Enabling factors of social virtual reality diffusion in organizations

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Research paper

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Abstract

Social virtual reality (SVR), or multi-user virtual reality, is an emerging technology that enables new ways of collaboration in industrial use. However, relatively little is known about the factors leading to the diffusion of SVR in organizations. This paper examines the diffusion of SVR in the context of architecture, engineering, and construction (AEC). Specifically, this paper identifies enabling factors that moderate the effects that the technological attributes of SVR have on its diffusion. Qualitative empirical data were collected in 12 semi-structured interviews and 14 focus groups with AEC organizations. The data were initially categorized in relation to Rogers' diffusion of innovations (DOI) theory's three most predictive technological antecedent factors of diffusion (relative advantage, compatibility, and complexity) and then iteratively refined based on a qualitative analysis. This study contributes to information systems literature in two ways. First, it identifies eight critical enabling factors that moderate the diffusion effects of the DOI antecedent factors of SVR. Second, propositions are derived concerning the specific effects these moderators have on the relationship between the DOI antecedents and SVR diffusion. As a practical contribution, organizations can better support SVR adoption efforts by evaluating the importance of these identified moderators in their organizational contexts.

Keywords: Virtual Reality, Social Virtual Reality, Adoption, Diffusion.

1 Introduction

Organizational use of virtual reality (VR) began in the 1990s when the first viable VR devices were introduced (Walsh and Pawlowski, 2002; Berg and Vance, 2017). However, the diffusion of VR—that is, the *collection of adoptions by individual users* (Straub, 2009)—was limited due to the low technological maturity and high costs of VR hardware and software (Hilfert and König, 2016; Mütterlein and Hess, 2017). After these initial attempts, VR was largely forgotten by industry for over a decade (Mütterlein and Hess, 2017). However, VR has recently experienced rapid development as prominent companies (e.g., Facebook and HTC) have started investing heavily in VR hardware and platforms (Kugler, 2017). These developments have now laid the groundwork for cross-sectional and extensive VR diffusion. Currently, the VR market is expected to grow significantly. For example, Digi-Capital (2019) predicts that the VR market will grow from approximately $3 billion in 2018 to $10–15 billion by 2023. VR is used in multiple industries, such as architecture, engineering, and construction (AEC; Whyte, 2003; Wang et al., 2018) and product design and manufacturing (Berg and Vance, 2017). These advancements warrant a fresh look into VR diffusion, since many organizations are now seriously considering adopting VR to support their work processes (Berg and Vance, 2017).

In VR, the user is effectively immersed in a completely synthetic and responsive virtual environment (Brooks, 1999; Bastug et al., 2017). In the past, VR use has mainly been considered to be an isolating experience, as most solutions were designed for single users (Kim et al., 2013). However, new multi-user VR solutions, which are referred to here as *Social Virtual Reality* (SVR), have now begun to emerge (Perry, 2015; Marr, 2019). In SVR, multiple users can interact with each other simultaneously in the same virtual space via avatars (Perry, 2015). Enhancement of professional collaboration has been identified as one of the more promising applications of SVR (Mütterlein and Hess, 2017). In the AEC industry, for example, SVR can enable more efficient collaboration between end-users and designers through better shared spatial understanding of proposed building design plans (Portman et al., 2015; Paes et al., 2017). Overall, practitioners and researchers have identified numerous value-adding use cases for SVR as richer collaboration is becoming increasingly possible within the virtual environment (Perry, 2015). Thus, SVR has the potential to increase organizational performance by improving collaboration between different stakeholders in industry value chains and by enabling efficient collaboration in situations in which physical meetings are not possible. However, wide diffusion of SVR is necessary if it is to create value for organizations, as business processes cannot be extensively adapted to utilize SVR with a limited number of users.

Much of the earlier VR research has focused on the technological development of VR systems and on single-user rather than multi-user VR systems (Walsh and Pawlowski, 2002; Kim et al., 2013). Although some research on VR adoption in industry has been carried out (e.g., Fernandes et al., 2006; Berg and Vance, 2017), there is still relatively scant research on the factors affecting the diffusion of SVR in organizations. In single-user VR, the user typically enters the virtual space alone to engage in specific work tasks (e.g., reviewing building designs). However, the focal technology of SVR is different, as SVR essentially involves multiple users collaborating in a shared virtual space wherein they share knowledge and create shared understandings with each other along the key business processes of an organization. This means not only that organizations have transferred and adapted business processes to SVR but also that multiple users can handle their collaborative efforts in that same space. Due to this technology use environment, SVR diffusion is likely influenced by factors other than those that influence single-user VR environments. Therefore, prior findings relating to VR adoption (e.g., Fernandes et al., 2006; Berg and Vance, 2017) are only partially applicable to SVR. Accordingly, identifying specific enabling factors that help SVR to reach a critical mass of users is imperative for effective SVR adoption in organizations. The present study focuses on this research gap by addressing the following research question: *Which factors enable effective diffusion of SVR in organizations?*

The present study draws on Rogers' (2003) diffusion of innovations (DOI) theory and focuses on its three most critical technological antecedent factors affecting diffusion: relative advantage, compatibility, and complexity (Tornatzky and Klein, 1982; Vagnani and Volpe, 2017). Although the DOI theory and the aforementioned antecedents have been found to be helpful in explaining the diffusion of various technologies (e.g., e-business) in organizations (Vagnani and Volpe, 2017), the applicability of DOI has also been criticized in the literature in the context of complex technologies that connect multiple users and information systems within organizational business processes due to its lack of suitable factors for addressing collective adoptions (Lyytinen and Damsgaard, 2001). Given that organizational SVR adoption fits this characterization, we aim to address the aforementioned criticism by enriching DOI with specific enabling factors that make SVR diffusion more effective in organizations.

The enabling factors of SVR diffusion were identified in a qualitative multiple-case study (Yin, 2009). Empirical data were collected through 12 semi-structured interviews and 14 focus groups in the AEC industry context. The data were then analyzed qualitatively in an iterative manner (Walsham, 1995). We propose the identified enabling factors as moderators for the relationships between the DOI antecedent factors and SVR diffusion in organizations, and we derive propositions on the effects of these moderators. We chose the AEC industry as the context of the study for three key reasons. First, the AEC industry has shown an increasing interest in SVR (Du et al., 2018). Second, a variety of multi-user SVR solutions (e.g., IrisVR and InsiteVR) are available for AEC, demonstrating the applicability of SVR within this industry context. Third and foremost, SVR is perceived to have great potential to solve communication difficulties between the highly fragmented AEC stakeholder groups by enabling efficient collaboration around 3D content in a 3D environment (Dubois and Gadde, 2002; Goulding et al., 2014; Du et al., 2018). Our study contributes to information systems (IS) literature by enriching the DOI theory in the AEC context with eight critical moderators for the relationships between the DOI technological antecedent factors and SVR diffusion. We further contribute to IS literature by deriving propositions on the effects of these moderators. As a practical contribution, organizations can use these findings to evaluate their readiness to adopt SVR and support their SVR adoption efforts.

This paper is structured as follows. First, the relevant theoretical background concerning SVR and DOI is presented in Section 2. Second, the methodology of the study is described in Section 3. Third, the findings of the study are presented in Section 4. Finally, the findings, propositions, contributions, and limitations of the study are discussed in Section 5 along with suggestions for future research.

2 Social Virtual Reality and Diffusion of Innovations

VR can be categorized into immersive VR, which can be experienced with special equipment such as head-mounted displays (HMDs) and cave automatic virtual environments (CAVEs), and non-immersive VR, which is experienced through 2D desktop interfaces (Brooks, 1999; Slater and Sanchez-Vives, 2016; Paes et al., 2017). In the present study, we focus on VR that utilizes HMDs to achieve a truly immersive VR experience, since this type of VR has been the central focus of the most recent VR developments. HMDs can be separated into three categories: mobile VR, stand-alone VR, and tethered VR (Anthes et al., 2016; Elbamby et al., 2018). Mobile VR refers to VR devices in which a smartphone is used as the display by plugging it into a VR HMD (Anthes et al., 2016). However, as some of the most prominent mobile VR devices are being discontinued (Protalinski, 2019), their relevance for organizations is decreasing. Stand-alone VR devices are also wireless, but they come with their own dedicated displays and processing power (Elbamby et al., 2018). Tethered VR devices are connected to and powered by an external laptop or personal computer (PC), enabling high-end VR experiences (Perry, 2015). Tethered VR HMDs are still required for many use cases since current wireless technologies are not sufficient for more demanding VR experiences. However, future 5G networks may partially help to solve this problem (Bastug et al., 2017).

Besides the technical improvements in VR devices (Kugler, 2017), the multi-user (or social) aspects of VR have also advanced significantly (Perry, 2015). SVR allows users in different locations to communicate in a virtual space via customizable virtual avatars as if they were face-to-face and manipulate virtual objects together (Bailenson et al., 2006; Perry, 2015; Bastug et al., 2017). SVR can help geographically distributed teams to work more efficiently and reduce unnecessary travel (Walsh and Pawlowski, 2002; Perry, 2015). The immersive nature of SVR can also increase organizational efficiency by helping stakeholders achieve mutual understanding in collaborative situations (Du et al., 2018).

Organizational use of SVR has great potential (Perry, 2015), but extant research on VR adoption is limited (e.g., Fernandes et al., 2006; Berg and Vance, 2017). Initial findings have stressed the importance of demonstrating the business value of VR to end-users (Berg and Vance, 2017). The importance of a champion for VR adoption has also been found to be crucial (Berg and Vance, 2017). Fernandes et al. (2006) emphasized the importance of securing top management support and clearly defining the objectives of VR adoption. Lack of vision and lack of clear measurable benefits of VR adoption have also been identified as obstacles for adoption (Suneson, 2014). Further, the lack of a dominant design for VR devices can slow down VR adoption (Whyte, 2003). This problem still exists, as can be seen with regard to the heterogeneous VR HMDs that are currently available. Motion sickness is still also an issue with VR HMDs, and women have been found to be more susceptible to it than men (Sharples et al., 2008; Munafo et al., 2017). The level of social interactions in SVR has been found to promote user enjoyment and positively influence users' intention to use SVR (Lee et al., 2019). However, relatively little is known about factors affecting SVR diffusion in organizations.

Diffusion is defined as a "process by which an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 2003, p. 35). Rogers' DOI theory can be used to study diffusion by examining the attributes of the technology itself, the communication channels by which the technology is spread among individuals, time (the rate of adoption), and the social system in which the technology is adopted (Rogers, 2003). Utilizing DOI to study how the technological attributes of SVR affect its diffusion has also been suggested in the literature (Fernandes et al., 2006). Since the utility of SVR depends on the number of users interacting with each other in the virtual space, it is important to reach a critical mass of users as quickly as possible in order to increase the value of SVR (Rogers, 2003). Although certain solutions (e.g., tethered HMDs) might provide more value for individual SVR users, the likelihood of their extensive diffusion in organizational settings over a long period is low, as they require a high level of technical competence. Thus, with regard to SVR use, organizations need to compromise between high task-specific performance, fit for individual users, and overall ease of use for end-users. Moreover, even if the decision to adopt SVR is ultimately made by management, the need to identify the needs of the collective in the organization is crucial because authority-based decisions do not guarantee successful adoption (Rogers, 2003).

According to the DOI theory, a technology's perceived attributes—relative advantage, compatibility, trialability, and observability—positively affect its diffusion, whereas the complexity of a technology is negatively associated with its diffusion (Rogers, 2003). Meta-analyses by Tornatzky and Klein (1982) and Vagnani and Volpe (2017) showed that relative advantage, compatibility, and complexity are the most critical antecedent factors in predicting a technology's diffusion in organizations. Although prior research has not specifically focused on the technological antecedents of diffusion of SVR, it is possible to identify the three key antecedents from existing literature. Relative advantage refers to the degree to which an innovation is perceived as better than earlier innovations (Rogers, 2003). The relative advantage of SVR can be seen in its more efficient means of knowledge transfer in comparison to existing solutions (e.g., video conferencing; Du et al., 2018). Compatibility relates to the degree to which an innovation is consistent with the values, experiences, and needs of its adopters (Rogers, 2003). Difficulties in transferring different design software file formats into SVR have posed integration issues with business processes in the AEC industry (Du et al., 2018). However, the increasingly prevalent use of building information modeling (BIM) has alleviated this problem (Miettinen and Paavola, 2014). Complexity refers to the perceived difficulty of understanding and using an innovation (Rogers, 2003). SVR can have high initial complexity due to its high immersion potential and novel interaction methods in comparison to traditional information technology (IT) devices (Mütterlein and Hess, 2017). Although particular antecedent factors of SVR diffusion can be identified in the literature, the specific factors that enable the effective diffusion of SVR remain missing. Our study aims to identify such factors in relation to the aforementioned DOI antecedents and thus address the limitations of DOI in explaining the diffusion of complex technologies such as SVR in organizations (Lyytinen and Damsgaard, 2001).

3 Methodology

This study was conducted as a qualitative multiple-case study (Yin, 2009). Case studies provide rich descriptions of phenomena in the specific context of inquiry and are therefore suitable for the exploration of new research areas of which little is known (Benbasat et al., 1987; Eisenhardt and Graebner, 2007). In addition, with multiple cases, it is possible to compare different findings and determine whether an emergent theme applies to a single case or to many cases (Eisenhardt and Graebner, 2007). Qualitative empirical data were collected from 20 case organizations in Finland (11 small and medium-sized organizations with under 250 employees and 9 large organizations with over 250 employees) by five researchers through 12 semi-structured interviews and 14 focus groups in three publicly and privately funded national VR research projects between 2017 and 2019. Purposeful sampling was used to gather rich data with relevance to our research (Patton, 2002). Interview participants were chosen from organizations that were already using SVR to some degree (9 organizations) or were in the process of exploring and adopting SVR to support their work processes (11 organizations). Gathering insights from organizations that had experience with SVR allowed us to obtain a thorough, accurate overview of issues related to SVR diffusion in the AEC industry.

The interviews and focus groups explored the perceptions and experiences of the interviewees in relation to SVR diffusion. The interviewees represented both public and private organizations and consisted of executive and management-level personnel, experts (e.g., construction engineers), and other employees (e.g., operative personnel) engaged in work in which SVR played an important part. The interviewees had varying levels of experience with SVR. In the semi-structured interviews, 42% of the interviewees were in senior management positions, 42% were in middle management, and 16% were experts. The focus groups included 49 participants in total, of which 33% were in senior management, 22% were in middle management, 30% were experts, and 15% were other employees. The focus groups also included pilot tests of both custom-developed and commercial multi-user VR products (e.g., InsiteVR) with different VR devices (e.g., Oculus Go). Observation notes on user behavior were taken in these test situations. Data were collected until we believed a point of saturation was reached.

The interviews and focus groups were conducted in Finnish, lasted from 30 to 90 minutes, and were audio-recorded with the consent of the interviewees. The relevant parts of the audio-recorded interviews and focus groups were transcribed for analysis. Although the data were primarily analyzed by one researcher, we also utilized investigator triangulation by exchanging detailed notes concerning the findings and interpretations for comparison between researchers (Patton, 2002). We drew on the DOI theory and categorized the data in relation to its three most critical technological antecedent factors. Once the data were grouped in relation to these initial categories, smaller pieces of data were given labels, which were then compared for overlap and redundancy and finally combined under higher-level labels (Creswell, 2015). Observation notes were used for confirming and disconfirming evidence from the interview data (e.g., interviewees' statements regarding their experience with VR were contrasted with their behavior in the VR testing situations). This process was iterated as new data was collected (Walsham, 1995). Specific moderators that strengthened or mitigated the effects of the DOI antecedent factors emerged as the final labels. Propositions about SVR diffusion were then derived from these moderators. Interview data from multiple case studies is considered to be suitable for generating theoretical propositions since the data is grounded in varied empirical evidence (Eisenhardt and Graebner, 2007). Altogether, eight moderators and propositions were derived from the data.

4 Findings: Eight critical moderators affecting SVR diffusion

In this section, we introduce the specific enabling factors that align with the three antecedent factors of SVR diffusion. These enabling factors are presented as moderators that affect the relationship between the DOI antecedents (relative advantage, compatibility, and complexity) and SVR diffusion. We base the DOI antecedents on the prior literature as follows: SVR's key relative advantage is *efficient knowledge transfer*, SVR's compatibility is *ease of business process integration,* and SVR's complexity is *perceived technology utilization difficulty*.

4.1 Collaboration intensity variables moderating relative advantage

Collaboration intensity refers to variables that depict the types of collaborative work activities in which the potential for multifold, active application of the opportunities provided by SVR are higher, thus strengthening the effect of SVR's key relative advantage (i.e., efficient knowledge transfer) on SVR diffusion. We identified two specific collaboration intensity moderators, namely collaboration around complex visual information and geographically distributed teamwork.

Collaboration around complex visual information. Most interviewees estimated the main relative advantage of SVR to come from the users' ability to comprehend the dimensions of 3D content and objects better than with 2D desktops, which can lead to more breakthrough moments. Consequently, SVR was seen to enable more effective reviewing of proposed building designs. This was considered to be especially relevant for non-professionals, who have difficulties comprehending 2D plans, but collaboration between different professionals could also be improved by SVR because many stakeholder groups (e.g., public officials) also need to give their input on design plans. Comparing different design options was also thought to be quicker and more effective with SVR than with physical models. Communicating design plans to stakeholders with SVR was thought to facilitate a better understanding of what was being delivered. Involving users in the early phases of the design process was seen as one of the most interesting areas for SVR use since this would enable different end-user needs to be taken into account more accurately. In one hospital case, for example, the architects were able to reduce the size of the rooms after the nurses had seen the design model in SVR and told the designers that the room dimensions were too large for their intended use.

"…when we send the floor plan as a PDF, relatively few truly comprehend how the space works even if they are experts in their own profession, when instead we could tell them to put on these glasses and tell them to wander around [the model] and think about how their process would work in the space… It's easier to think about how I would act and what I would need [in the space] in VR." [Architect]

Many interviewees considered the user experience to be much more intense in SVR than with 2D desktops, and some said that the designers often do not even have to ask questions from the users as they usually start giving feedback on their own initiative. Some interviewees thought that SVR would also make it easier to make observations about the needs of users, especially ones who are unable to explain their design improvements in an abstract form, since in SVR the designer can go through the review asynchronously from the user's point of view. However, SVR was not regarded as a panacea, as exemplified by one interviewee noting that *"Co-design is tricky, whether it's virtual or not"* [Architect/BIM Consultant]. Still, most interviewees thought that the more the organization's work tasks include collaboration around visual information, the more SVR could be utilized in the organization.

Geographically distributed teamwork. Many interviewees said that SVR enables a more natural way of communicating that is superior to other technologies, such as videoconferencing, giving it a relative advantage when compared to many existing solutions. The feeling of presence provided by SVR was seen by many as an advantage when compared to other existing solutions, as it is not as easy to get distracted with other work in SVR. Accordingly, the more remote teamwork is being performed in an organization, the more SVR could be utilized to enhance collaboration. Many interviewees considered SVR to be highly interesting for internal design coordination because designers and engineers currently spend a lot of time traveling. With SVR, it would be possible to hold regular and ad-hoc meetings more often because it usually takes a whole workday to attend a meeting at a separate physical location. This would increase the iterations that can be carried out in the design process. As building designs are becoming more complicated, bringing different design experts from different locations into SVR was seen as a way to increase quality, and save time and money.

"This makes it possible that when someone gets an eureka moment, he can then call a couple of designers and tell them to put the glasses on to check out the idea. This can be done live anytime problems or solutions arise, and the issues can be processed instantly." [Architect]

For social interaction, some interviewees thought that utilizing even basic VR HMDs, where the user's head and hands are tracked, could create sufficient social cues for interaction, although they believed that bringing facial expressions into SVR would further improve collaboration because it would allow users to gauge the interest of the different participants more efficiently. Some interviewees also noted that participating more anonymously in SVR with avatars could also make it easier to generate ideas when compared to videoconferencing or CAVEs, where the interaction is more formal.

4.2 SVR-technical infrastructure fit variables moderating compatibility

SVR-technical infrastructure fit refers to variables that depict the extent to which the current technical infrastructure can be integrated with SVR, thus strengthening the effect of SVR's compatibility (i.e., ease of business process integration) on SVR diffusion. We identified two specific SVR-technical infrastructure fit moderators, namely intra- and interorganizational IS integration and multi-device participation in SVR space.

Intra- and interorganizational IS integration. Some interviewees considered it to be difficult for small organizations to utilize SVR on their own, and many considered finding partner organizations with the readiness and willingness to use SVR to be a challenge. Different file formats and constantly changing industry partners were seen to pose compatibility issues in integrating SVR into work processes. Many interviewees thought that the possibilities for using SVR would increase tremendously if data were made to flow more efficiently in the AEC industry value chain. The interoperability of information systems was identified as a critical challenge. Many also stressed that the process of generating the VR model from design software would need to be as streamlined as possible. Currently, the visual models and the information that is attached to them do not transfer between programs easily in most organizations. Furthermore, organizations often use mutually incompatible design software, which forces them to create the models again at different building lifecycle phases.

> "*In order to create VR, you have to have some data points that will be part of VR, and those data points are quite often lost, or there is no data. We can start taking this [SVR] further with new buildings, but it's difficult to get to many of the data layers, especially in our industry.*" [CDO]

While many interviewees saw the need for BIM as self-evident at this point, they acknowledged that the knowledge management issues associated with BIM were a significant challenge. Many organizations currently employ BIM coordinators, who have to actively police users in order to keep relevant information up to date. Integration of native information models and the related design tools is also a problem, and many interviewees wondered whether it is possible to add their own design tools to the virtual space. Moreover, many software vendors have only recently started offering their design tools for SVR. This was seen to be critical if real interactive professional work is to be done in SVR. Recent developments were also seen to increase the level of interaction in SVR between users and the digital content. Currently, feedback is often collected by sending stakeholders PDFs and asking them to comment on them by email. Collecting user feedback directly to the virtual model rather than with traditional methods (e.g., post-it notes and email) was seen as an interesting possibility to collect more specific user feedback. This was also seen as a way to eliminate unnecessary documentation work.

Multi-device participation in SVR space. Many interviewees said it was not feasible to get every user to utilize a VR HMD to access the SVR space due to their limited availability and because of user reluctance. Appreciating the IT preferences of the users was seen as a key success factor for SVR diffusion and having the possibility to participate in SVR collaboration with multiple different devices was seen to moderate its compatibility with users. Many interviewees mentioned that motion sickness was still a significant barrier and holding meetings only with VR HMDs was not considered to be possible if some of the users start to feel unwell. Thus, many interviewees stressed that there must be multiple ways for users to participate in viewing the digital content in SVR.

> "*Is VR compatible with everyone? Not necessarily, that's the thing. You have to be able to join [the SVR space] with many different devices.*" [BIM/VDC Manager]

The interviewees also indicated that the current lack of a dominant design for VR HMDs highlights the importance of multi-device participation in SVR. Many interviewees stressed that organizations should be able to upgrade their VR HMDs without significant compatibility issues with SVR solutions as many organizations were currently evaluating which of the currently available VR HMDs were the best fit for their organizations. In this regard, the newer stand-alone VR HMDs were seen to bring new possibilities because they are already adequate for many tasks, such as for demonstrations for end-users and for basic design work. More advanced tethered VR HMDs were seen to be suitable for intense visualizations and for presenting designs for executive-level personnel.

4.3 Mitigating action variables moderating complexity

Mitigating actions refer to variables that depict measures that organizations can take to dampen the negative effect of SVR's complexity (i.e., perceived technology utilization difficulty) and thus increase SVR diffusion. We identified four specific mitigating action moderators, namely utilizing younger and more innovative users as lead users, testing SVR simultaneously with multiple users, aligning stand-alone VR HMDs for suitable work tasks, and increasing organizational competence with 3D models.

Utilizing younger and more innovative users as lead users. Most interviewees described the AEC industry as conservative and not very innovative. This was seen as an important factor that could slow down the diffusion of SVR. Many interviewees explained that only the most innovative users usually participate in SVR design sessions, and most design meetings are still held in a physical office. However, some interviewees predicted that the coming generational change in the industry would bring more openness to new solutions. One interviewee explained that younger managers and clients have shown increasing interest in new innovations, whereas the older cohorts are very conservative.

"Why we are interested in this is because of the coming generational change, younger folks are starting to take the reins and are more open towards these things." [CEO]

In many AEC organizations, the age demographics are quite old, and it often takes a while for many of the users to learn the basics of VR hardware and software. One interviewee highlighted the fact that only a few of the employees and clients have used a VR HMD for more than 15 minutes. Organizations also have limited opportunities to test VR hardware. However, in the test situations, most users found VR to be quite easy to learn and to use, and one architect even started explaining in detail about the coming installation work in the explored SVR space. Still, it was evident that only a few of the testers used VR daily, and none of them were immediately comfortable and efficient with VR use, indicating that they have also had little chance to use VR devices in non-professional contexts.

Testing SVR simultaneously with multiple users. In situations in which SVR could be tested, many of the participants expressed considerable hesitation about trying it out due to the perceived initial complexity of SVR. Furthermore, a problem that was identified in the test situations was that the other participants in the room could not see and hear what was going on in SVR, and hence the test user was isolated from others and could not be efficiently instructed in SVR use. Due to SVR use being highly observable in the physical setting, potential user embarrassment was also seen to be a barrier for adoption, especially if there is only one VR HMD for the group to test. Thus, when testing and learning how to use SVR, multiple users need to do it simultaneously to not put undue focus and pressure on a single tester. This also enables the users to assist each other in the use of SVR.

"…the social aspect has been a bottleneck earlier when I have been demoing the [VR] glasses. I can almost say that they have actually made communication worse because the social aspect has not been implemented in them. So, when someone puts on the glasses, I ask them what they see. Well, they say they got lost, they are in some kind of space. Then, I ask them what kind of space, and finally I just take the glasses from them and take them to the right place." [BIM/VDC Manager]

Some interviewees explained that they had experienced extremely positive or negative reactions to SVR in their work, which had affected other users' inclination to try it out. However, when SVR was actually tried in a test situation, every tester thought it was very simple to use. Many interviewees believed that users might be more eager to test SVR if others were doing it with them simultaneously.

Aligning stand-alone VR HMDs for suitable work tasks. Most interviewees stressed that the chosen VR HMDs need to work smoothly so that the user's attention can be focused on the actual content and on collaboration. They believed that this would reduce the negative effect that the complexity of SVR has on its diffusion in organizations. Stand-alone VR HMDs were considered to be easier to use than tethered devices since the updates are handled in a centralized manner by the VR HMD provider. In contrast, there are still very few complete end-to-end solutions available for tethered VR HMDs, which necessitates a certain level of technical expertise in handling VR hardware and SVR software. In one company, VR had been tried previously, but the tethered VR HMDs had been sitting on a storage shelf for the last two years due to multiple problems with the graphic cards and constant software updates, which made it difficult to use them daily with different stakeholder groups in a quick and efficient manner. Many interviewees saw the performance level of stand-alone VR HMDs as a critical issue because it limits what kind of digital content can be examined in SVR, and that tethered VR devices were still required for many of the more advanced SVR use cases.

"…those [tethered VR HMD] are more suitable for demonstration use, whereas these [stand-alone VR HMD] are starting to be sufficient for design work, architects and structural designers for example can fill in the blanks with their imagination…" [Architect]

However, since SVR is still new to most people, using SVR requires considerable facilitation. Many interviewees thought it required too much work and know-how to maintain tethered VR HMDs, whereas stand-alone VR HMDs could be adopted with relatively little effort since they do not have any external cables and beacons. Furthermore, the lack of available training in SVR use made stand-alone VR HMDs a more attractive choice for many interviewees.

Increasing organizational competence with 3D models. Large-scale adoption of BIM was considered to be a necessity for SVR adoption in the AEC industry. If model-based work becomes the standard, many interviewees thought that SVR use would follow quite naturally since this would reduce the complexity that users face in preparing the digital content for SVR. Many interviewees reported that relatively few organizations have adequate competence to set up and use SVR and its related technologies completely independently, and thus must use consultants to create and set up the 3D models. However, some of the organizations were already quite sophisticated with 3D models and SVR.

"Because all of our work is model-based, we can now make VR models from the design models very quickly. It [SVR] can easily be adopted as part of the design process because there is no one-week intermediate phase where the VR model is prepared, it can now be made in an hour and it's ready for viewing [in SVR]." [BIM/VDC Manager]

In some of the interviewed organizations, there were only a few PCs capable of smooth BIM and SVR use. The used 3D models in the AEC industry are often quite complicated, and therefore a powerful PC and a tethered VR HMD are often required to view them without performance issues. However, some interviewees noted that automatic model optimization was now helping to mitigate this issue. Currently, much of the content is also modeled on a case-by-case basis, which is expensive, and model reuse was still not as common as many thought it should be. In order to increase the utilization of 3D models, many interviewees also considered their gamification and interactivity to be crucial.

5 Discussion

In order to answer our research question, "*Which factors enable effective diffusion of SVR in organizations?*" we carried out a qualitative multiple-case study and identified eight critical factors that moderate the diffusion effects of SVR's relative advantage, compatibility, and complexity. These moderators and their effects are presented in Figure 1. Although these moderators may have multiple effects, we only included the main, or most effective, influences of the moderators in our model. The identified moderators for relative advantage and compatibility promote their positive effects on diffusion, whereas the identified moderators for complexity mitigate its negative effect on diffusion.

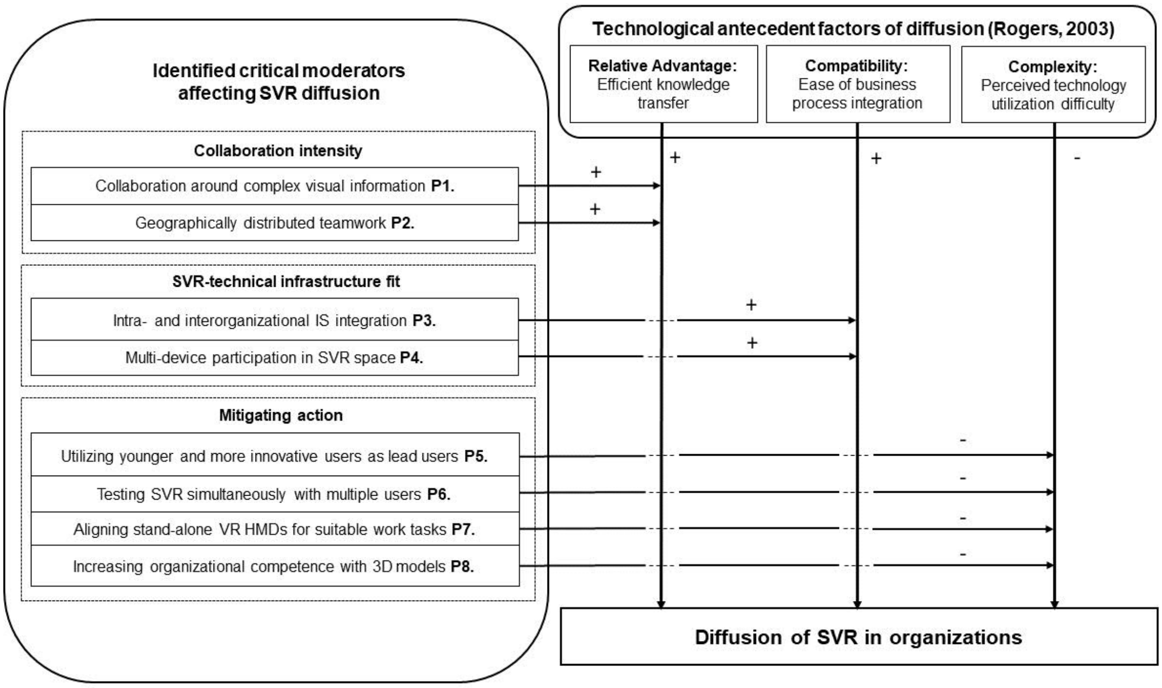

Figure 1. Eight critical moderators affecting the diffusion effects of SVR's relative advantage, compatibility, and complexity (Rogers, 2003).

Next, we examine the influences of the moderators on the relationships between the DOI antecedent factors and SVR diffusion. Based on this, eight propositions are derived and discussed.

5.1 Propositions on the effects of the moderators on SVR diffusion

The relative advantage of a technology is a positive factor in its diffusion (Tornatzky and Klein, 1982). We focus on the relative advantage of SVR in relation to its efficient knowledge transfer (Du et al., 2018). In the context of SVR diffusion, we identified two collaboration intensity variables that moderate the positive effect of this relative advantage: collaboration around complex visual information and geographically distributed teamwork. Since SVR is a highly visual technology, SVR diffusion in organizations will increase as more of its beneficial attributes, such as better spatial understanding of 3D models (Paes et al., 2017), are used in work tasks. We thus derive the following proposition.

Proposition 1: *Collaboration around complex visual information moderates the relationship between efficient knowledge transfer and SVR diffusion such that, as the level of collaboration around complex visual information increases, the positive effect of efficient knowledge transfer on SVR diffusion in the organization becomes stronger.*

In highly geographically distributed industries, such as AEC, SVR was seen to make it possible to hold meetings more often and perform more iterations on designs, thus creating value and time savings (Slater and Sanchez-Vives, 2016). The social interaction in SVR was also thought to be more natural than with video conferencing, making collaboration more efficient (Kugler, 2017). The findings indicated that many organizations aimed to reduce the number of physical meetings to create efficiencies and that SVR was seen as a potential solution in this regard. Thus, we offer the following proposition.

Proposition 2: G*eographically distributed teamwork moderates the relationship between efficient knowledge transfer and SVR diffusion such that, as the level of geographically distributed teamwork in the organization increases, the positive effect of efficient knowledge transfer on SVR diffusion in the organization becomes stronger.*

The compatibility of a technology has a positive effect on its diffusion (Tornatzky and Klein, 1982). We focus on the compatibility of SVR in relation to the ease of business process integration (Du et al., 2018). We identified two SVR-technical infrastructure fit variables that moderate compatibility's positive effect on SVR diffusion. First, compatibility was found to be moderated by the easy availability of digital content since handling and collaborating around visual content is crucial in enabling the use of SVR (Whyte, 2003). Furthermore, augmenting visual content with additional information sources would support decision-making and make collaboration more efficient in SVR. However, in the AEC industry, interorganizational IS integration between companies is at an even lower level than intraorganizational IS integration due to the fragmented nature of the industry (Gann and Salter, 2000; Dubois and Gadde, 2002). Organizations can therefore initially adopt SVR internally in a more limited fashion to improve internal processes and collaboration. However, interorganizational SVR collaboration was seen to emerge more slowly since different IS's would first need to be highly integrated to provide easy access to digital content. The following proposition is drawn from these findings.

Proposition 3: *Intra- and interorganizational IS integration moderates the relationship between ease of business process integration and SVR diffusion such that, as integration of different IS's both within the organization and between its partners increases, the positive effect of ease of business process integration on SVR diffusion in the organization becomes stronger.*

Second, making it possible to participate in collaboration in SVR with devices other than VR HMDs (e.g., laptops) was found to promote the positive effect of compatibility on SVR diffusion. The present findings indicated that users have different preferences regarding the use of VR devices, and many users still reported experiencing motion sickness with VR. The prevalence of these symptoms varies significantly between individuals (Sharples et al., 2008), and recent estimates have suggested that 25–40% of users experience some degree of motion sickness when using VR (Samit, 2017). This has significant implications for collaboration, as it can completely deter any collaborative SVR use with relevant stakeholders if some of them cannot use SVR because of these symptoms. Thus, SVR diffusion in an organization should increase as it becomes easier for users to participate in SVR collaboration with devices of their choice. Consequently, we derive the following proposition.

Proposition 4: *Multi-device participation in SVR space moderates the relationship between ease of business process integration and SVR diffusion such that, as the possibility for users to participate in SVR space with devices of their choice increases, the positive effect of ease of business process integration on SVR diffusion in the organization becomes stronger.*

The complexity of a technology is negatively associated with its diffusion (Vagnani and Volpe, 2017). We focus on the complexity of SVR in relation to its perceived technology utilization difficulty (Mütterlein and Hess, 2017). We identified four mitigating action variables that moderate the relationship between complexity and SVR diffusion. First, the present findings indicate that the coming generational change in the AEC industry should accelerate the diffusion of SVR since younger users were found to be more open to adopting SVR. The younger generation's experiences with video games and hedonic SVR use might also increase their capabilities in technical and creative SVR use (Portman et al., 2015). Furthermore, the current lack of available training for SVR exacerbates these factors since users have to engage in considerable self-learning to utilize SVR. However, gaining these skills also enables these users to act as champions of SVR in their organizations (Fernandes et al., 2006) and to provide effective peer support in the actual job context (Sykes, 2015). Since younger and more innovative users were not found to perceive the complexity of SVR to be as high as it was perceived by many other stakeholders, the negative effect of complexity could be diminished by utilizing these stakeholders as lead users in SVR adoption. Consequently, our fifth proposition is as follows.

Proposition 5: *Utilizing younger and more innovative users as lead users moderates the relationship between perceived technology utilization difficulty and SVR diffusion such that, as the utilization of these stakeholders as lead users increases, the negative effect of perceived technology utilization difficulty on SVR diffusion in the organization becomes weaker.*

Second, the perceived initial complexity of SVR was mitigated by simultaneous multi-user testing. The present findings revealed that most users learned how to use SVR very quickly despite their initial reservations, which helped them overcome their initial reluctance to use SVR. This is crucial to overcoming this initial barrier since the importance of trialability vanishes after an innovation is already in use (Karahanna et al., 1999). Multiple VR HMDs should thus be made available in the initial testing of SVR so as not to isolate a single user from other users. This would also allow users to more effectively perceive the multi-user nature of SVR and observe the benefits of SVR directly. Mütterlein and Hess (2017) also found that having only one VR HMD in a test situation could isolate a user from the group and distract the user from the VR experience. Thus, the sixth proposition is as follows.

Proposition 6: *Testing SVR simultaneously with multiple users moderates the relationship between perceived technology utilization difficulty and SVR diffusion such that, as the level of simultaneous multi-user testing of SVR increases, the negative effect of perceived technology utilization difficulty on SVR diffusion in the organization becomes weaker.*

Third, the present findings indicated that stand-alone VR HMDs possess the greatest potential for large-scale diffusion in organizations due to their better form factor and ease of use in comparison to tethered or mobile VR HMDs. For SVR to diffuse in industry, organizations need to find as many use cases as possible for SVR throughout the industry value chain to motivate users and organizations to overcome its initial complexity. Thus, organizations need to align stand-alone VR HMDs with work tasks in which their performance is sufficient to carry out the work activities. Berg and Vance (2017) also stressed the importance of the portability of VR devices for their large-scale adoption. Furthermore, as the most popular mobile VR devices are being discontinued (Protalinski, 2019), stand-alone and tethered VR HMDs will become the most important options available for organizations. Even though stand-alone VR HMDs will be essential for large-scale diffusion, tethered VR HMDs will still be required for certain demanding high-end tasks. This conclusion leads us to the seventh proposition.

Proposition 7: *Aligning stand-alone VR HMDs for suitable work tasks moderates the relationship between perceived technology utilization difficulty and SVR diffusion such that, as the alignment of* *stand-alone VR HMDs for suitable work tasks increases, the negative effect of perceived technology utilization difficulty on SVR diffusion in the organization becomes weaker.*

Fourth, increasing organizational competence with 3D models was seen to reduce the negative effect of complexity on SVR diffusion by making SVR content preparation easier. BIM and other digital solutions are increasingly being adopted in AEC to support design processes (Bryde et al., 2013). The task of converting design models between different design software and file formats has posed significant problems in the past (Suneson, 2014). However, the findings indicated that considerable progress has occurred in the automation of these steps. Moreover, a variety of SVR software dedicated specifically to the needs of the AEC industry have recently become available, making it easier for organizations to gain sufficient competence in handling 3D models. This has strengthened the foundation on which SVR can begin to diffuse in the AEC industry. Thus, our eighth proposition is as follows.

Proposition 8: *Increasing organizational competence with 3D models moderates the relationship between perceived technology utilization difficulty and SVR diffusion such that, as organizational competence with 3D models increases, the negative effect of perceived technology utilization difficulty on SVR diffusion in the organization becomes weaker.*

5.2 Theoretical and practical contributions

Our study makes two contributions to theory. First, this study contributes to the nascent literature on SVR adoption by enriching DOI with eight critical moderators of SVR diffusion in the AEC context. Drawing from Rogers' (2003) DOI theory and its following meta-analytical examinations (Tornatzky and Klein, 1982; Vagnani and Volpe, 2017), we focused our findings on the three most critical technological antecedent factors of diffusion: relative advantage, compatibility, and complexity, which we conceptualized for SVR with the help of prior literature as efficient knowledge transfer (relative advantage; Du et al., 2018), ease of business process integration (compatibility; Du et al., 2018) and perceived technology utilization difficulty (complexity; Mütterlein and Hess, 2017). Previous research has posited that DOI has limitations in explaining the diffusion of complex technologies (e.g., SVR) in organizations, and researchers have been invited to extend DOI to account for these contexts (Lyytinen and Damsgaard, 2001). Our study answers to this need arising from the literature by addressing the enabling factors of SVR diffusion in a qualitative multiple-case study. Our findings indicate that moderators relating to collaboration intensity, SVR-technical infrastructure fit, and mitigating actions affect the relationship between the DOI antecedents and SVR diffusion. These findings are important because they reveal detailed, multi-faceted ways in which organizations can reach a critical mass of users for SVR, thus enabling them to extensively adapt their business processes to exploit SVR.

Second, our study generated eight propositions that explain the effects of the identified moderators on SVR diffusion. Relative advantage is a critical positive antecedent of diffusion (Tornatzky and Klein, 1982). Our findings highlight that collaboration around visual information and remote teamwork further promote the positive effect of efficient knowledge transfer (relative advantage) because the beneficial attributes of SVR are utilized extensively in these use contexts. Regarding the positive diffusion effect of compatibility (Tornatzky and Klein, 1982), our findings indicate that IS integration and the users' ability to access SVR with multiple devices were found to moderate the effect of ease of business process integration (compatibility) on SVR diffusion because they enable a greater number of stakeholders to participate in the collaboration. Complexity is negatively associated with the diffusion of a technology (Vagnani and Volpe, 2017). Our findings indicate that multi-user testing, younger lead users, applicability of stand-alone VR HMDs, and organizational competence with 3D models mitigate the negative effect that perceived technology utilization difficulty (complexity) has on SVR diffusion. These factors enable more efficient handling of the examined content in SVR as well as an easier user experience due to more effective peer support and more easily operated VR hardware.

As a practical contribution, organizations can utilize the findings of this study to evaluate their readiness to adopt SVR. Effective SVR adoption requires significant resources and commitment from an organization and its stakeholders. The present findings indicate that organizations need to identify the task areas that best match the strengths of SVR in collaboration around visual content and in geographically distributed teamwork. Furthermore, integration of different IS's and competence with 3D models are important in enabling easy access to digital content. Users' initial impressions are also critical in adopting SVR, and SVR adoption should be efficiently facilitated to enable teams to overcome initial reluctance and the perceived complexity of using SVR. Furthermore, stand-alone VR HMDs should be used whenever possible to mitigate the complexity of SVR. Organizations should also identify champions for SVR adoption from among their younger and more innovative users. Overall, organizations can evaluate the relevance of these identified moderators in their organizational contexts and thus identify the relevant issues that they must focus on improving before adopting SVR.

5.3 Limitations and future research

The present study has some limitations. First, the qualitative study is limited to Finnish organizations and, therefore, the findings might not be fully transferable to other countries. The data were also collected from organizations that had shown an interest in SVR by participating in VR research projects. Therefore, organizations that had not yet considered SVR as a technology with the potential to be used in the AEC industry were not represented in this study. However, since the study aimed to understand the enabling factors of SVR diffusion, this sampling strategy was deemed necessary to gain insights into experiences with SVR technology. The AEC study context might also stress different aspects of SVR diffusion than other industry contexts. For example, the importance of SVR's ease of use might be more pronounced in the AEC industry due to its age demographics. There might also be limitations to the interpretive and theoretical validity of the study (Maxwell, 1992), as the iterative qualitative analysis process was carried out primarily by a single researcher. However, the co-authors reviewed the findings of this analysis periodically to mitigate such limitations.

Although this study has identified important moderating variables of SVR diffusion, the effect sizes and interrelationships of these variables were not examined in this study and thus could be examined in future quantitative and experimental research. We encourage researchers to operationalize the propositions generated in this study and evaluate them in future studies in different industry contexts. Future studies could specifically examine successful cases of SVR adoption in order to validate the proposed moderators or examine ways to deal with user resistance to SVR adoption, as proposed by Kim and Kankanhalli (2009). Our findings can act as a starting point for identifying enabling factors of SVR diffusion in other industry contexts and in examining whether similar moderators affect the diffusion of other complex technologies in organizations.

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