Commercialising reclaimed materials in earthworks – guidelines for productization and the process of appending these materials in the Finnish national code of practice

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ABSTRACT
To decrease the use of non-renewable natural resources as well as environmental effects of earthworks, natural aggregate materials can be replaced with recycled materials acquired from surplus soil, industrial by-products and waste, etc. When wishing to increase the usage of these reclaimed materials (="UUMA"- material), the usage must be straightforward for developers, designers and constructors alike. To make this possible, the materials must have design guidelines for their appropriate applications, they must be productized and CE marked or otherwise authorized, and the construction guidelines for the materials must be included in the Finnish general specifications for infrastructural construction works (InfraRYL). As productization is especially important in increasing the usage of UUMA-materials, guidelines for vendors are being drawn that present information on commercializing reclaimed materials to be used in earthworks. The guidelines for productization are being prepared in the Finnish national UUMA2 program (2013-2017, www.uuma2.fi), which was created to promote the use of recycled materials in earthworks.

Keywords: recycled materials, by-products, waste, productization, earthwork, guidelines.

1 INTRODUCTION

Significant amount of aggregates to be used in earthworks can be replaced with recovered materials acquired from surplus soil, industrial by-products and waste, mildly contaminated soil and reclaimed aggregates from existing earth structures. These materials are called UUMA-materials. The materials can be used either

- in earthworks
- in the raw or
- as components to replace or to improve the properties of non-renewable rock material.

The construction sites can be e.g. roads, streets, ports, industrial sites, parks, sport venues, etc.

Construction consumes over 100 million tons of rock materials in Finland annually. The consumption of aggregates totals on average 70–80 million tons annually.

The promotion of the use of recycled materials is a highly efficient way of improving material efficiency and can lead to a significant decrease in the use of non-renewable natural resources and energy consumption required in their transport. (Finnish Transport Agency 2014)

The use of recovered materials to be utilised in earthworks can be significantly increased by the productization and commercialization of materials and developing construction technology, planning and procurement.

2 UUMA2 PROGRAM

2.1 Goal

The goal of the UUMA2 program is to promote the use of recovered materials in earthworks and thus to decrease the use of untouched natural resources and environmental effects of earthworks (Figure 1). To get to the point where UUMA-materials are treated equally to standard construction materials, it is needed not only that material suppliers push their products to the markets, but also that legislation and public authorities support the use of these materials to create a demand. Both supply and demand are needed for the UUMA-materials to be accepted as standard construction materials. (Koivisto et al. 2015)

The UUMA2 program especially focuses on promoting eco-efficient project-specific material solutions and the productization of earthworks with recovered materials. The main focus of the program is in product development, in the development of planning and acquisitions carried out by clients and the related demonstration projects. UUMA2 program aims to:

- introduce more commercialised UUMA-materials to the markets
- support the development of planning and acquisitions carried out by clients
- decrease the use of rock and gravel materials in earthworks
- produce information for the development of the environmental legislation so that legislation supports eco-efficient new earthworks.

2.2 Development areas

Development is the key focus in UUMA2 program. There are five different development areas that will be advanced during the program:

1. Product development process for materials
   - Technical eligibility
   - Environmental suitability
   - Production process: logistics, storage
   - Applications
2. Development of construction technologies
3. Development of planning and design process
4. Development of acquisition methods
5. Development of environmental legislation.

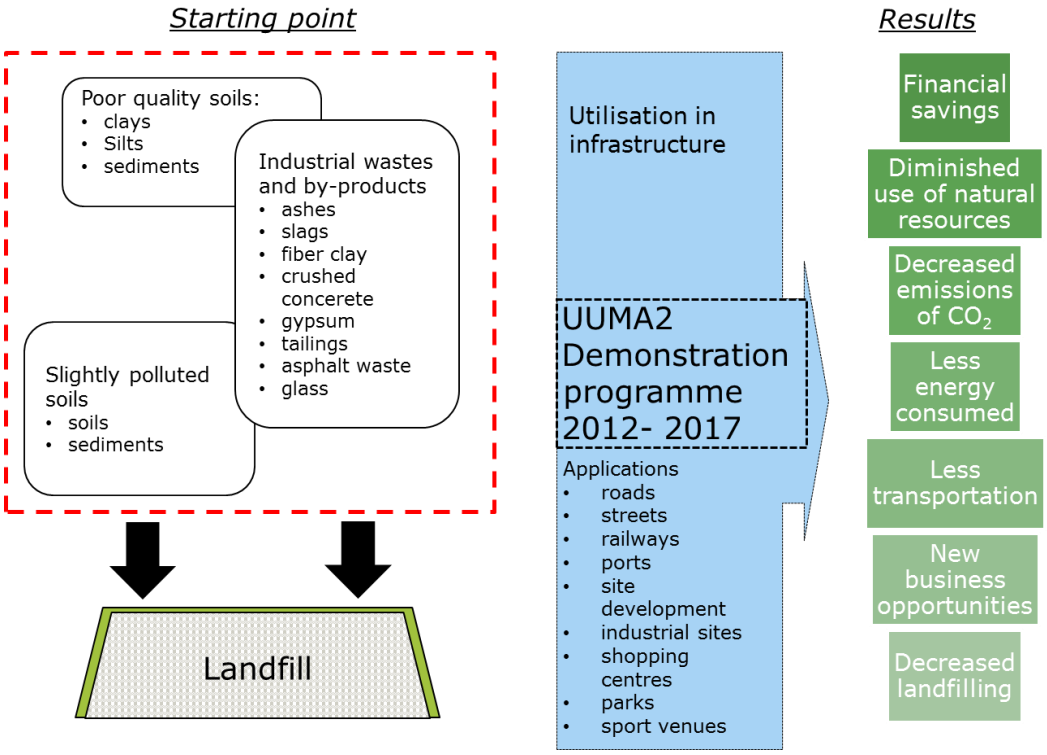

Figure 1. The aim of the UUMA2 program (www.uuma2.fi).

The implementation of the program is divided into different areas: product development, demonstration projects, regional projects, R&D (design processes, acquisition methods, research and development actions stipulated by environmental legislation) and dissemination of information (instructions, web pages, seminars, knowledge transfer to educational institutions).

Demonstration projects are large diverse infrastructure projects that advance the goals of UUMA2 program and serve the productization process of different UUMA-materials. Regional projects aim to increase dialogue and co-operation between different interest groups operating at the same region.

3 PRODUCTIZATION PROCESS FOR UUMA-MATERIALS

To ease the process of introducing new UUMA-materials to the markets, productization guidelines (UUMA2 program 2016a) have been compiled in the UUMA2 program.

The main idea behind productization is to develop a new product and bring them to the market so that the product will be able to compete with traditional materials.

Productization begins when there is a desire to make an actual product of an existing prototype. The basis of the whole process is to create a product that meets the requirements of the client as precisely as possible. Productization process describes the path from innovation of the product to its commercialization.

The first step is to define the requirements and limiting conditions for the product:

- in which structure / structural element does the client use the product
- how does the product fulfil the functional requirements of the structure / structural element
- properties of the product
- quality requirements of the product
- cost of the product
- delivery time and capacity of the product.

To fulfil the defined requirements, the material needs to be tested both in laboratory and in the field. A plan for quality control needs to be prepared to ensure the homogeneity of the material. If not known, the technical properties of the UUMA-material need to be established.

Test structures are used to check how production, delivery and construction can be implemented in practice. After this, pilot and demonstration structures are constructed to present the functionality of the product for developers. Finally, guidelines for design and construction are devised, upon which the production can be launched.

Different phases of productization process have been presented in Figure 2. Each of these phases is broached separately in the following chapters.

As an example of the progression of the productization process, the productization history of crushed concrete in Finland is presented in Figure 3.

4 DEFINING MATERIALS AND REQUIREMENTS FOR APPLICATIONS

4.1 UUMA-materials

The UUMA-materials that are used in Finland have been listed based on the material table presented in appendix A in standard EN 13242 from 2013 (not yet valid). The standard does not include all possible reclaimed materials, so the table has been complemented nationally.

However, the UUMA materials included in the UUMA2 program are defined by the program participants and their interests. At the moment the materials covered in the program are:

- reclaimed asphalt
- crushed concrete
- crushed bricks
- fly ash and bottom ash from municipal solid waste incineration
- fluidized bed combustion bottom ash
- desulphurisation residue from coal power generation industry

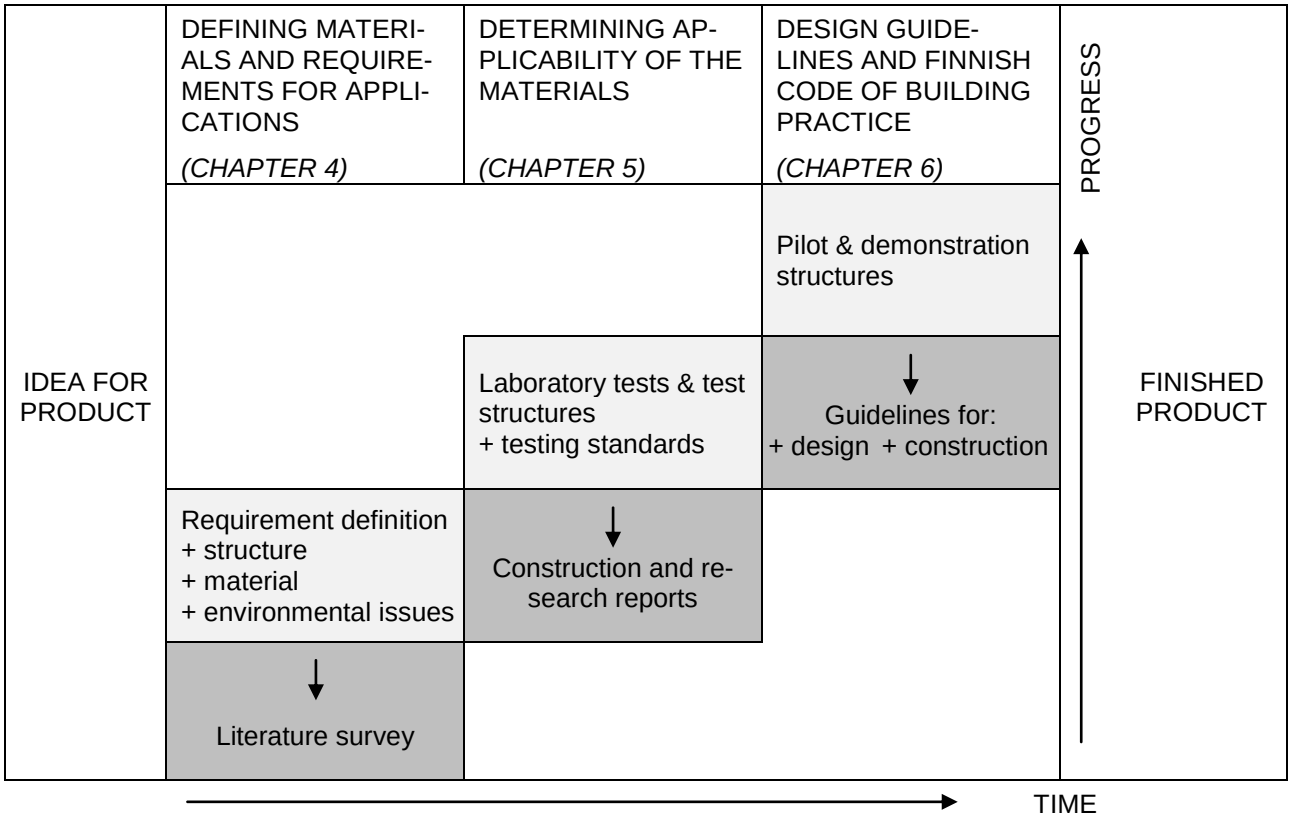

Figure 2 The main phases of the productization of UUMA-materials to earth construction.

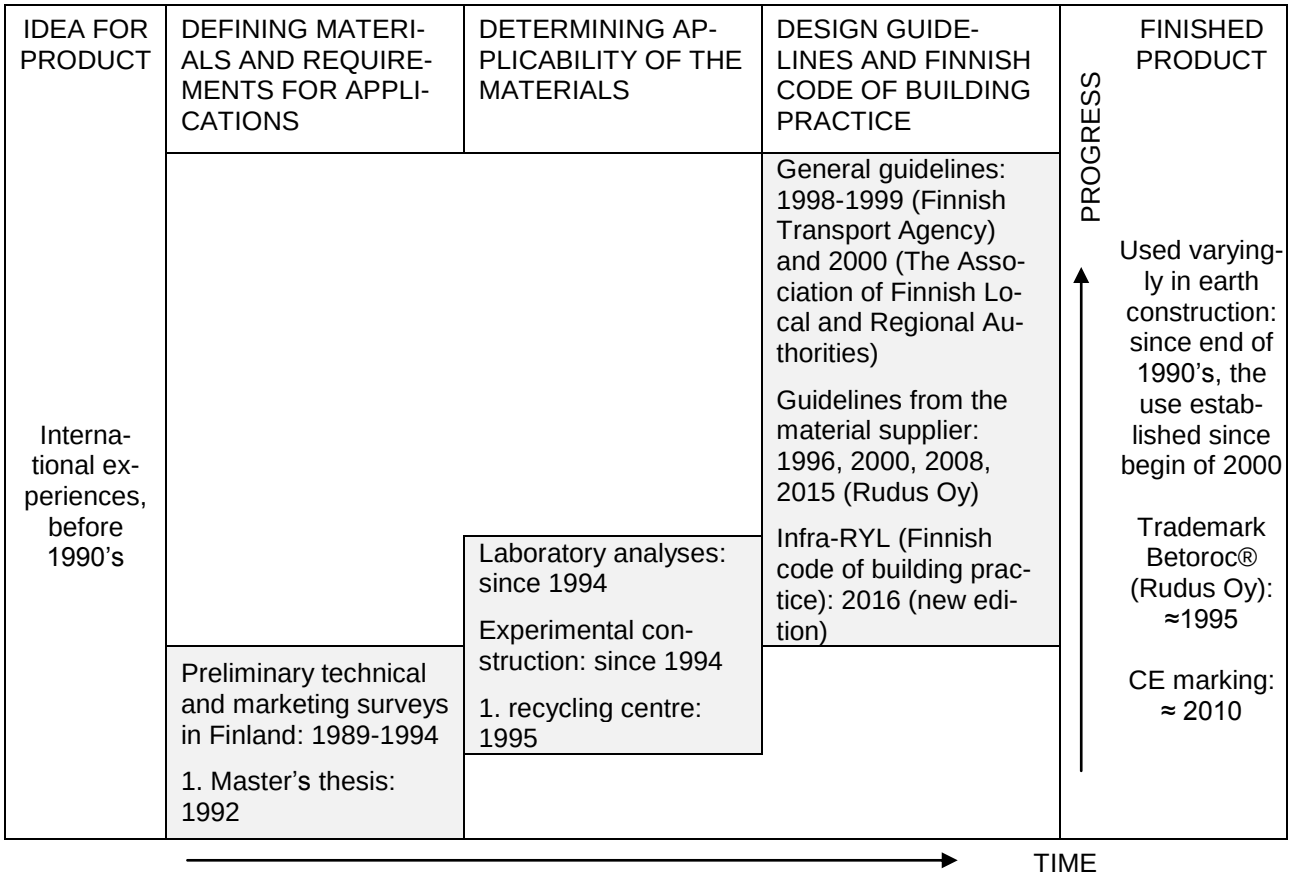

Figure 3 An example of productization of an UUMA-material. Case crushed concrete in Finland.

- coal fly ash and coal bottom ash
- biomass ash
- slags from steel industry
- foundry sand
- tailings sand from calcite mining
- gypsum from phosphoric acid production
- dredge residue and excavated soils
- residue from forest industry.

4.2 Possible applications for the materials

The productization process is based on the technical and functional requirements of the application (structural element). These requirements need to be fulfilled before the product is launched. The requirements are based on Finnish legislation, guidelines given by authorities, European standardization and other design and construction guidelines.

Possible applications for UUMA-materials to be used in covers a wide range of the infrastructural construction sector. Below are given the five main application areas considered in the UUMA2 program:

1. Roads and fields
   - roads, pedestrian and bicycle ways
   - parking areas, industrial areas
   - sports fields
2. Harbours and sea routes
   - used as a component or a binder in stabilisation of contaminated or soft sediments
   - as a massive structure or a mixture component in structural layers of harbour fields
   - in layer stabilisation of the bearing layer of harbour fields
3. Mass stabilisation
   - as binder / binder component in mass stabilisation of soft areas in all infra-construction sites
4. Environmental structures
   - noise barriers
   - flood barriers
   - liner structures in landfills etc.
   - protective barrier structures of tailings
5. Neutralising acidic materials
   - sulphidic clays
   - acidic tailings

Naturally, some UUMA-materials do not have high-enough technical quality for certain applications, whereas to some other applications certain materials have a too high quality.

5 DETERMINING APPLICABILITY OF THE MATERIALS

5.1 *Laboratory tests and test structures*

When material properties are tested, the aim is to find out the properties of a material in optimum conditions, normal working conditions and poor working conditions (e.g. when the compaction of the structure fails). The studies also aim to determine what can be done to eliminate risks and find solutions to circumstances where the risks have realized. (Finnish Transport Agency 2014)

Determining the applicability of an UUMA-material in an application requires laboratory tests. What kinds of tests are required depends on the material and the application where it is to be used. Whether the material is granular or continuum has a remarkable impact on the required test method.

Test construction requires a test site where ground conditions are uniform all over the test area. Test structures are compared to a reference structure or structures constructed on the same area. Design of test structures includes:

- gathering of the initial data and estimating its adequacy,
- finding out prior information and applications of the product,
- documenting of the construction site and materials,
- compiling of a proposition for and designing the test and references structures,
- documenting of the quality control procedures for the material and construction and
- compiling of research and documentation plans for the structures.

5.2 Testing standards

Following a standard ensures that the testing procedure is always the same and the test

results are comparable. This also makes it easier to set down quality requirements. Standards are recommendations by nature until they are made requirements by for example legislation, authorities or customers.

Reclaimed materials are discussed for example in the European standards for aggregates. Several harmonized standards have presented special requirements for certain reclaimed materials that differ from those given to natural aggregates, e.g. loss on ignition for coal fly ash or volume soundness for blast furnace slag. Using certain reclaimed materials as a stabilization binder or as a cement component has also been harmonized.

As part of the productization guidelines, a Standard study for UUMA-materials (UUMA2 program. 2016b) has been compiled, which summarizes the required properties and test methods for materials and applications from different standards and guidelines. To make it easier to consider which materials might be compatible to different test standards, the reclaimed materials have been classified in five different material types (Table 1):

1. granular
2. bound granular
3. massive consolidated, stabilised
4. elastic (under traffic load)
5. liner material

Examples of these material types are shown in Figure 4.

6 DESIGN GUIDELINES AND FINNISH CODE OF BUILDING PRACTICE

The final stage in productization process for UUMA-materials is to compile design and construction guidelines. The aim is to get these different materials included also in the different guidelines from public authorities and the Finnish code of building practice. When the UUMA-materials and their requirements are presented side by side to the natural aggregates in the guidelines, it makes it easier for the developers to accept the use of these less conventional construction materials in their construction projects.

The stage of compiling guidelines for some reclaimed materials included in UUMA2 program and how frequently the materials are used in infra construction is presented in Table 2.

6.1 Code of building practice and InfraRYL

The Finnish code of practice for infrastructures includes the infrastructural nomenclatures, InfraRYL requirements, Infra specifications cards, Regulations cards (laws, decrees, regulations by the authorities) and Product cards.

Table 1 UUMA-materials classified in different material types according to their material properties.

1. Granular		Crushed asphalt, Crushed concrete, Crushed bricks, Bottom ash from municipal solid waste incineration, Bottom ash, Fluidized bed combustion bottom ash, Foundry sand, Stope rejection, Tailings sand from calcite mining
2. Bound granular		Crushed asphalt, Crushed concrete, Granulated blast-furnace slag, Blast-furnace sand, Other slags
3. Massive consolidated, stabilized	***filler***	Fly ash, (coal-, bio-, etc.), Fly ash activated by cement, Ash mixes, Granulated blast-furnace slag, Desulphurisation residue
	+ aggregate	Excavated soils, Heap ash (moist), Dredge residue, Fibre sludge, Existing bearing course - layer stabilization
4. Elastic		Fibre ash (mix of fibre sludge and fly ash), Residues from forest industry, Shredded tires, Fibre sludge
5. Liner material		Excavated soils (fine-grained), Residues from forest industry, Stabilized dredge residue, Fibre sludge

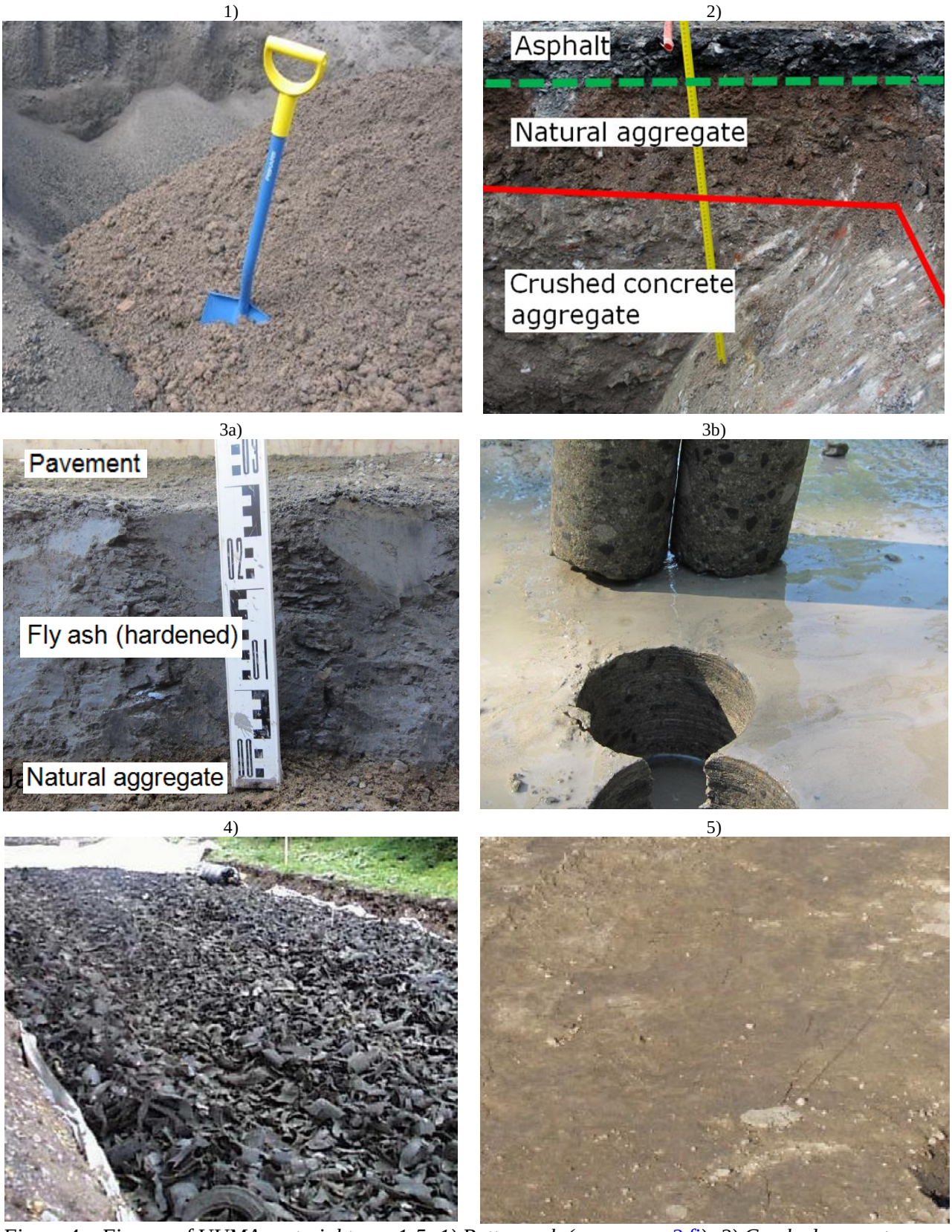

Figure 4 Figures of UUMA-material types 1-5: 1) Bottom ash (www.uuma2.fi); 2) Crushed concrete, re-hardened (Dettenborn et al. 2016); 3a) Cement stabilised fly ash; 3b) Fly ash stabilised crushed aggregate (Tarkkio 2014); 4) Shredded tires as a light weight material of street embankment (Forsman et al. 2002); 5) Stabilised surplus clay as a liner (Forsman & Leivo 2007). The explanations for the material types 1-5 are presented in Table 1.

Table 2 The frequency of use in infra construction and the stage of guidelines for some materials in the UUMA2 program.

Material	Guidelines from material suppliers	General guidelines (e.g. Finnish Transport Agency)	Material commonly used in infra construction*	Included in InfraRYL (2016)
Reclaimed asphalt	-	X	(X)	**-**
Crushed concrete	X	X	X	X
Crushed bricks	-	X	(X)	**-**
Bottom ash from municipal solid waste incineration	-	-	-	-
Coal fly ash	X	X	(X)	- **
Coal bottom ash and fluidized bed combustion bottom ash	X	X	(X)	- **
Desulphurisation residue	-	-	-	- **
Blast-furnace slag	X	X	X	X
Air cooled blast-furnace slag	X	X	X	X
Slags from steel industry	X	X	X	X
Foundry sand	-	-	-	-
Tailings sand from calcite mining	X	-	-	-
Gypsum from phosphoric acid production	-	-	-	-
Dredge residue and excavated soils	-	X	(X)	X
Shredded tires (and whole tires)	X	X	X	X
Fiber sludge, de-inking residue	X	-	(X)	-
Green liquor dreg	-	-	-	-
Lime sludge	-	-	-	-

* "X" = use is common, "(X)" = use is occasional, "-" = not used

** Infra product card under way (estimated to be completed in 2016)

InfraRYL 2010 Code of Building Practice - Infrastructure Handbook is meant for diverse infrastructural construction; -roads, streets, pipelines, bridges, etc. Its technical qualifications cover general quality requirements in construction, and it is continuously updated.

InfraRYL has been outlined into chapters according to the nomenclature. It includes constructional requirements and specifications, but does not contain actual design guidelines.

6.2 Design guidelines

Design guidelines are included in European and Finnish regulations, European standards, client specific design guidelines and design guidelines prepared by associations of the construction sector.

In Finland the most comprehensive ensemble of infrastructure design guidelines has been created by the Finnish Transport Agency, but even those only discuss some recovered materials (Public Roads Authority 2000, Finnish Road Administration 2007, Finnish Transport Agency 2014). Municipalities have collective design guidelines for the design of parks and streets. Also manufacturers of recovered materials have prepared some material specific design guidelines for infrastructures.

UUMA2 program aims to create a reference library of literature and guidelines of recovered materials that will be accessible through the UUMA web pages.

6.3 Bringing UUMA-materials to InfraRYL

So far only a few recovered materials are represented in individual structural elements in InfraRYL. One of the possible methods to include recovered materials in InfraRYL is to create an ensemble of them, where the InfraRYL requirements are discussed by the material. Another method is to produce a set of Infra specification cards of the recovered materials that will be developed into InfraRYL requirements at a later date.

7 SUMMARY

The UUMA2 program aims to have a significant effect on the increased use of recovered materials in infra construction. The result will be more eco-friendly and cost-effective structures and decreased carbon footprint for both the industry and construction sectors.

To ease the process of introducing new UUMA-materials to the markets, productization guidelines have been compiled in the program.

Different phases of productization process define the progress level of the process. In the first phase, requirements for the material and structure are defined as well as the environmental requirements. In the second phase, laboratory tests are done followed by construction of test structures. In the final phase, design and construction guidelines are compiled. The aim there is to get the materials included also in the guidelines by public authorities and the Finnish code of building practice. So far only a few recovered materials are represented in individual structural elements in the code.

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