduction of operational costs were the top risk and benefits, respectively, on most projects reported. Both reflect some form of financial cost or reward and might suggest that financial costs/benefits have a key underlying motivation for SC (this is supported by the declared motivations for SC, and SC strategies at the construction stage). On the other hand, immature technology, lack of skilled staff and immature market, were not considered as causes for SC risks. Does this mean that appropriate technologies and personnel are available to implement SC practices? The evidence from this study might suggest so, but further studies are required to generalise this to the wider construction sector.

6. Conclusions

This paper has presented the preliminary findings of a survey into SC practices on building projects in the UK. The aim was to gain insights in the actual implementation of SC and to explore whether there are any relationships between SC goals, strategies, techniques, risks, benefits and project specific factors. The relatively low responses to vital questions did not allow detailed analysis to explore these relationships. The findings can only be applied to the reported projects as there were insufficient responses to make generalisations to the wider construction sector. Another limitation is that the survey was conducted a few years ago and SC and other project practices might have changed over this period (e.g. a more recent survey of construction contracts in the UK showed that design and build procurement is almost as popular as traditional procurement – NBS (2015) – a different profile from the survey in 2012 (NBS, 2012)). However, the study does provide useful insights and raises questions for further research.
Key findings include the fact that current (at the time of the survey) practice with respect to goals and strategies fairly reflected the understanding of SC in terms of “ends” and “means” (HMG, 2008) although social aspects of sustainability were not reflected as much as economic and environmental factors. The findings also suggest a more positive attitude towards sustainable construction which is not just about compliance with regulations (‘box-ticking exercise). There appears to be however, a strong financial motivation for SC, suggesting that a strong financial case for SC might well encourage more SC practices.

Questions arising from the findings include: the level of awareness of SC goals and strategies by all stakeholders in a project (a subject explored by Rafindada et al. 2014 in their paper on sustainable construction project risks), the extent to which SC strategies are integrated across the project process (e.g. how SC design strategies feed into SC construction strategies), and whether indeed SC practices are widely implemented on building projects in the UK

References


Halliday, S. (2008), Sustainable Construction, Butterworth-Heinemann, Oxford

Her Majesty’s Government (HMG) (2008), Strategy for Sustainable Construction, Department for Business, Enterprise and Regulatory Reform (BERR), HMG


Next Generation Healthcare Buildings in South Africa: Complexities and Opportunities for Sustainability

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Email: pdejager@csir.co.za

Abstract

Hospitals are widely recognised to have complex design and engineering requirements. It might be argued that the unique functional constraints and operational demand placed upon the hospital building may counter sustainability imperatives. Yet it stands to reason that, even with this complex building type, there must be opportunity to reduce embodied energy, operational energy consumption, to manage water and waste, and to promote social cohesion without compromising the desired safe, effective, efficient healing environment.

In South Africa there has been a commitment to transform the healthcare sector through the introduction of National Health Insurance which is to unfold over a 14 year period from 2011. While this is primarily a funding mechanism, it seems inevitable that over time the principles of universal coverage, eradication of inequity, and accessibility will be reflected in the architecture provided to support service delivery.

In preparation for the National Health Insurance the South African government has increased spending on healthcare infrastructure and initiated several support projects to strengthen quality and accelerate delivery of capital projects. This includes the development of a comprehensive set of new national norms, standards and benchmarks for healthcare building. South Africa has adopted a contextual approach to determining its new guidelines, norms and standards. Key concepts which have a bearing on sustainability are discussed in relation to constraints and opportunities.

The next generation of healthcare buildings in South Africa has created an opportunity to embed principles of environmental consciousness and sustainability into the policies and practices of built environment professionals in the healthcare sector.

Keywords: Sustainability, healthcare, buildings, guidelines, developing country
1. Introduction

Health outcomes and healthcare service delivery is profoundly affected by the built infrastructure provided to support it. The South African (SA) Constitution confers rights to all citizens of access to health services and to an environment which is not harmful to their health or well-being. This underpins an imperative for health planners and built environment professionals to be vigilant in planning, providing and operating healthcare infrastructure. There is significant work to be done in SA, if it is accepted that it is currently not on a sustainable trajectory, which the 2012 UNU-IHDP and UNEP report contends (p 272). According to the report this is - in large part - due to poor health status and poor life expectancy. The dual epidemics of tuberculosis (TB) and HIV/Aids resulted in a life expectancy dropping from 67 years in 1998 to around 57 years in 2012. Unemployment is estimated to be 27% and climate change is likely to lead to increasing water stress, reduced food security and loss of species and ecosystems (UNU-IHDP et al, p 272). Sustainability is about a balance between economic, environmental and social dimensions.

In SA there has been a commitment to transform the healthcare sector through the introduction of the national health insurance (NHI) system which is to be unfolded over a 14 year period commencing in 2011 (National Department of Health [NDoH], 2011). Whilst ostensibly and primarily conceived as a funding mechanism, it is inevitable that over time the NHI guiding principles of universal coverage, eradication of inequity, and accessibility to services (NDoH, 2011, pp 16 – 19) will be reflected in the built environment. In preparation for NHI the SA government has increased spending on healthcare infrastructure and the NDoH has initiated several support projects to strengthen quality and accelerate delivery of capital projects (2012). This includes the development of a comprehensive suite of new national norms and standards for healthcare buildings (N&S), with the stated objective of providing a “sustainable set for all levels of health care facilities to inform and guide work related to all stages of the life-cycle from strategic planning through to operation and disposal” (Infrastructure Unit Support Systems [IUSS], 2014).

Although SA climate change mitigation commitments, legislation and policy now make it obligatory for built environment projects to address sustainability, there is currently limited guidance on how sustainable development can be integrated in built environment projects. There is also the perception that addressing sustainability in buildings will be expensive and complicated, and that there are a range of competing social, economic and environmental priorities. Hospital infrastructure is widely recognised to have complex design and engineering requirements even without the additional dimensions of environmental, social and economic sustainability. It might then be argued that the unique functional constraints and operational demands placed upon the hospital building as a type may trump greening imperatives, invoking “defensible exemptions”.

2. Objectives

The N&S is not intended to be applied in isolation, being required over and above a number of general legislative pieces and instruments. Of relevance to this paper this includes the SA
National Building Regulations (NBR)\textsuperscript{1}, the National Environmental Management Act (NEMA) and the Infrastructure Delivery Management System (IDMS)\textsuperscript{2}. Nevertheless, development of the N&S provides an opportune moment to embed forward-thinking principles of environmental consciousness, as well as social as economic sustainability, into the policies and practices of built environment professionals in the next generation healthcare building.

3. Method

With reference to the current status, and a desired future healthcare estate, researchers discuss the anticipated contributions of N&S over and above the NBR, NEMA and IDMS to the sustainability agenda, as well as identifying “defensible exemptions” and possible shortcomings. The headings of the ten points articulated in the Vision of Sustainable Smart-eco Building in 2030 (henceforth “Ten Point Vision”) by Chevalier et al was adopted as a broad framework to structure a qualitative analysis. This is discussed in the subsequent narrative.

4. Ten Point Vision

According to Chevalier et al, European standards and guidelines are inclined to approach the general principles of sustainability in a reductionist and fragmented fashion: Cited are the focus on progressive energy demand reduction and energy generation targets in new and existing buildings in Germany, France, and Italy. The authors posit that sustainable principles need to be SMART (specific goals that are strategic, measurable, assignable, realistic, and time-bound) (Doran, pp 35 – 36) on the one hand, and on the other hand progressive and ambitious. Chevalier et al propose a Ten Point Vision (2009) as a framework for sustainable smart-eco building. Although this is centred on the European context and for general building types over a twenty year horizon, it covers a range of issues, and has been selected by researchers of this paper as a suitable holistic generic framework.

The Ten Point Vision suggests sustainable smart eco-conscious buildings should:

- Apply the general principles of sustainability;
- Be designed or refurbished from a life-cycle perspective;
- Be designed or refurbished to be adaptable throughout the service life, with an end-of-life strategy;
- Have its environmental impact minimised over the estimated or remaining service life;
- Be healthy and comfortable for their occupants;
- Be established with consideration of their economic value over time;
- Have social and cultural value;
- Result from all interested parties’ involvement and be designed or refurbished to meet the occupants’ needs individually and collectively;
- Be completely integrated into a territorial strategy and accessible for all; and
- Be designed or refurbished to be user-friendly, simple and cheap to operate, with their technical and environmental performance measurable over time.

\textsuperscript{1} Conforming to National Building Regulations is a newly emerging trend in public buildings in SA, many having been declared exempt until circa 2010.

\textsuperscript{2} Can be accessed online from \url{http://www.cidb.org.za/}, applicable to the public sector only.
Each of these points is discussed systematically below as it pertains to the new draft N&S.

### 4.1 General principles of sustainability

The first point proposed in the Ten Point Vision is that buildings should conform to the Sustainability in building construction - General principles of as described in ISO 15392:2008. These principles are considered in relation to the N&S guidance in their entirety, and without regard for prioritisation and shown in Table 1.

<table>
<thead>
<tr>
<th>Criteria /Achieved?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continual improvement</td>
<td>A condition assessment method has been described. According to the published gazettes, compliance with N&amp;S is mandatory, unless a motivated exemption is applied for and granted. This feedback mechanism could facilitate continual improvement of guidelines and by extension, buildings. However, minimal systematic updating has occurred to N&amp;S since April 2014, limited to cost model tools which are updated quarterly for inflation and exchange rates and no means exists for systematically improving N&amp;S.</td>
</tr>
<tr>
<td>Equity</td>
<td>The N&amp;S were developed as a means of addressing inconsistencies in quality and expenditure in current capital work programs. As the application is only mandatory in the public sector its adoption will impact on new work in this sector, however is doubtful that will meaningfully impact most significant structural inequity (public vs. private disparity) and as it is not retrospectively applicable will only improve equity gradually (minimum 40 year replacement average).</td>
</tr>
<tr>
<td>Global thinking and local action</td>
<td>The developers of the N&amp;S have reviewed international literature and studied the Australasian Health Facilities Guidelines, British NHS Estates Standards, American Facility Guidelines Institute guides and concluded that these needed to be adapted to meet the specific opportunities and constraints of the local context. Some examples of SA context-specific considerations are with respect to preferential passive design response to climate opportunities, energy security, affordability constraints and airborne infection prevention and control.</td>
</tr>
<tr>
<td>Holistic approach</td>
<td>The N&amp;S address only conventional facility-based diagnostic and curative services, and do not address the health-promoting and preventive aspects of healthcare, nor alternative and traditional healthcare. To work toward overall building performance optimisation, interdisciplinary and novel approaches to design may be beneficial. N&amp;S assume consultants retain conventional roles and responsibilities.</td>
</tr>
<tr>
<td>Involvement of interested parties</td>
<td>During the development phases of N&amp;S, active involvement of identified experts and stakeholder representatives was encouraged through participation in a series of open workshops at which N&amp;S development were discussed in themed sessions. These include participants with both clinical and built environment expertise. There is a dedicated project website which provides an open forum for sharing, dissemination and on-going stakeholder input allowing passive feedback. Involvement of interested parties could be strengthened and more actively pursued by making post-occupancy evaluation mandatory – not currently considered.</td>
</tr>
<tr>
<td>Long-term consideration</td>
<td>The N&amp;S were drafted in a non-prescriptive way to allow for professional discretion and innovation. A future-healthcare environments workshop was held in order to anticipate future trends - such as telemedicine - which impact on healthcare infrastructure provision. However, current healthcare infrastructure planning is...</td>
</tr>
<tr>
<td>Partial</td>
<td>reactive and does not meaningfully take into account long-term dynamics in a structured way.</td>
</tr>
<tr>
<td>---</td>
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</tr>
<tr>
<td>7 Precaution and risk</td>
<td>The N&amp;S provides guidance on mitigation through building design, material selection for several identified risks such as infection, slip, security (theft, vandalism), human error etc. (Worldwide healthcare associated infections and adverse events occur in 10% of admissions. Comparable studies are not available for SA, but could be expected to be at least in the same order of magnitude.) Precautionary measures for construction activities are discussed. General risk associated with construction, delivery etc. are described in complementary codes.</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>8 Responsibility (moral rather than legal/financial)</td>
<td>The public sector is characterised by a complex organisational design. Originating in the Constitution, each province enjoys relative autonomy. Infrastructure stewardship is conventionally split between the custodian (public works departments) and line departments (departments of health). Public works’ core business is built environment-related but not necessarily versed in the specificities of healthcare requirements. Selection of built-environment professional consultants is usually based on a roster system. Without the prerequisite for prior experience (preferred by the private sector) there is a broader-based opportunity for participation in public-sector projects. This system does not, however, incentivise consultants to specialise in any public sector domain (including the health sector). User clients (i.e. facility-based health officials) are generally not repeat clients. Team member inexperience and a lack of formal guidance and regulation have led to extreme variation in form, quality, and cost of public healthcare infrastructure. N&amp;S have limited guidance on roles, responsibilities and “rules of engagement”. The conventions of practice are customary and described by the statutory professional councils (SACAP, ECSA, SAQSC) and through the IDMS process, however.</td>
</tr>
<tr>
<td>No but described in IDMS and statutory councils</td>
<td></td>
</tr>
<tr>
<td>9 Transparency</td>
<td>According to the Access to Information Act 2:2000, information related to public capital expenditure, healthcare infrastructure etc. should be available upon request. In practice this is rarely done, and this information is not readily available. Auditing in the public sector ensures compliance with the Public Finance Management Act 1999. Limited private sector information is disclosed to maintain competitive advantage. However in the spirit of generosity and pursuit of improved healthcare infrastructure, the N&amp;S development process inspired unprecedented cooperation and sharing of information.</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Life cycle perspective

The N&S includes documents on commissioning; decommissioning and maintenance address life-cycle stages beyond design, but are not explicitly geared for use in the design phases where pro-active measures should be introduced. The discipline of life-cycle analysis for construction materials and eco-labelling is in its infancy in SA and development of the N&S project has concluded without adequate reference to this discipline. Practical guidance on measuring or reducing embodied energy is not, for instance, addressed. The N&S cost model has been developed to take into consideration life-cycle costs. This takes into account that different building elements and materials have different expected service lives and in this way contribute to the quest for an affordable estate which does not solely focus on minimising initial capital costs. A decommissioning document forms part of the suite, but there is no guidance to identify or address end of service life and no mechanism to ensure implementation in practice.
4.3 Adaptable

The Ten Point Vision proposes that sustainable smart eco-conscious buildings should be designed or refurbished to be adaptable throughout the service life, with an end-of-life strategy. Typically hospitals and primary health care buildings are constructed using traditional brick and mortar generally resulting in fixed non-flexible structures. In an environment where technology dives rapid advancement in service delivery possibilities there is generally very limited flexibility built into health projects.

Given highly customised layouts of portions of hospitals (such as operating theatres) as well as the imperative to remain continuously operational, repurposing many components for other uses may be challenging: hospitals as currently constructed may not be good candidates for recycling and reuse. A flexible, adaptable open building systems approach may be appropriate in order to address the system uncertainties and complex specialised infrastructure requirements inherent in provision of healthcare. Open building systems may have the distinct advantage over conventional methodologies in healthcare settings of allowing building adaptation with minimal disruption to simultaneous service delivery or compromise to patient care. Yet services are conventionally provided from fixed, immovable structures which have lifespans of some decades. There is a document in the N&S suite for application of innovative building technologies - which may include open-building technologies - for clinics (i.e. small-scale). The number of larger scale healthcare buildings internationally adopting the open-building technology approach is limited with a few notable exceptions (INO Hospital, Bern, for example). In SA, migration to open building technologies would require non-trivial construction industry reskilling and building material supply transformation. Because of this, it is suggested that the requirement for adaptability be a defensible exemption for the health sector.

4.4 Minimising impact

The Ten Point Vision proposes that sustainable smart eco-conscious buildings should minimise their environmental impact over their estimated or remaining service life.

The National Environmental Management Act (NEMA) requires, inter alia, that building developers and owners must take reasonable measures to ensure that pollution or degradation of the environment is prevented or minimised in development and operation (NEMA Part 28). Local government has the authority to require an Environmental Impact Assessment and this prerogative is frequently exercised, more especially for green-field site development.

In support of the requirements contained in NEMA, the Environment and Sustainability document in the N&S suite (IUSS, 2014) provide a description of sustainable development and translates this into specific sustainable development objectives for the built environment and provides detailed checklists tailored specifically for healthcare infrastructure. These enable the setting of explicit and challenging targets to reduce operational energy consumption, manage water and waste for projects as well as systems to ensure that these are achieved, and provide a framework for self-assessment to ascertain the performance of projects in development and operation.
4.5 Health and comfort

The Ten Point Vision proposes that sustainable smart eco-conscious building should be healthy and comfortable for occupants. Patient and staff experience, healing environments, comfortable workplaces and prevention of healthcare associated infections and other adverse events are prioritised in the N&S.

In order to achieve indoor thermal comfort the Building Engineering Services N&S guide (IUSS, 2014) recommends that interventions should be considered, singly or in combination, in a hierarchy where passive and adaptive comfort systems are considered before fully mechanical systems. While there is a current paucity of detailed local climate data, the publication of local climate characterisation is expected shortly which will enable detailed evaluation of design response. TB, which is communicable exclusively through the air, is the leading cause of mortality in the region. It is recognised that building design and engineering has a role to play in mitigating risk as it impacts heavily on indoor air quality (World Health Organisation [WHO], 2009, CDC, 2005). Healthcare facilities inevitably bring susceptible and infectious individuals into close contact. According to Joshi et al (p 12) and Menzies et al (pp 593-605) and others, healthcare workers in middle and low income countries such as SA are at between four and 135 times more likely to contract TB compared to the background population. To address this major health risk, great care has been taken to describe design and engineering approaches to airborne infection that are locally-driven and are evidence based. The SA approach to building envelope design departs from one found in many European norms in that it does not generally promote hermetic sealing to reduce energy. Buildings are not typically heated or cooled for much of the year. Furthermore, perhaps in addition to considering comfort, sustainable building design could or should address well-being as criteria.

4.6 Economic value and affordability

According to the Ten Point Vision sustainable smart eco-conscious buildings should be established with consideration of its economic value over time.

Increasing expenditure to address the healthcare needs optimally rapidly raises challenges to affordability. There is abundant evidence that increasing expenditure on healthcare systems does not necessarily yield better outcomes (OECD). SA expenditure in health service provision (tracking the global trend) has risen steadily over recent years and there is international concern over the affordability (and hence sustainability) of this growth path. SA spends 8.3 % of its GDP on public and private sector health (The Presidency Republic of South Africa, 2011) and sectors compete for funding from a limited fiscus. An important challenge to the health system is capital, operational funding and staffing resource constraints. The whole healthcare enterprise must be carefully configured to ensure that operation of the full estate is affordable and sustainable. Integrated infrastructure planning which takes staffing, and operational resources which will be manifested over the building’s projected life is required. To a limited extent, the N&S cost estimation tools can provide this by means of order of magnitude projections which include indicative operational cost forecasts for the medium term funding horizon enabling long term budget forecasting and reconciliation during planning.
Healthcare spending in SA is inequitably distributed across the public and private sectors. Treasury reports that 48.5% of expenditure amounting to R120.8 billion is attributed to the private sector in the service of 8.2 million people (16.2% of the population). Nearly half (49.2%) of expenditure amounting to R122.4 billion is attributed to the public sector and is in the service of the remaining 42 million people (84% of the population) (National Treasury, 2012). Although these figures are not directly comparable (the public sector figure excluding infrastructure provision) the contrast in expenditure has seriously undermined aspirations of equity, access to care and social justice. The N&S do not address both sectors and therefore will not have a direct role in resolving this economic value disparity.

4.7 Social and cultural value

In SA healthcare services enjoy great social and cultural value and its infrastructure can be symbolic of societal values of caring. This can be demonstrated in community response to opening and closure of such institutions. In SA there are historical and emergent social and cultural distortions which are expressed in the built environment. Healthcare infrastructure can be broadly characterised according to whether it is privately or publicly funded. This distinction can be linked – albeit with some limitations – (generalisation being crude) to broadly differing capital investment and building stock traits.

The private sector generally embeds lean systems thinking in its projects and values economic return on investment and organisational agility. There is recognition that healthcare built environments are necessarily substantively built-to-purpose, and specialist expertise to brief and designs is valued. The private sector invests in developing briefing and project implementation capacity in-house and cultivates relationships with experienced built-environment professional consultants for competitive limited repeat business. The project managers who implement private sector building projects have decision-making mandate to the extent that it satisfies corporate requirements. Limited experimentation is accepted but there is generally a conservative approach to building design and capital expenditure. The private sector replicates its successes with incremental refinements and adjustments over time. The larger hospital groups have become highly experienced, savvy clients. The private sector has dedicated legislation3 which describes (amongst other things) some minimum space standards. There is general consensus that this legislation is outdated4 although it is still in used to regulate some aspects of service provision (such as granting of licenses for hospital beds).

Formerly the public sector was regulated by the now repealed SA Hospital Norms (SAHNorms) with reference to maximum allowable areas and costs. In the absence of national public sector legislation, the public and media tend to benchmark private sector with the public sector, and conclude that the public sector is failing. The disparity in expenditure discussed above is sometimes acknowledged (National Treasury, p 8), but there is widespread despondency and

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3 The Regulation 158 (“the R158”) or Regulation187 in the Western Cape province
4 last revised in 1993, in the pre-democratic era
lack of morale in the public sector despite significant successes and its crucial contribution to the uninsured majority.

4.8 Stakeholder involvement

Post-occupancy evaluations of three recently completed SA hospitals (van Reenen, unpublished) have found that there is no systematic involvement by communities in the design phase (although communities do get involved in ensuring local community employment in the facility when open and there is a structured national programme to involve local labour participation in the construction programme). There is only limited involvement of client department. For example, detailed mock-ups of rooms to convey actual size was not used as a technique.

4.9 Territorial strategy

According to the Ten Point Vision sustainable smart eco-conscious buildings should be completely integrated into a territorial strategy and accessible for all. SA has a healthcare infrastructure platform which reflects the pre-democratic era: Gaps where the majority of population did not receive basic services; overlaps and duplicate services where apartheid structures were separately provided for different race groups; and private sector facilities which emerged in the 1980s, exploded post democracy to serve the insured population. The N&S guidance was originally envisaged to address all life-cycle stages but infrastructure strategic planning was removed from the scope of work. There is no evident coordinated geospatial planning programme and no [published/ discernible/ explicit] territorial strategy. Project, site and service selection does not appear to be systematically supported, except by exception, by study of accessibility and population and demand dynamics. Furthermore, leadership have expressed the perception that healthcare services may not be effectively delimited to nationals only (Lindeque, 2015). If true and unmanaged this could overburden constrained resources. Even if untrue, such perceptions may undermine social cohesion and lead to xenophobia and conflict. Given that the investment in infrastructure is on average a 40 year venture, with enormous concomitant capital, operational and human resource implications, it stands to reason that the absence of a territorial strategy is a credible concern to achieving a sustainable healthcare infrastructure platform.

4.10 User-friendliness

According to the Ten Point Vision sustainable smart eco-conscious buildings should be designed or refurbished to be user-friendly, simple and cheap to operate (i.e. maintainability), with its technical and environmental performances measurable over time. The N&S guidance requires healthcare facility design to address user friendliness for occupants. In addition to the

Ironically N&S guidance material itself is not adequately user-friendly. For convenience, and to satisfy the development time of three and a half years ab initio, the guidance was divided into 46 work-packages and each discreetly developed. This has resulted in unfortunate repetition and an unnecessary volume of material (in excess of half a million words). It is also not easy to locate or navigate in its current repository.
NBR requirements, it dictates that facilities are of inclusive design (wheelchair friendly, well-signposted, clearly laid out etc.) and in this way address user-friendliness. There is an explicit requirement to exhaust passive design technologies first, then hybrid systems and finally mechanical solutions to promote simple and cheap operation as well as to address energy insecurity.

There has been substantial, serious lack of maintenance of public healthcare facilities (with few exceptions) over a period of several years resulting in a general poor condition of infrastructure (SA Institution of Civil Engineering [SAICE], 2011). The N&S include maintenance guidance, encourages adoption of green technologies and specifies that sub-metering is installed in facilities to allow for utility consumption monitoring, benchmarking and maintenance. By contrast, the private sector is already investing in measuring technical and environmental performance and building maintenance (it is tax incentivised). It readily retrofits building to reduce emissions and install green technologies (in order to avoid carbon tax, to benefit from carbon credits and to reduce operational costs).

5. Discussion

SA has adopted a contextual approach to determining its new N&S. The new national guidelines, norms and standards with embedded sustainability practices identified above are published on an open, electronic repository gazetted into mandatory use in the public sector new capital work. The application notes expressly require implementation to be done with due diligence and application. Professional consultants are not absolved of their professional responsibilities of design, engineering and management, and are required to make use of the exemption processes where a conflict arises with professional judgement. Exemption processes are defined, requiring consultants to motivate deviations from the code, and this potentially provides a feedback mechanism to alert administrators of weaknesses in documentation and challenges in implementation, provided that this is actively monitored. As the N&S documentation and software is extensive, a structured capacity building and support programme is required to ensure implementation.

The current replacement rate of SA’s healthcare infrastructure is in the order of 40 years (Abbott et al, 2008, pp 146-183). In order to address building design from a life-cycle perspective a modification of the traditional roles may be indicated. For example building engineering for ventilation and climate control is sometimes limited to mechanical design solutions. Optimised passive ventilation design through building envelop design could result in a more energy- and life-cycle-efficient solutions but may require both redefining the engineer and architect’s traditional roles and methods of interaction, as well as client procurement practice. It seems likely that unless these requirements are anticipated in the pre-project stages (conception of need, briefing and contractual arrangements of consultants) that business will be conducted as usual and that conventional practice will remain pervasive.
6. Conclusion

There is a legacy sectorisation of healthcare provision split between public and private sectors with distorted investment patterns, reflected in current built form for healthcare infrastructure in SA. Emerging policy aims to improve equity and access which could result in a new generation of healthcare architecture over time but needs to be opened to innovation in infrastructure processes as well.

If it is accepted that the European approach to sustainable practice is exemplified in the single workshop, and that it is relevant to South Africa, it can be concluded that the N&S succeed partially in applying the general principles of sustainability. N&S require healthcare facilities to be designed or refurbished from a life-cycle perspective and provides some guidance on an end-of-life strategy. SMART benchmarks have been provided to minimise environmental impact over the estimated or remaining service life. A number of important healthcare-sector and contextually responsive health and comfort approaches have been incorporated. Some infrastructure is established to ensure involvement of all interested parties’ and be designed or refurbished to meet the occupants’ needs individually and collectively. Design, engineering and refurbishment which is user-friendly, simple and cheap to operate, with its technical and environmental performances measurable over time is discussed from a number of perspectives in the N&S.

It might be argued that the requirement that healthcare facilities be designed or refurbished to be adaptable throughout the service life, may be a “defensible exception”, at least in the short to medium term given the complications described above. There are a number of sustainability criteria which may not be adequately addressed in the N&S. Whilst healthcare infrastructure undoubtedly has great social and cultural value, there is concern that sectorisation, and economic value will not be improved through the N&S, and that this is key to achieving a sustainable healthcare infrastructure platform. Finally there may not be the desired sustainable estate unless there is the introduction of a completely integrated territorial strategy in relation to both public and private sectors to attain facilities and services are accessible for all.

References


Centers for Disease Control and Prevention (CDC) (2005) “Guidelines for preventing the transmission of mycobacterium tuberculosis in health-care settings”, Morbidity and Mortality Weekly Report (MMWR), 54: RR-17, CDC, Atlanta, USA.


Developing Sustainable Energy Efficient Buildings – A Transnational Knowledge Transfer Experience between Norway and Kosovo

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Abstract

As transnational institutional development programs are often advocated as a knowledge transfer opportunity between the partner universities, this case study “Sustainable Energy Efficient Buildings – Knowledge Transfer between Norway and Kosovo” investigated the knowledge transfer (KT) processes from Norwegian University of Science and Technology to College ESLG in Kosovo. An inter-organisational knowledge of transfer theoretical framework from the business sector was applied to guide the present study. The data was generated through semi-structured interviews with key university officers, professors, and students in continuous education programs from College ESLG and documentary evidence analysis from two partner universities. Based on the thematic analysis of the data, the findings demonstrated that the curriculum mapping process, joint lectures between Norwegian and Kosovar professors, joint research, and joint study visits facilitated the knowledge transfer. While the transfer of knowledge most evidently resulted in institutional capacity development for the Kosovar College unit, that managed the transnational institutional development program, the dissemination of knowledge to other units within the college was more challenging due to communication problems between the Real Estate Department and other units within the college. Hence, other universities seeking to conduct knowledge transfer through transnational institutional development programs need to understand each partner university’s intention in establishing the partnerships, identify the beneficiary institutions’ needs before seeking knowledge input from the partner university and improve the communication between and within the universities for sustainable benefits. The study has been part of the SEEB project supported by the HERD/Energy 2013-2015.

Keywords: transnational institutional development program, knowledge transfer, case study, Norway, Kosovo
1. Introduction

The Kosovo higher education industry includes 7 public universities: University of Prishtina, University of Prizren, University of Peja, Faculty of Islamic Studies, University of Gjilan, Kosovo Academy of Public Safety, and University of Gjakova (Kosovo Accreditation Agency, 2014). Beside this, the Kosovo Accreditation Agency (KAA, 2014) provides only a list of the evaluations of institutions (around 34) without formal decisions and there is no valuable information on the Ministry of Education, Science and Technology (MEST, 2014a). From the report published by Education, Audiovisual and Culture Executive Agency of European Union (2012) it is understood that there are 23 private higher education institutions. Most of the private and public higher education institutions in Kosovo are involved in a number of international cooperation projects supporting the establishment of new study programs or teaching improvement.

While much of literature speaks positively of the value of transnational programs in assisting institutional capacity development for universities in developing countries, there is a scarcity of empirical research that informs how these transnational programs actually facilitate actual knowledge transfer (Vincent-Lancrin, 2007; Leung and Waters, 2013). There has been limited or no research at all focusing on knowledge transfer, particularly from foreign universities to Kosovar universities through transnational institutional development programs. Therefore, it is timely to investigate the Kosovar College’s perspectives about knowledge transfer from Norwegian University of Science and Technology to College ESLG through the transnational institutional development program. The uni-directional knowledge transfer from Norwegian University of Science and Technology, Norway to College ESLG took place as part of Programme in Higher Education, Research and Development (HERD) of Ministry of Foreign Affairs of Norway. Both institutions decided to cooperate in the field of energy because Norway leads in Europe in sustainable and passive buildings. In this regard, the Norwegian Parliament in January 2008, passed the law to consider imposing the passive house level for all new buildings by 2020 (Haase, 2010). In a less wealthy country such as Kosovo, households spent on average 1,210 Euros for electrical energy bills. According to the data of the Agency of Statistics of Kosovo (ASK) for 2012, around 30 percent of household expenses are spent on accommodation, a category in which electrical energy costs are included and covered. Also, Kosovo is faced with an increasing demand for electrical energy. Only during the second quarter of 2013 Kosovo used 857.7GW/h electrical energy of which households are the largest consumers of electrical energy with 56.4 percent (Efficiency for Development, 2014). The energy consumption in Kosovo homes for space heating is estimated at over 80% of total home energy consumption (Bowen et. al, 2013).

The present study focuses on the following research question:

*How does knowledge transfer occur in the context of a transnational institutional development program “Sustainable Energy Efficient Buildings/HERD” from NTNU to College ESLG, Kosovo?*

In attempting to answer the research question, the present study focuses at first on an inter-university knowledge transfer theoretical framework, adapted from business sector literature to guide the study,
and then subsequently discusses the research methodology employed to generate the research results. After outlining the results, the discussion and implications of the study conclude the article.

2. Knowledge transfer

The theoretical framework, which is relevant to the present study, is composed of inter-organisational knowledge transfer theories developed in a business setting and complemented with the literature review on knowledge transfer in the tertiary education (Courtney and Anderson, 2009). Although the term knowledge transfer is used extensively in the modern literature, it is very important to explain what is meant by knowledge transfer as used in the present study. The knowledge transfer is defined as “the process through which one unit is affected by the experience of another” (Argote and Ingram, 2000, pp151).

According to Bauman (2005), the transfer of knowledge means the modification of existing knowledge from a sender organisation (for instance Norwegian University for Science and Technology) for the purpose of addressing issues that a receiving organization (in the context of this research College ESLG) faces. Inter-organisational theories of knowledge transfer argue that knowledge transfer takes place in four stages such as: 1) intention to engage in knowledge transfer through expressing of intention either from the sender organisation or receiving organisation to engage in transnational institutional development program; 2) the structured process of knowledge transfer; 3) the unstructured process of knowledge transfer and 4) the institutional capacity development (Chen and Mc Queen, 2010).

The inter-organisational theories of knowledge transfer argue that at the inter-university level, knowledge transfer begins with the intention of either party to engage in a transnational institutional development program, which explicitly results in a formal agreement or application for a donor-funded program. Robertson and Jacobson (2011) argue that research in the business sector shows that the expression of the intention to either acquire (receiving organisation) or share knowledge (the sender organisation) is critical to knowledge transfer. Both authors argue that the intention to engage in knowledge transfer must be mutual. The receiver organisation must explicitly exhibit the intention to acquire knowledge, whereas the sender organisation also must have the intention to share knowledge (Easterby-Smith et al. 2008). Eldridge and Wilson (2003) further argue that both institutions of higher education must show a genuine interest to engage in knowledge transfer. Huang (2007) argues that for any knowledge transfer to be successful in any transnational institutional development program, both partners must clearly specify the types and scope of knowledge transfer.

A structured process of knowledge transfer includes four phases (Szulanski, 1996). There are: initiation, implementation, ramp-up, and integration. The initiation phase usually takes place by identifying the knowledge gaps in the beneficiary institution. The knowledge gaps must be identified clearly in the partnership agreement. If the knowledge gaps are clearly identified at the initiation stage, then the implementation takes place much more smoothly. During the implementation phase, both institutions work together to ensure that the knowledge shared is what was shared between two universities and that it is also appreciated and valued by the receiving institution. The ramp-up phase follows with the staff members of the receiving university applying the acquired knowledge and
resolving the knowledge gaps. Finally, at the integration phase, the acquired knowledge is institutionalized through the production of documents such as course syllabi, teaching methodology manuals and dissemination of the produced documents to other units of the university (Flores et al. 2012).

The knowledge transfer process may also be unstructured, which takes place in a spontaneous, informal, and unplanned manner (Chen and McQueen, 2010). The unstructured process of knowledge transfer depends on arising situational demands and individual dispositions. The unstructured process of knowledge transfer includes copying pre-existing knowledge products from the partner university and adapting that knowledge to the new context of the receiving university, independent of the sender university. In the unstructured knowledge transfer process, lecturers exchange knowledge without formal agreements, and the knowledge acquired can be applied individually or collectively by the lecturers (Chen and McQueen, 2010). In order for the knowledge which was acquired through the unstructured process to be retained and further shared within the institution, the recipient university must institutionalise the knowledge gained through production of documents at the institutional level. Then the knowledge gained through unstructured process has to be merged with the knowledge transfer that takes place through a structured process. This takes place during the integration stage (Argote et al. 2003). Whereas the theoretical framework proposes the unidirectional flow of knowledge usually from the sender to recipient university, authors such as Courtney and Anderson (2009) argue that the knowledge transfer takes place in a bidirectional way and requires interaction between the partner universities to fully appreciate the knowledge being transferred.

3. Methodology

A qualitative research method is used to explore the real interest of complex situations in the planning, which cannot be easily quantified. The qualitative research approach enables us to find reliable answers for research question posed. The qualitative method can provide the intricate details of phenomena, which can’t be derived through quantitative methods (Strauss and Corbin, 1990). The qualitative research technique is a more intrusive technique and less structured as the quantitative method, which enables the interviewer to gain in depth insight regarding the research topic (Jarrratt, 1996).

The present study uses qualitative research method, which includes semi-structured interviews and consultation of documents as two data sources. In total, 120 participants were invited to respond to semi-structured interviews. Out of 120 participants, 108 responded successfully. The successful respondents were: T3 professors from Kosovo participating in the Sustainable Energy Efficient Project, the chancellor of the College, 3 master students who spent one semester at NTNU as students and later, upon graduation, became teaching assistants at ESLG, 10 students who participated in the study visit in Norway, 60 master students who attended lectures that were jointly held by NTNU and College ESLG professors, and 31 participants from the ranks of other stakeholders that participated in conferences and symposia organised by both institutions. The respondents were selected from the ranks of those that were directly involved in the project and knowledge transfer. Although four professors from ESLG were foreseen to participate in the SEEB project according to initial
application, only three were involved in all phases of knowledge transfer and throughout the duration of the project. Ultimately, ten students participated in the study visit in Norway and all of them were selected as respondents. These ten students include also three students that took place in a semester exchange, however, the three students participating in two different categories were asked two sets of questions (one regarding knowledge transfer achieved through study visit and the other one regarding knowledge transfer achieved through spending one semester). Also, sixty students were selected from two generations of students that attended lectures and courses with NTNU professors. Forty students were selected from the group of forty students enrolled in the master program of Real Estate Management in academic year of 2013/2014 and twenty students were selected from the class of twenty students enrolled in the master program of Real Estate Management in academic year 2014/2015.

Finally, thirty one respondents that were selected from the stakeholders group were selected from the group of two hundred people who took place in conferences and symposia organized jointly by NTNU and ESLG. Thirty one respondents were selected in the way that they represent main stakeholders such as Kosovo institutions (Ministry of Energy and Ministry of Environment and Spatial Planning), local government (directorates of urbanism of Kosovo municipalities), private sector (construction companies), professional associations in the field of energy efficiency, and various international donor agencies. The names of the participants were coded. The students were grouped into three categories: 1) students that completed one semester at NTNU and upon graduation were promoted to teaching assistants at the recipient university and who also did the master theses with Norwegian professors; 2) students that participated in a study visit in Norway and 3) students who attended lectures with NTNU professors in Kosovo. Table 1 describes the types of respondents, code numbers and their characteristics.

<table>
<thead>
<tr>
<th>Respondents type/category</th>
<th>Code number</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professors</td>
<td>PROF</td>
<td>Only planners with ten years of experience that worked in municipality of Prishtina immediately in the period after the war</td>
</tr>
<tr>
<td>Chancellor</td>
<td>CHAN</td>
<td>Chancellor of the College as part of executive of College</td>
</tr>
<tr>
<td>Students that completed one semester at NTNU</td>
<td>STUD₁</td>
<td>Only students that completed one full semester at NTNU and completed their theses with Norwegian professors.</td>
</tr>
<tr>
<td>Students that participated in study visit</td>
<td>STUD₂</td>
<td>Only students that participated in a study visit at NTNU</td>
</tr>
<tr>
<td>Students that attended lectures with NTNU professors in Kosovo</td>
<td>STUD₃</td>
<td>Only students that attended direct lectures by Norwegian and Kosovar professors jointly in Kosovo for a full course</td>
</tr>
</tbody>
</table>
Other stakeholders involved in the project | STAK | Other stakeholders that attended the transfer of knowledge through organisation of conferences and symposia

The categorisation of cases is presented in Table 2.

<table>
<thead>
<tr>
<th>Category code</th>
<th>Category description</th>
<th>Case identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROF</td>
<td>Professors of ESLG</td>
<td>C1, C2, and C3</td>
</tr>
<tr>
<td>CHAN</td>
<td>Chancellor</td>
<td>C4</td>
</tr>
<tr>
<td>STUD1</td>
<td>Students that completed their semester at NTNU</td>
<td>C5, C6, and C7</td>
</tr>
<tr>
<td>STUD2</td>
<td>Students that completed their study visit in Norway</td>
<td>C8 to C17</td>
</tr>
<tr>
<td>STUD3</td>
<td>Students that attended lectures with NTNU professors in Kosovo</td>
<td>C18-C77</td>
</tr>
<tr>
<td>STAK</td>
<td>Other stakeholders that attended conferences and symposia</td>
<td>C78-C108</td>
</tr>
</tbody>
</table>

The interviews were conducted in Albanian and translation by a certified translator from Albanian into English was provided. The second source of data was the selected recipient college documents pertinent to the transnational institutional development program “SEEB”. These documents consisted of an application for the SEEB project funded by the HERD program of Ministry of Foreign Affairs of the Kingdom of Norway, annual reports from the SEEB project, curriculum documents such as course syllabi, conference agenda, filled student survey forms, conference participant’s feedback, and transcripts of meetings of the Steering Committee of the SEEB project. In the present study, the documents were categorised as secondary data used to corroborate the primary findings from the interview data.

The key constructs of intention to engage in knowledge transfer were; 2) the structured process of knowledge transfer; 3) the unstructured process of knowledge transfer and 4) the institutional capacity development were examined as specific themes used to investigate the date. Excerpts from the interviews discussing those thematic areas were compared and carefully examined. While there are excerpts relevant to these predetermined thematic areas, there are also excerpts from interviews that do not support the predetermined themes. In the end of analysis of interviews, the themes are determined as dominant if they show up in more than 50% of the responses of semi-structured interviews. Furthermore, the dominant themes were used to analyse the secondary source of data such as documentary evidence. In order to enhance the credibility of qualitative studies, the triangulation technique was used (Guba, 1981). In order to ensure the triangulation, parts from the documents in line with the dominant themes were grouped together in order to support the dominant themes, which enabled triangulation of the findings from the semi-structured interviews and the findings from the documents.
4. Research results

The present study shows how College ESLG responded to the knowledge transfer processes generated by the Sustainable Energy Efficient Buildings Project (SEEB)/HERD program. College ESLG was a good partner for this project, as the first faculty in Kosovo teaching and researching in the field of Real Estate Management, and with tradition of cooperating with international institutions from Slovenia and USA. Both institutions were interested to develop creative cooperation in the field from research and teaching perspective.

The study found that the Norwegian University for Science and Technology and College ESLG were involved in a structured knowledge transfer process, which means that both parties began negotiations at the initiation stage to apply for a joint project of institutional development of the college in the Western Balkans. Within College ESLG, the project coordinator C3, who is responsible for initiation of international projects within ESLG expressed the following:

“Yes we engage in a structured process of initiation of collaboration projects with foreign universities. It all begins with the letter of intent and then a memorandum of understanding is signed. Before signing any agreement, we at ESLG identify the areas in which we need support from the foreign universities. It is in our vision to engage in collaborative projects with strong universities that come from the developed countries, from which we can benefit in terms of gaining the necessary knowledge”.

Also upon negotiations between College ESLG, NTNU and Multiconsult, the parties signed the memorandum of understanding and also the application for an institutional development project entitled “Sustainable Energy Efficient Buildings” funded by the HERD program of the Ministry of Foreign Affairs of the Kingdom of Norway. As can be seen from the extract below, institutional development, curriculum development, and research capacity development were identified as key areas for knowledge transfer. A two-way interaction was needed to prepare the application for the SEEB project.

Main objectives of the project Sustainable Energy Efficient Buildings are to develop the institutional capacity of ESLG on energy efficient buildings and sustainable refurbishment. This include development of a master study program energy management in Buildings, develop research capacity at ESLG on energy efficient buildings and sustainable refurbishment, and building a network among academia, the construction industry, and authorities in Kosovo (Application for SEEB project, pp4). While the written application for project SEEB documented the jointly agreed intentions to engage in knowledge transfer on both sides, the views expressed by participants (case 1 to case 3) through interviews were not consistent with the written documents. For case 1 to case 3, establishing transnational institutional development program was unidirectional and seen as a way to seek and develop the institutional capacity of ESLG in the area of energy efficient buildings and sustainable refurbishment, as exemplified by the following excerpt.
C1 notes the following: “From the very beginning although the application for SEEB project provided for bi-directional knowledge transfer, we as ESLG were hoping to have more uni-directional knowledge transfer in the field of curriculum development, teaching methodology, research capacity development, and grading standards in the area of energy efficient buildings and sustainable refurbishment, where Norwegians lead in the world. It was our intention to acquire as much knowledge as possible from Norway in order to transfer it further to other stakeholders such as students, authorities, and construction industry”. In the above excerpt, we can see the expectation of College ESLG to engage in knowledge transfer that was clearly seen from expressions like “unidirectional transfer of knowledge” and “transfer it further to other stakeholders”. For participants at the school level, as represented by College ESLG Lecturer 1 above, the way to engage in knowledge transfer and development of institutional capacity was through curriculum collaboration with Norwegian University of Science and Technology. From the above excerpt we can see the expectation of College ESLG to have the knowledge transfer through curriculum development collaboration, development of teaching methodology through joint teaching and development of research capacity.

Nevertheless, in the application for the SEEB project we see that the knowledge transfer was planned to take place bi-directionally because also three Kosovar professors were planned to teach at NTNU so students and professors of NTNU also gain some insight about the teaching methodologies that are practised in Kosovo.

Following the initiation stage, the universities moved to the implementation stage. Regarding the teaching methodology collaboration, professors of ESLG that were involved in the project reported positively that they learnt a lot with regards to transfer of knowledge in teaching methodology development.

“The focus of Norwegian professors on practical methods “learning by doing” has facilitated my teaching process with students of ESLG later. I introduced the same teaching process that Norwegian professors used in the courses I teach” (Case 2).

In the development of teaching methodology through co-teaching and teaching collaboration, all respondents both professors and students think that the same effect would have not been achieved had the professors from Norway stayed only as quality assurers and not as co-teachers too.

C2 noted the diversity of teaching methodologies enriches the experience in the classroom, whereas C3 stated the following: “The methods of co-teaching are not a method of teaching in our country, and I think that this method should become a practice in all our higher education institutions in order to improve the quality of studies. The co-teaching brings more transferable knowledge”.

From the category of cases STUD1, C5 notes the following:

“Through co-teaching a comparative analysis between the situation in Norway and Kosovo was drawn. In this way we were able to acquire more knowledge that now we will be able to transfer it further to other students in our capacity as teaching assistants”
Regarding transfer of knowledge through curriculum development, the answers can be exemplified by the following excerpt:

“The curriculum development collaboration took place in a structured and unstructured way. The structured way was also foreseen by the application for SEEB project to develop together a master program in Energy Management. Due to requirements of Kosovo Accreditation Agency, the collaboration was focused on development of curriculum for the study program of Energy Management. Norwegian professors submitted us the course outlines and then we developed further the learning outcomes based on the needs of construction industry of Kosovo” (Case 1).

The knowledge transfer through curriculum development capacity is also foreseen in the original application for SEEB project, which states that one of main objectives is to develop the curriculum for the study program of Energy Management at master level (Application for SEEB project, pp5). Nevertheless, the transfer of knowledge in the curriculum development was not an import of everything from Norway. As C1 notes: “Not everything was copy pasted. We customised many of the course syllabi of the Energy Management program to the needs of Kosovo. In other courses of the Real Estate program we tried together to make comparative analysis between situation in Norway and Kosovo with regards to energy efficient buildings”.

In this regard nearly all respondents, both professors and students agree that they benefited a lot from the collaboration between Norwegian and Kosovo professors in curriculum development and they appreciate the comparative analysis between Norway and Kosovo. Students responded that they benefited from teaching techniques of Norwegian professors, course syllabi, updated suggested literature, and exercises with different software. In this regard, professors noted that they benefited from joint curriculum development, definition of course objectives and learning outcomes, discussion on literature list for courses, organisation of joint conferences, production of case studies for the courses, and joint assessment of students’ research papers and final examinations according to NTNU assessment methods and guidelines. The curriculum mapping process took place through exchange of documents and discussions between Norwegian and Kosovo professors. C2 notes: “We participated fruitfully in an exchange of emails and documents regarding curriculum of Energy Management study program”. This is corroborated also by a documentary evidence of transcripts of minutes of the Steering Board of Project SEEB (Minutes of Steering Board of SEEB project, June 2014 – October 2014).

With regards to transfer of knowledge through exchange of students for one semester at NTNU, C5 to C7 all agreed that they benefited a lot in transfer of knowledge especially through practical work in the laboratories of NTNU through involvement of people from the practice in the lectures of NTNU and lectures from practice work at Multiconsult in Oslo. The transfer of knowledge through study visits can be exemplified with the following interview excerpt from case 5:

“The study visits were a direct benefit for both students of ESLG and professors. The most important thing was to attend lectures in the company Multiconsult and hear people who are involved in direct practical projects. Also visiting the Zero Emission Building Power House in Oslo was a direct knowledge transfer. All the things we have learnt for one semester in
theory in sustainable architecture we learnt through a two hour study visit in that facility” (Case 5).

In terms of knowledge of transfer in research capacity development, the respondents do not think that the transfer happened successfully although it was one of main objectives of application for SEEB project (Application for SEEB project, pp4). All the cases from C1 to C3 stated that they did not have any opportunity to work together in research publications with Norwegian professors. C1 to C3 argue that the research capacity collaboration took place more in an ad-hoc way rather than in a structured manner.

With regard to knowledge transfer through joint conferences and symposia, respondents from the construction sector categorised with the code STAK agree that they learnt a lot from presentations of Norwegian professors. C88 noted the following: “I learnt a lot from the presentation regarding design of zero emission buildings and design of climate adapted buildings”. Nevertheless, few of the cases were critical of the content of conferences because as they say they wanted to hear more about sustainable building materials and technologies rather than general concepts of refurbishment.

In the integration stage, the extent of knowledge was rather limited to the level of program of real estate. Regarding integration stage C1 noted the following: “We worked very well in other stages but we did not work together to produce documents that would serve as manuals or documents that we could use college wise. We were supposed to establish a Center of Energy Efficient Buildings, where all the acquired knowledge during the SEEB project would have been transferred to, but we failed to established the center properly due to lack of funding, although the application for SEEB project provided for the establishment of such a center within ESLG. We were able to develop and accredit a study program in Energy together but failed in the establishment of the center”.

5. Discussions

The discussion of the present study centres on main findings. Firstly, the present study found the partners’ main intentions in establishing the transnational institutional development program were clearly understood by each other. On the other hand, the study found that knowledge transfer occurred through curriculum development collaboration — a structured knowledge of transfer process which was mandated by the application for SEEB project. The study found that also the knowledge transfer occurred through joint teaching of Norwegian and Kosovo professors and although the original role of Norwegian professors as foreseen by the application for SEEB project was to serve as quality assurers, the deviation from the application in ensuring higher teaching collaboration between Norwegian and Kosovo professors turned out to be positive.

ESLG and NTNU had similar aspirations, as presented in the project application for SEEB, which upon project implementation resulted in solid knowledge transfer to Kosovo professors and students. In this regard Leing and Waters (2013) argue that contrasting aspirations between partnering universities in a joint project are the main cause for termination of the partnership and elimination of further knowledge transfer opportunities within the partnership. Mercer and Zhegin (2011) argue that universities must comprehend what each partner university seeks in the joint project or program in
order for mutually beneficial activities to be developed and sustained. It is noted that this mutual comprehension took place between ESLG and NTNU and third partner Multiconsult.

On the other hand, although the research capacity development was foreseen to take place according to the application for the SEEB project and annual reports from the SEEB project, the study found that the research capacity development was not properly achieved. Contrary to this, the transnational programs can be seen as one of the main means for knowledge transfer from the foreign university but not the only means available (Gilbert and Gorlenko 1999). In the integration stage, the study found that there was no dissemination of knowledge transfer beyond the level of real estate program to the other units. Omerzel et al. (2011) argues that one way to ensure the retention, documentation, and accessibility of knowledge beyond individual lecturers’ knowledge base, is the development of a knowledge management system. The study found that this did not happen as part of the project where all knowledge transfer would be documented.

6. Conclusions

The present research, with the focus on the knowledge transfer in the context of a transnational institutional development program SEEB from NTNU to College ESLG, shows a positive correlation between two institutions. From the findings, all four stages of knowledge transfer were covered: intention to engage in knowledge transfer, the structured process of knowledge transfer; the unstructured process of knowledge transfer and the institutional capacity development. The cooperation was as bi-directional knowledge transfer; however the present research focuses only on the uni-directional knowledge transfer from Norwegian University of Science and Technology to College ESLG. With the help from NTNU a new study program was developed, customised to the needs of Kosovo. Joint teaching of Norwegian and Kosovo professors in Kosovo and students study experiences in Norway was evaluated as a very positive case of knowledge transfer. Both professors and students enriched the College ESLG with their academic and research experiences.

To conclude, knowledge transfer occurred mainly through a structured process which was arranged in the application for project SEEB. Although one of the tasks to establish a Centre for Energy Buildings did not materialise due to the lack of funding, research activities were provided through different ways. The SEEB project has contributed to an institutional development and knowledge transfer for education and research in the field sustainable energy efficient buildings in Kosovo.

References


Chen J and McQueen R J (2010) “Knowledge transfer processes for different experience levels of knowledge recipients at an offshore technical support center.” Information Technology and People 23(1): 54–79.


Impact of Prior Distributions of Energy Model Inputs on Prediction of Building Energy Retrofits

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Abstract

In order to reduce the performance gap between the reality and energy prediction, Bayesian calibration of building simulation models have been highlighted since it can take into account the stochastic nature of building systems. However, for the use of Bayesian calibration, quantification of prior information on uncertain inputs is a prerequisite. In general, the prior information on the uncertain inputs are not well established in the literature. Therefore, uncertain inputs are usually determined by subjective judgment of simulation users.

However, the results of Bayesian calibration can be significantly influenced by the prior distributions of simulation inputs. In this paper, the authors aim to assess the impact of the prior distributions of simulation inputs on Bayesian calibration of a given energy model and decision making of building energy retrofits. The author performed Bayesian calibration using two different prior distributions (uniform and normal). Then, two different prior distributions were propagated. Based on the propagated simulation outputs, decision making of building energy retrofit scenarios was studied. It is concluded that the decision making of energy retrofits is significantly influenced by the prior distributions of inputs.

Keywords: Building Energy Simulation, Energy Retrofit, Calibration, Bayesian, Prior Distribution

1. Introduction

It is important to have an accurate energy simulation model since it predicts the effect of Energy Conservation Measures (ECMs) for existing buildings. In developing an energy simulation model for existing buildings, a calibration technique must be introduced because in existing buildings, many unknown inputs usually exist such as infiltration, internal heat generation from people, lights and equipment, indoor room air temperature, etc. Such inputs are usually not deterministic but stochastic.

The model calibration is a process of estimating uncertain inputs to reduce the gap between the actual building energy consumption (observed data) and the predicted value of the simulation
model (model output) (Hensen et al, 2012). A number of studies have been conducted on the model calibration and parameter estimation. Recently, a Bayesian inference method has been highlighted since it can take into account the uncertainty of the building’ thermal behavior. Tarlow et al (2009) introduced a Bayesian network to construct a simulation model and estimate a building energy consumption. Hawarah et al (2010) proposed a method to predict occupant behavior and energy consumption in residential dwellings based on Bayesian network. Carbonari et al (2014) used a Bayesian network to construct a system model and predict the future state of the system for supporting the model-based optimal control. Booth et al (2012) used a Bayesian calibration method for quantifying the uncertainty in housing stock models. Yan (2013) used Bayesian statistics to predict the energy consumption of a building and performed a diagnosis of the building control systems. However, Bayesian inference results are dependent on prior probability distributions. Heo et al (2015) found that a Bayesian calibration is influenced by a different information (data) level. Riddle et al (2014) discussed the limitations caused by the size (number) of observed data.

This study aims to investigate the impact of ‘prior probability distributions of inputs' on the building energy model. In this study, the authors applied two different assumptions (uniform and normal) with regard to prior probability distributions of inputs. Then, the impact of such assumptions was analysed. Please note that the aim of this study is not to find accurate prior probability distributions of each input, but to identify the influence of such assumption on decision making of energy retrofits.

2. Bayesian Calibration

The calibration methods are divided into a deterministic and a stochastic method. The deterministic method uses an optimization algorithm to search for a set of unknown inputs which minimizes the difference between observed data and simulation prediction (Carroll et al, 1993; Park et al, 2004; Ascione et al, 2011; O’Neil et al, 2012; Dong et al, 2014). However, the deterministic approach tries to find a set of inputs that minimizes an objective function in the optimization process. Therefore, it cannot take into account the stochastic nature of inputs.

For the stochastic calibration, Bayesian inference has been widely used due to the recent improvement of computational speed and development of Bayesian inference techniques (Bishop, 2006). The Bayesian calibration quantifies uncertain inputs in the energy model as probability distribution as well as to propagate the effect (uncertainty) to the output of the simulation model. The Bayesian method requires information on prior probability distributions of uncertain inputs. However, since such information is not well established in the literature, prior probability distributions of uncertain inputs are assumed to be a normal distribution in most studies.

Bayes’ theorem is as shown in Equation (1). The posterior distribution can be estimated as a product of the likelihood function and the prior probability distribution.

$$p(\theta | y) \propto p(\theta)p(y|\theta)$$  (1)
where

\( \theta \): calibration inputs

\( y \): observed data

\( p(\theta) \): prior distribution of inputs

\( p(\theta|y) \): posterior distribution of inputs

\( p(y|\theta) \): likelihood function

Kennedy and O’Hagan (2001) reported a Bayesian calibration method (hereafter referred to as KOH method) as shown in Figure 1. The relationship between the observed data \((y(x))\), a true system response \((\zeta(x))\) and the simulation model prediction \((\eta(x, \theta))\) is expressed as shown in Equation (2).

\[
y(x) = \zeta(x) + e(x) \\
= \eta(x, \theta) + \delta(x) + e(x)
\]  

(2)

where

\( x \): observable or controllable inputs

\( \zeta(x) \): true system response

\( \eta(x, \theta) \): simulation model prediction

\( y(x) \): observed data

\( \delta(x) \): model discrepancy between \( \zeta(x) \) and \( \eta(x, \theta) \)

\( e(x) \): observation error

3. Target building

The target building (Figure 2) is an office building located in South Korea. The building’s gross floor area is approximately 8,415m². The simulation model was generated using DesignBuilder.
Then, uncertainty analysis, sensitivity analysis and Bayesian calibration were performed using MATLAB script files, executing a batch run of EnergyPlus simulation.

Figure 2: Target Building (left) and simulation model (right)

The values of inputs and their ranges (minimum value, maximum value) were first sought based on the literature (Macdonald, 2002; ASHRAE, 2013a; ASHRAE, 2013b; Hosni et al, 1999; Persily, 1998; CIBSE, 2006; ASHRAE, 2007; Guadalfajara et al, 2012; Garmsiri et al, 2014). In this study, the following inputs were treated as uncertain: thermal properties of the building’s envelope (conductivity [W/mK], density [kg/m³], specific heat [J/kgK] of opaque parts, U-value[W/m²K], SHGC[-] of transparent glazing), occupant density [person/m²], sensible and latent heat from people [W/person], lighting density [W/m²], equipment density [W/m²], operation hours [h], heating and cooling set point temperatures[°C], infiltration rate [m³/s.m²], ventilation rate [m³/s person], fan efficiency[-], pump efficiency[-], heating and cooling system’s efficiency[-], elevator electricity use [W].

Morris method (Morris, 1991) were used to find dominant inputs. In Morris method, the influence of inputs on the output is determined using Elementary Effect (EE). The mean of EE for each parameter represents the influence on the simulation output. As the result of Morris method, top eight dominant inputs were selected as follows: heating set point temperature, infiltration rate, cooling set point temperature, occupant density, ventilation rate, equipment density, lighting density, absorption chiller’s efficiency.

4. Comparison of posterior probability distribution

Bayesian calibration was carried out based on two different prior probability distributions of inputs (uniform, normal). The results of calibration (the posterior distributions of inputs) are shown in Figure 3.
As shown in Figure 3, the posterior distributions of inputs differ from each other. When the prior distributions of inputs were expressed as a uniform distribution, the estimated posterior distributions are not similar to uniform distribution but are inclined towards either the minimum or the maximum. On the other hand, when the prior distributions of inputs is assumed to be in a normal distribution, the posterior distributions are similar to a normal distribution.

5. Comparison of energy retrofits

The ECMs of the target building are summarized in Table 1. The old windows are to be replaced with new windows. New windows were selected based on ASHRAE (2013b). The old absorption chillers are also to be replaced with new efficient ones.
Table 1: Energy retrofits

<table>
<thead>
<tr>
<th>ECMs</th>
<th>before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>replacement of windows</td>
<td>U-value</td>
<td>4.0 W/m²K</td>
</tr>
<tr>
<td></td>
<td>SHGC</td>
<td>0.65</td>
</tr>
<tr>
<td>Replacement of Chillers</td>
<td>COP</td>
<td>Figure 3(c)</td>
</tr>
</tbody>
</table>

Figure 4 shows energy consumption distributions of design alternatives before and after retrofit. The expected energy consumption distributions are different from each other according to the prior distributions. When the prior distributions of simulation inputs are set to a normal distribution, the range of the uncertainty becomes greater (Figure 4(b)). It is noteworthy that there is an overlapped area between before and after the retrofits.

The determination of the range and distribution form is an unresolved issue in building energy simulation (Tian, 2013). The probability distribution of uncertain inputs need to be defined before performing stochastic analysis (e.g. uncertainty analysis, sensitivity analysis, stochastic calibration). However, prior information or knowledge with regard to uncertain inputs are not well established (de Finetti, 1974; Gao and Chen, 2005; Qiu et al, 2014). In previous studies (Booth 2012; Heo 212; Tian, 2013), the ranges or distributions of inputs were mainly dependent on the level of information and subjective judgment by experts. It can lead to inaccurate prediction of retrofit alternatives. The retrofit decision must be based on the objective and validated prior distribution. The prior distributions of uncertain inputs are usually determined by simulation users’ subjective judgment and therefore, decision making of energy retrofits based on such outcome can be biased.

![Prior-Uniform](image1)

![Prior-Normal](image2)

(a) Prior distribution – Uniform

(b) Prior distribution – Normal

Figure 4: Energy consumption distributions before and after retrofit

6. Conclusion

The paper reports a Bayesian calibration study investigating the impact of assumptions on the prior distributions of uncertain inputs. It is concluded that if there is no enough information on uncertain inputs, the energy model prediction can be biased depending on the assumption of prior
distributions of inputs. At present, if Bayesian calibration is to be applied to the simulation model of existing buildings, careful attention should be paid to the assumption of the prior distributions of inputs. As a future study, the data collected through the Building Energy Management System (BEMS) can be utilized in order to overcome the aforementioned disadvantage (lack of knowledge about uncertain inputs).

**Acknowledgement**

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**References**


ASHRAE (2013b) *ASHRAE Handbook Fundamentals*, Atlanta, USA.


A Framework for Measuring the Performance of Green Building

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Abstract

There is a diversity of factors responsible for inspiring green infrastructure action which can work either independently or in combination with one another; however, the South African built environment has been slow in adopting and implementing green principles in building construction projects. The lack of evidence with respect to green progress may suggest that indicators for assessing the performance of green buildings are not yet at the forefront of the construction industry agenda. This paper emphasises that green building benefits are real, and also shows the decision maker that even though there are risks factors involved when going green, there are critical factors and indicators as well, to ensure the successful implementation of green building. The purpose of this paper is to develop a framework aimed at promoting the growth of green building. The proposed framework is synthesised from a review of literature and current best practice. The framework suggests 31 performance indicators, the presence of which may assist construction industry stakeholders in pursuing the green agenda. The indicators can also be useful to monitor progress towards the economic, social and environmental goals of going green. This paper is part of on-going research, which aims to investigate the critical factors that inhibit the growth of green building in the South African built environment in order to accelerate the understanding and implementation of green infrastructure in the country.

Keywords: Criteria, green building, evaluation, performance indicators, sustainability

1. Introduction

As the field of green design evolves, various research studies (see Srinivas, 2009; Furr 2009; Naumann et al., 2011) are focusing on measuring the actual benefits of these designs, thus the performance of buildings that are considered ‘green’. Numerous projects in the United States of America (USA), and other countries are attempting to define the qualitative and / or quantitative measures of green buildings, and the data needed to implement and assess these measures. These relentless efforts are important to determine whether the expected impact on human
health and the environment has been achieved, and the related additional cost or saving (Todd & Fowler, 2010). Many types of tools are available to the construction industry, including sustainability assessment indicators, used for providing summaries and to focus and condense the complex surroundings into a form of manageable indicators (Suopajarvi, 2011). Building rating systems, also known as ‘building rating tools’ are one such type of sustainability assessment indicator. Green building cost and performance metrics (Todd & Fowler, 2010), the metrics include measurements for the cost and performance impact of water, energy, maintenance and operations, waste generation, purchasing, occupant health and productivity, and transportation. The metrics and protocol are being applied in the USA where green building designs are compared to similar buildings with more historically typical designs (Todd & Fowler, 2010). According to Gibberd (2011), the objectives of and criteria for green building designs should integrate environmental, social and economic performance requirements. In addition, the objectives and criteria should be aligned with good practice and government policy. However, studies demonstrates that historically green building performance indicators have been predominantly developed to assess some environmental issues and that, few of them could currently be considered to adequately assess the full range of sustainability issues (Lowe & Ponce, 2009; GBCSA-WGBC, 2013). On the socio-economic front, very little research has been undertaken to ascertain the linkages between green building practices and the socio-economic performance of green buildings, especially in the long term for purposes of sustainability evaluation (Kalua, 2015; Kamali & Hewage, 2015), and particularly in the context of developing countries. The reasons for this are in themselves, a potential area of further research but are likely to be, at least partially, due to the fact that environmental issues are typically easier to quantify and can therefore be assessed objectively. However, social-economic sub-issues are often difficult to assess either relying on subjective judgment, or complex calculations which do not sit well in assessment systems that aim to be objective and time / cost effective to use (Lowe & Ponce, 2009).

In the context of South Africa, the Green Building Council of South Africa (GBCSA) released its first assessment tool that improves or has the potential to improve environmental performance during the design and construction phase (GBCSA, 2014a). Furthermore, it should be noted that the GBCSA has also released its existing building performance tool for pilot application. The credits of the rating tool fall within three broad categories, and will consider measurable performance indicators such as water, energy and waste management, lease agreements, management contracts or procurement policies that define performance requirements, and building attributes that inform performance (DPW, 2013; Business Report, 2013). The rating tool will address demand from an entirely new segment of the property market in South Africa and allow effective and objective measurement of an existing building’s environmental performance in operation. However, specific design solutions with respect to how to achieve key performance indicators have not been prescribed (Business Report, 2013). Most recently, the GBCSA has also released Green Star SA Socio-Economic category indicators for piloting (GBCSA, 2014b). The Socio-Economic Category Framework has been established with key considerations and boundaries, such as building scale, stage of life, prioritisation, and objective assessment measures. The framework in terms of building scale addresses individual buildings only, excluding community, precinct or neighbourhood projects (GBCSA-WGBC, 2013). In terms of stage of life, the framework focuses on what can be
achieved mainly through the design and construction phases. However, the framework does not address the long-term operational phase of the building (GBCSA-WGBC, 2013). These challenges reflect the need to develop an all-inclusive indicators that are based on accurate scientific data as well as indicators that are easy to understand for the public and decision-makers (Sustainable Cities International, 2012).

Against this backdrop, the aim of this paper is to develop a framework aimed at promoting the growth of green building by establishing the need to engage with the balance of environmental issues as well as economic and social imperatives. This is a review paper and it significantly draws from reviews of literature deemed to be relevant to the aforementioned aim. The study is grounded in the context of developing countries such as South Africa. In order to enhance the growth of green building, monitoring and evaluation of green building performance should be carried out. It will also be necessary to establish a baseline of building typology performance, formulate an appropriate set of national indicators, measure progress in building performance, measure compliance to annual targets, and to project a trajectory toward meeting national goals (DPW, 2011). Gibberd (2002) affirms that to facilitate the application of knowledge developed, as well as the monitoring and evaluation of green building assessment, indicators, rating and labelling systems specific to Africa is required. Although the CSIR has developed an assessment system (see Gibberd, 2002) suitable for use in Africa, it relies on the further development of indicators specific to the challenges experienced on the continent (Du Plessis, 2005).

2. Research methodology

The research methodology adopted for this paper was to conduct a critical review of the literature, which explored key performance indicators for green building mainly on the basis of academic literature. According to Fink (1998), “A literature review is a systematic, explicit, and reproducible design for identifying, evaluating, and interpreting the existing body of recorded documents.” The analysis of documents pursues the aim of uncovering material that does not have to be created on the basis of data collection by the researcher. The objective for surveys of the literature are two fold; firstly, to summarise existing research by identifying patterns, themes, and issues. Secondly, this helps to identify the conceptual content of the field (Meredith, 1993) and can contribute to theory development. This study also follows a deductive approach. According to Goodwin (2002), a deductive approach takes the form of top-down reasoning from more general (by developing theory) to the more specific, whereas the inductive is the bottom-up logical process of reasoning from the specific to the general (theory). Mouton (2001) contends that the most common forms of deductive reasoning in science are the following:

- Deriving the hypothesis from theories and models, and
- Conceptual explications: when the meaning of a concept is clarified through the deductive derivation of its constructive meaning.

The Cape Peninsula University of Technology (CPUT) library databases ‘Compendex Engineering Village’ and ‘EBSCOhost GreenFILE’, were used to retrieve the appropriate journal and conference articles. Key words used were combinations of: ‘Green building’, ‘measurement’, ‘sustainability’, ‘performance’, ‘indicator’, ‘criteria’, and ‘evaluation’. These articles were further refined by reviewing abstracts and conclusions as suggested by Kamali & Hewage (2015). The common Key Performance Indicators (KPIs) were prepared, modified, and
combined to form the refined KPI set for each of the sustainability dimensions using the content analysis method. A broad definition of content analysis according to Holsti (1969) is "any technique for making inferences by objectively and systematically identifying specified characteristics of messages." All forms of documents, including electronic and printed, such as letters, books, survey reports, organisational papers, and advertisements, can be used as references.

2.1 Definitions and basic concepts

There are a number of key terms used in this paper and their definitions are as below.

Green building: is defined “as a construction project that is either certified under any recognised global green rating system or built to qualify for certification.” (Bernstein & Mandyck, 2013: 5)

Performance evaluation: This refers to the process of assessing or evaluating the performance of the whole building or its component parts, according to a set of performance targets, criteria or requirements (Foliente & Tucker, 2007: 1).

Performance indicators: Performance indicators are a set of measures that reflect the environmental credentials or performance of a building. It should be noted that in research literature, a distinction is made between environmental or 'green' assessment and 'sustainable' assessment; the latter includes the indicators covered in the former and extends its scope to include social, economic, and other indicators (Foliente & Tucker, 2007: 1).

Performance criteria: This is an expression or statement of the level of performance an indicator is required to achieve. It includes two elements: (a) a performance indicator, and (b) an acceptable value or range of values and grades (e.g. 1 star to 5 stars). Performance criteria may be quantitative or qualitative, or mixed (Foliente & Tucker, 2007: 1).

Sustainability: The WCED, which is known as the Brundtland commission of 1987, defines sustainability as ‘‘a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional changes are made consistent with future as well as present needs.’’ (WCED, 1987)

3. Rationale for key performance indicators

Performance indicators are quantifiable performance measures used to define success factors and measure progress toward the achievement of stated goals. The measures are typically referred to as Key Performance Indicators (KPIs) and used within a balanced scorecard as a method of consolidations (Feifer, 2011). KPIs are metrics (financial and non-financial) that are used by organisations and individuals to check compliance with stated requirements or to define and measure progress towards stated goals or objectives (Lowe & Ponce, 2009). Consequently, a KPI can be described as a “key part of a measurable objective which is made up of a direction, a target, a benchmark, and timeframe” (Jones & White, 2008). Foliente & Tucker (2007)
contend that occasionally, an assessment should be undertaken to check if the KPIs meet the performance targets set beforehand. In other cases, an assessment is done to obtain a snapshot of performance to which current and future facility improvement works can be compared (Foliente & Tucker, 2007). Lowe & Ponce (2009) affirm that the rationale for performance measure seeks to establish position and to monitor progress because organisations want to communicate performance to shareholders or costumers in order to stimulate interest. To Foliente & Tucker (2007), the objective may be to benchmark a particular building's performance intended or in service to others of similar type and / or size. Actual in-service performance matters most because impacts and consequences or benefits are real, it serves to validate design or refurbishment intent, and it contributes to knowledge and could improve future practice (Foliente & Tucker, 2007). Usually, KPIs are embedded within performance measurement and benchmarking systems (Lowe & Ponce, 2009). According to Newman & Jennings (2008), indicators are important in holding governments and communities accountable to their sustainability targets and goals. In addition, indicators provide data to guide policy-making and allow for comparisons to be made across local authorities, municipalities and provinces.

4. Identification and classification of performance indicators for green building

When identifying and defining key performance indicators for buildings three different performance levels can be distinguished, these are environmental performance, social performance as well as economic performance (Kamali & Hewage, 2015; Gibberd, 2011; Todd & Fowler, 2010). Traditionally, most green building rating systems have understandably tended to focus exclusively on environmental impacts. However, internationally within the green building movement there appears to be an increasing interest in the inclusion of social and economic impacts as well, and a shift in this direction (GBCSA-WGBC, 2013). Some researchers have argued that green building performance indicators should address two criteria (see Gibberd, 2011; Feifer, 2011), for instance Gibberd suggested environmental and building Criteria. Other researchers (see Ugwua & Haupt, 2007; Sham & Ma, 2013; Kamali & Hewage, 2015) have expressed contrasting view that green building performance indicators should address three criteria since the concept of sustainability usually spans three factors: social, economic and environmental. In recent years, building owners and designers, researchers, and academics have begun performing studies related to the costs and benefits of green design. Some of these studies attempt to address the full impact of green building designs, while others emphasise the economic aspects, the environmental impacts, and the social aspects separately (Todd & Fowler, 2010)

4.1 Economic performance indicators

In the context of developing countries such as South Africa, economic performance of green buildings is aimed at employment creation and economic opportunity. Employment creation is to encourage and recognise developments, which create employment opportunities through design decisions, and construction practices that include facilities for micro-enterprises, targeted employment for priority groups, and labour-intensive construction methodologies. More so, economic opportunity is aimed at encouraging the growth and development of small, micro and medium sized enterprises (SMMEs) through interventions during the design, construction and
operational phases of a building, including procurement of goods and services, and enterprise development support programmes (GBCSA, 2014b). Naumann et al. (2011) express similar sentiment that economic performance indicators are aimed at creation of permanent jobs in maintenance of green infrastructure, benefits for businesses including contractors, tourism and leisure businesses, land and natural resource, based enterprises, and the creative industries. Feifer (2011) contend that economical dimension contains four general indicators, covering the cost of a building up front and seen over years, maintenance and costs for operations, suitability for conversions, and number of refurbishment cycles. Other studies revealed that economic indicators encompass two aspects. For instance Sham & Ma (2013) research show that the two indicators cover asset value and building maintenance. On the other hand, the work of Andrade & Bragança (2011) classified these two aspects as cost and bureaucracy.

### 4.2 Environmental performance indicators

To Boyer, Creech & Paas (2008), the goal of environmental performance indicators is to contribute to conservation and sustainable management of resources. There are three general indicators within the environmental dimension, limited to the assessment of environmental impacts and aspects of a building on the local, regional and global environment. The quantifiable indicators are expressed mainly as a lifecycle assessment and with some additional quantifiable environmental information (Feifer, 2011). Environmental criteria should include; energy, water, indoor environmental quality, land, materials, and transport. Building criteria includes; greenhouse gas emissions, lighting power densities, potable water consumption, ventilation rates, electric lighting levels, individual comfort control, daylight, topsoil, recycling, and public transport (Gibberd, 2011; Sustainable Cities International, 2012).

### 4.3 Social performance indicators

Social performance indicators is the least studied and least understood aspect of building performance since the parameters to be included in this category have not clearly defined. It is often challenging to measure the actual effects of a given building on social, community, and health indicators according to Todd & Fowler (2010). Social performance indicator is to provide income or employment to community beneficiaries and contribute to community livelihood and well-being (Boyer et al., 2008), as well as social benefits through education, skills, volunteering, and community engagement (Naumann et al., 2011). The social dimension covers five indicators, mainly the impacts of a building related to its occupants, expressed by quantifiable indicators (Feifer, 2011). These factors were clustered into three key priority themes: employment and economic opportunity, education and skills development, health and safety, equality and community engagement, and benefit (GBCSA-WGBC, 2013). For instance, education and training in new skills for green buildings can help to sustain existing economic activities more efficiently and effectively as well as diversify the economic base of communities (Boyer et al., 2008). Because green building presents an opportunity to address some of the issues and problems that affect construction workers, such as the promotion for social dialogue in decision-making, providing equal access to opportunities and retraining of workers [International Labour Organisation (ILO, 2011)]. Improvements in community health and wellbeing that result from increased income, new skills and stronger community organisation can be signalled by more children attending school and improved access to health care.
Observing and documenting such changes for annual reflection will help triple bottom line enterprises ensure that the downstream social benefits are in fact being realised by their target beneficiaries (Boyer et al., 2008).

However, in the South African context, the performance indicators are categorised into two main groups. The first one is the environmental aspect and the second is the amalgamation of the social and economic aspect to form socio-economic category. The key performance indicators are summarised in table 1.

**Table 1: A summary of the key performance indicators**

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
<th>Performance Indicators</th>
<th>Key Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td>Energy</td>
<td>• Lighting power densities</td>
<td>Gibberd (2011)</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>• Potable water consumption</td>
<td>GBCSA (2014a)</td>
</tr>
<tr>
<td></td>
<td>Indoor environmental quality</td>
<td>• Ventilation rates</td>
<td>Sham &amp; Ma (2013)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Electric lighting levels</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Individual comfort control</td>
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<td>• Daylight</td>
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<td>Transport</td>
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<td></td>
<td>Emissions</td>
<td>• Greenhouse gas (GHG)</td>
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<tr>
<td>Socio - Economic</td>
<td>Employment creation</td>
<td>• Targeted employment during construction</td>
<td>GBCSA (2014b)</td>
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<td></td>
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<td>• Facility provided for micro-enterprise</td>
<td>Boyer et al. (2008)</td>
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<td></td>
<td>Economic opportunity</td>
<td>• Small and medium sized business development support.</td>
<td>GBCSA-WGBC (2013)</td>
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<td>• Procurement</td>
<td>Naumann et al. (2011)</td>
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<td>Skills development and training</td>
<td>• Cost of skills development and training as a proportion of total employment</td>
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<td>• Compliance with CIDB standard for developing skills</td>
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<td>Community development</td>
<td>• Inclusion of a community/public benefit facility</td>
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<td>Empowerment</td>
<td>• Implementing the principles of Broad-Based Black Economic Empowerment (BBBEE).</td>
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<td>Safety and health</td>
<td>• Safety and health for workers</td>
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<td>• Impact on local community</td>
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<td>• Materials toxicity</td>
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5. Strategies to selecting and improving key performance indicators

A systematic selection and monitoring of performance indicators as well as evaluation of projects and policies based on a common methodology would be necessary to continuously improve the development of performance indicators in the South African built environment. The approach to selecting indicators generally falls into two general categories, top-down or bottom-up. The top-down approach means policy makers define the goals and accompanying indicators, the data collected is usually highly technical and requires experts to interpret (Sustainable Cities International, 2012). Therefore, Buys & Hurbissoon (2011) contend that tertiary institutions or other service providers should provide green building training opportunities for all built environment stakeholders to take up the challenge in transforming the green building sector. The bottom-up approach is community-based and involves extensive consultation with stakeholders to select appropriate indicators. The key difference in the two approaches is complexity. Top-down processes involve more tools that allow for greater depth of analysis, while bottom-up processes are more basic and broad. It is possible to combine the approaches to create a hybrid approach; however this depends on the context. These two approaches reflect the need to develop indicators that are based on accurate scientific data as well as indicators that are easy to understand for the public and decision-makers. A solution to this problem that has been put forward is to select a set of ‘core’ indicators, which span the breadth of a community’s sustainability goals. These core indicators should be easily understood and demonstrate the linkages between multiple sustainability goals (Sustainable Cities International, 2012). Thus adequate understanding and knowledge of KPIs is a desirable first step towards achieving the educational goals. It is also one of the main underpinnings for successful institutional transformations, and efficient decision making in design, specification and construction, at various project-level interfaces, using appropriate decision-support tools (Ugwua & Haupt, 2007).

The effectiveness of green performance guarantees in practice should be assessed, including the existing tools and technical monitoring systems (for water, energy and waste) that are applied (UNEP-SBCI, 2014). Through performance guarantees, developers / owners can address the risk of not achieving a stated indicator of green performance, such as a level of certification according to a green building rating tool or a specified energy performance with associated financial benefits. The most common performance guarantee addressing green or resource efficiency includes water and Energy Performance Guarantee (EPG) (UNEP-SBCI, 2014). However, in South Africa, the development and implementation of Energy Performance Certificates (EPCs) is at its infancy stage as a draft standard of the EPCs has been developed by a working group under the auspices of DPW and DoE (DPW, 2013). More so, Water Performance Certificates (WPCs) are not available in South Africa, but the Green Building Council of South Africa (GBCSA) has introduced a Water and Energy Benchmarking Tool
which provides a basis for comparing a building’s water usage to measured benchmarks. The Water and Energy Benchmarking Tool is however limited to office type buildings (DPW, 2013). Therefore the continued advancement of mandatory performance indicators for new buildings would serve as powerful incentives for change in the green building sector (Globe Advisors, 2012).

6. Conclusions

Significant research gaps still exist in terms of key performance indicators for green building in developing countries. The situation in developing countries such as South Africa clearly requires further implementation of policy measures as well as further research as many developing countries have not yet introduced or are just about to introduce policy instruments to enhance the development of key performance indicators for green buildings. The outlined literature indicates growing interest in research with respect to a three dimensional performance indicators for green building in both developed and developing countries. However, the socio-economic dimension is often difficult to assess either relying on subjective judgment or complex calculations which do not sit well in assessment systems that aim to be objective and time / cost effective to use. These challenges reflect the need to develop an all-inclusive indicators that are based on accurate scientific data as well as indicators that are easy to understand for the public and decision-makers. It should be noted that this paper is part of an on-going comprehensive research project currently being conducted by the authors regarding the critical factors that inhibit the growth of green building in the South African built environment in order to accelerate the understanding and implementation of green infrastructure in the country. Only very few evaluation studies are currently available and even fewer include quantitative data on effectiveness of green building performance indicators in South Africa. Therefore, the long-term objective of the research agenda is to conduct an empirical study to identify:

- How the public, decision makers and practitioners perceive the level of importance and the degree of utilisation of key performance indicators as related to green building?

- What progress has been made in implementing / enforcing these indicators in South Africa?

- What are the most significant challenges associated with the implementation of the indicators?

- The development of a method for identifying the impacts of socio-economic indicators on a green building construction and assessment.

- The need to be able to determine the level of performance and how it compares to a more typical building in the same climate, with the same occupancies.
- Measures on how the indicators can further be developed and how this can be introduced into the economy to improve sustainability in residential building.
- A framework for post occupancy evaluation for green buildings according to a set of performance targets, criteria or requirements.

References


Gibberd J (2011) Green buildings: key considerations and opportunities for Government’s infrastructure programmes, CSIR.


Holsti O R (1969) *Content Analysis for the Social Sciences and Humanities*, Addison-Wesley, Reading, MA, USA.


Environmental Life Cycle Assessment (LCA) of Road Pavements: Comparing the Quality and Point of Application of Existing Software Tools on the basis of a Norwegian Case Study

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Abstract

Various software tools have been developed to evaluate the life cycle performances of roads to provide decision supports for road authorities and contractors. It is therefore important to compare the strengths and limitations of these software tools to understand the appropriate application and to identify the points for optimization. This study evaluated EFFEK 6.6, EKA, and LICCER software tools, by applying the environmental life cycle assessment following the ISO 14040 standard. The assessment was based on an open-air road (excluding tunnels and bridges) with a functional unit of one kilometer and greenhouse gas emissions as well as embodied energy indicators were evaluated in the considered software tools. The open-air road was modeled for each software tool with respects to road class H9 characteristic in Norway, classed as a national road. The assessment showed that the system boundary and purpose of use differed between the considered software tools. This resulted in performing the assessment only over A1 – 4 and B6 modules according to EN 15978 standard for the hypothetical open-air road to provide a comparable boundary condition. The results demonstrated that EFFEK overall yielded higher values for greenhouse gas emissions and embodied energy compared to the two other software tools, while, the three software tools quantified nearly the same amount of asphalt use within the 20-year analysis period.

Key words: LCA, asphalt, GHG emissions, embodied energy, road
1. Introduction

Roads as part of the transport infrastructure contribute to job creation and growth of GDP. However, roads are also corresponding to natural resource use, land usage, emission and waste creation. And, every year new roads are built, maintained and rehabilitated due to an increased demand for new roads and deterioration of existing roads. This growth in demand and increase in cumbersome issues (like availability of resources, environmental awareness etc.) puts decision-makers in a challenging position to address and comply with the various challenges.

Environmental life cycle assessment (LCA) is a well-established and standardized method and has been widely used due to the increased awareness in importance of environmental stewardship (ISO, 2006). LCA is a method that evaluates potential environmental impacts for a product or service over its full life cycle (ISO, 2006). And so far, different LCA studies have been conducted in the area of road infrastructure in order to better understand the environmental impacts associated with roads and road products such as ECORCE2, DuboCalc, PaLATE, SEVE, etc. (Zukowska E. A. et al., 2014). In spite of availability of different road LCA software tools (Hammervold, 2014), different areas of coverage could be found in the domain of software that might be due to various system boundaries and intended applications. This leads to the fact that some LCA software tools may show unexpected results.

The present work is aiming to evaluate three currently used software tools based on a hypothetical Norwegian road, especially regarding the results achieved in terms of embodied energy and greenhouse gas emissions. The considered software tools are EFFEKT 6.61, EKA2 and LICCER3. The hypothetical road is chosen from manual 017 “Road and street design” (NPRA, 2013b) and categorized as road class H9 with a total distance of one kilometer with annual daily traffic above 15 000 vehicles.

2. Methodology

Environmental Life cycle assessment (LCA) is a well established method and has been widely used due to the increased awareness of importance of environmental stewardship (ISO, 2006). LCA is a methodology that analyzes and evaluates the environmental impacts associated with a product system, service or activity in a systematic way through its entire life cycle (Baumann and Tillman, 2004, Lindfors et al., 1995, ISO, 2006). The entire life cycle or “cradle-to-grave” refers to the whole value-chain of a product that can be simply comprised of extraction, manufacturing, transportation, use, and disposal activities. These stages are explicitly illustrated by EN 15978 standard in figure 1.

1 http://www.vegvesen.no/
2 http://www.trafikverket.se/
3 http://www.eranetroad.org/
LCA is often performed to compare different product systems with a same functional unit, to find critical stages and/or processes (hot spots), or to document environmental performances as internal reports (Robèrt K. H. et al., 2002, Baumann and Tillman, 2004).

Based on a description that has been provided by International Organization for Standardization (ISO) within ISO 14040:2006 standard (ISO, 2006), a LCA is comprised of four main stages: goal and scope, inventory analysis, life cycle impact assessment, and interpretation (see figure 2) (ISO, 2006).

- Goal and scope describes what the target, purpose, and relevant choices are.
- Inventory analysis identifies input/output material, energy, and corresponding emissions.
- Life cycle impact assessment measures the potential impacts from the developed inventory in a qualitative way.
- Interpretation explains the results in each stage to increase the transparency and to help make more informed decisions.

![Figure 1: Modular information for building life cycles (CEN, 2011).](image)

**Figure 1:** Modular information for building life cycles (CEN, 2011).

**Figure 2:** Four stages of an LCA (ISO, 2006)

### 3. LCA tool

The three software tools, which are in the scope of assessment of this paper, are EFFEKT6.6, LICCER and EKA. Here, a brief description for each software tool is provided to represent the focus area of the LCA tools.
3.1 EFFEKT 6.6

EFFEKT is a software program that is developed by the Norwegian Public Road Administration (NPRA) (Hammervold, 2014). It is a tool that assesses cost-benefit and socio-economic analyses of road infrastructures. EFFEKT is particularly developed for and regularly used during early stages of road infrastructure planning (Miliutenko S. et al., 2014a), aiming at roughly estimating the consumption of inputs, cumulative energy use and GHG emissions in a context when little data for a new road project are actually available. EFFEKT is carried out to assess the impacts from alternative routes of a road project compared with a reference scenario (baseline) that helps for selection of solutions or prioritization of route alternatives within a road project (NPRA, 2007, Martinsen J. A., 2008). EFFEKT includes production, construction and some modules of use life cycle stages as shown in figure 1, but it excludes end-of-life and potential benefits and loads life cycle stages from its assessment (Liljenström, 2013). The main focus of the calculations is on impacts from major material production activities and selected construction activities.

3.2 EKA

EKA was developed by the Swedish Transport Administration to calculate inputs, cumulative energy and GHG emissions of different road maintenance activities for various asphalt types (Martinsson, 2014). The tool covers the entire asphalt production value chain (from input materials to the finished products) based on Swedish production techniques. This means EKA incorporates submodules A1 – 4, and also, it covers some parts of use, end-of-life and potential benefits and loads life cycle stages in its assessment. The final asphalt products in EKA tool are: hot mix asphalt, warm mix asphalt, half-warm mix asphalt, remixing (recycled asphalt), tank coating (surface treatment), and thin-layer coating (Martinsson, 2014).

3.3 LICCER

LICCER was a research project funded by ERA-NET with the aim at developing “an easy to use model based on existing tools and methodologies for Life Cycle Assessment of road infrastructure” (Brattebø H. et al., 2013). LICCER was to a certain extent motivated by EFFEKT and it evaluates inputs, GHG-emissions (in ton CO\textsubscript{2}-eq/year) and cumulative energy demand (energy use in GJ/year) in early planning of road infrastructure (open-air roads, bridges, and tunnels), as well as road furniture (O'Born R. et al., 2013, Brattebø H. et al., 2013, Liljenström, 2013, Miliutenko S. et al., 2014b, O'Born R. et al., 2015). LICCER includes production, construction and some modules of use as well as end-of-life stages, but it excludes potential benefits and loads life cycle stage from its assessment.

4. Case study

Manual 017 (NPRA, 2013b) entitled “Road and Street Design” was a guideline used in this study. The manual developed by the Norwegian public road administration (NPRA) provides technical requirements for the design of roads and streets and it does not discusses non-traffic related conditions (like landscape condition, geology, etc.) (NPRA, 2013b).
Based on the manual 017 (NPRA, 2013b), there are various road classes for construction of national main roads. Here, road class H9 is selected for the assessment, which is classed as the national main road. The road class H9 has a motorway standard with the speed limits of 100 km/h. The road must be built as a 4-lane road with driving lane and hard-shoulder of 3.5 and 3 meters wide, respectively, and it consists of a 23 meter wide roadway in total (NPRA, 2013b). Figure 3 illustrates the schematic view of the road cross-section.

![Figure 3: The cross section of national main road H9 (NPRA, 2013a)](image)

Due to the fact that there was no reference model for a typical pavement structure corresponding to design class H9, it was necessary to design a hypothetical road first in order to assess the environmental impacts from the road in a next step. To do so, empirical pavement design is selected based on chapter 51 in the manual N200 (NPRA, 2014). By means of manual N200, it is possible to design an empirical road pavement with some prerequisite input data such as subgrade condition, traffic load, road construction materials, climate condition and standard structure.

<table>
<thead>
<tr>
<th>Table 1: The structure of designed pavement for road class H9</th>
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<tr>
<td><strong>Layer</strong></td>
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<tr>
<td>Wearing course</td>
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<tr>
<td>Binder course</td>
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<tr>
<td>Base course</td>
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<tr>
<td>Sub-base</td>
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<tr>
<td>Frost protection</td>
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<tr>
<td>Total thickness</td>
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</table>

In the designing stage of a hypothetical road pavement, it is assumed that the road is located in Malvik municipality. The ADT in the opening year is assumed to be 15 000 vehicles\(^4\) (with 12% share of heavy vehicles) and it is assumed that annual heavy vehicles traffic growth is 1.4%. The frost amount \(F_{100}\) is 18 000 h\(^\circ\)C (it is assumed that the maximum correction factor is 1.3; annual mean temperature is 5.4\(^\circ\)C and average frost amount \(F_{100}\) is 18 000 h\(^\circ\)C) and road subgrade

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\(^4\) Annual daily traffic (ADT) above 20 000 vehicles is suggested for the road class H9 (according to manual 017); however from a hypothetical viewpoint in this paper, it is assumed the road provides service to ADT above 15 000 vehicles in its initial operation year.
consists of clay with Cu T4. Table 1 presents a theoretical pavement layers that designed for the hypothetical road.

5. Results

Although the introduced software tools have intentions to quantify GHG emissions and embodied energy associated with road projects, they slightly differ where they draw their system boundaries. EFFEKT 6.6 on the one hand covers production, construction and (some modules of) use stages (B1, B2 and B6) in its system boundary. And, LICCER covers more life cycle stages compare to EFFEKT 6.6 by including production (A1 – 3), construction (A4 – 5), use (B1, B2 and B6) and end-of-life (C1 – 3) phases. EKA on the other hand has a more limited coverage. EKA does not consider construction phase of a new road (stage A5) like earthworks, drainage system, unbound layers etc. in its assessments. Instead, it only evaluates embodied energy and GHG emissions associated with bound layer products within maintenance activities.

With respect to the described dissimilarities between the LCA software tools, it became clear that performing a full lifecycle “cradle-to-grave” was not applicable due to limitation in the system boundary of the EKA tool and not full lifecycle coverage by EFFEK 6.6 (as it is explained in EN 15978 standard (CEN, 2011)). Thus, in order to run a fare comparison between these three software tools, it has been decided to evaluate them based on the stages and the modules that they have in common. By doing so, it could be said that the maintenance module from the use stage (B2) as well as A1 – 4 modules are mutually covered by these three software tools (see figure 4).

![Figure 4: Life cycle stages and modules shared mutually between the three software tools.](image-url)
maintenance activity, the following equation is conducted to quantify tonnage of asphalt pavement.

\[ AS [\text{ton}] = (T \times L \times B \times 2.5) \]  \hspace{1cm} (1)

In formula (1), AS is the total tonnage of asphalt wearing course; T is the thickness of wearing course; L is the length of road; B is the width of road; and 2.5 (ton/m\(^3\)) is material density of asphalt.

Formula (1) is the same equation that is introduced by EFFEKT 6.6 in its manual (Straume A. and Bertelsen D., 2015) to calculate the amount of an asphalt wearing course. LICCER also proposes almost a similar formula, the only difference is the asphalt density. LICCER considers a density of 2.24 ton/m\(^3\) as a default for asphalt product, instead of 2.5 ton/m\(^3\) in EFFEKT\(^5\). Whereas both tools assume that a typical hot mix asphalt (corresponding to 96% of production of asphalt product in Norway) consists of 94% aggregates and 6% bitumen.

As many roads are designed based on certain standards to fulfil the pavement serviceability, various influential parameters influence the maintenance intervals (like traffic volume, climatic zone, subgrade strength, frost depth etc.) over years (Garbarino E. et al., 2014). In this paper, maintenance intervals are taken from report no. 358 (Straume A. and Bertelsen D., 2015) that suggests pavement lifetimes with respect to different traffic volume. It is also assumed in each maintenance activity, 0.04 meter of road is milled and replaced by new asphalt wearing course.

By inserting all the input values to the three LCA software tools, the following results can be observed (table 2):

<table>
<thead>
<tr>
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<th>EFFEKT 6.6</th>
<th>EKA</th>
<th>LICCER</th>
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<tbody>
<tr>
<td>Greenhouse gas emissions (ton CO(_2)-eq)</td>
<td>487</td>
<td>344</td>
<td>296</td>
</tr>
<tr>
<td>Embodied energy (GJ)</td>
<td>28 108</td>
<td>5 786</td>
<td>27 400</td>
</tr>
<tr>
<td>Amount of re-asphalting (ton)</td>
<td>8 330</td>
<td>8 400</td>
<td>7 526</td>
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</table>

6. Discussion

With respect to table 2, it became clear that the application of three different LCA tools to compare the hypothetical Norwegian national road (over a considered period of 20 years), led to different absolute and sometimes conflicting results. EFFEKT 6.6 showed higher GHG emissions compared to EKA and LICCER. However, by comparing embodied energy and asphalt, LICCER

\(^5\) As a simple solution to calculate asphalt consumption, it is proposed by NPRA that 1 cm of asphalt has approximately 25 weight per square meter (kg/m\(^2\)) (NPRA, 2005).
and EFFEKT 6.6 showed a close similarity in their results. Also, EKA and EFFEKT showed the amount of consumed asphalt with only small differences (less than 1%). Due to the differences in absolute numbers gained by the application of the three LCA tools, the main drivers need to be identified.

A more in detail analysis reveals that the level of details in data compilation and assessment were not the same in the software tools. EFFEKT showed its results in an integrated approach to indicate GHG emissions and energy as well as materials consumption (might be due to this fact that EFFEKT is intended to have a more informative way to communicate its results). Such a limitation in EFFEKT is because of high level of aggregation that makes it hard to see what the attribution of different attributors are for each material. For instance, a typical asphalt pavement consists of different input materials (like aggregates, bitumen and other additives) that have different transportation patterns and corresponding embodied energy, which in EFFEKT all attributors are aggregated and shown as one representative attribute. Nevertheless, LICCER and EKA showed an advantage over EFFEKT 6.6 due to giving a possibility to their users to go through different spreadsheets in their software tools in favour of finding the reference assumptions.

Concerning the illustrated disparity in the magnitude of the results (table 2), a possibility to do calculations manually would be seen as a large benefit. Equation 1 represents how the tonnage of asphalt wearing course can be quantified for all the three software tools. By replacing variables with their representative values, the tonnage of asphalt pavement during each maintenance activity can be quantified. The results from the calculation showed that LICCER and EKA quantify 1881 and 2100 tons of asphalt pavement are consumed in each maintenance cycle, respectively. The results demonstrate (if the maintenance activities are happening 4 times in the period of 20 years) that the numbers are aligned with the results shown from LICCER and EKA in table 2.

However, the calculation of consumed asphalt for EFFEKT was not straight forward because it is based on cost principles in its analysis. This means EFFEKT considers a yearly cost for every year in the analysis period due to expected future maintenance activities, which might be based on expert opinions. In the road example taken in this paper, EFFEKT calculated two different maintenance cycles through the analysis period of 20 years. It considered one-sixth of maintenance in the first maintenance cycle\(^5\) that would be attributed to the first year after construction of the road. However, in the remaining years (from the 2\(^{nd}\) year till the 20\(^{th}\) year), EFFEKT considered the maintenance activity would happen every other fifth year over the following 19 years (Kroksæter A., 2015).

\[
\begin{align*}
\text{Year 1: } & \frac{(0.04 \times 1000 \times 21 \times 2.5)}{6} \\
\text{Year 2} & \quad - \quad 20: \frac{(0.04 \times 1000 \times 21 \times 2.5)}{5 \times 19}
\end{align*}
\]

\(^5\) This mean that the first maintenance cycle is taking place after six years.
In the above formulas, 0.04 is the thickness of wearing course; 1000 is the length of road; 21 is the width of road; 2.5 (ton/m³) is material density of asphalt; 5 and 6 are maintenance cycles after five years and six years, respectively; and 19 is the number of years between year 2 and year 20.

One reason that LICCER shows a lower value in GHG emissions is because of the lower asphalt concrete density that is assumed in the section of material specification. In EKA and EFFEKT, the density of asphalt concrete is assumed to be 2.5 ton/m³; however, LICCER considers asphalt density of 2.24 ton/m³ as its default value. By only adding 0.26 to the presumed asphalt concrete density in LICCER tool, i.e. assuming the asphalt concrete is 2.5 ton/m³, the amount of bitumen consumption in each maintenance activity increases from 112.9 tons to 126 ton. This alteration in the amount of bitumen usage can correspond to additional 5.63 ton CO₂ eq. In addition, LICCER considers 5.99 kg CO₂ eq/ton corresponding to asphalt mixing plant in its assessment, which has the lower ratio compare to the other software tools. EKA considers approx. 21 kg CO₂ eq/ton for asphalt mixing plant, while, EFFEKT only shows one aggregated number (58.5 kg CO₂ eq/ton) for ‘asphalt’ that consists of GHG emissions from material extraction to placement on the road.

EKA showed a disproportional embodied energy compared to the two other software tools within the analysis period of 20 years. One of the rationales for such a deviation in the result is due to differences between values of bitumen embodied energy. EKA considers energy value of 720 kWh/ton (2.59 GJ/ton) for bitumen, but LICCER considers 52 GJ/ton (almost 20 times greater). This inconsistency in the result for the embodied energy of bitumen might be due to dissimilarity in the boundary of bitumen values chain. If we compare the results more in depth, it can be said that bitumen corresponded to approx. 85% of energy consumption in LICCER, but bitumen only had approx. 20% of contribution in EKA embodied energy. Furthermore, the results were compared with ecoinvent version 3.01 ‘Pitch’ production process7 (ecoinvent Center, 2013). The process by means of CML V4.01 impact assessment method showed the embodied energy is approx. 51 GJ/ton for bitumen production at the refinery. Given results and comparison with ecoinvent value show that the calculation done by LICCER is aligned with ecoinvent assessment. However, one should be consider is that the result in addition to data input consists in methodology of choice because the result may differ if another methodology is chosen. It is hence very important to carefully control for this dissimilarity via a systematic approach (as it is explained in the European Standard 15804:2012+A1 (CEN, 2013)) to reduce any miscalculation and successive misperception of results.

It became obvious that the three LCA tools have a focus only on greenhouse gas emissions and resource consumption, which raises the question why other environmental metrics (impact categories) are not considered. In fact, having a shorter list of impact categories makes the interpretation of LCA results easier for decision-makers, as it is all about comparing different product systems with a same functional unit. However, taking decisions on only a few LCA indicators carries multiple risks. In addition, it was not clear (except for EKA8), how the greenhouse gas emissions have been calculated in terms of considered greenhouse gases and

7 Pitch (Europe without Switzerland) | petroleum refinery operation | Alloc Def. U.
8 EKA includes solitary three climate gases in its greenhouse gas emissions that are: CO₂, CH₄ and N₂O.
impact factors. Due to this fact that Kyoto Protocol only covers six greenhouse gases in its first commitment period, which results in excluding short lived climate gases (e.g. black carbon) from its target. In fact, these short lived climate gases cause approx. 60% of overall global forcing (Rhodes S. P. and Schultz T., 2014). Hence, this is essential to be aware of climate gases that are not included in the assessment of GHG emissions, as they may have significant influence in the overall results.

Although this study by means of the three LCA software tools showed a range of results, it was essential to compare the results (from this study) with an Environmental Product Declaration (EPD) report (Nielsen C. S. and A., 2011) to evaluate the magnitude of similarities. The report showed that production and placement of asphalted gravel concrete (Agb11) contributes to 56 kg CO\textsubscript{2}eq and 1141 MJ per ton of asphalt pavement. By scaling up the result of the EPD based on the assumptions given earlier in this paper, the greenhouse gas emissions from the asphalt manufacturing in the 20-year period sums up to approximately 470 tons of CO\textsubscript{2}eq, which shows roughly similar to what has been shown by EFFEKT 6.6 tool. However, the result of embodied energy shows 9584 GJ during the same time period, which is not aligned with the results of the three software tools in this study. The reasoning of having similarity or dissimilar results for the embodied energy and the GHG emissions has not been possible to be further assessed. Due to the fact that the EPD report used another way of demonstrating the results, which made it impossible to compare the values with the other software tools.

7. Conclusions

To conclude, it can be stated that LCA needs a critical review in order to diagnose any possible hidden errors in life cycle inventory and LCA results. Given the fact that a small error can accumulate through the life cycle assessment and consequence a substantial error in the overall results. This study was performed with the intention to evaluate three LCA software tools (EFFEKT 6.6, LICER and EKA) to magnify the area of their coverage, strength and limitation of each software tool.

This paper assessed the software tools by comparing the results for a hypothetical road. The assessment covered resource consumption and greenhouse gas emissions as its proxy and considered road class H9 as it is hypothetical road. Although the supporting tools were intending to assess environmental performance of road projects, they had dissimilarities in their system boundary conditions. Therefore, the system boundaries for assessment were narrowed down to the maintenance phase within a 20-year analysis period.

In spite of the fact that the assessed tools addressed GHG emissions and embodied energy, there was no consistency in the results. These variations in the magnitude of results may lead to decisions on false grounds when it comes to making a comparison between different road options for decision makers. Therefore, having a transparent scope in LCA and explicit documentation make it possible for readers and future decision-makers to have a better insight into and therefore make more informed decisions based on LCA analysis. In addition, limitations and
recommendations are additional pieces of information that need to be delivered at the end of LCA works to declare and highlight the accuracy level for the intended users and readers.

It will be necessary that future LCA software tools integrate more details and additional data into their inventories in favor of making the LCA results more comprehensive and transparent. In addition, it would be beneficial to consider the pavement-vehicle interaction and the effect on energy consumption due to rolling resistance and geometry of roads as well. Winter service and effect of it on winter maintenance strategies, especially in cold climatic zones, can bring more dimensions to the scope of assessment. Including more environmental impact categories and using comprehensive database as well as impact assessment methods are very critical and need to be carefully handle in order to provide more thorough and fair environmental impact assessment. End-of-life material policy should include more than material transport after maintenance activities. It should cover more data like; amount of waste asphalt generated and stored in storage sites, maximum permissible storage time of waste asphalt in depots, etc.

References


ECOINVENT CENTER 2013. ecoinvent 3.01. In: CENTER, E. (ed.).


KROKSETER A. 2015. RE: EFFEKT 6.6. Type to EBRAHIMI, B.

LILJENSTRÖM, C. 2013. Life Cycle Assessment in Early Planning of Road Infrastructure: Application of The LICCER-model.


NPRA 2013a. E6 RANHEIM - VÆRNES. The Norwegian Public Road Administration (Statens Vegvesen).

NPRA. 2013b. Road and street design (Veg- og gateutforming) [Online]. The Norwegian Public Road Administration (Statens Vegvesen).

NPRA. 2014. Road construction (Vegbyggning) [Online]. The Norwegian Public Road Administration (Statens Vegvesen).


STRAUME A. & BERTELSSEN D. 2015. Documentation of calculation modules in EFFECT 6.6 (Dokumentasjon av beregningsmoduler i EFFEKT 6.6). The Norwegian Public Road Administration (Statens Vegvesen).

ZUKOWSKA E. A., JULLIEN A., CEREZO V., KEIJZER E., LORINO T. & BOUTELDJIA M. 2014. Deliverable D1.1: Assessment of current labelling approaches applied to roads design, construction maintenance and rehabilitation, as well as the products used to build them (asphalt mixtures and cement based materials).
Abstract

This paper describes development of a methodology to support better retrofit and maintenance with optimised energy consumption using evolving technologies in material, components and systems both at building and neighbourhood levels. It is based on a retrofit and maintenance scenario focused on specification of the functional requirements, databases requirement and system architecture for the construction and operation of the decision support tool. Decision support (DS) tools have already been developed for architects and building designers to choose best building design options with retrofit and maintenance in mind. However, there is a lack of understanding of the required data structures, databases, definition of the functional requirements and the variety of the possible system architectures for this application. The proposed DS tool will support Facility Management (FM) to design their option on Building Information Model (BIM) file by making best retrofit and maintenance decisions for improved energy efficiency (EE) without needing full knowledge of the latest technologies in any required subject and without being expert in building energy performance analysis and simulation. A detailed retrofit and maintenance scenario and its corresponding process map are developed and explained in details. Database requirements are extracted and discussed, leading to specification of the necessary structure and content with a level of details. The functional requirements for retrofit and maintenance design scenario are discussed and an exhaustive list is generated. The decision support tool was structured using four building blocks: (i) energy performance and simulation block; (ii) retrofit and maintenance options generator; (iii) optimisation block and; (iv) a decision making block based on Multiple Criteria Decision Making (MCDM) method.

Keywords: Decision Support, BIM, Building Energy Performance, Retrofit and Maintenance.
1. Introduction

This paper describes functional requirements and system architecture for decision support of energy efficient (EE) building design in retrofit and maintenance stage. Decision support (DS) tools are becoming more and more necessary for architects and building designers to make best energy efficient (EE) design decision, and support retrofit and maintenance projects (Ferreira et al., 2013). However, little has been done to identify the databases requirements to enable EE design that does support FM during operations. This paper draws the stages of the process for design of a decision support system including its required databases and decision making criteria. Functional requirements and system architecture are also elaborated in details toward development of the proposed DS tool. This is aimed to support facility management (FM) to design their maintenance or retrofit option on building information model (BIM) file through making best decisions for improved energy efficiency (EE) without being experts in the latest technologies of the required subject or being experts in building energy performance analysis and simulation. The necessary tools’ architecture includes the alternatives generator tool, the energy performance assessment tool and the DS tool.

In order to achieve sustainable development of our society, retrofitting existing buildings to improve their energy efficiency has become an inevitable task for the government of several countries (DOE, 2009), (Green Deal, UK GOV), (CBRE, Retrofitting Existing Buildings). Generally, a sustainable building retrofit programme consists of five key phases, from the project setup and pre-retrofit survey phase to the validation and verification phase (Ma, 2012). In this process, identification of retrofit options using reliable data is essential for a successful building retrofit project. To provide reliable evidence for selecting suitable retrofit measures, dynamic building performance simulation tools, such as TRNSYS (Santamouris, 2007), EnergyPlus (Chidiac, 2011), (Wei, 2014), (Ascione, 2011), IES VE (Ben, 2014) and DOE-2 (Zmeureanu, 1990), have been used widely in real projects. Design4Energy (D4E) is an ongoing EU research project, consisting of 17 partners from several countries in Europe, such as Spain, UK and Germany (Design4Energy). The project is aiming to develop an innovative Integrated Evolutionary Design Methodology, which can allow the stakeholders to predict the current and future energy efficiency of buildings and make better informed decision in optimizing the energy performance during the building life cycle. The work presented here is particularly focused on retrofit and maintenance stages. Within D4E a novel decision support tool based on dynamic building performance simulation therefore is being developed, and it meant to first be usable for building retrofit and maintenance projects to help stakeholders choose the most suitable retrofit/maintenance measure(s) for their projects (Fouchal, 2014).

The main decision making process focuses on using building simulation to predict the effectiveness of various retrofit or maintenance measures (alternatives) and inform the current development of a dedicated decision support tool for FM. Also the system relies in particular on adequate definition of database requirements in terms of components, parameters and indicators to automatically generate all possible retrofit or maintenance options. A set of databases are being developed for the decision support tool, this development includes identification of the requirements for IT systems, components, energy systems and, materials. Analysing existing database solutions was the first pre-requisite, then identification of databases’ characteristics using focus groups of potential users (architects, energy designers and FM) and finally tuned to suite the type of decision support tool being developed. Decision support tools have been key in the providing smartens of many design platforms for building practitioners, the system architecture in question here is the main engine of the Design4Energy (D4E) platform (D4E, web1). These platforms do provide basis for collaboration and knowledge sharing with updatable databases. The value of design platforms is in their workflow speed and quality, facilitating team contribution integration, and rapid feedback on energy performance (NREL’s OpenStudio, June 2015). OpenStudio started as an open source project to create a collection of
software tools for energy modelling. For these platforms databases is essential for their functioning. While xBIM is another open source development platform, which allows creating application for BIM based on the IFC standard (xBIM, June 2015). TNO BIM Server is another open source development platform, which allows creating application for BIM based on the IFC standard (bimserver, June 2015). The Building SMART Data Dictionary (bSDD) is a reference library or a framework that aims at supporting improved interoperability in the building and construction industry. It can connect software applications to product databases or attach specific attributes to construction designs. These references can include information from a product manufacturer, typical room requirements, cost data or environmental data (ifd standards, June 2015), (ifd-library, June 2015).

Multiple Criteria Decision Making (MCDM) integrates multiple indicators into a single meaningful index to allow ranking and comparing options for decision making, see figure 1 (Fouchal, 2015). It is an efficient statistical method to combine component indices arising from all the information sources into a single overall meaningful index, therefore ranking and comparing are feasible. MCDM has the ability to weight different alternatives and make judgement on various criteria for possible selection of the best/suitable alternative(s). A typical MCDM problem is when there are a number of criteria to assess a list of alternatives. Each alternative is represented by a single value for each of the criteria to permit the assessment and/or ranking, see figure 1. Complex decision requires consideration of multiple criteria (Zeleny, 1982).

Analytic Hierarchy Process (AHP) method as proposed by Saaty (1994) that is based on priority theory decomposes a complex multi-dimensional decision making problem into a system of hierarchies. It uses the relative importance of the alternatives in terms of each criterion. The AHP has the ability to logically incorporate data and expert’s judgement in the model for measurement and prioritising intangibles. As a complex and unstructured situation is broken down, its components are arranged into a hierarchic order including criteria and alternatives.

Component catalogues relational databases are accessible through internet protocols. The Building Component Library (BCL) by NREL provides searchable information about EE related technologies and a list of measures to meet energetic issues (Fleming et al., 2012). The included information can represent physical characteristics of buildings such as windows, walls, and doors, or can refer to related operational information such as occupancy, equipment schedules and weather information. Each measure and energy system can be downloaded as a XML, RB and OSM file describing these components (bcl.nrel, June 2015). Data Repository ISES is another cloud-based data repository. It contains information such as climate data or stochastic templates but most interestingly energy product and material catalogues containing energy properties of products and materials (ISES D4.1, 2014). The library uses the PLIB ontology model (based on ISO 13584). All information is saved in the ifc file format (ISES D4.3, 2014). The MagiCAD Product Database is a product catalogue or database that contains
over one million products from over hundred manufacturers. A designer can choose components through a plugin directly via the CAD-tool interface. This interface is connected to a plugin on the manufacturers’ site (MagiCAD, 2014).

In the following sections are presented the retrofit and maintenance scenario, the process map, the functional requirement and database requirement to finally develop the system architecture for the decision support tool.

2. Retrofit and maintenance scenario

A detailed retrofit and maintenance scenario is developed and described here; the corresponding process map is also developed and explained in details in the section to follow. The scenario starts with the facility manager evaluating the operation stage and maintenance data of an existing building and reveals some building performance changes which require serious attention such as undertaking some repair or upgrade to the building. An architect takes over and starts analysing historical data of operation, maintenance records as well as user behaviour data, monitoring data, the map of neighbourhood energy nodes and cost data. From this analysis it becomes apparent that some of the data is not compatible with building’s energy anticipated performance. He/she therefore request a thorough investigation of the causes of the energy consumption mismatch with original design in specific parts of the building which involves the heating system (Wei, 2015). A heating system expert is called in and identifies an old boiler as the source of the problem. The architect in collaboration with a building services engineer sketch a retrofit or maintenance design using a BIM model on the D4E platform. In doing so, the architect takes into consideration a number of parameters such as the local weather profile, facility management reports, financial status of the building owner and looks into other case studies to decide the best option forward for optimisation of energy level ahead of the conceptual design completion. At this stage, the architect considers the market and the various options for the energy performance of the project’s life cycle and cost of future operation and maintenance to prepare to discusses various design options with the client to make a decision.

Mainly two routes become possible depending on the budget in hand and existence of information on new source of district heating to become available in the near future within the vicinity of the building. These options are analysed and evaluated by the designer comparing the retrofitting improvements versus maintenance action. The D4E platform supports the designers by highlighting critical building zones. The designer can filter out the existing building data for transferring them to certain design tools (CAD, etc.). Using the different design tools the designers can develop retrofitting variants for further integration and analysis in the collaborative platform. The simulation tool integrated in the system enables running a number of analyses to assess the impacts of the proposed retrofitting or maintenance variants on the energy efficiency and compare them to historical data of similar existing buildings. The design is then passed on to the mechanical and electrical engineers as a BIM model. The 3D collaborative environment provides them the possibility to explore what-if-scenarios, they can drag components from the database library to modify and optimise the design. Furthermore the platform provides them with cost estimation of the different options on different terms (short to long). The information required during these activities will be stored into a common database.

3. Process map

During the operation of the building the stages described in figure 2 are followed. The process of identifying building issues during the operation phase are described, where the building’s under-performance is identified and adequate measures are undertaken through D4E platform.
However, the process map being developed has no specific focus in terms of the type of the building requiring retrofit and maintenance. It is developed on a higher level and aims to cover all possible requirements of domestic and non-domestic buildings. However, in the case of industrial and buildings with specific uses (e.g. health care centres) adjustments would be required for the process map to be applicable, including the need for appropriate population of the databases with relevant information. For the purposes of this research, to verify the retrofit and maintenance process proposed and to validate the decision support tool, a case study of 20 domestic buildings is used. The main limitations and potential of the developed tool are highlighted. Additional testing of the decision support tool would be required to further validate its applicability in different types of buildings.

### 3.1 Monitoring building operation (client & FM):

During the operation stage of a building the client (user/owner) and the facility management team undertake scheduled monitoring and/or observation of the building performance, generally using electronic monitoring devices such as energy meters, which measure the energy consumption and store it periodically into a file using common format such as Excel. The operational monitoring data are produced in the form of sensor data (of energy systems, of energy used by equipment, user behaviour, indoor air quality and moisture level), operation bills (of energy/utilities) and maintenance/repair bills. The client gets signals from daily use and observation of the building behaviour in terms of indoor air quality (e.g. thermal environment, visual environment and acoustic environment), sensors/energy monitoring data and operational cost. If the building’s indoor air quality level and moisture level have changed it may suggest that the building envelope or the energy systems have changed in a way that is not expected. Furthermore if the operational cost such as the energy bill has changed similar cause may apply. Under this kind of circumstances the client reports any observations to the facility management team. Similarly the FM team can make similar observations from the available monitoring data or studying reports from the client (written, emails or verbal), see figure 3. The data collected can be clustered as: (i) Building survey; (ii) Sensors and monitoring data; (iii) Client report & user interview; (iv) Review of maintenance strategy; (v) Access BIM files / As built drawings.
3.2 Requirement, data analysis and review of project's objectives

Based on operation data the facility manager defines their requirement to re-establish the normal operation of the building or to upgrade the performance level for example to comply with new regulations or simply respond to the client request. The energy expert and other energy system experts such as HVAC engineers will use Tool 1 to assess the reported building energy performance issue and set targets for remedy or upgrade. The target setting will involve selection of key indicators and defining the operating ranges for each indicator. The energy expert reviews the objectives traced to meet the use and operation needs, these are identified on the basis of the FM requirements and the expected energy performance of the building.

3.3 Search benchmarks and finalise key target setting

The benchmark browser and search tool will be used to set the benchmarking related targets. The standard methods and benchmarks for consideration in this project include CIBSE (Chartered Institute for Building Services Engineers) TM22, TM46, TM39, TM46 and TM 47, the AM11 Building Energy and Environmental Modelling (BEEM) (CIBSE Applications Manual 11) and the EPBD (Energy Performance of Buildings Directive), IPMVP (International Performance Measurement and Verification Protocol) in the USA, as well as the Performance Contracting Program standards ISO. Setting key target levels will be based on benchmarks and client requirements by setting the range extreme boundaries for each indicator being.

3.4 Retrofit or maintenance options generation and selection

Choosing of energy options, then run a feasibility study and produce a feasibility report for retrofit and maintenance will be carried out by the energy expert first through selecting variables to be used to form the options, see figure 4. These variables will be displayed to him/her under a list of drop down menus providing all possible and available variants of each component or action to incorporate of performed. This process will be possible by manual generation of options by the energy expert using a set of integration parameters which help to combine the variables in various ways to produce a list of possible options with potential to achieve the targets being set.

![Figure 4 decisions making on whether to do maintenance or retrofit](image)

The energy expert will use new methods to verify the process and the generated options while still having the power to alter the process of selection or add/reduce possibilities.

3.5 Decision making by the client and Produce of retrofit brief

At this point of the process a review of alternatives will be undertaken by the client using the decision support tool 11 to make an initial decision which is more suitable for the project, maintenance or retrofit. The feasibility results will be prepared in a format that will simplify the decision making of the client.

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If decision is to retrofit, a model has to be created. It starts by the client producing the brief which contains the expected energy performance, the KPIs and setting up the targets. The next step is defining the specification of the ideal solution in relation to the given client requirements.

### 3.6 Creation of retrofit alternatives concept designs

The remaining stages of the model will be completed by an Architect who will conduct an environmental analysis and building performance assessment. The architect generates a project program. Using Tool 4 which is the BIM design tool he/she sketches the spatial outlines of the retrofit alternatives onto the existing BIM data on the basis of the defined indicators. The produced LOD4 models will be analysed by the architect taking into consideration the site implication and adaptability to the surrounding.

### 3.7 Improve retrofit model

The BIM model is then improved with material data for better energy efficiency performance and CO2 emissions reduction. In this phase the architect takes into account the embodied energy of the materials, use recyclable materials whenever possible, introduces new materials, figure 5.

![Figure 5 modelling of the retrofit alternatives and undertaking of performance assessments](image)

### 3.8 Performance analysis for passive design

The architect has the option to choose to undertake some building performance analysis under the proposed retrofit alternatives using the energy efficient BIM. This procedure will mainly help to reduce the number of options that can be considered and even provide enough information to make the ranking on the basis of the chosen criteria from the list of the performance indicators. This procedure is conducted via the decision support tool 11 which is built on the top of an energy simulation tool, such as EnergyPlus, which is one of the most popular tools for dynamic building performance simulation. The decision support tool will perform building performance simulations to all possible retrofit scenarios preliminarily defined by the client and rank them using the chosen selection criteria.

### 3.9 Design concept and review by client

The architect finalises design alternatives with KPIs profiles using BIM and generate a design concepts for each potential alternative. Through the collaborative environment Tool 6 the client reviews the produced design concepts taking into consideration of his/her main requirements which include energy consumption, the construction cost and LCC.
3.10 Analysis of energy demand and Analyse energy alternatives at neighbourhood level

The energy expert will conduct an analysis of building energy demand using the energy simulation performance tool based on eeBIM Tool 5 and the energy match optimiser tool 7. Following this analysis the client via the collaborative environment will review of energy options for the selected retrofit options and narrows down the number of options which would be passed onto the architect on the collaborative environment Tool 6 to verify the BIM models of the selected alternatives in term of their energy matching potential. The energy expert will analyse the remaining retrofit alternatives from the previous steps for their higher potential to address the requirement already specified in the project and the pre-set targets using the target setting tool 1. The aim of this run of analysis is to evaluate the energy matching at neighbourhood level and rank them in their order of potential offered by each using a set of indicators which include energy price mode, renewable energy that is available or/and potential in the coming future and the existing or potential for energy production. At this stage the architect on the collaborative environment will verify using the updated BIM models (with embedded energy matching results) with selected alternatives for their energy matching potential at neighbourhood level.

3.11 Final approval of selected alternatives by client

The improved BIM models for the selected retrofit alternatives will be accessed through the collaborative environmental tool 6 by the client for final approval. At this stage if there is more than one alternative they will be listed in a ranking order on the basis of the most important indicators to the client to enable fast approval. If the decision that all requirements are meet by one alternative, it is then final approved and the corresponding concept design is also approved.

3.12 Maintenance options and analysis of maintenance options

If the initial review alternatives (at defining the options for retrofit or maintenance stage) by the client using the decision support tool 11 has resulted that maintenance is the most adequate approach to follow then a number of maintenance alternatives will be generated. The FM will lead this activity and start by analysing the LOD4 BIM model. Originally the feasibility results (Retrofit/maintenance) are prepared in a format (ranked on the basis of most important criteria only and presented it on the collaborative environment at high level of information only) to simplify the decision making of the client. The FM will study all the maintenance options that can be considered. He/she will check the potential for site implications to identify the metrics for the relevant indicators. The ranges for these indicators will be used together with the indicators for energy matching at both building and neighbourhood levels, complying with existing regulations and the client requirements. The decision support tool 11 with its energy simulation feature will be used to analyse the building energy performance, shown in figure 6.

![Figure 6 checking the retrofit solutions and evaluate the energy matching potential](image-url)
3.13 Selected options, review by client and ready for execution

Key performance indicators will be used to narrow down the maintenance alternatives. Maintenance solutions will provisionally be ranked on their performance feasibility.

As shown in figure 7 the client will use the collaborative environment Tool 6 to review the maintenance alternatives and the energy options that are made available by the FM study. At a high level of information the client review will consider the analysis provided by the energy expert on solutions for their potential of reduced energy consumption, cost and LCC, energy matching at building and neighbourhood levels. This review process will result in a single maintenance alternative being approved by the client. Through the collaborative environment tool 6, various experts that are relevant to the different components included in the final solution will be invited to access the BIM model which embeds the maintenance solution. The HVAC engineer will use tool 8 (BIM HVAC design and simulation tool) to analyse the final solution for its feasibility, compliance and adequacy to fulfil all relevant stake holders’ requirements. Similarly the electrical engineer will use Tool 9 (BIM electrical design and simulation tool) to verify that the solution selected is adequate to respond to the identified requirements.

4. Specification of the functional requirements for DS tool,

The decision making in retrofit and maintenance projects is supported by the energy simulation and actions for environmental influence through provision of energy system performance data and physical characteristics of building materials; cost simulation over the life cycle through e.g. the provision of data from similar real cases; design process through possibilities to share design results; owners’ decision through providing information on the utilization and sustainability aspects of existing components and energy systems; and FM decision in choosing the optimal action for the available boundary conditions. The functional requirements for retrofit and maintenance design scenario are discussed and an exhaustive list is generated. Most of these requirements will be focusing on components identification, compliance with regulations and how to undertake the adequate modelling and simulation for retrofit and integration. Table 1 shows the identified different requirements for the different users.

<table>
<thead>
<tr>
<th>User</th>
<th>Function required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner/Facility manager</td>
<td>Digital trading function</td>
</tr>
<tr>
<td>Architect</td>
<td>Decision support / optimisation function</td>
</tr>
<tr>
<td></td>
<td>Energy simulation function</td>
</tr>
<tr>
<td></td>
<td>Energy matching &amp; consumption estimation function</td>
</tr>
<tr>
<td>Building Energy designer</td>
<td>Information acquisition function</td>
</tr>
<tr>
<td>Information exchange</td>
<td>Filtering data &amp; interlinking function</td>
</tr>
<tr>
<td></td>
<td>Interaction with 3D sketch service</td>
</tr>
<tr>
<td>Building energy designer</td>
<td>Neighbourhood information acquisition and analysis function</td>
</tr>
<tr>
<td></td>
<td>Visualization functional module</td>
</tr>
</tbody>
</table>
5. Databases requirement

These will be captured from: Original brief from clients; Assessed against: building regulations; building design standards from ASHRAE, ISO and CIBSE, or commercial building performance rating methods such as BREEAM and LEED. Furthermore, through engaging existing users in workshops or through organised surveys. Some relevant examples could be requirement for more double glazing to meet the new standards; measurement of air tightness; measurement of natural daylight; need for smartness to support day to day activities; review of design life of different components; analysis of sensors data. The methodology adopted to identify the DB requirements for FM decision support included: Questionnaires and interviews with relevant end users. 30 responses were collected from different sectors, see Figure 2 and 3. 23% are Architects and designers, and another 20% are technology and solution providers.

Building components initially have to be manually stored by users. The DB requirements as reported from the literature search included: (i) User, through interaction has to provide a direct link to BIM models; (ii) Visualising data, choices of building architecture; (iii) BIM models, have to be accessible by relevant stakeholders such as engineers for energy systems; (iv) Solutions with their operational attributes, maturity, deterioration, experienced costs or best practices of similar projects; (v) Material characterization (e.g. type, functionality, thickness, thermal conductivity, density specific heat, internal and external solar absorption, and emissivity); (vi) Team management.

5.1 Operation and maintenance data requirements

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Occupant involvement</td>
<td>15 CO2 reduction targets</td>
</tr>
<tr>
<td>2 Client awareness</td>
<td>16 ROI</td>
</tr>
<tr>
<td>3 Building performance assessment</td>
<td>17 Potential for energy generation</td>
</tr>
<tr>
<td>4 Building fabric assessment</td>
<td>18 Potential for natural ventilation</td>
</tr>
<tr>
<td>5 Building operational history evaluation</td>
<td>19 Potential for thermal energy (heat) recovery</td>
</tr>
<tr>
<td>6 Operations issue</td>
<td>20 EE potential of wall insulation thickness</td>
</tr>
<tr>
<td>7 Historic data analysis</td>
<td>21 EE potential of window glazing layers</td>
</tr>
<tr>
<td>8 FM reports quality</td>
<td>22 Lighting efficiency and control</td>
</tr>
<tr>
<td>9 Fault pin-pointing/detection</td>
<td>23 Boiler/central heating efficiency</td>
</tr>
<tr>
<td>10 Contractual arrangement</td>
<td>24 Compliance with regulation</td>
</tr>
<tr>
<td>11 Performance of Energy using Products (EuPs)</td>
<td>25 Refurbishment option ranking</td>
</tr>
<tr>
<td>12 Performance of Energy systems</td>
<td>26 Hot water generation &amp; distribution system efficiency</td>
</tr>
<tr>
<td>13 Energy bills</td>
<td>27 Energy use vs. comfort conditions</td>
</tr>
<tr>
<td>14 Energy reduction targets</td>
<td>28 Client/user satisfaction.</td>
</tr>
</tbody>
</table>

The methodology adopted to identify the database requirement in terms of design for operation and maintenance besides of review of relevant literature, included standards and guidelines to first highlight the generic domains of requirement. The survey was conducted with the aim of gauging more specific requirement to different usage groups on databases which will support design for building operation and maintenance. During a workshop with experts in retrofit and maintenance the database requirements are extracted and discussed leading to the specification.
of the necessary structure and content with a certain level of details. Table 4 shows the list of indicators for retrofit and maintenance are used to characterise the requirements.

6. System architecture of the decision support system

The decision support tool was structured using four building blocks which are: (i) energy performance and simulation block; (ii) retrofit and maintenance options generator; (iii) optimisation block and; (iv) the decision making block that is based on Multiple Criteria Decision Making (MCDM) method. Decision support tools have already been developed for architects and building designers to choose the best building design options with retrofit and maintenance in mind.

The proposed DS tool would support Facility Management (FM) to design their option on building Information Model (BIM) file through making best decisions during retrofit and maintenance for improved energy efficiency (EE) without having full knowledge of the latest technologies in any required subject and without being an expert in building energy performance analysis and simulation.

Within Design4Energy which is the sponsoring EU project of this work three architects and other end users of the retrofit and maintenance decision support tool are partners and are active members who were involved in shaping and testing the work being described in this paper. An initial exploration has also been undertaken with a larger number of external architects and facility managers to agree and feedback on the format and the content of the decision support tool and its corresponding components. At later stage of this development it is intended to embed it into a holistic design platform during which a program of validation and demonstration will be conducted with a much larger pool of end users.

7. Conclusions

An identification of the required data structures and databases to support designers and enable Facility Management (FM) to make decisions on best retrofit and maintenance for improved EE has been conducted. The databases requirements and functionalities have been detailed. A set of necessary databases were proposed to enable optimal decision making by FM and perform adequate design of new build. The level of detailing the database requirements is provided in terms of information technology (IT), components and systems, materials and the stakeholders. To complete the study a validation by FM of the database is conducted using the new decision support tool for maintenance and retrofit to be used. The work focused on using building simulation to predict the effectiveness of various retrofit measures and inform the current
development of a dedicated decision support tool for FM in particular definition of database requirements in terms of components, parameters and indicators to automatically generate all possible retrofit or maintenance options. Analysing existing database solutions was the first prerequisite, then identification of databases' characteristics using focus groups of potential users (architects, energy designers and FM) and finally tuned to suite the type of decision support tool being developed. Decision support tools have been key in the providing smartness of many design platforms. System architecture was therefore developed for embedding the set of decision making tools into the platform. A retrofit and maintenance scenario was used to follow through the decision making process for which the necessary tools were specified in terms of their functionality and then designed.

8. Acknowledgements

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9. References

About NREL’s OpenStudio Application Suite and Development Platform https://www.youtube.com/watch?v=ovLt4-q_UEb, Accessed June 2015
CIBSE Applications Manual 11
Chidiac S.E., Catania E.J.C., Morofsky E., Foo S., Effectiveness of single and multiple energy retrofit measures on the energy consumption of office buildings, Energy, 36 (8) (2011) 5037-5052.
D4E, web 1: www.design4energy.eu
DOE, DOE to Fund up to $454 Million for Retrofit Ramp-Ups in Energy Efficiency, in ENERGY.GOV, September 14, 2009.
Ferreira et al., 2013
GOV, Green Deal: energy saving for your home, in, UK GOV. Available at: https://www.gov.uk/green-deal-energy-saving-measures/overview


Wei, Shen; Firth, Steven; Hassan, Tarek.M; & Fouchal, Farid. (accepted) 'Impact of occupant behaviour on the energy saving potential of retrofit measures for UK PB. International Conference on Sustainable xBIM, June 2015


ZmeureanuR., Assessment of the energy savings due to the building retrofit, Building and Environment, 25 (2) (1990) 95-103.
A Settlement of the Internal Heat Gain Schedule of LES (Living Environment Simulator) Using Statistical Data

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Abstract

The purpose of this study is to set internal heat gain schedule of LES (Living Environment Simulator) using statistical data and suggest total daily electricity consumption and time of maximum power generation based on set schedule. The result indicates that time of maximum power generation is individual and household labor activities and total daily electricity consumption is 6.5 kWh/day in weekday and 7.5 kWh/day in weekend. An additional study is required to review total yearly electricity consumption through setting internal heat gain schedule in winter and summer season on the basis of this work.

Keywords: Occupancy Schedule, Lighting Schedule, Equipment Schedule, Electricity Consumption

1. Introduction

As of 2008, approximately 12% of total energy consumption in buildings in the country is consumed in homes, and electricity consumption accounts for the highest ratio among the energy consumption in homes. The electricity consumption in homes is expected to increase gradually due to the improvement in the standard of living and enlargement of home appliances, and in order to reduce electricity consumption, it is necessary to estimate electricity consumption in the building and identify the form of energy consumption in the building by analyzing the pattern of home appliances usage which is directly and indirectly related to electricity consumption and the behavior pattern of occupants. However, there is no objective and reliable methods regarding setting of home appliance usage pattern and the behavior pattern of occupants presented in the country currently, and preliminary data required for estimating electricity consumption in the buildings is also insufficient.

Based on this background, the purpose of this study is to set the occupancy, lighting and equipment schedules of LES (Living Environment Simulator) implemented in Zero-carbon Green Home of Korea Institute of Civil Engineering and Building Technology (KICT) by using Statistics Korea's report on the time use survey1) and Korea Power Exchange's report on investigation of
home appliance distribution rate and electricity consumption pattern at home2) and present electricity consumption on LES home for one day and the time of maximum electricity consumption.

2. Setting of Internal Heat Gain Schedule

2.1 Summary of LES (Living Environment Simulator)

LES was implemented for the purpose of optimizing the operation of Zero-carbon Green Home by monitoring the quantitative electricity consumption while controlling the uncertainty of living environment.

The area of LES implemented house is 58 ㎡ consisting of the living room, kitchen, room 1, room 2, bathroom 1 and bathroom 2, and home appliances including lighting, TV, computer, refrigerator, washer, rice cooker, microwave oven, cook-top and vacuum cleaner are installed in the house. 3 household members were set for LES by referring to the 2010 Population and Housing Census Report3) and single-income family with a junior high school student was assumed by referring the gender and age distribution of householder. For the household members, 6 sets of bodies that humidification and heating control were available were established and placed on the living room (3 Sets), room 1 (2 Sets) and room 2 (1 Set).

Figure 1: Floor plan of LES
2.2 Selection of representative behavior of household members and linkage of home appliances

Since electricity consumption is affected by the behavior of occupants, it is necessary to set the schedule by determining major behaviors of occupants that consume electricity. In this study, the major behaviors of occupants were selected by referring to Statistics Korea’s report on the time use survey in 2009. In the report on the time use survey, the result of sample survey and estimation of people aged 10 or older how they utilized 24 hours a day for 5 years is presented separately by class.

In this study, the representative behavior time of household members was selected separately into weekdays and weekends based on the average time of householder, his spouse and a child in middle school of single-income family, and any behavior corresponding to less than one percent of 1,440 minutes a day (approximately 15 minutes) was excluded.

Table 1 above shows the relevant actual lighting and home appliances related to the representative behavior selected earlier. For the home appliances, only home appliances placed in LES home were applied, and the refrigerator and rice cooker not presented in Table 1 were set to operate 24 hours.

![Figure 2: Mean Time of Representative Behavior](image)

Table 1: Relationship Between Behavior and Home Appliance
Before setting the indoor heating gain schedule, the procedure to set 1,440 minutes for the sum of average representative behavior time of household members and the procedure to adjust the home appliance use time at 5-minute interval were carried out.

As shown in Figure 2, the sum of average behavior time of each household member for each weekday was less than 1,440 minutes because the behavior not to use home appliance was excluded in the procedure to link the representative behavior of household members and home appliances so that the time for the relevant behavior was omitted. In order to set 1,440 minutes for the total sum, the procedure to add the omitted time to the relevant behavior by considering the ratio of average time of each behavior to total time was carried out, and it is presented in Table 2.
Table 2: Rearranged Mean Time of Behavior

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Weekday [minute]</th>
<th>Holiday [minute]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Householder</td>
<td>Spouse</td>
</tr>
<tr>
<td>Individual activities</td>
<td>630</td>
<td>630</td>
</tr>
<tr>
<td>Household labor</td>
<td>0</td>
<td>270</td>
</tr>
<tr>
<td>Human relations &amp; Leisure activities</td>
<td>210</td>
<td>330</td>
</tr>
<tr>
<td>Learning</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Family care</td>
<td>0</td>
<td>130</td>
</tr>
<tr>
<td>Labor</td>
<td>480</td>
<td>0</td>
</tr>
<tr>
<td>Travel</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>Sum</td>
<td>1440</td>
<td>1440</td>
</tr>
</tbody>
</table>

The time of home appliance usage was adjusted at a 5-minute interval by referring to statistical data of Korea Power Exchange's report on investigation of home appliance distribution rate and electricity consumption pattern at homes, and 50 minutes a day were set for the time of cooktop usage which was not presented in the report by considering the average home management time.

Table 3: Time Use of Home Appliances

<table>
<thead>
<tr>
<th>Item</th>
<th>Report [minute]</th>
<th>Rearrangement [minute]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Washing machine</td>
<td>92</td>
<td>90</td>
</tr>
<tr>
<td>Computer</td>
<td>211</td>
<td>210</td>
</tr>
<tr>
<td>Electric rice cooker</td>
<td>535</td>
<td>1440</td>
</tr>
<tr>
<td>Microwave</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Vacuum</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>-</td>
<td>1440</td>
</tr>
<tr>
<td>Cooktop</td>
<td>-</td>
<td>50</td>
</tr>
</tbody>
</table>
The internal heat gain schedule on weekdays during intermediate season (March ∼ May, September ∼ November) was set based on the average behavior time of household members and the time of home appliance usage and presented in Figures 2 ∼ 4, and the weekend schedule was omitted for lack of space. The schedule of relevant behaviors was set first for the occupancy schedule of household members by referring to bedtime, wake-up time, time to start to eat, eating time, time of movement presented by Statistics Korea and other behaviors were set by referring to the time of home appliance usage and the number of bodies installed on each room. Lighting was set to operate while a household member occupied regardless of the intensity of solar radiation brought into indoor, and hourly usage rate on weekdays and weekends presented in Korea Power Exchange's report on investigation of home appliance distribution rate and electricity consumption pattern at homes was referred for the time of home appliance usage, and setting method was classified based on the time of home appliance usage. In case of a home appliance which was used for a long period of time, it was set to use at the time that exceeded the average daily usage rate, but in case of vacuum cleaner, washer and microwave oven that were used for a short period of time, it was set to use at the time of highest usage throughout the day.

Figure 3: Occupancy Schedule
3. Calculation of amount of electricity used

Based on lighting and equipment schedule, the calculation result of amount of electricity used for each hour on a weekday during intermediate season (March~May, September~November) was shown in Figure 5. The calculation result showed that the largest amount of electricity used on weekdays and weekends occurred between 7:30 AM and 8:30 AM and between 7:30 PM and 8:00 PM on weekdays and between 9:30 AM and 10:00 AM and between 6:15 PM and 6:40 PM on weekends which were the home management and personal maintenance activity times. The daily total electricity consumption was approximately 6.5 kWh/day on weekdays and approximately 7.5 kWh/day on weekends which were lower than 10 kWh/day presented in the precedent study4) used for comparison and verification with actual electricity usage. However, the electricity usage was calculated by designating only home appliances placed in LES as the items for calculation, so in order to draw the result which is close to actual electricity consumption in future, a study will be carried out by adding home appliance items.

4. Conclusions

In this study, the occupancy, lighting and equipment schedules of LES were set by utilizing the statistical data of Statistics Korea and Korea Power Exchange, and the time of maximum power generation and total daily electricity consumption at LES home on weekdays and weekends were presented based on the set schedules.
The annual amount of electricity used will be reviewed in future through winter and summer schedule setting by considering the heating and cooling apparatus.

Acknowledgements

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References


Korea Power Exchange (2011) “Survey on electricity consumption characteristics of home appliances”.


Life Cycle Cost-Efficient Near Zero Energy Hall Building for Nordic Climate

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Abstract

Finland’s first nearly zero-energy single-storey commercial/industrial building was completed in the spring of 2015 in Hämeenlinna. Built on the campus of Häme University of Applied Sciences (HAMK), the building is used for R&D and teaching purposes by the university and Ruukki Construction. There are only few years before the EU near-zero energy requirements will come into effect and thus it’s important to get real experiences of solutions before design of these buildings will be started. As a main result, the construction project was able to show that a building meeting these requirements and exceeding today’s strict energy-efficiency requirements by over 60 per cent can be built at a profit. In order to achieve the targets, special attention was paid to the steering of energy and life cycle efficiency during the whole project from early phase planning to the execution. Smart design and combination of different techniques including renewable energy sources enabled the end result that meet clearly forthcoming nearly zero energy regulations. Several techniques were utilized in the building. First, the energy need was minimized for example by extreme air-tight envelope and effective heat-recovery in the ventilation as well as by day-lighting utilization. Renewable energy sources have been utilized with an innovative way with building integrated solutions. In the ground energy system, the foundation piles have been utilized for heating and cooling energy extraction. Solar heat collectors have been used for boosting the energy pile system by charging the soil with solar energy. The life cycle optimization was based on integration of building energy simulations and cost calculations. This enabled to find the most cost optimum total solution to meet the future high energy targets.

Keywords: near zero energy building, energy pile, day lighting, life cycle costs, cost optimum

1 Introduction

Energy efficiency has risen to the same level as construction quality and cost efficiency to become one of the most important factors guiding construction projects. Investments in energy efficiency have already been made, particularly in residential and office construction. Single-storey commercial and industrial facilities are one of the most important building segments for steel construction in the EU. This building segment also has a relatively short life span, thus the building stock renews quickly compared to many other segments. These factors combined will validate the importance of energy-efficient solutions in new construction in this particular segment. In energy efficient concepts, buildings must be designed and executed as complete entities – not split up into subareas that are sub-
optimized separately. This approach is almost contrary to present-day construction, in which design and build are split up across several parties without the overall entity being properly managed. The execution of commercial, industrial and logistics buildings could be managed by, for instance, so-called alliance agreements, in which the parties involved are bound to share responsibility for executing buildings in accordance with customer requirements (in addition to technical cooperation).

More complex construction requirements, such as cost efficiency, quality, energy efficiency and environmental friendliness, also underline the need to plan and manage entities as a whole. Finland’s first nearly zero-energy “big-box” type single-storey building (nZEB) for commercial, logistic or industrial use was designed and constructed to meet an objective: to be a building with an economical lifecycle that saves energy and uses existing renewable energy sources (See Figure 1). In this project, special attention was paid on the co-operation with different parties and commitment to the common targets.

The new structure was designed and executed to enable economic use of the building and optimization of construction solutions. Optimization means selecting solutions based on investment outlays, additional usage costs and future savings. A well-insulated and airtight envelope in the building’s walls and roof enables savings in energy requirements, and the use of solar power, day-lighting and geothermal energy harness renewable energy for use in the building. The building’s economic performance was estimated by comparing the investment costs and life-cycle costs of a reference building and an nZEB building. The reference building level was agreed with the customer and designers.

![Completed nearly zero-energy building in Hämeenlinna, Finland](image)

**2 Technical solutions for the nearly zero-energy building**

**2.1 Building envelope**

The shell of the building walls and roof are highly significant for its energy efficiency. For this reason, the outer walls of the building are fitted with sandwich panel system, with ultra-airtight panels and carefully designed and executed seals between the panels, plinth, roof, windows and doors. The sandwich panels are composed of a glass-wool insulating layer between two thin steel sheets. The thickness of the insulation in both the wall and the corner panels is 230 mm, with a U-value of 0.16 W/m²K. The building’s roof incorporates a new type of prefabricated PIR roof elements with a U-
value of 0.12 W/m²K. Airtightness of the entire building has very big role in the heating energy demand. The measured airtightness of the entire building was as low as $q_{50} = 0.76 \text{ m}^3/\text{h} \cdot \text{m}^2$. Based on energy simulation, the heating energy need of this building with this level is 28% lower than that of the building with minimum air-tightness of $q_{50} = 4.0 \text{ m}^3/\text{h} \cdot \text{m}^2$, based on Finnish energy regulations.

![Figure 2: Energy panels with decorative printing.](image)

### 2.2 Utilization of day-lighting

The sizes and directionality of the building’s windows are optimized for energy efficiency. The large windows are aimed south-west. The need for artificial lighting is reduced by the windows, due to their directionality and surface area. Traditional large windows bring light in – but also conduct heat out. In this building, the glass windows facing south have been replaced by cell windows made of polycarbonate (See Figure 1). These “daylight” windows isolate heat well – the warm rays of the sun during the summer do not heat the premises. During periods of bright daylight, light coming through traditional windows in indoor areas causes glare. Instead of this, daylight windows distribute light into the premises in a pleasantly even manner without glare, and blinds are not needed. The building is equipped with a day-lighting control to reduce artificial lighting. The U-value of these day-lighting windows is approximately 0.84 W/m²K. The north-east wall of the building incorporates Ruukki Construction energy panel system clear windows, forming a dense structure with the panels. Lighting simulations, carried out by Tallinn Technical University, showed that the lighting energy saving potential is over 50 % in those spaces where day-lighting windows were used (high part of the building). Comparison of the lighting energy use with different lighting levels is shown in Figure 3.
Figure 3: Energy saving potential of the daylighting control (Building use: weekdays 8-17) for different lighting levels and different light transmissions (VT) of polycarbonate sheets.

2.3 Heating, cooling and ventilation systems

New types of radiation-based heating and cooling profiles developed during the project are installed in the building. The profiles are affixed to the underside of the roof element as shown in Figure 4. The radiation profiles generate either cools or heats the interior, depending on the season and the desired indoor temperature of the building. Radiant profiles work with a low temperature difference to the ambient air, allowing the heat pump installed in the building to perform well. The radiant system also reduces temperature variations on each floor in the building, thereby considerably increasing usage comfort and improving well-being at work and productivity.

Figure 4: Ruukki radiant profile and installation
Heating and cooling performance of the new product was studied with Comsol Multiphysics program by Finnish company Granlund Oy. Product properties such as material, colour, tube diameters and geometry were optimised with the tool to achieve high performance system. Share of the radiant part of the total heat output is about 76% and the total heating power is 77 W/m with average fluid temperature of 45ºC. In cooling mode, the cooling power is 31 W/m with average fluid temperature of 16.5ºC. Temperature distribution of the studied system in heating mode is shown in Figure 5.

Figure 5: Ruukki radiant profile integrated into the roof panel.

A new type of indoor heating and cooling system also reduces energy consumption compared to air-heating systems. A ventilation airflow is now required only for the influx and removal of fresh air – not actually for heating the premises. The mechanical ventilation machine is equipped with an 80% heat recovery system.

### 2.4 Renewable heating energy system

Geothermal energy is utilized for the building’s heating and cooling requirements. In total, 60 Ruukki Construction energy piles with diameter of 115mm and of 11m in length under the floor and columns are incorporated in the foundation to use renewable energy to heat the building. The energy pile system is based on steel foundation piles, Uponor double U-heat-collecting pipes (ø25mm) installed in the piles, connecting pipes via manifolds to the heat pump, and heat-transfer liquid. Figure 6 shows the heat collector pipes installed. Furthermore, two conventional heat wells of 200 m in length were installed for heating and free cooling of the building. The heat pump capacity is 32 kW. The performance of the steel energy pile system in Nordic conditions has been studied in several studies, for example by Nyholm (2011), Cervera (2013), Hassani (2014) and Döring et al (2015). According to these studies it have been showed that recharging of the energy pile field during the summertime is essential in order to guarantee the long-term behaviour of the system.

Figure 6: Heat collector pipes installed in the floor slab piles
A total of 24m² of Ruukki Classic solar collectors are installed on the roof of the building’s technical area. The Classic solar system integrates fully with the roof, as shown in Figure 7. Solar collectors accumulate thermal energy from the sun and transfer it to the soil through the energy piles. The soil is charged whenever there is heating potential available – even in January, thanks to the very low temperature level in the ground.

Figure 7: Roof-integrated solar heat collectors

The soil acts as a seasonal thermal reserve, much like a battery. Beneath the building, a clay layer extends to a depth of 11 metres. Clay has a greater thermal storage capacity than, for example, gravel. During the summer, the energy pile loop is closed from the heat pump, and is charged by the solar collectors. In the winter, the piles transfer energy from the soil to heat the building with help of heat pump. Cooling of the building is via the deep heat wells by free cooling utilizing the low temperature of the ground rock. The principle of the system is shown in Figure 8.
2.5 Building Integrated Solar Energy Solution

Solar power is also used in the outer walls of the building. Ruukki Construction’s on-wall solar panels, which generate electricity from the light of the sun for the building’s network, are installed on its southern façade. A total of 61 m² PV (Photovoltaic) panels with total peak power of 10 kW are incorporated in the wall (see Figure 9). The optimum amount of solar PV-panels is based on buildings own electricity, because it’s not economical to feed extra electricity into the public electrical network. Total electricity production of the system is about 7 MWh/year. In Finnish latitude the on-wall system is relatively effective, because of low angle of the sun.
2.6 Monitoring of the building

The building is equipped with a large number of energy meters and other measuring devices to ensure extensive monitoring and ascertain the real energy performance of the building. In particular, the energy pile and solar heat systems are monitored carefully to study the soil behaviour in the long run. Some building elements are also equipped with thermal-moisture sensors in order to monitor their condition throughout their life-cycle. Furthermore, the amount of snow on the roof is also monitored with a Ruukki Smart Roof application based on strain gauge measuring of the metal roof structure.

3 Building simulations

The energy efficiency of the reference building and the nZEB were determined by energy simulations with the IDA ICE 4.5 program (Equa Simulations 2014). The simulations were performed by Ruukki and Tallinn Technical University. The reference building represents the current normal, already very energy-efficient, construction custom. A simulation model included a model of the building with the structures and technical systems as well as the energy piles and heat wells. The initial data for the reference case and the nearly zero-energy case are given in Table 1. Many different alternatives were studied in order to find optimum solutions to the whole building. Special attention was paid to design and model the energy pile system carefully to guarantee long-term performance of the system. One important observation of the simulation was that further to recharging the soil with solar energy, heat losses though floor structures also help to keep energy pile field well balanced.

The final results for the energy demand and the delivered energy are shown in Tables 2 and 3. A comparison of delivered energies of the cases is given in Figure 10. The results show that it is possible to over than halve the total energy use of a building with smart design and solutions.
Table 1: Initial data for simulated cases

<table>
<thead>
<tr>
<th></th>
<th>Reference</th>
<th>nZEB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall, U-value</td>
<td>0.17 W/m2K</td>
<td>0.16 W/m2K</td>
</tr>
<tr>
<td>Roof, U-value</td>
<td>0.09 W/m2K</td>
<td>0.12 W/m2K</td>
</tr>
<tr>
<td>Window, U-value (avg)</td>
<td>1.0 W/m2K</td>
<td>0.87 W/m2K</td>
</tr>
<tr>
<td>Floor</td>
<td>EPS 150mm, $\lambda=0.034$</td>
<td>EPS 150mm, $\lambda=0.034$</td>
</tr>
<tr>
<td>Infiltration q50</td>
<td>4 m³/m² h</td>
<td>0.76 m³/m² h</td>
</tr>
<tr>
<td>AHU Heat Recovery</td>
<td>50%</td>
<td>80%</td>
</tr>
<tr>
<td>Lights</td>
<td>15 W/m²</td>
<td>9 W/m² (LED)*</td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td>68 l/m² a</td>
<td>68 l/m² a</td>
</tr>
<tr>
<td>People</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Fresh air (SFP=2.0)</td>
<td>1.5(2**) l/sm²</td>
<td>1.5 l/sm²</td>
</tr>
<tr>
<td>Temp. set points</td>
<td>18°C /25°C</td>
<td>18°C /25°C</td>
</tr>
<tr>
<td>Heating system</td>
<td>Air-heating</td>
<td>Radiant heating</td>
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<td>Energy source</td>
<td>District heating</td>
<td>Ground heat pump***</td>
</tr>
<tr>
<td>Cooling SEER</td>
<td>2.5</td>
<td>free cooling</td>
</tr>
<tr>
<td>Schedule</td>
<td>8–17 weekdays</td>
<td>8–17 weekdays</td>
</tr>
</tbody>
</table>

*day-lighting control in 2/3 part of the building based on lighting level of 300 LUX
**overall rate with air-circulation in air-heating case
***SCOP 2.7 (including circulation pumps and heat distribution losses)

Table 2: Energy demand and delivered energy of the reference case

<table>
<thead>
<tr>
<th></th>
<th>Energy demand</th>
<th>Delivered energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kWh</td>
<td>kWh/m²</td>
</tr>
<tr>
<td>Heating</td>
<td>88272</td>
<td>59.0</td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td>5918</td>
<td>4.0</td>
</tr>
<tr>
<td>Cooling</td>
<td>8502</td>
<td>5.7</td>
</tr>
<tr>
<td>Fans electricity (SFP=2.0)</td>
<td>18498</td>
<td>12.4</td>
</tr>
<tr>
<td>Pumps electricity</td>
<td>79</td>
<td>0.1</td>
</tr>
<tr>
<td>Lighting</td>
<td>51178</td>
<td>34.2</td>
</tr>
<tr>
<td>Total distr. heat:</td>
<td>94190</td>
<td>63.0</td>
</tr>
<tr>
<td>Total electricity:</td>
<td>73156</td>
<td>49.0</td>
</tr>
</tbody>
</table>
Table 3: Energy requirements and energy inputs of the nZEB case

<table>
<thead>
<tr>
<th>Energy demand</th>
<th>Delivered energy</th>
<th>kWh</th>
<th>kWh/m²</th>
<th>kWh</th>
<th>kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating energy</td>
<td></td>
<td>65619</td>
<td>43.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Heat pump</td>
<td></td>
<td>13490</td>
<td>9.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Top-up heating</td>
<td></td>
<td>4340</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td></td>
<td>5918</td>
<td>4.0</td>
<td>3694</td>
<td>2.5</td>
</tr>
<tr>
<td>Cooling</td>
<td></td>
<td>3353</td>
<td>2.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fans electricity</td>
<td></td>
<td>14302</td>
<td>9.6</td>
<td>14302</td>
<td>9.6</td>
</tr>
<tr>
<td>Pumps electricity</td>
<td></td>
<td>6254</td>
<td>4.2</td>
<td>6254</td>
<td>4.2</td>
</tr>
<tr>
<td>Lighting</td>
<td></td>
<td>19498</td>
<td>13.0</td>
<td>19498</td>
<td>13.0</td>
</tr>
<tr>
<td><strong>Total electricity</strong>:</td>
<td></td>
<td><strong>61578</strong></td>
<td><strong>41.2</strong></td>
<td><strong>41.2</strong></td>
<td><strong>41.2</strong></td>
</tr>
</tbody>
</table>

Figure 10: Comparison of delivered energies of the reference case and nZEB case

Furthermore, the annual yield of the building-integrated solar PV panels is approximately 7000 kWh/a. Thus the need for delivered energy decreases further by approximately 5 kWh/m², corresponding to a decrease in a primary energy use over 10%.

As yet there are no official requirements for nearly zero-energy levels in Finland, but the proposals made in the national “FInZEB” project (FInZEB 2015) indicate that this building would clearly meet future targets.
4 Economic feasibility studies

Economic feasibility studies and comparisons between the two cases were carried out. The economic calculations took into consideration all investment costs that differed in the two cases as well as future energy savings due to improved energy efficiency. The net present values of the future savings were determined based on a 6% interest rate and a 4% increase in the energy price. The initial price of electricity was 85 €/MWh and 65 €/MWh for district heating. All prices are excluding VAT. The results are shown in Figure 11. As Figure 11 shows, the nearly zero-energy solution is economically reasonable, with a payback period of around 9 years. Also, it should be noted that the real extra investments of the nZEB solution are only about 2% of the total construction costs. Solar PV installations are not included in the studies, because they were not included into the original design and their impact is easy to separate from the overall building energy performance. The separately calculated payback for solar PV installations is approximately 15 to 20 years.

![Figure 11: Net present values for the nearly zero-energy building compared to the reference building](image)

5 Conclusions

The project showed that the nearly zero-energy building is technically feasible if the energy demand of the building is reduced and renewable energy sources are utilized in a smart way. Energy simulation tools came in handy in the early design phase of the project. Air-tightness of the building proved to be one of the most important factor in the reduction of energy demand. Lighting simulations showed that there is also lot of potential in utilization of daylighting in this kind of buildings. Solar collector boosted energy pile system proved to work well to produce heating energy to the near-zero energy building. The project also showed that the nearly zero-energy buildings can be constructed in a Nordic climate in a cost-efficient way. The extra costs of energy efficiency may be very low if the building is optimized as a whole – not via sub-optimizing.
### Notation

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHU</td>
<td>Air Handling Unit</td>
</tr>
<tr>
<td>EPS</td>
<td>Expanded Polystyrene</td>
</tr>
<tr>
<td>SCOP</td>
<td>Seasonal Coefficient of Performance</td>
</tr>
<tr>
<td>DHW</td>
<td>Domestic Hot Water</td>
</tr>
<tr>
<td>nZEB</td>
<td>Near Zero Energy Building</td>
</tr>
<tr>
<td>SEER</td>
<td>Seasonal Energy Efficiency Ratio</td>
</tr>
<tr>
<td>HR</td>
<td>Heat Recovery of the ventilation system</td>
</tr>
<tr>
<td>$q_{50}$</td>
<td>Air-tightness of the entire building [m$^3$/h·m$^2$]</td>
</tr>
<tr>
<td>PIR</td>
<td>Polyisocyanurate insulation</td>
</tr>
<tr>
<td>SFP</td>
<td>Seasonal Factor of Performance</td>
</tr>
<tr>
<td>U-value</td>
<td>Heat conductivity [W/(m$^2$·K)]</td>
</tr>
<tr>
<td>VT</td>
<td>Visual Light Transmission</td>
</tr>
</tbody>
</table>

### References


A Study on Life-cycle Environmental Management of Civil Transportation Airport

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Abstract

In recent years, many new, enlarging and rebuilding civil transportation airports are under construction along with economic development. But the problems of environmental damage of civil transportation airports which have caught more and more attention in public are becoming the barrier to the civil aviation development. Based on the theory of environmental sociology, sustainable development and green airport, this paper have summarized the environmental management measures of international civil transportation airports and the laws related airport environmental of different countries. Then the life-cycle environmental management system framework of civil transportation airport is put forward, which points out that environmental management require integrated management through three dimensions, namely environmental management contents dimension, life cycle dimension and environmental management technology dimension. At last, in order to offer a new possible method for airport environmental management in operating period, the early warning system of civil transportation airport based on gray system theory is established and proved feasible through a simple case. The results of this paper can be the theoretical basis for the life cycle environmental management of civil transportation airport and contribute to solve the existing problems of environmental management of civil transportation airport.

Keywords: civil transportation airport, environmental management, life-cycle, environment early warming, grey system theory

1. Introduction

The amount of civil transportation airports is continuously increasing as the development of economy and the improvement of people's demand. However, the development of civil aviation industry has brought serious environmental pollution (Chen, Z., Li, H., & Hong, J., 2004) which causing that people living near the airport put up protests against airport pollution more frequently in recent years. For example, the Heathrow Airport (UK) expansion project has been protested because of environment pollution (BBC news, 2015) and Frankfurt airport has been protested by
nearby residents for more than 10 years because of night flight noise pollution (Ta Kung Pao Hong Kong, 2012). Civil transportation airports projects have a great impact on the environment in construction period and operating period, so the environmental pollution problems will be a main barrier to the development of civil transportation airports in both the present and the future.

FAA (Federal Aviation Administration, 2012) pointed out that the environmental problems of airport are the most important in the design and operation of a new airport. At present, the developed countries usually publish various laws and regulations related airport environmental to regulate the construction and management of airport. International airports have their own methods of environmental management, including recycling, low-carbon and intelligent measures. We have sort out some environmental management measures of airports, as show in Table 1.

<table>
<thead>
<tr>
<th>Airport Name (Country)</th>
<th>Environmental Management Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manchester Airport (UK)</td>
<td>Integrate environmental management into the business operation.</td>
</tr>
<tr>
<td>Oakland International Airport (American)</td>
<td>Implement the strategy of sustainable development including includes three parts: environmental responsibility, economic vitality, social equity; draw up rules of plane landing and taking off at night; build the noise isolation area near the airport.</td>
</tr>
<tr>
<td>Heathrow airport (UK), Hamburg airport (Germany), Frankfurt airport (Germany), De Gaulle airport (France) and Narita airport (Japan)</td>
<td>Charge relevant fees according to the noise DB level.</td>
</tr>
<tr>
<td>Phoenix Sky Harbor International Airport (American)</td>
<td>Through well design in the construction, every energy consuming equipment of the airport is intelligent which is able to be automatic power off when is not required</td>
</tr>
<tr>
<td>Athens International Airport (Greek)</td>
<td>Provide 422000 m³ reuse water for agricultural irrigation</td>
</tr>
<tr>
<td>Guangzhou-Baiyun International Airport (China)</td>
<td>Put the idea ‘land conservation, energy conservation water conservation, material conservation’ into planning and design</td>
</tr>
<tr>
<td>Beijing Capital International Airport (China)</td>
<td>Reduce energy consumption of air conditioning and lighting by using advanced technology and materials</td>
</tr>
</tbody>
</table>

In 2007, the Civil Aviation Administration of China brought up the concept of green airport for the new Kunming International Airport, then the concept of green airport begin to be prevalent in the Chinese civil aviation industry. The new Kunming International Airport demand all design units reflects green airport in the general planning, engineering design, etc. However, most of the policies and measures of environmental management of airport in China are limited in solving environmental problems after pollution. It has not established the life cycle environmental management system framework of civil transportation airport projects in China. Based on the
successful experience of civil transportation airports of China, this paper will put forward the life-cycle environmental management system framework of civil transportation airport is put forward.

2. Literature Review

There are also many researchers researched several related studies of airport environmental management. Kılkış (2014) simulated Istanbul Airport to forecast the position of the airports and point out the importance of environmental influence analysis as well. He got more knowledge of the influence of the terminal energy consumption and which elements played a decisive role in carbon emission by analyzing the energy of terminal. Bartels, Muller and Vogt (2013) interviewed residents around Cologne Bonn Airport about the satisfaction of the airport by phone survey, and the results showed that residents around the airport hold the trust that administrators will improve the living environment by taking some measures. Bartels, Márho and Müller (2015) pointed out that the noise figure of planes was not only considered about outdoor sound pressure level, the number of planes was also concerned. And this conclusion had a certain referential significance of how to reduce the noises. Duinkerken, Selderbeek and Lodewijks (2013) revealed that single engine glide, operation pulling and electro-motor putting on aircraft wheels can all reduce the carbon emission of airport. Electro-motor method got the most obvious effect on saving the plane launch cost and carbon emission. Zheng, R. H., et al(2008) analyzed the features of airport environment influence factors to build an evaluation index system of airport environmental impact, meanwhile he also built a comprehensive evaluation matter-element model with multiple index and layers of the airport environmental impact based on matter element analysis theory. Shen Y. (1999) proposed four ways: airport management measures, airport engineering measures, plane measures and airport auxiliary measures to solve the airport noise problem, she then suggested the airport administrative department to build professional management organization and also bring in legislative regulation. Tang X.Y. (2008) put forward that Green Airport idea should be throughout every steps during the airport construction and operation process, and airport garbage harmless treatment as well as resource comprehensive utilization project were suggested to be put into effect. Li Longhai(2008) focused on power saving goal, used passive energy conservation design method to plan the airport site in an overall point of view combined with the airport energy consumption analysis, and then the airport adapted to the site environment to achieve the energy saving. He did energy-saving design to the airport terminal in every building design, and stated that there are two aspects in the concept of Green Airport: conservation and environmental protection.

3. Research method

This paper mainly involves the theory of environmental sociology, sustainable development theory, and green airport. Environmental sociology focus on research interactive relationship between environment and human society (Hong D.Y., 2009), so environmental management of civil transportation airport is one of the important researches of environmental sociology. Sustainable development theory was becoming a hot topic in the environmental field which required the span of environmental management extended to life cycle from the early stage to the operating period (Blewitt, J., 2014). The theory of green airport demand that comprehensive
measure should be taken for keeping a harmonious coexistence of human being with the environment (The headquarter of Shanghai airport construction, 2010).

Based on the theory of green airport, environmental sociology and sustainable development theory, this paper have studied airport environmental regulations made by international civil aviation organizations and understood the airport legislation situations aiming to solve environmental pollution in countries around the world. We used the method of induction and extracted current situations to find effective practices which have been examined by applications in the past, combined with the regulations and practices of airports around the world, then they will be introduced into the effective environmental management system of civil transportation airport. Afterwards, the paper will put forward the life cycle environmental management system framework of civil transportation airport based on the practical experience of China large airport construction. This system can comprehensively and effectively improve the civil transportation airport environmental management status quo.

4. Life cycle environmental management framework of civil transportation airport

4.1 The part of life cycle environmental management framework of civil transportation airport

The life cycle environmental management (LCEM) system of civil transportation airport project includes three-dimensional space composed of X, Y, Z axis, as shown in Figure 1. The X axis shows three main environmental management contents of life cycle environmental management in the graph, the Y axis shows four management technology parts of environmental management in civil transportation airport construction project, and the Z axis represents three phrases of civil
transportation airport project.

4.2 The introduction of life cycle environmental management framework of civil transportation airport

4.2.1 Project phase of life-cycle of civil aviation airport

The Z axis of the framework is divided into early phase of construction, construction phase and operation phase according to the whole life cycle. The national regulations and policies related to environment are mainly for regulating various behaviors in the life-cycle of civil transportation airport and limiting the activities which can cause damage to the environment quality, and then to achieve sustainable development of civil transportation airports. Because of the different pollution sources in three stages, the management of each stage is different. The pollution sources of each phase is shown in Table 2.

<table>
<thead>
<tr>
<th>Life-cycle of civil transportation construction</th>
<th>pollution sources</th>
<th>influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early phase</td>
<td>Environmental impact on the operation: determine airport location, traffic planning, airport design and planning, afforestation level</td>
<td>The planning and design phase does not produce pollution, but the results will affect the environmental management of construction and operation period.</td>
</tr>
<tr>
<td>Construction phase</td>
<td>(1) construction noise; (2) dust; (3) water pollution; (4) air pollution; (5) construction waste</td>
<td>Strengthen the relevant measures to control;</td>
</tr>
<tr>
<td>Operation phase</td>
<td>(1) great energy consumption; (2) low utilization of energy; (3) high maintenance costs; (4) great pollution;</td>
<td>Bring about main impact to the environment, which phrase the environmental management focus on.</td>
</tr>
</tbody>
</table>

4.2.2 Life cycle environmental management technology of civil transportation airport

The Y axis of the framework shows that the life cycle of civil transportation airport is classified by management technology and composition. The life cycle environmental management system of civil transportation airport construction project can provide comprehensive support and guarantee for protection work. The main contents of the whole life cycle environmental management system of civil transportation airport construction projects is shown in Table 3.

<p>| Table 3 Environmental management system of the whole life cycle of civil transportation airport |</p>
<table>
<thead>
<tr>
<th>Phrase Composition</th>
<th>Early phrase</th>
<th>Construction period</th>
<th>Operation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institutions system and regulations frame</td>
<td>Environmental impact assessment System</td>
<td>Environmental supervision system; &quot;Three simultaneous&quot; system; Environmental protection completion acceptance system</td>
<td>Environmental post-assessment institutions</td>
</tr>
<tr>
<td>Public participation system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>technical method system</td>
<td>Environmental assessment for planning; Project environmental assessment; Environmental design; Environmental supervision; Environmental protection acceptance</td>
<td>Implementation and operation; Inspection and corrective actions</td>
<td>Environmental post-assessment</td>
</tr>
<tr>
<td>Management operation mechanism</td>
<td>Environmental policy formulation; Environmental planning</td>
<td>Preventive mechanisms (professional management, supervision and inspection management, integrated coordination management), the punishment mechanism</td>
<td>Management review</td>
</tr>
<tr>
<td>Public participation</td>
<td>Public consultation</td>
<td>1.media publicity and supervision; 2.set up public representatives; 3.hotline telephone consultation; 4.public reception day</td>
<td>public opinion survey</td>
</tr>
</tbody>
</table>

Life cycle environmental management institution system and regulations framework of civil transportation airport is a collection consists of environmental management systems, as shown in figure 2. It mainly include: the environmental impact assessment system in project planning phase and feasibility study phase; "three simultaneous" system, which mainly aims to put forward the requirements and regulations for hardware construction of environmental protection facilities; environmental protection acceptance system, aiming to implement the inspection and evaluation the environmental protection measures in whole processes (Deng T.J., 2009). Moreover, it also include three system which are studying and trying in China, name Environmental supervision system, aiming to manage the environmental behavior of whole construction process; Post environmental assessment system, mainly for the environment management of operation phrase, checking and review the environmental protection work before operation phrase; Public participation system, it means environmental protection needs the public participation in whole life cycle of the project so as to monitor the environmental management of all aspects and improve environmental management work.
The establishment of life cycle environmental management technology and method system of civil transportation airport construction project is from the perspective of technical approach. In order to improve the existing environmental management techniques and methods of the civil transportation airport construction projects, such as the planning assessment, environmental assessment, environmental design and environmental protection acceptance and improve efficiency, we analyze the different environmental impact and management requirements. The effective use of the life cycle of environmental management techniques is conducive to the implementation of environmental protection measures.

Building the life cycle environmental management operation mechanism, mainly based on the ISO14000 environmental management system and ISO9000 quality standard management system, is an important component of the life cycle environmental management of civil transportation airport. This operation mechanism will cover the process from environmental policy formulation, environmental planning to operation, check and evaluation which can complete the environmental management process systematically accompanied with overall process prevention and punishment mechanism. Carrying out the life cycle environmental management operation mechanism in overall civil transportation airport construction project helps to build an international widely recognized, standardized, systematic environmental management paradigm.

Public participation method is another basic method of environmental management. Building the public participation mechanism and approach of raising the participation is the basic of this method. This method is an important institutional guarantee for reducing environmental decision-
making errors, and perfected the content of life cycle environmental management system of civil transportation airport construction project.

4.2.3 The contents of life cycle civil transportation airport management

The X axis of the framework is classified by the management contents. The contents of life cycle environment management of civil transportation airport can provide the comprehensive content formulation and guidance for the environmental protection which promoted the comprehensive, perfection and validity of the environmental management. And the contents are reliable technical supports for the life cycle environmental management. The contents of life cycle environmental management of civil transportation airport was shown in Table 4.

Table 4 The contents of life cycle environmental management of civil transportation airport

<table>
<thead>
<tr>
<th>Phrase Contents</th>
<th>Early phrase</th>
<th>Construction period</th>
<th>Operating period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Technology Management</td>
<td>1. Reasonable site selection 2. Reasonable layout</td>
<td>Pollution prevention and technology control of construction</td>
<td>Pollution Abatement Technology (noise, air, land surface, solid waste, etc.)</td>
</tr>
<tr>
<td></td>
<td>3. Choose environmental friendly equipment and materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Technology and system upgrade</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Formulate rules for technology execution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Quality Management (QM)</td>
<td>1. Establish the quality index system</td>
<td>1. QM of construction environmental factors (water, noise, air)</td>
<td>1. QM of operation environmental factors (water, noise, air)</td>
</tr>
<tr>
<td></td>
<td>2. Environmental facility design</td>
<td>2. QM of construction environmental facilities (greening, health facilities, municipal facilities)</td>
<td>2. QM of operation environmental facilities (greening, health facilities, municipal facilities)</td>
</tr>
<tr>
<td></td>
<td>3. Develop environmental management system</td>
<td>3. QM of construction environmental management</td>
<td>3. QM of operation environmental management</td>
</tr>
<tr>
<td>Environmental Plan Management</td>
<td>Develop environmental policies and standards</td>
<td>1. Technical comparison and economic comparison</td>
<td>1. Assessment and acceptance of results</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Cost optimization</td>
<td>2. Technology promotion</td>
</tr>
</tbody>
</table>

Environmental technology management study the method and system of technology management of the construction life cycle of civil transportation airport from the perspective of technology. The technology management is integrated management of technology and technological base of the environment protection. Effective environmental management of technology can improve the usage of environment technology and environment protection in the life cycle of civil
transportation airport construction project.

Environmental quality management can be divided into quality management of environmental factors, quality management of environmental facilities and quality management of environmental management. Institutions and index system development are emphasized in the early stage of construction, and specific management quality evaluation is emphasized in construction stage and operation stage. Environmental quality management can improve the quality of the practice of environmental management, and can also contribute to the implementation of life cycle environmental management measures of civil transportation airport construction project.

Environmental plan management aim to improve the environmental management level on the experience and method aspects. Through developing policies to prevent in advance, optimizing in the process and post evaluation, environmental plan management provided experience accumulation and technical promotion at present and in the future for environmental management. It is also an important guarantee for reducing waste in the process of environmental management. And it can improve and perfect the existing environment management content.

5. Study on environment early warning of operating period of civil transportation airport based on gray system theory

The study on environment early warning of operating period of civil transportation airport can provide useful information for environmental management and improve environmental management level of civil transportation airport. Grey system theory is a kind of deepening and development of system thought. Grey forecasting model is a kind of short-term forecast tool, it can forecast the objects with raw data, and has higher prediction accuracy (Deng J.L., 2002). Modeling is based on the past and present known or unknown information, establish a GM model from the past to the future, to determine the trend of the future development of the system, to provide a basis for planning and decision-making. In this paper, the early warning of air pollution in civil airports, to a certain extent, shows regularity with the time change, and its index data has the character - small sample and poor information, so it is suitable to use gray system theory for early warning.

5.1 Selecting early warning factors

The environmental problems of civil transportation airport commonly include noise pollution, air pollution, water pollution, solid waste pollution and land use problems. The purpose of early warning is to provide support for decision-maker to develop solutions of environmental pollution. Typically, different environmental problem have different solution and different early warning system of environmental problem has similarity. So this section will only establish one warning system for one of the environmental problems. And the main purpose of this section is to discuss the feasibility of using the gray system theory in the environmental early warning of civil transportation airport, so in order to simplify study process, we select the concentration of NO\textsubscript{2} which is easily getting as the only early warning factors.
5.2 Defining the early warning standard

According to Chinese ambient air quality standards, we develop the ambient air quality standards and early warning standards, as shown in Table 5.

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>level</th>
<th>concentration limit (mg/m³, standard state)</th>
<th>air quality</th>
<th>Warming level</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂</td>
<td>grade I</td>
<td>&lt;0.04 &lt;0.08 &lt;0.12</td>
<td>Good</td>
<td>-</td>
</tr>
<tr>
<td>NO₂</td>
<td>grade II</td>
<td>&gt;0.04 &gt;0.08 &gt;0.12</td>
<td>Moderate</td>
<td>blue</td>
</tr>
<tr>
<td>NO₂</td>
<td>grade III</td>
<td>&gt;0.08 &gt;0.12 &gt;0.24</td>
<td>lightly polluted</td>
<td>yellow</td>
</tr>
</tbody>
</table>

Table 5 Ambient Air Quality Standards

5.3 Establishing early warning model based on gray system theory

(1) The NO₂ concentration of 5 consecutive days of Shanghai Pudong International Airport is shown in Table 6. (If you want to predict for longer period, you can choose the three day or week average value of NO₂ concentration as basic date.)

Table 6 The NO₂ concentration of Shanghai Pudong International Airport

<table>
<thead>
<tr>
<th>Date(Year 2010)</th>
<th>June 13</th>
<th>June 14</th>
<th>June 15</th>
<th>June 16</th>
<th>June 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂ concentration</td>
<td>0.103</td>
<td>0.109</td>
<td>0.117</td>
<td>0.116</td>
<td>0.121</td>
</tr>
</tbody>
</table>

(2) Building matrix based on gray system theory

According to grey prediction GM (1, 1) model,

\[ B = \begin{pmatrix}
-1/2 & 1/2 & 1/2 & \cdots & 1/2 \\
0 & 1 & 2 & \cdots & n-1
\end{pmatrix}
\]

\[ Y_n = [x_2, x_3, \cdots, x_n]^T = [0.109, 0.117, 0.116, 0.121]^T. \]

Then according to the formula \( \hat{a} = [a, u] = (B^T B)^{-1} B^T Y_n \), we can get the value of a and u and establish the early warning model.

(3) Calculating
Due to the complexity of the calculation, we use the computer software ‘math too’ to carry out the calculation. Sort out the calculation results to form and calculate absolute error and relative error, as shown in Table 7.

<table>
<thead>
<tr>
<th>Date</th>
<th>Actual Value</th>
<th>Predictive Value</th>
<th>Absolute Error (Residual Error)</th>
<th>Relative Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 13</td>
<td>0.103</td>
<td>0.103</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>June 14</td>
<td>0.109</td>
<td>0.1106</td>
<td>-0.0016</td>
<td>-0.01468</td>
</tr>
<tr>
<td>June 15</td>
<td>0.117</td>
<td>0.1139</td>
<td>0.0031</td>
<td>0.026496</td>
</tr>
<tr>
<td>June 16</td>
<td>0.116</td>
<td>0.1174</td>
<td>-0.0014</td>
<td>-0.01207</td>
</tr>
<tr>
<td>June 17</td>
<td>0.121</td>
<td>0.121</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.011</td>
</tr>
</tbody>
</table>

5.4 Model precision verification and prediction results analysis

According to the relative error of residual error, we can easily figure out the posterior error $C = 0.0021$. According to the precision requirement of the grey system theory, the established early warning model is qualified when the posterior error $C$ is less than 0.5. So the early warning model can objectively reflect the dynamic changes of air quality. In other word, the model can be used to predict the value of air quality index.

We can predict the NO$_2$ concentration of June 18 to June 20 through the early warning model. The prediction results are shown in Table 8.

<table>
<thead>
<tr>
<th>Date</th>
<th>June 18</th>
<th>June 19</th>
<th>June 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_2$ concentration</td>
<td>0.1247</td>
<td>0.1285</td>
<td>0.1324</td>
</tr>
</tbody>
</table>

Through the prediction results in Table 6, we can know that the NO$_2$ concentration is greater than 0.012 and less than 0.024 from June 18 to June 20. So the air quality is moderate according to the Table 3, and the warming level is blue. And the prediction results proved that using the gray system theory in the environmental early warning of civil transportation airport is feasible.

6. Conclusions

According to the problems of environmental management in the development of civil transportation airport, this paper puts forward the life cycle environmental management system from the perspective of practice and specifies the system need to include environmental
management content dimension, life cycle dimension and management technology dimension. And then the early warning system of operating period of civil transportation airport based on gray system theory is established and proved feasible through a simple case. The results of this paper can provide the theoretical basis for the life cycle environmental management of civil transportation airport and contribute to solve the existing problems of environmental management of civil transportation airport. The study in this paper has a great significance for the development of civil transportation airport in the environmental protection.

References


Ta Kung Pao Hong Kong (2012). No fly at night, Frankfurt Airport international status may be shaken. (available online http://news.carnoc.com/list/214/214581.html [accessed on 21/9/2015]


The headquarter of Shanghai airport construction (2010). Green airport. Shanghai: Shanghai Science and Technology Press. (Chinese)


SECTION 6

Building information modelling (BIM)
BIM tools and modelling guidelines proposed by a Brazilian public bank

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Abstract

The Brazilian public bank described herein, Caixa Econômica Federal, is essentially a financial institution, which has also historically maintained a technical department comprising more than two thousand civil engineers and architects. These professionals perform technical feasibility analyses of infrastructure and housing projects that apply for public financing. Due to this peculiarity, this public bank is one of the most important stakeholders in the Brazilian Architecture, Engineering, Construction and Operations (AECO) industry. Currently, the project analysis process is manual, paper-based, time and labour consuming. Facing this situation, the institution has established tasks likely to be automated through BIM (Building Information Modelling), and is now pursuing its adoption. Since there are not official modelling standards in Brazil, establishing them was deemed necessary to enable a BIM-based project analysis in near future. The aim of this paper is to analyse the proposed innovation through a discussion group that has experimented modelling with the guidelines and tools proposed by the bank. The purpose is to determine whether the proposition is viable and if future users will be willing to adopt it. Although the evaluation of the tools and project template proposed were positive, the results showed a broader issue of segregation between the disciplines of design and cost estimation. Those results may influence not only the acceptance of the technological innovation proposed by Caixa, but BIM adoption in Brazil in general.

Keywords: BIM, Feasibility analysis, Standardization, Modelling Guidelines

1. Introduction

Caixa Econômica Federal (Caixa for short hereafter) is a Brazilian public bank leader in financing construction and in transferring federal resources for public infrastructure and social housing. It holds a 67.7% share of the Brazilian housing financing market, which reached US$ 127.81 billion\(^1\) in 2014. The public infrastructure portfolio, which enables investments in the fields of urban mobility, energy, logistics, sanitation and others, presented a total balance of US$ 21.33 billion

\(^{1}\) The conversion rate applied was US$ 1.00 = R$ 2.6587 (current exchange rate in December 2014).
in 2014, an increase of 52.8% compared to the previous year, and a total volume of new contracts of US$ 12.52 billion (Caixa Econômica Federal, 2014).

The institution currently has 97,900 employees, and over 2,000 of them are engineers and architects, working in 74 regions in the country. Since there is a significant deficiency in construction and building regulation control in Brazil, the institution has been playing an important role performing technical feasibility analysis and verifying projects' suitability. Caixa is a notable improvement driver in the Brazilian civil construction industry through its requirements for project financing. An example is the demand that all low-income and social housing construction companies must be certified by the Brazilian Program for Housing Quality and Productivity (PBQP-H) (Ministério das Cidades, 1998).

The main objective of the technical department is to analyse the operations to ensure that the resources are correctly applied. Therefore, the work is dictated by a strict set of rules that are based on laws, public procurement regulation and demands by federal investments funds. A technical analysis of proposals verifies their compliance with the funding program guidelines, the suitability of the design to the intervention site, its functionality and technical feasibility, all combined with a verification of cost and schedule.

Currently, the analysis process is manual, paper-based, time and labour consuming. All documents are provided on paper, in an extremely bureaucratic process. The design is manually checked, and the most time-consuming task is the quantity take-off for comparison with the proposed budget. Facing up to this situation, the bank has established tasks likely to be automated through BIM (Building Information Modelling), and is now pursuing its adoption (Ferrari and Melhado, 2015). Automated design checking and cost checking are the two most critical activities and the latter was chosen to start the adoption of BIM by the institution.

Since BIM adoption rate in Brazil is low (McGraw Hill Construction, 2014), and there is not a national guide or reference for BIM-based design in Brazil, the institution believes that it is essential to provide modelling guidelines and tools in order to obtain project files adequate for analysis.

The aim of this paper is to analyse the proposal being developed for modelling guidelines and tools, considering that, if approved, it has the potential to become a national standard. The research method applied is the proposition of a structured exercise using the suggested Revit project template and two plug-ins, followed by a discussion group and a questionnaire. The purpose is to determine whether the proposition is viable and if future users will be willing to adopt it.
2. Research Context

2.1 Caixa Econômica Federal as a Policy Maker

In 2013, McGraw Hill Construction (2014) conducted a research that pointed out that 55% of the Brazilian contractors declared to have low BIM engagement, 70% claimed to have been using BIM for no more than two years, and 75% stated that less than 30% of their projects are in BIM. These data indicate that Brazil was still at an initial level of BIM adoption.

Referring to Succar’s BIM Capability Stages (Succar, 2010), the Brazilian Architecture, Engineering, Construction and Operations (AECO for short hereafter) Industry is pursuing BIM Stage 1, which is object-based modelling. Caixa Econômica Federal is considered in this paper as a Policy Maker (Succar and Kassem, 2015) due to its potential to disseminate standards, regulations, guidelines and best practices throughout the AECO Industry, therefore playing an important role in the diffusion of this new technology.

Although this Brazilian public bank has the prerogative to be a coercive and normative stakeholder, pressuring a top-down diffusion (Succar and Kassem, 2015), it has first adopted a passive approach, which consists, as Succar and Kassem point out, in making others stakeholders aware, encouraging and observing BIM adoption.

The institution acknowledged that the absence of modelling standards, guidelines and regulations would be a major barrier for any technological innovation in this area. Therefore, the efforts are towards providing tools and guidelines to the AECO Industry to allow a BIM-based project analysis, in a near future.

2.2 Guidelines and tools proposed

The proposal analysed herein was developed by a consulting company initially to solve an internal problem caused by restructuring in the National System of Costs Survey and Indexes of Construction (SINAPI for short hereafter), which is maintained by the institution and adopted by the government for public works budgets. Cost components were recently revised to consider more accurate rates of productivity (Oliveira et al., 2014), resulting in greater difficulty in choosing the correct cost component for each budget item. For example, a masonry wall that was previously associated with just one cost component now has its costs subordinated to the length of the wall, the existence of openings and to the type of mortar mix (mechanical or manual).

A project template and two plug-ins were developed in order to assist the cost estimator in choosing the right budget component for each design object, by filtering the options based on modelled characteristics or imputed information to the design. Revit was chosen due to its large diffusion in the Brazilian AECO Industry.

Firstly, to ensure standardization, a project template was conceived including loaded families and defined settings in order to provide a starting point for new projects (Autodesk, 2015). Thus, it is
guaranteed that the data used in the model have the characteristics necessary for the proper functioning of plug-ins.

Secondly, two plug-ins were developed for Revit. One of them helps creating wall coverings as separated walls, so the designer is able to easily define different characteristics for each (wall plug-in hereafter). Through this application, the user chooses a room to establish settings and select from a list of coating materials (pre-determined in the template) defining its height and thickness. The plug-in automatically creates a separate wall element for each coating layer attributed, which subsequently facilitates its handling and quantification.

Finally, another Revit plug-in (SINAPI plug-in hereafter) was developed to assist the specification of materials and components for each element modelled, relating them to a SINAPI cost element. As shown in Figure 1, in each room it is possible to select materials filtering possibilities according to the characteristics of the modelled object and enabling to export data to finalize the budgeting process.

![Figure 1: SINAPI plug-in](image)

3. Methodology

The benefits of BIM utilization are not yet established clearly and empirically; thus the decision of adoption is often based on speculated benefits (Barlish and Sullivan, 2012). Consequently,
verifying the user’s behavioural intentions towards the proposed technological innovation was considered important.

The research method applied was a group discussion in which a modelling exercise was proposed, followed by a structured and supervised discussion among the participants, and finally, at the end of the oral discussion, the participants answered a small questionnaire. The purpose was to encourage a widespread debate among research participants, thus verifying the real applicability of the proposed tools and project template.

The modelling exercise was developed so that the proposed project template and plug-ins would be employed in a real situation. The exercise consists in modelling a small house, applying its components and materials, and lastly creating a construction budget by choosing a cost component from SINAPI for each element of the model (Figure 2).

![Figure 2: Screen capture of the exercise](image)

To make sure that they would employ the tools correctly, a specialist guided the participants throughout the exercise. All the notes and questions were recorded along with their comments during the guided discussion.

Ten AECO professionals attended the workshop and they had a diversified profile, as seen in Table 1:

| Table 1: Workshop participants profile | 812 |
The workshop had an open invitation, and there were no fees collected. Having some experience with BIM was preferred but not mandatory to the participants. Their miscellaneous background enriched the discussion in which various points of view were available (Figure 3).

![Workshop presentation](photo-by-the-authors)

*Figure 3: Workshop presentation (photo by the authors)*

Besides spontaneous comments during the presentation and the exercise, the researchers proposed an open discussion about the points listed below.
• While modelling, what were your impressions regarding:
  o Difficulty and time to build the model?
  o Model visualization?
  o Differences from your own modelling practices?

• While using the wall plug-in and the SINAPI plug-in, what were your impressions regarding:
  o Operation of the plug-in?
  o Benefits of the plug-in?
  o Plug-in applicability in your daily practices?

The results shown herein are a compilation of the registration forms and questionnaire answers, in addition to a careful analysis of the discussion and questions from participants, recorded by the researchers.

3.1 Limitations

Even though the research method was satisfactory to investigate the main purpose of this article and to promote a broad discussion of the proposed object, it imposed a limited number of participants. There was an effort towards gathering a diverse group, but the possible influence of subjective views from the participants was taken into consideration in the final analysis.

4. Research Data

4.1 Participants profile

According to the information extracted from the registration forms and questionnaire, Architects and Civil Engineers were the majority in a young and well-educated group where at least half of the participants were postgraduates and under 30 years old (Figure 4).

The most popular BIM uses among the participants is for design coordination, visualization and presentation, quantity take-off and construction planning. Although most of them have some professional experience with construction cost planning, only three of the participants have already used a BIM software for this purpose, and they declare to be using Revit.
Motivations

The motivations for employing a BIM software for cost estimation noticed during the discussion were essentially related to innovation in design practices and for reducing cost estimating complexity. The changes in designer’s responsibilities with the adoption of a BIM-based design process were found to be a major concern, since some decisions related to construction planning, cost estimation and construction processes must be taken earlier in the project.

Some participants admit to neglect cost planning in the design process, and they recognize that there is a lack of integration between design and cost estimating.

When asked, all the participants agreed that if Caixa established a modelling standard, they would adopt it.

Benefits

The questionnaire results showed that most participants (88 to 100%) agreed that, compared to their current practice, it was easier, faster and more accurate to model, to extract quantities and to estimate project costs in the exercise (Figure 4).

There were also positive responses to the questions regarding the intention of use, suitability and perception of usefulness to their professional practices (Figure 6). During the discussion, it was pointed out that the wall plug-in would be very applicable to buildings with repetitive elements such as hotels, for example. In addition, most participants declared that it was easy to accomplish the exercise.
I would specify estimate costs like this in the future
Estimating costs was easier
Estimating costs was faster
I would specify materials like this in the future
Specifying materials was easier
Specifying materials was faster
I would repeat this QTO process in the future
The quantity takeoff (QTO) process was easier
The QTO process was faster
I would repeat this QTO process in the future
Estimating costs was easier
Estimating costs was faster
I would specify estimate costs like this in the future

Figure 5: Results in scale from 0 to 100% for agreement with statements about the design and cost-estimating process using the tools and guidelines proposed

Whenever possible I will use the tools and guidelines in my designs.
I plan to use the tools and guidelines in my designs when needed.
I believe that using the tools and proposed guidelines improves my work.
I believe that using the tools and proposed standards provides reliability to my work.
I believe that using the tools and the proposed guidelines will be helpful to my work.
My interaction with the tools and the proposed guidelines was given in a clear and understandable way.
It was easy to accomplish the exercise.

It will be easy to replicate what I learned using the guidelines and tools.
Using the new guidelines and tools are compatible with many aspects of my work.
The guidelines and tools are suitable to the way I like to work.
The guidelines and tools are suitable to my daily work.
I believe I have the necessary training to apply the tools and guidelines.
I believe I am able to replicate my knowledge even if there is no one to help me.
I believe I could achieve the same results using different tools and guidelines.

Figure 6: Results in scale from 0 to 5 for agreement with statements about use of tools and guidelines

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4.4 Difficulties

The main barrier acknowledged by the researchers was perceived during the exercise explanation, evidenced by the questions the participants were asking. Their inquiries reflected their unfamiliarity with construction processes, which lead to great difficulty in estimating costs. Furthermore, the participants appeared uninformed about SINAPI’s structure and guidelines, asking elementary questions about it.

About the plug-ins and project template proposed, some participants reported difficulties in designating objects specification with the SINAPI plug-in due to the various options it presents, making it evident that the filtering process of materials and components available should be more accurate. They also expressed some concerns about exporting the data to other cost-estimating software.

Ultimately, although the participants approved their training, they declared they would have some difficulty in reproducing what they had learned without any help.

5. Analysis

The modelling guidelines and plug-ins proposed can be considered approved, almost unanimously, with minor suggestions for improvement. The TAM (Technology acceptance model) postulates that a user's behavioural intention to use technology is related to the usefulness and ease of use perceived (Son et al., 2015), and the results indicate that the participants pointed out these qualities in the proposal.

However, it should be taken into consideration that most participants are comparing the proposed practices with non-BIM traditional methods. This fact can partially explain why some participants believe that they could achieve the same results using different tools and modelling guidelines: it is due to their interest in a BIM-based practice rather than a specific tool. The lack of modelling experience can also explain why they believe they could not reapply the exercise without help.

The results also called attention to the fact that design and cost estimating are segregated disciplines, and the professional responsible for the design is not always aware of the entire construction process, including the specification of materials and cost components. That is a major barrier, not only to the acceptance of the proposed tools and guidelines presented in this paper, but essentially to a BIM-based design and cost estimation practice (Gu and London, 2010).

6. Conclusions

Even though Caixa is a financial institution, it is also an important stakeholder in the Brazilian AECO industry and can be considered a policy maker due to its potential to disseminate standards, regulations, guidelines and best practices. Therefore, its efforts towards establishing modelling standards should be closely monitored because of their likelihood of becoming Brazilian national standards.
The aim of this study is to analyze the tools (plug-ins) and project template in development, which are based on modelling guidelines proposed by the institution. For this purpose, a modelling exercise was proposed followed by a group discussion and a questionnaire to identify users’ behavioural intentions towards the proposed technological innovation.

In spite of the focused purpose of the research, and the positive assessment of the plug-ins and project template, the results revealed a broader issue of segregation between the disciplines of design and cost estimation, evidenced in the difficulty demonstrated by the participants during the exercise. That may influence not only the acceptance of the technological innovation proposed by Caixa, but BIM adoption in Brazil in general.

Further studies should address this issue in terms of desirable professional qualification, responsibilities definition and impacts to the design process.

The continuity of this study will focus in the technical department of Caixa and the impacts of this technological innovation. Thus, analysing the organizational environment and the attitude of the employees in relation to the acceptance of change and innovation proposition.

References


A Framework of an Image-based Integrated Approach to Create As-Is Building Information Models for Existing Buildings

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Abstract

Building Information Modelling (BIM) provides an intelligent and parametric digital platform to support activities throughout the life cycle of a building and has been widely used for new building construction projects. However, most existing buildings today often do not have completed as-is information documents, nor existed meaningful BIM models. Despite the growing use of BIM models for relatively new buildings and the improvement in as-is records, incomplete or even incorrect information is still one of the main reasons for the low-level efficiency in facilities management. Furthermore, as-is BIM modelling for existing buildings is considered to be a time-consuming and expensive process, which requires great effort, time and skilled workers. Hence, developing an efficient way to create an as-is BIM model would be essentially the foremost step for effective operations and maintenance of existing buildings in their life cycle using cutting-edge BIM tools. We aim at developing a framework to establish a high efficient as-is BIM modelling system that integrates diverse building data in different formats (e.g., photo images, drawings, text data) with low cost, in order to improve efficiency and effectiveness of operations and maintenance, and furthermore possibly support refurbishment of a building. With this ultimate goal, this paper focuses on analysing state-of-the-art object recognition and reconstruction methods applicable for creating as-is BIM models, and summarises merits and limitations of these existing techniques and methods. Then, a framework is established with the most suitable methods on the basis of applying image sources and existing documents of the target building. The framework mainly includes a mechanism that supports automated creation of as-is objects with their meanings and information, and an assisting information library for the target building. The mechanism will use intelligent reasoning algorithms as appropriate such as the hybrid neuro-fuzzy algorithm in order to take into account possibilities of information shortage. The information library will mainly consist of four functional modules and four information modules (i.e., surface information, geometric representation, extracted information, and features information). Furthermore, key challenges and current progress are also addressed in this paper.

Keywords: as-is BIM model, hybrid neuro-fuzzy algorithm, information library, operations and maintenance
1. Introduction

On January 29, 2010, building collapse accident suddenly happened in Ma Tau Wai road, Hong Kong. An old six-story walk-up building suddenly crumbled at about 1:30PM. Four people died. Reasons for those accidents were often related to inefficient operations and maintenance (O&M) of facilities using traditional methods. With the increasing complexity of buildings in recent years, facilities management need a wide range of activities and building information associated to perform the activities. Hence, efficiently accessing to up-to-date information required for operating and maintaining a facility is essential and vital. Consequently maintaining the information up-to-date throughout the lifecycle of the facility is thus one of the most important tasks in O&M phase. The current situation, however, is that most existing buildings have only 2D drawings and text documents in a hard-copy format and/or in an electronic CAD format. These documents may not keep updated in time in the O&M phase. Thus, missing or incorrect building information would lead to inefficient decision making processes, which could cause significant delays in responding occupants’ daily requests and emergencies. There is an urgent need of effective ways to manage all the information in the O&M phase.

Building Information Model (BIM) has been proved to be an intelligent and parametric digital platform and could support activities throughout the life cycle of a building, including facilitating design, construction, and operations and maintenance of facilities. According to the McGraw hill Construction’s investigation of BIM in more than 10 countries, including North America, Europe, South Korea etc., the percentage of projects implemented with BIM increases sharply from an average of 39% to over 69% from 2013 to 2015 (McGraw Hill Construction 2014). It is proved that BIM has been widely used for new building construction projects, such as design authoring, existing conditions modelling, maintenance scheduling, and disasters planning (Kreider et al. 2010).

However, although the concept of BIM as a “database that stores, links, extracts and exchanges information”, presents a promising BIM use for operations and maintenance of facilities, the lack of effective methods to reconstruct BIM for an existing building has prevented stakeholders’ interest in using BIM data to support the O&M phase. They cannot fully utilize BIM technologies and get the most benefits. Furthermore, current methods and technologies of constructing as-is BIM models mainly depend on human effort. It is considered to be a time-consuming and costly process, and even sometimes reconstructing the as-is BIM model may be treated as a meaningless task and counteract benefits for civil infrastructure projects (Forns-Samso 2011; Lee and Akin 2009).

Nowadays, considering the extra effort and time of the reconstructing process, focuses have been mainly on developing effective and automatic/semi-automatic methods to address these problems. However, it is still a long way to achieve automated and highly efficient creation of as-is building information model for existing buildings. To reach this objective, we reviewed previous efforts in details, and merits and limitations of these existing techniques and methods are summarized (Chapter 2). Then, a novel framework of reconstructing as-is BIM models is established with the most suitable methods on the basis of applying image sources and existing...
documents of the target building (Chapter 3). Furthermore, our research progress and feasibility analysis of this framework is presented and discussed in this paper.

2. Literature Review

2.1 Overview of Fundamental Image Processing Methods and Image-based Building Reconstruction Approaches

Beginning with the Moravec (1981) corner detector, researchers began to keep an eye on image processing and make effort on matching up the geometric primitives (e.g., corners, edges) of the 2D images. Since then, researchers has tried to extract information from images and keep developing more reliable and stable functions as shown in Table 1. Inspired by local image descriptors, Lowe (2004) presented the Scale Invariant Feature Transform (SIFT) in 1999. This SIFT descriptor translated and detected image local features into scale-invariant coordinates for image processing. After that, Mikolajczyk and Schmid (2005) introduced an extended descriptor based on SIFT, which was the gradient location and orientation histogram (GLOH). This robust image descriptor improved the SIFT by changing the location grid and replying on principal component analysis (PCA) to reduce the size of images. This descriptor could outperform both SIFT and PCA-STFT, but it was relatively expensive from a computational perspective. An approach introduced by Bay et al. (2008) could be treated as a detector and descriptor for image matching. They developed Speeded-Up Robust Features (SURF) for object recognition and 3D reconstruction. This novel detector-descriptor scheme was inspired by the leading existing detectors and took advantages of them. It was proved to be an effective tool in feature extraction (Bay et al. 2008). The aforementioned methods review the fundamental methods. As shown in Table 1, researchers have applied these methods in image processing, interest point detection, object recognition, image matching etc. These methods (e.g., SIFT/SURF) are always set as the basic step of an image-based recognition and reconstruction system.

Referring to Table 1, image-based building reconstruction approaches are divided into feature representation-based approaches, wide baseline matching-based approaches, dimensionality reduction-based methods, clustering-based algorithms and others (reconstruction of image-based 3D point cloud model). The first approach mainly focuses on the process of feature extraction. The second approach relies on matching corresponding feature points between the query image and a reference image. The third approach eliminates features and enhances the efficiency by reducing the feature into a much lower dimensional subspace, and the fourth approach tries to group those image structures into different clusters by researching on their different relationships. Typical examples representing each approach are listed in Table 1. In addition, there is another image-based technology commonly used in the computer vision community. It can be used for creating 3D point clouds of the target building from a collection of overlapping images. Hence, it provides the possibility of 3D point cloud reconstruction from a set of images instead of laser scanners. One of the methods that are most commonly used in various industries is the Structure from Motion (SfM) (Wu 2013).
### Table 1: A brief summary of the typical fundamental image processing methods and image-based building reconstruction approaches

<table>
<thead>
<tr>
<th>Classifications</th>
<th>Different algorithms</th>
<th>Equation / literal expression</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fundamental image processing</strong></td>
<td>Corner detection</td>
<td>The earliest algorithm, which measured each pixel in the image, relied on similarity to decide each corner.</td>
</tr>
<tr>
<td></td>
<td>The Moravec corner detection algorithm</td>
<td>This algorithm improved the Moravec corner detector by implementing the differential of the corner and the local auto-correlation function.</td>
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<td></td>
<td>The Harris&amp;Stephens / Plessey / Shi–Tomasi corner detection algorithm</td>
<td>This detector provided an approximate solution, which intended to find the point ((x_0)) closest to all the tangent lines of the corner.</td>
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<tr>
<td></td>
<td>The Förstner corner detector</td>
<td>This algorithm is suitable for an image edge existing large curvature.</td>
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<td></td>
<td>The curve curvature corner detection algorithm</td>
<td></td>
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<tr>
<td></td>
<td>An affine invariant interest point detector</td>
<td>It was based on the multi-scale Harris detector and used the second moment descriptor with non-uniform Gaussian kernels.</td>
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<td></td>
<td></td>
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<tr>
<td><strong>Key-Point extraction/Feature descriptor</strong></td>
<td>The Scale Invariant Feature Transform (SIFT)</td>
<td>The SIFT descriptor will depend on character of the target image aiming at deciding a group of images as references. And then, in the light of the Euclidean distance of feature vectors, the target image would confirm the exact one from these entire candidates.</td>
</tr>
<tr>
<td></td>
<td>The gradient location and orientation histogram (GLOH)</td>
<td>The GLOH is a SIFT-like descriptor, which considers spatial regions for the histograms and uses PCA to reduce higher dimensionality.</td>
</tr>
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<td></td>
<td>Principal Component Analysis (PCA)-SIFT</td>
<td>Steps of the PCA-SIFT descriptor follow: (1) compute the local patch eigenspace for expressing the gradient images; (2) compute its local image gradient; (3) derive the compact feature vector for image matching.</td>
</tr>
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<td></td>
<td>Speeded-Up Robust Features (SURF)</td>
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<tr>
<td></td>
<td></td>
<td>This SURF is achieved by relying on integral images for image convolutions and using the Hessian matrix-based measure and a distribution-based descriptor.</td>
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<tr>
<td><strong>Line extraction</strong></td>
<td>The steps of processing:</td>
<td></td>
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<td></td>
<td>Edge detection; Edge thinning; Edge linking; Line fitting; Unsuccessful line segments cleaning; Corners connection.</td>
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<tr>
<td></td>
<td></td>
<td>* Edge detection (Sobel operator);</td>
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<td></td>
<td></td>
<td>* Edge thinning (Skeleton line extraction, Morphologic operators, Canny methods);</td>
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<tr>
<td></td>
<td></td>
<td>* Line fitting to edges (Polyline composition or decomposition algorithm, Tolerance based algorithm, Hop-Along algorithm);</td>
</tr>
<tr>
<td><strong>Image-based building reconstruction approaches</strong></td>
<td>Feature representation-based algorithms</td>
<td>Examples: 1). The hyper-polyhedron with adaptive threshold (HPAT); 2). The steerable filter-based building recognition (SFBR); 3). The SIFT/SURF based approach;</td>
</tr>
<tr>
<td></td>
<td>Wide baseline matching-based methods</td>
<td>Examples: 1). The fast wide baseline matching algorithm; 2). The augmented reality-based navigation systems;</td>
</tr>
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<td></td>
<td>Dimensionality reduction-based methods</td>
<td>Examples: 1). The linear subspace methods (LSMs) (such as: principal component analysis (PCA) and linear discriminant analysis (LDA)); 2). The manifold learning algorithms (such as: locally linear embedding (LLE), isometric feature mapping (Isomap), Laplacian Eigenmap (LE));</td>
</tr>
<tr>
<td></td>
<td>Clustering-based algorithms</td>
<td>Examples: 1). Hierarchical building recognition (HBR) based on vanishing point detection and localized color histograms; 2). The sketch-based representation method; 3). Clustering-based landmark recognition method;</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>Examples: 1). Reconstruction of image-based point cloud model: the range image-based reconstruction method based on the Structure from Motion (SfM);</td>
</tr>
</tbody>
</table>

Based on their contributions in image analysis, information mining and 3D geometry model reconstruction, many building recognition and reconstruction approaches have been further improved and tried to achieve fully-automated/semi-automated 3D reconstruction geometry models according to image sources. Furthermore, they are often treated as an essential step to create as-is BIM models for existing buildings.

### 2.2 Overview of Semi-automatic or Automatic Methods of Creating As-is BIM Models for Existing Buildings

As shown in Fig. 1, creating an as-is BIM model using different technologies can be divided into four main steps: 1) data capturing step in which various building surveying technologies can be chosen and raw data sets are collected; 2) data pre-processing step in which image processing methods are implemented and information is extracted; 3) object recognition step in which objects are classified into different groups and complemented by semantic information; 4) the as-is BIM models creation step in which each object’s relationships with others are identified and the primary partial information model becomes a semantically rich BIM model. Semi-automatic or fully-automatic Creation of as-is BIM models requires to streamline the process, starting collecting initial inputs (e.g., images) and ending up with constructing an as-is BIM model, while the whole intermediate processes apply semi-automated or automated techniques. In order to optimize this process, a reliable, high efficient, low-cost and automated method for representing BIM models accurately is imperative nowadays. Many researchers have focused on this field (Brilakis et al. 2010; Díaz-Vilarinho et al. 2014; Dimitrov and Golparvar-Fard 2014; Murphy et al. 2013; Nagel et al. 2009). For example, in order to simplify the overall process and to increase the flexibility and operability, a two-step BIM model construction process has been developed by Nagel et al. (2009). The creation process focuses on generating as-is BIM models from 3D geometry models. The intermediate layer uses CityGML building models. Furthermore, IFC (Industry Foundation Classes) building models also need to be created from CityGML. Since there are considerable gaps between the pure 3D geometry model and the as-is BIM model, it is difficult to achieve a fully automated creation process directly using this method. In addition, there are other limitations as well. For instance, the optimal and suitable data interpretation is still the essential concern (Nagel et al. 2009).

![Figure 1: The as-is BIM model creating process for existing buildings in life cycle](image-url)
Figure 2: Framework of reconstructing as-is BIM model
3. Framework Description

We develop an innovative framework that aims to address the limitations of existing methods and to provide a high-efficient and low cost approach to create as-is BIM models for existing buildings, which does not require skilled workers. The framework chooses the image-based approach and implements corresponding computing technologies for existing buildings, as shown in Fig. 2. The framework includes four stages: data capturing and building surveying, data pre-processing, object recognition, and constructing as-is BIM models. The specific tasks to achieve each stage are stated as follows:

**Stage 1:** Data capturing and building surveying step.

This stage mainly focuses on collecting raw building data. The building data should cover all necessary existing documents (e.g., existing CAD documents, paper works and maintenance information) and images taken from the target building. Images captured in this stage should follow two requirements: a) One single image should cover at least one completed object (e.g., a completed column); and b) Images should be taken from different views and try to contain enough information for one target object. Furthermore, a series of survey and interview with O&M personnel who is in charge of data repositories are suggest to perform to collect data on current situations and problems of as-is building conditions.

**Stage 2:** Data pre-processing step.

Based on the summary of image processing methods and image-based reconstruction approaches in Chapter 2, various image processing methods could be chosen in this stage. Pieces of building information (including surface information, geometric representation, extracted information, and features information) are extracted from images. In this framework, Hough transform is applied to detect line elements and confirm building information.

All these extracted information is saved in an information library (Fig. 3). This library provides building information and image data sources of target objects for whole reconstruction process. In the context of this information library, the geometry of a target region, the image intensities of a target region, the properties of a target region etc. are considered as measured information that is provided to aid the recognition of objects.

![Figure 3 Modules for creating the information library](image-url)
Stage 3: Object recognition step.

This stage uses intelligent reasoning algorithms to support object recognition and information matching. In particular, in order to take into account possibilities of information shortage and inaccuracy in the data in the forms of images and documents, fuzzy logic systems that can reason with imprecise information can be considered to adopt. From the preliminary studies on different intelligent algorithms, the hybrid neuro-fuzzy system is one of the most suitable algorithms for this framework. Fuzzy logic methods can make decisions even with incomplete or uncertain information. However, individual fuzzy logic methods cannot automatically acquire the rules used to make those decisions and has its own limitations. While, neural network is quite useful to deal with cases that relationships between inputs and outputs are complex. The hybrid neuro-fuzzy system combines fuzzy algorithms with neural network systems in order to overcome the limitations of each individual technique. Interpretability and accuracy, which are main strengths of the hybrid neuro-fuzzy method, are the key criteria of choosing algorithms (Chen and Pham, 2000; Robert 2001; Sumer and Turker, 2013).

According to building information stored in the information library, object recognition and information matching is implemented adapting the hybrid neuro-fuzzy algorithm (referring to Fig. 4). The recognized object with its related building information and the existing documents of the target building is developed to be the reference for constructing the BIM object. Then, descriptors are created to assist deciding and recognizing properties of the target object. The descriptors have two main functions: a) to bridge between the recognized object and the information library; b) to guide and connect the primarily recognized object to a matching BIM element type to construct a BIM object. Standard data models such as Industry Foundation Classes (IFC) can be embedded in the information library or BIM libraries in BIM authoring tools such as Families in Revit can be linked to the information library as the reference BIM element types in this process.

![Figure 4 Process of object recognition by adapting the hybrid neuro-fuzzy algorithm](image-url)
Stage 4: The as-is BIM model constructing step.

Referring to the images and existing CAD documents in the 3rd step, the exact BIM elements have been constructed. Since the as-is BIM model is not just a simple 3D geometry model, each independent BIM objects require specific classification, location information and relationships with other elements. This step organizes the individual BIM elements identified, and generates a complete an as-is BIM model, which based on LOD requirements and its functions. A further model check and validation is also necessary in the last step based on all the collected information.

4. Research Progress

Our research progress is at the 2nd stage now, which is the information extraction from collected images. Different image processing methods has been analysed in Matlab (shown in Fig. 5 left side). The Harris method and SIFT method are used to detect keypoints, and the Robert and fuzzy logic methods are used to detect edges. Image in the middle of Fig. 5 is collected by our research team using a digital camera (camera type: Nikon D7100) and it is a column of the parking place in one of the campus office buildings. We developed an application to detect necessary information (e.g., color and angle) from the collected images, as shown in the middle part of Fig. 5. It follows the route 2.1 in Fig. 2. Meanwhile, we also developed another application based on the Petzold Media3D library provided by Wu, X.S. (2009) to process CAD drawings in dwg and pdf file formats in order to confirm the location of each component (See the right part of Fig. 5). It is the route 2.2 in Fig. 2.

Figure 5 Research progress of information extraction
5. Discussions

The construction of an as-is BIM model focuses on surveying the geometry and surface of an existing building, improving this collected information into a primary semantically rich model and finally achieving a building information representation referring to the level of details (LoD). However, there exist various uncertainties and difficulties in this construction process, including:

- **From modelling aspect**: How to classify different building components in a high-efficient way? It is not easy to distinguish the target column from surrounding environments because of extra noises such as their decoration.
- **From information aspect**: How to collect the building information in a low cost way? It is usually expensive and requires skilled workers in building survey stage.

The framework presented in this paper aims at developing an automatic image-based approach to address these problems. It is expected that this framework of constructing as-is BIM has following merits:

- Images collected by using common digital cameras can be used as an input data, which is at relative low cost.
- The mechanism used and developed to implement the framework such as the hybrid neuro-fuzzy algorithm is suitable to recognize building elements from images, especially taken from environments that require uncertain or approximate reasoning. For instance, it is expected that the mechanism can extract building information by processing images taken from different angles of the target building, which could reduce the possibilities of producing recognition errors.

6. Conclusions

In order to achieve sustainable development throughout the lifecycle of a building, especially the O&M phases, it is urgent to adopt BIM in facilitate operations and maintenance of an existing building. Consequently, it is important and necessary to construct as-is BIM models for existing buildings. However, current methods and technologies of creating as-is BIM models mainly depend on extensive human effort and time. Although data may be collected automatically from diverse sources and methods (e.g., camera), managing useful data, recognizing building objects and conducting building logical relationships are all performed in manual or semi-automatic ways. In order to systematically automate the process of constructing as-is BIM models from images, CAD drawings and possibly other data sources, this paper gave a brief summary of fundamental image processing method, image-based building reconstruction approaches and existing systems to construct as-is BIM models. Then, we built a framework of an integrated approach to achieve the goal. The framework consists of four steps: data capturing and building surveying, data pre-processing, object recognition and BIM model creation. This framework aims to provide a foundation and guide to develop a system to construct as-is BIM with rich building information, without the requirements of extra high cost and skilled workers. We are at the 2nd stage of implementing the framework. We have developed modules to process column images and tested the modules using images taken from typical office buildings. Our
future works include implementing the 3rd and 4th stages and test the framework with different sets of office buildings in Hong Kong.

References


Abstract

Building Information Modelling (BIM) has for a number of years been seen as a systemic inter-organizational innovation that will have great impact on the efficiency of the construction process as a whole. In this study both successful and unsuccessful attempts to diffuse a BIM-service in the construction sector by a building material manufacturer has been studied through multiple data collection methods. Of special interest has been in what ways knowledge has been integrated, i.e. what mechanisms has been used in the case, since it is a key area for diffusion, and this is described and discussed. Furthermore, the contextual characteristics of the construction sector have been highlighted as influential on diffusion, especially when it comes to areas such as learning, flow of knowledge and feedback loops. Therefore, the context of the different cases and in what ways this affects the knowledge integration process is also described and discussed.

Keywords: Building Information Modelling, Diffusion, Systemic Innovations, Knowledge Integration Mechanisms

1. Introduction

BIM, Building Information Modelling or Management has in many ways been seen as an innovation that will result in drastic changes for the construction process at large (see for instance (Succar, 2009, Elmualim and Gilder, 2013). Eastman et al. (2011) describes BIM as the change of moving from paper-based modes of communication, i.e. using drawings on paper through the construction process to a process based on using electronic information and tools. This change has taken place and been developed through the use of ICT with web-pages, 3D CAD tools etc, avoiding some of the problems connected to the traditional process. The implementation and diffusion of BIM also generates a number of difficulties (see for instance (Succar et al., 2012). This can in many ways, among others, be related to the general problems related to diffusion of inter-organizational innovations, also called systemic innovations. Systemic innovations are holistic and relational to their nature (Colvin et al., 2014), require change of processes in a coordinated fashion by multiple firms (Taylor and Levitt, 2005, Taylor
and Levitt, 2007) and cover multiple relationships (Powell, 1998). Systemic innovations can be a number of innovations that together perform new functions, the relationship in-between the innovations are explicit, but most often there will be effects on other components or systems as well (Slaughter, 1998). Manufacturers and suppliers who are unaware of the changes required to implement their innovations, either in the links to other components, processes, or systems or in the product itself are likely to meet resistance in the spread of their products (Slaughter, 2000).

ICT development focus has for long, maybe too long, been on technical issues, and not on the diffusion perspective (Peansupap and Walker, 2006). BIM is in its nature inter-organizational with its focus on managing information throughout the construction process, and for construction, diffusing inter-organizational innovations poses many challenges. The characteristics of construction can be described by: the physical nature of the products and the structure of sector, the production of single/unique structures, the different types of clients (Briscoe, 1988), the importance of maintenance (Manser, 1994), iterant process, and the derived nature of demand (Bon, 1998). Production in construction is project-based and encompasses a large number of actors from different industrial sectors (Salter and Torbett, 2003).

Attempts at systemic innovation may prove to be problematic. Taylor (2006) has highlighted a number of constructs that influence diffusion of systemic innovations. These relate to the magnitude of the innovation and the level of change it has on affected parties and processes; the amount of “new” involved actors in each project, i.e. the organizational variety; the interdependence between tasks; the boundary strength or rigidity between trades; span, i.e. the number of affected professions and finally the alignment of the innovation with the work allocation in the network. A key issue related to these constructs is that they influence the ability for inter-organizational knowledge to flow. Knowledge creation and exchange is a key issue in the innovation process and its inherent diffusion (OECD, 2005). According to Rundquist et al. (2013) an ineffective flow of knowledge and limited knowledge integration constitutes a barrier for innovation. An additional complicating factor for construction is that in construction projects different types of professionals come together to work for a limited time; architects, engineers, project managers, craftsmen etc. These professionals have different knowledge types that needs to be managed through knowledge integration, i.e. combining new and previous knowledge (Wijnhoven, 1999, Rundquist, 2012). Knowledge integration can be done through different types of mechanisms that depend on different amounts of social interaction (Van De Ven et al., 1976, Grant, 1996). Due to these factors, choosing the most efficient mechanisms is central and following this, the aim of this research is to investigate what mechanisms has been used in one case when diffusing BIM, since it is a key area for diffusion, and this is described and discussed. Furthermore, the context of different cases is described and its effects on knowledge integration are discussed.

2. Knowledge integration, mechanisms and knowledge types

Knowledge is at the centre of the research presented in this paper. Knowledge is viewed as information, technology, skills and know-how in line with Grant (1996), with a view on
objective information as codified knowledge (Grant, 1996, Nonaka and Takeuchi, 1995). Codified knowledge is of special importance since it facilitates the transfer of knowledge (Prencipe and Tell, 2001). Finding ways to use codified knowledge for knowledge management is of interest for construction (Styhre and Gluch, 2010), although construction research has shown that construction is hesitant to codify and formalise knowledge (Styhre, 2008, Bresnen et al., 2005, Scarbrough et al., 2004). Senaratne and Sexton (2008) mean that codification could increase, but an important factor is that it should be done in balance with soft personalization strategies.

In research on knowledge management in general many different sub-concepts are used, and construction is no exception. Examples in construction are knowledge management (Robinson et al., 2004), sharing of knowledge (Styhre and Gluch, 2010, Styhre, 2008), and knowledge sharing and creation (Bresnen et al., 2005). In a comprehensive review on the concept of knowledge integration and concepts with similarities, Rundquist (2009) treats the concepts knowledge transfer, knowledge sharing and knowledge application. A main point in the review is that knowledge integration is a broader concept that covers the other concepts. This view is shared in this research. In Rundquist (2012), knowledge integration is defined as a process of combining new and previous knowledge. A similar definition is made by Wijnhoven (1999) saying that knowledge integration refers to the process of acquiring, sharing, and making use of knowledge by incorporating new knowledge into an existing knowledge base. Although both authors mean the same thing, Wijnhoven (1999) is a bit more explicit and forms a basis for this paper.

An objective for mechanisms is to integrate knowledge as efficiently as possible and mechanisms can be classified on a scale ranging from low interaction to high interaction. According to Johnson (1992) technological change requires more social interaction like dialogue and conversation and the more advanced innovations, scientifically and technically, the more complicated communication processes are required. Another implicating factor according to Van De Ven et al. (1976) is insecurity, i.e., difficulty and variability in the conducted work also affects what mechanism to use. This means that it is not just the level per se that sets affects what mechanism to use, but also how the work is perceived is influential. More insecurity requires more personal mechanisms. Another useful way of classifying mechanisms used in construction research relates to explicit and tacit knowledge, and a division of mechanisms into tools and techniques. Tools rely on the use of IT to share explicit knowledge. Techniques use a more human-centered approach to transferring mainly tacit knowledge (Carrillo et al., 2006, Carrillo, 2004).

Our main focus here is to have the level of interaction as a point of departure. We use four types of mechanisms defined by Grant (1996) as a point of departure that range from a scale of low to high interaction for integration of specialized knowledge: Rules and directives are un-personal methods such as plans, schedules, forecasts, rules, policies and communication systems; Sequencing treats organizing production activities in sequence to enable every specialist to do what he or she should; Routines are performed automatically and can be conducted simultaneously when the person conducting them are well acquainted with them and sees them...
as natural activities that we do without giving them much thought. The first three can be seen as a way of avoiding costs for learning and communication, and the last mechanism *Group problem solving and decision making* is as the title shows a mechanism with communication and interaction. The need for this mechanism increases with the growing complexity and insecurity in the activities that should be conducted as stated by Grant (1996).

### 3. Method

The study presented in this research focuses on a reinforcement company, the construction process of which the company is a part and their development and diffusion of BIM and BIM-related solutions and services. The study consists of data collection in two steps. The first step of data collection was initially used to map the situation of the case company through a broad approach focusing on the development of the company and its context. The initial mapping focused on content (what has changed), process (how has it changed), why has it changed (context) which is an important interplay for understanding changes (see Pettigrew and Whipp, 1991, Carlsson, 2000). The collection of data in step one lasted for about 6 months and comprised analysis of company documents, websites and 24 semi-structured interviews with company (internal) and external respondents. The semi-structured interviews provides a structure for meaningful interviews and discussions but also flexibility (Andersen, 1994, Merriam, 1994). The questions addressed the business situation of the company, including its development, objectives and challenges. The character and context of the construction industry, its development and IT related issues were also included. Development aspects are considered interesting from a diffusion point of view since they provide a picture of what ideas, solutions, products and services that are spread (diffused) and not. The interviews lasted from 30 minutes to two hours and were recorded. After the interview the whole interview was listened through and transcribed, although not transcribed in detail. Time-positions was written into the transcripts if sections of the recording were needed to listen to again. The material was summarized in a company report and the extraction has been done from this material and the transcripts, with a focus on the purpose of this paper and *on BIM as the change of moving from paper-based modes of communication, i e using drawings on paper through the construction process to a process based on using electronic information and tools.* The broad collection of data provided useful understanding for the findings.

Based on the extraction of data a new round of semi-structured interviews was conducted with four company internal actors; the technical manager, a sales representative working towards manufacturers of prefabricated elements, one team leader for the BIM/reinforcement engineers and one BIM/reinforcement engineer. These actors are working with diffusion related activities and the new round enabled an update of the situation from the first round and questions regarding the purpose for this paper were raised. The highlighted definition above was communicated in the interviews and the additional questions this time regarded what type of BIM and BIM-related solutions and services that has been diffused, to whom, why and under what circumstances. The compilation of data from the first round served as a support material and also enabled specific questions about the development of specific services. Company information about BIM and BIM-related solutions and services was also overviewed. The time
between the two steps of empirical collection was afterwards considered useful to provide a view on development is progressing. The material was overviewed, summarized and analyzed a number of times to find themes and categories that relate to the aim of the study. This was made from the collected data and the section Results from and analysis of the study show the final compilation of the collected data.

4. Results from and analysis of the study

The case study company is an international supplier of reinforcement and the Swedish affiliation was studied. The Swedish company has undergone development in line with the steel industry at large, with closures, mergers driven by a focus on economies of scale. This has led to increased competitive pressure not least from low cost countries. Due to the development and the extremely low development potential in the material, reinforcement, the company has put a lot of efforts on developing complementary services to strengthen the company’s competitive position. Among these are electronic solutions or solutions that build on such. The company has worked extensively with 3D-models with included information and 3D-visualisation, and on managing transfer of information back and forth from different systems. By using company solutions, information can be transferred between different systems and much can be automatized, for instance electronically generated specifications lists, visual planning is enabled, print-outs from different views and documentation. The company has introduced a new software in which reinforcement is specified, and it has many add-ons enabling electronic transfer between systems especially with the CAD-software. The company had a predecessor to the software, with many users, and by stopping development of that software, they have forced users in to the new version. Other services that are offered are assembly instructions and a service called color sorting and labelling. In short, this means that reinforcement comes sorted and labelled for simplified assembly. A result from the company’s development is that the company has created their own niche as a technically competent player with BIM and BIM-related solutions and services affecting customer’s processes and approaches.

4.1 Contextual factors

In the study it is evident that contextual factors affect the diffusion of BIM and knowledge integration regarding BIM, which are presented in the following text.

Project stress, short term view and a divided chain: Especially in the first round of interviews these factors were highlighted as affecting development and diffusion in general and thereby also BIM. An effect was that actors use the same solutions as they always, for instance to reduce insecurity and risks. By moving from one project to another without a proper evaluation and use of experiences this is not facilitating diffusion of new solutions such as BIM. It was also stated that different parts of the chain work with their part, not interacting to the extent needed. Subcontractors, like the case company often also come in to late in the RFP-process eliminating room for improvement and possibilities to come up with ideas and solutions.
Organizational width and rules: For starters a key issue is that individuals and organizations need to see benefits with the solutions and has an overall process focus. In the study, actors in the end of the construction chain were not considered pushing development further to a large extent. One approach enabling diffusion was that some of the large construction companies have decided that some projects should be defined as BIM-projects. This is of course of help for diffusion. A highlighted barrier from the external interviews was also that development needs investment that in turn needs to be paid, which many small companies cannot afford, so much development must be driven by larger companies. Since BIM spans many actors, organizations and process steps, the interviewed actors in step 2 all mean that organizations covering many steps of the chain and has a broad business are highlighted as most interesting and also pushes development forward in a way that others don’t. It might be that by working with BIM, activities in the chain are moved and changed. There might be additional work for one part of the chain but with a benefit for the overall efficiency. A possible explanation highlighted is that they can see overall effects of different solutions. However, it was also highlighted that rules within the companies, which can be rigid in larger companies, could be a barrier for implementation, for instance when installing software, support is needed from an IT-department and there could be rules regarding what software that is allowed to install. One mentioned example was also that turnkey contractors have other possibilities to develop solutions from their overall perspective and can be of great importance to move development forward. Another slight point was also that commitment and push from top management was evident in the more forward moving companies.

Personal characteristics and maturity: One of the key factors highlighted in the study is the impact of “IT-ability” among people as having impact on the diffusion of BIM. Many interviewees also thought that construction was lagging behind other sectors when it comes to IT-usage, especially interviewees with experience from other sectors. One of the external companies also had a clear strategy of NOT being first in the development of ICT-solutions, but instead implement solutions when it is clearly shown that they work. Overall, an opinion was that IT-usage should improve as the amount of young people increase, since they are more used to using ICT in their everyday life. Cloud-services, integrated services etc are common in much social media that is used today. The main factor that was enabling diffusion was however individual characteristics. People who are interested and use ICT-solutions enable diffusion.

Implementation in real projects and ease to implement: One of the key factors for diffusion highlighted in the study is to present and implement solutions in real projects. When showing the solutions in real projects, the company has been able to immediately use the solutions and show their immediate effects. An additional key factor has of course also been that the solutions are easily learnt and installed and not requiring too much additional efforts. The coloring services for instance, although not having to do with BIM, was considered easy to implement since they required no additional efforts by customers. 3D-visualisation as a discussion tool was for instance greatly helped by an adobe-application in which 3D-objects could be opened and rotated. It was also highlighted in both rounds that knowledge about IT-implementation has improvement potential especially in the area of supporting IT-implementation on construction sites, for instance to accomplish knowledge integration between developers and operative
personnel in understanding user needs and prerequisites and to educate on site. An additional point is also that when the company got external users in their solutions, this created an interest for the company’s other solutions.

Product type, usage and usefulness: Since a main part in BIM is 3D-models, this was specifically discussed and also led to highlighting other factors. It was concluded that 3D-models/visualization was useful to create an understanding for what a product or a specific object looked like, how it could be handled, and what problems that could arise and enabled lowered differences in interpreting the product. However, it was also stated as important not to overuse visualization since they were most useful for complicated objects. In the first round it was also evident that interviewees thought that it was most important to focus on increasing effectivity in relation to everyday operations, instead of having focus on the more visionary aspects. As the technical manager pointed out, everything is expected to go fast and simple.

4.2 Used mechanisms and their effects

The contextual factors presented above are important for the used mechanisms to become successful. Diffusion has been done through various types of mechanisms from high to low interaction with varying results, such as information letters, brochures, sales presentations, information meetings etc. The diffusion of the services has internally been considered moving slow, but the interest for the solutions has increased heavily. The company has presented solutions at various occasions. At first they were seeking interest from customers to implement the solutions and a first modest strategy was to get the solutions “out”. The company used a push-strategy to diffuse solutions in real projects with consideration to the contextual factors presented (these factors are also results from failed implementation and diffusion). Implementing the solutions in real projects has been done in several ways. Often instructions were sent out to users and a YouTube video has been used as a mechanism. Often when the company has made follow-up calls they have referred to this video and new users have been able to start up solutions by themselves. Company representatives have also been present at start-up meetings having time to help new users set up their solutions and they have also provided support for users not just by answering questions, but also by being pro-active and making follow-up to get users going. An indication from this is that more interaction intensive mechanisms are needed at the start but then users work easily by themselves.

One of the regional managers also stated the importance of being present and show oneself physically at the customers. This is important to create trust and it is also a method that sells products and services. This emphasizes construction as sector with face to face contact. An example of the usefulness of being present and work in projects is that the company has visited projects with 3D-visualizations of real project objects. By using this push strategy, people in projects have been “forced” to work with the solution and many have also stated that they really could see the benefits. Anyhow, according to the interviewees, customers seldom ask for 3D-models and the demand was actually stated as larger in-house for complicated, welded products, since the 3D-models visualized what the product should look like (which of course is a benefit to the customer since the product is correct). An important part as stated by the technical
manager is also that when the company launches new solutions, it is important for them to educate and create a demand for the services. This in itself highlights the need for more interaction intensive mechanisms for starters and when the need is established, other mechanisms can be used.

4.3 Summary of findings

To summarize the findings, the study shows that there are a number of contextual factors that influence diffusion and the knowledge integration that is needed for diffusion of BIM and BIM-related services and solutions. Thereby, the contextual factors also influence the choice of knowledge integration mechanisms. More interaction mechanisms are most likely needed in the start of a diffusion process and a key determinant for the choice of mechanism(s) is the knowledge base of the target groups.

5. Discussion

Speaking in metaphors, BIM can in many ways be the same as changing language. This metaphor is useful to create an understanding of the sometimes large magnitude of change that the entrance of electronic solutions constitutes in relation the former use of printed drawings and other paper-based methods in construction. Once again it is evident that contextual factors of construction complicate diffusion. Project stress, short term view and a divided chain has been mentioned many times in previous research and it also becomes evident that these characteristics form a basis for the rest of the contextual factors. A point regarding the divided chain is that by not interacting, knowledge integration is efficient from the perspective of “getting the job done”, but from a knowledge development perspective, potential new knowledge useful for the overall effectiveness of the chain is not being integrated.

For a systemic innovation like BIM, inter-organizational to its nature, diffusion in construction seems to require customers with control over several parts of the construction process. Both in the study and in previous research it has been shown that controlling the chain is of importance, either as having the overarching responsibility/control as emphasized here and in for instance Hjort et al. (2014) or by ownership of resources as highlighted in Taylor (2006). In the same manor, this can also be a barrier for diffusion, with actors having the prerequisites not using their power to implement and diffuse new ideas. What’s interesting in the case however, is that a supplier has the possibility to push the development forward and affect customers also, by taking contextual characteristics into account. As noted in the case and by Taylor (2006), it can also be concluded that the amount of adaptation in the process affects diffusion.

Another interesting point in the study is that construction seems to have a lot of potential in developing their change management and implementation skills. A key topic seems to be to make different actors of the construction chain meet and thereby start a knowledge integration process. In a way, knowledge integration is efficiently managed by different parts working autonomously together as emphasized by Grant (1996), but for knowledge development to take place it is necessary to incorporate new knowledge into an existing knowledge base as in the
definition used in this paper (see Wijnhoven (1999)). As the in the study, the reinforcement company seems to take their point of departure in the existing knowledge base and also seems to have accepted the current situation in construction. Based on the point that young people have another knowledge base regarding IT, a potential impact is that it will probably be easier to diffuse BIM in the coming years as there is a shift in active generations. The overall maturity regarding IT should therefore increase, but this is of course also dependent on solutions becoming easier to install and implement. Older generations have most likely created a habit on how to do things based on their experience and for many this is based in an era where IT was not as visible as today. Besides taking the knowledge base into account, the study also points out the need to solve day-to-day issues besides working with visionary aspects to start the change process. By solving “easy” problems, i.e. bringing forth solutions that solve problems with little or less effort from customers AND showing the potential in real projects, an interest for other solutions from the company becomes interesting.

When it comes to mechanisms the study does not contradict the preferred use of soft-personal modes in construction and the combination of mechanisms as pointed out by Senaratne and Sexton (2008). If the existing knowledge base does not deviate to a significant amount in relation to the “new”, personal contact can be said to be preferred in the start-up phase, but then codified knowledge can be used, i.e. more interaction intensive mechanisms starts the diffusion process and then codified knowledge can be used. Traditional codified knowledge, i.e. information in written form, seems also in this study less useful in construction. On the bright side, it is indicated that a useful mechanism to diffuse codified knowledge are instruction films (You Tube). This points out the potential of spreading codified knowledge using other mediums and in line with Senaratne and Sexton (2008) it advocates codification in balance with soft personalization strategies, i.e. highlights combination of mechanisms as useful. However, it’s not just about choosing the right mechanism to diffuse a solution, it’s also about having future adopters in focus, support these in the best way and make set-ups and systems simple.

It can be noted by the results that more interaction is needed along the chain with a more overarching focus which points in the same direction as pointed out by Taylor (2006) when comparing BIM implementation in Finland and USA. One of the key differences was differences in viewing the chain, where the US had a short term view and divided approach in the construction chain and Finland had a more long term view and a more cooperative process. A conclusion was that BIM-implementation was more favorable in Finland due to a more integrative view on the construction process.

6. Conclusions

Based on previous research and this study it is evident that Project stress, short term view and a divided chain affects knowledge integration necessary to diffuse BIM and BIM-related solutions. Due to this and the decentralized work-model, it is of significance to create a demand from the projects to use BIM and BIM-related solutions. A push-strategy has been found useful as a phase one strategy in order to create a need for BIM-solutions and thereby creating a pull from the “market” i.e. the projects. The influence from the organizational width and its set up of
rules is also visible, where an organization with a wider set-up of businesses along the construction chain is more likely to successfully implement BIM due to the ability to control the construction process. At the same time, the study shows that a small niche player also can affect the diffusion of BIM and its customers if contextual characteristics are taken into consideration in the implementation process.

With BIM and the transformation into an electronically managed information chain, different parts connect and become more dependent on each other. In addition, a key issue in the study is that adaptation to the existing knowledge base is of central importance for the diffusion of BIM. It is indicated that a major problem for the diffusion of BIM is the level of general knowledge about IT in construction. A higher knowledge level regarding IT seems to facilitate diffusion and as younger generations come into the sector the diffusion of BIM will most likely become smoother and faster. This is further enabled by the development of solutions that are easy to implement and understand. The study validates soft-personal modes as most useful and frequent in construction and validates the combination of different mechanisms as useful for efficient diffusion. The study furthermore indicates that new media can improve the diffusion of codified knowledge. Finally, an important aspect highlighted for the mechanisms is the necessity to introduce solutions in real projects, to show immediate advantages and discuss actual problems.

A final indication from the study is the need to develop change management and implementation knowledge to implement and diffuse solutions. Of interest for further studies is therefore to study approaches of implementation and change management in construction and evaluate what approaches that are specifically useful in construction research. Since the study also highlights that general knowledge regarding IT is of help for the diffusion of BIM, it can be of interest to study how knowledge in general or from other sectors can be used and implemented in the construction context and also what barriers that exist. In addition, the study has treated the aim in general and to validate the results further it could be interesting to go in more in detail in specific cases to get a picture of the diffusion from both inside the company and outside the company.

References


Level 3 BIM for Standardised Design Delivery, Refinement and Optimisation: Is it a real option in the UK?

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Abstract

Building Information Modelling has been hailed as a panacea which will overcome the endemic fragmentation and collaboration issues in the UK Construction Industry. The Government's target to make BIM mandatory for all public projects from April 2016, and its roadmap to Level 3 BIM are extensively discussed in the literature. It is now clear that a number of large main contracting companies such as the Kier Group, Laing O’Rourke have been positioning themselves as the market leaders in the delivery of projects using BIM. Despite such developments, the Government’s push and the general desire within the industry to make collaboration happen through BIM, industrial experience points to a number of important issues which can only be resolved by changing the way building projects are developed and delivered; and the way facilities are managed. Such changes would help close the performance gap by establishing feedback loops between operations, construction and design stages.

This paper reports on the findings of an Innovate UK-funded research project which aims to bring about these fundamental changes in the delivery, refinement and optimisation of standardised school designs. It sets the background by describing the context of this joint-venture between a major UK contractor and a local authority owned specialist offering national procurement frameworks. The multi-method approach to collecting, analysing and making sense of the case study data is explained. The key issues in achieving and using Level 3 BIM, e.g. competing processes and systems within the main contracting company, different levels and extents of use amongst the design and delivery teams, are then identified through one aspect of this case study. This discussion paves the way to establishing when, where, why and how Level 3 BIM should be utilised. The paper thus makes a novel contribution to the existing literature on BIM as it illustrates that BIM is not necessarily one size that fits all in terms of collaboration.

Keywords: BIM, collaboration, UK, standardised designs
1. Introduction

There have been a plethora of initiatives and discussions on the implementation of BIM in the construction industries across the World. It is commonly argued that the implementation of BIM will help these industries overcome their endemic reluctance to collaborate and thus achieve cost and time savings, and improved quality. Industry professionals, especially those who have had the experiential knowledge of using both CAD and contemporary BIM tools, will support claims that the capabilities and advantages inherent in the latter surpass the former. An extensive literature directed towards demonstrating the benefits of BIM either through implementation studies (Becerik-Gerber and Rice, 2010; Migilinkas et al., 2013; Li et al., 2014; Poirier et al., 2015) or some form of conceptual extension of the scope of different applications (Schlueter and Thesseling, 2009; Azhar et al., 2011; Wong and Kuan, 2014; Oti and Tizani, 2015) support these views. This literature, however, tends to rely on the perceptions of professionals of the benefits of BIM or of academics who theorise on how these benefits can be quantified in projects. Moreover, the uptake and diffusion of BIM appears to be slow across the industry. Certain studies (Azhar, 2011) have attempted to capture the reasons for such slow rate of diffusion. Despite this, there are indications that an evaluation of the current levels of BIM adoption is necessary to judge whether the desired Level 3 maturity is realistic in the UK. This paper aims to make a contribution to providing this evaluation through a ‘real-life’ BIM implementation case study.

It is divided into six sections. The second section outlines the case study context. The third section describes the methodological approach. An extensive literature review is then provided as evidence that there is a gap in the literature in terms of ‘real-life’ cases evaluating the implementation of BIM. A description of the design review meeting and the following user feedback session, which is the core of this paper, follows. The findings and observations are also discussed. Conclusions are drawn at the end of the paper.

2. The case study context

The case study that is presented in this paper is undertaken as part of an Innovate UK-funded research project, which is led by a British Main Contractor. The case study context is the delivery of standardised school designs as turnkey projects using a national framework agreement, which is set up by a public sector owned built environment specialist. Standardisation is particularly important for this project delivery approach as there is a clear advantage of using knowledge from one phase of the project life cycle to improve other phases. For instance, feedback from the operations phase can help to achieve continuous improvement of the standardised designs for potential future clients.

The Main Contractor aims to develop and adopt strategies to utilise the power of BIM in delivering, refining and optimising the standardised design as a ‘product’. This research project focusses on the integration of project data from construction and operation stages in a BIM environment and the capacity of BIM to facilitate collaboration between the main contractor, their consultants and supply partners. These ideas are tested as part of the continuous
improvement of the ‘product’. Thus, the opportunity for evaluating a ‘real-life’ BIM implementation approach to delivering projects is exploited. This paper reports on one aspect of this approach, namely the use of BIM in a collaborative design review meeting.

One of the first key deliverables of this research project was to develop a 3D federated model using the architectural, structural and M&E design models, locating the BIM implementation at the border between Level 1 and Level 2 BIM (Figure 2). The aim of the research project was to move this initiative to Level 3 by establishing and utilising feedback loops from the construction and operations phases of the building life-cycle. One aspect of this plan was to use Autodesk BIM 360 Field and Glue during the construction phase in order to integrate the project reporting and snagging information into the integrated model. This plan could not be implemented for three main reasons. First, 360 Glue/Field applications did not support the Main Contractor’s sophisticated H&S reporting processes in an automated manner. Secondly, there were issues around the amount of training that the site team would require and whether it could be accommodated within a very tight and relatively short construction phase. Third, the Main Contractor started to use Priority 1 to report snagging while these discussions were taking place. Priority 1 was considered to be a more suitable platform than integrating the H&S reporting process into 360 Field/Glue. Fourth, the standardised design and its delivery processes were set up such that the lessons-learnt from the construction stage and the associated requests for design change would be incorporated into the Design Review meetings. Hence, it was decided that the regular Design Review Meetings between the Main Contractor, their design consultants and Supply Chain Partners would be a more appropriate venue to evaluate whether the integrated BIM could enhance collaboration between partners.

3. The methodological approach

The rationale behind using a Design Review meeting as a ‘test-bed’ for the use of BIM for collaboration purposes was explained in the previous section. This section describes only the methodological approach utilised in order to collect data during a design review meeting, and to subsequently analyse it. The overall methodological approach adapted in the whole project is out of the scope of this paper.

A predominantly qualitative approach was the obvious choice for understanding how the use of BIM influenced collaboration within the design team, which included supply-chain partners, and the closure of the feedback loop from operations and construction stages to the design stage. The lack of existing research in this area and the opportunity to study the complex phenomena of collaboration and learning from experience in its natural setting were the fundamental reasons behind this choice. The design review meeting was set up to provide an occasion for real-time observations, and to gather feedback from the participants at the end of the meeting.

The key supply chain partners were challenged to come up with ideas on reducing the time it takes to weather-tighten the envelope. The architectural design consultants, roof contractors, aluminium systems and insulation suppliers, and representatives from the main contracting company, were represented at the meeting. Researchers attended the meeting as impartial
observers to collect data on the means and tools of collaboration that participants used. They also ran a real-time survey and a short focus group.

The participants were asked to complete a short questionnaire at the beginning of the meeting. This questionnaire was designed to collect demographic data and to establish each individual’s BIM readiness. This data was used in making sense of individual’s responses to the survey and the focus group discussions. The survey and the focus group aimed at gathering feedback from the participants on whether and how they thought the use of BIM influenced real-time collaboration. TurningPoint was used to collect survey data anonymously, and to display the results in real-time. As a result, it was possible to identify the key issues, i.e. those on which there was consensus or divergence of opinion, and thus to concentrate the focus group discussion on these issues. The focus group discussion was recorded. Key findings emerged from the content analysis of the focus group discussion.

<table>
<thead>
<tr>
<th>SEARCH CRITERIA</th>
<th>CONSTRUCTION DATABASES</th>
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<tbody>
<tr>
<td>&quot;Building information modelling&quot; AND/OR BIM benefits</td>
<td>Academic Search Complete (EBSCOhost)</td>
</tr>
<tr>
<td>AND &quot;Case study&quot;</td>
<td>121 discarded</td>
</tr>
<tr>
<td>Filter: Construction, Project, Design, Energy, building design, Construction Industry, Establish relevance: From title and abstract</td>
<td>42 articles selected</td>
</tr>
<tr>
<td></td>
<td>35 discarded</td>
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<td>7 showing relevance</td>
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**Figure 1: Literature search description**

This case study was complemented with an extensive literature review. The aim was to establish the extent of existing knowledge on ‘real-life’ BIM implementation case studies with respect to Level 3 maturity. Three scholarly, cross and multidisciplinary databases, i.e. Academic Search Complete, Emerald Insight and Science Direct were chosen as they provide access to foremost literature in the construction sector. Database searches were undertaken using these keywords: building information modelling, BIM, case study and benefits. The results were further refined by filtering them using construction, project, design, energy, and building design as additional
keywords in Emerald Insight and Science Direct. The EBSCOhost interface did not allow for the search results to be refined in the same way. The results are displayed in Figure 1. This filtering yielded 41 – 61 search returns in respective databases. The authors then scanned through the titles and abstracts to establish actual relevance. The systematic review therefore focused on the nine papers summarised in Table 2, and critically reviewed in the next section.

4. Literature review

It is important to start with an overview of the current state of BIM adoption in the industry. There is evidence in the literature that the uptake of BIM has been increasing across the globe. In the UK, the National BIM Survey Report focusing on SMEs indicated that the number using BIM rose from 13% in 2010 to 54% in 2013 (NBS, 2014). Similarly, Kiviniemi et al (2008) suggests that the ratio of BIM tools to Computer-Aided Design (CAD) use among companies in Denmark, Norway, Sweden and Finland is likely to increase from about 1:3 in favour of BIM. On a global scale, there have been positive indicators from the annual studies consistently conducted since 2007 by McGraw Hill Construction to gauge impacts and uptake of BIM in leading construction markets such as Canada, France, Germany, UK, US, Brazil, Japan, Korea, Australia and New Zealand (McGraw-Hill Construction, 2014). In most of these 10 countries there have been active efforts by both the private and public sectors to encourage the uptake of BIM. For example the UK government mandated government projects to be executed using Level 2 BIM maturity (Figure 2) from April 2016 (BIM-IWG, 2011). This has resulted in chains of events ultimately geared towards catching up with the BIM implementation boom. A number of higher education institutions have introduced BIM applications into their curriculum. There are a significant number of BIM- related research projects funded by the UK Government. Also, public institutions such as the BRE run short training courses (BRE, 2015). Workshops are also being held to promote the adoption of BIM by firms in the AEC industry. Despite all these efforts, it appears the industry is still struggling to get a full grasp of Level 2 BIM maturity.

Professionals are expected to be working in their separate software environments and models with the opportunity for federation at Level 2 Maturity (Figure 2). It is argued that such federation should aid with reducing the number of clashes between the designs provided by different disciplines. When this maturity level has been fully attained, it is expected that the industry will naturally attain the Level 3 BIM maturity.

Despite these aspirations, at the moment, it is difficult to establish from the literature whether and how well Level 2 BIM maturity has been achieved by the industry. The relevant literature (Table 1) that discussed BIM implementation tend to demonstrate the benefits of BIM through surveys of practitioners’ perceptions built around notions already established via BIM promotion campaigns (Gilkinson et al., 2015; Poirier et al., 2015). Others theorize how the benefits of BIM can be quantified on projects (Barlish and Sullivan, 2012; Lu et al., 2012; Pilehchian et al., 2015). However, robust empirical evidence detailing actual experiences of BIM adoption during the various phases of the project lifecycle is lacking in the literature.
The lack of evidence becomes even starker when the literature search results of 1102 articles are filtered and the results discarded for their relevance, i.e. reporting on ‘real-life’ benefits of BIM implementation. Only 9 of the original 1102 report on BIM benefits are based on practical experience of implementing BIM in any stage of the project life-cycle (Table 1).

Gilkinson et al (2015) discussed the benefit realisation based on six case studies that relied on popular BIM tools such as Revit, ArchiCAD and Allplan 3D. The aspects of BIM application in these projects include the architectural design of Knowsley Schools, Royal Opera House mechanical, electrical and plumbing design services, the structural steelwork of North Lakes Police Station and the Heathrow Airport Energy Centre, the services engineering of 1 Bligh Street, Sydney – a 28 storey building, structural design of four high-rise blocks of Wood Lane studios of an academic institution and the planning/scheduling of the extension of Queensland State Archives. The authors suggest that the tide may be turning in favour of BIM following the changes in the UK government policy as contractors and their sub-contractors will have to be BIM-ready to be able to secure centrally-funded contracts from April 2016. They also advocate the move from a building information model to a building knowledge model in order to exploit all the benefits of a digital model. Migilinskas et al., (2013) featured four cases executed in Lithuania using various BIM-enabled tools (STAAD.Pro, Bentley Structural, Bentley Triforma, Allplan, Tekla Structures and CADVENT). The aspects of BIM application included planning and design, construction scheduling and facility management in these projects. Azhar (2011) provides an earlier, similar study covering planning and design, construction scheduling/documentation and sustainability analysis of three case studies in Georgia, USA, and identifies associated trends and benefits in the AEC industry.

In a rather more detailed study of ICT innovation on a large hospital project in the UK, Davies and Harty (2013) discussed the implementation of ‘Site BIM’ system for site workers to use mobile tablet computers to access design information, capture work quality and progress data on
site. The tablet computers access coordinated 3D models developed in BIM-enabled tools hosted on site office servers equipped with document management system connected to a site database where progress reports, compliance targets, defects information and 3D viewer are logged and hosted. The authors argued that the use of Site BIM can be justified due to the large scale nature/complexity of the hospital project and the construction management procurement approach which required speed. Adjudged to be successful, the project was rolled out by a small team of construction project staff and enrolled IT personnel. Although details of BIM tools utilized were not clearly mentioned in the study, the accomplished tasks respectively appear similar to the functions of common data environment and field applications such as Buzzaw/BIMSight and Autodesk BIM 360 Field that were used in our case study.

Table 1: Literature on BIM implementation benefits

<table>
<thead>
<tr>
<th>Research source</th>
<th>Origin of study</th>
<th>Area/ life cycle phase</th>
<th>Main features</th>
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</table>
| (Gilkinson et al., 2015) | UK | Design, Construction | • Reports on a number of case study research projects  
• Identities benefits, challenges and opportunities |
| (Poirier et al., 2015) | Canada | Renovation construction works | • Based on action research  
• Measurement of labour productivity |
| (Lu et al., 2012) | China | Construction | • Based on the use of learning curves  
• Proposed measuring benefits of BIM as a learning tool on site |
| (Pilehchian et al., 2015) | Canada | Design | • Use of graphs and dependency matrix  
• Monitoring of design changes and their dependencies |
| (Barlish and Sullivan, 2012) | USA | Design, Construction and Post-completion | • Combined literature and case studies  
• Developing a holistic methodology to quantify BIM benefits |
| (Eadie et al., 2013) | UK | All stages of construction project | • Use of web-based questionnaire survey to gather information  
• Designed to gauge perception and experiences of participants in BIM implementation  
• BIM is more extensively used during the early stages of the project-life cycle |
| (Bynum et al., 2013) | USA | All stages of construction | • A survey-based analysis of BIM implementation  
• Application of inferential statistics on findings to establish relationship between BIM and project delivery |
| (Lindblad and Vass, 2015) | Sweden | Organisational management | • A literature and a case-based study to identify associated organisational change effected in steering documents and work process due to BIM implementation |
| (Davies and Harty, 2013) | UK | Construction | • Case study of ‘Site BIM’ system implementation  
• The use of mobile tablets to access design information, capture quality and progress of work on site |
This literature review illustrates that various scales and approaches of BIM case studies exist. However, studies which evaluate the use of BIM as a collaborative tool which facilitate the closure of the feedback loops from operations and construction stages to the design stage are missing. Moreover, more focused and detailed recounting of actual experiences is required to encourage cascading of candid practical accounts through the industry. In this light, this study presents lessons from the actual experiences of BIM application in a standardized turnkey project delivery. In this project, BIM is utilized as a learning platform to close up the operation/construction-design feedback loop.

5. The Design Review Meeting as a Collaborative Learning Platform

As stated above, the Design Review Meeting focused on reducing the time it takes to weather-tight the building. The participants are involved in the design and delivery of the product both at the strategic, developmental and operational levels. Each attendee has at least ten years’ experience in the industry. The delegates from the architectural consultants and the Contractor’s BIM Manager were the only delegates who have high levels of experience in using BIM environments. The majority of the participants (6 out of 9) had low levels of BIM-readiness.

The Product Director of the Main Contracting (MC) company chaired the meeting following an agenda that would enable collaborative envisioning of possible solutions. The BIM Manager of the MC walked the attendees through the 4D model and showed the construction simulation based on the 4D programme of one of the schools. Attendees also viewed a time-lapse video of the construction phase of the same project. An informal discussion which broadly followed the pre-determined agenda ensued. The attendees were willing to share their ideas and make suggestions for reducing the time to weather-tightness. In this context, high levels of collaboration were observed among the participants who were all driven by a desire to continuously refine the standardised design and bring about efficiencies in its delivery.

Despite all the intention of facilitating collaboration through the use of BIM, the use of the construction simulation and the federated model during the meeting was very limited. Throughout the meeting there was a preference towards using 2D information that had been drawn out of the 3D model. In one case, a 2D print out was quicker to make available than its digital version as a pdf file. The time-lapse video was preferred to the construction simulation when visualisation was required. It could have been argued that the time-lapse video is more effective in facilitating real-time collaboration than the construction simulation in this particular context. However, relying on time-lapse videos mean that the variations to the schemes are not considered as part of the Design Review Meetings. Although this business model centres around a standardised design, about 70% of the schemes are adapted for various reasons.

Perhaps the low levels of BIM exposure among the event delegates is the reason behind the little use of the construction simulation and the preference towards the time-lapse video. It also points toward the need for training but more importantly a focus on changing the way people conduct their day-to-day business, if the capacity of BIM to facilitate real-time collaboration is to be
exploited. This change can only happen if every company involved in refining and delivering these standardised designs are convinced that only BIM can deliver the business performance that will render each company a leader in their field. As identified by Lindblad and Vass (2015), even a large public client, which initiated BIM implementation in their own organisation, is not yet certain how BIM should and would influence the organisation. Hence, there is a need for robust methods for evaluating the impact of BIM on a business’ processes and performance.

The results of the anonymous feedback survey show that the majority of the attendees (7 out of 8) either agree or strongly agree that 4D visualisation made it easier for the delegates to share their ideas at the meeting, and encouraged them to share their ideas with others. One of the Product Managers working for the Main Contractor explains why:

“..when you bring the model up there, you are not trying to interpret it from a 2D drawing. It is the same as standing on site and looking at the detail and saying ‘can we do that better’…”

The Sales Director of the Aluminium Systems supplier corroborates as follows:

“I get involved in structural design very early on. Sometimes the Structural Engineer overdoes it for me. When I look at the 3D model, I can ask why certain elements are there. Then, they tell me that they are to receive my products and I tell them that I do not need it. Hence, early on in the process you can make an input. Very useful. Very easy to understand where the other person is coming from.”

This finding contradicts with the findings of Eadie et al. (2013) which identified that “the visualisation benefits were thought to be not as significant as the increased collaboration, reduction of waste and accuracy”.

Same positive responses were also achieved when the attendees were asked whether they were more willing to contribute ideas. The reasons behind this score also centre around the ease of understanding each other as a result of having access to the model. The BIM Director of the architectural consultants explains:

“You do not have to explain something to somebody. You can point to it. You can say: ‘look this is what I am talking about’. It is much easier than saying: ‘you know the little bit under the eaves ...’

It should also be noted that some of the delegates believe that collaboration is in the nature of this group mainly because they are involved in refining a standardised design. In this context, members of this group are already willing to share their ideas with each other. The 4D model makes the communication during the meeting more effective rather than facilitating collaboration in the first place.

Only 3 out of the 8 respondents agree or strongly agree that it was easier to coordinate the meeting as a result of 4D visualisation. Nearly all respondents are neutral that 4D visualisation helped identifying programme reduction opportunities or potential conflicts in the design solutions proposed. As such, the 4D visualisation facilitated a more effective sharing of ideas but it has not helped with evaluating the implications, e.g. cost and time, of incorporating these
ideas into the design. Delegates reported that this evaluation was better done in a more traditional way outside the meeting. The Product Director of the Main Contractor explains:

“"If you are considering what could have been done differently, by its nature you have not modelled it yet. If you have not modelled it yet, you cannot look at it in the software. It is more appropriate if people went away from this meeting, modelled stuff up, and we centred our discussions at the next meeting around [the model]. I think that would be really, really, really useful. We are a couple of steps before that point. I would say BIM helped us get our bearings today but we could have had a photo instead....

BIM is one of the tools at your disposal. Some tools are better at a certain juncture than others.... [BIM] is never going to be as intuitive as taking a felt-tip pen out and sketching it, unless your model is super-duper."

The BIM Director of the architectural consultants further elaborates:

“"You use a meeting like this to inform you when you go away. Everybody still works in their individual silos on their models which are then federated, obviously, and then clash detected. You could not necessarily work on your model because it is on your server and the engineer’s model is on his server till you get to a Level 3 environment where they are all stored in the same place. Even then, you are trying to access them remotely. So, the reality of it is, you all get together, you go through it in Navisworks, or whatever you are using. You make your notes, you mark the model up. You post that model. You go back to the office. You download it and you look at it. You make the changes. [A model] is incredibly useful in the right place."

This discussion illustrates that, at least in this context, a clash-detected digital model is produced following the traditional approach to integrating the architectural, structural and mechanical designs. It is clear that these professionals do not consider real-time collaboration to be an option even when Level 3 BIM is achieved. Also, the standardisation of the design and its delivery mainly using a framework contract seem to be more influential in facilitating collaboration than the BIM, which is considered to be valuable for visualisation purposes. This suggests that this team is a relatively long way away from Level 3 BIM and Gilkinson et al.’s (2015) suggestion to move to “building knowledge models”. More importantly, the professionals imply that one needs to establishing when, where, why and how Level 3 BIM should be utilised, rather than considering it to be a panacea for the industry’s collaboration issues.

6. Conclusions

The literature review demonstrated that there is a gap in the literature in terms of ‘real-life’ BIM implementation. One of the small number of case studies that can be found in the literature identified the scale, nature/complexity of the project and the procurement approach to be the key justifications for using BIM. User feedback from this case study points to similar situation. The standardisation of the design and the use of a framework contract for delivery play a more important role in collaboration than the use of BIM.
In this particular context, 4D visualisation is considered to help with sharing ideas and coming up with solutions to existing problems. This team considers that real-time collaboration facilitated by BIM is neither desirable nor possible in their context. Hence, BIM and other means of nD visualisation remain to be enablers rather than collaboration tools in themselves, placing this case study closer to Level 2 than Level  in terms of BIM implementation.

Although it is impossible to draw general conclusions from a single case study of a very specific approach to design and delivery, the literature review and the case study point to the importance of companies considering the implications of their BIM implementation strategy in different contexts. As such, project characteristics such as type, scale, complexity, procurement method, and the ease with which internal processes such as H&S reporting can be incorporated in the use of field applications such as 360 Field and Glue, should be taken into account. The development of a BIM implementation matrix with these characteristics would enable companies determine which projects are most likely to benefit from BIM implementation. The authors have identified the development of this matrix as a future research opportunity.

Acknowledgement

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References


Building Information Modeling; a New Business Trend in the Construction Industry of Iran

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Abstract

Building Information Modeling (BIM) is a 3D design tool that has been widely used in the developed countries and has become a profitable business. However, this procedure in developing countries is proceeding slowly. This research looks at BIM, as a new business tool, and uses SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis (a business method) to specify and analyze internal and external motivating factors in the construction sector of Iran. It also investigates industry readiness for implementing BIM in Iran. A questionnaire survey was conducted among a number of different parties within the construction industry. The outcomes of the survey were used to determine most important strengths, weaknesses, opportunities, and threats of BIM application in the construction industry and SWOT analysis was performed. Based on the survey results, internal environment properties (strengths and weaknesses) and external environment possibilities (opportunities and threats) were prioritized from respondents’ point of view. Regarding to survey results, structured interviews were conducted to formulate strategies for decision makers to introduce the new trends and encourage the construction companies to apply BIM in their projects.

Keywords: Building Information Modeling, BIM, SWOT Analysis, Construction Industry, Developing Countries

1. Introduction

“Construction is a large industry of small firms” (Fellows et al., 2002) that is divided into two major sectors: general building construction which includes residential, commercial, institutional and industrial buildings and engineering construction which includes highway construction and heavy construction (Bennett, 2003). The construction industry is a massive business with more than $3.9 trillion annual turnover and employs around 7 million directly and hundreds of thousands indirectly in the world (Jackson, 2010) it is estimated that in 2008 the construction industry in the US spent
around $1.288 trillion (National Institute of Building Sciences, 2007) with 2.53 million construction companies in 2007 (Levy, 2009). Buildings consume 40% of the world’s raw materials and 40% of the world’s energy (65% of U.S. electrical consumption is used in building); therefore, the construction industry plays an important role in energy consumption, economics and politics. Producing 40% of carbon and 20% of waste materials of the world, the construction industry has considerable impact on the environment. Taking into account these characteristics and over $600 billion estimated waste in the U.S. construction industry (National Institute of Building Sciences, 2007), it is essential to manage the construction projects.

Project management is applicable in the construction industry regardless of the size and complexity of the projects (Chartered Institute of Building, 2002). Construction management is defined by Patrick (2003) as “planning, scheduling, evaluation, and controlling of construction tasks or activities to accomplish specific objectives by effectively allocating and utilizing appropriate labor, material, and time resources in a manner that minimizes costs and maximizes customer/owner satisfaction.” Bigger and more complex construction projects require larger and more professional workforce. The project team must be effectively coordinated to achieve project goals. For this reason, 3-D modeling has been developed by technological advances to build a virtual model by computer much prior to construction phase (Levy, 2006). Manufacturing industries like the automotive industries have integrated design, production and operation phases by virtual design of their complex products. This technological approach has been applied to construction industry in the shape of BIM (Jones, 2008).

Smith (2007) defined BIM as “a digital representation of the physical and functional characteristics of a facility and shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life-cycle, from the earliest conception to demolition.” It is essential to consider that BIM should not be the goal, it is just a tool to help project members to achieve their goals (Kymmeld, 2008). BIM caused a revolution in the construction industry (Jones, 2008). As stated by Weygant (2011) “Just as CAD (computer-aided design) improved upon hand drafting, BIM is improving upon CAD. The difference is that BIM involves so many more project participants than just the architect.” However, this improvement has not been started yet or it is still in its infancy in some developing countries. In order to implement BIM in developing countries, it is essential to analyze the construction industry to discover its potential.

SWOT analysis in the construction industry has been performed in some studies. For example, Lu carried out SWOT analysis for the strategic planning in China, Ling et al. (2009) used it for A/E/C firms in Vietnam and Lee et al. (2011) conducted SWOT analysis for the strategic management in Korea. However, such an analysis has not been performed on BIM application in the construction industry in Iran. This study aims to bridge this gap.
2. Methods

A SWOT analysis has been conducted in this research. The SWOT analysis consists of three stages: identifying SWOT factors to know the internal specifications and the external elements which might affect the industry; designing SWOT matrix to provide a summary of the industry’s current situation and make strategic decisions to maximize utilization of resources strengths; gain profit from opportunities, minimize significant weaknesses and eliminate threats (Thompson et al., 2009).

A questionnaire consisting of three sections was designed. The first section was general information about respondents for further use in categorizing the data. In the second section, the level of knowledge about drawing and design tools and software was evaluated by close ended questions. This section provides awareness around the current situation of the construction industry’s parties and their skills. The third section contained questions about SWOT factors in the construction industry for BIM implementation. The characteristics of BIM and the construction industry in Iran had been studied through a comprehensive literature review and accordingly several alternatives for each factor were considered to determine their importance by 7 points Likert scale (zero representing not important and 6 representing most important). Based on the results of previous researches (Sanei Sistani, 2015, Sanei Sistani and Rezaei, 2012), practitioners in the consultants, design, and construction companies with basic knowledge about BIM were selected as respondents. Out of the 100 questionnaires that were distributed, 60 were responded.

Since the level of knowledge about BIM among Iranian construction industry practitioners is not so high and strategic management need broad knowledge about BIM, afterward, face to face structured interviews with 10 professors of civil engineering and architecture were performed. Based on the interviews, a SWOT matrix with two rows (opportunities and threats) and two columns (strengths and weaknesses) was prepared as a solution to overcome threats and weaknesses by managing strengths and opportunities. Considering four quarters of SWOT matrix, S-O (Strengths-Opportunities), S-T (Strengths-Threats), W-O (Weaknesses-Opportunities) and W-T (Weaknesses-Threats), analysis was carried out and strategies for decision makers were formulated.

3. Results and Discussion

SWOT factors for the construction industry in Iran were considered as a result of a detailed literature review and were validated by questionnaire survey as listed in Figure 1.
Figure 1. Weighted means of SWOT factors based on questionnaire survey
3.1 Strengths

*Existing large contractors with experiences in oil and power plant projects*  
Like other Middle Eastern countries, oil plays a vital role in Iranian economy. Due to cheap and easy access to oil, the number of power plants have been increased considerably. Petroleum and its related industries (oil platforms, oil refineries, pipelines, power plants, etc.) form some of the biggest construction projects which require serious attention in this section. Due to these needs, the domestic contractors tried to improve their capacities in executing huge projects (Faani et al., 2014b). Working on these types of industrial construction projects provides valuable experiences for the construction industry.

*Competitive market among large number of contractors*  
By increasing the number of graduates in civil engineering and architecture, the construction firms grow simultaneously. The more firms in the construction market, the more competition for winning the bids. The firms try to adapt themselves to new technologies; otherwise they will lose competitions (Sheikh Khoshkar et al., 2014).

*Conformity and flexibility for adapting with new technologies*  
The entry of a new generation of civil engineers and architects to Iran’s construction industry, the industry’s adaptability to new methods and technologies have been improved (Vatankhan et al., 2013). Their potential to advance makes the construction industry flexible towards the technological changes and alterations.

*Interaction with the large international companies in oil and power plant projects*  
As stated earlier, the petroleum related construction industry is one of most active fields in Iran. Working in this field requires cooperation with huge international oil companies at the highest level. This close relationship between the Iranian and the international companies has many advantages for the construction industry of Iran. For example, becoming familiar with the latest methods and tools, gaining valuable experience, getting involved in the international markets, etc (Faani et al., 2014b).

3.2 Weaknesses

*Absence of trained and experienced BIM professionals*  
Some of the Iranian universities do not even offer design and drawing as core courses in civil engineering and architecture disciplines. These courses include hand drawings or at the best cases 2D CAD drawings. In this situation, the graduate of such universities normally lack 3D modeling experience (Akbari and Safari, 2014). The few that have this skill, have learned it through self-study which in most cases is time consuming and not done in a correct way. It is obvious that without proper training, sufficient experiences would not be gained (Gu and London, 2010).

*Lack of competition between contractors for using BIM*  
The most important factor that could encourage an industry to use new tools is competition. Contractors were not motivated to use new tools unless there was a demand for using those tools; in other words, there was no demand for such
tools (Vatankhan et al., 2013). The supply and demand is a cycle and it is an ancient question that “which one is the start point of this cycle?”

Ignoring advantages of BIM Since the students have not had the opportunity to learn the latest design and drawing techniques and tools other than 2-D, the awareness about BIM and its advantages is very low. Adopting BIM in the construction industry demands serious attention in education and training at the first level (Asgari and Gerami, 2014). The construction management is moving from CAD to BIM, but in Iran moving from hand drawing to CAD has not been completely achieved yet.

Lack of organization for using new technologies The Iranian construction firms work with traditional design tools. BIM is a revolution in the construction industry, not only in drawing and design but also in tendering, construction, and mainly operation and maintenance (facility management). This alteration must be done by a well-organized policy (Faani et al., 2014a). Unfortunately, this organization does not exist in the construction industry of Iran.

Advanced tools’ shortage for presenting capabilities of BIM BIM is a high performance technological tool and requires to be appropriately presented to its users. BIM’s primary requirements including hardware, software and equipment like 3D projection and laser cameras have an important role in introducing BIM potentials (Qing et al., 2011). Obviously, in order to replace the traditional tools with the new technologies, BIM can be used as a new tool. However, BIM has its technological requirement (Akbari and Safari, 2014).

3.3 Opportunities

High number of graduates in civil engineering and architecture The annual rate of bachelor degree graduates in Iran ranges between 280 and 300 thousand yearly (Ameri, 2011). There is a high competition between graduates to be employed in the construction companies. The demand for engineers and architects with BIM knowledge encourage the graduates to learn these skills (Ahn et al., 2015).

Large number of public (governmental) projects The government is the biggest client in Iran’s construction industry. Although, this limits competition among clients, but competent organizations in this sector can be effective in persuading contractors to use BIM in different phases of the projects (Tafakor and ShaterZadeh Yazdi, 2014).

Attain a higher profit margin by saving time and cost through BIM The main advantages of BIM are time and cost reduction. BIM helps to prevent the clashes during the construction phase by creating a visual model of the project at the design stage (Ahn et al., 2015). These digital 3D models are also very useful for better understanding of project specifications, from conception to commissioning. In traditional methods, the coordination between different parties in a project mainly started at the construction phase, but by using BIM, the collaboration can be started at an early phase
which helps to reduce re-works and this can lead to considerable saving in cost and time (Ebrahimi and Mahmoodabadi, 2013).

**Chance of being unique in implementing BIM** BIM is a very new technological tool that is still in its infancy in many countries. The novelty of BIM offers an opportunity to be one of the first enterprises that implement it (Sheikh Khoshkar et al., 2014). Although there are difficulties in using a new tool for the first time, valuable experiences can be gained and the benefits of being a pioneer in an industry will create great opportunities for any company.

**Considerable number of practicable projects with BIM** BIM application might not seem to be economic for a company (according to high initial investment to start using BIM). Considering the government’s construction development budget of $34 billion 2011(Council of Ministers, 2011), it is clear that BIM application in noticeable number of projects could cover its initial costs in a short period of time (Mirjalili et al., 2014).

### 3.4 Threats

**Lack of legislations and standards for executing BIM** Standardization could be the first step for using BIM. The term of ‘Building Information Modeling’ must be clearly defined and its usage domain must be specified (Qing et al., 2011). The designers, owners and contractor must be aware of their responsibilities and duties for using BIM in projects. Whereas construction industry is very debatable, legislation is essential for preventing and solving disputes. BIM legislation and standardization must be assigned to an independent organization body and if such an organization does not exist, it can be set up (Shakeri et al., 2014).

**Lack of public sector attention to BIM usage** While public (governmental) sector does not attend to new technologies like BIM, construction industry faces this threat. Lack of organization in the Iranian government regarding BIM utilization has caused delays and an increase in projects cost (Faani et al., 2014a).

**Inadequate major private projects** Private clients try to gain more benefits by reducing time and cost. BIM could be a very effective tool in this regard, but unfortunately due to inadequate large private projects, there is a lack of encouragement and competition in the construction industry of Iran (Tafakor and ShaterZadeh Yazdi, 2014).

**Clients Unawareness about BIM application advantages** The clients are not aware of BIM and its advantages in reducing time and cost. Research works in construction management are not adequate and not successful in improving the clients’ knowledge about new methods in managing construction projects (Faani et al., 2014a). Without awareness about BIM and its usage, the construction industry has been slow in accepting this tool (Abubakar et al., 2014).
Lack of obvious policies and plans for the improvement of the construction industry  Despite the recent activities to integrate construction related ministries and spending more than 5 percent of the government’s budget for construction development, there are not clear plans to improve and update construction methods yet. Transition of the construction industry from traditional to modern methods requires effective planning and defining policies in macro scale (Asgari and Gerami, 2014).

Using traditional procedure by public (governmental) clients  The traditional structures of the construction industry in Iran have caused the clients to think it is risky to use BIM without the required experiences (Shakeri et al., 2014). It is impossible to use highly technical tools in the traditional systems. To improve the efficiency of the construction industry by using BIM, the construction projects procedures must be changed.

3.5  SWOT matrix

SOWT (or TOWS) matrix (Table 1.) shows how to use environmental and internal specific positive factors in the construction industry against negative external and internal factors to gain more benefit from the strength and opportunities and to overcome the weaknesses and threats.

S-O strategies are strategies for using strengths to take advantage of opportunities by pursuing them rapidly. These are future growth strategies. W-O strategies specify how to overcome the weaknesses that prevent the industry from taking advantages of these opportunities and are known as internal fixes strategies. S-T strategies determine how to use the strengths to reduce the likelihood and impacts of threats as external fixes strategies. W-T strategies are Survival strategies to overcome the weaknesses that will make threats a reality must be placed in W-T strategies quarter of SWOT matrix.

4. Conclusion

A serious trilateral synergy between educational, industrial and governmental organizations is required to persuade the construction industry to use BIM. The first step for adopting BIM in the construction industry is to show its advantages and potentials in time and cost reduction. This goal can be achieved by organizing conferences and seminars. After providing awareness and motivation about BIM and creation of demand, the educational effort must be concentrated on educating students through courses in universities; training engineers and architects through workshops and clients through conferences and seminars.

The Government must provide appropriate legislation and environment for using BIM. These legislations could be used to prevent disputes. Appropriate standards for BIM integration implementation could also be created. On the other hand, public sector must encourage contractors to use BIM. This can be achieved by making the use of BIM in large projects mandatory. Due to traditional characteristics of construction industry in Iran, institutional efforts for finding ways for
transition into technological age are required. This transition needs effective policies and long-term planning in macro scale.

Table 1. SWOT/TOWS Matrix

<table>
<thead>
<tr>
<th>SWOT/TOWS MATRIX</th>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing large contractors with experience in oil and power plant projects</td>
<td>Absence of trained and experienced BIM professionals</td>
</tr>
<tr>
<td></td>
<td>Interaction with the large international companies in oil and power plant projects</td>
<td>Lack of competition between contractors for using BIM</td>
</tr>
<tr>
<td></td>
<td>Conformity and flexibility for adapting with new technologies</td>
<td>Ignoring advantages of BIM</td>
</tr>
<tr>
<td></td>
<td>Competitive market among large number of contractors</td>
<td>Lack of organization for using new technologies</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPPORTUNITIES</th>
<th>S-O STRATEGIES</th>
<th>W-O STRATEGIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>High number of graduates in civil engineering and architecture</td>
<td>Provide appropriate legislation to use BIM in large public (governmental) projects</td>
<td>Educate civil engineering and architecture students to use BIM</td>
</tr>
<tr>
<td>Large number of public (governmental) projects</td>
<td>Encourage contractors through contractual requirements to reduce time and cost through using BIM</td>
<td>Provide awareness workshops about BIM’s advantages among contractors</td>
</tr>
<tr>
<td>Attain a higher profit margin by saving time and cost through BIM application</td>
<td>Training of engineers and architects to learn how to use BIM software</td>
<td>Demand for using BIM in public projects to encourage contractors to adopt BIM</td>
</tr>
<tr>
<td>Chance of being unique in implementing BIM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Considerable number of practicable projects with BIM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THREATS</th>
<th>S-T STRATEGIES</th>
<th>W-T STRATEGIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of legislations and standards for executing BIM</td>
<td>Partnership with private sector in public projects</td>
<td>Long-term policy to improve management in construction projects</td>
</tr>
<tr>
<td>Inadequate major private projects</td>
<td></td>
<td>Replace traditional methods with technological alternatives</td>
</tr>
<tr>
<td>Lack of public (governmental) sector attention to BIM usage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clients unawareness about BIM application advantages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of obvious policies and plans for improvement of construction industry</td>
<td>Establish or assign an institute to legislate and standardize BIM</td>
<td></td>
</tr>
<tr>
<td>Using traditional procedure by public (governmental) clients</td>
<td></td>
<td>Interaction with international companies for implementing BIM in large projects</td>
</tr>
</tbody>
</table>
The construction industry has a significant role in adopting BIM. Using BIM is a sound investment that helps each company to recover its cost once and for all and enjoy its benefits in long term. This investment can be done by training engineers and designers in BIM software application in n-D modeling. Large contractors involved in national projects can drive benefit of collaboration with the international companies and use their experiences in utilizing new technologies.

Building visual models with software at first stage of projects has become popular in the construction industry. BIM as a new technological high performance tool plays a key role in the construction industry and its advantages have helped this trend to grow rapidly. In order to enjoy the benefits of BIM, close synergy between related sections is essential for the building of the necessary infrastructures.

In this research, the characteristics of the construction industry in Iran were studies through a SWOT analysis. SWOT factors were identified based on a comprehensive literature review, structured interviews and a thorough questionnaire survey. The strategies considering the external and internal factors in three main areas were suggested. These areas are education, legislation and adoption strategies which must be pursued in parallel and without priority.

References


Framework for Enabling Scan to BIM Services for Multiple Purposes – Purpose BIM

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Abstract

Technology for scanning is in rapid development. More advanced solutions are available for lower cost of scanning, and simple methods are available for everyone. Use of a building information model (BIM) for facility management is gaining interest, there is still a large number of existing buildings without BIM representation. As-built drawings are not updated or unreliable. However, establish a BIM for an existing property is often costly, and hard to utilize for new purposes. Time and cost effective methods for flexible use is therefore wanted. Integrated Design and Delivery Solutions is used as theoretical frame for this study. The analysis explores the steps in the process of scanning and modelling, collaboration between people in establishing the BIM, and further use for multiple purposes within facility management. An overview of technology presents in relation to process and people to give support for ordering commercial scanning and BIM services. A scan to BIM project of an old apartment building is used as case for demonstrating a framework for “Purpose BIM”. This framework combines relevant technology, processes and personal resources for flexible and stepwise processes of ordering scan to BIM services. An outcome of this approach can be add-on services that can enable reuse previous work. This can result in extended use of BIM to multiple purposes in facility management.

Keywords: Purpose-BIM, process specification, product specification, scanning technology

1. Introduction

There is an increasing interest for integrating laser scanning as basis for establishing building information model (BIM). Laser scanning technology is in rapid development, likewise development of BIM software. Detailed scanning of heritage buildings is often presented as an example of the potential of scan to BIM, but most buildings are ordinary and need a more simple approach to maximize the cost/benefit relation. Even if there is a lot of available theology for
scanning and modelling a BIM, the projects are often motivated by solving one single task, by use of one technological approach, often by one single provider. Development of technology contributes to reduced cost, but the traditional processes have limited flexibility and the cost must be covered by only one use-case, or benefit. Often will small changes in requirements to the BIM – result in repeating almost the entire scan to BIM process. The impact is limited establishment of BIM for existing facilities, despite the benefits for using BIM for multiple purposes within facility management.

There is an increased number of papers regarding integration of BIM, based on various methods for laser scanning in BIM related conferences. This can be illustrated by activity at following BIM related conferences; the BIM 2015 conference had one entire sessions about BIM and GIS integration (Breibba et al., 2015), and the CIB-W78 IT in construction conferences have included papers which cover solutions where BIM can be established based on laser scanning (Issa et al, 2014 and Beetz et al. 2015). This integrated focus has also reaches standardization, where ISO/TC 211 about GIS and ISO/TC58/SC13 about BIM have joint workshop (Kim, 2012). The general focus of research is on issues related to technical interoperability, demonstration of laser scanning hardware and use of software for transforming point clouds into 3-D geometrical models and BIM.

The outcome of this concept paper is useful for building owner / facility manager (client) for design of specification or requirement for ordering scan and BIM services – especially when the purpose is not limited to only one purpose. Expected impact is increase return of investment. The outcome for service providers of scan and BIM services is in improved accuracy of deliverables in relation to client current and future needs. The proposed framework is called “Purpose BIM” and includes all elements from preparing of the project, capturing information by laser scanning, processing of information into BIM, and various ways of presenting results for different users and use cases.

2. Technology overview

2.1 Overview of methods and processes for scan to BIM solutions

The process from the decision to capture geometrical data describing the building to establish a BIM for solving one or more purposes consists of several steps. To be aware of these steps and the options within each steps can make it possible to order according to the principles of “purpose BIM”, see figure 1. This is possible even if purpose is unknown or multiple.
Figure 1: Overview, main stages in the scan to BIM process

Awareness of these steps, and potential between the steps and within each step, is one of the main motivation for this study, and will be explored later on in this paper. Use of the “Purpose BIM” is presented as a framework for an improved ordering of services to enable flexible use and options for future use with positive cost/benefit of the BIM model.

2.2 Overview of capturing geometrical data

Today there is a large variety of instruments used to create a BIM for an existing building. In this paper, we will refer to this as Interoperable Technologies, with reference to IDDS (2013) presented later in this paper. The different technics are mainly:

- Use the original building drawings (both digital and paper based)
- Tape measure (ruler or handheld laser)
- Static point based laser measurement (e.g. “Flexijet” or total station)
- Static laser scanner (terrestrial laser scanner mounted on a tripod)
- Laser scanner and other instruments mounted on a moving platform

We focus on the laser-based methods. These approaches have developed dramatic in recent years and have changed the way we capture indoor data. The “static point based laser measurement” approach use the concept “less is more”. This technique has a direct link into the modelling software, e.g. by use of Flexijet. The modelling and enrichment of the model is done on site. Which in many cases has a big advantage. On the other end of the scale, you find “laser scanner and other instruments mounted on a moving platform” which use a “more is less” approach. The goal is to measure as much as possible and also the same objects as often as possible. This method has taken technics from the robotics into use. The technique is called Simultaneous localization and mapping (SLAM). This is the key concept in autonomous robotics. The robot use SLAM to create a map of the surrounding and at the same time place itself in the map. This concept is now used by many manufactures of indoor measurement systems. These systems are special made to rapid create a building model. These techniques give new opportunities and new challenges. One problem with the more is less approach is that you also collect information that might be sensitive for the people living or working there. In such a situation, the data need to be handled with care. Different techniques have different accuracy capability and the performance improve rapidly with time. We have manly talked about laser scanners, but new software can put the traditional photogrammetry into new life. Examples of software are Autodesk Memento (https://memento.autodesk.com/about) and Agisoft photoscan (http://www.agisoft.com/).
2.3 Software for processing and enriching of scanned data

There are many different software, that can be used to perform the modelling work, adding attributes and relations to the building objects. Typically software is EdgeWise Building™ from ClearEdge3D (www.clearedge3d.com/), Pointsence for Revit from Faro (http://faro-3d-software.com/) and RECAP from Autodesk (http://www.autodesk.com/). It is also relevant to mention the DURAAK project (http://duraark.eu/).

To fulfil a real BIM the collected measurement of a building has to be enriched. This process is called Integrated Processes (see figure 2) in this paper (BIM-ing). To enrich the measurements different software solutions can be used. Some software are standalone solution, but most are plugins into typical architectural software like Revit from Autodesk, Archicad from Graphisoft and Microstation from Bentley. One important difference between the software solutions is the level of operator interactions, which is needed to create the BIM. This is often a time and cost consuming operations. Another difference is how the building objects are placed related to the point cloud. In most cases, the operator can select different settings, which will place the object based on Gaussian distribution, best fit or with different kind of assumption. Typical assumption is that two walls should meet perpendicular and that a wall should always be vertical.

3. Framework for scan to BIM

The dominating focus when exploring scan to BIM has been technology, which is presented in a systematic way. Other organisational issues are often very randomly explored and presented. It is therefore a need for a framework that include technology in a systematic way. In this respect is the Integrated Design and Delivery Solutions (IDDS, 2013) as theoretical framework. IDDS can be regarded as simplification of the socio-technical theory (Bostrom & Heinen, 1977) which is adapted to the AECOO construction industry. The IDDS framework is developed by the International Council for research and Innovation in Building and Construction (CIB) in order to optimize construction projects. IDDS is a powerful framework to explore and understand interactions between different imperatives. The three imperatives of the IDDS are illustrated in figure 2.

![Figure 2: The three imperatives of IDDS (2013), figure simplified by the authors](image-url)
In our study of the process of establishing a BIM for multiple purposes within facility management, we have used the model in figure 3 to describe the collaboration. Figure 4 illustrates the current situation in the case used in this study.

![Figure 3: Identifying imperatives for multiple purpose BIM based on IDDS](image)

![Figure 4: Example of unbalanced IDDS and limited purposes of scan to BIM](image)

The different imperatives are in our case exemplified by the following content:

- **Involvement of relevant people (Collaborating People):** architects, engineers, land surveyors, BIM specialists, landlords, residents,…
- **Available scanning technologies (Interoperable Technologies):** drawings, tape measure, laser scanner, total station, Flexijet, rangefinder, camera,…
- **Processes and methods for enrichment of BIM (Integrated Processes):** Software and methods for creating BIM.

The size of each circle can be changed due to current resources, e.g. the amount of relevant and available technology or the number of collaborating people. The relative position of the circles may also change according to the interaction in between the imperatives. Examples of this are the degree of harmonization of software and hardware or the maturation of new processes in the user communities. The resulting size of the centre region can then be regarded as an indicator for the possibilities for success. Small circles with large internal distance make it difficult to succeed. An example with very good harmonization of hardware and software, but with a limited number of skilled and collaborating people is shown in figure 4. The two lower circles are highly overlapping in figure 4. The problem is that the circle representing the relevant people purpose is small. The consequence is that command area for all three circles is very limited compare to figure 2 and 3. This means that the resulting BIM has very limited purposes.
4. Framework for Purpose BIM

Our evaluation of the case study is that an ordering guide would be useful for the collaborating people. The goal of an ordering guide is to maximize the common area between collaborating people, technologies and processes. The purpose is to help the buyer to order the product, that has the potential to give the best cost benefit ratio. A spin off to this is that the provider of BIM easy can understand the customers demand and expectation. In the early days of airborne laser, the industry had a problem. The buyers of airborne laser data had a poor description of their expectations. They had very different knowledge about airborne laser data and different approaches to control the result. The consequence was that some suppliers took the benefit of this and delivered data with bad quality, knowing that the probability to be discovered was minimal. After some years, the buyers became more professional and establish detailed specification and methods to control the result. The result of the new specification was that the quality of the products became more even. Another important effect was that the different providers could compete based on the same understanding of the customers expectations.

The first step in our framework is to establish a development plan with focus on collaborating people. This will decide which persons who have interest in the project and who should have access to the result. Another aspect is who should continue to work with the BIM to ensure that it is up to date. When the BIM is up to date, it is a “Living BIM”. The second task is to get an overview of the different challenges the collaborating people have and how BIM can be used as a tool to solve their problem. Based on this the accuracy level of the data capture can be established.

Table 1: Accuracy Levels of Data Input to further proceeding BIM model

<table>
<thead>
<tr>
<th>Accuracy level</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative accuracy *</td>
<td>0.003 m</td>
<td>0.01 m</td>
<td>0.03 m</td>
</tr>
<tr>
<td>Maximum average deviation *</td>
<td>0.01 m</td>
<td>0.04 m</td>
<td>0.10 m</td>
</tr>
<tr>
<td>Maximum deviation between measurement and model (at 1 meter above the floor)</td>
<td>0.01 m</td>
<td>0.03 m</td>
<td>0.10 m</td>
</tr>
</tbody>
</table>

Modelling assumption

| Modelling assumption | Exact modelling. The object should be placed on the average location of the point cloud | Exact modelling, but walls can be straighten up to be perpendicular to the floor or ceiling | Walls can be straighten up to be perpendicular to the floor, ceiling and walls |

* Calculated on a 0.2 x 0.2 meters surface
The accuracy level give the BIM provider an accuracy expectation to the final product. Both data capture and the modelling work is covered. Based on the accuracy level the provider can select the most cost efficient method to capture the data. One of the important messages in Table 1 is that you do not need a level 1 scanning if you during modelling will straighten up walls, floors and ceiling to ensure that they are perpendicular. This count if your intention is to use your model in further work and not the point cloud.

**Table 2: Information contend in BIM model, gives an overview of 3 different level of detail**

<table>
<thead>
<tr>
<th>Level of Detail (LOD)</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Full BIM</td>
<td>Slim BIM</td>
<td>BM (overview)</td>
</tr>
<tr>
<td>Relative content of information in BIM</td>
<td>Volume model, standard objects with attributes and relations</td>
<td>Volume model, standard objects Defined (limited) information</td>
<td>Volume model</td>
</tr>
</tbody>
</table>

The next step is the integrated processes. In this step, the measurements become a real BIM. Again, it is important for the buyer to have a conscious relation to the content of the BIM. A simple volume model is cheap, and this is classified as BIM class C. If you add standard objects, it is more expensive and more useful. Finally, if you add attributes and relations you get a full BIM and BIM class A.

**Table 3: Framework for Purpose BIM**

<table>
<thead>
<tr>
<th>BIM class</th>
<th>Accuracy level</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>Multiple purpose (Expensive)</td>
<td></td>
<td>Limited purpose (Moderate price)</td>
<td></td>
</tr>
<tr>
<td>Class B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class C</td>
<td>Limited purpose (Moderate price)</td>
<td></td>
<td>Single purpose (inexpensive)</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 illustrate the relation between the cost and applicability based on the criteria accuracy level and BIM classes. The highest accuracy product is level 1. If you combine this with the BIM class A, you get the most expensive product. BIM class A gives you a BIM with standard objects with attributes and relations. On the other end of the scale, you find accuracy level 3 and BIM class C. This is the cheapest product with less accuracy and no building objects. The accuracy level 1 has the highest flexibility. With high flexibility, you have the opportunity to change your BIM from an accuracy level 1 to accuracy level 3. You also have the opportunity to change from BIM class A to C and vice versa. If you create your BIM with the accuracy level 3, you are not able to change you BIM to the accuracy level 1 without new measurement, but the BIM class can be change. This means that accuracy level 3 has a lower flexibility than accuracy level 1.
Table 4: Framework for Purpose BIM examples

<table>
<thead>
<tr>
<th>BIM class</th>
<th>Accuracy level</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td></td>
<td>Rehabilitation</td>
<td>Facility management</td>
<td></td>
</tr>
<tr>
<td>Class B</td>
<td></td>
<td>Absolute documentation of geometry</td>
<td>Volume sketch and planning</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 illustrate which purposes, which accuracy level and BIM class are suitable for some example purposes.

5. Examples from the case study

The case study used in this paper is based on a project in Oslo, Norway. The building was built in 1890 and has a co-ownership organization with 16 different sections. A board selected by the co-owners controls the building. An important aspect was distribution of cost related to the total area of each section. The area of each section was unknown. It was desired to use the existing drawings to create the BIM. The problem was that the drawings where old and did not give a correct picture of the areal situation. Another problem was that the basement was not present in the drawings. The boarder also had maintenance tasks waiting ahead where they would like to using a BIM. The dream was to link the maintenance history, the today’s status and scheduled maintenance directly to building objects in the model. Additionally they needed a fire and evacuation plan. They also had a project where they needed to control the chimneys. Based on these needs the scan to BIM project was started. The Norwegian Building Authorities was interested in the project and decided to finance the project. The company Rendra won the project after public announcement. Rendra has developed an application for interoperability in construction projects based on BIM. Sweco BIMlab consulting engineers performed the measurement and modelling of the building. The data capture and modelling was scheduled to take 5 weeks. The static point based laser measurement called Flexijet 3D 4ARCHITECTS was used for data capture. The system is directly linked to Archicad, which means that the BIM is created directly on site. The total budget for the project was 200 000 NOK (approximately 22.000 €).

The result from the project was good. The boarder got a BIM they could use for area calculation of each section, storage room in the basement and storage room in the attic. This solved an ongoing conflict in the basement. From the BIM they can extract drawings like fire and escape plans, extract volume of the walls, framework to store information about the past, present and further for each building object. The new established BIM is a good starting point to establish a maintenance plan (DIBK, 2015).
In the evaluation of the BIM one of the section owners discovered that his apartment was 10 m² larger than the report form the latest valuer report (DIBK, 2015; chapter 4.6). It is likely that the areal in this report has been calculated with a tape measurement device, manual or digital. It is therefore likely to claim that the BIM provide the correct area calculation. The price pr. square meter in this area is higher than 50 000NOK (5400 €). This has a big influence on the value of the property.

The experience from the project shows that it is very time consuming to arrange access to all the different sections. Sweco BIMLab performed the measurement and informed that 25% of the time was used just to get access to the different sections DIBK (2015, chapter 4.7). In the evaluation of the result, the board claim that the model has a higher quality and richness than they actually needed (DIBK, 2015; chapter 4.3). There are for instance more objects present than they expected. This model is therefore a good opportunity to use the BIM for more purposes than initially intended.

We have concluded that it would have been beneficial to use a data capture method, which use less time on site and more time in the office. The main reason is that approx. 25% of the time was spent on getting access to the different sections. Flexijet scanning contain only what has been presented in the model. There is no extra data for further processing. This makes the method sensitive for missing registrations and it is difficult to document the quality of the model.

Table 5: Identification of possible purposes for the example case

<table>
<thead>
<tr>
<th>BIM class</th>
<th>Accuracy level</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>No Possible expansion</td>
<td>No Possible expansion</td>
<td>No Possible expansion</td>
<td></td>
</tr>
<tr>
<td>Class B</td>
<td>No Possible expansion</td>
<td>Case study</td>
<td>Possible expansion</td>
<td></td>
</tr>
<tr>
<td>Class C</td>
<td>No Possible expansion</td>
<td>Possible expansion</td>
<td>Possible expansion</td>
<td></td>
</tr>
</tbody>
</table>

The case study have an accuracy level 2 and a BIM Class B. Table 5 illustrate which direction it is possible to expand the BIM. The main reason for this limitation is the Flexijet method where you collect limited amount of data. It is not possible to enrich the model without revisit the building. If a “more is less approached” had been use it might have been possible to enriched the BIM without revisit the building. Then all BIM classes with accuracy level 2 and 3 would have been an option for expansion. If we assume the same starting point. This is illustrated in Table 6.
Table 6: Possible purposes for the example case collected with a “more is less approach”

<table>
<thead>
<tr>
<th>BIM class</th>
<th>Accuracy level</th>
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<tr>
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<td></td>
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<td>No Possible expansion</td>
<td>Case study</td>
<td>Possible expansion</td>
<td></td>
</tr>
<tr>
<td>Class C</td>
<td>No Possible expansion</td>
<td>Possible expansion</td>
<td>Possible expansion</td>
<td></td>
</tr>
</tbody>
</table>

6. Discussion

This concept paper is based on a literature overview of available technologies within hardware for scanning and software for processing captured data, in addition to use a real project as case. The practice of today is driven by use of technology offered by the selection of services from the scan to BIM provider. The proposed “purpose BIM” framework intent to enable an overview of applicable technology for capturing data, and by processing the data into BIMs applicable for multiple purposes. Overview of technology, process and competency (with reference to the trinity in the IDDS framework) enables the building project owner to manage the scan to BIM process by ordering or purchasing process. This study is therefore not a study of selecting the best technology, but how different technologies can be combined to enable a potential for multiple purposes in the future based on reuse of previous work (normally done at low additional cost as supplement to the primary job, e.g. a cloud scanning, when doing point scanning).

A real case was used as example for the scan to BIM process to explore how the “purpose BIM” can be applied. However, further empirical studies are needed to assess the reliability of the framework, in addition to further detailing and guidance. We have focused on accuracy level in the data collection, accuracy in modelling and the level of detail in the building objects. Especially the level of detail is general and need further detailing. In a comprehensive product specification, it will be necessary to have a full list of objects, which should be included in the model. It is also necessary to define which attributes and relation each object should have. In a complex building, this list may be long and complicated. If possible, it will be an advantage to create general rules instead of a complexed list. The comprehensive product specification is important to make sure that the model is created and enriched according to the contractor’s expectation. Additionally the providers have the possibility to calculate the cost more precise. This will contribute to a more fair competition situation where the provider know precisely what to deliver.
7. Conclusions

This study has introduced the “Purpose BIM” as a framework to support flexible ordering of services to solve multiple purposes at positive cost/benefit. This framework structure the ordering processes to combinations off accuracy level from scanning related to BIM classes for processing of scanned data for defined purposes and potential purposes.

An overview of technology and services is presented and illustrates possibilities for a more flexible process. Detailing the overview by current commercial solutions is recommended before practical use. On the other side, we see that the Purpose BIM as a framework will become more relevant to enable increased numbers of solutions by combining technology and processes and personal resources. An important aspect is to break-down into small work-packages or services that can act as options for further processing and enabling of new purposes.

Development of technology will increase the possibilities to combine various technologies at low cost and enable possible multiple use. This will be a key factor to make it common to use BIM in the facility management. With lower prices and flexible processes, the purposes can be extended to purposes we have not thought about or minor tasks, which normally are taken care off in a manual way. One key aspect in this framework is to set up development and feasibility plan to ensure a multiple purpose BIM. Another key aspect is to use the purpose BIM framework to select technology and process to maximize the cost /benefit ratio.

References


From BIM to CIM to Innovate Life Cycle Management of Entire Works and their Parts

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Abstract

During the last few years, many efforts have been made to promote the widespread use of Building Information Modelling (BIM) and to exploit its potentialities. Despite several important activities at international level aimed at creating standards, free tools and open languages for interoperability, the BIM approach has mainly brought enhancements to software for 3D renderings which now are able to represent complex models where information is directly associated to each object constituting the model itself. However, the exchange of information among different stakeholders has not improved significantly, most of all because real interoperability among software has not been achieved and because data sharing has to be independent of specific commercial software.

Along different life cycle stages, asset and facility management represents a very interesting field for the application of BIM strengths because it needs to store and use much information about the behaviour over time of different building materials, products and components. Moreover, because at international level (for instance, CIB W080 Commission is still working hard on this aspect) the lack of reliable tools for service life planning and data capitalisation from facility management is evident. It is then necessary to develop some methods for Service Life Planning and Management, to be easily integrated by maintenance data and used during the design of facility and maintenance activities. Therefore, only the development of specific Information and Communication Technology (ICT) tools for life cycle data use and sharing based on Industrial Foundation Classes (IFC) standards of the International Alliance for Interoperability (IAI) can actually enable exploiting BIM potentialities along the entire building process.

The paper presents a number of activities undertaken in the last few years by Politecnico di Milano in order to move from a BIM approach (where the modelling is central) to a Construction Information Management (CIM) system capable of allowing an effective integration and exploitation of building process data along the entire life cycle of construction works and their parts.

Keywords: Maintenance, facility management, Service Life, Life Cycle management systems
1. Introduction

Service life planning and data capitalisation from facility management are only the first steps for an efficient asset and maintenance management because it is necessary to develop specific ICT tools for life cycle data use and sharing [Daniotti et al. 2015]. Without an integrated information managing system, it is difficult to gain exhaustively each necessary input data and it may affect a correct maintenance planning and management. This causes a waste of money and time, but it can also decrease the effective control on the sustainability of the building process itself: for example, without the knowledge about laying procedures, in-use condition or end of life interventions for the specific construction site, the choice of sustainable products could be frustrated and Life Cycle Assessment (LCA) be incomplete.

That is why, in the last few years Politecnico di Milano has undertaken research activities in order to develop on one side an international platform for durability management, supported by reliable methods for Service Life estimation, and on the other side a national prototype of database for an efficient data exchange among different stakeholder of the construction chain. The adoption of the same object approach to the entire construction field (not only buildings, but also infrastructures, services, processes and anthropomorphic environment), together with sharing information independently from the model, allowed the creation of a Construction Information Management (CIM) system.

Hereafter the description of these two important tools, which in the future could be merged together in order to build a unique and interoperable platform to innovate life cycle management, capable to store objects with different level of complexity (from simple products to entire construction works).

2. The international platform for Service Life appraisal, data storage and sharing

As mentioned, Service Life planning is important in the design step because the set of taken choices must be influenced by the entire life cycle assessment of a building process. Moreover, the choice of the most suitable building components and materials to adopt has to consider not only their duration but also their failure rate curve over time: an effective sustainable process depends on an optimised maintenance planning and this is possible only through the knowledge of building components’ durability. Consequently, the need for more accurate Service Life data is essential, compounded by the necessity of a wider availability and an easier accessibility to such information. That is why, through the analysis of the necessary data to allow designers evaluating duration and planning maintenance, CSTB (Centre Scientifique et Technique du Batiment - the French Scientific and Technical Centre for the Building Industry) and Politecnico di Milano structured the French Reference Service Life (RSL) database [Hans et al. 2008].

Such a database contained some input data necessary to ICT tools for Service Life management and, therefore, became the starting point for integrating results from past research activities and
developing new research programmes to enhance and make it usable at international level [Daniotti et al. 2008].

The realisation of an international database involves the need to use a classification for building components and materials that could be valid beyond French and Italian borders and available for further implementations. A unique and efficient communication tool demands a standardised description of building objects that makes easy the communication among different subjects: in the construction field, this facilitates a faster individualisation of characteristics, a proper organisation of each set of documents and, eventually, reliable costs evaluation, time scheduling and sustainability assessment.

This classification system must have two essential characteristics in order to be proper for this purpose:

- to individualise univocally each family of objects and to allow every further piece of information to join in order to describe precisely each object;

- to be applicable to every class of objects, independently from its complexity.

Since the base of a classification system is the partition of a series of elements in classes, there are two different ways to group various elements:

- a direct grouping: elements are identified as belonging to a class, classes are organised according to a hierarchical order, so there are some main classes and, for each of them, some sub-classes and so on; for instance, the parts of a building are walls, floors, foundations, the roof, etc.; inside these groups, it is possible to identify other elements; an example of classification based on a direct grouping is MasterFormat, which is widespread in the USA and Canada;

- a combined grouping: there are different attributes for an element and this is identified by the free aggregation of these attributes; examples of this classification are the SfB and the Italian standard UNI 8290.

The first activity that was undertaken was to define the most proper classification system to adopt: therefore, it was necessary to fathom and study, first of all, existing classification systems adopted all over the world (Figure 1). This preliminary analysis showed the difficulty in classifying every construction element in an univocal way and, above all, a great fragmentation of these systems.

Consequently, it was necessary to propose and adopt another classification system that could be used at international level for the RSL database.
The SfB classification (Swedish acronym of Samarbetskommittén for Byggnadsfrågor - Cooperative Committee for Construction Issues) was born in 1956 with the objective to become an implementing classification system at international level. Realised in Sweden, it was presented in Holland in the presence of many experts from all over Europe. The first English version was translated into German and Italian. In spite of this transnational peculiarity, SfB classification has not been used on a large scale.

Another exception to local classifying systems is RUDC, part of UDC (Universal Decimal Classification) which was not directed toward the construction field, but to organise every kind of information.

The Italian standard UNI 8290 of September 1981, aimed at standardising the terminology to employ, represents an important step in supplying at national level a classificatory model, which gives, in the field of residential buildings, the classification and the articulation of technological units and of technical elements in which the technological system is divided.

The Construction Project Information Committee (CPIC) introduced the UniClass (Unified Classification for the construction industry) system in the United Kingdom in 1997 and it suggested a method for the building sector classification based on 15 tables. Each board looks at a specific information aspect and it can be used separately or linked together with other tables to express complex concepts.

MasterFormat represents the standard of communication more used in USA and Canada to organize the project contents and the relevant documents. The project, through the Construction Specification Institute (CSI) proposal, can be split into divisions and sections, with the aim of standardising a procedure to manage every type of project information.

OmniClass is a classification system that was accepted by the US building industry in 2006. It is a freely available standard based on a common language for the whole building sector and a
standardised system to classify information regarding the entire building life cycle, from planning to demolition.

Eventually, the Italian standard UNI 11337:2009 introduced a new framework approach to classify contemporarily functions, objects and processes/activities. It organises a list of items according to the logic of the works carried out, in order to permit analytical evaluations (as the cost per measurement unit for each intervention required by each work) and elementary evaluations (as the cost per measurement unit of technological units).

Therefore, for the international RSL database a new classification system was adopted: it is based mainly on SfB classification, UNI 8290 and UNI 11337:2009. As the necessity was to allow a collection of RSL data for building objects, this proposal does not contain the classification of activities, vehicles, tools, human resources or environments. For example, it can be used to individualize univocally a pillar, but not an activity like daubing, a vehicle like a crane, a tool like a trowel, a person like a bricklayer or a place like a kitchen.

Politecnico di Milano contributed not only to RSL definition, but also to create some grids for the application of Factor Method [Daniotti et al. 2010], considering moreover the elaborations on statistical basis lead on the climatic agents for accelerated ageing cycle definition [Daniotti et al. 2008]. As a consequence, the database for RSL collection became necessary not only for the convergence of all the information coming from the experimental researches, but also to constitute an indispensable tool for the application of existing methods for SLP (ISO 15686-2 and UNI 11156-3) and, in particular, of the Factor Method.

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Figure 2: From the French National RSL database to the international durability platform

To do that, each single building component is associated to a specific factor grid, which translates all the variables affecting Service Life into different sub-factors belonging to the seven main factors proposed by ISO 15686 Factor Method. Thus, the construction procedure of the database consists of four main steps, namely:
1) a grid is built for a given building component by a panel of experts;

2) the grid is shared among the stakeholders of the construction sector;

3) information regarding properties and service lives is collected by the stakeholders for the comprised sub-factors;

4) data are validated by the platform administrator.

3. INNOVance, the Italian database for Construction Information Management

Another step forward in evolving the BIM approach, through Building Information Modelling and Managing (BIM&M), towards CIM was made by Politecnico di Milano together with many important partners (Figure 3) during a three-year research project called INNOVance.

This research project, funded by the Italian Ministry of Economic Development, started in July 2011 with the aim to introduce a radical innovation into the Italian construction sector by creating the first national construction database and a prototype of interoperable BIM&M platform (Pavan et. al 2014).

To overcome possible inefficiencies due to incorrect or redundant exchange of information among actors of the construction chain throughout the entire life cycle of a work, Politecnico di Milano developed a new classification, naming and coding system that allows speaking an unambiguous language where synonymies and all the different meanings of the same word are clear and already defined [Daniotti et al. 2013]. The naming and coding system developed with INNOVance takes into consideration the entire construction work as the last output of the construction industry, analysing it from five points of view (Figure 4):
- the functional-spatial logic in order to highlight environment and functional areas in which the construction work is divided (for example, commercial areas inside a building);
- the technological logic for construction in order to disassemble it in its elements, from entire components to single products;
- the technological logic for equipment in order to disassemble it in its parts, from entire systems to single products;
- the anthropomorphic logic to represent all the changes on environment and those natural aspects related to it (e.g. excavation and embankment);
- the processual logic to individualise and codify activities, vehicles, tools and human resources.

Each of these logics contains three levels of objects, according to their complexity. Considering this hierarchy, the adopted coding system then defines a structure with an open compilation and seven fields, which can describe every element to be encoded, independently from the object complexity and the set system to which it belongs (Figure 5):

1. category;
2. type;
3. functional and in use characteristics or, for construction products, harmonised technical standard;
4. performance characteristics;
5. geometrical features such as geometry, shape, aesthetic and constructive traits;
6. dimensional features;
7. physical / chemical properties.

The reason for the choice of a fixed seven fields coding system is to standardize the output code and to have a coherent individualisation of each information inside the code itself.
Talking the “same language” with a common classification and coding system allows avoiding communication errors especially during design and construction. However, this was not enough to innovate the life cycle management. The second step was, therefore, to create a tool with a standardised procedure for data sharing to avoid misunderstanding, errors, over costs and delays, mainly due to documents and drawings that are not correctly interpreted and updated.

Consequently, exploiting the unambiguous classification system for every object and the defined hierarchical structure, Politecnico di Milano, in collaboration with Derga Consulting S.r.l. (a partner of SAP, acronym for System, Applications and Products, a software company which developed some Enterprise Resource Planning and data management programs) created a unique database to store and share information. This ICT tool allows collecting, for each object individualized in the above-mentioned hierarchical structure:

- standardised datasheets and specialised dossiers, with every useful document (images, videos, drawings, etc.) that can be easily enclosed;
- further informative attributes which cannot take place in the defined datasheets and dossiers;
- BIM objects in different file formats (among which, the interoperable IFC format).
A SAP ERP system (SAP NetWeaver) contains all the structured data. By unequivocal names, technical datasheets, specialised dossiers, complementary data and BIM objects, all organised in the INNOVance database and accessible by a user-friendly web portal (homepage in showed in Figure 6), each user can manage his projects, since the design brief and through all the further phases.

Through this website, many operations are possible: for example, manufacturers can create, upload and modify their construction products standardised datasheets, adding BIM objects too, designers can describe the technical solutions designed and share their projects; companies can consult data sheets established by designers and manufacturers, checking the correspondence between ordering and arrival of the goods.

The web portal constitutes an exchange platform (Figure 7) with:

- a public section, open to any user, where it is possible, for example, to find a BIM Library, and where information (graphical, alphanumeric or multimedia) is embedded into Generic BIM Objects (out of a specific context);
- a private section, open only to logged users, where it is possible to store a personal library of datasheets and dossiers and where, thanks to the so called BIM&M Server, in any stage of the construction process, they can convert generic BIM object from the BIM&M library into Specific BIM Objects (in a specific context).

This web platform aims at becoming an interactive footbridge among different stakeholders. To do that, as the quantity of collected information will be huge, there are different views of the database according to the user’s profile: this facilitates its use, filtering only useful data for the considered stakeholder, but leaving the possibility to search, visualise and, possibly, modify any other information of the database.
4. Conclusions

Asset and facility management needs to store and use much information about the behaviour over time of different building materials, products and components. Service life planning and data capitalisation from facility management are only the first steps for an efficient asset management because it is necessary to develop specific ICT tools for life cycle data use and sharing.

A strategic step toward the optimisation of both the building process and the whole construction sector is represented by a rationalisation of the information flows connecting construction process stages (planning, design, construction, use, management, maintenance, disposal or reuse) and the various actors involved (customers, users, designers, contractors, components manufacturers, etc.).

Starting from the expertise in developing the above-described international Reference Service Life database, Politecnico di Milano structured a complete Construction Information Management system: the INNOVance platform. This constitutes a unique collaborative tool, meant to store, elaborate and share every useful data along any building process and to support every actor involved in the process. Impacts on the entire construction field are evident: by its adoption and use, it is in fact possible to avoid misunderstanding in communication and redundancies in data, increasing the efficiency of building process along the entire life cycle of each construction work because the exchange of every information is associated to unique codes in a fast, interoperable and reliable way.

References


UNI 11337 (2009), “Building and engineering works – Coding criteria of works, activities and resources – Identification, description and interoperability”.


A Case Study of Building Information Modelling Enabled ‘Information Totem’ for Operations and Maintenance Integration

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Abstract

This paper reports upon the use of a semi-automated toolkit to aid the development of as-built Building Information Model (BIM) (As-built model reflects on-site changes by the contractor to the original BIM) from inception to final construction. An observational case study of two educational ‘multi-storey’ facilities obtained primary data from project archives and focus group meetings with key design team members. The results demonstrate that the data requirements for both structures evolve post occupation because of stakeholder tacit knowledge accrued via building operation and usage. The semi-automated toolkit developed can readily access operations and maintenance (O&M) manuals, retrieve room specific data (such as categories of equipment or building element) within the as-built BIM and, assist in the navigation and coordination of amendments and changes throughout the construction phase. This paper provides useful practice-based information for practitioners to develop suitable BIM data structures for future information requirements throughout a building’s lifecycle. The inherent value of the semi-automated toolkit resides in the facilitation of ease of handover for the Facilities Management team during the O&M stages.

Keywords: As-built model, BIM, Facilities Management, Operations and Maintenance, Maintenance management

1. Introduction

Succar (2009) defined Building Information Modelling (BIM) as a: “procedural, technological shift within architecture, engineering, construction and operations.” This definition was expanded upon by Eastman et al., (2011) who noted that BIM has shifted the way building information is managed, exchanged and transformed to enhance collaboration between project stakeholders. Garber, (2014) concurred with this view and suggested that BIM provides a platform for better design team integration and project coordination. From an operational perspective, BIM embeds key product and asset data, and a three-dimensional computer model that can be used for effective management of information throughout a project’s lifecycle from earliest concept
through to occupation and use (HM Gov, 2012). Consequently, BIM deployment throughout the building lifecycle is invaluable to organisations that seek to obtain value from the technology (Love et al., 2013; 2014). In essence, BIM represents a collaborative way of working, underpinned by digital technologies, which unlock more efficient methods of designing, creating and maintaining assets (HM Government, 2012).

Khemlani (2011) states that every constructed facility requires a bespoke BIM model, analogous to an owner’s manual, with mandates for model updates that correspond to periodic repair, or refurbishment works. In practice, BIM in the operations stage has been primarily connected to the roles and responsibilities of the Facilities Management Team (FMT) but this can create problems in other areas (Becerik-Gerber et al., 2012; Volk et al., 2014; Kassem et al., 2015). For example, Teicholz, (2013) reported upon a litany of issues which include: inconsistent naming conventions used; a myriad of bespoke FMT information requirements; inadequate data categorization in BIM and computer aided facilities management (CAFM) systems; poor information synchronization; and lack of methodology to capture existing facilities and assets. Delivering efficient operations and maintenance (O&M) procedures for buildings is therefore problematic and exacerbated by the vast complexity and volume of data and information generated (Mohandes et al., 2014).

The open access digital environment afforded by BIM provides a partial solution to this issue because it readily affords storage, sharing and integration of information for future use. Indeed, contemporary research demonstrates promising potential for integrating facilities management (FM) within a BIM environment at the post construction stage (Azhar, 2011). In aiming to characterise the hybrid BIM-FM environment, Kelly et al., (2013) observed that the following advantages could be accrued, namely: augmented manual processes of information handover; accuracy of FM data; and increased efficiency of work orders execution to accessing data and locating interventions. However, the construction industry currently resides within a transition period of adopting BIM. Industry practitioners are now selecting their own paths to cope up with the new technology in this rapidly changing environment and climate of exponential technological advancement. To date there remains a considerable dearth of applied studies that develop a hybrid BIM-FM environment and/ or report upon the tangible benefits of such to practitioners. With this in mind, this paper proposes a semi-automated toolkit (also known as an information totem) to aid the development of as-built BIM from design to final construction. A conceptual design for the toolkit is presented and is based upon a case study of two multi-storey educational buildings augmented with pragmatic input from the building’s FMT.

2. BIM Value for FM

Contemporary literature indicates that exploiting BIM’s inherent value adding capability within a building’s development remains questionable especially, during the transition period of adopting BIM within the project’s whole lifecycle (Parn et al., 2015). Despite the palpable benefits of BIM application during the design and construction stages, case-studies of its application during the management and maintenance of assets during the O&M stage of building occupancy remain scant (Kelly, 2014). Yet, Boussabaine and Kirkham (2008) reported that 80 percent of an asset’s cost is spent during O&M, leaving the benefits of BIM short lived at the
design and construction stages. In addition, Love et al., (2015) suggests that significant challenges are presented by an ill-equipped project team who lack standardized tools and processes, specific data required for operations and, maintenance and the workflow to deliver a digital model.

As a 3D modelling tool associated with a parametric database of components, BIM offers the FMT opportunities to manipulate and utilise information contained within 3D objects (HM Government 2013). However, Liu and Issa (2014) found that during the design phase, participants in a BIM project focus on clash detections and tend to ignore future-proofing maintenance accessibility. The authors (ibid) highlighted potential in BIM for designers to explore the background geometry and parametric database to add functions to help the FMT anticipate and solve maintenance accessibility issues. Similarly, Meatadi et al., (2010) and Motawa and Almarshad (2015) proposed additional tools to improve BIM’s performance at the O&M stage by effectively engaging stakeholders. Longstreet, (2010) further added that the value of implementing BIM increases exponentially as a project lifecycle unfolds. This is because BIM value in FM stems from improvements to: current manual processes of information handover; accuracy of FM data; accessibility of FM data; and efficiency increase in work order execution (Kassem et al., 2015). Consequently, FMT involvement during the BIM development process is essential because they can alert the building delivery team of any issues related to O&M of facilities. This synthesis of extant literature underpins the necessity to involve building operators/ management stakeholders in the design phase of a BIM project. Interestingly, Bosch et al. (2015) contradicted this position and concluded that the current added value of BIM in the operations stage was marginal due to a lack of alignment between the supply of and demand for FM related information and the context-dependent role of information. Although the antithesis of Bosch (ibid) is contrary to opinion within main stream literature, Kassem et al., (2015) did concede that a key challenge of BIM-FM integration is a lack of methodologies that demonstrate the tangible benefits associated with this hybrid merger.

3. As-built BIM Model Structure to Aid O&M

At the O&M stage, more than 80% of a FMT’s time is spent on finding relevant information because such expenses are often overlooked at the pre-construction stages by designers (Becerik-Gerber et al., 2012). Consequently, a number of studies are supportive of BIM application within the O&M stages (Patacas et al., 2015; Motamedi et al., 2013; Volk et al., 2014). This is because BIM provides an information conduit and repository (containing for example, manufacturer specifications and maintenance instructions linked to building components) in support of building maintenance management activities (Sabol, 2008). Such information and functionality is important when handing-over an accurate as-built model to building owners for the purpose of asset management. At present, laser scanning represents a common methodology used to create an as-built model of the completed project (Bennett, 2009). However, this methodology is time consuming and prone to human error and hence, as built preparation is perceived to be a time consuming and costly procedure (Huber et al., 2011). The Institution of Civil Engineers (ICE) (2015) state that these issues can largely be eliminated through the provision of a reliable, BIM-sourced suite of information. However, the technical expertise of the FMT represents a significant barrier to BIM and as-built model development and maintenance (Kassem et al., 2015).
McArthur (2015) suggests that identification of critical information required to inform operational decisions is a critical determinant towards configuring data retrieval techniques at the post-construction stages. Despite being emphasised by a number of authors (Meatadi et al., 2010; Motamedi et al., 2013), the issue of identifying critical information and linking them to the as-built model for O&M phase usage remains problematic. Meatadi et al., (2010) revealed that the inconsistency between demand and availability of particular information in an as-built model incur unnecessary expenditures. Thus, linking data and configuring the retrievable information within the as-built model for the project’s post-construction operational phase is a key issue that must be considered during the design and development of the BIM data.

4. Problem Domain: Big Data Acquisition

When utilising BIM technology, a vast array of data (commonly referred to as big data) is produced and integrated into existing objects within the 3D BIM (Bentley, 2003); where big data has been defined as high volume, velocity and variety data sets which pose extreme data management and processing challenges (Laney, 2001). Data within the model requires a structured method of information and data categorisation that can be tracked, validated and extracted. Grilo et al., (2010) argue that BIM should create a broader base for interoperability in order to be fully utilisable, such as standards on communication, coordination, cooperation and collaboration. The huge volume of data within an as-built model is a matter of concern in terms of extracting valuable information and knowledge from it during the O&M phase of a building, particularly for the FMT (Russom, 2013). Federated models are defined as the amalgamation of multiple models in one, namely: architectural, structural and MEP models (HM Gov, 2012). To further exacerbate this issue, not all data is contained within one federated model because the FMT often link BIM to additional relevant external databases, to create a highly integrated multi-dimensional model (Succar, 2009; Love et al., 2015). This mass of data creates opportunities for new thinking and/ or adopting alternative techniques for model data structuring (Bentley, 2003). Matthews et al., (2015), explored adaptation of cloud-based technology with object oriented workflow for as-built BIM scheduling. In a similar vein, this research adopts an ‘object-orientated workflow’ for real time data capture. However, the semi-automated toolkit proposed will predominantly be used to capture changes relevant to the FM parameters embedded within information totems. Information totems provide an additional layer of information structuring that are fed through to the federated as-built BIM model congested with high volume of data loads.

5. Methodology

This observational case study largely relied on project archival data and focus group discussions to explain as-built BIM preparation and the development of information totems. Specifically, the research sought to observe and report upon the processes and procedures adopted during the development of the as-built BIM to facilitate ease of handover for the FMT. Two multi-storey educational buildings located in the centre of Birmingham, UK were used for this study. Building one was build first and constituted phase I of the development and building two was built second
and constituted phase II. Primary qualitative data was collected using verbal interviews with key stakeholders which included representatives from the project management team (PMT) including the client’s representatives (i.e. the Building’s Estates Department) and design related disciplines (including the Architect, the Contractor’s BIM Manager, Principle Designer for Mechanical Engineering and Plumbing and the Lead Structural Engineer). Note that the Estate’s Department held three fundamental roles, namely that of: client’s representative; project manager; and Estates Department and hence, covered all three major phases of the building’s life cycle. Two meetings were held with the PMT over a 4 months period during 2015. Secondary data sources further complemented information obtained and consisted of project documents including contracts, bids, BIM execution plans, EIR’s and BIM protocols. Additional hand written notes were taken to record impromptu meetings or telephone calls held. Largely archival records of BIM documentation and contracts provided: i) an elaborate account of contemporary practices through the exploration of stakeholder experiences and interrogation of the images themselves; and ii) sponsoring organisations with opportunities to learn from everyday experiences of design team members and the FMT. During the study, FM associated aspects of BIM implementation were observed to evolve as a consequence of a synthesis of diverse opinions emanating from the PMT.

6. Case Study Discussion and Findings

Individual PMT group members claimed to have been inexperienced at utilising BIM technologies the outset of the project’s development during phase I. However, at the end of phase I team confidence grew, and the idea for an information totem was conceived and proficiency/competency gains were adopted in phase II. Information totems were described by the PMT as a placeholder for the room datasheets used during O&M stages of a development and are used for data input and retrieval. When formulating the information totem concept to ensure BIM and O&M data integration, the PMT considered various outcomes including: modelling requirements for FM; and model structure for data retrieval. The aim being to generate an information totem that would deliver interoperability and encapsulate the following attributes: i) increased coordination; ii) facilitated ease of communication link; iii) informed decision making; iv) enabled information exchange enabler between multiple stakeholders; and v) provided ease of navigation between BIM model and construction site. Different PMT members added room specific information into each totem; contractors then retrieved asset related information for guidance during the construction stages and attach construction progress photos to each totem. Data within totems was predominantly categorised into FM parameters, were often room bound and in the instances of open plan spaces, these divisions of space were allocated by the PMT during the building’s design. The totems themselves connected to multiple external data bases which are directly linked with room specific O&M manuals, maintenance frequency codes for different spaces and product fact sheets.

6.1 Asset Management at O&M stages

During the O&M phase, the client used of room barcodes (Figure 2) to aid the management of assets by allowing efficient access to data at the O&M stages. This same barcode was applied
within information totems and mapped into FM software utilised at later stages of the development, including the cloud based BIM platform used for both projects.

Figure 1. Information totem for site navigation

(a) View of the Information Totem in yellow from the cloud based federated BIM model.  b) Photograph of the same location on site as cross reference retrieved from the information totem.

Figure 2. Asset Management with room barcodes

(a) A Barcode tagged room in Phase II, barcodes are typically placed outside the rooms on doorframes. b) Individual steel barcode plates, typically an 8 Digit number bi-directionally linked with the information totem held in the federated model. These barcodes associated per room are used by facilities management team for ease of access to the digital O&M manuals and room asset data.

Table 1 displays the stakeholder disciplines and their input of information into the information totems during pre-construction, construction and post-construction stages.
Table 1. PMT use of totems

<table>
<thead>
<tr>
<th></th>
<th>Pre-Construction</th>
<th>Construction</th>
<th>Post-Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Architect</strong></td>
<td>Client room number.</td>
<td>Occupancy and room data sheet added in totems, linked with snagging list.</td>
<td>Asset information data. Link to O&amp;M manuals.</td>
</tr>
<tr>
<td><strong>Contractor’s BIM Manager</strong></td>
<td>Not applicable.</td>
<td>Site photos on a room by room basis. Snagging list.</td>
<td>Reports and links to finished room photos.</td>
</tr>
<tr>
<td><strong>Real Estate Department</strong></td>
<td>Mandating the information requirements of totems.</td>
<td>Finished room photos for BIM model snagging to ensure the as-built BIM model development is accurate.</td>
<td>Floor Plans. Links to O&amp;M documentation on a central database. Asset register information.</td>
</tr>
<tr>
<td><strong>Lead Structural Engineer</strong></td>
<td>Not applicable.</td>
<td>Navigation between model and construction site environment.</td>
<td>Reports. Asset information data.</td>
</tr>
</tbody>
</table>

Snagging is an expression coined in the building industry in the UK and Ireland. Snagging is defined as the process of defect identification and resolution (Sommerville and Craig, 2006). The contractor used disciplinary BIM models from the design stages to develop the project design. Design developments were uploaded in the BIM model using the federated cloud model and the updating of consecutive information totems. This federated model was used for a number of reasons, namely to: avoid clash detections; facilitate, 4D and 5D modelling; and provide a basis for the cloud BIM data base, where information totems are linked with the federated BIM. A cloud based BIM database and information totem parameters were managed by the contractor on site but was developed by the estates team. The information totems were gradually populated throughout the construction to provide a full database reflecting the changes of the as-built development. All BIM models were updated by the contractor to reflect the building completion. So called ‘BIM snags’ were developed to aid the development of the as-built BIM these were helped with site photographs and commentary attached to the federated model. BIM snags follow a similar function as snagging, except they are used to inform designers of any potential changes on site that need to be reflected in the as-built BIM. Laser scanned data was used to verify the validity between model and as-built building. Other documents not directly related to the BIM, such as equipment fact sheets, O&M manuals, documentation and drawings were linked into the cloud based federated model via the information totems. Currently the estates and research team are exploring ways in which Building Management Systems data (as an external source of data) will be linked via totems into the cloud based model.

7. Discussion

During the PMT focus group discussions, four main lessons emerged regarding the use of BIM and information totems during the project, namely: i) the creation of information totems; ii) limitations of a semi-automatic totem; iii) inflexibility of software providers; and iv) lack of
software integration. First, information totems were only adopted towards the end of phase I when the Real Estate Management Team realised that FM requirements (such as building heating and cooling loads, and building usage) could have been uploaded into the BIM at the design stage to inform the design and better meet client expectations. A MEP designer said: “Design data, such as ventilation rates, cooling loads could have been included in the design stages already, as the M &E contractors are often playing catch up from the other design team...” Second, it was apparent that the information totems developed were not fully automated and hence, as changes to specification occurred, manual updates were needed in the model. For example, when the contractor altered a specification provided by the Architect or MEP designer (at the construction and commissioning stages). The contractor stated: The totems still lacked automation, what would have been good was to have a live feed of the changes in the model with the totems, as they currently did not capture all of the changes in the model, some information had to be manually added to the totems...” Third, the BIM software designers (as external providers) were unwilling to implement bespoke modifications and amendments to their software. For example, information could not be exported into other file formats for usage in room data sheets or for snagging lists post construction. A BIM Manager said: “We were unable to export the totem information directly out of the software into a PDF, which could then be used as a room data sheet...” Fourth, the BIM model had a distinct lack of software integration capability and therefore, when clicking on the information totem, room elevational views could not be seen and these had to be extracted from other databases within the BIM model. A Project Manager said: “What would be useful is if we could have direct views of reflected ceiling plans, room elevations and floorplans just by clicking the totems faces, makes it easier to then share the model with subcontractors...”

However, these aforementioned issues apart, a largely inexperienced PMT valued the input guidance and advice from the client’s representative throughout the design and construction phase. This allowed the PMT to mature as a collaborative and collegiate partnership that allowed both phases of the development to be constructed and commissioned to all parties’ satisfaction and with minimal disputes arising. Efficiency gains were also made by individual PMT members who acquired new knowledge of BIM that allowed them to streamline their management of the project and ultimately cut costs without adversely impacting upon quality. For example, the Architect who employed ten people during phase I, reduced this to five people in phase II. In summing up the project’s success, a representative from the Contractor said: “Phase II has been one of most successful BIM project in our business, it has really pushed BIM all the way through the process right through to FM, and we haven’t actually done this on any other project to date”.

8. Conclusion

Extant literature illustrates that BIM-FM integration presents an ideal opportunity to produce accurate design data extended throughout a building’s lifecycle for retrieval during the O&M stages. This case study has revealed that an effective means of creating model infrastructure to manage data is essential at the hand over stages. By generating an information totem to add room and space related information between assets, the transition between BIM and FM is performed in an easier way for the FMT to adopt. The observations accrued from the case study have shown how an object orientated workflow can provide structure and develop complex as-built BIM
models whilst embedding key O&M related information. This paper has reported upon the use of a semi-automated tool-kit promoting the use of object-orientated workflows to increase coordination, ease of communication, information exchange, ease of navigation. Future work needs to look at how information totems could be linked into existing Computerised Aided Facilities Management (CAFM) systems to be utilised at during the O&M stages. Additional development of the totems is anticipated and future research efforts will now develop a fully automated information totem.

References


Institution of Civil Engineers (2015) “Leveraging the Relationship between BIM and Asset Management”


Stimulating BIM-related supplier innovations in infrastructure projects

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Abstract

Building information modelling (BIM) is a paradigm shift in the construction industry that transforms processes to achieve greater efficiency and effectiveness. There is an increasing need for rapid development of BIM, and no organisation can do it alone, and innovation collaboration with suppliers and other external organisations is an important means to complement an organisation’s knowledge base. The aim of this study is to explore how BIM-related supplier innovations can be stimulated by a public owner in infrastructure projects. Specifically, the study looks for the role of procurement in innovation. The study utilises an in-depth embedded single-case study method with 21 thematic interviews. The study applies ‘innovation catalysts’ identified in previous research projects as a frame of reference to identify different tactics the public owner can introduce to influence antecedents for innovation. The results of this study show that, to date, the public client’s efforts to enhance BIM-related innovations has been acknowledged by suppliers. However, the results have not always been satisfactory. The results of this study suggest the probability of BIM-related supplier innovations can be increased by systematically implementing the innovation catalysts. Reciprocal, long-term, and cross-project collaboration activities are needed at different levels of the overall project organisation and within the industry, and the consistency in communication and activities needs to be ensured throughout the organisation. The incentives and requirements included in the procurement documents are suggested to be a secondary tool to promote supplier innovation, after (other) antecedents for innovations are in place.

Keywords: BIM, supplier innovations, procurement

1. Introduction

The use of building information modelling (BIM) in its current context has evolved in building construction. For the infrastructure sector the terminology has not settled; e.g. InfraBIM has been suggested. In this paper, BIM is also used to cover the processes and technologies related to modelling in the infrastructure sector. The basic benefits of modelling are mostly the same, with some differences, due to the nature of operations and business in the sector. The core features of
BIM technologies, a digital 3D representation of designed structures with computer-readable semantic data, have developed into wide utilisation varying from software development to process re-engineering or “paradigm shift” (Shelden 2009), even supporting project delivery methods like Integrated Project Delivery (IPD) (e.g. Porwal and Hewage 2013). Benefits of BIM utilisation have been evaluated in several empirical research projects (see, for example, Azhar 2011; Barlish and Sullivan 2013; Bryde et al. 2013) and reviews (Smart Market Report 2014), proving the overall influence to be positive.

No organisation can develop BIM alone, and innovation, in general, is increasingly becoming the outcome of collective effort rather than the output of a single organisation (Chesbrough and Crowther 2006). Suppliers, including designers and contractors, are natural partners to the owner to collaborate in BIM-related innovations, as the benefits of BIM are achieved only if BIM is used at every stage of a supply chain. Even though the potential of involving suppliers in the innovation process has been recognised by previous authors (Schiele 2010), empirical analysis of supply-side involvement in the focal organisation’s innovation is still scarce (Luzzini et al. 2015).

To respond to this call, this study aims to answer the following research question: How can BIM-related supplier innovations be enhanced by the public client (owner) in infrastructure projects?

To research the phenomenon empirically, an embedded single-case study was conducted. We acknowledge that there are other approaches to enhance BIM-related innovations, but as the whole industry is built up in a project-based mode of delivery, this paper focuses on innovations developed as part of infrastructure projects, where the results directly support the investment project’s goals. Public owners have a significant role in the development of BIM. Public owners have an interest in developing the industry as whole, and also have possibilities to develop, as they are significant players in the field due to their large number of consecutive projects. Here, we define supplier innovation as innovation developed by or with suppliers (Aminoff et al. 2015). In this study, a modern definition of innovation is used. According to this definition, in addition to traditional product or service innovations, innovations can also be related to operating practices, management methods, or processes (Kamensky 2010).

2. Literature review

As this study is positioned at the intersection of supplier innovation management, innovation in construction projects, and BIM/digitalisation in the construction sector, we briefly discuss all of these aspects here.

2.1 BIM literature

BIM research literature contains a vast number of technology development reports and case studies of implementation. The innovation aspect in the BIM literature focuses on the adoption and diffusion of BIM methods. Taylor and Levitt (2004) found that systemic innovations diffuse more slowly than comparable incremental innovations in the project-based building industry. Succar and Kassem (2015) define BIM as organisational and systemic innovation rather than solely technological solutions proliferating incrementally. They also present a comprehensive
framework for BIM adoption (including implementation and diffusion at market level). Hua (2014) found that BIM diffusion is influenced by seven innovation culture dimensions, which are creativity, attitude to change, attitude to technology, attitude to learning, institutions, communication, and tolerance for dissenters; and communication was found to be the most prominent one in several phases of the diffusion. Linderoth (2010) argues that the disruptive nature of networks constituting building and construction projects creates the greatest challenge to maintaining and re-establishing the BIM network in consecutive projects. Linderoth (2010) emphasises the clients’ role in demanding BIM usage and concludes another aspect: “When clients and regulative authorities start to demand use of BIM in building and construction projects, the issue of whether or not to use it is resolved”. Porwal and Hewage (2013) introduce a partnering framework for public construction projects and suggest BIM adoption through BIM partnering and the development of a collaborative BIM model for the construction process. Love et al. (2014) point out that BIM implementation is not static, and asset owners should consistently ensure that BIM benefits are materialising at the right time.

2.2 Management of supplier innovation in infrastructure projects

From an innovation perspective, the construction industry can be approached as a complex system. For each project, a large group of organisations (owners/clients, contractors, designers, material suppliers, regulators, etc.) have to collaborate as a network for the outcome. In terms of innovation, this network creates multiple sources of innovation, initiated from both the top of the project organisation (clients, regulators, professional institutions) and from the bottom of the organisation (contractors, specialist consultants, designers and component suppliers) (Davies and Harty 2013). Previous research suggests that understanding the processes by which BIM is developed, adopted, and diffused requires consideration of the networked and project-based nature of the industry (Davies and Harty 2013). Significant amounts of the industry's work are delivered in and through projects, and temporary project organisations also make up a large percentage of the overall construction organisation. Previous literature has proved that clients can enhance innovation in construction in a number of ways (Blayse and Manley 2004; Lahdenperä 2007). In Section 4, we present innovation catalysts. Innovation catalysts are a systematic way to foster innovation in construction and infrastructure projects.

As the construction sector is not unique in all respects, the literature in other industries can also be applied. Involving external partners, such as suppliers, in the innovation process has proved to be useful in many industries (Chesbrough 2003), and recent empirical studies have proved the positive overall effects on innovation of the acquisition of external knowledge (Cheng and Huizingh, 2014; Roper et al., 2013). Recent literature has increasingly treated the topic using different terminology, such as open innovation, involving suppliers in innovation or innovation alliances (Aminoff et al. 2015). If an organisation has the necessary supply management capabilities, it can integrate internal and external resources and extend innovation across organisational boundaries. Interestingly, some authors emphasise utilising the supply network, in that firms should not just focus on innovation input from individual suppliers, but firms should rather adopt a more strategic approach to utilising innovation opportunities from the supply network (Narasimhan and Narayanan 2013). In utilising its supply network, the firm must to
commit to supporting innovation across the supply network (Musiolik et al. 2012), and mechanisms for two-way exchange of knowledge need to be implemented (Narasimhan and Narayanan 2013).

3. Method

A qualitative, single case-study design method was chosen to match the state of current theory and the exploratory goals of the study. A case-study design is applicable for identifying emerging themes and patterns, as it allows for acquiring rich and detailed data of the studied phenomenon (Eisenhardt 1989). Further, case research is an effective strategy in seeking to satisfy criteria of methodological rigorousness and practical relevance simultaneously (Ketokivi and Choi 2014). This study aims for theory-elaboration. It focuses on practices related to the focal organisation, and investigates several other organisations that are in relationships with the focal organisation.

The Finnish Traffic Agency (FTA) was chosen as the focal company for this study. FTA is responsible for Finland’s roads, railways, and waterways. FTA is the largest client in the infrastructure sector in Finland. FTA’s current spend on ongoing projects is 4.4 billion euros, and the purchases form 25% of the total infrastructure market size. FTA’s strategic goal is to increase the productivity of the infrastructure sector. The products and services are not produced by FTA itself, but are procured from suppliers operating on the open markets. Given this, FTA (i) has a strong interest in developing BIM, (ii) has good possibilities to influence BIM-related innovations, (iii) and has also a high strategic incentive to develop supplier innovation. Furthermore, FTA has already developed advanced procurement processes and has applied many new procurement methods to ensure a well-functioning market and to promote the productivity of the infrastructure sector. FTA participates actively in various national and international BIM development efforts and initiatives.

We combined multiple data collection methods, with interviews being the main method. Other data sources include informal meetings, presentations, and company documents, and two workshops. In total, 21 semi-structured interviews were conducted in the study. Interviewees included 9 owner (FTA) representatives, 4 designers, 3 contractors, and 5 other experts in this topic. Interviews were conducted in autumn 2014 and spring 2015, and one interview lasted 1-1.5 hours. We selected the interviewees based on several discussions with different managers in FTA. Interviewees were selected so that they represented a good balance of different organisations and different project types where BIM has been used. However, it should be noted that BIM has been mostly used in fairly large projects so far. Interviewees that presented smaller projects had only limited real-life experience of BIM. Data collection instruments included the following topics: interviewee information, and semi-structured questions about supplier innovations, BIM in procurement, and diffusion and adaptation of best practices in the use of BIM. The instruments were slightly modified for each interviewee, based on their position. Data collection was allowed to overlap with data analysis, as recommended by Eisenhardt (1989), in the form of running commentary and field notes to identify areas of emphasis and take advantage of flexible data collection. The interview recordings were transcribed. For the purpose of analysis
a conceptual coding process was conducted, to relate the information to the theory (Eisenhardt 1989).

We put a lot of effort into increasing the validity and reliability of the findings (Yin 2013). Semi-structured interviews help the interviewers to guide the discussion in the aimed direction, and minimise the risk of bias caused by poorly constructed interviews. The reliability was enhanced by constructing and following a case study protocol. Multiple data sources, such as informants from the FTA, designers, and contractors, as well as additional documents and reports, allowed data triangulation. This increased the construct validity of the findings in accordance with Yin (2013). The conclusions were verified in workshops with the FTA managers, to further enhance the construct validity. Furthermore, a chain of evidence was established by recording the interviews and writing field notes throughout the research process. External validity is addressed by grounding interview themes in extant research and reflecting the emerging findings with respect to previous academic understanding.

4. Framework of innovation catalysts

The study applies ‘innovation catalysts’ identified in a previous research project (Lahdenperä 2007) as a frame of reference to assess the state of the owner’s activity. The catalysts were determined as means of fostering innovation in construction and infrastructure projects. The work was based on extensive literature by means of contents analysis (e.g. Insch et al. 1997), which offers a sound methodological frame for conducting a rigorous and systematic literature review and is also shown to be common in practice (Seuring and Gold 2012). It is important to note that the categories were formulated in the terms of the material, and therefore the approach of contents analysis was inductive (cf. Mayring 2000). The source documents of the analysis include more than 50 research and practice-oriented papers. To name a few, Winch (1998), for instance, presented a theoretical view of the management of innovation in construction as a complex systems industry, while Ling et al. (2007) compared key factors in innovation grounding in a survey of project clients. Other distinguished sources were offered by Blayse and Manley (2004) and Bossink (2004). The former identifies the main factors driving or hindering construction innovation and ends up with an itemised list of innovation strategies that are widely acknowledged as important to innovation outcomes. Correspondingly, the latter studied, distinguished, and classified various drivers of construction innovation used by construction industry actors to stimulate and facilitate innovation processes. Eventually, the work resulted in numerous principles called innovation catalysts, pertaining to many different procedures that are considered critical in improving the preconditions for innovation in a construction project context. They were categorised in 12 areas, presented in a compressed form below, forming the framework for subsequent evaluation.

1. **Active and competent owner.** The owner, whose competence and participation in the development and implementation of the project is important as the setter and driver of challenging and realistic demands, plays the key role in the improvement of innovation possibilities.

2. **The need and performance approach.** Communication of needs and the procurement documents of the owner, which contain performance requirements, are preconditions for
sufficient latitude in development, so that the suppliers have a genuine chance of achieving novel, improved solutions.

3. **Long-term goals.** Solutions must be sought and assessed in continuous owner projects also based on the benefit of their repeated use. Use in a single project and its economic efficiency may be the only applicable criterion.

4. **Partner selection criteria.** The selection of a supplier for a project must be based on a genuine advantage comparison, supported by carefully weighted quality and cost factors, and/or assessment of their implementation possibilities, such as being based on competence.

5. **Comprehensive network co-operation.** Innovations are born as a result of the collaboration of many parties, which means that the team of suppliers and developers taking part in the project must be involved early enough in terms of design, in addition to the owner and the main implementer.

6. **Project organisation.** Conditions for overall optimisation of services are created by procuring services as entities, where the required skills are integrated in contractual frameworks that act as a guide towards the common goal.

7. **Confidence and openness.** Open design and information systems are developed for projects, and opportunities for co-operation are supported through development workshops, common space arrangements, and systematic and faster decision-making chains.

8. **Continuous interaction during the project.** The interaction between the parties, aimed at developing the project, must start early with respect to design and continue with an emphasis on goals throughout the project, with regular evaluations of the co-operation.

9. **Continued collaboration across projects.** The goal should be to conclude comprehensive partnership agreements covering several projects, or to acquire project portfolios in collaboration, which enables deeper interaction, learning, and profitable development of solutions.

10. **Use and ownership of ideas.** Rules of the game and competitive practices are to be developed and introduced so that it is profitable for those coming up with new solutions to present them and so that the innovator gains a competitive advantage from the innovation.

11. **Risk-sharing and payment bases.** Possibilities of co-operation and development orientation are promoted by harmonising the goals of the parties so that the risk of the entity to be implemented, as well as the benefits of its success, are shared between the actors.

12. **Information and knowledge management.** Information management systems are created for processing experiential knowledge and ideas, to enable the accumulation of knowledge (in time, within an organisation) and to serve as a tool in seeking new solution proposals.

5. **Results**

The following sections present the findings from the empirical data. Table 1 presents the results from interviews related to each innovation catalyst, and the assessments of designers (D) and contractors (C) regarding the current status of innovation catalysts, categorised into three classes: positive (+), neutral (0), and negative (-). The numbers 1-12 refer to innovation catalysts, as presented in Section 4.
Table 1: Research data based on innovation catalyst framework (D=Designer, C=Contractor)

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Assessment</th>
<th>Results</th>
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</thead>
<tbody>
<tr>
<td>1. Active and competent owner</td>
<td>D: - C: +</td>
<td>The client’s forward-looking, competent, and active role in BIM development was appreciated in the interviews. The client has successfully driven BIM-related activities in the infrastructure sector, which was considered to benefit the development of the whole sector. Partly due to these efforts, the foundation for BIM exists. The suppliers follow the client’s activities and aim to fulfil the client’s emerging requirements. The client would improve BIM innovation possibilities by being more active in daily activities in the projects.</td>
</tr>
<tr>
<td>2. The need and performance approach.</td>
<td>D: - C: +</td>
<td>Defining requirements that are not too detailed, giving designers and contractors more leeway and the chance for novel solutions, was perceived as a good strategy for the future in the interviews. This approach has been trialled in some projects; however, the impact on innovation has been very modest. To foster innovation, the appropriate level of requirements needs to be complemented with the client’s active participation in steering and feedback during project execution.</td>
</tr>
<tr>
<td>3. Long-term goals</td>
<td>D: - C: 0</td>
<td>The innovation targets, incentives, and evaluation of the results are implemented mainly on an individual project level. Based on the data, this approach is not optimal, because the main targets of a construction project typically somewhat contradict the innovation prerequisites. As an example, implementing innovations inherently increases project schedule risk. Furthermore, the project-centric approach does not very effectively support long-term development and learning, which would be important from an innovation perspectives.</td>
</tr>
<tr>
<td>4. Partner selection criteria</td>
<td>D: - C: +</td>
<td>Partner selection criteria are mostly based on company and key personnel references. This does not take innovation capabilities into account. Selection criteria suggested in the literature, namely company innovation processes, practices, and innovation statistics, have not been used. The quality criteria in the bidding process have little impact on the results of the process and, thus, are not seen as very attractive from a bidder’s perspective.</td>
</tr>
<tr>
<td>5. Co-operation network</td>
<td>D: 0 C: 0</td>
<td>Results on this catalyst are fairly limited. However, in some pilot projects, a larger network of different stakeholders, including research institutes, has been involved. This approach has received positive feedback.</td>
</tr>
<tr>
<td>6. Project organisation</td>
<td>D: - C: 0</td>
<td>Research data indicates that the bidding process and delivery model have very significant implications for the innovation possibilities in the project. Delivery models that are based on co-operation (e.g., alliance) offer much better antecedents for innovation compared to traditional models, where contractors compete mostly on price. Notably, competition based solely on price is used quite commonly when procuring design services. Designer-contractor interaction is one important element that can stimulate innovation. The chosen delivery model obviously has a major influence on the interaction. Therefore, acquiring design services and contractors separately is not always the best model from an innovation standpoint.</td>
</tr>
<tr>
<td>7. Confidence and openness</td>
<td>D: - C: 0</td>
<td>The alliance model has enabled an open, innovation-friendly atmosphere and changed decision-making in the projects. The PPP-model and Design-Build have been significantly worse in this respect. Pre-project development workshops for the client and bidders have increased the possibility for interaction, and received positive feedback in the interviews. This method has also yielded positive concrete results in the projects.</td>
</tr>
</tbody>
</table>
The results indicate that the client has actively implemented some innovation catalyst principles. Some other catalysts have been experimented with in a few projects, but are not used systematically throughout the project portfolio. The third group consists of catalyst practices that have not been used at all. The results suggest that using catalysts as a frame of reference offers a systematic method to analyse innovation practices in the projects. To further improve the possibilities for innovation, the client should focus more on the catalysts that have not been actively used so far. Specifically, efforts should be strengthened in the areas that have been used occasionally, and that have given positive results.

Generally, designers consider their possibilities for BIM-related innovation fairly weak, and were quite critical of the possibilities to develop innovations in the projects. This is somewhat alarming, as designers are in a pivotal role in developing BIM further. Designers naturally play a key role in the first phases of a project, and therefore they create the foundation for the BIM usage during the project lifetime. The possibilities for BIM-related innovations in the later phases of the project are significantly weaker if BIM potential is not fully realised from the start of the project. Currently, modelling means mostly additional work for designers, and this additional workload is not fully taken into account in the designer’s fees. A major portion of the BIM benefits are capitalised in the later phases of the project. Contractors, on the other hand, were fairly positive about BIM-related innovations. Based on the research data, contractors seem to have the best overall view of the infrastructure project and the role that modelling can play in it. Contractors
also get the most significant financial benefit from modelling. In particular, BIM-enabled automatic machine control increases contractor efficiency and enables cost savings.

The findings from our data emphasise the role of the project delivery model in creating antecedents for innovation, and the alliance model seems to offer much better antecedents for innovation compared to traditional models, where contractors compete mostly on price. Our results also emphasise the importance of consistency in the client’s behaviour and communication, as the suppliers are eager to support the strategies of the client.

6. Discussion

The findings of this study contribute to the literature by describing how a public client organisation can stimulate BIM-related innovation. As the infrastructure sector operates in a project-based mode of delivery, it is critical to understand how innovation can be stimulated in the projects. In the literature, BIM innovation is referenced as a somehow monolithic concept, although it is a wide set of methods, technologies, and processes. Each of these should be managed in order to achieve further development. BIM innovation is decentralised and should be implemented in cooperation with suppliers. Innovation in infrastructure projects, driven by clients, designers, and contractors, mainly focuses on added value, cost savings, or productivity, and BIM innovations are seen as enablers for those. In the interviews in this study, the interviewees often discussed innovation in general, and in some interviews it was difficult to guide the discussion back to BIM-related innovation. However, our results suggest that enhancing the antecedents for innovation in general also stimulates BIM-related innovation.

In this study, we utilised a framework of innovation catalysts, which is based on an extensive literature review conducted in a previous project, to assess the empirical research data. Based on the innovation catalysts, there is a multitude of different factors that influence the possibilities for innovation. A client can actively manage these factors. It is important to ensure that the antecedents for innovation are in place in the projects that aim for BIM-related innovations. Our results emphasise the role of procurement in innovation, as many of the identified methods that improve the antecedents of innovation require the use of advanced procurement strategies. Thus, this study also brings a further aspect to the purchasing literature, which discusses the involvement of procurement in supplier innovation (Johnsen 2009; Luzzini et al. 2015). Secondly, we observed that the perceptions of designers and contractors differ significantly, and this might prevent innovation goals from being reached. The main reason for this is that designers see that they do not get enough benefits from using BIM, and see it mainly as extra work. This is supported by the previous literature on inter-organisational innovation, which emphasises the importance of benefiting from innovation (Luzzini et al. 2015). The previous literature has also discussed the importance of congruencies in perceptions in achieving relationship targets (Aminoff and Tanskanen 2013). Thus, the client should focus on making sure that designers also get, and understand, the benefits of using BIM, either in the short term or the long term. There is some evidence (Barlish and Sullivan 2012) that the total costs of construction project have been lower than expected, even though the design costs have been higher due to BIM-based design.
Our study extends – in the context of BIM innovation – the previous authors’ proposition (Tawiah and Russell 2008; Lloyd-Walker et al. 2014; Lahdenperä 2007) that the delivery model influences the probability for innovation in general, with the alliance model offering the best antecedents. In theory, the PPP project model also opens up wider innovation possibilities, as the whole life-cycle of the construct, including operation and maintenance phases, is open for innovation. However, based on the data, PPP models have not led to good results from the viewpoint of innovation. In PPP models, the tight schedule and financial constraints are dominating criteria, and this leaves very few possibilities to take risks during the project. Risk inherently goes hand-in-hand with innovation. Our results also indicate that extensive PPP tender processes that are implemented in multiple phases create a difficult situation for bidders. They need to consider how much information to put into the tender response without revealing critical information to their competitors. Our results also emphasise the importance of consistency in the client’s behaviour and communication, as the suppliers are eager to support the strategies of the client. This is a common challenge in supplier innovation management (Luzzini et al. 2015), as there are different interests and objectives in different parts of organisations. Consistency is at risk, specifically, when the owner involves a separate construction management consultant to manage the project. Thus, by putting effort into systematic project-level influencing tactics, the client could enhance development and innovation activities. Moreover, in the project-based industry, the diffusion of innovation into consecutive projects has been seen as problematic (Taylor and Levitt 2004; Linderer 2010). It is obvious that the long-term asset owner should have the motivation and competence to support this kind of BIM implementation across projects. The results of this study also propose that one project is too short a time to assess innovation, and looking for innovation across projects might yield better innovation results in the context of BIM innovation.

This study presents initial but promising results on stimulating BIM-related innovation in infrastructure projects. The empirical context was, however, limited to a single case study, and thus the results need to be verified with further case studies. Second, it would be interesting to study how BIM-related innovation can be developed using approaches other than as part of an infrastructure project, for instance using innovation procurement models, such as the pre-commercial procurement model (PCP model).

7. Conclusions

Building information modelling (BIM) is a paradigm shift in the construction industry. BIM transforms and digitalises processes, and therefore increases efficiency and effectiveness. Importantly, BIM innovation is an enabler for more comprehensive digitalisation of the construction process. Because BIM influences many aspects of the construction process, BIM development and innovation requires a joint effort and good co-operation between many parties. This requires careful consideration, but can be very powerful when implemented successfully. This study investigates how BIM-related supplier innovation can be stimulated by the owner of infrastructure projects. Our results highlights that a public sector owner can stimulate supplier innovation by actively increasing the antecedents of innovation. We identify several tactics that a client can use to stimulate BIM-related innovation and, thus, to manage supplier innovation. Reciprocal, long-term, and cross-project collaboration activities are needed at different levels of
the organisation. The traditional way of managing infrastructure projects by sanctions does not optimally support innovation. Furthermore, based on the study, using economic incentives for innovation is not sufficient in many cases, as other project priorities might be in contradiction with the innovation targets. Innovation catalysts offer a systematic framework for the client organisation to assess the possibilities and preconditions for innovation in any given project. The results propose that the selection of delivery method strongly influences the antecedents for innovation – with the alliance model supporting innovation best.

8. References


Learning From SamBIM - A Norwegian Innovation Project About BIM-driven Collaboration in Ambitious Building Projects

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Abstract

This paper reports and discusses the status in a Norwegian research-based innovation project called "SamBIM – BIM-driven collaboration in the building process". The overall aim of SamBIM is to develop BIM-driven processes and collaborative models that boost value creation in construction projects, the AEC-industry and in the SamBIM-companies. SamBIM is funded by the Norwegian Research Council. The project partners are leading and R&D active companies in the Norwegian AEC-industry, representing various parts of the building process value-chain. SamBIM focuses in particular on the interface between programming, design, and the production phase. Important characteristics of the project is the holistic and interdisciplinary approach to phenomena studied in five ambitious real-life projects, the action research inspired methodology, and the use of change-agents as the "innovation gear" between research and practice. The SamBIM project concludes in 2016.

In this paper, we present preliminary results of the case studies. We furthermore investigate different foci, implementation angles, practice, and development of BIM-driven collaboration, both in the individual case project and in the SamBIM project in general. The paper discusses possibilities and challenges related to the research design and methodological approach of the innovation project. Knowledge development and learning across maturity levels, formal and informal implementation strategies, collaboration across scales (multidisciplinary dimensions, life-cycle perspectives), process models for collaboration, and measures to obtain high quality BIM-driven collaboration in the building process are among the subjects appraised. The multidisciplinary profile of the research team has been fruitful in order to grasp the complexity of the observed phenomena. The broad approach has made it possible to view SamBIM topics from different traditions, both practically and theoretically. The research has contributed to increase the industry partner's knowledge, as it has contributed to the scholarly literature (particularly through the two embedded Ph.d-studies).

Keywords: BIM, Building process, Collaboration, Case study, Implementation.
1. Introduction

In this explorative paper, we present and discuss the first lessons learned in a Norwegian ongoing research-based innovation project called "SamBIM – BIM-driven collaboration in the building process" (2012-2016). We address two main questions:

- How can we identify main drivers for successful BIM-driven collaboration?
- How can in-depth case studies of the building process in real-life projects reveal such drivers?

Implementing new technology alone does not necessarily improve the way we work and interact in building projects. Improvement seems to require an understanding of the interrelationship between technological, processual and people-related factors (Moum 2008, Owen et al. 2010). To manage and implement change and innovation processes is epically challenging in the AEC-industry (Architecture, Engineering, and Construction). The industry has some particular characteristics (Dubois and Gadde 2002, Eccles 1981), making innovations challenging to deploy (Harty 2005). Harty (2005) points out five factors central to understand how innovations are deployed in the AEC-industry: 1) Tasks are often conducted as collaboration between several firms, with own resources, practices and goals. 2) The work is project-based, and there are often large numbers of people and companies involved. 3) The work is dependent on information sharing across organizations. 4) The tasks intersect organizational boundaries. 5) Each involved firm influences on the project by own practices and expectations.

Inter-organizational collaboration, complex interdependencies, and the absence of a single actor who can ensure a unitary implementation and use of BIM for the whole project characterize the context of the SamBIM-project. In the following, we describe the SamBIM scope, objectives and the methodological approach. We furthermore present the case studies and some first tentative findings, before we explore on the two questions above. We wrap up the paper with some concluding remarks.

2. SamBIM's scope and objectives

The successful collaboration and interaction between the people involved in the programming, design and production of building projects is a key to value-creation. This has traditionally been a challenging quest in temporary and non-continuous project teams. Such teams are typically comprised of companies who have never worked together before, who are representing different roles, interests and disciplines, and who are responsible for different parts of the process. The implementation and use of BIM (Building Information Modelling) is expected to improve collaboration and enable new and more efficient ways of working. Around fifteen years ago, the first companies in the Norwegian AEC-industry started implementing and using various BIM-tools. The implementation of the first generation of BIM demonstrated positive effects on design team coordination. Still, the industry is yet not enhancing the full potential of BIM beyond the goals and achievements of individual participants and phases. An initial state-of-the art review in SamBIM identified a need for more holistic knowledge on BIM-driven
cooperation across phases and actors. SamBIMs multidisciplinary approach relates to architecture, technology and construction management as well as organizational studies and sociology.

The overall aim of SamBIM is to develop BIM-driven processes and collaborative models that boost value creation in the SamBIM partners, in the building projects, and in the AEC-industry. This is to be obtained by processes that are more efficient, customized end-products, better use of resources, reduced costs, less process-related building defects, and less waste. In SamBIM, leading Norwegian AEC-companies and research environments are together identifying and developing knowledge. Experiences are gained from exploring collaborative models and processes in real-life building projects with high BIM-ambitions. The partners expect research outcomes and innovations with positive impact on the planning and production of buildings, such as:

- Successful adaption of new working methods, for instance Lean Construction principles, ICE (integrated concurrent engineering) and more;
- Improved competence of the client, consultants and contractors when it comes to purchasing and supplying services in BIM-supported building projects;
- Improved information flow and coordination – with particular focus on the interface between programming (client requirements), design and production of building projects
- Better understanding of roles, responsibility and tasks – and of management and organizational drivers and barriers in BIM-ambitious building projects.
- Less errors and better buildings.

3. Methodological approach

SamBIM is an Innovation Project for the Industrial Sector funded by User-driven Research based Innovation (BIA), a programme of The Research Council of Norway (RCN). The BIA programme aims to promote value creation in Norwegian trade and industry through research-based innovation in companies and the R&D environments with which they cooperate (RCN 2015). Innovation Projects are owned by a company or an organization. They include research activities and knowledge development needed for implementing innovations and value-creating renewals. These projects call for a research methodology enabling a high degree of interaction between the industrial partners and the involved R&D environments. A successful implementation enabling a subsequent value-creating effect in the companies is crucial.

The SamBIM methodology addresses the premises of RCN in several ways (Fig.1). Firstly, action-research inspired case studies of real-life building projects serve as an arena for both data collection and interactive knowledge development. Important criteria for selecting the real life projects were: 1) High ambitions of BIM-use and collaboration, and 2) Participation of a SamBIM company in the project. The research group has carried out open-ended and semi-structured interviews (individuals and groups) at different levels in the companies: at strategic level (management, client), tactical level (project management), and operative level (architects, consultants, BIM advisers). The group has furthermore observed project meetings and other project process related activities as well as relevant documents. The questions are targeting processes, people involved, technologies used, and the interrelationship between these. This
paper primarily presents findings from these case studies. Secondly, based on the data from the first case studies, thematic working groups were established to elaborate on cross-case challenges. Thirdly, the industry partners have kicked off company-internal development projects. Fourth, Ph.D-students are digging deeply into core issues of SamBIM. SamBIM is a learning hub, interconnecting and boosting knowledge development and implementation across the arenas in Figure 1. An important measure for ensuring a close interaction between the different learning arenas, and between the industry- and research partners, has been the so called "change agents". Each of the companies involved have appointed an employee to this role. The change agents support SamBIM as "innovation-gears" and gate-openers, acting as two-way contact points between research and practice. They assist the research activities by driving necessary internal coordination, mobilisation, and information work in their companies. They are giving access to case studies, driving forward some of the thematic working groups, and they are active participants in workshops and SamBIM project meetings.

4. SamBIM as a learning hub

4.1 The SamBIM consortium

The project owner of SamBIM is Skanska Norway, one of the biggest contractors in Norway. Skanska’s industry partners are Statsbygg (building commissioner), Multiconsult (an interdisciplinary consultant company) and LINK Architecture. All of them are R&D active and linked to international sister companies or equivalent organizations in other countries. They are front-runners in BIM implementation, and are involved in networks and joint initiatives such as BuildingSMART, Lean Construction Norway and more. Together these companies represent the stages of the building process crucial to SamBIM: programming, design and production. The industry partners have committed a multidisciplinary research group as required by the complex and broad objectives of SamBIM. The R&D partners are SINTEF Building and Infrastructure, Fafo, and The Norwegian University of Science and Technology (NTNU). Around five researchers and two Ph.D-students are involved in the project on a continuous basis, with expertise from architectural and engineering sciences, technology implementation, process-related research and social sciences.

4.2 Thematic focus areas

Both researchers and industry partners contribute in the thematic working groups, established by the need to dig deeper into specific topics:
Barriers and drivers for collaboration; aims to identify barriers and drivers for co-location/integrated concurrent engineering in the design phase of constructions projects, opportunities and obstacles for mutual adaptation of technology, and organization and process among actors in the design phase. Ambition: to publish a publicly available collaboration guide.

Lean Construction; aims to facilitate arenas where topics related to Lean Construction are discussed and further developed, and to obtain a more unambiguously perceived term, both by researchers and industry partners. Ambition: to collaborate with the Lean Construction Norway network to spread the results of the SamBIM project.

A common process model; aims to develop a common process model for the building process, from cradle to grave. The SamBIM findings have been communicated to a national initiative on a new norm for describing the stages of a building process, inspired by the RIBAs plan of work in the UK.

4.3 The case studies – tentative findings

The SamBIM-team has carried out five case studies of real-life building projects (Table 1). Two of them are still ongoing (spring 2016). This section briefly presents tentative findings from each of these case studies.

<table>
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<tr>
<th>Case Characteristics</th>
<th>Risløkka</th>
<th>Veitvet</th>
<th>Deichmanske</th>
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<th>Eikefjord</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Road authority building (refurbishment)</td>
<td>School building (new)</td>
<td>Public library (new)</td>
<td>University building (refurbishment)</td>
<td>School building (new)</td>
</tr>
<tr>
<td>Project delivery method</td>
<td>D-B</td>
<td>PPP</td>
<td>D-B-B</td>
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</tr>
<tr>
<td>SamBIM actor involved</td>
<td>Statsbygg</td>
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<td>Statsbygg &amp; Skanska</td>
<td>Skanska</td>
</tr>
<tr>
<td>SamBIM focus/initiativ</td>
<td>BIM, ICE</td>
<td>BIM, PPP</td>
<td>BIM, process model</td>
<td>BIM, ICE, Lean, “BIM kiosks” (on-site)</td>
<td>Procurement, BIM, collab. model, lean, big-room</td>
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</tbody>
</table>

4.3.1 Risløkka

The case deals with the refurbishment of a medium-sized office building located in Oslo, for the Public Roads Administration. Statsbygg acted as building commissioner. Already in the pre-design phase, Statsbygg appointed this project to become a SamBIM case study. Because of the connection to SamBIM, Statsbygg and the design team agreed on testing out the following Lean Construction-inspired work principles in the design phase:
- Co-location of the design team and Statsbygg twice a week;
- Working principles inspired by Integrated concurrent engineering;
- The use of a so-called planning matrix and action items.

Bråthen et al. (2014) and Bråthen and Moum (2015a) identify driving and restraining forces affecting the BIM implementation in this case study. Rather than just studying its effects, the actual implementation was also in focus. The analysis displays that a successful implementation of BIM largely depends upon a participative and co-operative process at the ground level. At this, the significant project participants must be involved in the development of a BIM-implementation-plan. This plan should reflect interests and goals of the involved parties. The analysis points out that related discussions and negotiations can ensure ownership and the design team participants' commitment to an innovative and, for some, unfamiliar BIM-process. The study also shows that working principles based on Lean Construction contributed to a more dynamic design team. Especially the combination of BIM and co-location opened up for working in a new and more efficient way. When working co-located the designers used BIM to show each other possible solutions and problems and could make clarifications and decisions “there and then”. According to our informants this implied faster decisions and better interdisciplinary working compared to a “traditional design process” (Bråthen et al. 2014). However, such a way of working requires that all participants are present and have decision-making authority.

4.3.2 Veitvet

The Veitvet primary and lower secondary school was a public-private partnership project (PPP), partnering the turnkey contractor and property developer Skanska and the municipality of Oslo. It was a Future-build and BREEAM Very Good project, with high environmental ambitions (passive-house level). It seemed that the project had a high potential for innovation and collaboration between the professional participants of the building process. The SamBIM partner LINK Architecture had a role as responsible architect. Initially, the BIM ambitions were high, and the ambitions from the research project SamBIM should be implemented in the Veitvet project. Due to different circumstances, the project was however withdrawn as a case quite early in the SamBIM project.

The findings reveal that the project in practice seemed to develop into a traditional turnkey project, and that the formalized BIM requirements neither were met nor implemented. The collaboration seems to have failed, partly due to challenges concerning the PPP model and contractual structures between the ”partnering” participants (fixed prices), and partly because the model for collaboration was not sufficiently developed and/or rooted in the contractors' management. Both BIM model and paper drawings were requested by the project management, which may have resulted in an unclear perception of the model for project management and collaboration (as a mix of traditional management and BIM) (Flyen 2016a). Even if Veitvet was terminated as a SamBIM case project, the experiences had major ripple effects and seem to have made a vast contribution to the later development of a Skanska process model for collaboration used in subsequent projects.
4.3.3 Deichmanske

In 2013, Oslo Agency for Cultural Affairs commissioned a new library building. The new main branch of Deichman, Oslo's public library, is currently under construction in Bjørvika. The SamBIM partner Multiconsult won the main engineering contract for the new library, including the responsibility for coordinating the design team. Together with three other consultant companies, they are responsible for the detailed design phase. Multiconsult has for several years been developing a generic process model for BIM-enabled projects. As a part of the Deichman project, Multiconsult wanted to streamline and improve their model further, through experiences and insight from this significant project. Related to this aspiration, SamBIM’s research partners have mainly focused on the following topic in this case:

- Effects of connecting BIM to the process model through milestones. This implies that decisions about the model status in different zones of the building will be frozen at a certain date.

Skinnarland (2015) found that using a Multiconsult process model has been a valuable experience for the various actors in the design team. Using the model puts pressure on the actors to make decisions in accordance with the model, often on an earlier point of time in the process than they normally do. The informants considered the model to have contributed to more and better interdisciplinary collaboration within the design team. However, Skinnarland (2015) found a mismatch between Multiconsult’s position within the design team and their possibility to put pressure on the other companies to make all their decisions in accordance with the model. Consequently, one important conclusion from the case study is that too little attention was devoted by Multiconsult on core elements in the implementation and development process of the process model. The model was introduced to all participants in the design team without sufficient discussion. Hence, a necessary ownership was not created, nor a common vision for the use of the process model. These shortcomings were probably significant for the less successful results compared to what was expected when using the model in the detailed design phase.

4.3.4 Urbygningen

The case deals with the refurbishment of a University building named Urbygningen at the Norwegian University of Life Sciences located outside Oslo, with Statsbygg as the building commissioner. The preliminary design completed in 2009. In 2013, Statsbygg initialized the detailed design phase. The ongoing construction phase started in August 2014. The design team consists of several Norwegian, Oslo-based companies. The SamBIM partner Skanska was chosen as the general contractor. Statsbygg wanted to test the following in the design and construction phase, respectively:

- BIM combined with co-location of the design team, methods inspired by lean design methods;
- BIM for site workers in the construction phase (“BIM kiosks”).

Statsbygg’s expectation was that BIM and the lean-design-inspired work principles would lead to better collaboration among the involved actors, and thus lead to an improved design process.
The data suggest that this principally occurred. The findings indicate that BIM combined with some of the lean work principles yielded good results regarding the intentions, through linking the team stronger together, technologically as well as organizationally. In particular, it turned out that the combination of BIM and co-location of the design team created good results. The findings indicate that this approach helped to improve the inter-organizational and interdisciplinary collaboration. It fostered faster communication and made improvements in latency, as well as contributing to a better social climate in the design team. However, the data also suggest that not all parts of the contractual “BIM and Lean-package” were equally successful in practice. The analysis indicates that the various pieces of the lean and BIM concept were emphasized differently in the implementation process. Elements given little or no attention in the implementation process are less likely to lead to good results. In the construction phase, Statsbygg and Skanska introduced so-called «BIM computer-kiosks» in order to allow site workers on-site access to 3D models. Bråthen and Moun (2015b) investigated the use of the computer kiosks and the related consequences. The findings indicate that there are great advantages by adopting BIM and similar technology at the construction site. This relates, among others, to the fact that the workers obtain a more holistic understanding of the planned building through the excellent possibilities for visualization. The workers get the ability to investigate particularly complex issues and to access details that hardly can be seen on a traditional paper drawing. In addition, the findings indicate that in certain cases the data kiosks facilitate a greater level of face-to-face collaboration between site workers. This occurs because workers meet, both planned and randomly, to discuss in front of the computer kiosk while using the model for visualizing complex issues. This means that the data kiosks can pave the way for new on-site collaboration forms.

4.3.5 Eikefjord

The Eikefjord primary and lower secondary school case is a comprehensive demolition- and new building project situated on the coast of Western Norway. The project- and building owner is Flora municipality. The execution model is interaction based turnkey contracting. The SamBIM partner Skanska is the Turnkey contractor (engineering, procurement and construction). The researchers from the SamBIM project have been following the project from the initiation of the design-build and tendering competition, through the design process and start-up of construction works. Eikefjord is the fifth and final case-project in SamBIM. The process encompassed demolition, relocation and temporary housing of school functions, building of the new school and sports arena, and build-up of outdoor areas. The school operations were to be running parallel to the demolition of the old school and building of the new, with operations partly in the localities of the old school, temporary barracks, and gradually employing the new buildings. Skanska generated an internally developed collaboration process model prior to the initiation of the early stages in the design-build tendering competition. The case project was a pilot for the new process model. The project team was complete already from the initial stages of the competition, adapting full collaboration, team building, and collective experience learning from early design and composition of tender. Skanska managed the project and the project design team, had the BIM coordinator and a process supervisor/change agent to follow collaboration process. Consultants, architects, and manufacturers were both locally- and
Oslo based. Both collaboration- and BIM ambitions were initially high, and the research focused on the following areas in the collaboration process model employed in the case project:

- Implementation of a collaborative focus from initialization of design-build and tendering competition;
- Lean-construction inspired backwards planning/scheduling and implementation of tendering, design and construction stages;
- High BIM-ambitions, both in tendering, design, and construction, and as a support tool for close collaboration;
- Workshop-based collaboration approach, with frequent gatherings;
- Virtual and physical BIG-ROOMs in the design phase.

The primary focus of the newly developed process model ensured collaboration and co-localization from initial start-up, and upheld the baseline goals agreed upon throughout the whole of the process. Due to the partners’ different localities, a continuous focus on collaboration has been imperative. The use of virtual and physical BIG-ROOMs, frequent workshops, and clarification of expectations for deliverables for each other to the next gathering has been important drivers to achieve this goal. The Lean construction-inspired scheduling approach yielded complete overview of all participants and interfaces. Both holistic and interface coverage between professions has successfully been ensured by the all-team and two-party clarification meetings during the workshops. The consensus-based rules for collaboration and workshop-based process ensured a rapid and effective design process, but required that all participants were present and had decision-making authority in the workshops (also the owner). The results of the earlier case projects in SamBIM seems to have inspired, and partly driven, the development of the Skanska collaboration model. The experiences with the model so far are very promising in terms of efficiency and quality of both collaboration and project results (Flyen 2016b). The model has thus proven to be an important driver for collaboration and the use of BIM in construction projects. Further, the participants have expressed that this way of collaboration is inspiring and positive, and that they want to continue to pursue this approach in further projects.

5. Discussion - Learning from SamBIM

What are the first lessons learned across the single case studies and adjacent activities? In the following, we discuss how the SamBIM team has identified main drivers for successful BIM-driven collaboration. We elaborate on three key topics: 1) learning loops and maturity levels 2) implementation strategies and, 3) commitment and continuity.

5.1 Learning loops and maturity levels

Three factors were particularly challenging throughout the project: 1) to achieve a shared understanding of ambitions, activities and roles, 2) to find appropriate case studies and, 3) to close the gap between the ambitions and the various maturity levels in the organizations and the projects. The initial ambitions of SamBIM were high. The starting point was a broad and holistic view on developing new ways of collaboration, enhancing the full potential of BIM. The partners wanted to develop new generic models and methods, which, in the next step, should be
applicable for other actors in the Norwegian AEC-industry. To orientate in this rather complex
landscape of interdependencies, and to operationalize the overall objectives into definite actions,
required much effort in the first stage of SamBIM. The related discussions between the
researchers and the practitioners (and the study of state-of-the-art elsewhere/in the industry)
gave valuable guidance. Based on the knowledge gained from the case studies and the
discussions about the goals and ambitions, the SamBIM-team decided to establish three
thematic working groups as an arena for elaborating the selected cross-case topics as previously
described. An important function of this work is to transform the pool of empirical data into
definite and applicable outcomes for the industry partners. Important topics in the SamBIM-
team discussions were e.g.; to which degree can the SamBIM project realistically hope to
influence on cultures of collaboration within real-life projects and organizations? What is
process-innovation for each of the partners involved?

Finding real-life projects to match the high ambitions of investigating new ways of
collaboration and advanced BIM-use from early design to production was challenging in the
first stage of the SamBIM-project. The partners had thus to apply a rather pragmatic approach to
narrowing down the scope and limiting the ambitions. It was necessary to adjust to the restraints
of the available case studies, and to the maturity of the involved organizations. Still, as the
project developed and the insight and the maturity of the industry partners increased, new cases
replaced or succeeded the initial ones. The new projects could thus benefit from the preceding
experiences. An example is Skanska's steep learning curve on their way from the Veitvet to the
Eikefjord case.

Would SamBIM have benefited from a more limited scope and more mature case studies from
the beginning? Not necessarily. To move from the overall picture down to the details, and to
research the not-perfect real-life situations might have been challenging, time-consuming and
partly painful. This process has however also revealed findings and experiences, which might
otherwise have remained undiscovered. More important, this process has been useful in order to
harmonize the progress with the actors' need for time to move upwards on the learning ladder,
step by step.

5.2 Formal and informal implementation

The case studies show, in different ways, the importance of a good understanding of
implementation drivers and related strategies. An obvious implementation driver for "SamBIM-
working" (BIM-driven collaboration) is formal contractual requirements of the client (for
instance early contractor involvement and co-location/big-room solutions). The SamBIM
findings do however indicate that this is not enough to achieve successful implementation and
related change of traditional practice. Not only formal, but also informal drivers of
implementation can be powerful. For instance a dedicated design manager (or a change agent),
who, with a personal engagement and belief in what he/she is doing, motivates and inspires
colleagues or a team to try out new technologies or ways of working. A good implementation
strategy should include formal measures, as it should take into account, be aware of, and utilize
the power of informal drivers such as involvement and participation of involved parties.
5.3 Commitment and continuity

Initially, one of the case-study criteria was that at least one SamBIM industry partner had to be involved in the building case projects. The role (and the authority) of the partner in the project affects the ambitions and possibilities of a broad implementation. Statsbygg and Skanska in their client or turnkey contractor role could put pressure on the implementation of the SamBIM-approach (top-down). The architect or the consultant company (bottom-up) did not have the same impact in the projects with an external and not "SamBIM-committed" client. To create interest and commitment among all building project participants, would enable a broader impact and probably also enhance greater benefits. This is however not always possible, and calls for activities with realistic scope, adjusted to the constraints of what is possible to test or change. Tight collaboration between research partners and industry partners is an important premise for success in innovation projects such as SamBIM. In AEC-companies, there is often a high labor turnover and change of people in management positions. The SamBIM-companies have been no exception to this. Throughout the project period, the team members in the SamBIM group have changed several times, including the project management. This creates challenges for the team building and the continuity of the work. The same situation has also partly characterized the building projects studied. Changes in work force can affect both positively and negatively on the progress and success of a project. They are however unpredictable and not possible to influence on. This makes it even more important to create robustness in organizing such tight research-practice collaborations.

6. Concluding remarks

A motivation and crucial expectation of the industry partners (and the Norwegian Research Council) is that the SamBIM-activities will contribute to actual improvement of their practice. This is relevant both for the building projects they are involved in, and for their own organizations. In order to wrap up this tentative report, we summarize how in-depth case-studies of the building process in real-life projects has revealed main drivers for successful BIM-driven collaboration:

- Learning across the case-studies has been highly valuable. To develop knowledge step-by-step from case to case has given an added value to the SamBIM project beyond what would have been possible with parallel and isolated cases;
- To develop and implement research-based knowledge on holistic, “soft” and hard-to-measure issues in real life settings is challenging. In SamBIM, it has been important to allow for maturation, unexpected findings, necessary corrections and limitations as the insight and understanding among the partners have gradually grown;
- The dynamic interchange between the four knowledge development arenas (Figure 1) has been highly valuable. The activities have boosted each other and the progress of the SamBIM project. They have also stimulated learning loops and continuously pushed the partners into investing in new fields;
- The multidisciplinary profile of the research team has been fruitful in order to grasp the complexity of the observed phenomena. The broad approach has made it possible to view the SamBIM topics from different traditions, both practically and theoretically. The research has contributed to increase the industry partner's knowledge, as well as to the scholarly literature (the latter particularly through the Ph.d-works);
• The close interaction between the researchers and the industry partners has been a driver in SamBIM, with the dedicated change agents in front;
• The complexity of both the consortium and the research requires clarified roles and responsibilities, and a common understanding of aims and ambitions;
• In SamBIM, it has become important to both strive for the high and ambitious goals (long runs), and grasp for the low-hanging fruits (short runs). The Urbygningen BIM-kiosk or the big-room of Risløkka enhanced an immediate effect which was useful and motivating, and which created pride and ownership among the actors involved.

The SamBIM project will be completed in the autumn of 2016. Important work to be done in the last stage of the project are the cross-case and cross-activity analyses and summaries, the deliveries of the thematic working groups, and the dissemination of the findings from the project in its totality.

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7. References


RCN (2015) (available online

http://www.forskningsradet.no/prognett-bia/Programme_description/1226993636103  [accessed on 24/11/2015])

The Implications of BIM Use on Communication Channels in the Design Process

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Abstract

This research aims to explore the implications of building information modelling (BIM) implementation for existing communication channels used in design processes across various professionals in the Kingdom of Saudi Arabia. Although there is much research on communication channels in terms of their effectiveness, related to collaborative environments such as face to face meetings vs. computer-mediated communication (CMC), there is relatively little research known about the consequences of implementing BIM on the existing mechanisms used for communication within firms. In doing this research, three different sets of concepts have been mobilised with the aim of understanding the dynamic processes of communication across diverse professionals in general and within BIM collaborative environments in particular. These concepts are theoretical models of the communication process (from linear to interaction processes); team theory, and cross professions collaboration theory. These were reviewed to identify 38 distinct factors, selected in relation to how relevant they are to potential changes in communication channels. The factors are grouped into three major themes; collaborative team characteristics, leadership and methodology of information exchange. These are then used to develop a framework to examine the implications and effects of BIM on communication channels. Empirically, a pilot case study strategy is employed, with data collected from four medium-large firms in KSA through semi-structure interviews and a questionnaire. The initial findings of the case-study reveal that the changes in communication channels experienced through using BIM differed depending on several factors. Although many factors were common across the three sets of literature, their influences empirically were diverse. Factors such as resistance by professionals to change to new or alternative communication channels not only referred to the lack of training or education but also, to a ‘familiarity’ factor. Furthermore, there is an influence of ‘spreading rumour’ (pre-existing assumptions and expectations) on adoption of communication channels which appeared more at the decision maker level.

Keywords: Communication channels, BIM, Professionals, Influential factors, KSA Firms
1. Introduction

There is an ongoing debate about what BIM is. A number of definitions from professionals and researchers alike have described the BIM philosophy in different ways. For some, BIM is 'data sharing, and not only data exchange' (Nour 2012: 1), for others it is an integrated model (Sebastian 2011), or it is 'a software application' (Aranda-Mena et al. 2009: 420), or shared digital representations, and language allowing interoperability (McGraw-Hill 2008). As the perceived definitions differ, this leads in turn to enquire about how design representations are exchanged across BIM communication channels. This research aims to explore the implications of building information modelling (BIM) implementation for existing communication channels used in design processes across various professionals in the Kingdom of Saudi Arabia. The paper is structured as follows; first, relevant literature on communications, teams and collaboration are used to describe the extraction of factors which may influence communication channels in BIM projects, following this, the iterative research approach for this pilot study is discussed. The analysis is then presented under main themes of team characteristics, leadership, and information exchange processes, before the main findings and conclusions are described.

One of the core features of BIM is ‘interoperability’ (Succar 2009), defined by IEEE (1990: 114), as “the ability of two or more systems or components to exchange information and to use the information that has been exchanged”. This process of exchange and sharing of information reflects two pillars of BIM work; communication and collaboration (Azhar et al. 2012). Referring to the findings in the literature, in relation to the role of the collaborative team, there is a consensus about team work is a third pillar. Reviewing the literature in BIM shows a consensus about the main challenges faced in successfully implementing new innovations (i.e. BIM) in general, and information sharing in particular. These common challenges include lack of training team members, and resistance to change (see e.g.; Azhar et al. 2007; 2012; Dossick & Neff 2011; Harty 2008; Homayouni et al. 2010 ). Although the keystone of (BIM) is the communication process, which enables stakeholders, to collaborate effectively and deliver correctly the desired information (Xue et al. 2012), there is still some deficiency in communication processes within BIM projects. Moreover, to date there is relatively little research about the consequences of implementing collaborative approaches such as BIM on the existing communication channels used. In this respect, this study will identify ‘what’ happened to the existing communication channels and ‘why’. In this study, the channel refers to ‘as the medium of communication: the material through which the content is sent’ (Dainty et al. 2006:112). The research draws on three theoretical approaches: communication theories, team theory (Brennen et al. 2007), and cross-profession collaboration theory (Amabile et al. 2001). In doing so, selected factors from those theories have been addressed in relation to how relevant they are for recognising changes in communication channels. This study consisted of selecting 38 factors, which were grouped into three major categories (themes): the methodology of information exchange, collaborative team characteristics, and leadership.

In the communication literature, definitions of communication reflect at least two concepts. The first describes communication as the process of exchange information among sender and receiver to equalize information on both sides (Otter & Prins 2002). This approach focuses more
on the ‘transmission aspects’ of the communication process forming a linear model and one-way process (Eckert et al. 2005). The second describes communication process as; ‘transmitting messages from one person and the receiving (and successful understanding) of those message by another’ (Torrington & Hall 1998:112). Roger and Kinck (1981:63) describes the communication process as; ‘a process in which the participants create and share information with one another in order to reach a mutual understanding’. Emmitt and Gorse (2007:3) define communication as, ‘sharing of meaning to reach a mutual understanding and to gain a response’ and this definition has been used widely in the communication literature. These definitions focus on, as Maier et al. (2008) referred to, obtaining an equal understanding, rather than measuring the information flow from-and-to the receiver. In the design process, sharing a mutually understating between participants is a fundamental prerequisite for any successful communication process (Eckert et al. 2005). In this regards, three communicational models are used. With growth in network speeds, information communication technology (ICT) opens opportunities for professionals to communicate in a different way; from texting, chatting, to visual communication (Sidawi et al. 2012). Beside this, in collaborative design environments, communication becomes much more complex, and professionals have numerous choices of various communication channels to employ (Gabriel & Maher 2002; Eckert et al. 2005). The availability and diversity of communication channels has been proposed by Gabriel and Maher (2002) as the main criteria for the success of collaborative communication. Nevertheless, in general, there are studies pointed to influential factors behind either the changes in channels in particular, or on the selection of those channels which may differ from one work environment to another. Despite the distinction of contexts, there is a consensus on some of those influential factors, for instance individual’s preference (Watson-Manheim & Belanger 2002; Gabriel & Maher 2002), organizational culture (Homayouni et al. 2010; Watson-Manheim & Belanger 2002) and physical environment (Dainty et al. 2006; Watson-Manheim & Belanger 2002). Interestingly, scholars’ views toward communication and collaboration (e.g. Ebrahim et al. 2009) also suggests that a team member is a leading unit in the process of communication and collaboration, who impacts and is influenced by the surrounding environment. Within the context of the design process, it is fundamental to understand the core role of team members within communication process; as being a sender and receiver.

In our study, the categorization process was conducted via sequential steps: 1) Break down all the most possible influential factors from the three literature areas; 2) Identify factor definitions from different sets of literature; 3) Group the factors into themes; 4) comparison and rearrangement of the factors (an iterative process); 5) Arranging them in a schedule in which classified them into three various themes, and under each theme, factors and sub-factors. Such categorization has been developed in order to address the possible impact of these sub-factors either to main factors, or directly to communication channels used. This process facilitated recognition of themes in the aim for developing an analytical framework, and in order to empirically examine the implications of BIM on communication channels used. These three themes are; Methodology of information exchange, Collaborative team characteristics, and Leadership. Importantly, the overlap between these factors within each theme, or across these three themes assists in developing questions for the pilot study in relation how these factors are relevant to change communication channels used. The factors have been extracted from three
main sets of literature and relevant theories mentioned above; in terms of their potential influence on these main areas, and subsequently to their potential to change communication channels used. Surprisingly, despite considerable commonality between these factors, some differences appeared. The main aim of this research is to explore the implications of BIM execution on existing communication channels in the design process used by various professionals. In order to accomplish this aim, the objectives are: a) to understand how the communication process works; b) to identify various factors influencing change in communication channels used, and; c) to identify the communication channels enabled by BIM tools. To meet the purpose of the study, a case study strategy will facilitate to answer questions of 'what' happened, and 'why'. However, conducting a pilot study is also an initial step to refine the empirical questions, to identify suitable cases, and test the data collection approach for further empirical study.

2. Research Design

To meet the purpose of the study, a case study approach facilitated gaining a rich understanding of the research context (Morris & Wood 1991). Additionally, applying a pilot case study approach as an initial phase contributes in revising the data collection plans in order to be appropriate to the context of data, and rehearse procedures to follow (Yin 2009). Importantly, using a case study strategy from Saunders et al. (2009) perspective enables answering our research question in regarding of 'what' happened in communication channels, and 'why'.

Based on the reviewing the communication literature, employing a qualitative method is appropriate in seeking to understand communication channels, and this is usually achieved by using semi-structured interviews. Questionnaires were also developed to try and collect contextual data, and to refine the interview protocol. Observation is also common in communication research. However, this was excluded from the pilot study owing to the nature of Saudi’s society, which makes it difficult for this technique to be applied successfully, especially for female researchers. The data was collected from the three firms, and the last case was with a participant from the Ministry of health in KSA. The research was conducted using telephone interviews between June and August 2015.

This research was designed to pursue a sequential exploratory strategy, hence questionnaires followed by interviews employed. The two main objectives for initially distributing questionnaires were to identify the different kinds of communication channels used, and to measure the frequency of the use of these identified communication channels within BIM. Not only that but the quantitative data also helped further to crystallize our empirical interview questions by narrowing our focusing for the most likely influential factors (Creswell 2009). A triangulation strategy was employed within each case for the pilot study target which facilitated us to test the research interview questions for anything unclear or uncomfortable in relation to the context (Bryman 2012), which improved the questions quality (Yin 2009). It is worth noting that, the interview questions used were initially drawn from the literature, and tested with experienced professionals with BIM for more than 4 years. The interview questions were refined using the questionnaires’ responses providing insights into the numbers and types of
channels and potential influential factors that were discussed in the interviews. The semi-structured interviews were conducted with an architect, BIM coordinator, and project managers across four organisations in order to get a range of viewpoints.

3. Analysis and Preliminary Results

3.1 Theme 1: Team characteristics

**Resistance to Change:** With regards to resistance to change, respondents referred to several factors. A recurring one was having had previous negative experiences with either particular approaches, software, or technology used to communicate. Besides this, negativity by some who had a previous negative experience shared their colleagues either at the individual or manager level was evident. However, based on the respondents’ views, those people who ‘resist change’ have generated incorrect information regarding, for example, the difficulty level, and effectiveness for desired tasks. It was thought that external software salespeople played a role in convincing individuals and management to adopt certain BIM communication approaches over others. Also, the BIM coordinator noted that ‘We are obliged to follow up with the senior management directives particularly which related to the mechanism used for communication channels for information exchange’ (BIM coordinator, Case 1). However, it was thought that there has not been an obvious change in communication channels used, particularly at the level of individuals. In this respect, the project manager (PM) for the medical centre project in Riyadh, commented that: ‘one of the challenges we were faced with is to get our employees away from using the communication channels were not listed in the planned communication model. Especially for large-projects cases, using normal E-mails system by some, were wasted the required information from the rest of the team members, especially if such person has been changed’ (PM, Case 2).

However there was a difference between the use of specific communication channels (such as email) and technologies. The participants were often surprised when asked about the role of spreading ‘incorrect’ rumours in changing or resisting changing the communication channels used. From their responses, the influence of rumour appeared more on technology use in general, rather than channels, in particular. In view of this, at the end such technology can involve use of a range of alternative channels. Therefore, the ultimate influence will be at those channels. Along with rumour impacts, there is an indication that change or impact is rooted in resistance or the influence of software vendors ‘as one of the influential factors, most likely generated by the members who against to change, and a software salesman’ (BIM manager, Case 3). Individual preference was also important. Respondents noted that, ‘Individual’s preference is existing, playing a vital role on communication channels used, and appeared more obvious especially by the decision-makers’ (PM, Case 2). However, in another response, seems that the individual preferences are often constituted as a considerable challenges to the project manager. Thus preference led some professionals to remain using the hand sketches and the typical E-mails as a means to exchange and shared information, interpreted by the PM as due to a ‘familiarity issue’. (PM, Case 2; PM, Case 4). The last sub-factor is the presence of older generations within the teams. Within a BIM environment, and from the BIM coordinator’s
perspective ‘the old generation refused to utilize a new technology, because they believed such technology will reduce their value and capabilities...Yeah, don’t surprise, this is what they believed’ (BIM coordinator, Case 1). Such resistance led other professionals to return back to use the traditional means which are not including on the communication protocols; for exchanging and sharing information. For instance, FTF meetings, hand sketches, E-mails and paper-based documents. Related to this, some responses showed the influence of the lack of computer skills (e.g. as related to Encoding-Decoding Knowledge). The BIM coordinator said ‘sometimes we defined an assistant to do all the technical things for him; due to their deficiency on how to dealing with the technical issues, and the process for encoding-decoding. This in turn, ‘led some to use alternative channels..... thus, had made some changes in the type of communication channels used, and then on the workflow process’ (BIM coordinator, Case 1).

The diversity of skills, knowledge, and experience among professionals: As inferred from the dialogue with the BIM coordinator the influence of the diversity of skills, experiences, and knowledge among professionals on channels used is an important factor. He indicated that ‘Because of the different skills and experience among the engineers; it was one of the reasons behind the misunderstanding of the outputs of the BIM simulation programme,... especially appeared more on the technical and mechanical drawings stage...Oh yeah, in this case, some experienced professionals do not have any choice, except to follow the lower-skilled professionals on their way to design, by using a 2D projections (CAD)... Certainly, in that case, they used E-mails as a channel to exchange rather than BIM server’ (BIM coordinator, Case 1).

In the other hand, increasing the level of the professionals skills and experience, from the perspective of some respondents, contributes as well on making changes on communication channels. They were depended more often on BIM tools not only for exchanging data but also, for shared what other professionals were exchanged as well. Thus it contributes to ‘reduce the dependency degree on the typical known communication channels, for seeking the desired information’(BIM coordinator, Case 1).

The presence of competition among professionals: Within BIM collaboration, and when attempting to explore the interrelated impact between the role of rumour and changes in channels, rumour often appeared at the managers’ level. However, at the individual level it was less obviously noticed. And, consequently referred to the existence of the high competition level among professionals, as interpreted by the BIM manager: ‘In my experience, I haven’t seen it much because there are some challenges, and the high level of competition. So, people just focus to be the best, yes to be the best.. the negative actor might be existed, but his influenced could not be noticed’ (BIM manager, Case 3). This suggest a more change oriented factor where the competition to perform can lead to individuals adopting new technologies and communication channels.

3.1 Theme 2: Leadership

It appears from responses that there is an important role played by the team leader or manager for making changes on the existing channels used for communication. Some of these are explicit and appeared more directly, and others indirectly. Nevertheless, they still have influenced the
communication channels used. For instance team member selection (e.g. in terms of collaboration skills, experience, etc), availability or provision of training and educational courses, and lack of clear task coordination. Although classifying the influences type on communication channels as either is direct or indirect is beyond the scope of this pilot study some interrelated impacts have appeared which resulted from such factors. For instance, the individuals’ differences for absorbing a new technology, and refusal to change by the old generation are restricting other team members to older (traditional-typical) types of communication to exchange and share the CAD files by E-mail, and paper-based documents.

As was said by the BIM coordinator, 'In any project, normally team working at the same level of the performance and experience, and such selection is a core role of leader... Another strong factor is the type of the project, some projects are less difficult, the choice of the employees must be commensurate with their performance, background, experience, and skills’ (BIM coordinator, Case 1).

Another emerging factor is the lack of providing appropriate technical training, and educational courses according to the project and firm needs. Along with these, the lack of tasks coordination in terms of setting up a technical FTF meetings, especially at the outset of the project is considered as having some impact on channels. Typically, such procedure uses to clarify what the information requirements are, and who is responsible for what tasks...etc. However, the initial findings have not shown a direct influenced on the existed channels. There were expectations from the respondents, such as the project manager, that ‘ambiguity around the provided information regarding what, and to whom they have to send such information... or sometimes, what the required information is, might lead to the need for documenting the communication process which will occur between the sender and receiver’ (PM, Case 4). However, when was being asked to provide examples, he commented by saying that “Yes, Example, ok if the required information is almost enough to be sent via phone call, or through informal FTF conversation,.. but the sender, or might be the receiver were afraid, that the other person might be stated he didn't receive anything... oh yeah, in that case might the actor use some means which provide a documentation feature, let say, E-mail system’. However, the initial findings have not shown a direct or clear influence for the lack of tasks coordination as a factor on the existing channels. It suggests, however, that it can impact on the trust level between participants, which subsequently leads to revert to alternative channels. For instance, using the E-mails as a substitute for the phone calls; for the documentation purposes. It is worth mentioning that all the participants without exception indicated the influential role of the decision makers in terms of identifying the communication protocols. Such protocols refer to the required communication channels, and the applications for project management to be used. Such decisions are according to the project, and the firm needs.

3.2 Theme 3: Information Exchange Processes

The responses indicated that interoperability, which BIM technology should provide, facilitated the process of sharing, exchanging and modifying information and documents. In terms of BIM changing the communication channels, the BIM coordinator said that ‘The process became clear to all participants which facilitated communication process and information exchange...
person has the ability to see all adjustments, instead of talking with each person and explaining individually to him. Or, send a request for information via E-mail’ (BIM coordinator, Case 1). Another PM stated that, ‘the E-mail system has not used mainly as before in BIM-enabled projects’ (PM, Case 2). In view of this, it appeared that BIM has reduced not only the frequency and use for the FTF meetings but also reduced use of the E-mails system and hand sketches as well. Along with this, delayed responses by less active participants (e.g. old generations) and the differences in time zone were contributors. For instance, inactive participants resulted in shifting from exchanging the BIM models using a BIM server, to utilizing CAD and exchanging via E-mails. The majority of the respondents did not indicate a clear and direct impact of incentive and rewards structure in changing communication channels. However, one of them said that ‘it might be influenced, especially on some cases. Such case, when the team member who did their duty correctly, and at the competitive time’. In exploring how this might work, and influence channel use, The BIM coordinator said ‘BIM has facilitated the process for sharing information around design details, but not shown of how they did these procedures’. He consistently said that ‘if the work procedures have done, or the technical issues have sorted it out, but in easier and faster way than what we planned to, normally leader asked him for sharing these knowledge with other team members, and this person is rewarded for his efforts’. In view of this, we could infer from his dialogue that the reward structure was contributing to improving the process for sharing knowledge, and addressing the lack of technical skills considered by respondents as one of the influential factors towards changes on channels used. Consequently, the rewards structure eventually influenced the communication channels used. In addition, the responses are shown to influence both the project characteristics (e.g. project’s needs, scale, types, and the level of complexity), and the contract form for the partnership agreement. In view of this, the lack of information provision regards the contractual agreement, in terms of clarifying the communication protocols such as the number of meetings, communication means (e.g. channels, project management applications) had made changes on communication channels according to both of the project managers for Case 4; and Case 2.

4. Discussion

In an effort to illuminate the identity of the influential factors implicated in changes in communication channels, we performed a case study approach for (4) cases with (4) interviews (4) interviews and (8) questionnaires. The above analysis from the preliminary interviews yields several findings that relate to the previous research in the communication, team, and collaboration literature. In this regards, the empirical result of this research uncovers some emerging influential factors as shown in Figure (1). The evidence from the case studies supports the literature suggesting influential factors, but in our study their type of effects were different. Our empirical findings revealed sets of relationships in relation to the aspects for communication, teamwork, and collaboration, and subsequently their potential influences on communication channels used. Although the evidence from the case studies supports the literature suggesting that individual preference, resistance to change, and organizational culture are important, it is worth noting that, the factor we have termed ‘spread of rumour’, has not been addressed yet on communication literature but appears an influential factor behind channels changes during the design process. Our findings disclosed that it played a critical role at the
level of the decision maker (i.e. manager) alongside the influential role of the software vendors in selecting technologies and therefore communication channels. However, the influence of rumour was more difficult to see at the level of individuals. This is due to, as respondents referred to, the presence of high competition level among professionals within BIM work environment. This resulted on developing their skills constantly, and following up the managerial instructions.

Figure 1: The emerged influential factors, and themes

To illustrate this, the individual’s preference for using some certain communication channels instead of others was due to several factors, with the familiarity factor as one of the main causes, despite having training and educational courses. Our findings are consistent with the findings of Watson-Manheim and Belanger (2002), despite the context being different, that there is consistency in term of factors, and in the interpretations behind impacts and changes. The familiarity factor appeared more clearly with the older generation professionals who are claimed to have a lack of computer skills. These previous factors constitute the action of ‘resistance to change’. Within a BIM-based project the relative absence of hand sketches as a ‘familiar technique’ was considered less acceptable for older generations. It was found that the need for using hand sketches as non-verbal communication paired with BIM tools is being used less than before (i.e. non-BIM cases). But our findings suggest, in this respect, that the absence of such techniques might constitute a threat to older professionals’ status and the level of their hand-drawing skills developed during their careers. Such skills may be the very reason why they arrived at such position in their companies. Alongside this, we might also consider the importance of hand sketches as a visual language as Sebastian (2011) stated, and a vital communication tool from the view of Homayouni et al. (2010) which is used to support clear communication during meetings. Although FTF meetings may be the most preferred means to communicate (Gabriel & Maher 2002), our findings are consistent with Dossick & Neff (2011) in terms of hand sketches being used less during meetings in BIM projects. Surprisingly, the skills, experiences, and knowledge as high or low for the team members, have contributed to making changes on communication channels used. To illustrate that, highly skilled professionals can shift faster between using the traditional channels (e.g. E-mails system, phone calls) to utilizing BIM tools (e.g. BIM server, open request on Revit® building design software). In contrast, at the low-level skill, the need for face to face discussion remained along with emails for making inquiries. The main feature of BIM as an interoperable system, not only potentially
produces a free error design, but also facilitates sharing what others have exchanged, pointing to problems identification and inquires directly in the Rivet models. These features not only reduce design errors but also, reduced the dependency degree on (one to one) meetings, emails, paper-based documents (e.g. hand sketches) and informal discussion. These findings seem to be agreed with the findings of Dossick & Neff (2011) in examining the changes occurring by using BIM. In addition, another influential factor is the documentation requirements and the need to record the communicational content to provide evidence for the process of exchanging the official information among professionals. Particularly, it found the work environment sometimes characterized by a lack of task coordination among professionals. Furthermore, if there is a lack of trust, there is arguably a need to record the process, which is consistent with Watson-Manheim & Belanger’s (2002) findings regarding influences on channels choice. However, this could also be attributed to ineffective leadership, as indicated by Ebrahim et al. (2009), and Amabile et al. (2001). Another common influential factor from the communication aspect, is the communication protocol’s form included in the contractual project requirement, and partnership agreement. Our findings are consistent with Emmitt & Gorse (2003) in that the definition of the formal communication channels are associated with the contractual requirement for each project. The communication protocol, as our results revealed, differed according to project types, project scale, partner type, and the level of complexity. This diversity in protocol resulted in changes of the channels used from context to context. These findings seem to be agreed with Dainty et al. (2006) in arguing that the need to expand communication across organizational boundaries is an inevitable consequence of increasing the project scale, and subsequently results in expanding types of channels used. Furthermore, our findings indicate that the project management applications and their variety are based on the project type or firm’s need which can cause differences in communication channels used from context to context. According to the questionnaire results, our study reveals some of the current types use of communication channels, and how often they are being used on the BIM-based project. However, our preliminary results did not allow us known about the percentage rate of used for each channel or whether this percentage rate for a particular channel is decreased, or increased after implementing BIM. However, overall the use of email, FTF meetings, video conferencing and phone calls are still employed within BIM environments, but the use rates are less than non-BIM projects.

5. Conclusion

This paper explored our key question of what happens to communication channels with BIM-enabled projects and why, by employing empirical case studies on the emerging role of the technology (i.e. BIM) on communication processes within design. Our study presented a comprehensive list of factors which have been examined by the relevant theories; communication, teamwork, and collaboration literature, to date. Such factors categorized according to their influences in such areas of literature which in turn, facilitated the previous process of data analysis. This study identified 38 factors, which can be considered as a guide to figure out the potential changes on communication channels used, as a new approach that has not been addressed yet in the current literature. Such addressed factors are the fundamental step in identifying the changes on channels for any new technology. This study provides a first step
in this direction. Based on such analysis for the pilot case study and literature, there is some commonality on the influential factors across various research areas. However, the results presented in our study are seen as an initial attempt, therefore more extensive research needs to be undertaken to understand the implications of BIM. In this respect, this study concludes that relying on communication theories only, such as were used initially, are not sufficient to understand and subsequently interpret the occurred changes thoroughly in a complex environment (i.e. BIM). Therefore, the employing of the three communication theories, although there are relatively diverse, including teams and collaboration, have provided another dimension and insights to our study. Finally, a few limitations of this pilot study should be noted. First, the much of data is reliant on a relatively small number of participants' feedback. Second, there is no substantive quantitative data to help verify these views, for instance with indications for the percentages rate for using each channel. These will be considered as further research is undertaken.

References


Nour, M., 2012. BIM support for design change management and workflow approval. In *ISCCBE*. Moscow, Russia: 14th International Conference on Computing in Civil and Building Engineering.


Integration of FM Expertise and End User Needs in the BIM Process Using the Employer’s Information Requirements (EIR)

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Abstract

Projects in the construction industry typically involve complex information flows from early design, through construction, to facility management (FM). Building Information Modelling (BIM) tools and workflow processes are considered key enablers for collaboratively managing such information across phases of the project lifecycle. With the increased adoption of BIM by the construction industry, there are heightened expectations for increased engagement of facility managers (FMs), users and clients in the BIM process. This is based on the proposition that BIM can benefit the operational phase of a building, which contributes the most to the building lifecycle in terms of overall cost, sustainability and usability. The study aim was to investigate current levels of understanding and adoption of BIM by facility managers in practice. Three research questions were investigated: (a) How client and FM engagement with BIM workflows can be improved through early contemplation of their requirements; (b) what are the perceptions about BIM and its potential impact on the FM industry from an FM, user and client perspective and (c) what information is required by FM from the BIM process to maximum optimisation of assets in the operation phase.

Mixed research methods, including: a literature review of academic and industry publications (e.g. case studies, industry best practice, standards and guidelines), an online survey of FM professionals and focus groups, were used to address the posed research questions. The findings highlight the need for further education regarding BIM guidelines and standards. In particular, new and more FM/client-focused BIM strategy documents, EIR and other templates are required. Many existing templates (e.g. EIR) are not focused on client’s needs. Guidance is required on developing BIM strategies based on understanding the client’s Organisational Information Requirements (OIR) and Asset Information Requirements (AIR) in order to develop an EIR that specifies what, when and how information should be delivered. This will improve timely decision making during design and ensure that the right and correctly structured information is delivered to clients at handover for their Asset Information Model (AIM) to help optimise the operation of their assets.

Keywords: Facility Management (FM), Building Information Modelling (BIM), Employer’s Information Requirements (EIR), Asset Information Model (AIM)
1. Introduction

BIM is driving rapid change throughout the design and construction (D&C) industry and increasingly is becoming the chosen process across Europe and the wider world for the planning, D&C of buildings and infrastructure projects. Many D&C professionals have already gone through the paradigm change required to adopt and implement BIM. However BIM has not yet had a significant impact on the FM industry. This is creating a growing knowledge gap about BIM between the D&C and FM industries. The BIM workflow process when managed properly should start with a clear specification of the client’s asset operation and maintenance (O&M) information needs in the EIR. At present, this is not happening, as many clients and FMs do not yet have adequate knowledge and experience to fully engage in the BIM process. If this problem is not addressed many potential benefits of BIM may not be fully realised.

2. Literature review

There is growing recognition that BIM can deliver significant economic, social and environmental benefits in the creation, O&M of assets and buildings, especially when value is considered over the whole life cycle. The UK Government for example recognised the added value BIM can deliver in its 2011 Construction Strategy as an aid to ensuring “the country gets the social and economic infrastructure it needs for the long-term” (Cabinet Office, 2011). With respect to ROI and who benefits most in the BIM process; the SmartMarket Report (McGraw Hill Construction, 2014) reports “three quarters of all contractors’ surveyed report a positive ROI on their investment in BIM”. However the key beneficiaries of BIM are ultimately clients and end users (Eastman, et al., 2011). Other research looking at ranking stakeholder financial benefits in relation to BIM has indicated that clients benefit most financially from BIM followed by FM (Eadie, et al., 2013). This is because BIM models and their associated information can be used throughout the whole lifecycle of buildings, infrastructure and assets (BSi, 2013). This is critical to understanding the most significant savings and benefits can be realised over the longer operational use phase.

In relation to whole life costing, research shows up to 80% of the O&M cost of an asset can be influenced in the first 20% of the design process (ISO, 2008). FM operational expertise and input is thus critical in the early stages of design to avoid expensive decisions which can have long lasting implications (Ashworth, 2013). Other research shows that FM and the O&M of a building equates to 60% of the overall costs of a project (Akcemete, et al., 2011). They suggest significant financial gains can be achieved by specifically targeting this aspect of a project. Clients, in particular, can achieve worthy benefits on their construction projects by adopting BIM technologies and workflows to guide their delivery process to higher quality and performance for a whole building life cycle (Eastman, et al., 2011). Research also shows 39% of contractors assign greatest value in projects to adding O&M data to models for the owner (McGraw Hill Construction, 2014). However, research shows that BIM adoption in the O&M phase is currently less than 10% and potentially significant un realised benefits could be achieved if more focus was given to the impact of BIM in the O&M phase (Eadie, et al., 2013).
To help stakeholders the UK government has put in place a framework of BIM standards and guidelines for the BIM process. PAS 1192-2 (BSi, 2013) states the start of the BIM process should be a “clear understanding of the client’s OIR and AIR” and that one of the “fundamental principles of level 2 information modelling is the provision of a clear EIR”. It defines the EIR as a “pre-tender document setting out the information to be delivered, and the standards and processes to be adopted by the supplier as part of the project delivery process” and that the “EIR should be incorporated into tender documentation to enable suppliers to produce an initial BIM Execution Plan (BEP)”. The Government has provided an EIR template for stakeholders (BIM Task Group, 2015), however the author believes that a more client focused template is required.

PAS 1192-3 (BSi, 2014) describes the ultimate purpose of the BIM process is to “provide information into the client Asset Information Model (AIM)” which should be “the single source of approved and validated information related to the asset(s)”. BIM can provide a fully populated asset data set for CAFM systems and therefore reduce the time needed to obtain and populate asset information. This enables FMs to achieve optimum performance more quickly, reduce running costs, and refine target outcomes (BIM Task Group, 2015). The data should include: “data and geometry describing the asset(s) and the spaces and items associated with it, data about the performance of the asset(s), supporting information about the asset(s) such as specifications, operation and maintenance manuals, and health and safety information”. However clients/FMs are the only stakeholders that ultimately understand the client needs, and can specify these for the EIR at the start of the BIM process. BS8536 (BSi, 2015) aims to help, promoting “the early involvement of the operations team or FMs and by extending the commitment of the D&C team to post-handover asset aftercare to ensure its correct, safe, secure and efficient operation in line with environmental, social, security and economic performance targets”. Thus to ensure the BIM process works fully, the client/FM have to be included early.

With respect to FM knowledge and awareness of BIM; surveys such as the BIM4FM survey (A working group of BIM Task Group) have tried to understand the perception of BIM by FM, end users and clients. The survey found that “although people are aware of BIM there is still a significant audience that is unsure of how BIM is used within the built environment” (BIM4FM, 2013). 63.2% of respondents were “unsure of whether their organisations plan to use BIM in the future”. The NBS National BIM Report 2015 (NBS, 2015) also provides some useful insights from the construction industry perspective on BIM: 50% said they were currently using BIM and 95% of respondents believe “they will be using BIM within 5 years”. However 67% also reported that “the industry is not clear on what BIM is yet”. Other research work has shown that many D&C professionals (93.6%) agree with the UK Government’s BIM strategy decision to mandate level 2 BIM on all public sector projects by 2016 (Eadie, et al., 2015).

3. Methodology

A mixed method approach was used; 1) a literature review to identify issues and to design the online survey form, 2) A survey conducted through two Swiss FM associations with the aim of understanding and establishing a benchmark of the understanding and adoption of BIM and how it will impact on the FM industry (399 people accessed and 68 completed the survey), 3) A
focus group workshop titled “FM and BIM in Research and Practice” using results from the questionnaire to select topics for discussion. Three separate focus topics were discussed with the aim of establishing the information needs/outputs to inform the creation of a more FM client-orientated EIR. Topics were: (a) FM operational: information needed for space management? (b) FM financial: information needed for decision making? and (c) FM personnel: training/skills needed to be able to engage with the BIM process? A final focus group with all attendees then discussed, reflected and summarised the individual group findings.

Twenty participants engaged in the focus groups with stakeholders across the whole life cycle. International representation came from; UK, Switzerland, Germany, Denmark, Norway, Netherlands and the US. Participants were from professional bodies; IFMA, the Danish FM Network (DFM), the Norwegian FM (NBEF) and the British Institute of Facility Management (BIFM) Soft Landings team. FM and D&C practitioners attended from; BAM UK, BAM Deutschland AG, Mace Macro, ISS, Halter AG, eneco, Robertson FM, FES FM, Auwiesen Immobilien AG, UniversitätsSpital Zürich and Glasgow Life. Academics attended from; Zurich University of Applied Sciences (ZHAW) and the Netherlands Hanze University, Groningen.

4. Survey findings

There were 68 fully completed online questionnaires, a response rate of 17.04% from the 399 people who opened the survey. The respondents included stakeholders over the whole life cycle of a building: 18 planning consultants, 15 internal FM providers, 14 building owners/agents, 9 external FM providers, 3 CAFM suppliers, 2 architects, 2 investors/clients, one building contractor, one procurement manager, one data manager, one surveyor and one government administration officer. The profile of company size by no of employees is shown in Figure 1. The majority, 38.2% of respondents were from companies with 1000+ employees.

Respondents Figure 1: Size of company by number of employees down of the type and size is shown in Table 1.

<table>
<thead>
<tr>
<th>Type of space</th>
<th>Total m2 (Gross)</th>
<th>Average m2 (Gross)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office / administration</td>
<td>7,707,293</td>
<td>296,434</td>
</tr>
<tr>
<td>Laboratories / industry</td>
<td>2,395,407</td>
<td>140,906</td>
</tr>
</tbody>
</table>

1 CAFM: Computer Aided Facility Management
They were asked about general knowledge/experience of BIM and how they perceive BIM will impact on the FM industry. With respect to experience: 41.2% had no experience with BIM, 33.8% had some, and 25% gave no answer. The majority of respondents (55.4%) as shown in Figure 2 believe BIM will have a significant impact on the FM industry within 5 years.

The respondents were then asked about their perception and understanding of BIM with a series of questions (previously used in the NBS survey). Table 2 shows their responses. A Linkert scale was applied and the mean score calculated using the numerical values (1=disagree, 2=somewhat disagree, 3=somewhat agree and 4=agree). The table scores were ranked according to the mean score.

Table 2: Perception and understanding of BIM

<table>
<thead>
<tr>
<th>Question/statement</th>
<th>Agree %</th>
<th>Somewhat agree %</th>
<th>Somewhat disagree %</th>
<th>Disagree %</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>The FM industry is not sure what BIM actually is (n=54)</td>
<td>33.3</td>
<td>57.4</td>
<td>7.4</td>
<td>1.9</td>
<td>3.22</td>
</tr>
<tr>
<td>BIM is all about real time collaboration (n=53)</td>
<td>26.4</td>
<td>41.5</td>
<td>17.0</td>
<td>15.1</td>
<td>2.79</td>
</tr>
<tr>
<td>BIM is all about software (n=54)</td>
<td>3.7</td>
<td>13.0</td>
<td>53.7</td>
<td>29.6</td>
<td>1.91</td>
</tr>
<tr>
<td>BIM is for new buildings not existing buildings (n=55)</td>
<td>3.6</td>
<td>14.5</td>
<td>27.3</td>
<td>54.6</td>
<td>1.67</td>
</tr>
<tr>
<td>BIM is simply a synonym for 3D CAD drawings (n=55)</td>
<td>0</td>
<td>7.3</td>
<td>16.4</td>
<td>76.3</td>
<td>1.31</td>
</tr>
</tbody>
</table>

Respondents were asked about their familiarity and knowledge of the Governments BIM guidelines and standards as well as the Swiss BIM guideline “SIA Merkblatt 2051 BIM” which is currently in development. The answers are shown in Table 3:

Table 3: Knowledge and familiarity with BIM guidelines and standards

<table>
<thead>
<tr>
<th>Guides and Standards</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swiss guideline SIA Merkblatt 2051 BIM (In development)</td>
<td>25.0</td>
</tr>
</tbody>
</table>
ISO 15686 Building and constructed assets – Life cycle costing 13.2
Other: (See below for details) 7.4
PAS 1192-2: 2013: Capital/delivery phase of construction projects using BIM 7.4
BS 1192-4: Fulfilling employers information exchange using COBie: code of practice 5.8
PAS 1192-3: 2014: Operational phase of assets using BIM 4.4
ISO 55000: 2014 Asset management 4.4
CIC BIM Standard Protocol for use in projects using Building Information Models 2.9
CIC Guide for Professional Indemnity Insurance when using BIM 2.9
CIC Outline Scope of Services for the Role of Information Management 0

Other guidelines and standards the respondents were familiar with were: the Swiss “KBOB Guideline for Building Documentation in Buildings”, the “Penn State BIM Planning Guide for Facility Owners”, the “NATSPEC” document suite and the German “Research Initiative ZukunftBAU”. Respondents were also aware of various online forums promoting BIM best practice such as the UK BIM Task Group, BuildingSMART, COBIM from Finland etc.

Respondent’s perceptions of the potential benefits of BIM to FM are shown in Table 4. A Linkert scale was applied and the mean score calculated using the numerical values (1=disagree, 2=somewhat disagree, 3=somewhat agree and 4=agree). The table scores were ranked according to the mean score.

<table>
<thead>
<tr>
<th>Potential benefits of BIM to FM</th>
<th>Agree %</th>
<th>Somewhat agree %</th>
<th>Somewhat disagree %</th>
<th>Disagree %</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct data transfer to FM CAFM/other systems (n=50)</td>
<td>50.0</td>
<td>44.0</td>
<td>2.0</td>
<td>4.0</td>
<td>3.72</td>
</tr>
<tr>
<td>Simulations e.g. energy use, fire evacuation etc. (n=51)</td>
<td>47.1</td>
<td>37.3</td>
<td>15.6</td>
<td>0.0</td>
<td>3.61</td>
</tr>
<tr>
<td>Improved transition construction to operation (n=55)</td>
<td>56.4</td>
<td>30.9</td>
<td>7.3</td>
<td>5.4</td>
<td>3.58</td>
</tr>
<tr>
<td>Visualisation of buildings for customers/investors (n=55)</td>
<td>49.1</td>
<td>40.0</td>
<td>9.1</td>
<td>1.8</td>
<td>3.56</td>
</tr>
<tr>
<td>The use of BIM may improve profitability (n=42)</td>
<td>26.2</td>
<td>50.0</td>
<td>19.0</td>
<td>4.8</td>
<td>3.55</td>
</tr>
<tr>
<td>Faster cost and life cycle cost estimation capability (n=51)</td>
<td>41.1</td>
<td>39.3</td>
<td>15.7</td>
<td>3.9</td>
<td>3.47</td>
</tr>
<tr>
<td>Improved space management (n=53)</td>
<td>41.5</td>
<td>37.7</td>
<td>18.9</td>
<td>1.9</td>
<td>3.43</td>
</tr>
<tr>
<td>Improved asset maintenance response times (n=52)</td>
<td>36.5</td>
<td>44.2</td>
<td>11.6</td>
<td>7.7</td>
<td>3.37</td>
</tr>
<tr>
<td>Reducing the cost of insurance for buildings (n=40)</td>
<td>7.5</td>
<td>25%</td>
<td>52.5</td>
<td>15.0</td>
<td>2.90</td>
</tr>
<tr>
<td>Improved health &amp; safety for operational FM tasks (n=47)</td>
<td>10.6</td>
<td>29.8</td>
<td>42.6</td>
<td>17.0</td>
<td>2.74</td>
</tr>
</tbody>
</table>

Respondents were asked how they thought FMs could make best use of BIM to help FM. The results were ranked based on frequency of mentioning and are shown in Table 5. Respondents also identified other potential uses as: exact planning during construction, quantity surveying, data-imports for CAFM tools, business continuity and service and maintenance optimisation.

<table>
<thead>
<tr>
<th>Possible uses of BIM by FM</th>
<th>% Response</th>
</tr>
</thead>
</table>

947
Life cycle costing 28.85
Cost savings 26.92
Increasing operational efficiency 26.28
Reduction of carbon emissions and energy savings 12.82
Other 3.21
I don’t know how facility management will use BIM 1.92

The respondents concerns with respect to the adoption and implementation of BIM were ranked based on frequency of mentioning as shown in Table 6. Other concerns identified were: legal liabilities, early FM involvement, uncertain ROI, stakeholder buy in, familiarisation with BIM, data management and the danger of BIM creating a “data cemetery”.

Table 6: Concerns regarding BIM and FM

<table>
<thead>
<tr>
<th>Concerns regarding BIM</th>
<th>% Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>The cost of implementation (time and resources)</td>
<td>19.61</td>
</tr>
<tr>
<td>Data management</td>
<td>19.61</td>
</tr>
<tr>
<td>Availability and knowledge about BIM guidelines and specifications</td>
<td>15.03</td>
</tr>
<tr>
<td>Basic BIM knowledge/training and its benefit to our operation</td>
<td>14.38</td>
</tr>
<tr>
<td>The incorporation of BIM into contracts and legal concerns</td>
<td>12.42</td>
</tr>
<tr>
<td>Unfamiliar technology and integration with CAFM tools</td>
<td>10.46</td>
</tr>
<tr>
<td>Other</td>
<td>8.50</td>
</tr>
</tbody>
</table>

Respondents were asked about their perception of possible barriers to the adoption and implementation of BIM. Their responses were ranked based on frequency of mentioning and are shown in Table 7. Other possible barriers included: fear of change, people wanting to stick to traditional work practices, if we can really achieve collaborative working, needing to change existing fee systems, lack of BIM standards, ROI on BIM, lack of coordination regarding implementation of BIM in the FM industry and ongoing management of BIM models and associated data in the operational phase.

Table 7: Possible barriers to the adoption and implementation of BIM

<table>
<thead>
<tr>
<th>Possible barriers in the adoption and implementation of BIM</th>
<th>% Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of internal expertise</td>
<td>23.48</td>
</tr>
<tr>
<td>Costs</td>
<td>21.74</td>
</tr>
<tr>
<td>A lack of demand from clients</td>
<td>20.00</td>
</tr>
<tr>
<td>Other</td>
<td>18.26</td>
</tr>
<tr>
<td>BIM is not always relevant to our projects</td>
<td>9.57</td>
</tr>
<tr>
<td>The projects we work with are too small</td>
<td>6.96</td>
</tr>
</tbody>
</table>

5. Focus group findings

The findings of the three separate focus groups with respect to the selected FM topics are summarised in the subsequent three sections. These are followed by key issues raised during the whole group’s review of the findings and observations.
5.1 FM operational requirements for space management

Space reporting: FMs need information which allows the quick generation of tailored reports identifying all building and asset spaces by: name, type, size, volume, finishes and materials and where appropriate ownership. The space information should be delivered in a hierarchical manner with a unique and agreed “space naming system” specified by the customer. Space should be appropriately zoned to allow zoning for fire, security, rental and other purposes. Space flexibility information should be included for potential future change. The information should allow FMs to understand the quality level of the space and demands to be made on it. Ideally BIM models should link directly to CAFM tools to allow visualization of spaces and assets within the CAFM software. This will save on time in visiting spaces to address problems.

Space inventory and cost data: The information should include data/information on all assets within each space. Each asset should then have attached information detailing: asset/serial no, cost, life expectancy, warranty period, service costs, manufactures maintenance requirements etc. as well as who is responsible for each asset (in terms of purchase, replacement and servicing). This information should be available well ahead of building handover to allow transition planning and FMs to calculate detailed operational and replacement costs and the ability to benchmark costs and future performance, tenders and for managing projects.

Space concepts, logistics and use: FMs need to have a clear understanding of the design logistics planning concepts for the movement of people/equipment, access routes and space for changing pieces of plant and equipment at the point they need to be replaced. FMs need all relevant information for the planned use of buildings/assets/spaces at handover as well as how each space could be used in the future. This should include how easily spaces can be reconfigured to accommodate flexibility and change of use.

5.2 FM financial requirements

Asset and life cycle cost data: the BIM model should include all cost information for assets i.e. replacement and installation costs, life expectancy, service/maintenance costs etc. This will benefit FMs for both daily operational management as well as forward financial planning for asset replacement or refurbishment. This data should be available at the relevant data drops in the established design process (RIBA stages and COBie drops). Ideally this information should be migrated into the chosen CAFM tool by the construction contractor well before handover.

Commercial model data: It was acknowledged that there could be sensitivities around the issue of commercial information, but having full transparency of the builders procurement cost data will allow FMs to better understand and build their FM operational and asset replacement programmes faster and more accurately for clients.

Cost sensitivity and design efficiency: FMs should work closely with other stakeholders during the process as outlined in BS8536 from initial development of the EIR to identify information and concepts in the BIM process ensuring that site/building specific issues such as transport,
logistics etc. are thought through from an FM operational perspective. This will help ensure cost accuracy, less change requests and provide regular feedback mechanism for more accurate sensitivity analysis with checks made as appropriate at every stage/phase.

5.3 FM personnel: training and skills requirements

**BIM training:** The group reported most FMs have heard of BIM but have little or no practical experience. Members of the BIFM Soft Landings team reported that BIFM are currently working on guidance documents to help FMs develop an EIR and fully engage with the soft landings process. The FM staff should have training with respect to the BIM process and management of BIM models and associated data to ensure they can access, manage, amend and update data during the transition and operation phases. A key issue discussed was the need for FM to understand how the data will feed into CAFM / BEMS (BMS) and other FM systems. It was felt there was a risk that many of the potential benefits may not be realised due to poor training and a lack of understanding as to how the models can be used to FM advantage. If FMs are not able to interrogate BIM models there was concern about models being kept up to date.

**A FM handover training roadmap:** should be a requirement in the EIR to ensure FM teams are fully involved with commissioning at the right time and receive appropriate pre-handover training. The group reported that adequate funding, resource and time for training are often lacking in projects and regularly squeezed into unrealistic timeframes at the last minute as D&C teams struggle to meet project deadlines. The FM team need to acquire BIM skills but also should have a different attitude and approach to embrace the possible benefits of using BIM models. The FM team should have adequate training and involvement during the design process whilst the models are being developed to allow them to give their clients feedback and suggested improvements as well as becoming familiar with the models and developing the skills to use them for visualisation and other uses.

**Post Occupancy Evaluations (POE):** FM staff should be included in the planning of POE for the Soft Landings process to ensure they understand how the BIM process and models will be used to help verify that the building is performing as per the design criteria and to understand any variations that may occur due to occupant behaviour or other factors.

5.4 Focus group discussion on the impact on the EIR

**Defining FM information needs/outputs:** the whole group agreed it was difficult to tie down the required information needs/outputs and when they would be needed in the BIM process.

**Guidance and templates:** the whole group felt it would be beneficial to have specific guidance and templates to help clients/FMs draft and complete an FM/client-orientated EIR.
6. Discussion

With respect to research question (a) *How clients and FMs engagement with the BIM workflow process can be improved through the early contemplation of their requirements?* the research confirmed a key issue impacting on both the D&C and FM industries is both are still not sure what BIM actually is. The research found that 57.45% of FMs and clients (somewhat) agree with this. This broadly aligns with the BIM4FM survey reporting that 63.2% of FMs were uncertain if their organisations had plans to use BIM. The 2015 NBS survey shows the D&C figure even higher at 67%. The research focus group feedback highlighted “most FMs have little or no practical experience of BIM”. This was backed up in the survey which indicated 41.2% have little or no practical experience of BIM. Other research from the D&C industry reports less than 4.05% use of BIM for FM operations with 54.05% never using it for FM (Eadie, et al., 2015). This is not surprising when we consider these figures together with the fact that most FMs have not yet had any significantly exposure to BIM projects and although many FMs have heard of the raft of Government BIM standards and guidelines, many have a poor understanding of the detailed content. This aligns with the focus group feedback that “as a community FM is on a sharp learning curve with respect to understanding how the BIM will impact on their FM operations”.

The NBS 2015 survey reports a general increase in D&C knowledge and adoption of BIM with 75% of respondents aware of the UK Government defined levels of BIM and 59% claiming to be already achieving level 2. Other research found this figure to be 53% (Eadie, et al., 2015). Not surprisingly the RIBA Plan of Work (RIBA, 2013) was noted as the most common BIM standard/publication used by D&C organisations. PAS1192-2 (BSi, 2013) is also well known. Other research (Eadie, et al., 2015) found the most common standard was BS 1192-7. However with respect to the support of FM in the operational phase the NBS figures did not look so good. Only 12% in the D&C industry have passed on “the model to those responsible for continued management of the building”. Also the use of COBie (which is essential for capturing data for FM CAFM systems) decreased slightly on the previous year with less than 1 in 5 respondents using COBie. The top 4 barriers to using BIM were (74%) lack of in-house expertise, (67%) lack of training, (63%) no client demand and (56%) cost. However “contrary to what the literature about the potential of BIM for FM, current state suggests it is rarely used with a very low figure (4.05%)” (Eadie, et al., 2015). This all indicates FMs and clients need to educate themselves about the BIM process and understand how BIM standards and guidelines can be used to their own advantage in generating FM/client-orientated BIM strategies and EIRs.

With respect to research question (b) *what are the perceptions about BIM and its potential impact on the FM industry from an FM, user and client perspective?* the time scale of 5 years seems to be a common figure. The research showed 55.4% of FMs feel BIM will have a significant impact on FM industry within 5 years. According to NBS, 95% of the D&C industry believe they will be using BIM on projects in 5 years. The figure of 5 years also ties in with other research indicating that “although BIM usage will have increased by 2016 it will not have reached the 100% level 2 stipulated by the Government” (Eadie, et al., 2015). With respect to the general perception and understanding of BIM, the focus groups and survey highlight that
although a detailed knowledge of BIM guidelines and standards is lacking most FMs were general informed about BIM basics with (41.5%) somewhat agreeing BIM is about real time collaboration. Regarding software; (53.7%) somewhat disagreed that BIM is all about software and the majority of FMs agreed BIM is not only applicable to new buildings (54.6%) and also the majority (73.6%) believe BIM is not simply a synonym for 3D CAD drawings.

Concerning the main uses of BIM by FMs the research broadly aligns with the previous BIM4FM survey findings. Life cycle management was ranked top in both research surveys. Making cost savings was ranked 2nd in the research (3rd in BIM4FM survey) and increasing operational efficiency was 3rd in the research (2nd in the BIM4FM survey). Carbon reductions were in 4th place in both surveys. Regarding the key concerns there was some alignment with the cost of implementation ranking number 1 in both surveys. However the BIM4FM survey ranked integration with current technology and CAFM as 2nd whilst this was 6th in the research survey. Training and knowledge concerns were ranked 3rd in the BIM4FM survey and 4th in the research. Data management was ranked 2nd in the research and 3rd in the BIM4FM survey.

With respect to research question (c) what data/information is required by FMs from the BIM workflow process to maximum optimisation of assets in the operation phase; this was more difficult to address. A few FMs were aware of the Government EIR templates but most did not have a detailed understanding. Those that did commented that the templates are not FM/client-orientated. The individual and whole group feedback demonstrated how difficult it was to identify specific FM information/outputs in a clear way that would allow succinct wording for an EIR document. It was felt further research work is required in this area and it was hoped the development of new templates for BIM strategies and EIR documents by BIFM and Government bodies will help FMs in creating “client-orientated” EIR documents.

7. Conclusions

The research indicates that although BIM is rapidly becoming the norm in the D&C industry, the majority of FMs and clients do not yet have a thorough knowledge of the available BIM guidelines, standards and workflow processes and few have any practical experience of BIM. There is a need to further educate the FM industry to address the potential growing knowledge gap between the D&C and FM industries. To help achieve this further research should investigate the development of FM/client-focused BIM strategies and EIRs. FMs should engage early in the D&C process, and assume ownership of the EIR on behalf of their clients to ensure client and FM information needs are adequately addressed. This will help ensure the right information is delivered and structured in the right way to use in existing FM CAFM systems. There is a real danger that if these issues are not addressed many of the potential benefits of BIM may remain unrealised in the operational phase, especially if information from the BIM process ends up in a data cemetery due to a lack of BIM knowledge and skills in the FM industry.
References


Ashworth, S., 2013. *Added Value of FM Know-how: In the Building Whole Life Process*. Prague, EuroFM.


New Value Chains to Construction

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Abstract

Value chain analyses are utilized to study the value process production of companies. For the construction industry, several change agents are affecting the value chains in usage. To address this development, this article reviews what is considered to be the state of art in additive manufacturing methods and 3D measuring technology. Consequently, a new value chain is proposed for construction employing these technologies which is then compared to the current value chain in the construction industry. These emerging technologies may radically alter the construction industry and the way in which consumers procure construction services. Accordingly, disruptive technologies, digitalization, and servitization will likely have a profound impact on the business models and value networks in construction.

Keywords: value chain, additive manufacturing, 3D measuring, augmented reality, digitalization

1. Introduction

A value chain is a model of the corporate value forming process, first introduced by Professor Michael Porter (1985) in his book, “Competitive Advantage: Creating and Sustaining Superior Performance”. For the last 30 years, it has been applied to understand and analyze industries and has proven a useful mechanism for portraying the chained linkage of activities that exist within traditional industries, particularly that of manufacturing. It has also to a great extent framed modern thinking about value and value creation.

Accordingly, value chain analysis is a process whereby a firm identifies the primary and support activities that add value to its final product and then analyzes these activities to reduce costs or increase differentiation. The value chain represents the internal activities in which a firm engages when transforming inputs into outputs. In this chain, each step of the production process is
identified and described for an individual product starting from its source materials, and each of these nodes in the value chain causes an incremental increase in the overall value. These nodes can be physical production steps, such as weaving cotton, or they can be intangible steps, such as associating the product with a brand. Until the 1990s, a central component in value creation for a company was the generation of economic benefit for its shareholders. However, during the previous two decades, the production of customer value has now become the core aspect in value creation. This has been coupled with the application of methods from design and the social sciences to branding and service development activities. This shift in focus has in turn led to the multidisciplinary study of intangible value creation wherein value is understood to be produced by all actions of a company, and formed on individual, social, and societal levels (Tikka & Gävert, 2014).

The concept of a value chain has assumed a dominant position in the strategic analysis of industries. However, the model is underpinned by a certain value-creating logic, and its application results in accordant strategic postures. As products and services have now become ever more dematerialized and the value is ever more created in networks and alliances, the value chain concept can no longer properly uncover all sources of value. As such, the focus of value creation and analyses has now shifted to value networks, meaning that value is co-created by a combination of players in the network. Adopting a network approach, organizations focus not on the company or the industry, but rather on the value-creating system itself. In contrast to the value chain logic, these functions are performed simultaneously rather than sequentially, and mutual adjustments are required with respect to network scope, capacity, and the technical properties of the concurrent services. The value network is a business analysis perspective that describes the social and technical resources within and between businesses. The nodes in a value network represent people (or roles). The nodes are connected by interactions that represent tangible and intangible deliverables. These deliverables take the form of knowledge or other intangibles and/or financial value. These value networks thus exhibit interdependence and account for the overall worth of products and services (Peppard & Rylander 2006; Allee 2000 & 2008; Santoni & Taglioni, 2015).

Beyond the value network approach, Porter has further expanded his value views to include shared value which means that value creation exists not only for companies and customers but to the larger society. He suggests that companies often remain trapped in an outdated, narrow approach to value creation. Focused on optimizing short-term financial performance, they overlook the greatest unmet needs in the market as well as the broader influences on their long-term success. Companies too often ignore the depletion of natural resources vital to their businesses, the viability of suppliers, and the economic distress of the communities in which they produce and sell (Porter & Kramer, 2011).

The construction industry has also faced challenges. Originally focused on industrial logistics, construction companies are transforming into service businesses. Following this transformation, a construction company becomes primarily a service provider from the point of view of its clients. Thus, the era of technical specifications and minimization of costs is rapidly coming to an end.
Several possibilities exist for improving customer value creation in construction businesses. In addition to advances in brand definition and customer interaction, these possibilities are driven by technological development. The digitalization in general is changing value chains, with large online operators changing businesses. Some specific technologies that may affect construction are also emerging. Additive manufacturing, or as it is sometimes called, 3D printing, is changing the manufacturing industry. The development of construction applications is a topic of much interest. Secondly, the consumerized AR and VR technologies are attracting interest for developing applications also in construction. In addition, the applications of 3D technologies are being enabled by the 3D measuring equipment and UAV’s also being increasingly available for consumers. Together, these technologies may profoundly change the construction industry. In this article, we review these technologies, and present a scenario for future construction, utilizing them. We compare this scenario to the current dominant value chain in construction. Finally, the factors that may prevent the change in the industry are discussed.

2. Current value chain in construction

In order to map the current value chain, it is worth assessing the supply chain in the construction industry, as presented by Vrijhoef and Koskela (2000). Based on their observations of a typical construction supply chain (Figure 2), it is possible to map the corresponding value chain for the same parties (Figure 3).
3. Change agents

3.1 Additive manufacturing technologies

Additive manufacturing (AM) techniques were originally developed as prototyping methods for product development in the manufacturing industry; one particular application being the prototyping of injection molded plastic components. Later on, they have become widely known as 3D printing methods and have spread to several new application areas with the emergence of affordable machinery. At the same time, the technology of 3D printing has advanced while the selection of ‘printable’ materials has grown (Schubert et al., 2013). In an editorial for the Rapid Prototyping Journal, Campbell, Bourell, and Gibson (2012) summarize the four benefits that are pursued with the adoption of AM technology: customization, improved functionality, reduction of total amount of parts, and aesthetics. As an example of improved functionality, they list a number of features from the aerospace industry that have been attained with AM: integrated mechanical functionality, reduction of required assembly features, and internal features of components (e.g. cooling ducts).
3D printing techniques have also been forecast to revolutionize the construction industry. Some research on this topic has already been conducted (Buswell et al., 2007), and some experimental projects have also been carried out (3DRS, 2015). For example, Lim et al. (2012) reviewed three different AM processes capable of achieving 3D printing with concrete-like materials. The authors estimated the potential advantages of these techniques for construction, and formulated a list of properties: increased freedom of design, reduction in mold costs, and integrated functionality of individual components (e.g. ducts). AM methods may, in future, enable the cost-efficient manufacturing of large, geometrically complex, unique components from materials applicable to construction (e.g. concrete). This could fundamentally change the way in which current buildings are designed using identical, geometrically relatively simple, concrete elements. Therefore, 3D printing technology is highly relevant for the construction industry as it is directly linked to logistics, customization, virtual models, and manufacturing.

### 3.2 3D measuring

One of the first consumerized 3D measuring methods was the utilization of depth cameras, such as Microsoft Kinect. Depth camera images can be turned into point clouds, and applied in 3D reconstruction (Izadi et al., 2011). Commercial devices intended for indoor measurement are already on market (Matterport, 2015). 3D scanning sensors based on depth camera technology have even been integrated into smart mobile devices (Google, 2015). However, typical issues when using depth cameras are the low measuring range as compared to laser scanning (Falie and Buzuloiu, 2008) and noise in the depth measurements resulting in a limited accuracy (Izadi et al., 2011).

Laser scanning technology has also developed quite rapidly. One of the key development directions is the miniaturization of measuring equipment, price reductions for sensors, and increased ease of use of the measuring instruments. For example, mobile laser scanning (MLS) has reached a point where the entire MLS system can be easily carried by a single person, or flown aboard an UAV (Kukko et al., 2012); currently, systems weighing only a few kilograms have been prototyped.

3D measuring can also be performed using photogrammetry. As computational capacity has increased, the automation of image analysis and 3D reconstruction has become possible. Image-based systems can even be built from quite affordable components (Straub et al., 2015). Applications of these algorithms from consumer camera data sets have also been presented. The process of 3D reconstruction from unordered sets of images consists of, firstly, an estimation of the camera orientations (e.g. Snavely et al., 2006) and, secondly, a dense 3D reconstruction from image pairs (e.g. Hirschmuller, 2008). To enable this, various algorithms exist for fast but dense stereo vision. They have been compared in different contexts, among others, by Sunyoto et al. (2004) and Ahmadabadian et al. (2013).

In addition, other sensor types can also be utilized. For instance, Rosser, Morley and Smith (2015) propose a solution where orientation sensors commonly found in current smart phones are used, together with the device camera acting as a sight, to obtain a coarse outline of a room footprint.
These footprints are then processed together with the house footprint (obtained from survey data) to produce a coarse 2.5D building model. Interestingly, although this solution was based entirely on consumer hardware and commonly available data, it was still able to reach an accuracy of some tens of centimeters.

### 3.3 Augmented reality

Another technological development with an approaching impact on the construction industry is the utilization of virtual reality (VR) and augmented reality (AR) in creating immersive visualizations of virtual environments. Several projects have already employed AR/VR technology in visualizing BIM models. In this fashion, AR technology will be employed both to visualize 3D models in their future installation site and to help guide the installation activities (Behzadar & Kamat, 2005). Consumer products enabling AR or VR have been released or announced by several companies during the last year, including Samsung Gear VR, Oculus Rift, Sony Morpheus, Google Cardboard, and HTC Vive.

### 3.4 Multi-sided platforms

The aforementioned value networks are becoming more and more dynamic due to the emergence of multi-sided platforms (MSPs) enabled by digitalization. These platforms typically connect two or more sides of the market via online services, benefiting from the network effects, i.e. the platform becomes more attractive the more it increases its users and complementary service providers. Different from supply chain platforms which feature, for example, mass customization, these platforms act as a foundation upon which external innovators can develop their own complementary products, technologies, or services (Gawer and Cusumano, 2014). Well-known examples of MSPs that have already disrupted traditional industries and their business models include among others, Uber for taxi services, AirBnB for accommodation services, Amazon for retailing, and Apple Pay for banking.

Such MSP operators thrive on data-driven customer intelligence and customer experience, enabled by faster innovation capabilities and greater profits than other industries in general. These ecosystem drivers provide a branded platform for a leading customer experience, offer seamless third-party products and services, and match customer needs with other service providers, extracting “rents” from the business transactions (Weill and Woerner, 2015).

These platforms also generate new end-user services difficult to envision beforehand, enabled by an open innovation ecosystem. Often the platform operators originate from outside the traditional industry players, bringing with them ecosystem business design and a complete customer understanding, thereby disrupting traditional production-oriented business models.

The tools empowering an individual consumer for interior design tasks are already emerging in the software market (Planner 5D, 2015), and it is arguably just a matter of time before these become integrated into the actual purchasing and manufacturing activities.
4. Scenario: future design and construction process

It is possible to combine the techniques of 3D measuring, such as terrestrial laser scanning (TLS) and 3D printing. In so doing, replicas of real world objects can be produced (Virtanen et al., 2014). The combination of 3D printing and 3D measuring opens up significant possibilities for mass customization in the construction industry. By utilizing the 3D measuring tools available in a smart phone, an individual consumer can produce a 3D data set of his or her apartment. The measured data can be further processed, automatically or semi-automatically to produce a 3D model of the measured space. Afterwards, the 3D model can be applied to design components. For example, a space divider can be planned using pre-made parametric models that are then semi-automatically adapted to each individual space, using the 3D model as a reference for measurements. This design process can be achieved by the consumer in an online service. The designed components could thus utilize the possibilities offered by AM. They can include the necessary mounting features, and their internal structure can be optimized to reduce material consumption and maximize strength. The components can then be manufactured using numerically controlled (NC) machines, such as 3D printers. After delivery, the parts would then be assembled on site. As the components are made to measure, the installation time is minimized. This process is illustrated in Figure 4.

5. Discussion

The current value chain in construction is based on suppliers who manufacture individual parts from a single material (e.g. tiles, sheets, and beams) which are then used in manufacturing (e.g. furniture), or modified and installed on site (e.g. construction materials). As the manufacturing of
these parts is a traditional industrial process, they are geometrically simple, and there can be a considerable number of these manufacturers. Furthermore, for more complex entities, such as furniture elements, there are direct suppliers (who manufacture furniture) and indirect suppliers (who manufacture materials). In contrast to this, additive manufacturing enables the production of varying, geometrically complex components. As the manufacturing process is tool free, unlike casting methods for example, and is not based on manufacturing the object by removing material from a starting piece as with milling for example, the geometrical variation of parts or complicated geometry does not increase production costs. Therefore, components of varying shapes can be manufactured by the same manufacturer, without using a large amount of pre-made parts. In the most minimalist of situations, the only indirect supplier would be the producer of the printing material. Thus, from a myriad of manufacturers producing geometrically simple objects in longer value chains, manufacturing shifts to a small number of key manufacturers producing complicated objects in a short value chain.

From an economic standpoint, the industry is moving from an incremental increase in value in small steps (manufacturing materials and parts, manufacturing components, and construction on site) to a rapid increase in value in one jump (AM manufacturing of components). The operator controlling the AM manufacturing step has subsequently more control in terms of scheduling and price determination. The amount of excess inventory, logistics, and warehousing are greatly reduced, freeing resources in the process. For the consumer and designer, this shift also increases the amount of customizability. In turn, fewer compromises must be made to adapt the final design to the limited offerings of manufacturers and available components.

An analysis of future value chains in the construction industry is subject to large uncertainties. Making predictions based on technical developments alone is not sufficient, as the construction industry is also affected by other factors, such as regulations that may also change. In addition, the large commercial operators in the field have an influence over the entire system. Finally, it is unrealistic to assume that a single value chain could serve all situations encountered in the construction industry. The supply chain presented in Figure 3 is originally drafted for the development of new projects. Retrofitting a single apartment and construction of a new residential area are inherently projects of a different scale and a different producer-customer relationship. While technological developments will affect both small and large scale construction projects, the resulting value chain configuration may be quite different. Moreover, the value chain presented in this article is clearly more oriented towards renovation operations than the construction of new buildings, which was the focus of Vrijhoef and Koskela (2000).

Like any new process, change takes time, especially in an industry as fragmented as construction. There are several barriers for quick adaptation of the new technologies and radical changes in the value chain. According to Edie et al (2014) the greatest barriers for BIM adoption (in order of importance) are the following: lack of flexibility of organizations, lack of supply chain buy-in, lack of vision of benefits, cost of software, cost of training and lack of technical expertise. Organizations are clearly unsure about their own capabilities and those in their supply chain. Hail et al (2012) highlight the importance of coordination given to the complex nature of construction. They point out the following key barriers of coordination: the nature of construction vary and the
same technological methods cannot be used universally, traditional contractual arrangement can prevent to be open for new methods, construction participants may not have a common view, and the approach of construction management may vary between partners. Construction players do not need only new technological tools but also new mental models and management approaches to coordinate their projects towards a more innovative and cost-efficient implementation. Bernstein and Pittman posit - as early as in 2004 – three interrelated barriers for BIM adoption that are still relevant: the need for well-defined transactional business process models, the requirement that digital design data be computable, and the need for well-developed practical strategies for the purposeful exchange of information (Bernstein & Pittman 2004).

6. Conclusions

Additive manufacturing techniques suited for construction are beginning to emerge as commercialized tools. Concurrently, three dimensional (3D) measuring can be performed with laser scanning, scanners utilizing the triangulation principle, or photogrammetry. As these technologies have developed, 3D measuring has become increasingly available to consumers. By studying the current state and development direction of the technology, it becomes more feasible and more likely to forecast the possible value chains of future construction and estimate their impact on the industry.

By combining sensor technology, 3D measuring, AR, VR and 3D printing, the entire chain from planning, measuring to manufacturing and delivery can be digitalized, covering the entire life cycle of the built environment. In future construction, the user should be able to measure the to-be-altered environment with a mobile device, thus producing a digital model to be used in planning. In the planning phase, a new installation, such as fixed furniture, can be assembled from a set of pre-designed modules and individually produced 3D printed components. In this situation, design, visualization, cost estimation, and logistics planning are performed with online systems. After the order is placed, the pieces are manufactured, delivered, and finally installed. Digitalization will push the business models towards data-driven, multi-sided platforms where value-added services and servitization will change the current constellations of value networks.

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References


Matterport (2015) 3D For the real world, (available online http://matterport.com/ [accessed on 30/11/2015])


Planner 5D (2015) Create home design and interior decor in 2D & 3D without any special skills (available online https://planner5d.com/ [accessed 30/11/2015])


Smart Water – Intelligent Integration of Information Systems of a Water Utility

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Abstract

The largest water utility in Finland, Helsinki Region Environmental Services Authority (HSY) has started a Smart Water development program. Among many other objectives, this program aims at adopting and extending (1) a standardized data model for water and sewerage networks and (2) a data integration system to enable various ICT systems of HSY – such as the Network Information System (NIS), Customer Information System (CIS), Supervisory Control and Data Acquisition System (SCADA) and Network Investment Management (NIM) – to better interact with each other and also with ICT systems of external partners.

The part of the Smart Water program described here is implemented in cooperation with other large Nordic water utilities and Nordic water utility associations. The plan is to adopt and further develop the network data models developed in Denmark and currently owned by the Danish Water and Wastewater Association (DANVA). The Danish concept of Digital Water Company – Det Digitale Vandselskab (DDV) – has been established by DANVA in order to lift the digitalization and standardization work for water and wastewater networks to a more advanced level, making sure that the ICT strategies, system integrations, data exchanges, workflows etc. are in harmony with the common business processes of the Danish water companies. The aim of this joint Nordic effort is to adopt and further develop the DDV data model into a common Nordic data model applying open data source code and open data model. The ownership, maintenance and intellectual property rights of the Nordic data model should be with public non-profit organizations. The future benefits will be huge for the participating Nordic water utilities, but also for external business actors co-operating with water utilities. For instance, the possibility to share standardized water network data with planning and design consultants, contractors and authorities directly in the digital format can take the water utility sector to the modern Building Information Model (BIM) environment compatible with other infrastructure sectors. This will also open new and innovative business opportunities for commercial ICT service providers. In addition to the participating utilities, such as HSY, the results of the project give other water utilities encouraging examples of innovative developments in knowledge management towards smarter and more intelligent water and sewerage services.

Keywords: data integration, ICT system, open data model, open source code, smart water, water networks
1. Introduction

Water supply and sewerage services are invaluable for functioning of the society. Water services and systems are data and information intensive. Vast majority of the water infrastructure is in water and sewerage networks which are buried underground. The huge amount of networks, long life-cycle and a large number of potential information points makes availability and management of data and information related both to physical condition and actual operations of the networks challenging. Sophisticated supervisory control and automation systems are already used to manage network operations better. However, in general the holistic utilization of data related to network operations is not yet very advanced and smart in most water utilities. A common problem is that there is not enough measured data of adequate quality, to facilitate e.g. proper hydraulic or qualitative situation analysis of the network. Electricity utilities in Nordic countries are much more advanced in applying ICT systems in network management than water utilities, but electricity utilities have in most cases applied larger “all-in-one” ICT systems instead of integrating several decentralized systems.

The aim of this paper is to introduce recent and ongoing developments of intelligent ICT-applications of Helsinki Region Environmental Services Authority (HSY) in water and wastewater network management. HSY has started an ambitious Smart Water development program, which covers several key areas of its operations. Among many other objectives, this project aims at adopting and further expanding to Finnish utilities (1) a standardized data model for water and sewerage networks (location and properties, condition, hydraulic and quality data) based on the Danish experiences, and (2) a data integration system to enable various ICT systems of HSY – such as the Network Information System (NIS), Customer Information System (CIS), Supervisory Control and Data Acquisition System (SCADA) and Network Investment Management (NIM) – to interact better with each other and also with ICT systems of external partners such as consultants, contractors and authorities. The aim of this project is also to show examples and encourage other Finnish water utilities to advance and improve their water related ICT systems towards more intelligent and holistic management systems. HSY is in the Finnish context a very large water utility compared to all other utilities. On one hand its novel and innovative approaches would be important in paving the way for future utility management practices for other utilities, but on the other hand this “size polarization” is challenging for functioning markets. However, due to their size HSY and other largest Nordic water utilities together can also have a positive impact on the market behaviour within the ICT systems supplier market.

2. HSY’s Smart Water program

2.1 HSY and its water and wastewater systems and their management

Helsinki Region Environmental Services Authority (HSY) is the largest water and wastewater operator utility in Finland and one of the largest in Nordic countries. HSY produces water and sewerage services to about 1 million people in Espoo, Helsinki, Kauniainen and Vantaa cities.
HSY’s water and sewerage section has about 430 employees and its annual turnover is about 230 million euros.

The length of HSY’s water distribution network is about 3 000 kilometres and wastewater sewerage network about 2 800 kilometres. In addition there are storm-water sewers for about 2 200 kilometres. There are altogether 12 elevated water towers, 32 booster pumping stations, about 520 wastewater pumping stations and 52 storm-water pumping stations, 3 water treatment plants and 2 wastewater treatment plants. Total value of the water infrastructure assets is at least 1.6 billion euros.

HSY uses Network Information System (NIS) to manage information related to its water distribution and sewerage networks. There is one master system in use, which is complemented by several other GIS systems for specific uses. In addition to Network Information System, HSY uses a number of other ICT applications in its operations. These include for instance Supervisory Control and Data Acquisition System (SCADA), Customer Information System (CIS), Financial Information System (FIS), Business Intelligence Software (BIS) and several authority level ICT systems. Most of these applications are currently operated more or less as isolated applications with not much compatibility or integration between each other. Knowing the enormous amount of data and information collected and utilised in a large water utility, this situation is definitely seen as a challenge and inefficient utilisation of resources.

2.2 Overall scope of the Smart Water program

HSY’s Smart Water program consists of several sub-projects, such as:

1) HSY’s open piloting platform for business-based product development
2) Intelligent measuring devices in water and wastewater networks
3) New condition assessment technologies for water and wastewater networks
4) Integration of water services related and other ICT systems (e.g. Financial Information System)

Business companies are given the opportunity in the Smart Water program to pilot their innovations and products in real-life situations in HSY’s water services systems, including physical network infrastructure and data related to systems. The first sub-project aims at creating principles and opportunities for implementing these pilot projects. Pilot installations will be done in co-operation between HSY and the participating companies. Results will be available for both HSY and the companies.

The second sub-project aims at developing intelligent measuring devices or probes to measure key parameters available in water and wastewater networks, focusing on pressure, flow and acoustic parameters related to leakages. Measured data is used e.g. to establish real-time situational view of the network operations, thus supporting decision-making especially in exceptional situations. Data also helps in understanding the complex operation of water distribution and sewerage systems and in improving customer service. Initial findings suggest utilisation of probes based on membrane technologies (MEMS).
The third sub-project aims at developing methodologies and technologies to assess structural condition of water distribution network and for CCTV inspections of sewerage pipes. Knowing the huge total length (about 5000 km) of HSY’s wastewater and storm-water sewerage networks, the aim of establishing a holistic view of the network based on measured data sets rather challenging requirements for the assessment methods. The focus will be on developing interpretation methods for sewer inspections, based e.g. on machine vision interpretation of CCTV or laser scanning material.

The fourth sub-project on integration of HSY’s water services related ICT systems is the main topic of this paper and is discussed in more details in the following chapters.

### 2.3 Integration of HSY’s water services related ICT systems

The main objective of this sub-project is to develop an efficient, generic data integration system in order to facilitate data transfer and two-ways interaction between the existing ICT applications. The ICT systems in use by the water services are among others:

- Water distribution control system, SCADA
- Remote operation and control system for wastewater pumping stations
- Systems for customer information, customer relations and communication
- Systems for network information and network investment management
- Hydraulic modelling applications (water, wastewater and storm-water networks)
- Regional spatial data information system
- Financial Information System (FIS), Business Intelligence System (BIS)

The leading idea of the sub-project is to utilise the abundant, high quality measured and validated data from the utility’s various processes and to integrate the ICT systems through well-functioning data exchange and integration between systems. Thus, the central element is the data integration system. Each data item should have one data storage location in the master data system. Copying data items to other satellite ICT systems and possible further data refinement is done in the master system, but updating can be done in satellite systems.

Figure 1 illustrates the basic concept of the data integration system in the water utility’s ICT application system. ICT systems (System 1-n) are used e.g. to control water and wastewater networks, to manage network or customer information, to hydraulic modelling, to manage investments, or to create situation view for managers. Data to any ICT system from another system will be exchanged using a centralised data integration system. Additional systems can be added easily (“plug-and-play”). The concept also has a service interface for external ICT systems used e.g. by consultants, contractors, administrative bodies, etc. These will be controlled through access code systems. The concept as such is based on the principle of open data model.
Figure 1: The principal idea of data integration system in HSY’s water services related ICT architecture (Janhunen, 2015).

Benefits of integration of different ICT systems include:

- No need to manually transfer or feed data from one system to another, which reduces work, and errors and speeds up data management
- Makes it possible to choose for each purpose an ICT application which suits best from technological and functional point
- Makes it possible to develop applications flexibly and provides opportunities for software suppliers of different sizes. New (small) agile software suppliers can provide specific ICT programs for specific purposes.
- ICT programs can be renewed or procured flexibly by modules.
- Data can be updated to a master database from other applications.
- Data can be further refined during integration and transfer.
- Risks related to the use of only one software supplier (“vendor lock”) can be minimised. Vendor lock easily increases total costs and makes product development too rigid.

3. Development of the network data models

HSY has started discussions and plans to adopt and further apply for its network management operations a data model developed in Denmark for the Danish water and wastewater sector. The
Danish Water and Wastewater Association (DANVA) has developed a concept called the Digital Water Company (in Danish Det Digitale Vandselskab, DDV). DDV as such was established in 2011 in order to lift the digitalisation and standardisation work in the Danish water industry to an advanced level, ensuring that e.g. ICT-strategies, system integration, data exchange, workflow etc. in harmony with the common business processes in the Danish water companies (Asmussen, 2012). This is in line with the Danish government’s strategy together with the local authorities for enhancement of digitalisation 2011-2015.

The Digital Water Company (DDV) is a co-operation project between Danish water companies and the Danish Water and Wastewater Association (DANVA). DDV focuses on guidelines and best practices for increased alignment between business processes and data. The four main tracks of DDV are: (1) digitalisation and change management, (2) standardisation in the water industry, (3) external standardisation and co-ordination, and (4) customer focus and customer trends. Standardisation within DDV includes e.g. terminology and data models, data quality, accessibility and reuse, interface descriptions and data exchange. In external standardisation e.g. the requirements coming from the INSPIRE directive are taken into account.

Already in 2004 DANVA developed a data model for registration of wastewater pipes called DANDAS, followed in 2005 by a data model for registration of water pipes (DANVAND). In 2008 a model was added for data model maintenance purposes (D&V). The principles of data models concur with Service Oriented Architecture (SOA) and are in line with the requirements of the INSPIRE directive. Figure 2 shows the linkage between different data models within DANVA’s DDV concept.

Figure 2: DANVA’s data models and their interconnections (Gadegaard 2015).
Network data models (DANVAND and DANDAS) include a standardised description for water and wastewater networks and their components. Example of the structure of the data models is shown in Figure 3.

In 2015 some of the largest water and wastewater utilities and national water and wastewater utility associations in Denmark, Sweden and Finland commenced negotiations and plans for adopting and applying the Danish DDV-concept also in Sweden and Finland. All the Nordic so-called “6-city water utilities” are involved in these negotiations.

One of the main reasons for HSY in applying the DDV-concept in Finland is the need to adopt a data integration system to enable compatible and integrated use of data and information in a standardised format between the various ICT-applications in use. The basic model needs to be extended for this purpose. Extending the Danish open data models to other Nordic countries also requires that in each country a competent and neutral body will be identified and engaged to administer and coordinate the use and maintenance of data models. Water utilities adopting data models in their operations should be prepared to finance the costs of administration and coordination.

There are several commercial data integration ICT-applications available on the market, for instance those developed by Oracle, Microsoft, Napcon and others (Seppälä 2015). There are, however, some concerns in HSY for using fully commercial data integration applications. Adoption and development of such fully commercial data integration software would lead to a continuous and deep market dependence from the software supplier. Another important point is
that a non-commercial data integration system could easily be replicated to other water utilities in a much more affordable manner than a fully commercial system. Examples of non-commercial data integration systems include e.g. Mule, Geoserver, and PostGIS database. An ideal situation would be a combination of non-commercial and commercial systems for instance on a 50/50 basis. An illustration of a commercial generic data integration system is shown in Figure 4.

**Figure 4: Schematic example of a commercial generic data integration system (Seppälä 2015).**

HSY has good and practical reasons for its policy of finding a balance between non-commercial and commercial ICT systems. HSY has already fallen into a vendor lock situation regarding some of its ICT systems, which has caused excessive development and maintenance costs and inadequate interest from the supplier’s side for further product development.

The trend towards open data systems and advanced data exchange between systems is in the long run a win-win situation for both system end-users and system suppliers. For end-users the main benefits are faster product development and improved quality when data is exchanged easier and without errors between data systems. ICT system suppliers need to review their revenue logic in future, because customers will increasingly shift from one-supplier closed systems more towards open data source and open data exchange systems. The new paradigm benefits more new and innovative system suppliers, but also traditional closed system suppliers may expand their business if they are agile enough to renew their business strategy.
4. Discussion and Conclusions

HSY as a large water and wastewater utility has a dire need to establish smart and well-coordinated system of collecting and utilising data from its operational and managerial data systems. As part of a larger Smart Water development program, HSY intends to improve its utilisation of high quality measured data from its water and sewerage systems through extensive and advanced ICT system development.

Instead of entering into a massive one-supplier system, HSY wishes to build its system on the existing decentralised ICT systems which are integrated through a data integration system. Moreover, the plan is to develop a non-commercial data integrator instead of using generic commercial data integrators. However, as a whole HSY intends to apply a balanced combination of non-commercial and commercial ICT systems for its operations. This will also ensure a healthier market situation and avoid the one-supplier vendor lock situation.

Adoption and local tailoring of data models developed in Denmark for the water industry has been identified in HSY as a priority solution to achieve functioning integration of ICT systems, being essential part of HSY’s Smart Water project. HSY works in co-operation with the Nordic 6-city group water utilities to develop national applications of the Danish DDV model. Discussions between the Nordic water utilities and associations are ongoing, but the actual implementation of the Nordic expansion of the Danish DDV model has not yet been started. Besides the participating Nordic water utilities, there is need to organise administration and maintenance of locally tailored data models in each participating country.

HSY’s aim is also to show examples and encourage other smaller Finnish water utilities to advance and improve their water related ICT systems towards more intelligent and holistic management systems. This is one reason why a non-commercial data model and data integration system has been chosen as the basis for development. This makes it easier for other Finnish and other Nordic water utilities to affordably start using the data models and integration system compared to fully commercial systems. Wider deployment of these non-commercial systems could also have a positive impact on the ICT supplier market in the Nordic countries.

In addition to HSY’s internal benefits of integrating its own ICT systems, another key result is the possibility to share standardized water network data with planning and design consultants, contractors and authorities directly in the digital format can take the water utility sector to the modern Building Information Model (BIM) environment compatible with other infrastructure sectors. This will also open new and innovative business opportunities for commercial ICT service providers.
References


Digitising UK Construction: Closing the Gap between UK Government Aspirations and Industry’s Ability to Deliver

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Abstract

While the UK Government’s 2016 BIM mandate could filter through construction supply chains and touch even the smallest organisations, respondents to recent surveys have questioned the ability of industry to upskill and respond to the challenges encapsulated in digitisation (Knutt, 2015). As Small and Medium Enterprises (SME) and micro-firms form the majority of UK construction organisations, the adoption of BIM by SMEs is a vitally important factor in delivering on aspirations to digitise the UK construction sector. Implementing innovation within SMEs is complex and a non-linear process, suffering from scarce resources, lack of skills and systematic measurements, which can result in implementation failure and frustration for SME managers. (McAdam et al., 2010) Based on literature review and data gathering from industry experience, this paper will scope out and identify key challenges faced by BIM 4SME in reaching out to a fragmented construction sector. Driven by strategic objectives, UK construction is faced with embedding digital working into whole life supply chain activities. Perceived barriers may include cultural issues, the embodiment of industry step change, engagement with disruptive technologies and the ability of SMEs/micro SMEs to embed innovation into status quo work practices and forward planning. (Christensen, 2000; Vanheverbeke, 2012). The purpose of the research is to develop an evidence based and representative perspective on where UK construction SME/micro SMEs sit as a key industry group in responding to UK Government’s mandate for digitisation.

Keywords: BIM, SMEs/micro-SMEs, reach, knowledge transfer, assimilation
1. BIM 4SME; genesis and paradigms for change

According to Government figures, construction contributes almost £90 billion gross value (GVA) added to the UK economy representing almost 6.7% of total output and sustaining 280,000 companies. (Anon., 2008) It has been argued that the UK construction industry is highly fragmented, (Egan, 1998) (Pringle, 2012), both by international standards and in comparison with other domestic sectors. Over 90% of organisations in the built environment sector employ less than 10 workers, and almost 72,000 firms are one-person operations. Fewer than 130 construction organisations have a workforce of 600 or more. It has been noted that these large firms generate only around 25% of the industry’s output by value. Supporting professional and technical services are similarly diverse. Even the largest UK construction company commands only a 3.5% share of the market; this would not even place it within the world’s top 20 construction organisations.

During 2011, the UK Government’s Construction Strategy was published. (Cabinet Office, 2011). The report announced the Government’s intention to require collaborative 3D BIM (with all project and asset information, documentation and data being digital) on its centrally funded projects by 2016. In effect, UK Government embarked on a four year programme for sector modernisation with the key objectives of: reducing capital cost and the carbon burden from built environment construction/operation by 20%. Pivotal to realising these ambitions was the adoption of information rich Building Information Modelling (BIM) technologies and processes which it was perceived would unlock new more efficient ways of working for construction to facilitate realisation of strategic industry targets.

The BIM Task Group established a number of working groups (including the so called “BIM4s”) to take its message to UK construction. BIM 4SME is a pan-discipline industry group with a specific remit to interact with the UK’s SME and micro-SME construction communities. Membership draws from a range of professional and industry representative interests. Since 2012 BIM 4SME has developed its remit to:

- Raise awareness of BIM within the SME marketplace
- Ensure SMEs understand the requirements of Level 2 BIM relevant to their role in the supply chain
- Demonstrate the value proposition / business benefits to the SME: better efficiency, better information and better decision making
- Make sure the SMEs understand the risks of doing nothing with regards BIM implementation
- Help SMEs get ready for the Level 2 switch over: where they are and what next?
- Produce simple guidance around the BIM process in simple English and to match business needs

While realisation of UK Government objectives for digital working is predicated on wholesale buy-in by the construction sector, at November 2015, there were no reliable indicators in place to record industry’s state of readiness to deliver on the 2016 BIM mandate. The authors would
argue that without appropriate indicators, it is impossible to predict whether or not the Government’s ambitions for digitisation of construction are deliverable.

To date, BIM 4SME has relied on volunteer effort to disseminate its messages framed around perceived benefits of adopting open and collaborative BIM. The group hosts a website specifically targeted towards SME/micro organisations and BIM 4SME’s Linkedin page has stimulated online discussion and debate. (For example, in a recent post, the UK Government’s 20% cost saving target has been challenged) In addition to the framing and application of BIM standards, protocols and the like, the authors would argue that upskilling of the construction sector needs to be informed by evidence based critique from stakeholders.

Since 2014, BIM 4SME has run a series of BIM clinics for practitioners, contractors, sub-contractors and suppliers. Although BIM 4SME could be described as a “push” organisation, its developing knowledge base relies primarily on interactions with SME practitioners and industry organisations. In that context, BIM 4SME’s mission could be interpreted as bridging between evangelical (UK Government protocols) and evolutionary (developmental industry models) approaches to BIM uptake (Kouider and Paterson, 2014).

2. Research Methodology

2.1 Research Aim and Objectives

The authors’ hypothesis suggests that as we approach the end of 2015, UK Government’s aspirations for the digitisation of the construction sector may not be matched by industry’s ability to deliver. The aim of this research is to benchmark the state of readiness among SMEs/micro-SMEs in addressing UK Government’s 2016 BIM mandate. Following a literature review, data gathering will take a representative slice through construction supply chain organisations to identify skill/knowledge gaps. The investigation will also attempt to determine how the challenges of BIM adoption by SMEs could best be addressed at strategic industry level to facilitate delivery on key targets such as cost saving and carbon reduction.

The objectives of the research are:

1. Review construction SME statistics from the literature and identify perceived challenges to engagement with BIM in the UK.
2. Scope out perceived barriers to BIM adoption within SMEs.
3. Identify key challenges for the BIM 4SME group in reaching out to a fragmented industry struggling to address the need to embed digital working into design, construction and supporting supply chain activities.
4. Make evidence based recommendations to strategic UK construction organisations on how challenges inhibiting the digitisation of construction could be overcome.
5. To enhance the capability of BIM4SME as an industry organisation in providing effective support to facilitate SME engagement with BIM.
2.2 Research Strategy

The phenomenon of this research is contemporary, socially constructed and may change over time. Thus, epistemologically subjective with presupposed interpretive approach of the social phenomena, focusing on the details of situation and the subjective meaning of the motivation of the social actors, aligned with the interpretivism and in opposition with positivism theoretical perspective of research (Saunders, 2012).

The research adopts a multmethod qualitative methodology, investigating in depth small samples to obtain rich and deep data to be analysed. Themes and patterns will be identified using an inductive approach ranging from the specific to the general. The objective is to create a conceptual framework for analysis through cross-sectional sampling of SME/micro built environment organisations.

The methods adopted are literature review, data gathering from case studies provided by BIM 4SME organisations, interviews of BIM4SME experts, and observations from BIM Clinics. BIM Clinics involve SME firms approaching industry experts to discuss company experiences and concerns with BIM; a significant opportunity to observe interactions between the BIM 4SME organisation and SME practitioners. Finally, in broadening the sample from BIM 4SME contacts, the research will capture data from interviews with SMEs practitioners to increase the scope of perceived barriers and key challenges with BIM adoption.

All data trawled from the research will be systematically reviewed using content analyses: describing, connecting and classifying data through the identification of patterns emerged from the data (Gray, 2004).

3. Literature Review

3.1 SMEs in the UK Construction Industry

More than 90% of the UK construction sector comprises the small, medium sized and micro organisations (SMEs) described by the European Commission as the “engine room of the European economy” (EC, 2013). Small and Medium Enterprises (SME) is usually defined by companies with less than 250 employees. In addition, for capital allowance purposes in the UK, SMEs would have turnover of less than £22.8 million and a balance sheet of less than £11.4 million pounds (HMRC, 2011). In 2015, there were 5.4 million SMEs in the UK, accounting for 99% of the UK business and 48% of the country turnover (Rhodes, 2015, Business Statistics).

Moreover, SMEs can be divided into 3 groups:

- Micro companies – 0-9 employees
- Small Companies – 10-49 employees
- Medium Companies – 50-249 employees

The construction sector enterprises accounts for 18% of the UK all business, but only 8% of employment and 7% of turnover. The reason for that is the large amount of micro companies in
construction, boost the overall number of companies, but not the number of employed in the construction sector (Rhodes, 2015).

Although the official construction statistics cannot offer exact figures for SME numbers and turnover, they do highlight the importance of SMEs to the UK construction industry. Due to the classification adopted in the Official Construction Statistics (2015), if considering firms within the range from 0-114 number of employees, (therefore excluding medium sized companies with 115-249 employees) SMEs represent 96% of all firms in the construction sector, accounting for 61% of total value of work in the UK construction. These figures would be likely to rise if medium sized enterprises in the range of 115-249 employees were included in the overall range.

### 3.2 SME BIM adoption

BIM awareness is growing in the UK, according to recent survey published at NBS National BIM Report (2015), 95% of respondents were aware of BIM, and 48% are currently using BIM in their organisations. That is a significant increase in the use of BIM from 2010, which was a small 13% of respondents using BIM, but it also demonstrate that despite evidence of awareness, the majority of construction enterprises have not yet engaged with BIM. In the authors’ view, lack of clear definition as to what “BIM” means, could be a significant qualification to meaningful interpretation of the statistics.

International surveys demonstrate that large companies are leading the way into the uptake of BIM. For example, the Smart Market Report (2014) stated that 34% of the large firms reported more than 5 years’ experience with BIM, while half of this amount (16%) of small firms would have the same experience. However, it is not clear how the report categorised company sizes labelled as “large” and/or “small”. NBS (2014) survey reported awareness and use of BIM by size of firm, comparing firms with 1-5 employees and firms with more than 6 employees, as Figure 1 shows. This survey confirms that small companies are behind large companies in the engagement with BIM. “large” and/or “small”. NBS (2014) survey reported awareness and use of BIM by size of firm, comparing firms with 1-5 employees and firms with more than 6 employees, as Figure 1 shows. This survey confirms that small companies are behind large companies in the engagement with BIM.
Figure 1: BIM Usage and awareness, by number of people in organisation. Extract from NBS National BIM Report, after NBS (2014)

Figure 2: Barriers for BIM adoption, by number of people in organization. Extract from NBS National BIM Report, after NBS (2014)
When asked about the barriers for BIM adoption the lack of client demand is the most important reason for companies with 1-5 employees, while for companies with more than 6 employees the lack of in-house expertise is highlighted as the principal barrier, as Fig.2 above demonstrates.

Because collectively SMEs represent a majority stakeholder in the UK construction sector, their engagement with BIM is crucial for the realisation of UK Government’s 2016 mandate. This preliminary research suggests that there is a lack of detailed information about micro, small and medium companies BIM adoption in the UK and a lack of evidence based data about the challenges and barriers which SMEs face when migrating to digital working; specifically BIM adoption.

3.3 Challenges and Opportunities

The authors would argue that embodying BIM into construction SME business models is likely to involve disruption to status quo work practices and workflows. Unlike manufacturing industry, the construction sector faces the challenge that every building is different, “a unique prototype, developed by a team of consultants, contractors and other suppliers that may never have worked together before and may never work together again.” (Anon., 2015)

Also BIM involves engagement with new technologies, step change because of the ways in which information is embedded in data rich models and the use of unfamiliar protocols, for example the IFC format for file exchange. Harvard Business School professor Clayton M. Christensen coined the term disruptive technology. Christensen (1997) separated new technology into two categories: sustaining and disruptive. Sustaining technology relies on incremental improvements to an already established technology. Disruptive technology lacks refinement, often has performance problems because it is new, appeals to a limited audience, and may not yet have a proven fit with some organisations’ business models.

Christensen pointed out that large organisations are designed to work with sustaining technologies. They excel at knowing their market, staying close to their customers, and having a mechanism in place to develop existing technology. Conversely, they have trouble capitalising on the potential efficiencies, cost-savings, or new marketing opportunities created by low-margin disruptive technologies. Christensen noted that it was not unusual for a large organisation to dismiss the value of a disruptive technology because it does not reinforce existing company goals. On the other hand, due to their adaptability and structure flexibility, SMEs are more likely to engage with radical innovations, which have the potential to generate high financial returns (Adegoke et al, 2007).

In the UK, there is a commercial pressure to implement BIM with the Government mandating BIM use on public project and non-public clients demanding BIM at tender stages. In some large organisations as Skanska, Laing O’Rourke, Arup, and HOK, BIM may be part of a company’s strategy for innovation and engineering excellence. Across large industry organisations, CEOs and strategists have acknowledged BIM as a potential driver to improve efficiency and increase profits. BIM may be mandated for all new company contracts and
services (Jordan and Jeffrey, 2013) Considering that large organisations rely on supply chains (including SMEs) to deliver their projects, these companies could be pushing the uptake of BIM by small and medium sized firms.

It has been argued that, in the future, engagement with BIM may influence the awarding of contracts/sub-contracts and consequently a significant opportunity for SMEs to win business. As highlighted by UK Government spokesperson Chloe Smith, during her 2013 presentation to the BIM4SME group: “As an SME, no matter what your role in the built environment is, it is highly likely your business will or should be involved in the BIM process whether through supplying or managing data.” Smith argued that SME BIM engagement could be either be via a publicly funded project, or as part of contractual requirements from a supply chain partner (Platts and Eynon, 2013).

SMEs with appropriate BIM expertise could have a commercial advantage when engaging with projects managed by BIM enabled main contractors. In addition to single contract relationships, SMEs could also benefit from repeated business and long-term relationship with established and new supply chain partners. Another opportunity for SMEs is the possibility to tailor their input to a “just-in-time” methodology to reduce risks of abortive work, re-work and errors. For example, by using a main contractor’s digital site model, a steel sub-contractor could design and detail assemblies to fit with site constraints and/or simulate site handling logistics. Historically, sub-contractors may engage late in the design/construction processes with heightened risk of abortive work and on-costs. BIM can potentially offer unseen benefits for a range of supply chain partners, particularly sub-contractors and suppliers.

A further opportunity is for SMEs to develop new BIM related products and services for commercialisation in national/international AECO markets. While BIM transforms the way the industry works, new products and process are going to be demanded by the industry. Being at the forefront of innovation can bring a competitive advantage. Innovation is essential for firms’ competitiveness, survival and growth. It can drive competitive advantage, improve productivity and enable companies to capture higher value components of the value chain.

The construction contracting industry in particular is perceived to have low levels of innovation, (measured by research and development) compared with other sectors. Although expenditure on wider innovation such as design and organisational innovation is between two to three times larger than industry’s expenditure on tangible assets such as machinery and tools, (£7.42 billion versus £3.15 billion in 2007) the proportion of firms innovating still ranks low relative to other sectors. A literature review carried by UK Government Department of Business Information and Skills highlighted several reasons for the apparent low levels of innovation in construction: (i) high level of industry fragmentation and limited collaboration; (ii) procurement impacting on the level of collaboration; (iii) sub-optimal knowledge transfer and lost learning points; (iv) issues around market uptake and awareness of benefits from innovation; and (v) access to finance and risk-averse attitude to innovation (BIS, 2013).
The literature suggests that SMEs are receptive to engagement with disruptive technologies. SME and micro organisations tend to be structurally lean, agile and potentially adaptable to innovation. However, industry surveys suggest that large companies are leading the way on BIM adoption. This research found that some large contractors may have reached significant levels of BIM maturity in the UK and internationally. Paradoxically, it is small and medium companies which constitute the majority by numbers of the UK’s construction sector. In fact, in terms of construction supply chain characteristics, main contractors may manage the projects but sub-contractors/suppliers, (mostly SMEs), which actually do the work. For example, the literature has suggested that, for example, on a £25 million contract, the smallest sub-contract could be as little as £10k. Therefore, it is crucial to understand factors which impact on SME engagement with BIM. As a strategic issue, the adoption of BIM by SMEs is critical for the UK construction industry to achieve high levels of expertise and engagement with digital working. Also at operational level, to achieve alignment with short/medium term Government targets.

4. Preliminary Findings

4.1 Drawing from the BIM4SME Experience

Tables 1.2 outlines a range of perceived challenges to step change in work practices based on industry/practitioner data gathered and collated by BIM 4SME team between September 2012 and March 2013. These parameters were factored into BIM 4SME’s launch in London in April 2013. In articulating possible challenges/barriers, the intention was to stimulate discussion among focus groups at the launch event. Also to scope out priority areas for forward planning and testing by data gathering, analysis and the framing of appropriate recommendations as outlined earlier in the paper. Perceived challenges were structured at strategic (industry) and operational (organisation) levels. There may well be interdependencies between factors identified at strategic/operational levels. That premise will be tested during Phase 2 of the research between January and March 2016 through further data gathering from SME organisations.

<table>
<thead>
<tr>
<th>Strategic challenges</th>
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<tr>
<td>• Lack of objective advice and critique within the industry</td>
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<td>• BIMUK forward plan for education/training, FE/HE, industry etc</td>
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<tr>
<td>• Are national BIM surveys carried out to date representative</td>
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<tr>
<td>• Lack of R+D culture in UK construction. (historical + contemporary)</td>
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<td>• Fiercely competitive market situation suggests favours those with knowledge</td>
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<tr>
<td>• Fast moving pace of technological change</td>
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<td>• Downstream dissemination of UK Government strategy is a volunteer effort</td>
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<tr>
<td>• Lack of clear and achievable protocols, eg common templates for construction of BIM models</td>
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<tr>
<td>• Unclear legal framework (are risks perceived or real)</td>
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<tr>
<td>• Parallel information flows on BIM from professional, regulatory, statutory bodies (PSRBs)</td>
</tr>
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Table 1: BIM and strategic industry challenges
Operational challenges

- Cost of tooling up and risks of redundancy of software/hardware
- Training costs
- BIM wash blurs consistency of message
- BIM overload syndrome. Associated anti-BIM backlash particularly from micro-
  SMEs
- Lack of familiarity with BIM language/concepts eg “soft landings”
- Weakest link in the chain eg only one project team actor BIM compliant
- Variable levels of client engagement with BIM. Do clients perceive added value
- How robust is data embedded in and exchanged between models, eg thermal
  modelling, cost data etc
- Risks of uncertainty/abortive work related to organisations engaging with BIM on
  live projects while still way down the learning curve
- Lack of exemplars from BIM users on small projects. Little evidence to back up
  claims of collaborative working in 3D environment other than on large projects.

Table 2: BIM and operational challenges for SMEs/microSMEs

5. Conclusions

Following the publication of the 2011 UK Government Construction Strategy, the industry has
witnessed an increase in the awareness and use of BIM. In addition, industry groups became
established to offer support and guidance to construction enterprises. BIM 4 SME is part of the
BIM Task Group which aims to facilitate the transition from conventional to digital working in
micro, small and medium enterprises.

The literature has demonstrated that most construction sector employment comes from SMEs,
which are companies with up to 250 employees and up to £11.4 million turnover. In the UK
construction, Industry SMEs represents the hugely majority of construction firms, accounting
for more than 61% of the total value of work in the sector. Despite the recognised adaptability
of SMEs with respect to innovation, the paradigm shift to digital working in construction is
currently being led by large organisations. Preliminary findings from BIM 4SME industry
workshops held between September 2012 and April 2013 identified a number of
challenges to BIM uptake; these were classified at strategic and operational levels. The next phase of the
research will test perceived challenges by sampling from a representative cross-section of
construction SMEs. The summative part of the study (Phase 2) aims to make recommendations
to the industry groups that are supporting SMEs in their BIM journeys. To date, the research has
highlighted not only challenges, but market opportunities for SMEs and BIM.

Traditionally, the UK construction sector is risk averse. Construction’s fragmented morphology
combined with the unique nature of building projects tends to mitigate against change. Even
when collaborative approaches to working prove successful, it is difficult to maintain significant
levels of continuity over time. On the other hand, BIM technologies and digital processes are
seen as motivational factors which could bring improvements to industry performance. The next
stage of the research will also expand on the analyses of key challenges for BIM 4SME in
reaching out to SMEs faced with embedding digital working into design, construction and
supporting supply chain activities. Drawing from industry data gathered and taking an evidence based approached, the concluding phase of the study will propose ways to overcome perceived challenges and provide continuing support to SMEs in engaging with BIM. Realising high level objectives for digitising UK construction (cost and carbon reduction) must take account of industry’s capability to deliver.

References

http://www.publications.parliament.uk/pa/cm200708/cmselect/cmberr/127/127i.pdf
http://www.designingbuildings.co.uk/wiki/Supply_chains_in_construction
http://ec.europa.eu/enterprise/policies/sme/facts-figures-analysis/sme-definition/
http://www hmrc.gov.uk/manuals/camanual/ca23170.htm


http://www.bimplus.co.uk/news/bim-now-norm-little-faith-2016-readiness/


http://www.building.co.uk/fragmented-construction-industry/5043358.article


http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN06152


The Potential of 4D Modelling Software Systems for Risk Management in Construction Projects

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Abstract

Any construction project is full of risks, which if not minimized or eliminated can jeopardise its outcome. The sources of risks vary from project to project. With refurbishment projects, information is scarce leading to making assumptions about them, which generally entail risks. On the other hand, very new and very large projects are complex involving many disciplines and generating too much information in the different phases of construction life cycle. Actions by stakeholders in the different phases related to the project information have implications on quality, cost and schedule-related risks. Building Information Modelling (BIM) has been hailed as a solution to many challenges in construction including risk management. Applications of BIM in quantity surveying, project planning, facilities management and sustainability have been extensively researched and now common in the scientific literature. However, research about risk management in a BIM-enabled environment is still very sketchy. This is compounded by the plethora of BIM software systems which overwhelm end-users to be able to make informed decisions about their uses in risk management. The work presented in this paper is the first step of a more comprehensive research aimed at improving the understanding of risk management in a BIM environment. The focus of the investigation is about the potential of and limitations of 4D BIM software systems in managing construction risks. A purely desk-top study has been adopted to achieve the aim of this study.

Keywords: BIM, construction, efficiency, nD modelling, risk

1. Introduction

Similar to most projects, construction projects are highly subjected to risks. This is further exacerbated by their complexities, dynamism and peculiar nature (Rostami et al., 2015; Taillandier et al., 2015). Rostami et al. (2015) argued that construction projects are subjected to more risks and uncertainties because of the varying range of activities and transformation involved from the planning stage to completion. Such activities include complex planning procedure, regularly bespoke and time-consuming design as well as costly production processes. Furthermore, construction projects are becoming increasingly larger and more complex in physical size and cost. If not effectively managed, the risk associated to this huge size can lead to
losses (Chen et al, 2012). Also, projects are based on teamwork with different interested stakeholders, and the co-operation among them is formed around extensive, disparate and interrelated processes. People are very unpredictable in behaviour, compounded by unpredictable external environmental risk factors in delivering projects can be very high. Construction projects involve a lot of decision-making with consequences on the project’s success or failure (in terms of cost, time and quality) and on its environment (Taillandier et al. 2015). Sawhney et al. (2014) argued that construction is confronted by challenges such as time and cost overruns, wastage, low levels of standardisation, fragmentation, inconsistent procurement practices and low use of technology. Studies by Abderisak and Lindahl (2015) revealed that cost and time overruns are quite common with increases in the range of 50-100% being more regular and an increase of over 100% is not an unusual case. The risk associated with cost and time overruns will have immense effects on the outcome of any project if not properly managed.

Digitization of construction using BIM offers innovative ways to effectively manage construction risks (Hartmann et al, 2012; Tomek and Petr, 2014). Mott MacDonald, a management, engineering and development consultancy, defines BIM as “a coordinated set of processes, supported by technology that adds value through creating, managing and sharing the properties of an asset throughout its lifecycle (Mott MacDonald, 2015).” In order to support BIM workflow of processes, a market for BIM technologies has significantly grown in recent years. Although the growth of BIM software is great, its huge number and other technical issues have posed challenges for end-users. Lee and Sexton (2007) argued that there is a lack of holistic information for relevant construction parties regarding the characteristics of the various software packages and their appropriate uses. Furthermore, issues of non-compatibility (interoperability) among software packages are still too common. Day (2011) argued that depending on the software put to use, BIM models get very large in file size as the level of detail increases and this poses problems to computers with limited memory sizes. Fazli et al (2014) claimed that one of the major weaknesses is getting different file formats to function properly when creating a combined building information model. When data is taken from the original BIM model, a certain value is attained and when converted into another file format, a different value can be generated. A recent study by Abanda et al. (2015) led to the identification of differences between 122 BIM software systems across different construction domains. However, the study was top level with lack of details on specific domains. Building on Abanda et al. (2015), this study aims to conduct a detail investigation of BIM risk management software systems with focus on interoperability amongst the different software systems. Three main objectives employed to achieve the objectives of this study are: an Investigation into why construction risk management is required; the identification of the various commonly used scheduling and 4D BIM software for construction risk management; an investigation into the interoperability amongst the scheduling and 4D BIM software systems.

To facilitate understanding, the remainder of this paper is divided into 4 sections. In section 2, the methods used to achieve the aim of this study are examined. To provide the context of this study, in section 3, risk management in construction is explored. This is followed by an assessment of the traditional scheduling and 4D BIM software systems, where emphasis was placed on the type of operating systems supporting the software, the import/export file formats of the software and
whether risk has been integrated into the software. In section 4, the key findings and how the study objectives have been achieved are discussed. The paper concludes by a way of summary in section 5.

2. Research methods

Given that the core of this study is based on interoperability, its definition is important to provide a context for the adopted research method. Generally four types of interoperability exist in the literature. These are syntactic, technical, semantic and organisation interoperability (Rezaei et al., 2014). For purposes of this study, the focus is on syntactic interoperability which refers to the ability of two (or more) separate systems or software programmes to communicate and exchange data (or information) with each other and use the data (or information) that has been exchanged (Rezaei et al., 2014; Bahar et al., 2013). With this definition in mind, four criteria for the different software to be reviewed were established. The first criterion considers whether the software can be installed on two most popular operating systems, i.e. Mac and Windows. The second was based on how legacy scheduling/risk management tools were integrated into 4D BIM tools. By integration we mean the ease with which 4D BIM can read into legacy scheduling and/or risk management tools. The third criterion is about the file exchange formats inbuilt into the software system. The last criterion is about whether risk is integrated as part of the scheduling or 4D BIM software systems. These criteria are captured in the framework shown by Figure 1.

![Interaction](image)

*Figure 1: Factors qualifying the potential of construction scheduling software*

Based on Figure 1, an extensive literature review from peer-reviewed sources and vendors’ websites was conducted. Giving the emerging nature of BIM, peer-reviewed studies about BIM software are scarce and the few existing studies have tapped information from vendors’ websites (e.g. Crawley et al. (2008) and Abanda et al. (2015)). In examining the vendors’ websites, the specification documents were explored to identify the different operating systems, file exchange formats supported by the different software systems, whether scheduling and/or risk software was integrated in 4D BIM software systems and finally, whether risk has been integrated in the software. To further gain clarity about the set criteria for this investigation, some of the software
were installed and explored. That led to the identification and inclusion of 34 project scheduling, 3 legacy risk management software and 20 4D BIM software systems.

3. Risk management and its digitization in construction

Risk management involves creating uncertainty awareness, qualifying the risks, managing the controllable risks and curtailing uncontrollable risks impact by risk allocation/appointment (Liu et al. 2007). There are many definitions of risk management, all portraying the fundamental goal of minimizing the impact of risk. According to Irimia-Dieguez et al. (2014), risk management is the systematic process of identifying, analysing and responding to project risk. Also, Tohidi (2011) defined risk management as the process of identifying and assessing risk, and applying methods to reduce it to an acceptable extent. Hence, risk management involves the process of determining the likelihood of risk to occur, taking necessary steps to examine its effects and fashioning out ways to prevent or lessen the effects, in the event that it occurs. Generally, managing projects revolves around the proper management of the delivery of project objectives in terms of time (scheduling), cost, quality and safety as most risks emanate from them. The focus of this study is on risk associated with construction project scheduling. In emerging BIM paradigm, 4D stands for scheduling in a BIM tool. As such the discussion ensuing in this section concerns the applications of risk management in traditional software systems and contemporary risk management approaches in BIM enabled environments.

3.1 Risk management in traditional scheduling software

Project scheduling is important for construction project managers as it facilitates their task of tracking and managing the triple constraints of time, cost and quality of projects (Faghihi et al., 2014). Planning and scheduling in construction normally involves activity sequencing in space and time, taking into account other construction processes like procurement, resources, spatial constraints, etc. Traditionally, bar charts (Gantt charts) are used to schedule construction activities but these methods have been unable to show how or why certain activities are linked in a given sequence (Eastman et al., 2011). Once these schedules are created, there appears to be no direct link between the computer-aided-design (CAD) drawings and the construction schedule. As the design progresses in typical project scenarios, the construction manager reviews any updated drawings, then updates the schedule to reflect these design changes where such clarification depends on the accuracy of the construction manager (Hardin, 2009). Eastman et al. (2011) further argued that the spatial components aren’t adequately captured by the traditional methods and nor are they linked to the building model. Further claims were that scheduling (using the traditional methods) is manually intensive and often at times does not concur with the design thereby creating complications for project stakeholders to understand the schedule and its impacts on site logistics. Two most common software systems used in traditional scheduling are MS Project and Primavera. It is important to note that traditional software has been in existence for ages even before the advent of BIM and/or 4D BIM modelling. While some traditional scheduling software systems have compatible plug-ins with 4D BIM, others do not. Also some have integrated BIM while others have not. A summary of the different project scheduling software uncovered are presented in Table 1.
<table>
<thead>
<tr>
<th>Software</th>
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<th>Import file format</th>
<th>Risk analysis integration</th>
<th>Operating system</th>
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</table>

3.2 Risk management in 4D BIM software systems

Sebastian (2011) argued that BIM is not the same as the widely known computer aided design (CAD) because it goes beyond generating the traditional digital (2D or 3D) drawings. It is an
integrated model in which all process and product information is combined, stored, elaborated and interactively distributed to all relevant project actors. Also, the proposed design and engineering solutions can be assessed against the client’s requirements and expected building performance using BIM. The use of BIM during the construction phase can support good communication network between the building site, the factory and the design office (Sebastian, 2011). Fazli et al. (2014) also argued that communication processes that exist between stakeholders in a project can be enhanced massively through BIM. This is in contrast to traditional projects in which building visualizations (views) are made from scratch while BIM-based projects, the visualizations can be made from previously created models and can be monitored real-time. The schedule of construction is directly linked to the 3D model, enhancing visualization of the sequential construction or sequence activities of the building, thus allowing schedulers to visually plan and communicate activities in the context of space and time (Eastman et al., 2011). Furthermore, Hartmann et al. (2012) discussed that project risks are communicated as a risk inventory using Gantt charts and sketches that however, do not allow project managers to completely visualize and understand risks, their location on site and their implications on project deliverables making it hard to collaboratively examine and mitigate project risks. The argument was that 4D models capture both the temporal and spatial aspects of schedules and communicate schedules more effectively than Gantt charts. In the experimental study carried out by Reizgevičius et al. (2013), they argued that 4D models can shorten construction time by 1/3. Furthermore, they claimed that the use of 4D CAD model can reduce mistakes to a greater extent (twice as much) in construction processes and help in detecting and removing them more quickly. In Hartmann et al. (2012), a case study showed that if time schedule is aligned well with existing risk management processes, design teams can use 4D models to visualize project risks in time and space. Mahalingam et al. (2010) discussed that 4D CAD are beneficial in the planning and construction stage where in the former, it will be useful in communicating the construction plans and processes to clients who can then visualize the project and convey their suggestions, approval or disapproval. In the construction stage, it will be particularly useful in comparing the constructability of work methods visually in order to detect conflicts or clashes. It also serves as a visual tool for contractors, clients, subcontractors and vendors to review and plan projects’ progress. The summary of the 4D BIM software uncovered in this study are presented in Table 2. Even if many 4D software deal implicitly with many aspect of risk management (logistics, space, etc.), the risk analysis integration considered here is the explicit feature included in the software. It is important to note that some of the software systems are also 5D BIM systems, i.e. 3D plus cost dimension.

<table>
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<th>Import formats</th>
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<td>Cinema 4d, Blender, 3ds max, .RVT</td>
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4. Findings and discussion

Tables 1 and 2 provide an overview of some scheduling and 4D BIM software systems and how they integrate with BIM. The software systems were classified according to the different criteria set in section 2. A summary of how the research objectives were achieved will be discussed.

Table 3: How the research objectives were achieved

<table>
<thead>
<tr>
<th>To investigate why construction risk management is required;</th>
</tr>
</thead>
<tbody>
<tr>
<td>This was achieved through a literature review and discussed in sections 1 and 3. In section 1, the rationale for risk management in construction projects was examined. Then in section 3, the rationale and benefits for digitising risk management were discussed.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>To identify the various commonly used scheduling and 4D BIM software for construction risk management;</th>
</tr>
</thead>
<tbody>
<tr>
<td>This was achieved through an extensive literature review. Peer-reviewed and vendors’ websites served as source of information. The findings from this review were presented in Tables 1 and 2.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>To investigate the interoperability amongst the scheduling and 4D BIM software systems;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once the software systems were identified, the specification manuals were read to determine the software characteristics (e.g. file import and export format). Furthermore, in some cases some of the software had to be installed and explored to determine whether it is compliant with BIM, types of file exchange formats and whether it contains risk components.</td>
</tr>
</tbody>
</table>

By achieving the objectives, four main findings were uncovered. Firstly, some traditional construction scheduling software are BIM compliant and also contain a risk analysis component. For example, Asta PowerProject has a risk component, and its project can be read by 4D BIM software system (e.g. Synchro). Secondly, most traditional scheduling software are not yet integrated in BIM and do not contain a component for analysing risk in construction (e.g. Project Xpert and Rational Plan Professional). Thirdly, some 4D BIM software systems have a risk analysis component (e.g. Synchro and Vico) while others do not (e.g. Navisworks). The last is that some scheduling and 4D BIM software systems can be installed on Mac and/or Windows operating systems. The findings from this study can be modelled using a Venn diagramme (Figure 2) which reveals the relationship between the different software systems.
5. Conclusions

With construction projects increasingly becoming larger and more complex, there is the need for efficiency in the way construction activities are carried out. The construction industry is known for its inefficiencies, and amongst many, scheduling (time) risk is not left out. This study has explored the domain of risk management through which an understanding of the various problems that give rise to risks in construction projects was achieved. Consequently, some of the available traditional scheduling software systems were examined based on their compliance with BIM. However, it was clear that these software systems are not quite efficient in specifically managing scheduling risk. With the global advancement in technology, BIM has emerged as a technology capable of bringing more efficiency in the way the industry operates. It is in this regard that a critical appraisal of 4D BIM software systems was carried out. Although, BIM is still in its early phases, one of the benefits of BIM is that it can further enhance better risk management through 4D modelling. Through 4D modelling, project managers can be able to visualize the virtual construction of any project, identify any risk associated and make more subjective decisions rather than objective decisions. The traditional software systems are not capable of doing so but with 4D software systems, this is possible. This has been illustrated through the different literatures in this paper as well as the critical appraisal of some of the 4D software systems presented. Nonetheless, this study has not investigated how schedule risk management can be performed in a BIM environment. Future studies will focus on the processes of undertaking schedule risk management in a BIM environment for proper understanding of how to manage risk using BIM.

References


Hardin, B (2009), BIM and Construction Management: Proven tools, methods and workflows. 1st edn. Indiana: Wiley Publishing Inc.


SECTION 7
Facilities management
Visualization of Facilities Management KPIs during Early Design Using BIM

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Abstract

The use of building information modelling (BIM) in Facilities Management (FM) is a central topic of study in the construction industry at the moment. Most of the current research in the subject is focused on using BIM to efficiently deliver handover building information, support maintenance activities and close the loop in the building lifecycle. However, the use of BIM opens another set of opportunities for FM professionals that can help them to be part of a more integrated design process. This paper studies the involvement of FM professionals during the early design phase supported by the use of BIM tools. BIM tools are capable of simulating and predicting different parameters that can be utilized by FM professionals and later be used as FM key performance indicators (KPIs) to support their decision making process. In addition, the paper presents the Multi KPI visualization tool that enables the compilation of simulation results related to energy, cost and sustainability. By using the Multi KPI tool, a facility manager is able to influence in an integrated design process which opens a new set of innovative opportunities for the FM field that can positively impact the building lifecycle.

Keywords: facility management, building information modelling, key performance indicators, early design, KPI visualization

1. Introduction

During the last decade building information modelling (BIM), lean practices and integrated project delivery methods have been the major drivers of innovation in the architecture, engineering and construction (AEC) industry. With the increasing complexity of building projects and increasing number of unknowns, the combined use of these three methods has allowed for making more accurate predictions that can meet the client requirements, cost, schedule and quality of the project (Khanzode et al., 2007). After experiencing the benefits during design and construction, the project owners are also interested in extending the benefits of BIM in facilities management (FM) and possibly cover the building lifecycle. BIM for FM has been a topic of discussion for several decades, but in practice the implementation in FM is still in an early phase without yet being as successful as in design and construction. A range of potential applications of BIM in different areas of FM have been proposed in the literature such
as for operation and maintenance (O&M), asset management, space management, performance management and as a building information database (Forns-Samso et. al., 2015). However, the implementation in these areas bring along organizational, technological and process issues that need further investigation. In addition, research in this area is predicated on the premise that facility managers are only involved in the operational phase limiting different approaches on how BIM can be a useful tool for facility managers. Additionally, a thorough description of the FM industry has been constantly overlooked or mainly focused on operational activities and neglecting the value input facility managers can bring in supporting strategic level decisions in the design phase.

2. Literature Review

2.1 Facilities Management

Facilities management is said to cover all aspects of property, space, environmental control, health and safety, and support services, and it requires that appropriate control points are established in the organizations (Alexander, 2013). As a young discipline, the FM business field developing rapidly and continuously (Elmuain et al., 2010). In the past FM was often regarded as merely a sub-profession such as maintenance, caretaking, or cleaning of buildings or it was considered as a secondary discipline of principal professions in the categories of real estate, engineering, architecture and construction (Atkin, 2009). The current trends indicate that FM will be moving from operational to strategic because of its potential to in creating value for business activities (Meng and Warren, 2015). As such, the participation of FM professionals is growing, evolving and not only active in the post construction phases but also in the early phases of design.

Barrett and Owen (1993) divide FM into operational and management functions as two broad categories by function analysis. Operational functions are the daily or routine support functions involving workers. Activities at this level have a regularly short-term scope, and involve specific processes, simple and straightforward, such as repairing, replacing, cleaning, refurbishing, etc. Traditionally, operational functions were performed by in-house departments in educational and healthcare facilities but they had to be multifunctional and the personnel had to be multi skilled. Currently, it is more common that non-core business activities are outsourced to external specialists who can provide effective and efficient services (Meng and Warren, 2015).

Management functions can be distinguished at tactical and strategic levels. Tactics are action plans involving managerial operations for specific and routine activities (Johnson et al., 2008). Such activities are for example, safety procedures for prevention or proper use, maintenance plans and care of maintenance resources. Activities on this level support responsible behaviour in the workplace and the continuity of working conditions. At the strategic level there is consultation and non-routine planning aimed at making the best, long-term use of the organization’s physical resources and overall facilities. Johnson et al. (2008) see management strategy as dealing with the complexities of ambiguous, non-routine situations which can affect the direction and future of the whole organization. Strategic decisions demand an integrated
approach since the entire organization should move in the same development direction. Strategy is needed to cope with the prospect of an unknown and changing future. Although long term forecasting can only hypothesize about the future, strategic planning aims to reduce uncertainty by choosing a preferred path and a reasonable long term direction for the development of the organization.

2.2 BIM for FM

The research in the area of BIM for FM has increased rapidly in the last years. A recent literature reviews by Forns-Samso et al., (2015) summarizes the potential BIM uses in different functions of facilities management. The area with stronger focus is in supporting maintenance activities in building operations. Such potential uses include visualization and location of building components with access to real time information concerning attribute data and historical maintenance information. It also facilitates the scheduling of maintenance tasks and the ability to virtually develop a maintenance program without need of making a site visit. However, all of such uses depend on the accuracy, consistency and reliability of the data.

The second category with stronger focus is information management. Information management deals with improving data management during the lifecycle, handover information, as-built/as-maintained model used for the operational phase. Articles in this category investigate about interoperability, information exchange standards such COBie, IFC, FMie etc. and data management procedures. The vision in this research area is geared towards a lifecycle information management approach by capturing information from initial phases of the project through demolition. Major concerns with this implementation are towards the processes and roles for data capturing and data maintenance during the building lifecycle. Supportive concepts are used from industries such as manufacturing, automobile, and shipping with a strong focus on product lifecycle management (PLM). In addition, the literature considers emerging requirements for the capture of Building Performance Attribute Data.

The third category is the use of BIM for building performance which is mostly concerned with tracking and monitoring energy consumption, thermal performance, and components performance. Based on the literature building performance can be measured by integrating other systems such as requirements management, energy simulations tools and building automation systems.

The fourth category is in the area of asset management which is strongly related to maintenance activities but are more closely related to tactical decisions such as assessing the service life of components, maintenance programs, historical data and predictions about equipment failures and replacements. The area of asset management seems to have wider publications from Australia and UK.

The fifth area is space management which is concerned with activities related to real estate functions and cost. Publication numbers in this area are the lowest but it could be because already sophisticated systems such as Computer Aided Facility Management (CAFM) or
Integrated Workplace Management Systems (IWMS) have been widely used in the area of space management and BIM has not found a distinctive application from what already exists.

As described BIM for FM has many potential applications. However, there are only a few studies that show potential uses of BIM for FM in the early phases of design and how to support strategic level decision in FM. With that premise the current study gives a perspective how BIM can be utilized by FM professional in the early phases of design.

### 2.3 Early involvement of FM expertise during design

The involvement of FM professionals during early design phases is perceived of high value for entire facility lifecycle. Jaunzens et al., (2001) produced a guide that includes the participation of the facilities management team that is part of a client organisation in the design of future facilities and how the FM team’s position within the client organisation, its level of expertise and relationship with the design team affect this participation. In this study, they were able to identify issues relevant to facilities management which should be stated in the design brief, namely maintenance, flexibility and adaptability and the environmental policy.

Jensen (2009) proposed a typology of four mechanisms for knowledge transfer, to establish an integration of building operation considerations in building design. Jensen’s mechanisms of knowledge transfer are the following: (1) Utilizing building operation experiences to create codified knowledge, increasing designers’ awareness as a result, (2) Boosting the skills and capabilities of facilities managers, increasing designers’ awareness as a result; (3) Using power to guarantee that designers seriously take into consideration building operation issues through facilities management participation; (4) Using power to guarantee that design teams seriously utilize codified knowledge.

Wang et al (2013) proposed a framework with the use of BIM to engage facility managers in the early design stages. The main activities improved were in space planning, energy analysis and maintenance planning. Using BIM as a source of information proved to be valuable for collaboration and reduction of life cycle costs. Enoma (2005) states that FM involvement at the design stage will add value to the facility by “ensuring less ‘rework’, emphasising value for money, efficient control of the supply chain and team work”. However, the main barriers of FM involvement are the increased cost in with their participation and when the client is not the end-user of the building.

### 2.4 Key Performance Indicators

KPIs have become progressively more established within several industries as a performance measurement system. The advantages of using KPIs in facilities management is to direct the managerial effort towards more important areas of performance, and can be embedded in the FM services contract to clearly present the required outcomes and their relevant monitoring and control. It is important that KPIs are relevant, measurable or quantifiable in order to make appropriate comparisons (Lavy et al., 2014). The majority of KPIs generated in FM are the ones related to the cost of maintenance and operation, revenue, space management, and environmental and safety issues.
KPIs have become a part of growing area of analytics, a field that deals with prescriptive analysis. Prescriptive means that decisions regarding how to improve the performance of a facility are made based on data analysis. It utilizes the process of optimization to identify the best solution. In other words, it prescribes how to achieve the best outcome considering the effects of variability. This is recommendation phase where decision and support are coupled with expert opinions to create tactical and strategic guidance for the organization. The process of data analysis may be performed using actual or simulated data that is based on reasonable assumptions. In summary, the process of analytics can be effectively used with simulated data to analyse the relationships and impacts of KPIs.

Within this context the analysis of different KPIs using simulated data can be beneficial for facility managers during the early design phases to support their strategic level decisions. Different BIM platforms are able to assess the facilities lifecycle performance using simulations such as ECOTECT, TRNSYS, Riuska etc. However, they are not extensively used by facility managers because, as explained previously, relevant FM KPIs contain a wide range of parameters that cannot be interpreted by a single simulation platform. Therefore, it is needed a platform that can visualize a different set of parameters derived from different applications. This research try to cover that gap by presenting the Multi KPI tool described in the next section.

3. Research Goals and Objectives

To widen the scope in the use of BIM for FM, its implementation should not only focus in facility managers supporting operational activities but also involve them actively in early design phases where FM professionals can provide valuable input in the decision making process, add value in the facility design and lead to a more integrated design process.

The goal of this study is to propose a platform that compiles dynamic simulation results from different BIM platforms and present the simulation outputs as Key Performance Indicators (KPIs). KPIs can be visualized and analysed by facility managers to improve the decision making process. KPIs can be for instance, total energy consumption, CO2 emissions, total cost of energy consumption, investment cost, maintenance cost. The following are the specific objectives for this study:

1. Widen the scope of BIM for FM to be used in the early phases of design
2. Employ different simulated KPI outputs useful for Facilities Management
3. Visualize and analyse the relationship between input variables and KPIs using a sensitivity analysis and uncertainty analysis
4. Demonstrate using visualization techniques the generations of different scenarios and supported decision making
4. Research Methodology

This project uses design science methodology. The use of BIM for FM has been widely discussed in the last years without achieving tangible benefits. Within this context, design science research is an accepted problem-solution finding method that it is suitable for this study. Design science would mean designing a framework/tool as an artefact that would help the construction industry but essentially facility managers make use of BIM and support their decision making process. Vaishnavi and Kuechler (2004) described a model of the general process followed by design science research and its multiplicity of as practice variants.

The process for design science research contains different steps and the expected outcomes from each step: (i) Awareness of the problem which uses different sources to find an interesting problem in an industry or a reference discipline. The outcome is the proposal, formal or informal, for new research effort. (ii) Suggestion is the following step from the proposal, it is an essential creative step where a new functionality is envisioned or enhanced from an existing one. (iii) Development which focuses on the novelty of the artefact being developed and does not necessarily be construction of an artefact but design of it. (iv) Evaluation is where the artefact is evaluated according to the criteria explicitly explained in the proposal. Deviations from expectation, both qualitative and quantitate, are carefully noted and must be explained. It also contains an analytic sub-phase where hypothesis are made about the behaviour of the artefact. (v) Conclusion is the end of the research cycle and final stage of the research effort. The result concludes with the deviations of the behaviour of the artefact from the revised hypothetical revisions. It places a great emphasis on the knowledge contribution in the area of research.

In this project we focus on the suggestion-development phase where the artefact is envisioned or partially created as part of the development phase.

5. Multi KPI Decision Support Tool

The development of Multi-KP is intended to support multidisciplinary work and enhance collaboration between projects teams. Also, it should support the facility manager, owner, decision maker, in analyzing the impacts of key performance indicators. The Multi-KPI tool helps teams to work in a more structured way but enabling flexibility and interaction in the analysis of alternatives facilitating the decision making process. Multi KPI tool uses concepts in the development of decision support systems (DDS) tools in information systems. As such, the Multi-KPI should function as a critical tool for the rapid comparison of different evaluation criteria that could support facility managers. Therefore, Multi KPI should help the complex decision making process, assist in evaluating alternative options or scenarios, deal with complexity and have a clear, reproducible procedure. The Multi-KPI is developed as a web-based decision making application that uses a graphical multi-attribute utility analysis to evaluate and compare alternatives based on key performance indicators.
5.1 Energy Simulation

Simulation modelling has been usually used for the facility’s energy performance. Augenbroe (2002) stated simulation modelling is now being more widely applied in post-construction phases such as commissioning and facility management. In fact, simulation has become an integral part of the whole building design, engineering and operation process. In this project we use energy simulation platform RIUSKA to obtain the different Key Performance Indicators related to energy consumption and CO2 emissions.

5.2 Cost Simulation

Lifecycle cost analysis is used to evaluate the economic feasibility based on the calculation of the equivalent values of all the important costs that occur within the life span, with particular focus on buildings or the major components of buildings. An LCCA is conducted using the following four steps. (i) The analysis target is identified, which is the first step toward making a cost-effective decision by creating and evaluating the alternatives that can meet the minimum performance standards. (ii) The basic assumptions are established for the LCCA, including the analysis period and discount rate. In addition, the initial investment cost, operating cost, alteration/replacement cost, and other associated costs are confirmed, and the time of occurrence of each cost is verified. Because these cost items occur at different points in time, it is important to convert each cost to the value at a single point in time. (iii) The LCC is calculated for each alternative by adding up the costs according to the type for each alternative. (iv) The related indices are calculated to evaluate the economic feasibility (the LCC including the net savings, savings-to-investment ratio, and payback period. In addition, a sensitivity analysis can be implemented to complement the LCCA methodology, which will provide reliability to the LCCA results.

Figure 1: Visualization of the of key variables through a sensitivity analysis
5.3 Sensitivity Analysis

The subject of sensitive analysis (SA) is to learn about the influence each design variable has on the studied KPIs. This knowledge is needed to perform educated design changes to improve the design in exactly the desired way. The aim of the sensitivity analysis step is to find a design with optimised KPIs. Figure 1 illustrates a sensitivity analysis example.

5.4 KPI Visualization

Applying analytics to conceptual design has proven difficult because a problem typically has multiple targets and is imprecise with respect to one or more of these objectives (Shaw, Miles et al. 2008). The interaction of professional expertise and computer-based exploration therefore is essential for the process to be successful. Facility managers need to be able to understand general performance trends as well as variable sensitivities in order to make informed decisions in guiding the optimization process. Advanced plotting tools that enable multi-dimensional data visualization have proven useful for this purpose. For example, such as pareto graphics (Khajehpour and Grierson 2003), hyper radial visualization, parallel coordinate (Parmee 2005; Parmee, Abraham et al. 2008) plots and radar charts have proven useful for this purpose.

Parallel Coordinate Plot (PCP) is a simple way to visualize multi-dimensional data in two dimensions as shown in Figure 2. PCP shows each of the desired variable and the KPIs are presented in parallel to the coordinate axes. Each axis can have its own value range and can either be continuous or discrete variables. Discrete variable axis enables the use of non-numerical values. The visualization shows the result obtained or the results of the values of the variables depending on the approach taken, and combined these with a certain result of all the values of the line between the axes.

Although the number of variables and the objective function that can be presented in this type of visualization can be infinite, the large amount of variables will make the visualization difficult to read and find correlations of the variables may be difficult. Appropriate use of the quantitative objective function variables and visualization strategies facilitate the use and understanding.
Figure 2: Parallel coordinate plot for the decision-making using the developed multi-KPI analysis prototype tool.

The value of the variable ranges can be adjusted so it facilitates the selection of the best solutions within a desired number of parameters and therefore achieve the best desired result. It is also easy to visualize by assigning to each result and its constituent variables on the line that falls within the desired ranges. The color visualization also helps to determine the most appropriate solution. By utilizing interactive visualization options to restrict the values of the parameters and their results, so that solutions that not fall within those parameters will change colors to for example, gray, therefore we can better focus on a limited number of solutions.

Figure 3: Decision making analysis via scatter diagram.

The scatter diagram is usually used to analyze the relationship between two variables. The pattern of the intersecting points can graphically show the relationship of the variables and usually validate or invalidate cause-and-effect relationships. Scatter diagram graph can be represented in two variables of the objective function, however a third variable is also possible but projection a three-dimensional visualization could be difficult to read and interpret in practice. A more intuitive way to use the third dimension is the coloring of the points of the third objective function value and the color legend, graphs, presentation as shown in figure 3.

6. Conclusions

As described above, FM is a complex and fast growing business that responds to the demands and economic pressures of the built environment. Latest trends indicate that FM, which traditionally focuses on technical issues, is having stronger impact on a strategic level. In other
words it is developing from purely technical to more market driven service. The role of facility managers in early design should become more prominent. The use of different BIM tools enables FM professionals to make various long term predictions. The Multi-KPI which gathers different simulation results could be a powerful tool to be used by facility managers to visualize different KPIs related to FM that can improve can their decision making process.

Acknowledgements

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References


Hendriks, R., Perceptions of Facility Management in Europe, in School of Business and Services Management. 2013, JAMK University of Applied Sciences.


Identifying the Inefficiency and Poor Performance of the Delivery of Services

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Abstract

The construction industry has had a history of non-performance in the delivery of services [in terms of on time and on budget]. Other industries such as IT and professional services have also experienced non-performance. The problem seems complex, as there are many participants who are involved in the project non-performance including the owner, the buyer, the vendor, sub vendors, manufacturers, designers, and project managers. An industry structure analysis proposes that the problem is caused by parties managing, directing, and controlling (MDC) another party. This could happen anywhere in the supply chain. This paper proposes that a major source of the non-performance in projects is caused by project managers who are managing the projects from the different construction supply chain participants including the owner, the designer, the vendors, and procurement. This has been identified in numerous project tests where the objectives of the test was to minimize the MDC in the projects and the major difficulty was the resistance from project managers. The paper also proposes that the project managers are educated to manage, direct, and control in their education and training, including their professional certifications from the Project Management Institute (PMI) and the International Project Management Association (IPMA).

Key words: project management, risk management, low performance, resistance to change, delivery of service

1. Introduction

Organizations in the construction industry have had problems with delivering services on time, on budget, with high customer satisfaction. This problem has been seen in multiple industries, particularly highly technical ones, such as construction and information technology. The poor delivery of services has been documented in the construction industry worldwide for over 30 years (Latham, 1994; Egan, 1998). However, after many years and billions of dollars invested in research, the solution remains elusive (Goff, 2014). Similar to the construction industry, the information technology (IT) industry has had similar documented performance information of poor delivery of services, and has struggled to efficiently and effectively complete projects since its origins. A literature search has identified the source of the problem
is still unknown to industry in consistently and efficiently delivering high performance services. Very few
in industry and academia have created a successful hypothesis, run cycles of tests, which resulted in the
changing of industry practices (Kashiwagi, et al., 2008). The most impactful research identified, has led to
conclusions that pre-planning is critical, hiring contractors who have expertise will result in better
performance, and risk is mitigated when the supply chain partners work together, and expertise is utilized
at the beginning of projects. One of the issues making it difficult to identify the problem of the poor
delivery of services is the number of parties involved in the supply chain. The supply chain parties are
segmented into various silos of communication. Each silo communicates using technical jargon. The
technical communication increases complexity and make it more difficult to identify the source of
inefficiencies. Research has also shown that the continued education of industry participants maintain the
status quo and are perceived to be ineffective in driving positive change (Goff, 2014).

2. Problem

Due to the current reactive environment of delivering services, the result has been ineffective (Lepatner,
2007; PWC, 2009; Yun, 2013). Research has shown the following poor performance metrics:

- 2.5% of projects defined as successful (in terms of completing the full scope, on time and on
  budget).
- 30% of projects are completed within 10% of original planned cost & schedule.
- 25 to 50% of projects do not efficiently align labor on projects.
- Management inefficiency costs owners between $15.6 and $36 billion per year in the world.
- Rework by contractors is estimated to add 2-20% of expenses to a contractor’s bottom line.
- An estimated $4 billion to $12 billion per year is spent to resolve disputes and claims.

The industry has struggled with overcoming poor delivery of services, and has not seen any significant
improvement in the last 3-6 decades. The fact remains that the industry as a whole does not understand
the source of its own problem and has not done anything effective enough to fix it. The problem is also
being proliferated by multiple parties: manufacturers of systems and materials, owners, buyers, owner
project managers, procurement personnel, general contractors (GC), subcontractors (SC), and GC/SC
project managers. Literature research has shown that both the construction and information technology
industries having significant documentation of the performance of the delivery of services. Both
industries have had similar results. In the United States, construction performance has been low
(Kashiwagi, 2013):

- Productivity has decreased by .8% annually.
- Construction companies have the second highest failure and bankruptcy rate (95%).
- Over 90% of transportation construction jobs are over budget.
- Almost 50% of time is wasted on job site.

According to numerous reports in information technology, the poor delivery of services has been
similarly documented (Kashiwagi and Kashiwagi, 2014):

- US Accountability office identified 413 IT projects--totaling at least $25.2 billion in expenditures
  for the fiscal year of 2008 as being poorly planned, poorly performing, or both. With just under
  half being re-baselined at least once.
- European Services Strategy Unity reported 105 outsourced public sector ICT projects with 57% of contracts, which experienced cost overruns with an average cost overrun of 30.5% and 30% of contracts which were terminated.
- McKinsey & Company analyzed over 5,400 projects and reported 50% of IT projects on average are 45% over budget, 7% over time, 56% less value than predicted, and 17% of projects end so badly they can threaten the life of the company.

In a recent study to better understand why the performance of the delivery of services was poor, it was identified that the current delivery systems and management theories have been based on management, direction, and control. The study reviewed 780 publications in five major databases [EI Compendex, Emerald Journals, ABI/Inform, Google Scholar, and ASCE Library]. From the 780 publications reviewed, 103 delivery systems were analyzed and compared. Additionally, 10 company management models were assessed. Lastly, the top 22 major buyer/supplier theories were identified including: Lean Construction, Supply Chain Management, Total Quality Management (TQM), Just in Time (JIT), Project Management Body of Knowledge (PMBOK), and Conflict Management (Kashiwagi, 2013). In the study, the authors identified some management experts (e.g. Marcus Buckingham, Jim Collins, Edward Deming, Peter Drucker, W.L. Gore, and Ricardo Semler) that proposed that the management, direction, and control methodology is not an effective or efficient approach. Though repeatedly implemented by the management experts over the past seven decades, the non-traditional idea has not been recognized as a valid solution by current delivery methods or management theories. According to the management experts identified, MDC may be the cause of project nonperformance. Additionally, they identified the following as more accurate alternative concepts of practice to improve performance:
  - Adjust structure to fit the constraints of the people.
  - Select the right people and put into right position.
  - Formulate team philosophy, draft people to fit into the philosophy, then change the philosophy to match the constraints of the people you drafted.
  - Use the strengths of people.
  - Take the path of least resistance; let nature take its course.
  - Shift management model to an alignment model, which sets the environment and the course of the organization.
  - Remove management, and create transparency, resulting in increased accountability of all stakeholders.
  - Set up alignment model that empowers employees to choose their own work and who they will become accountable to until completion of work.

### 3. Proposal

The researchers propose to look into the traditional idea of management, direction, and control (MDC) to identify if the concept increases performance. The researchers propose to identify the results. If the results identify MDC does not improve performance then to create a new project management model that is not based on MDC and see if it can help resolve issues occurring in the industry.
4. Methodology

The researchers propose a mixed methods approach to carrying out the proposal, involving two types of research: Literature and Case Study research. To identify if MDC improves performance the following will be performed:

1. Identify the success of MDC in solving major social issues
2. Identify if construction has experienced the same results.
3. Confirm the potential source through testing.
4. Identify key components in the industry who can test out the solution.
5. Identify how to document, and proliferate the solution in the key components.

5. Success of MDC in Solving Social Issues

A literature search was performed to identify if the idea of management, direction, and control is a viable option to improve performance. In order to better understand this idea, and if it parallels what the management experts have identified, the researchers looked outside of the delivery of services area. The researchers identified dominant examples in society, where the principles of control were implemented. The goal was to potentially gain additional insights for the entire professional services community, to either strengthen the argument for or against the use of control principles. Some of the most dominant examples of societal issues were identified such as Prohibition, Drug War, Gun War, Prison System, and Immigration.

5.1 Prohibition

Prohibition will forever be one of the most dominant examples of one entity failing to control another. The United States just finished World War I and due to the progressive era [widespread social activism and political reform] in the U.S. in the late 1800’s and early 1900’s, alcohol consumption and politics were perceived to go hand in hand causing government corruption. In fact, many factions, including religious organizations were at the heart of the discussion. It was not until January 1917 that Congress first convened and began discussion and partial implementation of the removal of alcohol distribution to restrict access. On October 28, 1919, Congress officially passed the Volstead Act, overruling President Woodrow Wilson’s veto, to enforce the eighteenth amendment (prohibition). Prohibition went into full effect January 1920; until it was repealed, December 1933 by the ratification of the twenty-first amendment signed into law as the Cullen-Harrison Act by President Franklin Roosevelt. The devastation that the era of prohibition left in U.S. history has been extraordinary. In total, the prohibition lasted nearly 14 years, and started with great intentions to decrease crime through the removal of alcohol distribution and access to consumption (Burns, et al., 2011; Tracy and Acker, 2004). What actually occurred was the following:

- Increased law enforcement.
- Increased funding.
- Increased access to alcohol.
- Increased alcohol consumption.

- Increased criminal activity.
- Decreased taxes collected through alcohol.
The government’s attempt to control the American people attempting to restrict access and consumption did not work and only increased costs without decreasing access or consumption. People will always do what they want. Some additional dominant statistics are the following (Blocker, 2006; Peck, 2011; United States, 2008; US Treasury Department Bureau of Industrial Alcohol, 1932; Warburton, 1932):

- Prohibition law violations increased 102%.
- Drunkenness and disorderly conduct increased 41%.
- Drunk driving increased 81%.
- Theft and burglary increased 9%.
- Federal convicts increased 561%.
- Total federal expenditures increased 1000%.

### 5.2 Drug War

Popularized by President Richard Nixon in 1971 with his public declaration “America’s public enemy number one in the United States is drug abuse,” the drug war has its roots starting in the 1800s. Opium was beginning its popularity in the American Civil War, and cocaine was just as popular. Drugs like cocaine, heroin, and morphine were readily accessible for medicinal purposes in both health drinks and remedies. Due to an increase in addiction to these drugs, the first set of regulations to control it and restrict access was in 1906 when the Pure Food and Drug Act began requiring doctors to label their medicines. Shortly after, a number of increasingly more serious regulatory statutes took effect, such as the Harrison Narcotics ACT in 1914 (first federal drug policy), down to the creation of the Federal Bureau of Narcotics in 1930 (Sharp, 1994; Rosenberger, 1996). Though many attempts to restrict access and consumption through regulation was good intentioned, it found its match during the flower revolution of the 1960’s. Access to drugs and its consumption was at an all-time high during this decade, to the point that it caused the newly elected President Nixon to make an address against drugs that has lasted over 40 years. Not using hindsight and learning from Prohibition regarding restriction of access and consumption of substances, the war on drugs has utilized more resources and seen less improvement than the Prohibition of 1920.

Interestingly, the U.S.’s second attempt to use MDC to restrict access and consumption of substances has resulted in the following (Drug War Facts, 2014):

- Increased funding from less than $100M to over $25B.
- Increased law enforcement.
- Increased arrests from 1M to as high as 2.5M.
- Increased prison population over other arrests by over 50%.
- Maintained or increased drug use.

#### 5.2.1 Portugal/Netherlands/Canada/Uruguay

Realizing the drug war has increased cost without decreasing consumption or criminal activity, four countries (Portugal, Netherlands, Canada and Uruguay) have all decided to decriminalize the use of drugs in some way. The Netherlands decriminalized drugs in the 1970’s, Portugal in 2001, Canada in 2003, and
Uruguay in 2013. The Netherlands and Portugal governments created committees of the smartest minds to study the effects of drugs and the cost to continue enforcing rules and regulations. What is interesting though is in the Netherlands, all drugs are illegal, but the government recognizes any form to control it only causes greater issues. Instead, they have tolerated the use of drugs at a certain limit sold in coffee shops, which has resulted in drug use levels no greater than other countries and drug related deaths (2.4M) being the lowest in Europe (Mayer, 2014; Hari, 2015). According to the latest performance information published on Portugal’s decriminalization of all drug use, the numbers show similar results (Aleem, 2015):

- Continued drug use decreased from nearly 45% to less than 30%.
- Drug induced deaths decreased from nearly 80% to less than 20%.
- HIV infections decreased from nearly 45% to less than 10%.
- Increase in drug treatment by nearly 50%.

What each of these countries realized, was the prevention of drug use by increasing control does not work, and it is better to help align the people then punish them.

### 5.3 Additional Dominant Control Examples

There are many other examples documenting the inefficiency of control, and how the use of no control, has increased production and reduced cost and time:

1. **Gun Laws** – the U.S. “removal of guns” activists have attempted to have laws passed as a form of control to decrease access to guns and deaths of violent gun users. This attempt to prevent the access to guns and prevent death has only increased cost of the ATF (Bureau of Alcohol, Tobacco, Firearms and Explosives), without a significant decrease in deaths or access (U.S. Department of Justice, 2010).

2. **Prison Systems** – The U.S. thought that it could control the people they incarcerated to educate and rehabilitate them to prevent them from committing further crimes. The U.S. in general has been unable to reduce the number of law breaking individuals through incarceration, and has been one of the largest failures of control (ProCon, 2010).

3. **War on Poverty** – In the 1960’s the U.S. declared “war on poverty.” It has tried to use control to level the poverty in the U.S. through multiple government-controlled programs. The reduction of poverty has not been successful (National Poverty, 2014).

History has identified that one entity cannot control another entity; therefore, any attempt to manage, direct, and control someone should produce consistent predictable results of low performance. Similar to the findings of the management experts that any attempt to use management, direction, and control are not effective and efficient, has become evident in the social case studies presented. The pattern identified seems to be that when one entity attempts to manage, direct, and control others, the opposite desired outcome occurs instead. Whenever control is exercised, the following occurs:

- Cost increases.
- Time and resources increase.
- Increase in stress and decision-making.
- Risk increases.
- Overall performance diminishes.
Based on observation and deductive logic, the practice of MDC is inaccurate and increases risk. In the whole history of man, many people have attempted to control others with no success. The delivery of services is no different. The industry has been plagued with MDC, and it is the leading cause for all poor project performance (Kashiwagi, 2013).

6. Longitudinal Case Studies: Minnesota and MEDCOM

In order to better understand if MDC was a viable option to improve performance in industry, a two six-year longitudinal study [users in the state of Minnesota and the U.S. Army Medical Command (Table 4 and 5)] was conducted. Each user used a best value (BV) system called the Performance Information Procurement System (PIPS). PIPS is a revolutionary approach to improving the delivery of services. PIPS proposes the replacement of management, direction, and control with the utilization of expertise. The system was first conceived in 1991 as part of Dean Kashiwagi’s dissertation (1991). PIPS was originally, strictly a selection process. The first test of the process was performed in 1994, used to select roofing systems and contractors for private organizations including Intel, IBM, and McDonald Douglas. The system was documented and performed so well for the roofing industry, the system spread to other construction areas. PIPS has since been tested in the entire supply chain (construction and non-construction services). Its developments have been researched and developed, by the Performance Based Studies Research Group (PBSRG) out of Arizona State University (ASU), in support of professional groups like the International Council for Research and Innovations in Building and Construction (CIB) and the International Facility Management Association (IFMA) for the last 23 years, and has been identified as a more efficient approach to the delivery of professional services. It has identified that the main cause of non-performance in delivering services is due to management, direction, and control. The two studies identified the following similar issues:

- Inefficient internal management structure.
- Poor performance in the delivery of services.
- Did not know how to identify the performance of their services.
- Looking for an approach to help them improve their project performance.
- Needed a way to improve the management structure.

The BV system identified the following observations:

1. BV application has been a total success by providing transparency.
2. Expertise lowers costs and increases performance.
3. An expert vendor can accurately identify a project’s scope and cost.
4. Measurement brings transparency and minimizes decision-making and MDC.
5. A visionary core team must be organized that is optimal in terms of a high-ranking visionary leader, and visionary project management and procurement components.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># of Projects</td>
<td>110.00</td>
<td>129.00</td>
<td>122.00</td>
<td>92.00</td>
<td>27.00</td>
</tr>
<tr>
<td>Original Awarded Cost ($$)</td>
<td>$181,945,282</td>
<td>$177,275,551</td>
<td>$183,989,041</td>
<td>$107,091,486</td>
<td>$16,278,439</td>
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<tr>
<td>Final Awarded Cost ($$)</td>
<td>$193,881,007</td>
<td>$187,844,708</td>
<td>$192,602,961</td>
<td>$110,952,677</td>
<td>$16,352,909</td>
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</table>
### Table 5: State of Minnesota Best Value Performance

<table>
<thead>
<tr>
<th>General Overview</th>
<th>Overall</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
<th>Group E</th>
<th>Group F</th>
<th>Group G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of Projects</td>
<td>399</td>
<td>1</td>
<td>8</td>
<td>21</td>
<td>10</td>
<td>3</td>
<td>355</td>
<td>1</td>
</tr>
<tr>
<td>Total Awarded Cost ($M)</td>
<td>$434.88</td>
<td>$0.19</td>
<td>$37.81</td>
<td>$17.24</td>
<td>$5.07</td>
<td>$29.50</td>
<td>$332.70</td>
<td>$12.36</td>
</tr>
<tr>
<td>% where BV was lowest cost</td>
<td>54%</td>
<td>0%</td>
<td>83%</td>
<td>42%</td>
<td>33%</td>
<td>33%</td>
<td>55%</td>
<td>0%</td>
</tr>
<tr>
<td>Overall $$ Change Order Rate</td>
<td>8.83%</td>
<td>-</td>
<td>3.73%</td>
<td>4.04%</td>
<td>1.27%</td>
<td>2.54%</td>
<td>10.16%</td>
<td>4.53%</td>
</tr>
<tr>
<td>Owner/Client</td>
<td>7.61%</td>
<td>-</td>
<td>2.15%</td>
<td>1.08%</td>
<td>0.33%</td>
<td>0.34%</td>
<td>8.83%</td>
<td>1.16%</td>
</tr>
<tr>
<td>Designer</td>
<td>0.69%</td>
<td>-</td>
<td>1.66%</td>
<td>2.07%</td>
<td>0.63%</td>
<td>1.57%</td>
<td>0.33%</td>
<td>2.55%</td>
</tr>
<tr>
<td>Contractor</td>
<td>0.01%</td>
<td>-</td>
<td>0.21%</td>
<td>0.17%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.01%</td>
<td>0.21%</td>
</tr>
<tr>
<td>Unforeseen</td>
<td>0.52%</td>
<td>-</td>
<td>0.12%</td>
<td>1.06%</td>
<td>0.31%</td>
<td>0.63%</td>
<td>0.51%</td>
<td>0.62%</td>
</tr>
<tr>
<td>Overall Schedule Delay Rate</td>
<td>47.17%</td>
<td>-</td>
<td>35.31%</td>
<td>1.59%</td>
<td>16.38%</td>
<td>7.44%</td>
<td>51.68%</td>
<td>12.73%</td>
</tr>
<tr>
<td>Owner/Client</td>
<td>21.92%</td>
<td>-</td>
<td>15.26%</td>
<td>0.00%</td>
<td>7.41%</td>
<td>3.93%</td>
<td>24.13%</td>
<td>5.45%</td>
</tr>
<tr>
<td>Designer</td>
<td>4.47%</td>
<td>-</td>
<td>5.69%</td>
<td>1.59%</td>
<td>8.97%</td>
<td>0.00%</td>
<td>4.48%</td>
<td>7.27%</td>
</tr>
<tr>
<td>Contractor</td>
<td>2.65%</td>
<td>-</td>
<td>10.93%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>3.51%</td>
<td>2.42%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Unforeseen</td>
<td>4.54%</td>
<td>-</td>
<td>3.42%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>5.04%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Number of Satisfaction Surveys</td>
<td>233</td>
<td>0</td>
<td>2</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>212</td>
<td>1</td>
</tr>
<tr>
<td>Vendor</td>
<td>9.5</td>
<td>-</td>
<td>9.0</td>
<td>9.9</td>
<td>-</td>
<td>-</td>
<td>9.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Selection Process</td>
<td>9.7</td>
<td>-</td>
<td>8.5</td>
<td>10.0</td>
<td>-</td>
<td>-</td>
<td>9.6</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Table 4 and 5 both identify the results of both studies. The following conclusions were made:
- The owner/client and their representatives were the biggest source of project deviations.
- The BV PIPS minimized the cost and time deviations.
- The vendor performance was outstanding when the owner/client minimized MDC.
- Cost was minimized and within the budgets.

#### 7. Analysis

The research conducted by PBSRG identified the solution to the inefficiency of delivering services was in the overall structure of the industries and not a technical issue in any of the industries. It also showed the potential of the BV PIPS [utilizing expertise] to improving industry performance. Each BV case study shows a dominant improvement in performance of delivering services, simultaneously decreasing owner/client MDC. The case studies support the following concepts of the BV approach:
• The replacement of MDC with the utilization of expertise may be the most needed change required to improve industry performance.
• The utilization of expertise leads to lower costs, higher performance, and value. This is despite some industry perception that expertise is too costly. Then, when faced with massive failure due to the utilization of vendors without adequate expertise, they blame the complexity of the projects.
• If the expert must be managed, directed, and controlled, they are defined as a non-expert.
• Transparency minimizes the level of complexity and increases the value of experts and their expertise.

8. Proliferating the BV Solution

The very successful BV approach has been researched and developed for 22 years in construction and non-construction industries, and has been shown as an alternative to delivering services with documented performance information. It has been identified as a complete procurement/risk management system. The same technology has been taken into the classroom of the ASU Barrett’s Honors program, and has had the following results:

1. Most popular Honors class at ASU [Rate my professor rating of 4.9 (out of 5.0), 150 slots fill up in less than an hour, ASU engineering class ratings of 4.7 (out of 5.0), led to identification of Dr. Kashiwagi being one of the top teachers in 2013].
2. Students with problems have made drastic improvement in their personal lives to stop taking pharmaceuticals, stop drinking, implementing a life makeover, becoming transparent, and having an increase in accountability and responsibility.
3. Students learn complex concepts four to five times as quickly using natural laws, simplicity and common sense.

The Barrett’s Honors College has exposed the innovative solution to 7th and 8th graders in summer programs. The results have been outstanding. The high school education effort has paved the way for additional BV endeavors. The curriculum from the course has been compiled into a single class package that can be incorporated into any educational program. The results of the BV college and high school courses has led to additional key partnerships:

• St. Louis High School, a prominent school in Honolulu, Hawaii, has adopted a semester-long curriculum in the fall of 2015. A second private school in Honolulu is also interested in the education program
• A successful summer 2015 program was tested on 116 undergraduate Brazilian engineering students. This effort was carried out to identify if the BV-FM education could be taught quickly (in two months) and could attract students with limited English capability to the methodology.
• Tempe High School has initiate a semester long leadership academy at the first high school in the Tempe School District. The program is being pushed by an ASU coordinator who has watched the ASU honors program, the Barrett Summer Scholars program, and the 2015 successful Brazil undergraduate engineering program
Many other entities in the supply chain can benefit from the testing and implementation of the BV solution to include PMI, IFMA, IPMA, NIGP, Union organizations, Owners, Contractors, Manufactures, K-12 institutions, and Universities. The future of delivering services is to educate professionals to become someone who can utilize expertise and not manage, direct, and control. They must be able to escape their silo to increase value to the company by utilizing expertise to minimize cost.

9. Conclusion

Organizations have struggled for decades to deliver services efficiently and effectively. Due to increasing numbers of parties in a supply chain, projects have become more complex and less transparent. Due to the complexity of projects, management, direction, and control has become a staple practice in attempt to increase performance. Many project management models and delivery systems have not moved from the practice of management, direction, and control, and it has been identified as the leading cause for non-performance. Management experts such as Deming, Buckingham and others, along with dominant societal case studies such as the Prohibition and the Drug War have clearly identified that any attempt to manage, direct, and control others will result in low performance. A new approach called BV PIPS, which shifts the use of management, direction, and control to utilizing expertise, has been significantly documented to improve the performance of delivering services, and closely relates to the principles of no control identified by such management experts. The researchers further identified that the same solution, BV PIPS, is applicable to all supply chain participants in all industries, and the most important participant is the “project manager” who is doing the integration between silos in the supply chain. Lastly, the BV approach education program has been shown to successfully increase the number of highly qualified entrants into the professional industry. In testing the education curriculum on college and high school students, it has been found that students of varying ages, backgrounds, and degrees of study can learn proven high-performing industry management techniques. Students can begin learning these concepts at a young age, thus creating a pipeline of competent students entering industry. The researchers recommend future research to take project managers and propose a methodology to educate, apply, and document the results of their efforts, as well as create a pipeline of qualified and competent young students entering industry.

References


Abstract

Ability of individuals to work independent of time and place alter the optimal way of supporting core tasks of mobile workers in physical and virtual environments. Information resources are increasingly accessible to individuals, decision making power is shifting from organizations to individuals, sizes of organizations shrink, number of organizations increases and value is increasingly generated by smaller collaborating actors in networks rather than massive individual organizations. These shifts make collaboration facilitation more complex: partnering organizations and their employees are more and more scattered which creates demand for services that connect people to collaborate physically and virtually.

Collaborative practices, such as meetings and workshops, are being arranged and managed in both physical and virtual environments. Collaboration that takes place in virtual platforms is usually considered less time-taking and more sustainable in terms of carbon footprint but often include major technical nuisances. On the other hand, face-to-face collaboration can be considered more straight forward and fruitful but getting everyone in the same meeting room at the same time can be a challenge.

Therefore, this paper explores the service potential of facilitating collaborative practices by supportive services that are manifested in virtual and physical dimensions of space. It aims to increase understanding on the literature gap between virtual and physical work environments and reflect it to literature on collaborative knowledge work. It does so by first introducing lean management approach and knowledge worker typologies. Second, it discusses results of fourteen interviews and three workshops on collaborative knowledge work practices. Third, it synthesizes the results. Fourth, it discusses the implications and limitations of the study.

Keywords: Collaborative practice facilitation, Facilities management, ICT management
1. Introduction

Knowledge workers can increasingly work independent of location and time (Laing 2014). Technology enables flexible working opportunities providing more freedom of choice regarding where, when, with whom and how each individual works. At the same time, the ability to dictate work habits from the top of the organisation down to individual employee decreases. Organizations are becoming flatter, boundaries between organizational silos are blurring, and increased flexibility allows more agility and change responsiveness (GSA 2009). The new setting requires more proactivity from both the organizations and the employees.

At the same time, According to a study with 578 respondents on national meeting habits in Finland (Kokousbarometri 2015), an average employee attends seven meetings in a week, spends nine and a half hours attending meetings and over six hours to other meeting-related tasks weekly. With the average of six persons attending each meeting, one meeting is worth an individual work day, eighteen per cent of the meetings are arranged from a distance, a fourth of the meetings were considered to be possible to arrange without a meeting and 42% of the meetings are considered inefficient. Three fourths of all the meetings were reported to be internal. 56 % of the informants of the study thought that there are always or seldom too many meetings.

But the dilemma is that an increasing amount of value and knowledge is co-created 1) through internal collaboration interactions in groups rather than by any single employee alone, and 2) through external collaboration together with the partners and the customers. The increased freedom causes a variety of manners of conducting tasks which does not come without its implications. It is increasingly difficult to match times, locations and activities with peers, colleagues, clients and partners. Need for collaboration exists but an increasing amount of time is wasted in trying to collaborate rather than collaborating both in physical and virtual spheres. Collaboration activities require thus more effective facilitation and services to support them.

To understand the collaboration dynamics in physical and virtual spheres, this paper outlines the opportunities and challenges in arranging collaboration activities face-to-face and from a distance. It aims to increase understanding on service potential regarding support for collaborative knowledge work.

It does so by first introducing lean management approach and knowledge worker typologies. Second, it makes an overview of novel collaboration tools available on the market. Third, it discusses results of fourteen interviews and three workshops on collaborative knowledge work practices. Fourth, it synthesizes the results. Fourth, it discusses the implications and limitations of the study.

1.1 Literature overview

1.1.1 Lean approach to physical and virtual collaboration

Lean thinking is a business management approach which aims to capture customer value in value creation phase (Koskela 2000). Lean can be approached through three main concepts:
customer value, waste and continuous improvement (Jylhä 2013). Increasingly, as the value is co-created with the customers (Grönroos and Ravald 2011), customer value refers to the subjective perception of a service or a product for the customer. Waste refers to the types of activities that are conducted but that do not create any value for the customer (Jylhä 2013). Continuous improvement refers to the requirement of constantly improving processes and operations to minimize waste and to stay competitive in customer value creation (Jylhä 2013).

Two valid measurement concepts in lean especially in regards to collaborative activities are resource efficiency and flow efficiency. Resource efficiency is about optimizing at the level of an expert individual. Flow efficiency is about optimizing as a team for a feature. (Rothman 2015).

In terms of lean for collaboration, the latter is more valid.

Lean concept originates from Japanese car industry and has been largely used in product development practice (Rothman 2015). It has also been introduced in the field of construction management (Koskela 2000) and more recently in real estate management (Jylhä 2013). In addition, scholars in IT production have discussed lean (Plenert 2012). Lean has also been discussed in the context of team effectiveness between teams that regularly meet face-to-face (Van Dun and Wilderon 2012) and those that are globally virtual (Maznevski and Chubova 2000).

Van Dun and Wilderon (2012) outline five fundamental rules in literature of Lean orientation to management:
1. Specify the value-creating and non-value creating activities from customer perspective.
2. Identify all the necessary steps to produce the service across the whole value stream.
3. Ensure that value-creating actions flow without interruption.
4. Only make what the customer requests.
5. Continually remove waste at work as it is uncovered.

They furthermore identify four main enablers for effective lean team collaboration: Higher level leadership Support, Strategic and Structural clarity, HR policy, Resource Abundance.

However, there are no studies looking at lean as an overarching approach to compare physical, virtual and hybrid ways of collaborating in teams. Therefore, this piece of research aims to build bridges over the disciplinary silos by focusing on identifying the customer and the waste types in collaboration activities in knowledge work.

### 1.1.2 Knowledge worker as a customer in physical, social and virtual spheres

So if the organisations consist of individuals and the aim of workplace infrastructure is to support organisations, let us assume that a lean team is an ideal way of removing waste from organizational knowledge practices. The question for the managers of the supporting infrastructure then is: What does it take to facilitate these knowledge workers in the future?

To identify what actually creates value for the customer, we need to first identify the customer. In the context of providing services for collaborating knowledge workers, the demands are heterogeneous. The dilemma is that not all the knowledge workers are the same, not all their activities are the same, and not all their demands are the same. The most suitable working styles for each individual depend on the relative tasks, abilities, personal preferences and relationships with other members in relation to the organization, the team and the projects underway. Then again, not all the individual wishes can be fulfilled as individuals tend to be selfish and might not
see a greater good. An interesting example is that of Yahoo’s back to office campaign some years ago.

There are various approaches to categorizing knowledge workers. We hereby briefly review some of the most recent shifts and typologies from social, virtual and physical knowledge facilitation aspects. The most relevant points are listed in Table 1.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Conclusion</th>
<th>Field of research</th>
</tr>
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<tbody>
<tr>
<td>Van Dun and Wilderon (2012)</td>
<td>Enablers for effective lean team collaboration</td>
<td>Higher level leadership Support, Strategic and Structural clarity, HR policy, Resource Abundance</td>
</tr>
<tr>
<td>Reinhardt et al. (2011)</td>
<td>Knowledge worker roles and actions</td>
<td>Personas of controller, helper, learner, linker, networker, organizer, retriever, sharer, solver and tracker.</td>
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<tr>
<td>Morgan (2015)</td>
<td>Shift from knowledge workers to learning workers</td>
<td>Learning overcomes knowing.</td>
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<tr>
<td>Bennett et al. (2012)</td>
<td>Four generations at workplaces</td>
<td>Facilitation of knowledge exchange between generations through mentoring millennials, teamwork, collaborative working and virtual workplace.</td>
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<tr>
<td>Lake (2014)</td>
<td>Smart flexibility</td>
<td>Flexibility means the same work with different tools at different times in various locations.</td>
</tr>
<tr>
<td>Matthews et al. (2011)</td>
<td>Collaboration personas</td>
<td>Collaboration personas for Community of practice, Project team and Task team.</td>
</tr>
<tr>
<td>Miller and Marsh (2014)</td>
<td>Digital renaissance</td>
<td>Technology is most effective when invisible.</td>
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</table>

From the social knowledge facilitation point of view, Reinhardt et al. (2011) outlined nine roles and action types of knowledge workers that all contribute to the overall organisation: Controller, helper, learner, linker, networker, organizer, retriever, sharer, solver and tracker. Morgan (2015) suggests that the whole concept of a knowledge worker is challenged by that of learning workers as knowing is not useful anymore when all the knowledge is available but rather ability to learn.

On the other hand, from the physical knowledge facilitation side, Bennett et al. (2012) discuss the tricky situation of facilitating four different generations at workplaces at the same time and approaches the problem from a merely demographic aspect. In general, the technical capabilities and attitudes towards working between the generations are different and in addition, the heterogeneity among each generation is huge. Bennet et al. (2012) suggest four
workstyle criteria to overcome these problems: Mentoring Millennials, Teamwork, Collaborative working and the Virtual workplace.

Lake (2013) introduces the idea of flexible working. In his view, flexible working is not about doing a radically different kind of work. It is about doing basically the same work with different tools at different times in various locations. Both of these dynamic ideas increase individuals’ autonomy, proactivity and demand for education and common rules for collaboration.

Matthews and her peers (2011) propose collaboration personas as a design tool for workplace collaboration in the virtual sphere to unleash collective intelligence. They outline two main problems in virtual collaboration tools: the adoption problem and the use of inappropriate tools for collaboration. They argue that the end user segments in digital tool planning tend to focus on individual rather than collaboration needs. Thus, they outlined three types of teams: A community of practice, A project team, a task team. They also identified four phases of collaboration: Starting, Planning, Executing and Reporting. Miller and Marsh (2014) discuss the role of digital renaissance in the workplace, arguing that technology is most effective when it is invisible.

A proposal for the interrelations of the different dimensions are shown in Figure 1.

![Figure 1. Interrelations of social, virtual and physical workplace environments.]

Figure 1 pinpoints the demands of meeting more face-to-face in the beginning of any project and then again the ability of collaborating virtually in order to execute and report the collaborative tasks.
1.1.3 Waste from collaborating knowledge worker point of view

The actual value of any supporting service for a collaborating team of knowledge workers is getting their job done, i.e. creating value to a customer or various customers. In reality, much time is wasted in non-value creating tasks that could be automatized or totally neglected such as searching for an appropriate meeting place, ordering appropriate food, searching for a parking place, searching for emails, colleagues arriving late to meetings, connections not functioning, and so on.

So in terms of the outlined research problem, the customer is a team of collaborative mobile knowledge workers. The most simple collaboration activity, such as a meeting, can include multiple potential added values and waste flows from the knowledge worker point of view. This section explores literature on types of collaboration wastes in three scales of real estate service, office and meeting.

Jylhä (2013) identified six sources of waste in real estate services: price minimisation over cost minimisation, poorly managed information, inability to improve, unmatch between process and customer value, sub process optimization over value creation process optimization, and constantly overemployed employees.

Taylor (2014) claims that as much as 90% of all the work in the office can be considered waste. Taylor suggests that waste in an office can be seen to include at least process, physical environment, information and people waste. In the physical sphere, the largest nuisance in an office is interruption which can happen as frequently as every three minutes (Taylor 2014). Furthermore, Taylor (2014) claims, that it takes 20 minutes to get focused again on the task one was conducting before interruption.

According to a national query in Finland, on average two hours per person per week is waste in meetings (Kokousbarometri 2015). The main nuisance was considered to be not sticking to agenda, the second largest issues was someone being late from the meeting, the third getting to the actual agenda, the fourth the decision making and the fifth the unfunctioning meeting tools and equipment (Kokousbarometri 2015). It was concluded that on average in an organization of a hundred employees, the potential savings that could be achieved by removing waste from meeting practices reach up to 1.5 million € annually and save 5 hours 22 minutes from an employee’s average week.

On the other hand, offices facilitate informal encounters that can help in proceeding with projects without heavy meetings. In comparison to offices, working from home increases solitude and the amount of information waste which is the largest nuisance in the virtual sphere. One can easily get carried away by overflowing email boxes and endless social media and link jungles. Working from third places can potentially increase interaction outside the home organization but requires more proactivity from the knowledge workers.
1.1.4 State-of-the-art of available collaboration services

What kind of services are there on the market to remove the outlined wastes? There are plenty of applications to help multinational corporations in collaboration such as Trello, Fingertips, Slack, Dropbox, Microsoft OneNote, Outlook, Skype for Business, Adobe Connect, Sharepoint, Google Drive, Doodle, etc. To get an idea, this chapter outlines examples of these kinds of services that could help in removing the waste types identified in literature.

For unfunctional equipment, there tends to be helpdesks and centers but physical help is rarely available. However, some office space providers such as Technopolis offer a service where the virtual meetings begin and end automatically whenever wanted and support is available during the office hours.

For sticking to agenda, there are various types of tools that help in focusing on relevant topics. One example is Trello that provides a visual tool for organizing and following project execution. Another software is called Fingertip which helps before, during and after the decision making with various integrated tools. In physical sphere, there are various small and medium sized consultancies that provide professional – usually thematic - facilitation services such as Fira Verstas.

For the waste theme of unfunctional tools for information processing, there is a vast variety of softwares and applications available. The softwares tend to focus on a specific task of organizing, sharing, reporting or executing a task. The problem is, however, that they are not always integrated, meaning that the application may not discuss with each other. That is why for example a company called Apped mainly provides mobile applications that are always integrated to the business softwares.

To overcome the waste of getting to the agenda, applications such as Trello, Fingertip and Onenote help by visualizing tasks, responsibilities and following the decision making. Fingertip also provides a larger tool box for planning before, executing during and analyzing after decision making.

For motivating latecomers to be on time, there are not as many solutions on the market, but Latejar is an example of a gamelike app where people are motivated to come early because otherwise they would need to pay to the Latejar based on the time they are late.
<table>
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<tbody>
<tr>
<td>Price minimisation over cost minimisation</td>
<td>Physical</td>
<td>Unfunctional equipment</td>
<td>Physical</td>
<td>ie. Technopolis help center, Sharepoint</td>
</tr>
<tr>
<td>Poorly managed information</td>
<td>Information</td>
<td>Not sticking to agenda</td>
<td>Virtual</td>
<td>ie. Trello, Fingertip, Facilitation consultancy services such as Fira Verstas.</td>
</tr>
<tr>
<td>Inability to improve</td>
<td>Unfunctional tools to process information</td>
<td></td>
<td></td>
<td>ie. Trello, Slack, Fingertips, Outlook, OneNote, Yammer, Twitter, Facebook, Whatsapp, Silverbucket, Apped, Sharepoint, Doodle, Google Drive, Dropbox, QlikID, Salesforce.</td>
</tr>
<tr>
<td>No match between process and customer value</td>
<td>Process</td>
<td>Getting to the agenda</td>
<td>Social</td>
<td>ie. Trello, Fingertip, Onenote, Facilitation consultancy services</td>
</tr>
<tr>
<td>Sub process optimization</td>
<td>Decision making</td>
<td></td>
<td>ie. Fingertip</td>
<td></td>
</tr>
<tr>
<td>Employees are constantly overemployed</td>
<td>People</td>
<td>Latecomers</td>
<td></td>
<td>ie. Latejar</td>
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</table>

This literature and market overview outlined a proposal for approaching collaboration in physical, virtual and social dimensions of space. The proposal is utilized by reflecting the empirical analyses to it in the next section.

2. Method

This paper combines literature overview and service analyses with empirical data using the approach of building propositions based on case study evidence as suggested by Eisenhardt (1989). First, it looked into the types of collaboration activities in the network era by introducing recent modern knowledge worker persona types that scholars have identified in literature in fields
of knowledge, workspace and ICT management. Second, it focuses on analyzing data from 15 interviews and 3 workshops on collaborative activities in physical, social and virtual dimensions of space.

The interviews were semi-structured and they aimed to identify the typical wastes and potential sources of improvement for collaborating activities in physical, social and virtual sphere. The interviews were conducted, transcribed and analyzed by the research team consisting of four researchers from November 2014 to November 2015. The analyses were done in a two day workshop with a sensemaking technique where three of the researchers who had conducted the interviews together read and discussed each interview based on which they synthesized the results.

The analyses structured the data in three waste and improvement clusters from front-end and back-end aspects of a service organization. Accordingly, the waste types can be approached through social, physical and virtual lenses. The potential for improvement in these dimensions is introduced in Table 3.

Table 3. Potential for improvement in collaboration services in social, physical and virtual spheres

<table>
<thead>
<tr>
<th></th>
<th>Front-end improvement potential</th>
<th>Back-end improvement potential</th>
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</thead>
<tbody>
<tr>
<td>Social</td>
<td>Clear package, one click away</td>
<td>Easily accessible services, one touch point</td>
</tr>
<tr>
<td>Physical</td>
<td>Location and equipment</td>
<td>Big data and tracking</td>
</tr>
<tr>
<td>Virtual</td>
<td>Education for applications</td>
<td>Connectivity and analyses of big data</td>
</tr>
</tbody>
</table>

First, it is noteworthy, that the users are individuals in a hurry who try to reach each other and be effective. Thus, simple clarity of any collaboration service is crucial in collaboration services. From the end-user perspective, it is increasingly relevant to have a clear unique package the content of which is clear, to have one touch point and be one click away from whatever is needed for the collaboration activity—so whatever one needs, there has to be one clear instance responsible for it and it has to be easily accessible. From the service provider aspect, the services must be made easily accessible and clear even though there would be multiple providers. The user must know one place one click and one package that is relevant for him/her.

Second, the location of collaboration activities is crucial. The informants found it irritating to be always changing places and to be searching for the optimal solution where to work in depending on whom to meet. From the service provider aspect, this means that big data usage is crucial for improving services for collaboration. So tracking collaboration activities based on which services can be directed to the right places. The same technological solutions must be available everywhere, so that users from different locations can do the same things.
Third, the management of overflowing information was considered tricky. The lack of education for new applications was seen as a major reason why technology is not in as good use as it could be and digital detox was considered a way of exiting the constant information flow. Connectivity issues were considered frustrating which must be taken care of by the collaboration service provider whether it is access to files or connecting a video conference call. Also the analyses of the real time big data has to be taken care of in order to direct services better proactively rather than reactively.

3. Results

The results propose collaboration activity guidelines that can be clustered in physical, virtual and social clusters. The improvement and waste types of these clusters can be approached from front-end (end user) and back end (service provider) aspects.

![Figure 2. Proposal for collaboration service potential](image)

It is noteworthy that different scales of teams can be supported by the collaboration infrastructure services and probably the demands are different as are the lifecycles of the scales of teams. In the beginning of any project, more collaboration that connects people physically together is required whereas execution and reporting can be more easily done without face to face meetings and usually even more effectively delivered via virtual collaboration channels. The largest service potential in the back end seems to lie in easily accessible, easy to use big data tracking, collection and analyses whereas the front-end is suggested to hold largest potential in education, relevant locations and up-to-date equipment and clear packaging with easily accessible services.

4. Discussion

There seems to be a demand for services that would support clear structures and offer collaboration as a holistic service through one touch point, one click away. Regarding the front-end, this would require effective education for the end users of the potential service in the virtual
sphere, focal locations and equipment in all the locations of the physical sphere and clear packaging one click away for the end users regarding the social dimension. Regarding the back-end, this type of service would require access to multiple data sources in order to track the people and their locations and match that with the relevant collaboration space locations that would be connected without boundaries. The service should however offered from one touch point and should be easily accessible.

The described types of services that offer some part of the components exist in the market such as Facebook, LinkedIn, Tinder, Yammer, Skype, Foursquare, Yelp, Worksnug, Venuu, Fingertip, Trello, Onenote, Silverbucket, Google Drive, Sharepoint, Dropbox and Slack among others. A competitive business idea could be to collaboratively produce and integrate the most relevant data in the back end by following big data flows in order to be able to offer a one-click away collaboration service for the end users.

5. Conclusions

This paper aimed to outline service potential of collaboration services in physical and virtual dimensions of space. It outlines a conceptual framework for developing services that would support collaboration in physical and virtual spheres. In order to develop it further, specific requirements of the collaboration personas could be explored and a prototype should be made to test its components in the market. Extensive future research is thus required in order to make the collaboration clash happen.

References


Changing Societal Expectations and the Need for Dynamic Asset Lifecycling and Obsolescence Management

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Abstract

Current revolutions within the consumer electronics market are having dramatic effects upon how businesses are able to deliver their services with the continued embedding of technology within our lives. Conversely, this is currently having a direct impact upon long life assets with life expectancy in the region of 15+ years, an impact, which is believed to only increase. The term asset in this context refers to systems and their internal components, for example security systems and their orthogonal components i.e. intruder detector components, CCTV cameras, recording equipment, automated security doors, controls etc. This is a rather middle to top-level view upon the term asset and components; you will find literature referring to components as the individual electrical and material elements of a product. The mismatching of lifecycles due to contrasting market conditions is driving unforeseen obsolescence investments across the Built Environment, highlighting the current neglect of obsolescence within static asset lifecycle planning. As society changes, so do the expectations of service delivery from the Built Environment. The pressures imposed by these changes upon Facilities Managers will demand resultant changes in how services are delivered, maintained and supported throughout their useful lives. It is the combination of societal demands for a greater connected, interactive and smarter Built Environment and the effects of technological change upon obsolescence that will be covered in this paper. This paper will build upon a current Engineering Doctorate project into obsolescence and asset management to speculate both the importance of developing a dynamic approach to planning asset lifecycles and possibly how this would materialise in the future. Evidence will be provided in the form of a case study, reviewed literature and current live trends, supporting the title of this paper. The main conclusions include the growing evidence that what is being witnessed across the Built Environment will likely increase and also that more advanced industries have experienced the same problems previously. It is therefore seen as a growth area for the Built Environment to reduce the impact of obsolescence and ensure that service delivery continues to meet societal expectations.

Keywords: Asset Management, Lifecycle, Obsolescence, Service Delivery, Facilities Management
1. Introduction

Since 1965 when Gordon Moore first speculated about the future trend of computational power, Moore’s Law, technology has continued to support this original foresight (Mack 2011). Regardless of the readers’ views upon privacy, data, statistics and the like, there is a wealth of literature both within the main stream circles and academic journals, illustrating the dramatic change we are all experiencing and the plethora of change to come. Every day in 2015 over 75% of UK adults use the Internet, for a variety of needs, with almost 100% of them using it ‘on the go’ (Office for National Statistics 2015). These two statistics are more than double the uptake of 2006. Similarly, an independent report produced by the World Economic Forum in 2015 identified from a survey of 800 executives and experts, from the ICT sector, that by 2025 the first 3D printed production car would be on the road and the Built Environment would encapsulate 1 trillion sensors connected to the internet (World Economic Forum 2015). Much of the above can be found within literature associated with the term the ‘Internet of Things (IoT)’. IoT is founded upon the increasing computational power and reduction of cost and size of sensor technology (Moore’s Law), making the embedment of such technology financially viable on a large scale. In addition to the trends and developments made within industry, there are social implications of such change, Michael Felton of the New York Times created the diagram in Figure 1, which demonstrates the rapid increase of technology adoption in American households. This powerful illustration shows not only how technology is quickly finding itself within the home, but also how once a new form of technology has become accepted it quickly saturates. Technology trends such as the IoT offers a wide variety of benefits for both building occupants, through service delivery, and Facility Managers through data collection and analysis (please see Big Data, Predictive Analytics and Machine Learning).

Gravier & Swartz (2009) described another side to the above trends and coined it ‘the dark side of the technology curve’, within which it was highlighted that obsolescence and lifecycle mismatches would carry significant operational and financial costs. Obsolescence occurs when a component or asset is no longer suitable for current demands or is no longer manufactured or supported. Obsolescence is not a new term, phenomena or problem, however in light of the above trends it is tipped to greatly effect the Built Environment in the same way it challenges the Oil & Gas, Avionics, Aerospace and Defence industries. This paper will draw upon new findings from a case study experiment, illustrating the cost of ‘the dark side of the technology curve’ within the Built Environment.
2. Literature Review

The following section will cover two key themes; recent trends around the IoT and the changing expectation of service delivery within the Built Environment, regarding asset obsolescence. The purpose being to capture the future changes that will effect our buildings and how we deliver services, and also the wider implications/demands upon lifecycling techniques and standards.

Depending on whether you reference MIT Technology Review, International Data Corporation (IDC) or business consultancy firm Gartner, forecasted projections of 28, 32 or 33 billion connected devices will exist by 2020 (SIEMENS 2014). Such an expansion of devices, both producing and collecting data, will become inevitably wide reaching. Google trends currently illustrate distinct search patterns, telling a story of how large sections of society are becoming actively aware of the IoT, shown in Figure 2.

![Google Trends - Interest Over Time](image)

*Figure 2 Google Trends for the terms 'IoT' and 'Internet of Things', publically available data from www.google.co.uk/trends/

In light of the above figure, it is felt by this author that such trends will effect society in both an active and passive way. Meaning, we as members of society will either actively adopt new services, now possible through big data analysis and the medium of smart phone applications for example. Alternatively, lives of some sections of society, will passively be effected by efficiencies, now possible through discrete optimisation modelling and data driven decision making, traffic flow for example. Ultimately however, as we have witnessed with the adoption of smart phone technology, once the concept has been accepted, it quickly becomes expected. Therefore, whether you actively or passively partake in the trends outlined within this paper, subconscious acceptance of new performance levels of service delivery is likely.

The above theory, aligns with the views of ‘mutual shaping’ with regards to ‘social shaping of technology (SST)’, where society and technology development are not independent of each other but rather influence and shape each other mutually (Williams & Edge 1996; MacKenzie &
Wajcman 1985). This is a contrasting view to the previously followed technology determinism views upon technology development, heavily associated with Karl Marx. SST directly tackles the conflict between technology development, in this context relating to the IoT, against societal values and expectation, in this context relating to privacy and service delivery expectations. Does technology development shape society? Or conversely will society shape the development of technology?Interestingly, Williams & Edge (1996) explain how the concept of SST involves the idea of ‘choices’ (though not necessarily conscious choices), meaning in a ‘mutual shaping’ context, society will consciously and subconsciously effect and be affected by technological change within the Built Environment.

In 2014, SIEMENS as part of their ‘pictures of the future’ magazine, reported that the Asia Pacific region were investing more into the IoT than Europe or North America, shown in Figure 4 (SIEMENS 2014). This mirrors the analysis undertaken by Google, in Figure 3, showing that six of the top seven countries searching for information regarding the IoT are from the Asia Pacific region. The result of such activity has led to these areas also holding both the largest number of and fastest growth rate of patents related to the IoT, typically linked with organisations such as LG Electronics and Samsung (LexInnova 2014).

![Figure 4](image)

*Figure 4 Year on year increase in IoT investment, percentage of respondents within report, adapted from SIEMENS (2014)*

![Figure 3](image)

*Figure 3 Google Trends of the terms 'IoT' and 'Internet of Things', publically available data from www.google.co.uk/trends/*
The IoT is on course to disrupt and revolutionise the performance of FM service delivery, currently being capitalised by organisations located from the Asia Pacific region. This will inevitably effect society in both our professional and personal lives, potentially changing our expectations of service delivery within the Built Environment. There is academic and industrial evidence supporting the above relationships, however whether they are causal is yet to be clearly understood, therefore the real impact of such change upon both service delivery and society, is not well defined. This paper will now draw the readers’ attention to the other side of the above trends covered within this literature review, focussing on obsolescence and the life sustainment issues created by lifecycle mismatches.

Obsolescence occurs within assets when they are no longer manufactured or supported, this occurs in both software and hardware, recently exacerbated by the explosion of the consumer electronics market and the resultant shortening of lifecycles (Feng et al. 2007; Solomon et al. 2000; BSI 2007). Solomon et al. (2000) produced Figure 5, which conceptually introduces how both obsolescence is inevitable and also time related. A single asset, or collection of assets within a system, will contain hundreds and often thousands of components, which will contain their own lifecycles. The length and profile of these respective lifecycles are dictated by market forces and manufacturers. This unknown characteristic of assets within the Built Environment, creates lifecycle mismatches, causing supportability issues for FM and building users. This predominantly unrecorded, side effect of technological advances was coined as ‘the dark side of innovation’ by Gravier & Swartz (2009). The case study featured within this report begins to quantify the scale of the impact of the aforementioned dark side. A bibliometric analysis, shown in Figure 6, illustrates the rising research attention towards obsolescence. However, following gap analysis it was identified that consideration for the assets found within the Built Environment, and end users as opposed to manufacturers receive little attention.

![Figure 5 Obsolescence lifecycle stage, from Solomon et al. (2000)](image)

The crux of obsolescence within assets, is the dependence upon life expectancy of assets and their components and the need to lifecycle cost the projected intended life the asset. This is further complicated by the BS ISO 15686-2:2012 for Service Life Planning of Buildings and Constructed Assets containing the following caveat:
“[Lifecycle Planning] ... does not cover limitation of service life due to obsolescence or other non-measurable or unpredictable performance states.” - (BSI 2012) Service Life Planning

It is common practice to provide a nominal figure in years for the expected useful life of assets and major components, this prescriptive approach and has proven to be sufficient. This paper will challenge the applicability of such stationary methods for assets and asset systems that now experience dynamic variations of lifecycles and life expectancy as markets change at a faster rate.

In summary, there is evidence suggesting that the Built Environment as we know it, is to become digitised in the coming decade with an abundance of new data streams being created. Service delivery will experience dramatic improvements through the adoption of smart data analysis, providing tailored services to increase satisfaction of building users. Once wide spread, this is likely to become accepted as the norm and therefore a change in societal expectations upon service delivery by FM. In order to keep up with this trend and adopt further technology within our buildings, the effects of obsolescence are likely to increase, impacting both operationally and financially upon FM. It is logical, to therefore extract a need to improve obsolescence management techniques in tandem with ‘dynamic’ lifecycle methods to mitigate these effects both more precisely and strategically.

3. Research Design

This paper has adopted a case study design, using a UK based PFI funded London office building, which has a 100,000 m² foot print. This particular PFI was a refurbishment contract and the case study investigates into the effects of obsolescence into key long term asset systems. The time frame featured within this paper spans from 2010 to 2015, a decade on from practical completion of refurbishment works. A quant point to note, as the average life expectancy of software will predate this case study, whilst the ‘mother’ systems will require sustainment through and beyond this study.
Following discussions with the PFI contractor regarding historical procurement patterns and knowledge from the literature review, it was suggested that the following three systems be considered for this case study:

- Fire Alarm System
- Security System
- Building Management System

Historical purchase orders were analysed to investigate the pattern of investments, against the pre-planned lifecycle expenditure for these systems. Specifically, any lifecycle investments associated with obsolescence were also extracted to begin formulating evidence to the scale of impact of obsolescence within this case study.

Further to the above data, meetings were held with the respective organisations involved within the supply and maintenance of the above systems to explore additional context. This qualitative element of this paper, adds to the numbers that feature within the discussion section.

In summary, it was felt a PFI funded piece of infrastructure was an appropriate case study, as it provided unparalleled access into commercial information, which if resided within the public sector would unlikely be available. PFI contracts also provide a set of constraints and drivers to optimally operate asset systems, whilst strategically planning their lifecycle replacement, creating further incentives for all stakeholders to understand the impact of obsolescence further.

### 3.1 Case Study Evidence

Figure 7 is a lifecycle budget for the case study site, spanning from 2005 to 2015, illustrating the annual planned expenditure to replace assets in a prescriptive manner. This projection, naturally is management by an Asset Manager and the profile can change if there are both unexpected failures of assets and unexpected expenditures. The highlighted bars show the focus of this case study, the period 2012 to 2015, where the three case study asset systems were investigated. Note, the profile of the lifecycle expenditure and how in the year 2013, around a decade on from refurbishment, considerable investment was planned. Whilst this has logical

![Building Lifecycle Capital Expenditure](image-url)

*Figure 7 Building Lifecycle Capital Expenditure, across length of PFI to date*
narrative, it is not data driven and it is not dynamic. The efficiency of a lifecycle fund is reliant upon the competence of the Asset Manager, and their ability to reactively reorganise programmes of replacement to offset costs.

In order to investigate the current impact of obsolescence driven investments, a snapshot of the time frame 2012 to 2015 was taken and then illustrated in Figure 8. As you can see across this short period there were considerable investments related to obsolescence (~ £1.5m). Note, it is not solely the financial size of these investments which can pose a problem for lifecycle management, but the unforeseen nature of the majority of these investments. Requirements that did not exist prior to their identification can put pressure on FM and the operational business of service delivery. Evidently, there are financial drivers to research into the management of obsolescence and lifecycling techniques, however, it is the operational impact in life critical environments i.e. major hospitals that prove to be the overriding driver.

Figure 8 Case study comparison of obsolescence related investments and individual lifecycle expenditure

Mining the data further, two things were discovered; firstly, within the case study asset systems 10 years on from installation, 90%+ of the annual lifecycle expenditure was driven or associated with obsolescence, shown in Figure 8. Evidence that the effects of obsolescence may be cyclical

Figure 9 Case study obsolescence associated investments compared to total lifecycle expenditure for entire site
in behaviour. Figure 9 illustrates the total annual lifecycle expenditure across all systems, across the same period, 44%, 85% and 60% of the expenditure related to obsolescence was found within the three case study systems. Evidence, that the 80:20 rule is likely to apply, important when seeking to strategically manage obsolescence within the Built Environment.

In summary, the evidence provided by this case study have speculated that obsolescence may behave in a cyclical fashion, occurring in a repeated manner. Also, the Fire Alarm System, Security Systems and Building Management System are likely to concentrate your obsolescence driven investments and if only limited resource are available, to focus them on these assets. Finally, there is sufficient evidence to demonstrate that obsolescence is effecting the Built Environment currently and if managed reactively, can create significant additional lifecycle expenditure, which can cause both operational issues and lifecycle management issues.

4. Discussion

In the UK BS 8544:2013 for ‘Guide for life cycle costing of maintenance during the in use phases of buildings’, is widely used, it details the methodology for lifecycle costing (LCC) of maintenance for in use phase assets (BSI 2013). The methodologies encompassed by this British Standard, whilst comprehensive have two fundamental weaknesses. Firstly, due to their prescriptive nature, the effectiveness of LCC is dependent upon the competence of the individual performing the methodology and their respective experience and knowledge. In practice, it is common for this individual to change over time and for information sharing or continuity planning to fail. Secondly, the information gathered in the ‘capture stage’ of asset LCC must remain ‘live’ or dynamic in order to be applicable to the real world situation. In practice, it also not uncommon for this requirement to not be robustly implemented, therefore classifying the data being used for LCC obsolete or out of date. However, a competent and experienced Asset Manager may still posses the knowledge required to effectively manage assets through their lifecycle, maintaining their operational status.

This paper draws upon several major trends that when implemented will drastically shorten the lifecycle of many, previously long life, asset systems. This shortening will encourage obsolescence and reduce the time available to manage and plan asset maintenance. These aforementioned forces, will require a more dynamic approach to LCC, that is more flexible to sudden changes in market conditions, deeming specific component(s) obsolete, effecting useful life supportability.

The case study that features within this paper highlights how, within one example, current Asset Management practices are failing to avoid obsolescence driven investments. This has driven additional lifecycle costs and also applied short term operational risks to the organisation. Ultimately, this paper seeks evidence to suggest that the current practice for LCC should be readdressed, in order to avoid what Thomsen et al. (2015) label as ‘obsolete buildings’; where building demands have changed and service delivery has failed to adapt. A recent example of
the impact this can have upon the Built Environment could be, the changing buying behaviours of UK supermarket shoppers. The Financial Times reported that British Supermarkets are to write off billions of pounds from the value of their supermarkets, due to consumers shifting their preference to smaller outlets and online shopping, deeming the large style supermarket as a business model obsolete (Grover & Grover 2012).

4.1 Need for Dynamic Lifecycling

The term ‘dynamic’ in this paper refers to a method that is flexible and adaptive to characteristic changes. For example, a LCC method that considers obsolescence throughout the useful life, proactively monitors performance and condition deterioration, whilst amending the expected life and lifecycle replacement strategy would be considered flexible. In other pieces of literature this type of decision making model, have been described as ‘data driven’ as opposed to an ‘expert system’.

Academic literature by Bradley & Guerrero (2008), Sandborn (2013), Feng et al. (2007), Gravier & Swartz (2009) and many others, all suggest that the impact of obsolescence is only going to increase. These thoughts were echoed by those decision makers within the aforementioned case study, who were witnessing it’s effects first hand. If current methods remain stationary, whilst the trend of obsolescence risk increases, then the shift to meet growing societal expectations in the future will be a costly one.

Finally, to illustrate the possible future impact of obsolescence driven investments within the case study that features within this paper, Figure 10 was created. To create Figure 10, an assumption was made on the behaviour of obsolescence within long life asset systems, that lifecycles of components within systems across a building were so misaligned that obsolescence driven investments would occur on an almost annual basis in various systems. This would be represented on a lifecycle budget projection as a random/constant percentage of the annual expenditure. In order to project these percentages, the case study profile was extrapolated across the remainder of the PFI contract and visualised as a percentage of the actual planned lifecycle budget for this building.

![Figure 10 Extrapolated future obsolescence related investments as a percentage of planned Lifecycle expenditure for remainder of PFI](image-url)
The accumulative investment associated with obsolescence for this single PFI contractor is potentially staggering. By 2032 an additional total of £20 million could be assigned to obsolescence related investments. Note, what this projection does not account for, is whether these investments are in addition to the current lifecycle planned expenditure or inclusive. This is unknown due to the timing of an obsolescence driven investment, which will massively impact an Asset Manager’s ability to offset other planned lifecycle expenditures to keep the annual within budget.

5. Conclusion

To conclude, we refer back to the title of this paper ‘changing societal expectations and the need for dynamic asset lifecycling and obsolescence management’ and cover the key trends and points made.

In 2015 now more than half of the planet now live within cities, creating a dense urban environment. Researchers across academia and industry are both seeking to implement new technology to create new methodologies for service delivery across the Built Environment, in a way that previously was not possible, advances in this area come under the umbrella of the IoT.

History has shown us that whilst it is unclear whether society shapes technology, or vice versa, it is clear that as soon as technology is commercially accepted, it quickly becomes expected. It has been speculated within this paper that when FM actively embraces the IoT and provides new levels of service delivery, building occupants will quickly adopt and expect a consistent new service level.

The IoT has the potential to improve service delivery in almost every context, however this paper dives deeper into the ‘dark side’ of technological advancement and the cost of obsolescence when seeking to support asset systems within the Built Environment. Connected to obsolescence are the current LCC methods, which have proved to be sufficient in modern construction. The case study that featured within this paper has provided some evidence that the cost associated to obsolescence is significant and growing. The reactive manner in which obsolescence is currently managed and its current separation from the LCC methodology, has created a demand for a more dynamic approach, which is likely to be more data driven. This paper features some work from a current Engineering Doctorate research project, which is developing and testing data driven decision and risk tools for mitigating obsolescence.

Finally, whilst this paper illustrates a single case study which may not be homogenous across the industry, if academia is to be believed and the risk posed by obsolescence is only to increase and the industrial research on modern trends are to be believed. Then we need to adapt our methods now, in preparation for the changes we are all going to witness in both our personal and professional lives.
6. References


The Role of Leadership and Organizational Climate in Fostering Innovation in Construction

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Abstract

Leadership has been identified by many researchers as one of the most important antecedents of innovation. Previous studies tend to conclude that transformational leadership, through motivating followers to change their status quo, has a higher positive impact on organizational innovation when comparing with transactional leadership. However, the relationships between transformation leadership and innovation are inconsistent. These contradictory findings, to certain extent, suggest that the influences of leadership on innovation can be influenced by various mediators, such as innovation climate in an organization. Leaders foster innovative behaviours of followers by creating a climate that facilitates the innovative activities through, for instance, forming organizational routines to assist in achieving innovation. This organizational climate, in turn, influence the impact of leadership on innovation. Innovation has found to be essential in enhancing work effectiveness, efficiency, and business performance in the construction sector. However, hindered by various factors, construction has long been recognized as low in innovation. Success of innovation requires intimate collaboration between multiple stakeholders in developing innovation blueprint and sustaining commitment towards innovation in technically complex areas. However, due to the different value propositions amongst organisational members, tension may arise, which affects the collaboration. Hence, this study aims to investigate the mediating effects of organizational innovation climate on the leadership-innovation relationships. A questionnaire survey is designed which adopts: i) the multifactor leadership questionnaire for assessing the perceived leadership style, ii) the innovation culture scale, and iii) the innovation scale for measuring the ability of an organization to innovate as perceived by followers. The relationships are tested by factor analyses, reliability analyses, correlation analysis, and multiple regression modelling using SPSS and Lisrel. Seven factors are identified, including charisma, intellectual stimulation, individualized consideration (transformational leadership) and contingent reward (transactional leadership) for leadership; support for innovation and resource supply for innovation culture; and innovation performance. The findings reveal that support for innovation plays a significant mediating role on the influences of both transactional and transformational leaderships on innovation. The results of this study lay solid platform for further longitudinal, qualitative studies for the dynamic intertwining relationship between leadership and innovation culture across the organizational innovation process.

Keywords: Construction, Innovation, Leadership, Organizational Climate
1. Introduction

Success of innovation requires intimate collaboration between multiple stakeholders in developing innovation blueprint and sustaining commitment towards innovation in technically complex areas. Due to the different, or even competing, value propositions amongst the stakeholders, tension may arise, affecting the collaboration (Adner, 2012). Therefore, leadership has been identified by many researchers as one of the most important antecedents of innovation (e.g., Amabile, 1998; Jung et al., 2003). While extant research tends to contribute useful insights into the associations between leadership and innovation, its ability to guide management practice is limited by the predominance of studies which focus on leaders’ behaviours and on transformational leadership in particular. Although understanding how transformational leadership influence follower’s creative behaviours is worthwhile, a more important concern for organizational leaders is how to lead organizational innovation across different situations and environment.

Leadership, such as leaders’ psychological states and behaviours, are personal characteristics of a leader. A type of leadership effective in one situation/environment may thus not be in another (McLaurin, 2006). According to Fiedler’s contingency theory (1972), the effectiveness of team performance is contingent upon two factors, namely the motivational pattern of a leader and the contextual factors which empowers a leader. Motivational pattern mainly refers to the leadership types of a leader, such as task-versus-relationship oriented leadership (Miller et al., 2003) and transformational leadership (Carter, et al., 2014); while contextual factors are referred as situational favourability which determines the degree to which a situation [e.g., organizational climate (Haakonsson et al., 2008)] allows the leader to have power and influences tasks (McLaurin, 2006). Hence, based on the central assertion of contingency leadership theories, this paper proposes that the relationship between leadership and innovation of followers are contingent on an organization’s innovation climate.

2. Leadership and Innovation

One of the first researchers in the field of innovation was Schumpeter in 1934 who defined innovation as “the commercial or industrial application of something new – a new product, process or method of production; a new market or sources of supply; a new form of commercial business or financial organization” (see Stone et al., 2008; p.II-2). The definition evolves along the development of innovation research. Summary of extensive literature suggests that innovation can be defined as a process of “generation, development and implementation of ideas” (e.g., Dulaimi et al, 2005; p. 566) in different forms (e.g., process, marketing and management innovation), which are new (i.e., “novel to the institution” (Slaughter, 1998; p. 226)) and are expected to yield enhanced value (i.e., “reduction in cost and/or time associated with project delivery and improve the quality of outcomes” (Kissi et al., 2012; p. 12)). Grounded on the above broad definition, various typologies of construction innovation are identified, such as radical versus incremental innovation, bounded versus unbounded innovation, and ‘hypercube’ of innovation (Harty, 2008).
However, different types of innovation work in conjunction. More importantly, innovation has to evolve so as to convert the ever-changing business challenges into opportunities. In the complex socio-economic environment where an organisation needs dynamic capabilities and competencies to solve challenging tasks, innovation competence (which constitutes a type of dynamic capability) is a crucial factor (Teece and Pisano, 1994). While creativity is often referred as the source of innovation (e.g., Amabile, 1998), the ability of an organisation to create novel design, construction, management and/or service delivery approaches in the competitive industrial environment is typically dependent on individuals’ domain of knowledge and capability. More importantly, competency is a key element predicting performance of construction professionals (Dainty et al., 2005) and the inability of construction parties, clients and clients’ agents to adopt or absorb innovations generated by other stakeholders (e.g., contractors or consultants) hinders innovation in construction (Manley, 2006). Innovation competency governs the innovation behavior of individuals and is defined as the disposition of individuals “to act and react in an innovative manner in order to deal with different critical incidents, problems or tasks that demand innovative thinking and reactions, and which can occur in a certain context” (Cerinšek and Dolinšek, 2009, p.166). In this study, innovation competency, which can endure for a reasonably long period of time in a construction firm, is used to examine the ability of its employees to innovate in various forms to enhance performance and competitiveness at organizational levels.

Leadership has been identified as one of the most essential antecedents of innovation (e.g., Amabile et al., 2004; Mumford et al., 2002), which influences not only individual creativity but also organizational innovation (e.g., Gumusluoglu and Ilsev, 2009). Leadership, as an instrument of goal achievement (James et al., 2007), has been identified as a convergent process that acts on both organizational culture and individual behaviors (Ostroff et al., 2003). Based on the organizational goals and values perceived by a leader from the organizational culture, s/he puts intentional efforts into influencing and aligning the values, visions and behaviors of followers with that of the organization. The fundamental function of leadership for innovation is to facilitate interpretations of followers by providing meaning, to enable followers to generate, interpret and implement innovative ideas in a manner that ensures alignment with organization’s mission (Berson et al., 2006). In this process, leadership and the organizational climate are entangled.

According to Bass and Bass (2008), leadership refers to "an interaction between two or more members of a group that often involves a structuring or restructuring of the situation and of the perceptions and expectation of the members...directing the attention of other members to goals and the paths to achieve them" (p.25). Transformational and transactional leaderships are the two main types of leaderships identified in the literature, in which transformational leadership refers to leaders whose focus is in fostering the higher order intrinsic needs of followers, in preference to immediate self-interests, through idealized influence (charisma), intellectual stimulation, or individualized consideration, while transactional leadership refers to leaders whose focus is in establishing an exchange-based relationships with followers through rewarding goal achievement (Bass and Avolio, 2004). Previous studies tend to conclude that transformational leadership, through motivating followers to change their status quo (Keller,
2006), has a higher positive impact on creative climate and organizational innovation when comparing with transactional leadership (e.g., Jung et al., 2003, Elenkov and Manev, 2009).

However, the relationships between transformation leadership and innovation are heterogeneous (i.e., correlations ranging from positive to negative) (e.g., Basu and Green, 1999; Shin and Zhou, 2003). These contradictory findings, to certain extent, suggest that the associations between leadership and innovation are contingent and that these associations can be influenced by various moderators, such as organizational climate [e.g., support for innovation (Jung et al., 2008) and climate for excellence (Eisenbeiss et al., 2008)]. In this study, the moderating effects of innovation climate on the leadership-innovation relationships are investigated.

3. Organizational Innovation Climate

The sociological approach to creativity takes the view that both the level and the frequency of creative behaviours are influenced by the social environment (Woodman et al., 1993). Following this theme, climate can be defined as a psychologically meaningful description of the work environment (James and Jones, 1979), and “a set of attributes specific to a particular organisation that may be induced from the way the organisation deals with its members and its environment” (Campbell et al., 1970, p.390). “For the individual member within an organisation, climate takes the form of a set of attitudes and expectancies which describe the organization in terms of static characteristics … and behavior-outcome and outcome-outcome contingencies”.

According to Scott and Bruce (1994), a climate for innovation can be conceptualized as support for innovation and supply of resources. Support for innovation refers to an organization which not only supports employees in pursuing new ideas, but also tolerates diversity among them (Siegel and Kammerer, 1978). Change is essential to the development and implementation of any innovative ideas (Poole and Van de Ven, 2004). Through managing changes in policy, procedures (i.e., first-order changes) or changes of fundamental organizational assumptions, like vision and core values (i.e., second-order changes) properly, an organization evolves (Rothwell et al., 2010; Wang and Sun, 2012). On the other hand, although diversity between employees may induce workgroup conflicts and decrease work efficiency, it is important to organizational innovation (Florida and Gates, 2003; Milliken and Martins, 1996; Scott and Bruce, 1994). It is because only employees with tolerance of diversity can be open-minded to new or improved ideas at work (Anderson and West, 1998). In addition, to nurture a group of creative employees, organizations should supply adequate resources, such as time, human resources, material, management support, so as to allow them to pursue innovation at work (Kesting and Ulhoi, 2010).

Support for innovation climate “reflects collective perception among team members that their collaborative, innovation-related activities are expected, valued and supported in the team” (Chen et al., 2013:1020). It enables members to innovate effectively by promoting a more collaborative environment whereby team members assist, support and coordinate with each other in their attempts to innovate (Chen et al, 2013). According to West (1990), higher levels of support for innovation climate motivate individuals to initiate and persist in innovative behaviours and transformational leadership fosters innovation through support for innovation by encouraging
members “to collaborate and to assist each other with idea development and implementation” (Eisenbeiss et al. 2008:1440). Hence, the association between leadership and innovation performance can be affected by innovation climate.

A transformational leader has the ability to arouse and change members’ propensity for longer-term and more creative perspectives (Bass and Avolio, 2004), that is the leader stimulates members’ efforts to be innovative by questioning their assumptions, reframing problems and approaching situations in new ways. At the same time when transformational leaders internalize the organizational climate /culture for innovation through sensemaking, their externalization of this sensemaking shapes the organizational climate /culture of followers, resulting in followers valuing creative thought processes and innovative work approaches (Jung et al, 2003). Since organizational climate and culture represent collective social construction (Mumford et al, 2002), they serve as a sense-making device and guiding principle for more innovative work processes that could ultimately lead to innovative performance in terms of new products and services (Scott and Bruce, 1994).

4. Research Method

Based on the above, quantitative method based on questionnaire surveys is employed to test the hypothesized relationships using correlation analysis, regression modelling and structural equations modelling. Questionnaires of this study are equally distributed to 500 respondents from different organisations of client developers, construction consultants, and contractors in China. Both purposive sampling and convenience sampling are used. Data are returned from 158 respondents (31.6% response rate) via email, web-based questionnaire system, fax return, and face-to-face meeting. There is a good mix of respondents from different professional disciplines (34.8% project management, 16.5% architecture, 15.2% structural engineering, 13.9% quantity surveying, 8.2% building services engineers, and 11.4% others) and management levels (46.1% middle management, 29.8% professionals, 19.5% senior management, and 4.5% others). There are 73.4% of respondents who have amassed more than 5-year experience in the organization (36.7% more than 15 years, 25.3% 11-15 years, 20.3% 1-5 years, 11.4% 6-10 years, 6.3% less than 1 year).

The questionnaire has three main parts: i) the multifactor leadership questionnaire (MLQ) scale (Avolio and Bass, 2004), ii) the innovation climate scale (Scott and Bruce, 1994), and iii) the innovation scale (Kaiser and Holton, 1998). Respondents are asked to rate their responses on a 5-point Likert measurement. To further confirm the factor structures in the current study which target the construction sector, confirmatory factor analysis is conducted to justify the validity of the factor structures of: transformational and transactional leadership (i.e., charisma, intellectual stimulation, individualized consideration and contingent reward), innovation climate (i.e., support for innovation and resource supply), and innovation. Confirmatory factor analysis aims to test and confirm specific hypotheses concerning the structure underlying a set of items (Pallant, 2005).

The analyses are conducted by structural equation modelling using Lisrel 8.7. Although four fit indices are usually suggested to quantify the degree of fit of a structural equation model (Kline...
1998), six fit indices are included in the current analysis. The resulted model fit indices are satisfactory, in which the relative chi-square values ($\chi^2$/df) are between 2 and 5 (good model fit; Diamantopoulos and Siguaw, 2000); the values of root mean square error of approximation (RMSEA) are lower than 0.08 (a reasonable model fit; Bollen and Long, 1993); the comparative fit indices (CFI); the goodness of fit indices (GFI); and the relative fit indices (RFI) are higher than 0.8 (the closer to 1, the better the model fit; Diamantopoulos and Siguaw, 2000). Meanwhile, the Cronbach’s alpha value of each factor is above 0.6, indicating acceptable reliability (Hair et al., 1998; Pallant, 2001).

5. Results

The correlation results indicate that innovation is correlated positively with all leadership and innovation climate factors, including charisma, intellectual stimulation, individualized consideration, contingent reward, support for innovation, and resource supply, at $p<0.01$ significance (refer to Table 1). The results also indicate that all leadership factors are significantly and positively correlated to support for innovation and resource supply at $p<0.01$ significance, acting as support to the moderating effect of innovation climate on the leadership-innovation relationship.

| Table 1: Correlation between Innovation Climate, Leadership, and Innovation |
|---------------------------------|---|---|---|---|---|---|
| Factors                        | LD1 | LD2 | LD3 | LD4 | IC1 | IC2 | INN |
| Leadership                      |     |     |     |     |     |     |     |
| Charisma (LD1)                  | 1   | -   | -   | -   | -   | -   | -   |
| Intellectual stimulation (LD2)  | 0.769*** | 1 | -   | -   | -   | -   | -   |
| Individualized consideration (LD3) | 0.741*** | 0.710*** | 1 | -   | -   | -   | -   |
| Contingent reward (LD4)         | 0.657*** | 0.686*** | 0.703*** | 1 | -   | -   | -   |
| Innovation Climate              |     |     |     |     |     |     |     |
| Support for Innovation (IC1)    | 0.571*** | 0.498*** | 0.498*** | 0.486*** | 1   | -   | -   |
| Resource supply (IC2)           | 0.562*** | 0.556*** | 0.563*** | 0.542*** | 0.774*** | 1 | -   |
| Innovation (INN)                | 0.432*** | 0.428*** | 0.381*** | 0.406*** | 0.695*** | 0.664*** | 1 |

To investigate the moderating effect of innovation climate on leadership-innovation relationships, hierarchical regression analysis is performed using pairwise deletion (Aiken and West, 1991). Two models are developed for the moderating effects of the innovation climate variables [i.e., support for innovation (Model 1) and resource supply (Model 2)] (refer to Table 2). In the first step of each model, the four leadership variables are added. In the second step, the moderators are added. Subsequently, in the final step, the interaction terms of the moderators and the four leadership variables are added to test the hypotheses. The values of $R^2$, adjusted $R^2$ and significant F change are shown at the bottom of each model. Only support for innovation (IC1) is found to have significant moderating effect (sig. F change < 0.05 as shown in Model 1).

Results show that before taking the interactions into account, the four leaderships are not significantly associated with innovation, indicating that the influences of leaderships on innovation are not simple straightforward effects. Support for innovation (IC1) is positively

| Table 2: Hierarchical regressions |
|----------------------------------|---|---|---|
| Variables                        | Step 1 | Step 2 | Step 3 |
| 1065                              |     |     |     |
related to innovation (Step 2 of Model 1). However, after the interactions are taken into account (step 3 of Model 1), the influence of IC1 on innovation becomes insignificant. The interaction model containing IC1 as moderator of the four leaderships significantly adds value to the final model, in which the interactions of IC1 with intellectual stimulation (LD2 x IC1), with individualized consideration (LD3 x IC1), and with contingent reward (LD4 x IC1) on innovation are significant (Step 3 of Model 1).

Results show that before taking the interactions into account, the four leaderships are not significantly associated with innovation, indicating that the influences of leaderships on innovation are not simple straightforward effects. Support for innovation (IC1) is positively related to innovation (Step 2 of Model 1). However, after the interactions are taken into account (step 3 of Model 1), the influence of IC1 on innovation becomes insignificant. The interaction model containing IC1 as moderator of the four leaderships significantly adds value to the final model, in which the interactions of IC1 with intellectual stimulation (LD2 x IC1), with individualized consideration (LD3 x IC1), and with contingent reward (LD4 x IC1) on innovation are significant (Step 3 of Model 1).

To determine the nature of the above interactions, simple slopes are established for the significant interaction resulted in Table 6 (Aiken and West, 1991) (refer to Figures 1a-c). Under high support for innovation (one standard deviation above the mean), high intellectual stimulation and high individualized consideration foster innovation, while under low support for innovation (one standard deviation below the mean), vice versa. Under both high and low support for
innovation, the higher the contingent reward, the better the innovation; while the degree of innovation is still higher under high support for innovation.

Figures 1a-c: The interactions between leadership and support for innovation on innovation

6. Discussion

Previous research on leadership and innovation tends to investigate transformational leadership as a whole (e.g., Bass et al., 2003; Pieterse et al., 2009), while inadequate focus has been put on the multi-dimensional nature of transformational leadership. Theoretically, transformational leadership composed of different factors, including charisma, intellectual stimulation and individualized consideration (Avolio and Bass, 2004). The different effects of these sub-factors on performance and innovation have been indicated. For instance, in Howell and Avolio (1993)’s study on business performance, charisma and intellectual stimulation are found to have positive impact on performance, while individualized consideration are found to have negative impact. In addition, Elenkov and Manev (2009) indicate that the interactions with sociocultural factors, such as power distance and uncertainty avoidance, change the influences of intellectual stimulation and individualized consideration on innovation from positive to negative and positive respectively. The results of this study further provide evidences that transformational leadership should not be considered as a whole. Under the interaction of support for innovation, transformational leadership of intellectual stimulation and individualized consideration have significant influences on innovation.
On the other hand, previous studies tend to conclude that transformational leadership fosters followers’ creativity and innovation performance, while transactional leadership hinders them (e.g., Jansen et al., 2009; Jung et al., 2008). However, the results of this study indicate that contingent reward, a type of transactional leadership, has positive relationship with innovation under both high and low support for innovation. The higher the support for innovation, the higher the level of innovation is under the same level of contingent reward. Contingent reward leadership influence innovation through inducing compliance (Yukl, 2002). Followers carry out leaders’ orders to obtain agreed awards. Thus, contingent reward leadership rely on open communication, which is important for innovation (Kickul and Gundry, 2001). Under high support for innovation climate, organizational members have higher strength on the values of innovation behaviours, which smoothen the process of communication for reward for innovation.

Transformational leadership does not necessarily foster innovation. Negative relationships are found between intellectual stimulation and innovation under low support for innovation. Intellectual stimulation leaders stimulate followers to rethink the ways they perform their works and engage in problem-solving activities in which new ideas may be resulted from the process (Bundy, 2002; Rafferty and Griffin, 2004). However, under the climates of low support for innovation, followers may not value creative ways of doing things. The intellectual stimulation of leaders can be conflicting to what the followers interpret from their environment, resulting in confusion, worries and concerns, which worsen their performance. Similarly, negative relationship is also found between individualized consideration and innovation under low support for innovation. Leaders applying individualized considerations respect and concern about follower’s personal needs and development (Bass and Avolio, 1994). With leaders’ understanding and support, followers are more willing to respond to change (House and Mitchell, 1974), which is essential for innovation. However, under the climates of low support for innovation, the perception that change is not valued prevails amongst followers, and that role conflict may occur between the perceived innovation climate and the individualized innovation stimulations from leaders, hindering innovation.

The results of the current research, conducted using quantitative methods, provide a foundation to examine the hypothetical relationships. However, quantitative methods attempt precise measurement of variables, while qualitative methods aim at seeking how and why things happen (Cooper and Schindler, 2006). The quantitative analysis results have not provided insights on what contribute to the differences in the associations between leadership and innovation under moderations, and why. Meanwhile, the study results are made based on sample from China only. Previous studies have indicated the influence of national culture on organizational climate and management (e.g., Hayton et al., 2002; Testa, 2009). To achieve an in-depth understanding of the leadership-innovation relationships and the moderating effects of innovation climate, it is recommended that qualitative, longitudinal research methods be adopted in further research to investigate the influence of national culture on organizational climate, leadership and innovation at organizational level worldwide.
7. Conclusions

Previous studies tend to indicate transformational leadership as an important determinant of innovation, over transactional leadership. However, evidence to this effect has been inconsistent. The results of this study unveiled one of the possibilities for the inconsistency through identifying the moderating effect of support for innovation climate on the leadership-innovation relationships: i) Intellectual stimulation leadership is associated with increased innovation when support for innovation climate is high; ii) individualized consideration leadership is associated with increased innovation when support for innovation climate is high; and iii) the positive relationship between contingent reward and innovation can be found under both high and low support for innovation, even though the degree of innovation is higher under high support for innovation. Previous studies have investigated the influence of national culture on organizational climate and leadership. The results of this study, based on the sample from China, lay ground for further studies to investigate the relationship between innovation climate, leadership and innovation in the construction sector worldwide.

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References


James, L.R., Jones, A.P. (1979) Organizational structure: a review of structural dimension and their conceptual relationship with individual attitudes and behaviors, Organizational Behavior and Human Performance, 16, 74-113.


A Study on the Optimization of Intelligent Building Operations Based on Case Study of the Industrial Innovation Center in Taiwan

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Abstract

The estimation of the next ten years, buildings will become the main reason of resource depletion. The energy consumption of global commerce and residential buildings will be responsible for nearly half of total consumption. Not only does the building process require energy consumption, the daily operations and maintenance of facilities will consume large amounts of resources. To solve issues of high energy consumption and high maintenance costs of the buildings, intelligent analysis methods are now used to increase overall efficiency. The operation models of intelligent buildings encompass many variables, so further research is required to understand the effects of the different factors and characteristics. By combining the various measurement standards and data, a more effective intelligent building operation model may be established to isolate the relativity of the physical environment and humans’ biological effects, and through striking a balance between the physical and biological variables, the optimal operation model for intelligent buildings may be found and allow for the achievement of comfort and maximum environment benefits with the least amount of consumption. In the intelligent buildings, there will be many products and facilities dedicated to the comfort and health of the users, hence improvement of system efficiency and optimal operation model is based on the basic requirements of the users. The primary objective of this study is to use the building management mindset to analyze, through scientific means, the interactions and effects of “health”, “comfort”, and “energy efficiency” in intelligent buildings. Therefore, this study hopes to maintain the current conditions of indoor environment quality and comfort and establish “An Optimal Intelligent Building Operation Model” and conduct research and verification on case studies that have obtained the Taiwan Intelligent Building Labels.

Keywords: Intelligent building, Optimal operation model

1. Introduction

In order to promote sustainable development, energy-saving and carbon reduction of buildings, as well as to lead industries to innovate and integrate, the Executive Yuan established National Council for Sustainable Development Network in 1995. The first Green Building evaluation system in Asia, EEWH system (Ecology, Energy saving, Waste reduction & Health) was then
developed based on the regulations on energy conservation in Taiwan. In 1999, the Architecture and Building Research Institute, Ministry of the Interior propelled the National Council to set up *The Evaluation Manual for Green Building*. The indicators were Greenery, On-site Water Retention, Daily Energy Efficiency, Carbon Reduction, Waste Reduction, Water Resource, Sewage and Garbage Improvements. In 2002, the Biodiversity Indicator and Interior Environment indicators were included to form the nine major indicators of the current Green Building Evaluation System.

Meanwhile, the Architecture and Building Research Institute, Ministry of the Interior was also conducting researches on Smart Living Space. After over ten years of researching since 1992, the Institute carried out the standard of quantification evaluation and instruction of standard operation based on the Intelligent Building Evaluation Index in 2003. The Institute established the Intelligent Building Evaluation Manual and started to accept the applications of Intelligent Building Evaluation Index. The Executive Yuan then continued to promote intelligent building and the industrial integration of ICT (Information and Communications Technology). In 2010, a new version of the Intelligent Building Evaluation Manual was established which included the eight major indicators of Unified wiring, Information and Communication, System Integration, Facility Management, Safety and Disaster Prevention, Health and Comfort, Convenience and Friendliness and Energy Efficiency and Management. The grading system of Intelligent Building Label and Green Building Label both identify five grade levels as follow: Diamond, Gold, Silver, Bronze and Qualified.

The industrial innovation center (IIC) in central Taiwan is the first building grading Diamond in both Intelligent building label and Green building label. The main purpose is to enter central department of Industrial Technology Research Institute and two foundations in institute of information industry information. By constructing advanced detection analysis simulation and high-level research lab, the operation between open lab and incubator were connected in order to assist central Taiwan promote technology innovation ability. The plan includes three main topics such like advanced greenhouse systems, smart devices and sense-based design.

Although we can now develop automatic and intelligent building with the advances in ICT industry, in this Era of Big Data, we can make use of the giant data base which is built up automatically or semi-automatically during the operation process to store, transform, analysis and calculate data. The data can then be applied in technology to develop a more efficient intelligent system of building. It may even help develop a technology that people can manage the building and city through the cloud with a simple device to enjoy a smart living in the future.

Taiwan is located in a subtropical zone and the latitude range of the South and the North is only around three degrees. Yet, the geographical environment and climate of Taiwan are varied. All regions are faced with different environmental issues which need different solutions. In addition to giving the priority to human health, an environmental quality which the users feel comfortable is necessary. Strategies appropriate to the local conditions and optimized operating
mode of intelligent building should also be developed to achieve energy conservation of air condition, illumination system, acoustic and mechanical such facilities.

It should also be considered that if the degrees of the intelligence of building and energy saving are in a direct proportion, and if the benefits of intelligent system to the users are greater than the operating cost as well as the damage to the system’s life cycle. Most of the equipment brings damage to the environment during the production process and if the intelligent building is overdesigned just to fulfil the intelligent building evaluation index, or there are too many types of equipment, or the equipment are always updated and replaced, the initial concept of intelligent building evaluation index may be broken.

Except the physical index which can be referred to the data, some of the index related to the feeling of users may not be quantified. With the big data, we may tell the trend and changes of the intelligent system. Analyzing the correlation of different data, we may develop an operating mode which works for the Central Taiwan Innovation and Research Park. Thus, the objectives of this research are as followed:

1. **Apply big data in the field of architecture**
   With the integration of data mining tools, big data analysis method and automation system, manufacturing intelligence (MI) can be built to explore and analyze enormous data and information related to the environment of building and the users. MI can be used to explore potential useful information and great forms and concepts for the basis of building management and optimizing resource distribution.

2. **Build an optimized operating mode of intelligent building**
   With the collection of records and data of past experiences, including power consumption, air condition consumption, indoor environment quality, power management system, facilities management system, electrical light current system such big data, data mining can be conducted according to the different degree of intelligence. The correlation and anticipation of the systems and elements of intelligent building will then be analyzed. The analysis will include a matching of the records of power consumption of intelligent building, correction of the related parameters of the building’s optimization and test of model in order to build an optimized anticipated model of intelligent building.

2. **Literature Reviews**

The biggest global issue in this century is how to face the climate changes and reduce carbon emission. In order to reduce the emission, architecture department now becomes the newer approach with bigger potential then industry department. The data reported by the US Department of Energy in the US shows that buildings consume about 41% of primary energy, more than transportation sector and industry sector. (U.S. Department of energy, March 2012)

Not only the energy wastes during the building construction, the progress of facility operating and maintaining but also consume a lot of resources. Especially the consumed resource during
facility operating process accounts for up to 80-90% of the entire building life cycle consumption. (Luisa F. Cabeza, 2014)

With the advances in ICT, stronger systems of the communication network of buildings, and enhanced automation of facilities, buildings are being developed from individual control to intelligent buildings with centralized and automatic control. IB integrates DT and buildings, which enhances the operating efficiency of building and the living quality of residents. The intelligence of buildings is developed by technology which includes two main categories: “environment” and “human”. Regarding “environment”, sensor technology and automatic facilities are utilized to enhance the efficiency of sustainable energy conservation, disaster prevention, and facilities management. Regarding “human”, technology is applied to offer intelligent services which make the living safer, healthier, more convenient and comfortable. (Architecture and Building Research Institute, 2011)

The old research methods predicting energy consumption include the ways as follow. (1) vector regression analysis (Bing Dong, 2005) (2) hybrid neural network model (M.R. Amin-Naseri 2008) (3) Decision Tree (DT) (Ahmed et al., 2011) In recent years, with the rapid changes of the structure and pattern of technology, the world has gone through the Era of IT (Information Technology) and the Era of ICT (Information and Communications Technology). It is now getting to the Era of DT (Data Technology). During the Era of IT, machine automation were developed which the machines were manipulated by signals. During the Era of ICT, the transmission paths of signals were changed that people could integrate data, audio and video through different communication methods to make the manipulation more convenient. In the future Era of DT, there will be smart machines which operate in a human’s logic without manual manipulation. (Liao et al., 2012)

Data Mining Technology is an artificial intelligence application, rapid gathering valuable information from several kinds of data, for instance, massively parallel processing (MPP) database, distributed database, cloud computing platform, Internet and expandable storage system. Fu Xiao et al. proposed a five-step framework for Data Mining, including data preparation, collection analysis, valuable data mining and clue finding. The data was converting to proper format during the data preparation, enabling to improve the collection quality when it comes to implementation. Moreover, it can also help us to find the hidden value in the huge amount of data by using association rules. (Xiao and Fan, 2014)

### 3. Methodology

Overviewing the previous researches, the demonstration and discourse on intelligent buildings are quite fragmented, some of them only focus on the environment but ignore the issues on power consumption while some of them focus on energy saving but ignore the comfortability of health of users. However, there are various factors related to the operation of intelligent building. If there is only one factor focused, the evaluation may fail to reflect the real situation. To understand the impacts of differential factors, various measurements should be applied and big data should be analyzed to develop an optimized model for Central Taiwan Industrial Innovation and Research Park. Its efficient operation should also be ensured in order to achieve the least power consumption, highest comfortability and environmental efficiency. The research
methods are as followed.

1. **Literature review and comprehensive analysis.**
   Case studies on intelligent building in Taiwan will be conducted. There was a revision of the Intelligent Building Evaluation Index in 2011. The indicators were added to eight from seven and the buildings would be awarded with the labels of diamond, gold, silver, bronze and pass. Thus, this research will focus on the buildings which meet the new version of index and divide them into different categories. Later on, there will be an analysis on different buildings according to their level of intelligence.

2. **Application of Data Mining on the statistics and analyses of operation information.**
   It is very important to analyze the temperature, humidity, illuminance and power consumption of every part of the building and the micro-climate of the exterior part at the phase of data collection. Data Mining is one of the most important methods when applying big data. It is used to reveal the hidden information. Statistical analysis and models building are applied in Data Mining to look for the patterns and relationships of the data.

3. **Simulating the operating mode of Central Taiwan Industrial Innovation Research Park through data analyses.**
   After analyzing, the most applicable temperature, humidity, illuminance and controllable factors will be obtained and they should be applied to the actual operation of the system. An analysis on the power consumption and other external factors should then be carried out. We will revise the related parameters of the optimized model and set up a testing model in order to develop an anticipated model of optimized intelligent building of Central Taiwan Industrial Innovation Research Park.

4. **Discussion**

There are 78 rooms and 104 public spaces in the IIC located in central Taiwan. In this discussion, first we analyze electrical power utilisation. There are four types such as, Heating, Ventilation and Air Conditioning (HAVC), electricity supply for power, for lighting and for socket. From the monthly power consumption record (*Fig.1*), July is the highest month for power consumption. Due to the high temperature, the high electricity use is also observed. Interestingly, the power consumption is less before December of 2014. The possible reason is that the part of equipment was not installed yet or the staffs were not fully entered.
Figure 1: Types of power consumption and average temperature

The bar chart (Fig. 2) shows the monthly power consumption proportion for 78 indoor zones. For example, the power consumption in September and October in the office of Greenhouse system Technology Center (Room A110) accounts for over half of the annual consumption. On the other hand, in most of the rooms, the main electricity consumption happened from June to August.

Figure 2: Monthly power consumption of different areas.

The annual electrical power consumption is shown in Fig. 3 and the power consumption of HVAC accounts for 45% which is nearly half of the annual consumption. Taiwan is located in a subtropical zone and the climate is hot with high humidity. The IIC is located in central Taiwan where the annual average temperature is around 23°C. The average month temperatures from
June to August are higher than other months, sometimes up to 30°C, therefore, the need of the HVAC (air conditioning) is extraordinary increased.

![Pie chart showing electrical power consumption](image)

*Figure 3: The proportion of annual electrical power consumption*

The power consumption of Rapid Prototyping Center (Room A121) in the highest of the whole building and it accounts for almost 10% of the building’s annual consumption. The accumulated power consumption of air condition of Room A121 is the highest among the rooms in the building. The power consumption of air condition of Room A219 met the highest in May and July. As the temperature of June and August was higher than the temperature of May and July but the power consumption of air condition of June and August on half of that of May and July, the factor of temperature may be excluded. The power consumption of air condition of Room A223 met the highest in July and it may be due to a more frequent use of that space.

The office of Greenhouse Technology Center on the first floor (Room A110) consumed nearly double of the average monthly air condition power in February. The office of Greenhouse Technology Center on the second floor (Room A205) consumed nearly five times of the average monthly air condition power in April and it may because the office was more frequently occupied that month.

*Table 1: Room number and name*

<table>
<thead>
<tr>
<th>Room Number</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A110</td>
<td>the office of Greenhouse System Technology Center on the first floor</td>
</tr>
<tr>
<td>A121</td>
<td>Rapid Prototyping Center</td>
</tr>
<tr>
<td>A219</td>
<td>Computer Aided Design Greenhouse Laboratory</td>
</tr>
<tr>
<td>A223</td>
<td>Automatic Cultivation System Laboratory</td>
</tr>
<tr>
<td>A205</td>
<td>the office of Greenhouse System Technology Center on the second floor</td>
</tr>
</tbody>
</table>

The top 15 rooms are responsible for 50% of the annual electricity consumption in whole building. There are five rooms, A121, A219, A223, A110 and A205 which the main electricity consumption of these rooms are all from HVAC. The four main factors of HVAC system are Building type, Equipment distribution, Outdoor environment and User behavior. In this study,
the Building type and Equipment distribution are set as fixed factor, then the relationships between outdoor temperature and power consumption will be observed. After that, by changing the behavior of the users, the electric consumption of the IIC will be adjusted.

By using Data Mining, the frequency of the staffs enter or exit the rooms from June to August and the relevance between the HVAC electrical consumption and usage by staffs can be analyzed and investigated. Fig. 4 shows the occupancy in different period in those five rooms, excluding the access of the security guards and cleaning staff. From the Fig.4, the period without staff passing can be estimated by Replace Missing Value Interpolation Line. Next, by using Data Mining and we found out the unoccupied period are mostly in afternoon.

![Figure 4: the period without staff passing](image)

![Figure 5: the frequency of the staffs enter or exit the rooms from June to August in A223](image)
Figure 6: the frequency of the staffs enter or exit the rooms from June to August in A110

Figure 7: the frequency of the staffs enter or exit the rooms from June to August in A121
Figure 8: the frequency of the staffs enter or exit the rooms from June to August in A205

Figure 9: the frequency of the staffs enter or exit the rooms from June to August in A219
5. Conclusions

From the analysis above, the HVAC electric consumption has no absolute correlation with temperature, the number of users are also possibly involved. In this analysis of the five rooms, the time was set as variable factor. If the HVAC system was set electricity-off during 12:45-13:15, it is expected in simulation data that nearly 6% of electric consumption can be saved during the period from June to August. In other public space, since the lowest temperature that the air conditioner can adjust to is limited, if we set the temperature to 1 or 2 Celsius degrees higher, the air condition will consume less power and it will not be over-run. In addition to some of the spaces mainly use power current and the power current consumption may not be forced to reduce after an optimized operating mode is set up since the consumption is related to the period and frequency of use. However, if the power consumption can be changed due to the temperature or other controllable factors, we may adjust the standard temperature or physically change the temperature so as to reduce the power consumption of air condition.

The charts above show only the analysis of five rooms which are responsible for 50% of entire building electric consumption and only the prediction of the three months with highest temperature of all the rooms in IIC. In the following research, we expect to use the data of all areas in analysis and also take the combination of the using frequency, temperature and other quantifiable factors into consideration. The IIC has been operating one year and half only, there will be more data to be collected and analyzed afterwards. By using the data, the operation will be predicted and run for test. With the analysis of Big Data, the more accurate and smarter ways of operation can be provided, in order to optimize the operation mode.
References


A Study on the Integration of Logic Systems in Intelligent Building System

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Abstract

To promote carbon-reduction of buildings, increase living qualities and guide the innovative development of the industry, Taiwan has authorized the promotion program of Intelligent Green Buildings in 2010, and the program will be co-organized and led by the government departments in collaboration. However, are these intelligent buildings operating “intelligently” according to the Taiwan Intelligent Building Evaluation System and actual implementation situations? Although Taiwan has self-developed automatic sensor and communication technologies for a long time, the “response” feature of the sensor technology in the building facilities and systems are inadequate for the automatic operation and maintenance of the intelligent systems. This is a hidden issue within the intelligence system development that needs to be answered. Hence, this study will focus on the automation of operation and maintenance of environmental factors detected in ICT and the disaster prevention, electrical supply, water supply, wastewater, air-conditioning, communications and transport systems. For example, when indoor carbon dioxide concentration exceeds 1000ppm, the air-conditioning system should open a shaft to allow fresh air to enter; when indoor air quality returns to preset conditions, the system will automatically shut down the ventilation system. This study shall use Taiwan case studies that have achieved the highest level of Intelligent Building Label as targets and explore the relations and links between the different connected systems and the controlling logics. In other words, it will mean using an integrated series of logic controllers to determine system responses, allowing the building to function with consciousness and create human-centered living spaces according to different requirements or basic environmental factors, so that the building may become a truly intelligent building entity.

Keywords: Intelligent Building, Logic System, Integration
1. Introduction

With the advance of modern technology and demand of people, the automated systems of different kinds of building have been constantly innovated and developed. There are various and complex innovations and development, for instance, air condition, electrical power and illumination system. However, the applying service subsystems from different manufacturers usually have different coding format which cause the differences of communication rate, coding format, ways of synchronize and communications specification. As a result, resource cannot be shared between the system facilities and the messages cannot be transmitted and coordinated which limit the efficiency of services management and the development of sustainable operation management. Therefore, this research focuses on the environment factors detected by the monitoring system and also the facilities such as disaster prevention system, electrical system, water supply and drainage system, air condition system and communication of the intelligent building system. It focuses on the automation of operation and maintenance management as well. In short, this research has applied a series of logical integration to give the building the features to serve as a more occupant- friendly and favourable living space according to different demand or environmental condition to become a real intelligent building.

In this research, we have reviewed the Industrial Innovation Center in Taiwan's experience on applying for the Intelligent Building Label. We have found that there are some problems of the operation of intelligent buildings needed to be discussed; especially the links and the interaction between each intelligent system which fail to achieve the original goals. Since they are still manual-controlled, they are not intelligent but automated. The significance of intelligent buildings is lost when the designed intelligence does not work well. For example, when the air quality detector senses poor indoor air quality, it draws fresh air into the indoor proactively to reduce the indoor concentration of CO2. However, if the temperature is high outside, the drawn air will also raise the indoor temperature which increases the need of air condition. This example only presents the failed coordination between two facilities and we can imagine how complicated it is when an intelligent building connects a number of facilities at the same time. Hence, to achieve “intelligence”, we must find the key points and directions of system integration, as well as focus on the strategies of software system integration and planning and the feasibility studies. The system integration and logic establishment of the coordination between the software and hardware in intelligent buildings should be analyzed. The objectives of this study are as followed:

1. System integration and logic establishment
   Through case studies, we have analyzed the links between each system, as well as the main factors affecting the logic establishment and other correlation coefficients. We hope to enhance the intelligence of buildings which serve as a human-oriented and favourable living space based on different demands and environmental conditions.

2. Enhancement of efficiency of intelligent buildings
   When the management efficiency and the ability in system integration of intelligent buildings are enhanced, the operation cost of buildings can also be reduced. With the automated devices and systems, the limited resources and the spaces may be utilized and developed to offer a comfortable, safe and convenient environment, as well as to save the buildings’ expenses and resources consumption.

2. Literature Reviews

This research focuses on the integration of logic systems in intelligent building system; therefore, The literature review and theoretical framework include the following topics:
(1.) The definition of intelligent buildings and the importance of system integration
(2.) The application of intelligent systems
(3.) The definition of logic and the logic that this research adopts
2.1 The definition of Intelligent Buildings

In short, intelligent building refers to the integration of information and communication technology (ICT) into a building in order to enhance the efficiency of the building’s management and the living quality of occupants. Regarding “human”, internet technology is applied to offer intelligent services such as assistive functions of safety, health, convenience and comfort. Regarding “environment”, sensor technology and automated facilities are applied to raise the sustainability and energy efficiency, safety and disaster prevention, and facilities management efficiency of buildings( Architecture and Building Research Institute, Ministry of the Interior, 2012).

Professor Clements-Croome from University of Reading defined that intelligent buildings are not completely buildings of high-technology but are able to change in accordance with the needs of occupants. They have to be highly-sustainable and provide the occupants the space to interact so as to enhance the living efficiency(Derek,2013). Thus, we believe that we should pay high attention when we analyze how to enhance the buildings from the “automated” stage to “intelligent” stage based on the progress of modern technology, as well as the architectural development in this generation.

High technology
(active sensing, communications, etc.)

 perceive

Automation technology
(energy management, automation controlling, etc.)

“Automatic” VS “Intelligent”

Figure 1 Relation between “automatic” and “intelligent”

The integration of a building’s facilities with other related intelligent construction technology is emphasized in the functions of intelligent buildings. The integration includes automated building systems and technologies, occupied space, operating and management mechanism and how to introduce high-performance control functions to achieve the safety of air condition, illumination and disasters prevention such facilities, energy conservation and environment protection while maintaining good indoor environment(Wen,1999).

Currently, when it comes to the formation of intelligent space, the most discussed issues are (1) device heterogeneity, (2) device awareness, (3) come and use, (4) limited resource, (5) integrated multiple service management, (6) home service sharing, (7) security, (8) quality of service (QoS), (9) pay per use, (10) user authentication and (11) preference. It is to be hoped that through the integration of human, the internet and facilities, the intelligence of facilities can be enhanced and introduce the central concept of “human oriented”, as well as include the related topics of health, comfort and safety(Shaikh, P. H, 2014)( Architecture and Building Research Institute, Ministry of the Interior, 2012).

Moreover, as we have come to a new generation, there have been more technological and automated services introduced in accordance with the occupants’ demand. Nonetheless, the types of system are varied and always increasing. For intelligent buildings, what is saved from resource sharing, and the maintenance, change and expansion in the future of these different facility systems, or the coordination between systems and enhancement of manipulation management will affect the sustainable development of buildings. Consequently, it is necessary to consider the system integration of building which is expected to increase the efficiency of management and integrated services, reduce the dependence on labor force as well as the operating and management cost of buildings in the future.
2.2 The definition of Logic

The definition of the term “logic” includes (1) the principle of objective things, (2) a theory or a view point, (3) the rule of thinking and (4) the science of reasoning.

According to the annual report of Bureau of Energy, Ministry of Economic Affairs, in addition to special types of buildings (for example, tracks in a railway station, telecommunication equipment rooms, wastewater treatment plants and warehouses), the air condition system and illumination system account for the most electrical power consumption of different sorts of buildings. In average, the air condition system and the illumination system account for approximately 32% to 54% and 15% to 30% of the total electrical power consumption respectively. In another word, they account for 60% to 70% of the total consumption of the buildings (Taiwan Bureau of Energy, Minst of Economic Affairs, 2013). (See Figure 2)

Hence, a conclusion of the above statement is conducted when discussing logic in this research. The proportion of electrical power consumption is the basis of logic control; for instance, the proportion of electrical power consumption of air condition system, sockets and illumination are respectively 45.8%, 17.1% and 15.4% in a research building (Figure 3). According to a foreign study on energy saving potential, the system for distinguishing energy consumption is also divided into four categories (Nguyen, 2013). After categorizing the buildings, we have mainly discussed these four types of consumption. In brief, we have first controlled the equipment which consumes the most electrical power, following other equipment.
However, in order to achieve improvements in building energy use at this stage, logic discussions of individual systems are necessary based on the illumination of public buildings and the air condition system (C. Aghemo et al., 2013); studies discussing the adoption of a classification method are also required to draw up an air condition system control logic (G. Graditi et al., 2015), etc. in a reasonable usage method with the living space as an example; however, the single system is generally adopted as the study case.

3. Methodology

3.1 Literature Review and Theoretical Framework

With various technologies, designs, and equipment related to intelligent buildings, in order to gather information about intelligent building applications and the current situation of development, we will collect both domestic and foreign design data related to intelligent buildings, as well as relevant literature regarding energy saving technology, equipment, design concepts, etc., in order to make a review to better understand the latest application condition of this technology and provide a reference and application for subsequent studies and discussion.

3.2 Correlation Analysis

This study adopts data collection and research as analysis research methods. Therefore, it first categorizes each system as 「Air conditioning, Illumination, Sockets, Power Current」 through the intelligent buildings, then performs a preliminary screening of the space, and finally discusses the relationship between the average total electricity consumption of air conditioning, illumination, sockets, power current and the total quantity of the electricity of the above four items together. As mentioned above, in order to observe two or more variables to determine whether other variables can be predicted from another major variable, 「Correlation Analysis」 in the statistics will be adopted as the method of this study: Pearson’s Correlation will be adopted to analyze the correlation degree of the two, and the correlation coefficient ($\gamma_{XY}$) may serve as the pointer of linear correlation between two continuous variables and is defined below:

$$\gamma_{XY} = \frac{s_{XY}}{s_Xs_Y}$$

$\gamma_{XY} =$ Sample correlation coefficient  
$s_{XY} =$ Sample covariance  
$s_X =$ Sample standard deviation of $X$  
$s_Y =$ Sample standard deviation of $Y$

(1) The value of the correlation coefficient is constant between -1 and +1.

(2) +1 shows that X and Y belong to the completely positive linear correlation, while -1 shows that they belong to the completely negative linear correlation. If the value of the correlation coefficient is very close to zero, then no linear relation exists between X and Y.

(3) The correlation degree represented by the correlation coefficient is shown in Table 1.
After calculating the correlation coefficient, its value was found to be increasingly close to 1, indicating that the space is more correlated to the system of this class, thus improving the understanding of the correlation degree of usage amount of these four electricity consumption classes in a space, determining the order of use of each system, and discussing its operation logic.

4. Discussion

We have taken the Industrial Innovation Center in Taiwan as an example. The interior system is categorized into “air condition”, “illumination”, “sockets” and “power current” and the actual electrical power consumption have been discussed.

<table>
<thead>
<tr>
<th>Table 1 Correlation degree represented by the correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation coefficient (r)</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Above 0.8</td>
</tr>
<tr>
<td>0.6 - 0.8</td>
</tr>
<tr>
<td>0.4 - 0.6</td>
</tr>
<tr>
<td>0.2 - 0.4</td>
</tr>
<tr>
<td>Below 0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2 Categories of intelligent system of Industrial Innovation Center in Taiwan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>System</td>
</tr>
<tr>
<td>Air quality</td>
</tr>
<tr>
<td>Air condition system</td>
</tr>
<tr>
<td>Environment and wind monitoring system</td>
</tr>
<tr>
<td>Automatic pay station for car parking</td>
</tr>
<tr>
<td>Environment monitoring system</td>
</tr>
<tr>
<td>Leak and flood detection</td>
</tr>
<tr>
<td>Facility management system</td>
</tr>
<tr>
<td>Other light current system</td>
</tr>
</tbody>
</table>
Furthermore, as the place of this case lies in a circum-subtropical zone, the summer climate from June to August is the hottest part of the year. Therefore, the total electricity consumption data (as shown in Figure 4) of each space from June to August of 2015 is summarized to discuss the topics that can be researched, analyzed and improved with regard to the relatively extreme values. Of the 205 spaces, 51 had an electricity consumption that exceeded the average value, including seven spaces with an electricity consumption that exceeded the standard deviation of 1. This study classifies the use of each space as follows:

<table>
<thead>
<tr>
<th>Home automation system</th>
<th>Elevator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Assisting</td>
<td></td>
</tr>
<tr>
<td>Information Service</td>
<td></td>
</tr>
<tr>
<td>Fire alarm system</td>
<td></td>
</tr>
</tbody>
</table>

(Data source: Summarized in this study)
Figure 4 Electrical por consumption of different spaces
<table>
<thead>
<tr>
<th>Office</th>
<th>Glasshouse Laboratory</th>
<th>Facility space</th>
<th>Classroom Conference room</th>
<th>Lobby,Corridors,Restroom,Restaurant,Car parking,Storage</th>
</tr>
</thead>
</table>

**Figure 5** Proportion of electrical power consumption of different spaces in June.

<table>
<thead>
<tr>
<th>Office</th>
<th>Glasshouse Laboratory</th>
<th>Facility space</th>
<th>Classroom Conference room</th>
<th>Lobby,Corridors,Restroom,Restaurant,Car parking,Storage</th>
</tr>
</thead>
</table>

**Figure 6** Proportion of electrical power consumption of different spaces in July.

<table>
<thead>
<tr>
<th>Office</th>
<th>Glasshouse Laboratory</th>
<th>Facility space</th>
<th>Classroom Conference room</th>
<th>Lobby,Corridors,Restroom,Restaurant,Car parking,Storage</th>
</tr>
</thead>
</table>

**Figure 7** Proportion of electrical power consumption of different spaces in August.
4.1 Different space type analysis findings

Figure 5, Figure 6, and Figure 7 show the 51 spaces whose total electricity consumption exceeded the average value from June to August. Among them, the designation A, B, C, D, and E below indicate the class of space; the number represents the code of each space; and the areas marked with a yellow color block represent the total electricity consumption of this space that exceeds the standard deviation of 1. According to the electricity consumption proportion of each space with different uses, the main energy consumption class and total electricity consumption (as shown in Figure 8) of the space also differ.

/A/ Office Space

The consumption of electricity for illumination, sockets, power current, and air conditioner items mostly presents a relatively uniform usage state. The systems’ categories calculated using the correlation coefficient are summarized below from highest to lowest; as its value becomes closer to 1, the space is more correlated to the system of this category: **air conditioner** (r=0.934), **illumination** (r=0.845), **sockets** (r=0.783), and **power current** (r=0.118).

Furthermore, we drew a scatter diagram of the correlation degree, as shown in Figure 9. Using air conditioning as an example, the x-axis represents the average electricity consumption of the air conditioning category from June to August, and the y-axis represents the total electricity consumption for illumination, sockets, air conditioning, and power current from June to August. The scattered point is more densely distributed in the simple linear regression trend on-line, indicating that the air conditioning is more correlated to the office class space.

Using the system of Central Industry Innovation Research and Development Zone of Taiwan’s Industrial Institute as an example, the system logic deduction used for office space is as follows: **Air conditioning system > Illumination control > Firefighting system.**

Among them, the electricity for sockets is the electricity mainly consumed by office equipment. The electricity for the power current is generally not applied in the system, so there is no arrangement.
/B/ Glasshouse and Laboratory

Owing to the fact that the areas are majorly used as glasshouses and precision instruments are used and installed there, there is a more apparent use of air condition comparing to other space types (e.g. Figure 8, code 35, 36, 41, and 44). The correlation coefficient of each class is summarized below: **air conditioner** (*r*=0.992), **sockets** (*r*=0.628), **power current** (*r*=0.625), **illumination** (*r*=0.428). The system logic deduction is: **Air conditioning system > Air quality system > Firefighting system > Illumination control**

Among them, the electricity used for sockets is mainly the electricity consumed by greenhouse or research equipment, except for the part of electricity consumed for detection of the firefighting system. The electricity used for the power current is also the same; thus, there is no arrangement.

Figure 9 Correlation diagram of each system class in the office space

Figure 10 Correlation diagram of each system class in the glasshouse and laboratory space
/C/ Faculty Space

There are many huge machines in this space type which generate heat during operation. Therefore, air condition is necessary to adjust the temperature so as to maintain the operation of machines. The correlation coefficient of each class is summarized below: power current(r=0.990), sockets(r=0.134), air conditioner(r=0.058), illumination(r=0.029). The system logic deduction is: Emergency generator system > Environmental control power system > Firefighting system > Air conditioning system > Illumination control.

![Figure 11 Correlation diagram of each system class in the faculty space](image)

/D/ Classroom, Conference room and Exhibition space

In addition, some of spaces are only occupied sometimes so they only consume power for illumination during normal occasions, such as experience room, meeting room and show area. (Figure 5.6.7 /D/ class of space) . The correlation coefficient of each class is summarized below: air conditioner(r=0.889), illumination(r=0.525), sockets(r=0.505), power current(r=0.067). The system logic deduction is: Air quality system > Air conditioning system > Illumination control > Firefighting system. The electricity used for sockets is mainly the electricity consumed by the equipment, while part of the space may have electricity consumption with regard to power current under particular usage conditions. Therefore, this correlation is extremely low.

![Figure 12 Correlation diagram of each system class in the classroom, conference room and exhibition space](image)
/E/ Lobby, Corridors, Restroom, Restaurant, Car parking and Storage

The major electrical power consumption of this space type is quite different. For example, illumination is the major consumption for the car parking, air condition is the major consumption for the lobby, pantry and elevator lobby, and power current is the major consumption for the kitchen. The correlation coefficient of each class is summarized below: air conditioner (r=0.851), sockets (r=0.636), illumination (r=0.490), power current (r=0.081). The system logic deduction is: Air conditioning system > Air quality system > Firefighting system > Illumination control.

As we have mentioned, the air condition system and illumination account for the most electrical power consumption of most of the buildings which is approximately 60% to 70% of the total consumption. Nevertheless, our case studies findings show that the air condition system and power current actually account for approximately 70% of the total consumption (see figure 14). From the data shown above, we have inferred that it is because the analyzed building is a research institute which mainly relies on the air condition and power current. Apart from that, it may also be resulted from the good design of adopting the natural lighting of the Industrial Innovation Center which can satisfy the demand of illumination. The illumination only accounts for 11.25% of the total electrical power consumption.

Figure 13 Correlation diagram of each system class in the other space

Figure 14 Proportion of electrical power consumption of Industrial Innovation Center between June and August
5. Conclusions

According to the statistics of the annual review report of the Bureau of Energy, Ministry of Economic Affairs in its study of the proportion of electricity consumption in different classes of buildings, it arranged as the following four categories according to the proportion of total electricity occupied: air conditioning, power current, sockets, and illumination electricity. Furthermore, as the above arrangement is only the order of “Total Electricity Consumption” obtained in the case, if the order and control logic of the four system classes are thus deduced, the final conclusions obtained will be unable to completely apply to the space of the ABCDE classes according to their spatial characteristics. Therefore, discussions shall be respectively made according to different “Space Properties”.

Furthermore, through the 4.1 Discussion of each space class section above, the deduced system order of A to E classes is obtained. From the perspective where the logic model of the system applied in this space is deduced, in order to comply with this study’s purpose of making energy saving and efficient improvements, different spaces and usage methods can be followed to establish intellectualized regulations and controls according to the logic precedence order, as well as to practically summarize the energy saving countermeasures required for this space in a more friendly way. This research case is illustrated as follows:

(1) /A/ Office space; /B/ Glasshouse and Laboratory; /D/ Classroom, Conference room and Exhibition space; /E/ Lobby, Corridors, Restroom, Restaurant, Car parking and Storage

The system class mainly used for the above spaces mostly takes “Air Conditioning” as the bulk; therefore, this study considers air conditioning energy saving practices and can also further the understanding of the usage situation of spaces (for example, according to the investigation on people’s use of some spaces, in the state of non-use for a long time, the system will automatically judge to turn the air conditioning off, regulate the temperature, etc.).

(2) /C/ Faculty Space

The main electricity consumption for the system classes of power current, sockets, air conditioning, and illumination is a small amount. With limited re-improvement efforts with regard to energy saving, in order to maintain the equipment operation in the faculty space, a certain amount of electricity consumption shall be required for the power current. Therefore, this part may determine the mechanical and electronic design during the construction or choose the equipment with better energy saving performance in subsequent updates.

In a future study, the data of other months of each space of the Central Industry Innovation Research and Development Zone will be analyzed, more space information will be adopted to discuss the actual situation in closer relation to this case, and the related data of other construction environments will be collected. Then a detailed discussion will be made on each system of intelligent buildings in order to summarize the establishment and operation of each system of intelligent buildings and inter-system logic models.
References


Wen,Xiu-Ling,(1999),Development Prospect of Taiwan Intelligent Living Space

Taiwan Bureau of Energy, Ministry of Economic Affairs (2013.12) “Building Energy Efficiency Application Manual” Available at: http://www.ecct.org.tw/print/files/1021231%E5%BB%BA%E7%AF%89%E7%AF%80%E8%83%BD%E6%8A%80%E8%A1%93%E6%89%8B%E5%86%8A.pdf. Accessed 10 November 2015.
Investigating the Maintenance Management Practices
for Urban Roads in India

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Abstract

The demand for quality urban infrastructure has been increasing rapidly in developing countries. In India, there is a huge demand and supply mismatch in the urban infrastructure sector and this situation has been further worsened by the poor maintenance of existing infrastructure. Urban roads in India are reeling under similar scenario and the poor quality of urban roads has been affecting convenience and safety of road users. In this context, the analysis of maintenance management practices followed by the urban local bodies (ULBs) for urban roads was carried out. A case study based approach has been adopted to analyse the maintenance management practices in three urban local bodies. The case study analysis indicates the absence of structured process for prioritizing maintenance of urban roads. A model has been developed for prioritizing the maintenance of urban roads using fuzzy logic approach. The findings of this research study would help the officials of ULBs to allocate constrained resources in more effective manner and ensure better quality urban roads.

Keywords: Maintenance Management, Urban Roads, Urban Local Bodies, Fuzzy Logic

1. Introduction

Road network is one of the important factors that contribute to the economic growth of any country. It is imperative for economic progress that roads are well laid out and maintained. Although the Indian road network is large, next only to the road network in the United States of America, an underlying problem is the quality of roads. Roads are often poorly maintained, leading to delays and disruption in traffic, environmental pollution, and inefficiencies in economic transactions.

According to a report published by High Powered Expert Committee (HPEC), constituted by the Government of India for estimating the investment requirements for urban infrastructure services, an investment of USD 82.67 billion (2009-10) and 44% of investment in urban infrastructure are required over the next twenty years for improving urban roads (Ministry of Urban Development, 2011). The achievement of objectives of any infrastructure depends not only on construction of the asset but also on quality maintenance of the created asset. The HPEC’s report mentions that only 1.7% of per capita investment on urban roads is spent on maintenance in India. This compromises on the life of the asset and fails to earn the value of investment on asset creation.

In India, the responsibility of urban road maintenance lies with the urban local bodies (ULBs). The poor maintenance management practices among ULBs have been often mentioned as the reason for the current poor state of Indian urban roads. In this context, a research study was carried out to understand the road maintenance management practices followed by ULBs and develop a model for...
the prioritized maintenance of urban roads in India. This paper describes outcomes of this research study.

2. Research Methodology

The research methodology for this study comprised literature survey, case study, questionnaire survey and modelling with fuzzy logic approach. A review of literature was first performed to understand the current practices among ULBs for maintenance of urban roads and best practices, decision frameworks and models for urban roads. This was followed by case studies of maintenance management practices in three ULBs in the state of Gujarat. The primary objective for these case studies was to understand how the urban local bodies undertake the maintenance management of urban roads and analyse these processes from a theoretical angle provided by the framework discussed in section 3. The challenges faced in adoption of systematic process for maintenance management of urban roads were also identified.

Three ULBs in the state of Gujarat, India were selected. These three urban local bodies are among three prominent cities in the state. These ULBs were selected on the basis of parameters like urban population, geographical area, length of urban roads, capital expenditure of ULBs and financial allocation towards construction and maintenance of urban roads. The profile of these three ULBs is shown in Table 1.

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Aspects</th>
<th>ULB – A</th>
<th>ULB – B</th>
<th>ULB – C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Population [No]</td>
<td>55,70,585</td>
<td>44,62,002</td>
<td>16,66,703</td>
</tr>
<tr>
<td>2</td>
<td>Area [sqkm]</td>
<td>464.16</td>
<td>326,515</td>
<td>159.95</td>
</tr>
<tr>
<td>3</td>
<td>Length of Urban Roads [km]</td>
<td>2399</td>
<td>2874</td>
<td>1000</td>
</tr>
<tr>
<td>4</td>
<td>Administrative and Political units of ULB responsible for road construction and maintenance</td>
<td>Road &amp; Building Committee [E], Road Project Department [A], Road Department [Z]</td>
<td>Standing Committee [E], Road Development Department [A], Road Department [Z]</td>
<td>Standing Committee [E], Road Project Department [A], Road Department [Z]</td>
</tr>
<tr>
<td>5</td>
<td>Capital expenditure of ULBs [Million INR]</td>
<td>20750</td>
<td>16251</td>
<td>2612</td>
</tr>
</tbody>
</table>

[E]: Elected Wing, [A]: Administrative Wing, [Z]: Zone Level, 1 USD = 66 INR, 1: Year 2011 (Census of India, 2011), 2: Area under the jurisdiction of ULB, 3: In the year 2011

All these ULBs are from the state of Gujarat and therefore suited a natural comparative multiple case study research design. These ULBs shared similar policy environment and procedures at the state level, but differed in parameters such as organizational structure, aspirations of political members and ULB officials, organizational procedures and practices, and road infrastructure assets. Therefore, our case study design provided natural controls of the study as well as environment for analytical generalization and theory building.

The data pertaining to case studies was primarily gathered by semi structured interviews with the officials of ULBs, and this data was supplemented and supported with the information gathered from municipal manuals, archival records, websites of ULBs, contract agreements, organizational policies and guidelines pertaining to maintenance practices in selected ULBs. The interviews were recorded...
and further transcribed. The transcripts were analysed with the NVIVO software, and the analysis involved “axial coding” – line by line coding of transcripts, gathering of similar information under different themes and preparation of final themes by merging and consolidation of related themes. Table 2 provides background of interviewees. In total, 18 interviews were carried out in three urban local bodies. The themes that has emerged from the analysis of these interviews are discussed in Section 4.

**Table 2 Information about Interviewee**

<table>
<thead>
<tr>
<th>Sr No</th>
<th>ULB</th>
<th>Level of Authority</th>
<th>Designation</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ULB-A</td>
<td>Top Level</td>
<td>Additional City Engineer</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Middle Level</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bottom Level</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>ULB-B</td>
<td>Top Level</td>
<td>Chief Accountant</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Middle Level</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bottom Level</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>ULB-C</td>
<td>Top Level</td>
<td>Budget Head, Additional City</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Engineer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Middle Level</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bottom Level</td>
<td>1</td>
</tr>
</tbody>
</table>

The last step involved development of a model for the prioritisation of urban roads for maintenance. Fuzzy logic along with MATLAB software was used for modelling. Three road networks from these ULBs were selected for the application of this model. The process for the development of model is as follows:

1) The earlier two steps – literature review and case study analysis assisted in the identification of factors for prioritization of urban roads and modelling these factors,

2) For defining inputs, data collection was done based on two questionnaires for ‘Importance of the factors’ and ‘Importance of the factors with respect to roads’, and

3) Fuzzy logic was applied in two stages for the responses of the officials to achieve the prioritisation of the urban roads for maintenance.

- Stage 1 – Application of fuzzy logic for officials’ responses for ‘Importance of the factors’ as well as for ‘Importance of the factors with respect to roads’.
- Stage 2 – Application of fuzzy logic for Stage 1’s outputs with reference to particular urban road network for carrying out prioritization of roads for maintenance operations.

### 3. Maintenance Management for Urban Roads

As part of the first step of this research study, literature was surveyed in order to analyze the various processes involved in the maintenance management of urban roads. The maintenance management has been conceptualized from process perspective with steps like deciding objectives of road maintenance, assessment of road performance, planning and decision making, and interventions to be
adopted for road maintenance. These steps are not necessarily sequential in nature; rather there is cooperation and coordination required among them for effective maintenance management. The identified processes are presented in Figure 1 and briefly as follows.

![Maintenance Management Processes for Urban Roads](image)

**Figure 1 Maintenance Management of Urban Roads**

The road maintenance objectives elaborate the reasons behind undertaking road maintenance (Schraven et al 2011; Adey et al 2014). The ULB deciding the maintenance strategy for urban roads may pursue single or multiple objectives. The challenge faced by ULB is to strike a balance between these varying objectives. Safety and accessibility can be primary objectives which are required to be fulfilled by any ULB because they emphasize on the basic requirements for human accidents and road connectivity. Convenience and appearance focus on the quality of the road and the operational efficiency (impacts of the road quality on vehicles’ performance). The management of traffic as well as road conditions result in good quality of life. Environmental considerations focus aspects like noise and air pollution.

Road performance assessment is typically undertaken to understand the conditions of existing road infrastructure asset and the outcome of this assessment provides valuable suggestions for deciding future courses of action (Schraven et al 2011; IRC 1989). The archival data that includes age of the roads and the past operations that were carried out on the roads as a part of maintenance must be analyzed. The performance measurement can be carried out with visual inspection and / or measurement methods or tools. Visual inspection includes recording the details of maintenance requirement based on the visual observation while measure methods and tools uses advanced road pavement monitoring equipment for assessing damage and its intensity.

Planning and decision making is important as it formulates the philosophy for the maintenance works (Sharma and Vohra 2009; Too 2012; Osman and Nikbakht, 2014). The rules and standards for maintenance work are decided based on the maintenance policy formulated and adopted by the ULB. There are diverse sets of stakeholders involved in both policy formulation and implementation. Therefore, the technical system of maintenance management, which is the focus of processes like deciding maintenance objectives and road performance assessment, is intertwined with the social system involving asset managers, users and political decision makers. Based on the maintenance policy and stakeholders viewpoints, financial resources are allocated for the maintenance of urban
roads. The interaction between the above three processes, results in the design and implementation of appropriate intervention strategies. These interventions aim to maintain quality of asset and provide targeted user benefits (Sharma and Vohra 2009; Too 2012). It involves the use of contracting mechanisms like percentage rate contract, performance base contract etc. and new innovations like polymeric roads, micro surfacing etc.

4. Case Study Analysis

4.1 Collaboration between actors involved in the socio technical system

The evidence from the case studies indicates that the process of maintenance management is complicated by the involvement and interaction of multiple stakeholders. The effectiveness of this process hinges on identifying the urban road as a “socio technical system” and striking a balance between expectations of different stakeholders. Osman and Nikbahat(2014) discussed the complex interactions that occur between the agents like roadway users, asset managers and politicians for roadway performance and asset management. They have modelled these interactions with game theoretic approach, indicating how behaviour of various agents involved in the asset management impacts their collective decision making behaviour. Similar scenarios have also been observed with “cooperative as well as non-cooperative game” between different set of stakeholders. The influence of politicians in the sphere of selection of roads for maintenance and fund allocation prominently emerged in the case analysis. Often, this influence is contested by the administrative officials of the ULBs. The dislike towards undue influence of politicians in the decision making process was aptly narrated by an official of ULB – A:

“Political involvement also plays significant role in prioritisation but that doesn’t mean that the road is not required to be prioritised. We don’t adopt the suggestions of political parties if road is really not required to be maintained.”

The absence of meeting of minds of politicians and technical persons was summed up by the ULB – A official:

“I want to tell you that ideally requirement should be generated by technical department and not by any political corporators at zonal level but still the situation is the same only. There are many roads which we have made according to our technical knowledge avoiding the suggestion by the political councillors.”

Although, there was a common agreement between these important decision makers – politicians and administrators over collecting feedback from the road users for understanding maintenance needs, there was disagreement over the question of whose opinion would have a final say in the maintenance management process. This non-cooperation observed between asset managers and politicians over the prioritization of urban roads for maintenance stems from the lack of appreciation of urban roads as a “socio technical system”. This often results in undue delays and short sightedness in the decision making process.

4.2 Policies and guidelines required for effective maintenance management

The policies for maintenance management of urban roads help in articulation of strategic goals and charting out procedures to achieve these goals. The case study organizations have been following set
procedures for the maintenance of urban roads; however, these procedures lack strategic orientation and direction. The interviews with the ULB – A, B and C officials revealed that there is lack in clarity over the objectives to be pursued for the maintenance of urban roads and they were considered implicit part of any maintenance approach. As a result, the benchmarks for assessing effectiveness of maintenance strategy were often either not set or vague. All ULBs expressed that they sought guidance from the manuals prepared for maintenance by National Highway Authority of India (NHAI) and Ministry of Road Transport and Highway (MORT&H). However, lack of particular policy and/or manual for the maintenance of urban roads was mentioned as a key impeding factor by many interviewees from these ULBs. Diverse views over maintenance objectives among the officials of a single case study ULB and financial constraints faced by these ULBs necessitate the clarity over maintenance objectives. An official of ULB – A mentioned the objective for maintenance and its effectiveness as follows:

“See, when we talk about the urban roads they already have thickness of 1m. So, there base is very strong. They just require there riding surface to be appropriate. Yes but one thing is very important and that is quality of maintenance. If quality of maintenance is improved then many issues can be resolved.”

Most of our interviewees mentioned improvement of “quality of riding surface” as a maintenance objective, with a little or no mention about the other objectives like accessibility, convenience, quality of life and safety. Scharaven et al (2011) stressed the importance of formulating “infrastructure objectives” before undertaking maintenance by public agencies. They postulated that clarity on infrastructure policies and objectives would result in 1) devising of appropriate maintenance strategies, 2) formulation of indicators and maintenance norms for assessing effectiveness/performance of maintenance strategy, and 3) cost efficiency in maintenance management.

The absence of maintenance policy also affects allocation of financial resources. The construction of new roads gets priority over maintenance of existing roads during allocation of financial resources. This clearly shows that budget for maintenance is not satisfied considering the requirement of the new construction. This results in poor life cycle of the created asset. A comparison of financial resource allocation towards construction and maintenance of roads in three ULBs (Refer Table 3) shows that despite increase in construction of new roads, maintenance is not prioritised and/or focused as required. The backlog in allocation of financial resources is higher in the case of ULB-A and ULB-C. In case of ULB-B, construction of roads as well as maintenance has increased over time. Therefore, design of maintenance policies and objectives in the case study ULBs is essential.

Table 3. Financial budget for construction and maintenance of urban roads

<table>
<thead>
<tr>
<th>Year</th>
<th>2010-11</th>
<th>2011-12</th>
<th>2012-13</th>
<th>2013-14</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ULB – A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>971.10</td>
<td>876.51</td>
<td>1099.52</td>
<td>757.45</td>
</tr>
<tr>
<td>Construction</td>
<td>518.87</td>
<td>675.61</td>
<td>2147.82</td>
<td>2088.36</td>
</tr>
<tr>
<td><strong>ULB – B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>431.26</td>
<td>482.56</td>
<td>614.53</td>
<td>702.01</td>
</tr>
<tr>
<td>Construction</td>
<td>861.50</td>
<td>1176.98</td>
<td>1972.63</td>
<td>2279.57</td>
</tr>
<tr>
<td><strong>ULB – C</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>93</td>
<td>103.9</td>
<td>135</td>
<td>125</td>
</tr>
<tr>
<td>Construction</td>
<td>544.3</td>
<td>590.5</td>
<td>711.3</td>
<td>538.6</td>
</tr>
</tbody>
</table>

Figures in million INR. 1 USD = 66INR
4.3 Role of private sector in maintenance management needs to be managed effectively

The construction and operation of highways in India has seen a gradual shift towards increased private sector participation with contracting mechanisms like build operate transfer (BOT), annuity contracts and engineer procure and construct (EPC) contract. Similar trends were observed in the case study organizations with increased participation of private contractors. Traditionally these ULBs have been undertaking maintenance of urban roads with in-house equipments, labour and technical personnel. However, over the years, these ULBs have changed the approach and now different contracting mechanisms are adopted for private sector involvement. This transition in the contracting mechanism was shared by an official at ULB-C as follows:

“Another important thing I want to add is that before 10 years works have been done in house. Outsourcing is invited from 10 years only. Now as a packaged and performance based contracts are given to the contractors.”

Small maintenance jobs are executed with in-house resources while large maintenance activities are undertaken with private sector participation. Two contracting models in these ULBs were primarily used: percentage rate contract and performance-based contract. Performance-based contract encourages technical innovation of private sector with the use of techniques like micro surfacing, milling process, polymeric roads, etc. The adoption of technical innovations for the maintenance of urban roads was summed up by an official as ULB-B as under:

“In recent past we have done experiments on it. With the help of plastic waste we have constructed the roads. Now we are checking the performance. Another thing which we are doing is micro surfacing. Sometimes the only upper layer of the road has get deteriorated that doesn’t mean that we will construct the whole road again.”

The case study evidence indicates that the primary reason behind increasing involvement of private sector in maintenance of urban road was improved quality and cost effectiveness. However, it is important to note that the capacity of ULBs to manage these innovative contracting and technical mechanisms is a central factor for achievement of benefits with private sector participation. Too (2012) mentions this capacity as “technology absorptive capacity, i.e. the ability to embrace and capitalise on new technologies to enhance their maintenance management process. Our analysis shows differences in the “technology absorptive capacity” among the ULBs. ULB-A and ULB-C lag in the adoption of innovations due to constraints such as lack of skills to investigate feasibility of carrying out these works, absence of financial resources and so on. Although ULB-B has adopted performance-based contracts to a larger extent, the capacity to monitor and assess benefits from these contracts is lacking. Therefore, these ULBs must initiate steps towards creation of technology absorptive capacity, as mentioned by Too (2012), in the immediate future.

5. Development of Road Maintenance Management Model

The case study analysis of the three urban local bodies indicated the need for structured approach towards maintenance management of urban roads. The third stage of this research study focused on development of road maintenance management models. This stage can assist decision makers in urban local bodies in the selection of appropriate urban roads for maintenance.
A literature survey has been carried out focusing on different modelling methods for road prioritization. This led to the selection of the fuzzy logic approach for the maintenance model. Although fuzzy logic was developed in 1965 as a part of soft computing research, the method gained attention only after a decade. In spite of having roots of soft computing, fuzzy logic has been widely used as a prioritisation model. Tah and Carr (2000) have studied construction project risk assessment using fuzzy logic. In this model, severity of the risk is first derived and then the probability of their occurrence is analyzed. Fuzzy logic is used to map the input with the help of realistic output. When the ratings given to the various factors do not include the probability of the consideration of these factors, they do not provide a realistic approach. Fuzzification of these ratings considers the importance of these factors as well as the probability of them falling in the criteria for that rating. Probability of occurrence is measured by different membership function in fuzzy logic. The same approach can be applied in this research, where in fuzzy logic is used to know the importance of the factors for the prioritization of urban roads for maintenance. Then, for particular road networks, significance of these factors can be derived for establishing prioritization of urban roads. A literature survey has been carried out for the identification of factors for the prioritization of urban roads for maintenance. The case study analysis carried out in the previous step helped in refining and grouping factors that emerged from the literature survey. There are 12 factors in total which are grouped into five categories: social, decision makers, environment, maintenance operations and their impact, and road performance assessment (Table 4). Three road networks from the ULBs, that formed the part of analysing maintenance management practices, were selected for the application of model for prioritising the roads for maintenance operations.

5.1 Fuzzy Modelling

5.1.1 Data collection

The responses of officials associated with the maintenance of urban roads in these three ULBs were collected in the form of questionnaires.

Questionnaire 1 - Importance of the factors: The objective of this questionnaire was to know the importance of these factors from the viewpoint of officials who are only responsible for road prioritization.

Questionnaire 2 - Importance of factors with respect to roads: The reason behind conducting this questionnaire survey was to consider the importance of the factors for a particular road network for prioritising maintenance of different roads.

Table 4. Factors for prioritization of urban roads

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Social</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Commercial Developments</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>1.2</td>
<td>Infrastructure Expansion</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>2</td>
<td>Decision Makers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Responses of Elected Wing</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>2.2</td>
<td>Users’ Satisfaction</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
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### Environment

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### Maintenance Operations and Their Impacts

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<th>Y</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time Taken for Maintenance</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
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<td></td>
<td>Life Cycle</td>
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### Road Performance Assessment

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<th>Y</th>
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</thead>
<tbody>
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<td></td>
<td>Road Safety</td>
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<td>Y</td>
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<td>Road Condition</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

Y: Yes; N: No

#### 5.1.2 Fuzzification

The ratings collected by officials were first fuzzified in order to achieve sharp output. Ratings by the officials have certain probability of occurrence which was achieved by their fuzzification. These inputs were fuzzified with the help of Gaussian curve membership function, which can generate a smooth input. For applying rules for fuzzification, “and” function was used. The function takes the minimum value of the all inputs at is the optimum rating given to it. This function defuzzifies it with Gaussian Curve Membership Function.

Gaussian Curve Membership Function (Gaussian Curve Membership Function, MATLAB- gaussmf)

\[ y = \text{gaussmf}(x,[\sigma c]) \]

The symmetric Gaussian function depends on two parameters \( \sigma \) and \( c \) as given by

\[ ||(-x-c)||^2/(2\sigma^2) \]

\[ f(x;\sigma,c)=e \]

The parameters for gaussmf represent the parameters \( \sigma \) and \( c \) listed in order in the vector \([\sigma c]\).

#### 5.1.3 Defuzzification

In order to achieve a sharp output, the rankings given by the officials had to be defuzzify. The triangular-shaped membership function was used for this. The centroid of this triangular membership functions were considered and output was generated. Based on the ratings given by this triangular membership function, ratings were considered for prioritization of urban roads.

Triangular-Shaped Membership Function (Triangular-Shaped Membership Function, MATLAB-trimf)

\[ y = \text{trimf}(x,\text{params}) \]

\[ y = \text{trimf}(x,[a b c]) \]
The triangular curve is a function of a vector, \( x \), and depends on three scalar parameters \( a \), \( b \) and \( c \) as given by,

\[
f(x; a, b, c) = \begin{cases} 
0, & x \leq a \\
\frac{x - a}{b - a}, & a \leq x \leq b \\
\frac{c - x}{c - b}, & b \leq x \leq c \\
0, & c \leq x 
\end{cases}
\]

Or more compactly by,

\[
f(x; a, b, c) = \max\left(\min\left(\frac{x - a}{b - a}, \frac{c - x}{c - b}\right), 0\right)
\]

The parameters \( a \) and \( c \) locate the “feet” of the triangle and the parameter \( b \) locates the peak.

### 5.1.4 Application of Fuzzy Logic in MATLAB

Fuzzy logic was applied in two stages to analyse the importance and impact of the factors for road prioritisation for maintenance. **Stage 1 (Part 1):** Ratings collected from questionnaire 1 were fuzzified. The fuzzification of these inputs provides the importance of the factors irrespective of roads on which the model would be applied.

**Figure 2. First Stage (Part 1) Fuzzy Structure**

**Stage 1 (Part 2):** Ratings from questionnaire 2 were fuzzified to know the impacts of the factors with respect to roads of that particular road network.

**Figure 3. First Stage (Part 2) Fuzzy Structure**

**Stage 2:** Outputs from Stage 1 (Part 1 and Part 2) were considered as inputs here, and fuzzy logic was applied to give the fuzzified ratings for the factors with respect to their importance and the impacts with respect to the roads. The fuzzy output gave the impact of every factor generated on the roads of
this road network. Roads with highest number of the factors having highest were prioritised as they have the highest requirement of maintenance.

Figure 4. Second Stage Fuzzy Structure

6. Conclusions

Case study analysis indicated that ULBs face challenges on various fronts while carrying out the maintenance management of urban roads. These challenges can be broadly categorized under different themes like collaboration between stakeholders, need for maintenance management policies and guidelines and capacity for managing involvement of private sector. The ULBs and development actors must initiate strategic steps for addressing these challenges. The prioritization of urban roads for maintenance is the central theme for maintenance management processes, which becomes very complex owing to expectations of different stakeholders. The factors identified for the prioritization of urban roads in this research study along with the maintenance management model would help decision makers in systematically arriving at a decision to select appropriate roads for maintenance. This model would not only assist in meeting immediate needs of roads prioritization but also systematize the entire process of maintenance management.

7. References


Construction Entities Tracking Based on Functional Integration and Online Learning with Site-customized Datasets

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Abstract

In construction domain, visual tracking of construction entities has received high attention and many researchers have investigated tracking methods. Although previous methods showed promising results, it has still limitations to reflect various characteristics of construction sites and entities: dynamic movements and various conditions (shapes, colour, type). One of the most common methods is tracking with probability, but it is sensitive to abrupt shape/scale changes and dis/re-appearances of objects. For the other methods based on pre-trained detectors, it is impractical to collect training datasets for all possible conditions such as entity types, colours and shapes. To deal with such shortcomings, a novel tracking method based on functional integration and online learning was proposed in this paper. Functional integration enables to track a target object under its dynamic movements by running a detector and a tracker at the same time. Online learning is able to reflect various characteristics of a target object developing site-customized datasets in real-time and automatically. The proposed method was validated with the video data recorded from the real construction sites. The results showed it has a high potential for tracking construction entities with 87% of a precision and 86% of a recall rate. It was possible to track a target object under its dynamic movements for various object types and their different colours and shapes. With the acceptable tracking performance, visual analyses on construction sites can be improved.

Keywords: Vision-based, Tracking, Detection, Functional integration, Online learning, Site-customized datasets

1. Introduction

On construction sites, a number of construction entities (e.g. workers, equipment) are scattered within the limited area; thus, unexpected events such as safety accidents occur frequently. The needs for on-site information have increased to manage the crowded and busy working environments effectively and efficiently. In detail, site information such as input entities, work in progress, and working/idle time can be used for the productivity and safety analyses (Gong and Caldas, 2010; Memarzadeh et al., 2013).
To collect site information, direct observation or survey/interview-based methods have been commonly performed. However, such methods revealed the following limitations: error-prone, time-consuming, and expensive processes (Navon and Sacks, 2007; Gong and Caldas, 2010; Chi and Caldas, 2011). To overcome such shortcomings, real-time vision-based site monitoring systems have been proposed due to its potential to extract various site information automatically and support decision making in project management (Chi et al., 2009; Chi and Caldas, 2011; Gong and Caldas, 2013; Memarzadeh et al., 2013; Golparvar-Fard et al., 2013).

To produce meaningful information from video streams, a high performance tracking should be acquired: the essential information including locations and types of the target entities can be generated from tracking processes. Moreover, the tracking can provide additional information for enhancing project management performance such as working type, idle/working time, and other productivity or safety related movements (Memarzadeh et al., 2013; Golparvar-Fard et al., 2013).

In response to the needs of tracking methods, many researchers have investigated tracking methods for construction entities. However, they have a low applicability due to a difficulty of reflecting various characteristics of construction sites and entities. It easily fails to track a target construction entity when it moves dynamically, and it is impractical to develop datasets that includes all possible conditions on construction sites. To overcome the limitations, this paper proposes a novel tracking method based on functional integration and online learning. It is expected that functional integration is able to track a target object under dynamic movements and online learning enables developing site-customized datasets.

2. Literature Review for Problem Setting

Many tracking methods have been investigated to understand site conditions more accurately. Tracking algorithms using Kalman filters or particle filters were simple and popular methods for object tracking (Hue et al., 2002; Yilmaz et al., 2006). Chi et al. (2009) presented the tracking method based on the background subtraction and pre-trained classifiers. A point matching method was suggested to track construction workers and equipment (Brilakis et al., 2011). Colour and spatial modelling algorithms were also proposed by Park and Brilakis (2012). Such tracking methods can be categorized into two main approaches: tracking with probability and tracking by detection (Yilmaz et al., 2006). Tracking with probability methods infer the posterior movements (e.g. location, velocity, and acceleration) of target objects with the comparison to their priori movements. It is performed with user initialization in the first image and it does not need any pre-training process. However, the algorithms are sensitive to tracking failures such as shape/scale changes of objects and dis/re-appearances after in and out from the camera’s field of view and occlusion of target objects (Yilmaz et al., 2006). In contrast, tracking by detection methods are relatively robust in handling those failing cases since they use pre-trained detectors. However, to train a robust and powerful detector, various datasets and time-consuming tasks are required. In addition, the quality of dataset significantly determines the detector performance (Dollar et al., 2009; Benenson, 2014). Furthermore, tracking by detection methods are not able to realize objects that are not presented in the training dataset.
Although the previous tracking methods showed the acceptable results, it has a difficulty to reflecting the characteristics of construction sites and entities. The characteristics are represented by two main factors: site conditions and entities. First, surrounding conditions—which should be considered as the background in the detection and tracking process—vary on sites. Different types of equipment appear on different sites (Figure 1), which means that target objects to be tracked are difficult to be decided in advance. Second, each entity has high intra-class variations. Concretely, not only the same type of equipment has diverse colours and appearances but also appearances and shapes of the same object can change due to different working postures and camera’s viewpoints (Figure 2). Moreover, the entities are easily disappearing or re-appearing because of occlusions and moving in and out of a single camera’s view.

Those characteristics of construction sites and entities reveal practical limitations of the previous tracking methods. When developing training datasets for tracking by detection, it is very impractical to include all possible conditions of different surrounding conditions, various types of equipment, and high intra-class variations. In other words, it is labour-intensive to pre-collect training datasets to satisfy all possible working conditions. In case of tracking with probability, it is difficult to handle shape changes and re-/dis-appearances effectively. In summary, the most of previous tracking methods in construction have limitations to reflect the complex characteristics of real construction sites. This paper presents a novel tracking method based on functional integration and online learning with site-customized datasets. The proposed method is expected to have high potential for the long-term tracking under the dynamic working environments as well.

Figure 1: (a-1) Trucks from site A. (a-2) Excavators from site A. (b-1) Truck from site B. (b-2) Excavators from site B. (c) Truck from site C.
as re-tracking in case of dis/re-appearances. It is also applicable to unknown objects developing training datasets in real-time and automatically.

3. Technical Development

The proposed method is composed of two main concepts: 1) functional integration of a detector and a tracker and 2) online learning with site-customized datasets. The details for each concept are described in the following sections.

3.1 Functional Integration of a Detector and a Tracker

Functional integration is a process of running a detector and a tracker at the same time and determining final results as comparing and analysing their results. The detector functions independently in each frame, finds a target object, and it offsets effects by shape/appearance/scale changes; however, it requires a time consuming pre-training step. The tracker estimates locations of a target object considering the object state in a moving condition such as velocity, location and shape among the consecutive image frames (Kalal et al., 2012). Thus, it easily fails and is not able to recover when the shape/appearance suddenly changes and an object moves out of camera’s field-of-view or re-appears after occlusions. To share their advantages and reduce shortcomings, a combined detector and tracker was designed to act at the same time as shown in Figure 3. The errors can be corrected by each other. The sensitiveness of the tracker to occlusions, re-appearances, and abrupt shape changes can be reduced by the application of the detector. The detector can be trained with the automatically labelled datasets from the tracking results. Such functional integration also helps to generate the effective positive (i.e., objects that should be tracked) and negative (i.e., background) samples during the detector training.

3.2 Online Learning with Site-customized Datasets

Online learning is a training or real-time learning process using the data that is updated while mapping tracked objects from corresponding labels in the dataset in sequential images (Shalev-Shwartz, 2011). There are two main differences from the offline learning. First, training dataset is produced from working environments where the object detector is applied. Second, it can be
applied for unknown objects. Based on the online learning, it is available to train a detector for any types and non-rigid objects by capturing datasets from the construction sites where the detector is applied; thus, the training datasets can be developed and customized by different site characteristics without a pre-collection process.

### 3.3 Framework of the Proposed Method

The framework of the proposed method is described in Figure 5. There are total three steps: 1) initialization, 2) functional integration and 3) online learning. Details of each step are described as follows.

**Initialization.** In the first image frame, initialization should be carried out. In Figure 4, a target object can be initialized with the bounding box by users, and the positive and negative samples for training datasets are produced online by considering the boxed area. The positive samples are extracted from shifting up/down/left/right the initialized box by 5% as shown in Figure 4. Contrary to the positive samples, the negative samples are generated in other regions in the image frame. Parts of the target object are not included in the negative samples, but it can be possible to have information related to non-target objects. After producing training datasets, the first step of online learning is performed to train and activate the detector. In case of tracking, tracking starts immediately after the initialization step is finalized.
Functional integration of a detector and a tracker. Detection or tracking errors can be identified by comparing the results and their confidence. There are four cases: 1) both of them succeed, 2) both of them fail, 3) tracking fails and detection succeeds, and 4) tracking succeeds and detection fails. When both of tracking and detection succeed (the first case), the location and the size of the object are determined with the confidence and generates the black bounding box as shown in Figure 6. In contrast, when tracking and detection failed (the second case), the tracker stops to find an object and waits until the detector succeeds to find an object, and the searching area of the tracker is then reset by the detected information. It is possible because the detector scans all image pixels to localize a target object and performs independently in a single frame. This function enables to deal with dis/re-appearances caused by full occlusions or out-of-view movement. For the third case, the result of detection is accepted and searching area of the tracker is relocated at the detection area as explained previously. It allows the tracker to recover the target object. Finally, in the fourth case, tracking results are selected but the failure of detection is considered as the negative sample of the training datasets. However, the positive samples are extracted from the tracking results. Such technical approach that produces positive and negative samples makes the detector more robust.

Figure 5: Framework of the Proposed Method.

Figure 6: Dataset Example of Online Learning. (a) Positive samples. (b) Negative samples.
Online learning with site-customized datasets. Based on functional integration of the detector and the tracker, the training datasets can be created. The detection can either succeed or fail. If the detection fails, the detected area is extracted for the negative samples to avoid similar errors. For the positive samples, the relocated area by tracking results can be assigned as the target object. Reversely, when detector localizes an object correctly, the detected area is selected for the positive samples and the negative samples are produced from the area except the detected area. The online learning based on the functional integration the detector and the tracker can customize the detector to the target object and background as shown in Figure 6.

4. Experimental Results

4.1 Data Collection and Description

To validate the performance of functional integration and online learning with site-customized datasets, the experiments were conducted with the video stream obtained from different construction sites where various types of equipment operated. Normal vision cameras were used for the data collection.

As shown in Figure 7, the collected datasets included various types of construction entities and working postures in different point views from four different sites. Occlusions and moving in and out of camera’s field of view also existed and led tracking to become challenging. Total streaming time was about 45 minutes; the number of total frames was 64,968; and the resolution was 720 x 480. The proposed method was applied to unknown objects, which means that it does not need any pre-trained detector.

4.2 Quantitative and Qualitative Results

For the quantitative evaluations, the precision, recall rate and F-measure metrics were analysed. The precision is the number of true positives divided by the number of all responses, and it explains the reliability of the proposed method. The recall rate is the number of true positives divided by the number of target objects in all sequences. The high value of recall rate specifies whether the detector or the tracker works stable. The F-measure is calculated by the precision (P) and recall rate (R), \(2PR / (P + R)\).

Table 1 summarizes the performance results. The processing time was 6 – 15 fps that satisfied real-time processing. The average precision and recall rate were 87% and 86% respectively.

![Figure 7: Examples of the Collected Dataset. (a) Dataset from site A. (b) Dataset from site B. (c) Dataset from site C. (d) Dataset from site D.](image-url)
means that the proposed method has high potential for tracking construction entities, and the characteristics of sites and entities can be promisingly handled by the proposed method. Figure 8 and 9 shows the examples of the results. The bounding boxes were the predicted locations of the target objects. The Figure 8 explains the functional integration of the detector and the tracker that allows tracking the object in the long-term time frame. In Figure 8(a) describes the effects of error corrections. When the tracker/detector was about to miss the object, the detector/tracker relocated the tracking/detection position and it significantly reduced the sensitiveness to tracking/detection failures. Figure 8(b) is the dis/re-appearances. Although the truck re-appeared after out of camera’s view, the proposed method was able to steadily re-track the target. It showed the robustness to dis/re-appearances and occlusions.

The results of online learning with site-customized datasets are illustrated in Figure 9. The datasets produced in real-time and online are illustrated in the left/right hand-side as the small image patches in Figure 9. With the site-customized datasets, the partial occlusion was able to be handled effectively as shown in Figure 10(a). Moreover, the difficulties of shape changes in different viewpoints were offset. As the backhoe rotated (the viewpoints change) as in Figure 10(b), the tracker kept localizing the backhoe correctly. In Figure 10(c), it showed the objects are kept tracking under the dynamic environment. Although the excavator had pose variations such as digging, hauling, dumping, and swinging, the method was able to maintain tracking with the application of the correction process.

<table>
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<th>F-measure</th>
<th>Processing Time</th>
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<td>0.8654</td>
<td>0.8667</td>
<td></td>
</tr>
<tr>
<td>Track</td>
<td>0.8913</td>
<td>0.8792</td>
<td>0.8852</td>
<td></td>
</tr>
<tr>
<td>Loader</td>
<td>0.8455</td>
<td>0.8455</td>
<td>0.8455</td>
<td></td>
</tr>
<tr>
<td>Backhoe</td>
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<td>0.8511</td>
<td>0.8511</td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>0.8653</strong></td>
<td><strong>0.8621</strong></td>
<td><strong>0.8637</strong></td>
<td><strong>6 – 15 fps</strong></td>
</tr>
</tbody>
</table>

*Figure 8: Functional Integration of a Detector and a Tracker.*  
(a) Error Correction and Relocation. (b) Re-tracking for dis/re-appearances.
5. Conclusions

This paper proposed a novel method that can track construction equipment in the long-term considering the unique and complex characteristics of construction sites and entities. The main components are 1) functional integration of a detector and a tracker and 2) online learning with site-customized datasets. The results showed the high potential for tracking various types of...
equipment under dynamic construction environment. With the acceptable tracking performance, it is available to achieve visual analyses on construction sites. However, the study can be still further improved with the following issues. The first issue is an expansion to multi-target tracking. For application on real construction sites, multi-target tracking should be implemented. Second, the proposed method should be applied to more various types of construction entity.

Acknowledgement

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References


Relevance of Five Generic Business Ideation Approaches vis-à-vis Contexts Embedded within Construction Markets

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Abstract

In general, ideation encompasses the formation of ideas or mental images of things not present to the senses or simply the creation of new ideas. Business ideation is herein perceived to be the core area within future-oriented business management (BM). The main aim of the paper is to assess and advance the relevance of the five generic approaches to business ideation vis-à-vis firms targeting contexts embedded within construction markets. A typology differentiates between the fitting, value-creating, profit generating, systemizing, and commercializing approaches. It is argued that each approach is, at minimum, highly relevant in the case of business unit (BU) management targeting preferred client investment and procurement behavior within construction markets. Approach 1 involves BUs aiming at fit between clients and their needs as well as units’ offerings and operations, respectively. Professional clients couple needs with preferred procurement methods whereas competing BUs are trying to achieve best fit between solutions and client behaviors. This approach calls for research on how to sustain such fit between a BU and clients when changes occur. Approach 2 enables BUs to create value by specifying high-value propositions, producing value to clients, and capturing their fair shares of produced values. Farsighted clients look for more or novel values for construction investments and, thus, units are collaborating and co-producing values to clients. This approach calls for research on a BU’s value co-production with such clients, value capture, and offerings integration. Approach 3 accommodates BUs that are focusing on generating profits, achieving high-profit levels, and sustaining them. Pioneering clients pursue complex investment aims that can be met only by radical solutions. This approach calls for research on a BU’s profit-generating mechanisms related to clients with complex investment needs and radical solutions. Approach 4 facilitates BUs to systemize businesses around core ideas. Sectoral clients have large or complex needs and, in turn, units are satisfying them by engineering systems as wholes and delivering them as parts. This approach calls for research on BUs with systems and clients, multi-dimensional investments, and system engineering as wholes and parts. Approach 5 facilitates BUs to couple ideas with commercializing dimensions such as entrepreneurship, innovation, business development, venturing, or spin-offing. Risk-taking clients prefer to enter high-innovation contracts and, thus, units are offering novel solutions and emerging business cases. This approach calls for research on a BU’s entrepreneurial competencies and risk-taking clients, wicked investment needs, and high-innovation contracts. In the same vein, the suggestions are put forth to CIB-related scholars for directing research on along the BM and ideation dimensions and adopting most relevant approaches. Likewise, management in firms and BUs competing in construction markets are encouraged to assess the business case-sensitive relevance of each of Approaches 1-5 and try out those with initial high relevance.

Keywords: Business ideation, business management, construction markets, literature review, management concepts
1. Introduction

Managing a single business (un)successfully is herein seen the most fundamental area of strategic management. In the same vein, business management (BM) research is perceived as the most important and evolving sub-field within strategic management research. Within the BM scope, the focus is on managing business issues. In general, ideation encompasses the formation of ideas or mental images of things not present to the senses or simply the creation of new ideas (OED 2012). Business ideation is herein perceived to be the core area within future-oriented BM. The focal contexts are embedded within construction markets, i.e., the contracting, design, construction, servicing, project-based, and life-cycle aspects of capital and construction investments in natural resources usage, energy supply, telecommunications, transportation, infrastructure, manufacturing, general building, and other real estate concerns.

This paper is part of the pioneering reviewing of construction-related BM research (e.g., Huovinen 2003a, 2006a-b, 2015a-c). The nature of this paper is that of reporting on the conduct and findings of a focused review of relevant published, conceptual knowledge about business ideation as part of BM. The rationale is that advancements can be designed based on the revelation of the current states of business ideation affairs via a review of the 71 construction-related BM concepts that have been published via the formal channels between 1990 and 2013. The main aim of the paper is to evaluate and advance the relevance of the five generic approaches, i.e., the fitting, value-creating, profit-generating, systemizing, and commercializing business ideation vis-à-vis firms and their business units targeting contexts embedded within construction markets. Accordingly, the three sub-aims are as follows:

- How is the reviewing being conducted? What are the degrees to which the authors have designed their 34 (out of 71) construction-related BM concepts along the business ideation dimension? The focused review is reported upon in Section 2.
- What are the generic Approaches 1-5 to business ideation? How relevant is each of them in the case of business unit (BU) management vis-a-vis business ideation with contexts embedded within targeted construction markets? Approaches 1-5 and 13 high-degree concepts are briefed as well as the approach-specific relevance is assessed in Section 3.
- How to advance the relevance of Approaches 1-5 vis-à-vis managing business ideation related to contexts within construction? The suggestions are put forth in Section 4.

2. Reviewing of Construction-Related BM Research

2.1 Four reviewing rounds between 1999 and 2014

The four reviewing rounds have been carried out in 1999-2003, 2006, 2010-2012, and 2014. Cooper’s (1998) approach and the same limitations have been re-adopted to protect the validity. The coherence has been maintained by focusing on research on firms based in the OECD countries. Exceptionally, references originating from Singapore and Hong Kong have been included due to the authors’ British Commonwealth heritage and research on international construction. Hart’s (1998) guidelines have been relied upon. The design of the method for the reviewing of conceptual research, i.e., the replicable handbook-based and invented-here ways
have been documented, used, and reported upon in Huovinen (2003a, 2006a-b, 2013 and 2015a-c). The search for eligible concepts has been conducted comprehensively within the volumes of 21 journals in construction and those of 47 journals in business administration. Concerning the other channels, the degrees of the comprehensiveness vary. The reviewer submits the lists of all the channels on request. So far, the reviewing has resulted in the identification of 71 construction-related BM concepts that have been published between 1990 and 2013.

2.2 Focused review of business ideation as a dimension for designing 71 construction-related BM concepts

For the assessment, the four degrees of the design of a particular construction-related BM concept along the business ideation dimension were pre-defined as follows:

- **High degree**: A concept’s primary parts include all the three core elements of business ideation, i.e., needs and clients, offerings, and operations and/or resources.
- **Medium degree**: A concept includes only one or two core elements.
- **Low degree**: A reference containing a concept only addresses issues in business ideation.
- **No degree**: A reference does not contain any explicit aspects of business ideation.

The assessment revealed that 48% or 34 (out of 71) construction-related BM concepts include also the elements for managing business ideation. There are 13 (18%) high-degree, 6 (8%) medium-degree, and 15 (21%) low-degree BM concepts (Table 1).

<table>
<thead>
<tr>
<th>No. (%)</th>
<th>No. (%)</th>
<th>No. (%)</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High degree business ideation</td>
<td>Medium degree business ideation</td>
<td>Low degree business ideation</td>
<td>No business ideation at all</td>
</tr>
<tr>
<td>13 (18)</td>
<td>6 (8)</td>
<td>15 (21)</td>
<td>37 (52%)</td>
</tr>
<tr>
<td>All construction-related BM concepts</td>
<td></td>
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<td>71 (100)</td>
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</tbody>
</table>

The assessment validity has been protected against the five biases as follows. **Concept Inclusion Bias 1** involves this reviewer perceiving that an author has designed a concept along the business ideation dimension even if this author has not done so. This bias has been minimized by assessing each reference in the same way and quoting only the necessary parts that contain 34 (48%) construction-related BM concepts designed along the business ideation dimension. Future reviewers can test the inter-concept consistency of inclusion by repeating the assessments, i.e., reading and confirming the same quotations or rejecting them. **Concept Exclusion Bias 2** involves this reviewer perceiving that an author has not designed a concept along the business ideation dimension even if this author has done so. 37 (52%) “no degree” assessments indicate that this reviewer did not identify business ideation. Future reviewers can test the inter-concept consistency of exclusion by repeating the assessments, i.e., reading and confirming the exclusions or identifying business ideation elements in them. After the inclusion, **Degree Assessment Bias 3** is related to this reviewer’s reliance on a pre-specified scale of the
three conceptual degrees instead of a quantitative scale. This reviewer could assign one of the three pre-defined degrees to each of 34 concepts without hesitation. Future reviewers can test the inter-concept consistency of degree assignments by reading and confirming the same degrees or assessing changes in them. Or, they could re-specify a scale of degrees. Concept-Approach Correspondence Bias 4 is related to the mapping of each of 13 high-degree concepts onto one or more business ideation approaches (Table 2). This reviewer could map each concept onto one generic business ideation approach based on the identification of the theoretical roots and elements. Future reviewers may deepen this analysis, e.g., by itemizing each (sub-)element within the references and quoting them in a set of more detailed tables to allow cross-approach comparisons and correspondence identification. Concept Author-Reviewer Bias 5 is related to a fact that this reviewer has designed 14% or 10 (out 71) concepts. 7 (out of 10) concepts have been designed along the business ideation dimension. Thereof, this reviewer assessed that he has designed 3 high-degree, 1 medium-degree, and 3 low-degree concepts. Future reviewers can test the inter-concept consistency of the assessment outcomes versus each of the four other biases in the case of 10 concepts designed by this reviewer.

3. Five Generic Business Ideation Approaches

In general, OED (2012) defines that “to idea is to give a particular form or character to…” In turn, ideation encompasses “the formation of ideas or mental images of things not present to the senses” or simply “the creation of new ideas”. Aligning with Normann’s (2001) root principle of fit, a business idea is herein defined to consist of the three core elements, i.e., a focal firm is (i) targeting an environment with potential clients and their needs, (ii) developing and leveraging its offerings that best satisfy targeted needs, and (iii) organizing a BU and, thus, performing operations, enabled by its resources.

How is business ideation being approached within strategic management literature? Previously, this author has identified and differentiated between the five generic approaches to business ideation, i.e., fitting, value-creating, profit-generating, systemizing, and commercializing approaches, based on the respective dimensions, preferences, and rationales (Huovinen 2013). The rationales are overviewed, the 13 high-degree, construction-related BM concepts are briefed, and the relevance is only qualitatively assessed approach by approach as follows.

3.1 Fitting business ideation and its relevance

Firms are crafting business ideas and accommodating causal fit concerning their offerings and operations versus targeted clients and needs. Applying Normann’s (2001) abstract definition, a business idea is a unique, historically evolved set of factors related to each other, i.e., an environment with needs and values as well as a BU’s offerings and other internal factors. The overall principle is one of consonance or fit. Adopting Drucker’s (1994) recognized theory of business, the three sets of assumptions can be defined about (a) an environment, i.e. society, market, clients, and technologies, defining what a BU is paid for, (b) a specific mission, defining what meaningful results are and envisioning how a unit makes a difference in a targeted economy (society), and (c) core competencies, defining where a unit must excel to
maintain leadership and accomplish its part of a firm’s mission. Such a theory can be validated with the four specifications, i.e., the assumptions must fit reality, one another, be known and understood throughout a unit, and be tested constantly. There are the two measures for preventing the current theory from becoming obsolete, i.e., to abandon it and study non-customers. Readily, many fitting business ideation concepts have been designed as part of corporate planning concepts.

Among the 13 high-degree, construction-related BM concepts, the four concepts have been designed along the fitting business ideation dimension. Winch and Schneider’s (1993) four high-degree strategies for UK architectural practices, based on the project complexity and the client’s quality preference, capture many core fitting elements, i.e., (1) the strong, CAD-based delivery of designs with repeat elements for simple buildings at low fees and overheads, (2) strong experience and value engineering, coupled with many disciplines or specialization, to meet requirements related to complex buildings, charging a premium due to high value, (3) strong ideas and identifiable style with the articulation of a competence related to prestige buildings, coupled with charging a premium due to reputation for original, exciting ideas and a figurehead, and (4) strong ambition of young practices with few clients, and charging low fees.

Jennings and Betts’ (1996) high-degree four strategies for quantity surveying practices in the UK capture many core fitting elements, i.e., (1) differentiation-based execution for small and medium-sized practices with a varied client base and simple, tailored, quality services to ensure repeat business, charging average fees, (2) differentiation-based expertise for larger practices with clients in niche markets and predominantly new areas, and complex, technically differentiated services, charging above average fees due to image of quality, adaptability, and professionalism, (3) cost focus-based efficiency for fairly new practices with simple, fixed projects, specific competences, optimized staff/salary levels, and rock-bottom prices, and (4) differentiation focus-based experience for larger, older practices with experience in complex projects and/or hand-holding services, and interpersonally bonded clients, charging a premium. Each strategy also identifies an IT-use level and a staff structure.

Lowendahl (2000) has designed the three high-degree strategies for US professional services firms with many fitting elements. (a) Client relation based strategies emphasize a unique ability to understand and help particular client groups. Performance is measured as client satisfaction, client retention, and follow-on contracts. Strategic assets involve senior professionals with reputation and client relationships. (b) Solution or output based strategies emphasize the exploitation of superior organizational competences. Vulnerability is related to solution obsolescence. When clients accept contracts without naming professionals, this is a sign of the successful development of collective routines and reputation. A challenge involves the motivation of R&D people to create new solutions to a large group of clients. (c) Problem solving or creativity based strategies result in highly complex firms typically delivering services based on innovations. Firms cannot avoid dependence on key individuals. Top managers are likely to be the best professionals who are willing and able to accept managerial responsibilities.
Helander and Möller’s (2007) high-degree, dynamic model for a system supplier’s customer strategy is based on the categorization of a client’s strategies, with many core fitting elements, i.e., independence of supplier strategy A, shared expertise with supplier strategy B, and reliance on supplier expertise strategy C. A system supplier assumes (i) an equipment/material supplier role to causally couple with an independent customer’s strategy A, (ii) a solution provider role to couple with a sharing client’s strategy B, and (iii) a performance provider role to couple with a dependent client’s strategy C. It seems that a supplier can extend its role only when a customer’s strategy is compatible with the aimed role. A supplier’s role may be dependent on interrelated activities and coordination mechanisms so that a client can close its knowledge gaps and start to perform activities that a supplier has performed in the past.

Thus, it is herein argued that in construction Approach 1 is highly relevant, at minimum, in the case of BU management aiming at causal fit between buyers and their needs, a BU’s offerings to satisfy needs, and its operations enabled by key resources. Targeted professional clients couple needs with accommodating procurement methods whereas a particular BU achieves best fit between its solutions and such client investment and procurement behavior.

3.2 Value-creating business ideation and its relevance

Firms are crafting business ideas, specifying high-value propositions, and organizing BUs to actually produce values under contracts with clients and to capture shares of produced values. Applying Slater’s (1997) founding client value-based strategy, market segments are selected, value propositions are created to establish positions of competitive advantage, necessary capabilities are developed for understanding client needs, and promised value is delivered. Relying on Ramirez’ (1999) pioneering value co-production framework, BUs and clients could increasingly co-invent, combine, and reconcile values where interactions (offerings) are units of value creation and clients’ roles are new factors of production. Applying Kothari and Lackner’s (2006) typical value creation cycle, value is defined (sources and quantification), created, delivered for clients (flow and outside in -based processes), and captured (shares of profit, wallet and market). The value that clients receive from a focal BU’s offerings is being determined by product, access, experience, and cost attributes.

Among the 13 high-degree, construction-related BM concepts, the five concepts have been designed along the value-creating business ideation dimension. Pinto et al.’s (2000) high-degree value chain analysis, based on partnering and a technique of client-based project success includes many core value-creating elements. A project supplier can redefine itself as a long-term partner for enhancing a client’s competitive advantages and operations as well as eliminating disadvantages. Through value chain analyses, a supplier tailors project bidding, engineering, design, fabrication, and delivery in a manner and for a price that gives a client an advantage over using alternative methods or competitors. Client satisfaction is ensured through contract development, a client’s multiple levels, and project-specific phases. In order to achieve an overall project success, a supplier enters cooperation with subcontractors to offer superior service to clients where technology is to a great extent undifferentiated.
Metais and Meschi’s (2005) high-degree, core competence-based strategy for strategic flexibility via linking the value chain and resources of an (oil and gas) plant contractor involves many value-creating elements. A strategic architecture links a contractor’s value chain and core competencies. There are four processes, i.e., (i) to understand market and invent new products, by analyzing products and services in cooperation with customers, (ii) to design generic solutions, (iii) to design and produce customer-specific solutions, and (iv) to operate solutions (constructed facilities). The five core competencies are project development, project execution, technologies, processes, and operation. This architecture enables to make choices between forms of a value chain and between types of competitive advantages. In unstable environments, core competencies allow for varying and adjusting a contractor’s value chain, as a resource network, according to an industry’s stakes.

Hawk’s (2006) five high-degree, most promising business ideas for stakeholders in construction are as follows: (i) intelligent systems applications, (ii) lateral thinking capabilities, (iii) environmental concerns, (iv) decentralization needs, and (v) leisure time facilities. The nine high-degree recommendations for international construction development include many value-creating elements, i.e., (1) embrace consumer ideals, (2) seek new business ideas in cross-border customer relationships, (3) add new value potentials via innovative design and global procurement processes, (4) use of global construction to discover new local visions, (5) accommodate diversity while embracing the contradictory, (6) adapt and adopt cross-border design and production, (7) find and organize new knowledge across the globe, (8) innovatively avoid limits in hierarchies, and (9) integrate the Asian and European models of construction.

Salonen et al.’s (2006) high-degree supplier centric systems model for the enhancement of competitive advantages consists of the eight value-creating elements, i.e. (i) finding new ways to enhance customer value, (ii) adopting a supplier centric systems model with a shift to a systems integrator’s role, (iii) identifying buyers who appreciate maximum value, (iv) insulating a systems integrator from threats via entry barriers, e.g., cost advantages, economies of scale, switching costs, unique and valuable resources, (v) acquiring and possessing required resources, e.g., superior systems know-how, systems oriented sales force, service capabilities, control of physical components, (vi) controlling costs, e.g., through standardization, (vii) integrating value propositions either as lowered total costs or enhanced performance for buyers throughout value chains and the life-cycles of systems, and (viii) communicating value to customers to change the predominant, buyer centric business model to the supplier centric one, e.g., signaling to gain top management’s awareness and getting a mandate for containment of customers’ line worker opposition as well as maintaining interfaces.

Kujala et al.’s (2010) high-degree typology of the five empirical business models of a power plant supplier also captures a value-creating scope. A 5-model framework was developed for the analysis of a project supplier’s business models based on the six characteristics, i.e. customers, value propositions, competitive strategy, a position in a value network, an internal organization and capabilities as well as logic of revenue generation. The 1st model of basic installed base services involves product-oriented revenue generation logic. The 2nd model of customer support services involves process-oriented
value propositions and transaction-based revenue generation logic. The 3rd model of operations and maintenance outsourcing involves product-oriented value propositions and relationship-based revenue generation logic. The 4th model of the delivery of life-cycle solutions involves process-oriented value propositions and relationship-based revenue generation logic. The 5th model of the development of life-cycle solutions involves process-oriented value propositions and relationship-based revenue generation logic accepting more risk and upfront costs as well as requiring more extensive business, market, and stakeholder management capabilities (in comparison with the 4th model).

Thus, it is herein argued that in construction Approach 2 is highly relevant, at minimum, in the case of BU management creating value by specifying high-value propositions, producing such value to clients, and a BU capturing its fair share of produced values. Farsighted clients look for markedly more or novel values for construction investments and, thus, a BU is collaborating with technology-intensive suppliers, proposing integrated offerings, and co-producing value.

3.3 Profit-generating business ideation and its relevance

Firms are crafting business ideas to achieve high-profit BU performance and also to sustain it. Adopting Slywotzky et al.’s (1999) multi-pattern approach to profitability, the rules of games can be redefined and new profitable business designs be recreated in terms of high client relevance, a consistent scope of products and value chain activities, a terrific profit model, a powerful source of differentiation and control across markets as well as a supportive, reinforcing organization. All this is enabled by the early, continuous recognition of evolving profit patterns such as mega, value chain, customer, channel, product, knowledge, and organization. The recognition, identification, and analysis of such patterns are based on paying attention to story-telling, mapping a strategic landscape, measuring degrees of mindshare by business designs as well as deciphering conditions and triggers for next profit-making patterns.

Among the 13 high-degree, construction-related BM concepts, only one concept has been designed along the profit-generating business ideation dimension. Leinberger’s (1993) high-degree dichotomy of project-oriented and process-oriented businesses in US real estate markets captures many profit-generating elements, coupled with risk management. Project-oriented business exhibits five marketing characteristics (one project at a time, no guarantee of a next project, different projects, higher margins, higher risk), six financial characteristics (unique deal, changing financing markets for both equity and debt, project-by-project financing, huge financing needs, limited access to public equity market, and potential for surprises; restructuring of vehicles), and six organizational characteristics (job shop, barely contained anarchy, exciting and ever-changing, fighter pilots, high turnover, addicted to change). Process-oriented business exhibits differences in its five marketing characteristics (business stream, repeat business with satisfied customers, customer similarity, lower margins, and lower risk), six financial characteristics (uniform contract structure, consistent financing, corporate financing, working capital needs, broader access to public equity market, stable financing structure), and six organizational characteristics (assembly line, efficiently organized, consistent, ship’s crew, stable workforce, slow adjustment when change occurs).
Thus, it is herein argued that in construction Approach 3 is highly relevant, at minimum, in the case of BU management focusing on generating profits, achieving high-profit performance levels, and sustaining them. Pioneering clients pursue complex investment aims that can be met only by radical solutions and, in turn, a BU is highly competent in innovating and proposing solution-driven values, realizing values, and capturing exceptionally big portions of them.

3.4 Systemizing business ideation and its relevance

Firms are crafting systemic business ideas as well as modeling or designing businesses and organizing businesses as systems. Applying Osterwalder and Pigneur’s (2010) generative business model, rationales can be defined, i.e., how BUs create, deliver, and capture value as well as cover the four areas of a business (clients, offers, infrastructure, and viability). The 9-block logic of how to make money includes (i) client segments, (ii) value propositions, (iii) communication, distribution, and sales channels, (iv) client relationships, (v) revenue streams, (vi) resources, (vii) activity performance, (viii) partnerships for outsourcing and resource acquisitions, and (ix) a cost structure. Business model innovations result from the objectives, i.e., (a) to satisfy existing but unanswered needs, (b) to bring new technologies or offerings, (c) to improve, disrupt, or transform markets with better business models, or (d) to create markets.

Among the 13 high-degree, construction-related BM concepts, the three concepts have been designed along the systemizing business ideation dimension. Huovinen’s (2003a) high-degree, 5-element, knowledge-based system for managing a firm’s business units in global capital investment markets captures the core systemic elements in knowledge-based ways. (i) A unit advances front-line strategies and offerings for best solutions, high client satisfaction, and high firm profitability. Value-adding knowledge enables to pre-empt client needs. (ii) A unit integrates global, local, and contract-specific business processes for high dynamic operative effectiveness, ensured by virtual knowledge. (iii) A firm nurtures core technology for creating advantages. Innovative knowledge involves business-opportunity perceptions, a foresight, a technology platform, a core competence architecture, a core offering portfolio, and innovation paths. (iv) A firm governs and optimizes business-specific frames. This knowledge covers ownership, top management, venturing, financing, and firm-market interactions. (v) A firm extends its frame via collaboration with global and/or local parties. This knowledge includes synergistic ways of opportunity exploitation, benefit balance, and risk avoidance.

Huovinen’s (2004) high-degree, 5-element, organization-based system for managing a firm’s business in capital investment markets captures the core systemic elements in organization-based ways. The 1st value-adding front line enables a BU to pre-empt client needs, excel among competitors, and meet its goals in the short term. A unit integrates the 2nd business processes for ensuring virtual effectiveness. A firm nurtures the 3rd back-end core technologies, competences, and offerings. Innovative organizing involves a core competence architecture and a matrix of core processes and project types where teams play flexible, integrative roles. A firm governs the 4th BU frames. Framing solutions cover ownership, top management, venturing, financing, resource silos, and firm-market interactions. The 5th extended frame includes collaborative ways of front-lining, process integration, competence fusion, benefit balance, and risk avoidance.
Huovinen’s (2011) high-degree, 5-element, high-sustainability system for managing a firm’s business in construction-related contexts captures the core systemic elements, i.e. a BU advances the 1st strategies and offerings also for the highest degrees of sustainability. Offerings with no/low negative impacts enable to pre-empt or over-satisfy client needs and meet high-sustainability goals in the short term. A unit integrates the 2nd business processes also for minimizing carbon footprints. A firm nurtures the 3rd back-end or core technologies also based on high-sustainability foresights. A firm governs the 4th frame of each business also for high sustainability. The 5th extended frame is also based on sustainability.

Thus, it is herein argued that in construction Approach 4 is highly relevant, at minimum, in the case of BU management systemizing or modeling its business around a core idea. Sectoral clients have large, multi-dimensional investment needs and, in turn, a BU is satisfying needs by engineering systems as wholes and delivering them as modularized parts.

3.5 Commercializing business ideation and its relevance

Firms are crafting business ideas and coupling them with new legal and organizational business entities, i.e., through entrepreneurship, innovation, business development, venturing, or spin-offing. Applying Looser and Schlöpfer’s (2001) traditional, 8-part business plan, business ideas can be identified and rolled out to start up high-growth businesses. Innovating may result in new products/services and/or business systems. Adopting Hamel and Breen’s (2007) radical approach, management innovations alter managers’ work or modify organizations and, thus, advance the goals of respective BUs. Principles, processes, and practices are being reinvented. A management innovation could have a unique capacity to create a long-term advantage when one or more of three conditions are met, i.e., (a) a novel management principle, (b) systemic with a range of processes and methods, and (c) a rapid-fire innovation. When higher tiers denote higher levels of value creation/defensibility in a hierarchy, the 4th tier of management innovations comes out above the 3rd tier of strategy innovations, the 2nd tier of product/service innovations, and the 1st tier of operational innovations.

None of the 13 high-degree BM concepts has been designed along the commercializing business ideation dimension. Nevertheless, it is argued that in construction Approach 5 is highly relevant, at minimum, in the case of BU management coupling its business ideas with intensively commercializing dimensions. Risk-taking clients with ‘wicked’ investment needs desire to enter high-innovation contracts and, thus, a BU is nurturing and using entrepreneurial competencies for the making of novel solutions and the realization of business cases profitably.

4. Conclusions

It seems that the business ideation dimension is being recognized among construction-related researchers, at least by the authors of the 13 high-degree BM concepts published between 1990 and 2013. Indicatively, the number of these high-degree concepts corresponding to one of Approaches 1-5 varies between zero and five (Table 2). Nevertheless, it is herein argued that each generic approach to business ideation is, at minimum, highly relevant in the case of BU
management targeting preferred client investment and procurement behavior within construction markets.

Table 2: Correspondence between five generic approaches and 13 construction-related BM concepts designed to high degrees along the business ideation dimension.

<table>
<thead>
<tr>
<th>Approach</th>
<th>1 Fitting ideation No. (%)</th>
<th>2 Value-creating ideation No. (%)</th>
<th>3 Profit-generating ideation No. (%)</th>
<th>4 Systemizing ideation No. (%)</th>
<th>5 Commercializing ideation No. (%)</th>
<th>All high-degree BM concepts No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of concepts</td>
<td>4 (31)</td>
<td>5 (39)</td>
<td>1 (8)</td>
<td>3 (23)</td>
<td>0 (0)</td>
<td>13 (100)</td>
</tr>
</tbody>
</table>

It is suggested that CIB-related scholars design next construction-related BM concepts along the business ideation dimension and adopt the most relevant approaches, respectively. Approach 1 calls for research on how to sustain fit between a business unit and professional clients when changes occur. Approach 2 calls for research on value co-production with farsighted clients, value capture, and offerings integration. Approach 3 calls for research on profit-generating mechanisms related to pioneering clients with complex investment needs and radical solutions. Approach 4 calls for research on systems related to sectoral clients, multi-dimensional investments, and system engineering. Approach 5 calls for research on entrepreneurial competencies related to risk-taking clients, wicked investment needs, and high-innovation contracts. Management in firms competing in construction markets are encouraged to assess the business case-sensitive relevance of each approach and try out those with initial high relevance.

References


Towards Responsive Workspaces - Identification of Service Paths for Time-and-Place Independent Work

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Abstract

The development of technologies, change in the ways of performing tasks and user preferences empower time-and-place independent work. Time-and-place independent work is becoming rather the rule than the exception. Half-empty offices and long traveling distances do not motivate employees anymore. Therefore, an attractive and welcoming work environment needs to be created. The definition of a workspace has evolved from strictly physical space to work towards virtual and social dimensions of knowledge creation. Virtual and social dimensions play an important role in a workplace due to digital revolution and empowerment of big data. Particularly, it helps to understand workers and their needs better and provide services that correspond demand which could then be called as a responsive workspace. A change towards responsive workspace becomes a challenge for real estate service providers as well. In order to gain competitive advantage, real estate service providers need to respond to the changes in the market. Therefore, this paper aims to analyse currently available services that support time-and-place independent work and identify key features and the course of service advancement that could help develop responsive workspaces. The aim is achieved by developing a service path framework. Literature review combined with market studies are used as methods for framework development. Literature review handles the trends of working environment and the market study consists of data of a hundred firms that offer services to support time-and-place independent work. As a result, key service paths are identified. Paths refer to a range of services, concepts and other solutions that support or contribute to time-and-place independent work. Four paths, characterized by space, community, technology and logistics as main business drivers, form the primary base of the framework. From this, new service paths that support different steps of knowledge creation processes emerged. Based on the framework, new business opportunities can be explored by real estate service providers. Further research can build on these findings by using other approaches, e.g. service design methodology or value co-creation theory.

Keywords: workspace, time-and-place independent work, services, framework
1. Introduction

New characteristics of the design and architecture of spaces and urban area, organisational transformations and changing ways of work need to be explored in order to support different needs of organisations. These rapid changes in the market and advancement of technologies challenge FM service providers to quickly respond to the developing needs and concentrate, above all, on supporting the worker. To understand the ways how time-and-place independent knowledge work can be supported, various services are analysed and paths are identified.

First, the paper discusses the theory related to knowledge processes and workplaces and identifies components of responsive workspace, then the role of FM service providers is shortly discussed. After the literature and theory review, the analysis of services is described and results are presented. The paper ends with discussion and conclusions related to the development of responsive workspace and the opportunities for FM service providers.

2. Literature

2.1 Knowledge creation

In today’s quickly changing environment and technological advancements it becomes difficult to compete with anything other than the knowledge that an organization holds. Nonaka and Toyama (2003) discuss the knowledge theory of the organization to explain the process of knowledge creation and utilization. The knowledge creation is a process of interactions and problem solving happening between individuals, organization and environment. In many organizational theories, the environment outside the organization is ignored and its effects to knowledge creation are disregarded.

Nonaka (1991) tried to overcome this drawback and take environmental and organizational relationships into consideration by introducing the theory of SECI and studying interactions between them. In the knowledge creation theory, the knowledge is classified into tacit and explicit, where tacit knowledge is intangible and related to skills or points of view, while explicit knowledge is objective and rational, and is easily expressed with language and numbers (Senoo et al., 2007).

This classification lead to the development of SECI model for the knowledge creation process in four different conversion models: Socialization, Externalization, Combination, and Internalization. The process usually starts from converting new tacit knowledge through experience sharing and every day social interactions and is called Socialization process. Through the process of Externalization, the tacit knowledge is then transformed into explicit knowledge and gains tangible form such as documents or images. The personal knowledge and experiences are shared, and a person tries to find the meaning in these shared forms of knowledge. After the Externalization process and knowledge sharing with others, the knowledge is collected from different sources, combined, and processed into a more complex explicit knowledge through so called Combination process. In this step of the process, a lot of different tools are used and in
many cases it involves virtual environment and virtual tools for knowledge creation and processing. When explicit knowledge is perceived and applied in everyday situations, it is transformed into tacit knowledge again, and benefits the knowledge of one’s own. (Nonaka and Toyama, 2003).

Knowledge creation process is time, space, and relationship specific because it needs a place where information gets meaning through interpretation. This need leads to an introduction of “Ba” concept (Nonaka and Toyama, 2003). “Ba” originally means place and is considered a factor in a knowledge creation process that connects time, place and relationships with others (Senoo et al., 2007). Senoo et al. (2007) identified two “Ba” environments: physical (e.g. office) and virtual (e.g. email). However, Nonenon (2004) argues that there should be a combination of virtual, physical, and social places (e.g. mental space, ideas) as only virtual places cannot fully replace face-to-face interactions. These interactions are more important aspects in the knowledge creation process than the space itself (Huhtelin and Nonenon, 2015).

Organisations should aim at better understanding of complex knowledge creation process in order to increase their competitive advantage. Understanding employees and creating an environment that supports their needs should become a main priority of those organisations and their service providers.

2.2 Workplace

For a long period of time, workplace in the office was considered as a setting where employees followed orders (Senoo et al., 2007). In that setting, an office layout was appraised from a management perspective with staff left away from the decision-making process. Only later, starting from early 2000’s, the workplace research showed the importance of Facility management (FM), IT and HR collaboration in order to improve collective activities and performance of employees.

In 2008, Vischer suggested that built environment is a necessity and it acts as a mediator between people and tasks and activities they perform. The better users are supported in their tasks, the greater is the effectiveness of the built environment they are in. Author divided users into three groups: individuals, the team, and the organization which was also related to the phenomenological perspective of space, which was considered in layers, starting from the “personal space” and moving towards universal space (Vischer, 2007b).

The understanding of “traditional” office space has changed when technological development created possibilities to carry out tasks in different places, including spaces outside traditional office walls. Data from different observational studies show that, on average, conventional workplace at the office is occupied 42-45% of the typical day (Laing, 2013). In his book “Work and the City” (2008), Duffy discussed traditional practices related to work time and work place. Nowadays, knowledge work is done not only through face-to-face collaboration in the office but also virtually. Virtual and remote teams also cause changes in work times as quite often team members are located in different time zones. Also, most of routine individual tasks can be
automated and other highly intellectual tasks can be performed elsewhere and not necessarily in the traditional office building. These changes have an impact in how buildings and cities are used and how work can be combined with other activities.

Traditional office space became less about the employee interactions in a physical environment but more about individual’s ability to work with digital information at the workstation and the role of a workplace has gained a different approach both in practice and in research. Nowadays, integration of various activities and possibility to be a part of various virtual and social networks that enable employees to create new knowledge are the most of important attributes of a good workplace (Lister, 2010).

2.3 Knowledge creation in workplace

New approaches towards workplace and its ability to support knowledge creation processes started in early 2000s. In 2004, Nenonen introduced the concept of four places that vary based on the type of work that is performed and space used to perform work (Fig. 1). Author argued that a Connective place is an external space where one needs to perform more intangible work (create tacit knowledge). Structural place includes external spaces where tangible work is performed and Formal place is internal environment where tangible work is done. The last place, used for knowledge creation, is internal, and intangible work is performed there. That place is called a Reflective place.

![Figure 1: Work environments based on Ba concept (Adapted from Nenonen, 2004)](image)

Huhtelin and Nenonen (2015) discussed the environment that supports knowledge creation and knowledge work. According to the authors, the aspects of spaces and services in Ba framework are:

- Spaces and services that support informal interaction and idea creation – Originating Ba;
- Spaces and services that support formal meetings – Dialoguing Ba;
- Digital platforms - Systemizing Ba;
- Spaces that support learning-by-doing - Exercising Ba.

Originating Ba is supported by spaces and services that support informal interaction – it needs to be a place where tacit knowledge can be transferred and co-created. Dialoguing Ba is supported
by services and spaces that support formal interaction, and it is a matter of resources how to organize it as one function for empowering time-and-place independent work.

Table 1 introduces the generalization of discussed topics. According to Nenonen (2004), a workplace is combined of three components: physical space, virtual space, and social space. Thus, support services should be provided to all of those together to ensure smooth knowledge creation process and transition from one quadrant to another. Choo & de Alvarenga Neto (2010) introduced different steps in knowledge processes: knowledge creation, sharing/transfer and use of knowledge. These can be assigned to the three attributes of workplace. Different work types are also identified and categorized under three workplace environments.

<table>
<thead>
<tr>
<th>Attribute of workplace</th>
<th>Physical Space</th>
<th>Virtual Space</th>
<th>Social space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge process</td>
<td>Knowledge creation</td>
<td>Knowledge sharing</td>
<td>Knowledge use</td>
</tr>
<tr>
<td>Work types</td>
<td>Formal meetings</td>
<td>Virtual platforms</td>
<td>Informal interaction and idea sharing</td>
</tr>
</tbody>
</table>

2.4 The role of FM service provider

In order to understand the role of workplace and find new ways how to develop spaces that enable time-and-place independent work, two field of research should be analysed. Organizational theories claim that poor physical environment can have a negative impact on the performance but a good physical environment has little or no consequence to performance. Thus, a physical environment was considered as a hygiene factor in Maslow’s pyramid for many years and ignored by organization studies. Then, traditional facilities management (FM) theory divides FM services into three levels: (1) Strategic FM that supports organizations; (2) Tactical FM that supports business units; and (3) Operational FM – supporting end users, or in other words – knowledge work. FM’s role is to place the non-core business at the service of the core business in such a way that real estate would be turned from the cost item into the element that adds value to overall organisational performance. However, in practice, many organisations still consider real estate and workplaces as a hygiene factor and a cost item.

In order to change the understanding of FM as operations’ management, a philosophy was developed by Cairns. Cairns (2003) questioned the “irrelevance” of the physical environment and its placement in the Maslow’s pyramid. He claimed that a modern workplace is “not an activity container for paid work but contains representations of all other major social places in the modern society”. He explained that workplace must be seen as presenting different solutions to various physical and social problems simultaneously within the same assemblage of physical artefacts. This view is supported by Deb Roy (2015) who describes FM as something that: (i) delivers
effective and responsive services; (ii) enables changes in the use of space in the future; (iii) makes assets cost effective; (iv) creates competitive advantage to organisation’s core business; and (v) enhances organisation’s culture and image.

Changes in the ways of working and the needs of employees and, thus, organisations, will affect how facilities are operated, maintained, and what services will be needed. FM service providers need to understand that effective and responsive services can be delivered only if they are flexible and adapt to the changing environment fast. For that, a good understanding of services that support workplace and work processes is needed.

3. Empirical part

3.1 Methodology

This study follows the steps of a qualitative approach in order to build hypotheses from the collected data (Eisenhardt, 1989). According to Yin (2003) a qualitative case study approach is suitable when the phenomenon and conditions are hard to divide and conditions relevant to the phenomenon need to be taken into consideration.

Extensive list of services were analysed with few service examples for an in-depth understanding as they enable creation of more robust theories grounded by diverse evidence (Eisenhard and Graebner, 2007). These services were analysed in multiple levels in order to get a better understanding of cases and the phenomenon related to those (Yin, 2003). The analysis of services was done by using Business Model Canvas tool, developed by A. Osterwalder (2004, 2010). Business model as a concept should be capable of reflecting how that vision can be converted into practice as it is between the strategic and operational layers. The understanding of a workplace covers three environments: physical, virtual, and social and knowledge processes are also divided into three steps: knowledge creation, sharing and usage. So data was analysed by taking into consideration these different aspects. Osterwalder (2004) provided a conceptualized tool to formalize the elements of business, relationships, vocabulary and semantics of a business model. This tool allowed to structure the business offering and logic into several levels with value proposition being the central topic for the approach.

3.2 Analysis of data

During the process, 103 service businesses were analysed in total. Based on the Business Model Canvas tool, six key business dimensions were identified: value proposition, main user segment, revenue streams, resources, cost structure, and service providers for the first round of analysis.

After the initial analysis of services, the second round of analysis was conducted in order to identify the emerging patterns in the data. The revenue streams, resources and cost structure were not classified as these were not the focus of this research, so only main user segments, service providers and value propositions were sorted into categories. The main user segments were divided into three user personas which were constructed by using a story-telling approach and
based on the time and the way the person works: 24/7 mover; 5-9 executor and 5/7 socializer. Then, the service providers and their value propositions were clustered into 3 main categories: Online platforms and Technology developers who provide technology (software, hardware, etc. e.g. Microsoft, Samsung), Spaces and Landlords – who provide physical infrastructure (e.g. letting spaces), and Places and Community operators – who operate and facilitate connections of people and organizations in either physical or virtual space (e.g. Facebook) and thus supporting knowledge sharing. After the initial clustering of services based on their value proposition, they were combined into four categories:

- Space: businesses and value propositions are mainly driven by real estate. It usually includes renting of premises for a fixed long period of time and is a square-meter based business for single organization or individual. For example, a BC (business centre) Papula can be put to this category;

- Community: businesses and value propositions are mainly driven by a community - likeminded people who have a common goal or want to share their thoughts in a certain theme. This category would include various events, conferences such as Nordic Business Forum, Slush, and others;

- Technology: businesses and value propositions are mainly driven by technology business like the development of a sophisticated software or hardware. Oculus, Built Environment Sensoring or other similar businesses can be put into this category;

- Transportation: businesses and value propositions are mainly driven by logistical needs to transfer tangible things or people from one place to another. This category includes businesses such as DHL, VR, various taxi companies and others.

4. Results

After the second round of analysis and clustering of services based on their value propositions, the analysis on ways these services and businesses can support actual knowledge processes in the workplace was done. Results implied that the original four paths do not provide the needed answer, and new categories were emerging, mainly because of the technological development and the need to connect different resources from previous categories. Thus, the emerging new service groups were created based on the resources they are connecting and steps of knowledge processes they support or promote (Figure 2):

- Collaboration – services that support collaboration and businesses are driven by connecting physical space and community. Usually they include flexible contracts and shared spaces, co-working spaces such as Hub13, Kontoret and similar.

For example, mobile applications that allow users to know where people are, what they are doing, and who they are near, this way allowing serendipitous encounters.

- Sharing – services that enable knowledge sharing and businesses are driven by connecting community with technology. Community members participate in creating the content. E.g. LinkedIn, Airbnb, Lyft, Hoffice.
Organizations can create networks through different platforms such as LinkedIn or Facebook that allows organizations to understand how the inside community inside works. Such examples could be tags that are worn by employees to track their social behaviours online and within the organization, create possibilities to collect data and monitor team interactions and styles of communication.

Figure 2: Services supporting work environments and knowledge processes

- Access – services that provide access to knowledge. Service providers create businesses by connecting physical spaces with technology or virtual platforms. E.g. Venuu, LiquidSpace, Foodora, MaaS.

Technologies that also connect people to the Internet of Things (IoT), facilitating marketplaces based on the intelligence of physical proximity.

5. Discussion

Identified service paths demonstrate an emerging trend of connecting multiple resources to provide value to the customer by supporting workplace, its user and knowledge creation processes. The value of new services is perceived through co-creation, in other words, by connecting different service providers and users in service design and value proposition.

The concept of value co-creation was first introduced in theory of service – dominant (S-D) logic, presented by Vargo and Lusch (2004). Value co-creation has been adopted as a core concept for the development of service system science and relates to innovations and collaborative consumption. New emerging services, which were analysed in this research, employ value co-creation and, thus, reflect innovations. Furthermore, changing workplaces indicate collaborative consumption approach. Previous case studies suggest that the future of the workplace will change not only in terms of how and where work is accomplished but also in terms of how the workplace is consumed by its users. For example, a growing relevance of collaborative consumption provides possibilities for users to choose from a wider pool of options and gain greater control of their work environments by using workplaces on as-needed basis in desired location or
environment. A good example of these types of collaborations could be WeWork spaces and their Shared resources in USA. The network of small businesses benefits from shared resources such as healthcare plans, car rental memberships, offices amenities, and others.

As stated earlier in the paper, the workplace consists of 3 components: physical space, virtual space and social space. The workplace enables three processes related to knowledge: the creation of knowledge, knowledge sharing and the use of knowledge (Choo & de Alvarenga Neto, 2010). Therefore, FM services for supporting workspace need to take into consideration all three components and three processes - services for informal interactions, formal meetings, and also services that support virtual work. However, analysed services and businesses are mainly connecting two out of the three workplace components and one or two knowledge processes: either supporting knowledge creation, knowledge sharing, or improving the ways of using of the knowledge.

5.1 Limitations

FM services outside traditional categories are researched scarcely. Previous studies concentrated on services provided for organisations and their none-core activities. In parallel, another approach to services supporting knowledge exchange within and beyond organisation has emerged. Therefore, more studies regarding knowledge processes and workplaces that involve premises other than organisational offices are needed to support tentative findings.

The selection of the analysed services might be questioned as a qualitative approach and, also, the inductive research require careful selection of cases in order to avoid informant bias and present empirical richness. Also, according to Yin (2003), returning to the global issues after the analysis of individual units might be challenging.

The clustering of services can be argued as no users and service providers were interviewed, it was intuitive and based mainly on expertize of multiple researchers that were involved in the data gathering and analysis. The usage of Business Model Canvas tool can also be questioned as it is not widely used in research environment.

6. Conclusions

The results of this analysis indicate that FM practitioners should concentrate on offering work environment that supports various knowledge creation processes. It is not enough to provide technological solutions, space, and services related to social environment separately, but collaboration between service providers is necessary. In practice, it might require much closer collaboration and partnerships within organisation’s departments as well as working together with outsourced services’ providers. For FM service providers outside organisations, this increased collaboration and supporting knowledge processes means that they need to change own business strategies and try to understand processes of end users, in other words, employees of organisations, to be able to offer services that meet their needs the best.
Technology is increasing the value of physical places by facilitating both physical and virtual networks together rather than replacing the physical place as it is. So the logic of using technology and combining it with the new ways of working is that new kind of workplaces can be shared, used more intensively, in various ways and on-the-need basis. In order to respond to knowledge workers’ demands and improve communication processes through simultaneous transformation of all workplace environments, FM should provide flexible services, and offer various co-working and workplace on as-needed basis models. Workplaces should provide all needed services and be designed in such an environment what would create possibilities for and facilitate various social, intellectual, commercial and other types interactions within and between organisations.

Further research could include a comprehensive analysis of knowledge creation processes and changing ways of working inside organisations could help in identifying service opportunities for real estate service providers. Also, the services under identified categories could be explored in more detail in order to understand how real estate service providers’ business strategies should change.

References


Duffy, F. (2008) “Work and the City (Edge Futures, Book 3)”, Published by Black Dog Architecture


Role of Water Cooperatives in Water Service Production - Lessons from Finland and Denmark

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Abstract

This paper examines water cooperatives in Finland and Denmark, and in particular it delves into the future of water cooperatives. During recent years, the trend has been that big is beautiful -- larger organisations can achieve economies of scale. Is there still a role for water cooperatives in the future? Both in Finland and Denmark cooperatives have played, in particular in rural areas, an important role in the development of economic activities and improvement of living conditions. Water cooperatives are still very common. More than 40% of the Danish population is supplied water by a total of 2,500 water cooperatives; Finland has roughly the same number of water cooperatives. In both countries municipalities are, in principle, responsible for the provision of water services for the inhabitants. In Denmark cooperatives have a strong status in legislation as water service providers outside large population centres. Finland is a sparsely populated country with large rural areas between built-up areas. Municipal water utilities cannot afford to extent their networks in rural areas. Development of improved water services has been left to the residents and cooperatives have proved to be a workable solution.

Keywords: water, cooperatives, Finland, Denmark

1. Introduction

Finland has a long tradition of water cooperatives, which presently number over 1,500, and supply water to 13% of the population, mainly in rural areas (Luukkonen 2013). Larger towns and cities are typically supplied by public water utilities. Water cooperatives in Finland are quite different from each other even though their basic task – to produce water and often also wastewater services – is similar. The Finnish water sector has a lot in common with that of our neighbour Sweden, except for water cooperatives. Sweden has hardly any water cooperatives, and the same applies to Norway, too.

On the other hand, in another Nordic country, Denmark, water cooperatives play an even bigger role than in Finland. More than 40% of the Danish population is supplied water by a total of 2,500 water cooperatives. Contrary to Finland, cooperatives in Denmark have no
role in wastewater management which is by legislation the responsibility of the municipalities. At the beginning of the 20th century, virtually all the needs of rural communities were met by cooperatives (Birchall 2004). In farm product processing and distribution cooperatives still play a major role. Dairy cooperatives, for example, hold a market share of 97% (DGRV 2015). A newer development has been windmill cooperatives, which were established in particular during the 1980s and the 1990s so that at the turn of the century 80% of the windmills were owned by cooperatives. This trend has changed in more recent years as more utility-size wind projects have come online. (Cook & Lin 2015)

Elsewhere in Europe water cooperatives exist e.g. in Austria, Germany and Italy. In Austria, cooperatives cover 12% of water services being important for sparsely populated areas (Bauby 2012). Cooperatives have operated as regional energy utilities in many parts of Germany for well over 100 years. Over the last three decades more than 800 new cooperatives have been founded in the field of renewable energies in Germany (DGRV 2015). In the USA, cooperatives are the most common organizational form of water provision in suburban and rural communities and totally there are about 3,300 water cooperatives (ILO 2015).

Water cooperatives are private utilities. They are established, owned and managed by the people who are also the beneficiaries of their services. One basic principle of cooperatives is that members have equal voting rights, which means that an outsider cannot become an owner and thereby a decision-maker in the cooperative.

Cooperatives resemble private companies in that they need to cover their costs with the income they generate. But, according to cooperative principles, there is no need to generate profit to be distributed to the owners. Any profit is used to improve the system and the quality of services. Cooperatives operate on the 'full cost coverage' principle. Thus their tariffs reflect the real cost of the service provided. In many countries the activities of municipal water utilities, on the other hand, are subsidised by the state or local authorities.

This paper examines water cooperatives in Finland and Denmark, and in particular, the future of water cooperatives. In recent years, the trend has been “big is beautiful” – larger organisations can achieve economies of scale. Is there still a role for water cooperatives in the future?

2. Water cooperatives in Finland

Water cooperatives in Finland differ dramatically according to their physical environment, settlement pattern, acute needs of the population, and the legislation in force at the time of establishment. They can be classified into the following five groups (Takala et al. 2011, Pietilä 2015):

1) Water cooperatives established prior to 1950 in rural areas
2) Water cooperatives established in rural areas in the 1950s through the 1970s
3) Water cooperatives established in rural areas during the 1980s and 1990s
4) Water and wastewater cooperatives established since the 2000s.
5) Water cooperatives for rural townships established mainly in the 1950s
Only a few cooperatives of the first group provided sewerage services since wastewater was at the time discharged mainly into the septic tanks of individual properties. These cooperatives were established and operated solely by their members, as municipalities or the state did not have any support mechanisms in place (Juhola 1990). Wooden pipes were widely used and pipe laying and related work were mostly carried out by the members themselves. The initiators of the cooperatives were those whose demand for water was most urgent, such as dairy farmers. Since the 1950s the structure of the Finnish farming sector has changed dramatically: the number of dairy farms is now a fraction of what it used to be, but water cooperatives still exist.

The second group of water cooperatives was established when Finland was slowly recovering from World War II – since 1951 it was possible to apply for a subsidy or loan from the state to construct water or sewerage systems in rural areas. During the early years these subsidies were marginal and had hardly any impact on the economy of the cooperatives. As state authorities supervised all projects funded by state subsidies or loans, the resulting improved workmanship had a much bigger impact. Municipalities were not entitled to these support measures, only rural systems.

The third group of water cooperatives was established as some municipalities decided to extend their water supply and wastewater systems to rural areas in order to provide safe and reliable services to a larger share of their population. Several municipalities supported cooperatives by giving technical assistance in planning and construction, by subsidies, or by guaranteeing cooperatives’ bank loans. For instance, the municipality of Pudasjärvi has 40 cooperatives, most established in the 1980s (Pietilä 2015). After Finland joined the EU in 1995, it has also been possible to get subsidies for cooperatives via some EU funding mechanisms.

The fourth group came into being after 2000 to supply water and increasingly also wastewater services in rural areas. People have become more aware and require higher quality drinking water. The water of their own private wells does not necessarily meet their requirements. On the other hand, people have also moved to rural areas thereby increasing population density there, which makes centralised water supply and sewerage a more viable solution. People moving from towns and cities are used to centralised services and ere are not interested in having and operating their own individual water supply or sewerage systems.

In 2004, legislation concerning wastewater disposal requirements for properties not connected to centralised sewerage (with their own disposal system) was tightened radically. As a consequence, most of the water cooperatives established since then also provide sewerage services. In addition, many previously water-only cooperatives have also built sewer systems. It is typical of cooperatives established in the 2000s not to have their own water intake or wastewater treatment facility. They buy water from a larger entity, typically a municipal water utility, and discharge wastewater to a municipality’s sewer network. Only a few cooperatives have built their own water intake or wastewater treatment plant in the 2000s. The shift from owning a water intake to buying water from another utility started earlier as can be seen from Table 1.

Table 1. Water sources of private water utilities(1) in South-West Finland (Rynänen 2003)
The fifth group of cooperatives was established at a time when few rural towns had a centralised water and sewer system – residents relied on their own wells and septic tanks. Over the years, these cooperatives have expanded and presently cover not only the township but also the surrounding rural areas so that coverage can be up to 99% of the population of the entire municipality. Many of these cooperatives have from the beginning also provided sewerage and wastewater treatment, while some originally established for water supply only have later expanded their activities to cover wastewater services as well. (Vihanta 2013)

3. Water cooperatives in Denmark

In Denmark water cooperatives have had, and will have also in the future, an important role in the provision of water services to the citizens. Typically in cities and larger towns water is supplied by municipal water utilities, but in smaller towns and in rural areas water is supplied by private water undertakings, which are mainly cooperatives. As municipal water utilities are typically large, their number is only somewhat over 100 while there are about 2,500 water cooperatives. The size of these cooperatives varies from 10 to 20,000 households, while on average one cooperative serves 400-600 households. The number of cooperatives has during the recent decades gradually decreased via mergers, as in 1990 there were still more than 3,000 of them. Water supply is very decentralised in Denmark. In addition to cooperatives, there are some 50,000 households not connected to centralised supply that use their own private well. (GEUS 2015, Sørensen 2010)

In Denmark, the source of water is almost entirely groundwater and normally the quality of the water is good enough for drinking water requirements. In fact it is not allowed to treat drinking water using chemicals. Water is chlorinated only in exceptional circumstances. By area, Denmark is a rather small country (42,900 km²), with a relatively big population density of 130 inhabitants/km², compared with only 16 inhabitants/km² in Finland. Extensive farming in Denmark in the vicinity of wells and boreholes has resulted in groundwater contamination in particular in the form of excessive concentrations of nitrogen and pesticides. As a result, annually tens of water supplies have been closed during the last decades. This problem has been tackled in recent years by tighter regulation on the use of fertilizers and pesticides. (GEUS 2015)

Danish water cooperatives have established a joint organisation, Danske Vandværker
(Association of Waterworks in Denmark), to assist and support its members. This association has a staff of about 15 experts who can help the cooperatives in various technical, financial, legal etc. questions. The organisation has also produced tailor-made guides and manuals, and it has arranged education and training events. Danske Vandværker has also negotiated an attractive insurance policy for its member cooperatives. (Danske Vandværker 2016)

4. Strengths and weaknesses of water cooperatives

Cooperatives fit very well into the EU’s subsidiarity principle – decision-making at the lowest appropriate level. In Finland, at least in political discussion and decision making, the trend in the recent years has been the opposite – big is beautiful and more economical. That may be true in other sectors, but not necessarily in water services, which are by nature local activities. Merging of large networks in rural areas does not automatically provide the economic benefits of larger units. The relative effectiveness of large water utilities in cities derives more from high population density than the utilities’ high productivity. Also in Denmark the trend has been towards larger units. A thorough municipal administration reform was carried out in 2000, when the number of municipalities was reduced from 271 to 98. Consolidation of water sector has also been discussed (Sørensen 2010).

Operation of small cooperatives is typically voluntary work. People are often willing to do voluntary work in their own neighbourhood or at the village level, but if a cooperative covers several villages, people no longer consider it their own and are less motivated to work without compensation. In Denmark the strengths brought up in connection with cooperatives include: a) dialogue and political contacts with many stakeholders through a widespread network, b) large public support, and c) direct contact to local authorities. Possible weakness may be a financially weak starting point but this can be overcome by cooperation with municipalities, utilities and investors. (Danmarks vindmølleforening 2009). In Finland, municipalities have often co-financed the investment costs of water cooperatives with up to 25% and also guaranteed cooperatives’ bank loans (Pietilä 2015).

It is true that many water cooperatives are small, and they often lack sector technical or economic skills and knowledge. But, on the other hand, their systems are also often very simple thus requiring much less expertise compared to the utilities of towns and cities. In Finland, the majority of small water cooperatives do not have their own water intake but buy water from a municipal water utility. Similarly, only a few cooperatives run their own wastewater treatment plant but discharge wastewaters into a municipal utility’s network. Thus they only have to take care of their own wastewater networks. In Denmark, water supply is almost entirely based on the use of groundwater and water cooperatives draw water from their own wells or boreholes.
At least in Finland, members of water cooperatives are often quite passive as long as everything goes well, and do not attend official meetings. But the meetings can be crowded and very intense, for example, if there is a need to increase tariffs substantially, or if someone tries to take over the water cooperative against the will of the people.

Many water cooperatives, in particular smaller ones, are facing difficulties. The active members are getting old, and it has proven difficult to get the younger generations involved in voluntary work. All those involved need to increase their knowledge and improve their skills. Undocumented tacit knowledge can also be a problem. Only the older employees of the cooperative who constructed the pipe network know its exact location. When these people retire, locating the networks will require much effort. Cooperatives could buy and utilise certain expert services, but as the members are used to cheap tariffs, higher charges are resisted. On the other hand, as there has not been much demand for expert services suitable for water cooperatives, only a few service providers exist at least in Finland. The situation is gradually improving as cooperatives are slowly becoming more trusting of external expert services, or they just have to use them when none of the members of the cooperative is willing to be in charge of the activities.

Closer cooperation between water cooperatives may ease some of the problems small cooperatives are facing. In Denmark the cooperatives are well organised as they have established their own support organisation, Danske Vandværker. In Finland a similar
organisation called SVOSK (Association of Finnish Water Cooperatives) was established in 2009, but so far the resources and activities of SVOSK have been rather modest in comparison with its Danish counterpart. SVOSK has organised annual national water cooperative workshops and training events with various partners. In the Kouvola Region, in South-East Finland, some 30 local water cooperatives established a joint association to support their activities. Similar regional associations are also planned elsewhere. (Pietilä 2015)

In Finland larger water cooperatives (the fifth group) are in a much better situation. They are large enough to employ enough staff to run their operations. In comparison to municipal utilities of the same size, these cooperatives have a clear operating principle – to produce good quality services to members with funds collected through charges. Municipal utilities are subject to political control which often makes long-term planning difficult. The goal of politicians is too often success in the upcoming elections, not necessarily the long-term good of the community.

The benefits and problems of water cooperatives are summarised in the SWOT-analysis below (Vihanta 2013, Pietilä 2015).

Table 2. SVOT analysis of water cooperatives

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Possibilities</th>
</tr>
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<tbody>
<tr>
<td>flexible decision-making</td>
<td>official status in municipality’s water service structure</td>
</tr>
<tr>
<td>decisions normally made without voting</td>
<td>residents no longer need to take care of their individual systems</td>
</tr>
<tr>
<td>no political motives in decision-making</td>
<td>cooperation and quality of joint activities can be improved and less need for voluntary work</td>
</tr>
<tr>
<td>creates solidarity</td>
<td></td>
</tr>
<tr>
<td>clear operating principle: expenses are covered by charges</td>
<td></td>
</tr>
<tr>
<td>municipal boundary does not restrict activities</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weaknesses</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>reliance on one person</td>
<td>members get tired of voluntary work</td>
</tr>
<tr>
<td>lack of skills</td>
<td>not enough voluntary activists</td>
</tr>
<tr>
<td>members get passive after system is operational</td>
<td>in a small unit personal relations may get strained</td>
</tr>
<tr>
<td>one or a few active persons may direct activities in an unwanted direction</td>
<td>authorities’ requirements become unnecessarily strict</td>
</tr>
</tbody>
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5. Role of water cooperatives in the future

Water cooperatives will remain important water and wastewater service producers in rural areas in Finland. Municipal water utilities will not be able to cover the rural areas to the extent that cooperatives have been able to. In Denmark cooperatives have a much stronger status as they are defined in the legislation as preferred water supply organisations in rural areas. The number of water cooperatives in both countries is expected to decrease as small cooperatives merge with each other or into a municipal utility.

The majority of water cooperatives are small and largely managed on a voluntary basis. It is
useful to have support systems for these small cooperatives so that their operation and management practices reach a more permanent and professional level. In Denmark, this is already quite well organised via Danske Vandværker, but in Finland only the first steps have been made. Cooperation between cooperatives should also be encouraged.

There are a number of larger water cooperatives which operate as professionally as municipal utilities of the same size. Such cooperatives can be expected to remain independent water and wastewater service producers. In a number of municipalities in Finland a cooperative takes care only of water supply and distribution while the municipality is responsible for wastewater services. Some municipalities would like to transfer the responsibility for wastewater treatment to the local water cooperative.

In principle, Finnish water services are not affected by the financial situation of the municipalities since, according to the law, all costs related to water and wastewater service production should be covered by water charges. The charges should be sufficient to also cover maintenance and investment costs in the long term. In the case of municipal water utilities this principle does not always apply. In many municipalities the profit earned by the water utility is used to support other municipal sectors. That is not bad in itself – the money benefits the municipality’s residents. Nevertheless, if the water utility is left with too little to spend on renovation and rehabilitation, the future of water services is threatened. With water cooperatives the equation is simple, as all costs are covered by charges, and any profits are used to improve the service.

6. Conclusions

According to the Finnish legislation, municipalities are responsible for water and wastewater services within their areas. Yet, a number of municipalities have no water or wastewater utility but a cooperative provides these services for their residents. In some such municipalities water distribution coverage is up to 99%, which is well over the national average of just over 90%. Several municipalities are currently discussing their sewerage management with the local water cooperative. They would like to transfer the responsibility for the sewerage system to the cooperative.

In Denmark cooperatives have a well-established role in water supply outside large population centres. Wastewater management is by legislation the responsibility of the municipalities. This is different from Finland, where cooperatives often take care of wastewater as well.

The ultimate goal of water and wastewater cooperatives is straightforward: to produce good quality service to their members and cover related costs by the income they generate. As cooperatives are not under municipal administration, they are not subject to political decision-making. On the other hand, as they do not have to earn a profit for their shareholders, no external price regulation is necessary. Cooperatives are well in line with the commonly agreed principle of subsidiarity which suggests that decisions should be made as close to the affected people as possible.
Ageing infrastructure is a common problem in European countries. The renewal rate of the water and wastewater infrastructure of many Finnish utilities is unacceptably low. At the current rate of renewal, the pipelines would have to serve for 200 years, which is simply impossible. In Denmark, too, pipeline renewal rate of municipal water utilities is not sufficient. On the other hand, many water cooperatives have been able to maintain their networks and renew ageing pipelines in due course. Yet, the water tariffs of these water cooperatives can be lower than those of municipal utilities of the same size. Our findings suggest that the cooperative is a more efficient management organisation than a municipal utility, but further research is needed to confirm that.

The public sector in many European countries will face serious financial challenges in the future. People will live longer than before, which is going to increase pension, health care and other social security expenses. At the same time, the share of the working age population will decrease. Consequently, at least in Finland and Denmark, the current welfare state can no longer be sustained on public funding alone. New ways of providing public services must be found. Cooperatives are a successful example in the water sector.

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**References**


A Decision Support System (DSS) in the Cloud for Collecting, Measuring, Reporting and Forecasting Productivity in Construction

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Abstract

Measuring productivity for accurate forecasting in construction scheduling is one of the most important problems that managers face nowadays. The traditional measurement methodologies are obsolete and offer deficits in (measurements of) standardization, which causes inaccurate assumptions during the planning phase of a project, affecting the predictability during its execution. With the aim to contribute to the solution of this issue, a new methodology for information acquisition under cloud computing and storage was developed to provide the necessary tools for collecting, measuring, and reporting the production work in order to compare the results between different projects and subcontractors. The objective of this paper is to introduce how the tool was obtained, the process of its creation and the benefits obtained from its implementation. This approach enables the manager to notice the progress of each of the projects, compare them with each other, and make decisions to improve processes; thus, increasing productivity and reducing variability. In addition, this tool provides a starting point to apply advanced forecasting techniques for more accurate predictions in real, and complex environments under volatile conditions. This paper fits into the category of "Advancing Products and Services" because it describes a program that innovates the production control work.

Keywords: Construction industry, productivity, technology in construction, forecasting in construction.
1. Introduction

Average annual growth of Colombian construction over the last five years is 16.8%, compared to the rest of Latin America and the Caribbean, with an average annual growth of 10.2%. This makes the Colombian construction industry the third largest in the region (data from the Ministry of Commerce, Industry and Tourism, 2013). Despite the elevated operative costs and low productivity yielded by traditional construction methods, project revenue has been considerably high in the past. Nevertheless, competition in the industry has greatly increased over the last few years, which has pushed constructors to restructure construction methods in order to improve productivity to be more competitive in the market.

Measuring production rates in construction plays a crucial role when it comes to improve on-site productivity as these rates are indispensable for the controlling and planning of civil projects. According to a study on productivity rates by the International Labour Office (ILO):

*The critical figure is the productivity norm. (...) If the task is underestimated by 30 per cent, (...) the direct cost of the project will increase by 30 per cent. Conversely, if the tasks are overestimated, then much of the workforce will not be able to meet its targets and there will be considerable disruption and discontent on site. Estimating the correct productivity is probably the most important decision for the engineer (ILO, Stield, Brudefords & Shone, 2003).*

Thus, the importance of developing an efficient method allowing for data collection and analysis of construction productivity is highlighted, with the aim of facilitating the accurate decision making, in order to help improve construction productivity.

Current production rates measurement in Colombia is not standardized or effective. This gives way to sizable issues in planning activities and decision making. In most cases, measurement formats are confusing and inefficient, which fosters the input of incorrect information. Not being comfortable with the structure of the format, the operators in charge fail to put enough effort in filling it out correctly. Moreover, performance measurement is not among the functions of any operative position. Therefore, this task is sometimes accomplished by the Lean engineer, sometimes by the administrative engineer, the foreman or foremen in charge, or is even neglected altogether on occasion. In sum, this absence of staff charged with measuring activity productivity, along with lack of clarity in the formats, makes for low reliability in performance control, thus affecting future construction work and accurate decision making aimed at improving productivity.

Considering the foregoing, a Decision Support System (DDS) was designed, consisting of an application allowing for the measurement of productivity in a friendly, intuitive and efficient fashion. In the same manner, it processes the information and generates reports that can be used to make accurate decisions, thus improving the efficiency of the processes and of the on-site activities.

The main objective of this work was to create a largely useful product for any construction company. For this reason, the development process for the model was based upon the methodologies found in the book *The Lean Startup* by Eric Ries (2011). The book touches upon the importance of carrying out an iterative process involving the final user, in order to develop a high quality product while investing the least amount of resources possible.

2. State of the art

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Measuring productivity in the construction industry has acquired meaningful importance over the last few decades (Rivas et al. 2011). Nevertheless, Colombia has seen little advance in this topic due to the large revenues left by the industry in past years. Nowadays, measurement of productivity does not happen for most projects, as it is a dispensious activity. In general, the 5 Minute Test (Koskela, 1992) lean tool is applied instead of measuring the daily progress of a given activity. This Test includes measuring staff performance in a given activity for five minutes, which allows reducing time wastage by optimizing space and processes. However, this is not a tool that allows checking an activity’s daily progress. Numerous studies have been conducted on the topic of productivity since the 1960s to this day, largely owing to growing market competition and the need of companies to increase their revenue. Chart 1 shows the percentage of articles published on academic journals since the 1980s. The chart shows that interest for improving productivity is still quite relevant in the construction industry.

In 1965, the United Nations conducted a study on factors affecting on-site productivity, focusing on repetitive processes in construction operations (Enshassi et al. 2014). In 1974, NECA conducted a study on the influence of different climatic factors on workforce productivity (Rivas et al. 2011). Some authors have looked at the topic from other perspectives. For instance, in 1986 Borcherding, Palmeter and Jansma studied unproductive times affecting the efficiency of construction work. Other authors examined the topic in 1997 and 2005, using advanced statistical models and software programmers to determine the variables affecting productivity, as they considered such variables to be too complex for the human brain to process (Dolage & Chan, 2013).

Despite great efforts to improve productivity, Colombia continues to have problems measuring it properly. Construction companies lack standardized methods to collect and process the information, let alone consider determining the factors affecting productivity.

### 2.1. Methodology

The project was developed in three stages, namely: initial analysis of the current situation, proposal of the DDS, and development of the application. These stages shall be described from here on.
2.2. Initial Analysis

The first step in determining the problems to measure production rates was visiting construction sites to observe how the data was collected. The main issues observed in the processing and analysis of production data are as follows:

a. Problems with the construction companies in taking, processing and interpreting the site productivity data. This issue is evidenced in the following aspects:
   1. Lack of item standardization, along with duplicate activities.
   2. Excessive or lacking specificity. Usually, activities are not sufficiently differentiated according to the characteristics directly affecting its productivity (e.g. vertical or horizontal veneers). There are also instances of excessive specificity, differentiating activities by completely irrelevant characteristics (e.g. distinguishing between a 30x30 red horizontal veneer and a 30x30 white horizontal veneer).
   3. Difficulty of standardization activity measuring units, or lack thereof.
   4. Lack of clarity about who is charged with measuring production (DT – Data Taker). Sometimes, data collection is too dispendious, and is therefore neglected.
   5. Though there are adequate formats for data collection and analysis, the DT does not use them properly. This leads to incorrect or incomplete data input, which clutters the reports and makes proper data analysis impossible.

b. Lack of reliability in the results due to the absence of a representative sample. By failing to continuously following up on activity productivity, there is not enough data to have a statistically representative sample, leading to biased reports.

c. Activities are only measured once a day. If only one measurement is available for one given activity, the subsequent reports will reflect that the activity does not vary, that is, that production is constant in time. Construction is a complex system, affected by multiple factors. For this, to state that production is constant and unchanging is unlikely.

d. The reports generated are not easily understood or interpreted.

e. Lack of initiative from the staff involved in proposing measures to improve the internal handling of data collected on-site. Oftentimes, a passable information collection and processing format exists, and no effort is made to improve it.

f. Lack of human and material resource allocation for the development of real follow up and control on project progress.

g. In view of the foregoing problems, the need to devise a system to solve them became evident: the creation of a DDS for the collection, measurement, reporting and forecasting of data productivity rates.

3. Proposal of a DDS for Productivity in Construction

The initial proposal presented to the company contemplated the improvement of the quantification of production units, aimed at bettering estimate reliability. Thus, the purpose was for the amounts to be updated using the amounts obtained in a construction site to design a database with production rates. The objective was to build a relational, parametric database per work unit and project type. To that end, a strategy was defined in order to collect information and feed the database.

At first, the construction company requested the database to be built in Excel. However, doing so in a web server yielded better results, as it allowed for better data processing (greater speed and ease of handling). After submitting these observations, the company agreed. Moreover, the company requested for a strategy sustainable in time to allow anyone to develop this methodology.

Three options for the collection of data were analyzed: the creation of a simple printed format for the use of foremen on-site or, in special cases, of the operator executing the activity to fill out unsupervised;
the creation of an Excel sheet to be accessed from a tablet or smartphone allowing for data input as the site is reviewed; and finally, the design of a web page allowing for data input or, in the event that internet access is not available, for the printing of the format. After studying all three alternatives with the company, the third proposal was selected. Hence, a user-friendly web page was created, that accomplished the efficient collection of production rates on-site, and that also considered the factors affecting the selected type of productivity, in order to conduct a future study about said factors.

To guarantee product quality and user satisfaction, a simple application that ensured easy, quick and human-error-proof collection, was perused. Its main objective is to be a support for on-site decision making. According to these characteristics, the model has the following features:

1. A single data collection format requiring the input of just a few data associated to each productive unit. Also, it differentiates input information according to the periodicity of registration, and sets up daily, weekly or monthly measurement.
2. It allows for the input and storage of productive units, contractors and non-compliance causes in order to standardize data collection, thus avoiding duplication. When the user inputs production data, the activity, the contractor and the non-compliance cause must be selected from a list. If any of these elements does not exist, it must be created.
3. It carries out all the calculations, eliminating the possibility of human error in data processing.
4. It displays the general results (weekly, monthly or general) obtained from the calculations in graphs or dynamic charts to make reading the information, as well as observe trends easy. Moreover, it allows for the download of measured information in Excel format, which can then be used transversally in other applications.
5. It allows for the measurements to be performed on any mobile device with internet access. In the event such a device is not available, data collection formats can be printed out, and the data will have to be entered manually at a later time.
6. It makes the selection of contractors efficient. Based on the compliance percentage found in the database, the process of selecting contractors will be improved considering their previous compliance with their commitments.
7. It uses the results obtained by the page for the planning and programming of current and future projects.
8. It has a wide database, with a considerable amount of man-hours daily production data. With this information, the daily man-hours average will be available, which can be used to forecast the duration of an activity using realistic data based on rigorous observation instead of theoretical data based on experience or the subjective opinion of the planners.
9. It allows for fast data analysis using the general reports it delivers, through comparisons between projects, between activities and in set time periods, with the purpose of finding the problems emerging at the site and plan strategies to help mitigate them to improve on-site production.

4. Development and Implementation of Productivity DDS

Once the web page had been chosen as the means to measure production rates, the exploration of functions that could of interest to the client was perused. To that end, the interface of the web page was the first deliverable to be designed seeking to verify that the client was pleased with the design and considered whether the functions therein selected at the time were relevant. Such functions were:

- The option to create a new project with its corresponding initial characteristics.
- The option to have a database of the production rates per project.
- The option to divide the factors affecting productivity for each project in 4 groups (factors defined at the beginning of the project, factors to be measured monthly, factors to be measured weekly, factors to be measured daily).
The option to have an Excel downloadable report per project with all the production rates data in a user defined date range reporting the following:

- Total daily production.
- Daily production per contractor.
- Number of workers per contractor.
- Non-compliance causes.
- Daily possible production had non-compliance causes been null.

The option to have a tab listing the company’s unified activities, with each activity having its own unit of measurement.

Specifically for factors affecting productivity, the possibility to use a neural network or vector methods to determine the real influence each of these factors could have on the activities measured, was proposed. In spite of the great complexity and the elevated number of field measurements needed to configure the aforementioned networks or methods, the decision was made to do so as it was considered to be a very useful tool for any construction company. The client approved the proposal, and these initial proposals were put on production track for the web page.

In a later meeting, the client was shown the tools approved for implementation. Upon exploring the functionality of the web page, the company expressed some concerns. Hence, the functionality expected by the company was revisited. In the following meeting, a series of general reports on the company production rates was proposed, comprising graphs comparing daily production of an activity across projects. It is of note that at first these reports were built in Excel tables and dynamic graphs in order to test and modify them prior to their inclusion in the application.

The first report executed dealt with average daily production per project. This report shows the real production rate, the maximum production rate and the minimum production rate for a specific activity (see Chart 2).

![Chart 2: Average Daily Production per Project](image)

The second report executed dealt with the production rate for each activity. This report shows the daily average production rate for each activity using a dynamic table (see Chart 3).
The third report executed dealt with the monthly average production rates. This report shows the monthly production rate achieved for each activity or in general (see Chart 4).

![Chart 3: Production Rates for each Activity](image)

The fourth report designed dealt with the month-to-month project production rate. This report shows the monthly average production rate for each project (see Chart 5).

![Chart 4: Monthly Production Rates](image)
The fifth report submitted dealt with wasted hours per project. This report showed total hour wastage per project (see Chart 6).

Once these reports were verified, they were included in the application. This prompted a meeting with the company where several agreements were reached. The company would unify its activities to avoid repetition. Likewise, developers would add the same graphs, but including production per man-hours into the application, in addition to other additional graphs on non-compliance causes per month, and per activity, a graph with the compliance percentage per contractor, and modifications to the format of the graphs. The implementation of these adjustments, including a user manual for the application, satisfied the client’s requirements. The manual is included in Appendix (number).
5. Results Obtained

Owing to the foregoing, the DDS allowing for the measurement of activity performance, was developed. In addition to this, the application makes all the calculations and produces general reports for their analysis and consequent improvement of the future company forecasts. This application does not only use the performance of each activity, but also the non-compliance causes and displays compliance percentage, which allows for deeper, more accurate analysis. In order to view the reports, it is necessary to enter the time lapse desired (the software requires a start and an end date). Each of the reports produced by the application shall now be described. See the user manual in Appendix (number) for details on how to produce each report.

5.1. Production Rates per Project (I1.1)
This report shows production rates for each activity differentiated by the different projects created to date. This report includes two graphs. The first shows the Forecasted Production Rates (FPRs), the Measured Production Rates (MPRs), the Maximum Production Rates (MaxPRs) and Minimum Production Rates (MinPR). The second shows compliance percentages (CP) for the activities in each project.

5.2. Real and Forecasted Production Rates per Man-hours (I1.2)
This report shows the FPRs and the MPRs in report I1.1 per man-hours. This report does not include a graph for compliance percentage, as it is the same shown in I1.1.

5.3. General Production Rates (I2.1)
This report shows a chart including the production rates differentiated by project. If no project is selected, the software displays a chart with all created activities measured in the time lapse defined by the user.

5.4. General Production Rates per Man-hours (I2.2)
This report is similar to I2.1 – General Production Rates, but this one shows production rates per man-hours.

5.5. Weekly or Monthly Activity Production Rates (I4.1)
This report displays daily measured and forecasted average production in months or weeks lapses. It allows selecting a particular project or all projects simultaneously. Additionally, it shows compliance percentages for each month or week.

5.6. Monthly or Weekly Average Real and Forecasted Production Rate per Man-hours (I4.2)
This report is similar to Monthly or Weekly Average Real Production Rate, but this one shows production rates per man-hours. The compliance percentage graph is equal to that in report I4.1.

5.7. Monthly or Weekly Average Real and Forecasted Production Rate (I5.1)
This report shows three graphs. The first graph shows the forecasted production rate. This bar graph shows daily forecasted production for a specified activity in each month or week (depending on the selection). Moreover, daily production per project is differentiated, with each project having an independent bar and color. The second graph shows measured production rate. This graph shows daily average measured production in each project for the specified activity and time lapse. The third graph
shows the compliance percentage for the selected activity, in the specified time lapse, in the selected time unit and per project.

5.8. Monthly and Weekly Real and Forecasted Production Rate per Man-hours (I5.2)
This report allows the study of the real and the forecasted average performance of an activity in a specified time lapse. This report is ideal to estimate learning curves and evaluate the impact of measurements taken aimed at increasing productivity.

5.9. Non-compliance Causes per Project (I6.1)
This report shows non-compliance causes per activity in each project. In the event that no activity is selected, the total of non-compliance causes for all activities is displayed. It also allows for the simultaneous selection of several projects for their comparison.

5.10. Non-compliance Causes per Month (I6.2)
This report shows non-compliance causes emerged monthly or weekly. Moreover, the information can be filtered by activity or by project.

5.11. Non-compliance Causes per Activity (I6.3)
This report shows non-compliance causes per activity and the amount of man-hours that production was stopped. This allows to study hour wastage per project and activity, in order to make decisions and see their impact in time.

5.12. Compliance Percentage per Contractor (I10)
This report shows the historic compliance percentage each contractor has displayed in the specified time lapse.

6. Conclusions
This study evidences some of the problem faced by civilian construction work stemming from the lack of an adequate method to collect, process and analyze production data. This makes the use of real data difficult in decision making and future planning processes.

One of the tasks of the Production Data Taker is to check up on the effective advance of the work using the compliance percentage. Comparing the real production rate with the forecasted production rate, the activity’s real advance percentage is revealed. This grants better foresight in making decisions affecting the execution of that activity, as well as its predecessors and successors, while preventing errors in intermediate and short-term planning. This allows for reality-adjusted planning to reduce uncertainty regarding a master plan activity, avoiding delays and other problems already identified through the non-compliance causes.

Since the program was designed with the objective of avoiding data collecting mistakes, activity duplication and typing errors were also averted. The software makes all the calculations automatically, which eliminates human error.

In order to make contracting easy, the program allows for the comparing of compliance percentages for each contractor. This lets companies evaluate each contractor and work with those that have greatest compliance with the company. Likewise, the Production Data Taker shall assess whether the actions taken on-site aimed at improving productivity were effective. This will only be achieved if the company
devotes the required time to on-site data collection and input, as these are indispensable for the reports to show changes in productivity.

7. Recommendations

• The construction company shall define the degree of specificity for their applications. The same criteria must be applied to all their projects in order to unify the measurements.
• Read the user manual to use the software correctly.
• Inputting information collected prior to the implementation of the program is discouraged, as it can be incomplete or contain unnecessary details for the software.
• The software designed in this study is a pilot software, subject to future improvement. Companies are requested to submit suggestions as they implement the tool.
• A later study on the factors affecting productivity shall be conducted. This study shall define whether the use or a neural network, a vector or another method is convenient. The result of that study is expected to provide arguments for each factor, that is, to experimentally define the factors affecting productivity in the Colombian construction industry.
  o Once the factors affecting productivity are identified, data collection regarding the same is expected, as well as the creation of a database with information relevant to them.
  o The development of a vector method or a neural network is expected in the future, with the aim of mathematically verify the degree at which these factors affect on-site productivity. These methods are expected to provide arguments for each factor, thus aiding in determining which factors are relevant and which are not. In the case of relevant factors, the duration of affected activities can then be adjusted, thus increasing project duration predictability.
  o This information could be used in a later article about the chosen factors affecting productivity, and how to neutralize their negative effects, seeing as some factors cannot be eliminated.
• To learn more about the usage of this tool, click below to download the userguide:

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