European Commission, Horizon 2020 Programme

MORE-CONNECT project

Guide of material alternatives in relation to reuse and the combined energy and materials impact of prefabricated elements

3 October 2017

This project has received funding from the European Union's H2020 framework programme for research and innovation under grant agreement no 633477.The sole responsibility for the content lies with the authors. It does not necessarily reflect the opinion of the European Communities. The European Commission is not responsible to any use that may be made of the information contained therein.

This work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 15.0001. The opinions expressed and arguments employed herein do not necessarily reflect the official views of the Swiss Government.

Prepared by

econcept AG, Gerechtigkeitsgasse 20, 8002 Zürich, Switzerland, www.econcept.ch / + 41 44 286 75 75

Institute of Heat, Gas and Water Technology of Riga Technical University, Kipsalas str.6A-247C, Riga, Latvia

University of Minho, School of Engineering, Civil Engineering Department, Azurém, 4800-058 Guimarães, Portugal, www.uminho.pt, +351 253510200

Czech Technical University in Prague, University Centre for Energy Efficient Buildings, Třinecká 1024, CZ-273 43 Buštěhrad www.uceeb.cz / +420 224 356 701

Huygen / SBS Center, Parkweg 22B, 6212 XN Maastricht, The Netherlands, www.huygen.net, +31 880322222

Tallinn University of Technology, Ehitajate tee 5, 12616 Tallinn, Estland, www.ttu.ee

WEBO, Spoelerstraat 15, 7461 TX RIJSSEN, The Netherlands

Innogie ApS - Thrigesvej 23 - 7430 Ikast, Denmark

Invela, Store Ladegårdsvej 6, 4180 Sorø, Denmark, www.invela.dk

Authors
Roman Bolliger, MSc in Biology, BLaw, DEA en études européennes
Walter Ott, lic. oec. publ. UZH, Economist, dipl. El. Ing. ETH, Raumplaner ETH/NDS
Anatolijs Borodinecs, Prof. Dr.sc.ing. Institute of Heat, Gas and Water Technology
Manuela Almeida, PhD in Mechanical Engineering, Associate Professor
Ricardo Mateus, PhD in Civil Engineering, Assistant Professor
Ana Mestre, MSc in Energy Engineering and Environment
Antonín Lupíšek, PhD in Environmental impacts of buildings, MSc in Architectural Engineering
Martin Volf, MSc in Architectural Engineering
Tomáš Vlach, MSc in Architectural Engineering
Targo Kalamees, PhD Tallinn University of Technology
Kalle Kuusk, PhD Tallinn University of Technology
Peep Pihelo, MSc Tallinn University of Technology
Ronald Rovers, Prof. em. IR
Bart Voortman
Stephan Olesen, Business Development Engineer, BSc
Finn Christensen

Table of contents

Summary

Material alternatives with respect to reuse in prefabricated elements

Background

There are important drivers for strengthening the reuse of building materials, such as climate protection and environmental aspects, economic aspects, conservation of scarce resources, the image of companies, as well as legislation. However, there are also significant obstacles, such as a lack of reliable supply of reused materials, information deficits about possibilities and current reuse activities, uncertainties regarding the properties and often lacking certification of reuse materials and lack of qualified craftsmen, designers, planners and engineers.

Opportunities and challenges for MORE-CONNECT solutions

In terms of reuse several opportunities and challenges of MORE-CONNECT solutions were identified. A distinction is thereby made between the reuse of previously used materials in MORE-CONNECT solutions on the one hand, and the future reuse of material from MORE-CONNECT solutions on the other hand.

Regarding the future reuse of material from MORE-CONNECT solutions, prefabricated elements have on the one hand the potential to restrict possibilities for reuse, as there may be more connections between the materials in prefabricated solutions compared to non-prefabricated solutions, and such connections may hinder their reuse. Furthermore, the prefabricated elements may include composite materials, which are disadvantageous for reuse. On the other hand, prefabricated solutions also have the potential to facilitate dismantling and re-use of the elements, or their dismantling off-site - which may be an advantage compared to traditional structures which need to be decomposed on-site and require scaffolding for instance.

Concerning the reuse of previously used materials, the MORE-CONNECT solutions offer opportunities to promote the reuse of materials, as the quality of the materials can be much better monitored, ensured and documented in an industrial process with prefabricated elements in comparison with on-site renovation activities. Furthermore, by providing a stable frame which can be filled with various materials and by allowing industrial use of materials, it is easier to include previously used materials or recycled materials into the renovation process.

Based on experiences gathered in the MORE-CONNECT project, several recommendations are made regarding material alternatives in relation to reuse:

Recommendations for building companies with respect to the use of reused materials for the MORE-CONNECT solutions:

— It is important that the potential of prefabricated elements for facilitating the reuse of materials is recognized and that this potential is realised.

— It is important that product companies declare and highlight the materials used for their products, provide the prerequisites to separate and reuse the components of their products and document for the building company materials used, embodied energy, separability and possibly indicate future reuse possibilities or decommissioning/disposal procedures.

Recommendations for building companies with respect to future reuse of parts and materials in MORE-CONNECT solutions:

— In the design of the prefabricated solutions it is therefore important to take the topic into account, paying attention to issues related to separability and efficient recycling processes.

— In particular, we recommend to ensure that prefabricated solutions are designed in a way that its components are easily dismountable and separable. We recommend to use as little as possible fasteners and joins, or at least to ensure they are easily separable, to ensure future reuse of timber materials and to facilitate the dismantling of panels' parts.

— We encourage making use of the opportunity that industrial production of prefabricated elements offers to keep well track of materials used in the prefabricated elements and to facilitate thereby their reuse at the end of their lifecycle.

Recommendations for policy makers with respect to the use of reused materials in prefabricated solutions as well as with respect to the future reuse of parts and materials:

— We recommend to require that product companies declare the materials used for their products, provide the prerequisites to separate and reuse the components of their products and document for the building company materials used, embodied energy, separability and possibly indicate future reuse possibilities or decommissioning/disposal procedures. A measure with interesting potential to foster reuse would be the development of Environmental Product Declarations (EPDs) for building materials/components with respect to reuse.

— It makes sense to establish measures to track more systematically and to document more precisely the types and characteristics of materials used in construction processes.

— We recommend to include the topics of reuse of materials in the education and training of building professionals and planers.

— In order to promote the reuse and the recycling of construction materials it makes sense to introduce stricter requirements on construction waste utilization and separation.

— It is important that demonstration projects showcase the safety and durability of reused materials.

- We recommend to require that all public buildings are constructed or renovated in a way which facilitates later reuse of materials, and to include related criteria in public tenders.
- We recommend to require public authorities to consider the use of reused materials in all of their building constructions and renovation activities.

Material alternatives with respect to the combined energy and materials impact of prefabricated elements

Background

Taking into account embodied energy and embodied emissions is currently not a common requirement for making assessments of the energy performance of buildings according to the EU EPBD. However, it is known that the more energy-efficient a building gets, the larger is often also the relative impact of embodied energy and embodied emissions. The share of embodied energy with respect to total use of primary energy is increasing with decreasing operational energy use due to energy related building renovation, even if the relevance of embodied energy in building renovation is lower than in the case of new buildings. It is therefore important to take embodied energy into account, with a view to optimizing the combined energy and materials impact of prefabricated elements.

The reuse of materials, as discussed above, is an important factor for reducing the combined energy and materials impact of renovation materials. There are also further factors beyond that. In particular, bio-based materials play an important role in reducing the combined energy and materials impact of renovation materials, as often their production requires less energy input, causes less greenhouse gas emissions and is more sustainable than other types of materials.

Here, a focus is made on the energy and climate impact of materials. However, there are also important resource scarcity/depletion reasons other than energy, which speak in favour of reuse of building materials. This is the case for example with respect to gravel, sand, and copper. There might also be strategic and geopolitical reasons for reduction of dependence of the construction industry on materials imported from far distances or unstable regions of the world.

Opportunities and challenges for the use of materials with low combined energy and materials impact in MORE-CONNECT solutions

There are various opportunities for using materials with particularly low embodied energy in prefabricated elements. Similarly to the advantages with respect to the reuse of materials, the frame provided by MORE-CONNECT solutions provides the opportunity of using various materials with low embodied energy impact.

A specific challenge is to have processes and products making use of reused materials or providing solutions which allow for future reuse. Furthermore, it is a challenge to build up a reliable network of suppliers and installers of materials with low embodied energy. Currently typical thermal insulation materials have an extended network of retailers, predictable materials properties, and trained craftsmen. Materials with more favourable life cycle properties have to compete with such materials.

The reuse of materials contributes to a low combined energy and materials impact of MORE-CONNECT solutions over their lifecycle. However, there may also be trade-offs between the reduction of the combined energy and materials impact and the reuse of materials, as shows the example of textile-reinforced concrete: It requires less material input than for example steel-reinforced concrete, yet the related material can be less easily reused at the end of its lifecycle.

Based on experiences gathered in the MORE-CONNECT project, several recommendations are made regarding material alternatives in relation to the combined energy and materials impact of prefabricated elements, beyond the recommendations made already with respect to promoting the reuse of materials. Some of these are the following:

Recommendations for building companies:

— For architects, engineers and other building companies we recommend to become more conscious of the embodied energy of the materials applied in projects, which allows to obtain the know-how to select products and processes that help to reduce the overall energy footprint of buildings.

— The already existing production lines used by MORE-CONNECT project partners could be modified in the future in order to allow for thermal insulation the application of loose materials such as cellulose or wood fibres, which often have a particularly small overall combined energy and materials impact.

— It is fundamental that the environmental impact of the products is taken into account by every construction company.

Recommendations for policy makers:

— We recommend to make databases of environmental impacts publicly available and to require that data is provided for specific products. Currently, the uncertainty in LCA data is quite high and the available databases in most countries do not provide specific data for a majority of available building materials.

— We recommend to take into account embodied energy in building regulations.

— We recommend to promote solutions based on prefabricated elements such as MORE-CONNECT solutions, as they can easily include low-impact materials such as loose fibres, hemp or cellulose.

1 Introduction and background

The MORE-CONNECT project focuses on prefabricated modules for renovation of buildings. This report aims to provide information on material alternatives for such prefabricated modules with respect to the following topics:

— Reuse of materials

— Combined energy and materials impact of materials

With respect to the topic of reuse, the report aims to provide information on two different questions: (1) how previously used materials can be reused in prefabricated modules developed in the MORE-CONNECT project, and (2) how materials used in the concepts developed by the MORE-CONNECT project can and will be reused in the future at the end of their service life.

Reuse is understood here to refer to the reuse of materials as such, as well as to recycling, i.e. the breaking down of components and materials that cannot be reused in their entirety into recyclable components (downcycling) and the reuse of such components (Kim et el. 1998).

Reuse of materials is important to reduce life-cycle energy consumption associated with building renovations, to reduce construction waste, and to close material cycles, thereby contributing to more sustainable building renovation solutions. Between 5-10% of total energy consumption across the EU is related to the production of construction products (European Commission 2014). Furthermore, construction and demolition waste constitutes a third of total waste generated in the EU. A large share of construction and demolition waste is in principle recyclable, yet the average recovery rate in the EU is below 50% (European Commission 2014). This highlights the importance of efforts to increase reuse of materials.

The report aims to identify both opportunities for reuse of materials as well as obstacles preventing widespread reuse.

The principles to be followed within that context in the EU are stipulated by the Regulation 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products. According to this regulation, basic requirements for construction works shall constitute the basis for the preparation of standardisation mandates and harmonised technical specifications. One of these basic requirements refers to the "Sustainable use of natural resources" (Regulation 305/2011 Annex 1, point 7):

7. Sustainable use of natural resources

The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:

(a) *reuse or recyclability of the construction works, their materials and parts after demolition;*

(b) *durability of the construction works;*

(c) *use of environmentally compatible raw and secondary materials in the construction works.*

According to Annex 1 of Regulation 305/2011, subject to normal maintenance, construction works must satisfy these basic requirements for an economically reasonable working life.

These aspects are to be taken into account when defining the criteria for products to be allowed on the internal market and in particularly to obtain the CE label.

National Product Contact Points for Construction designated by Member States are expected to provide information on the provisions within their territory which aim at fulfilling these and other basic requirements for construction works (Regulation 305/2011 Art. 10, para. 3).

Furthermore, according to the Waste Framework Directive 2008/98/EC of the European Parliament and the Council of 19 November 2008, Art. 11 para. 2 letter b, Member States shall take the necessary measures designed to achieve the following target:

by 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight.

Within that context, it is therefore of particular interest to know how the MORE-CONNECT solutions to be developed are expected to perform with respect to the criteria of reuse and materials impact defined by Regulation 305/2011, and what recommendations can be given with respect to a good performance according to these criteria. This aims to make a contribution both to the implementation of Regulation 305/2011 as well as to the Waste Framework Directive 2008/98/EC. Furthermore, these objectives are in line with the EU action plan for the Circular Economy (European Commission 2015) as well as the Roadmap to a Resource Efficient Europe (European Commission 2011). The focus of this report with respect to reuse of materials is accordingly on information and recommendations how to ensure that materials used in prefabricated MORE-CONNECT elements meet or exceed the requirements regarding reuse or recyclability.

The present report also aims to provide information on the combined energy and materials impact of prefabricated elements. This refers in particular to taking into account embodied energy and embodied emissions of the materials used for building renovations applying MORE-CONNECT solutions. This topic is on the one hand closely linked to the topic of reuse, as the inclusion of reused material may lower the combined energy and materials impact of the MORE-CONNECT solutions. Similarly, increasing the future reuse of material from MORE-CONNECT solutions at the end of their life-cycle may contribute to reduce the energy and materials impact. On the other hand, there are further choices which can be made regarding the types of materials used in the MORE-CONNECT solutions that have an impact on the combined energy and materials impact. This concerns in particular the increased use of bio-based materials, in line with the European Commission's Strategy for a Bioeconomy for Europe (European Commission 2012). Taking into account embodied energy and embodied emissions is currently not a requirement for making assessments of the energy performance of buildings according to the EU EPBD. However, it is known that the more energy-efficient a building gets, the larger is often also the relative impact of embodied energy and embodied emissions. The share of embodied energy with respect to total use of primary energy is increasing with decreasing operational energy use due to energy related building renovation, even if the relevance of embodied energy is lower than in the case of new buildings (Ott et al 2016). Furthermore, the absolute impact of embodied energy may increase as well, as the extraction of materials from their natural environment may require more and more resources, as the related remaining stocks become more difficult to access. At the same time, through the choice of material the embodied energy impact can be reduced. It is therefore important to take embodied energy into account, with a view to optimizing the combined energy and materials impact of prefabricated elements.

Based on experience gained in the project, recommendations are elaborated for construction companies and policy makers on how to increase the reuse of materials related to prefabricated elements, and how to decrease the combined energy and materials impact of such elements. Topics covered address design, declaration, labelling and production procedures.

Rebound effects are not part of the scope of the report.

The report builds on experience gained in the various geoclusters of the MORE-CONNECT project. Accordingly, the findings presented in this report are often divided into one subchapter for each geocluster.

This report is prepared as part of Task 3.5 of the MORE-CONNECT project. The title of the task is «Life cycle assessment of concepts». It is linked to various other tasks of the MORE-CONNECT project, in particular:

— Task 2.1 Initial performance criteria and requirements towards a life cycle approach

— Task 2.2. Multifunctional modular solutions for facades and roofs

— Task 3.2 Modular concepts: development and design selection

— Task 3.4 Performance criteria assessment of concepts

— Task 6.1 Selection of favorable concepts to market

2 Material alternatives in relation to reuse

2.1 General opportunities and challenges with respect to reuse

The reuse of building materials can play an important role in reducing the consumption of limited natural resources as well as in reducing primary energy use and greenhouse gas emissions of building renovation activities. This may also reduce costs and dependency of national economies on import of raw materials.

Generally, «materials» in construction can be reused at various system levels:

— Reuse of buildings;

— Reuse of buildings' subsystems/ structures;

— Reuse of building elements;

— Reuse of building materials.

The first two aspects are covered by the project at a general in the sense that it focuses on building renovation, not on newly constructed building. An objective of the whole MORE-CONNECT project is to improve the energy performance and the usability of the existing building stock and thus to extend the service life of respective buildings. The last two aspects are discussed in more detail in this report.

Besides reusing, a high impact has also the extension of service life, which helps to keep existing materials in use.

Forces driving the reuse and recycling logistics are climate protection and environmental aspects, resource conservation, economics, legislation and corporate citizenship (de Brito and Dekker 2003).

Reuse of materials helps reduce the overall carbon footprint and the environmental impact of building renovations; accordingly, there is an interest to make use of related opportunities.

For example, approximately 25% of energy is saved when glass wool is recycled, in comparison with primary material (European Commission 2014). For rock wool, savings due to recycling are in the order of 5% with regard to energy consumption and related emissions (European Commission 2014). For metals an overall reduction of impacts of more than 90% can be achieved for aluminum and copper and about 15% for low-alloyed steel (OVAM Ecolizer 2011, cited in European Commission 2014).

There are various possible drivers for the reuse of materials:

A first driver may be economic reasons. Some companies earn money on reuse. For example, the price of recycled glass is about 60-80 EUR/tonne, which is sufficiently below the 90 EUR/tonne necessary to compete with virgin material (European Commission 2014). Another example from a different economic sector is ReCellular, which is a company that trades in refurbished cell phones. Others earn money indirectly. Canon reuses materials to strengthen their relations with their customers.

A second driver is that legislation especially in Europe has increased for example regarding recycling quotas, packaging regulation and manufacturing take-back. This is a driver for reusing activities. This may become an even more important factor in the future.

A third driver is corporate citizenship. Companies want to do good for all of their stakeholders and the whole world. This translates into extensive reuse programs for many firms.

However, there are a number of obstacles with respect to the reuse of building components and materials (Dechantsreiter et al. 2015, European Commission 2014):

— Lack of inclusion in tendering processes
— Information deficits about possibilities and current reuse activities
— Lack of qualified staffToo short time window for separation during deconstruction
— Lack of market structures for reused building materials and building elements, lack of economies of scale
— Image problems of reused products
— Differences in quality with respect to new materials or insecurity about the quality of reused materials, lack of adequate certification procedures
— Additional work associated with reused materials, for example additional cleaning work
— Partly higher prices for reused materials
— Composite materials and today's construction processes make separation of materials more difficult
— Liability and guarantee questions regarding the reuse of materials, insufficient regulation of such questions
— No instructions and information documents for all persons connected to the construction process
— Lack of information, declaration and labelling for products/materials which could be reused
— Separation not integrated in the destruction processes
— Lack of knowledge about ecologic advantage of product recycling
— No regulation on re-use of components of building products

A particular obstacle are the mentioned differences in quality with respect to new materials or the insecurity about the quality of reused materials and their possible health risks or even toxicity. The differences may range from purely visual differences to characteristics which prevent reuse, for example wood elements that have been treated with chemicals such as fungicides or insecticides. Already the clarification of the quality status requires work, i.e. it is not just only lack of quality that this is an obstacle, yet the insecurity itself is already an obstacle.

Because of a precautionary approach, there may even be regulations which prevent the reuse of certain materials, because of a risk of problems with pollution. In Germany, for example, the BImSchV regulation for controlling pollutants requires certain types of wooden construction elements to be burnt as a precaution against such potential pollution. Also when it is allowed to reuse materials, care needs to be taken concerning chemicals which may be released to the environment during separation procedures. For example, for reuse of EPS, control of flame retardant HBCD is a challenge (Albrecht and Schwitalla 2014).

2.2 Specific opportunities and challenges for MORE-CONNECT solutions with respect to reuse

2.2.1 Introduction

In this chapter, specific opportunities and challenges for MORE-CONNECT solutions with respect to reuse are documented per geocluster. A distinction is thereby made between the reuse of previously used materials in MORE-CONNECT solutions on the one hand, and the future reuse of material from MORE-CONNECT solutions on the other hand.

The MORE-CONNECT solutions developed are specific for each geocluster and location where case studies are carried out. The scope of MORE-CONNECT solutions investigated at the six locations is broad. Most of them consist of prefabricated panels for the insulation of buildings' exterior walls, yet there are also other MORE-CONNECT solutions.

2.2.2 Experience in Latvia

<u>Overview on MORE-CONNECT solution</u>

Figure 1 illustrates the MORE-CONNECT solution from Latvia:

«Overview on thermal insulations for the MORE-CONNECT solution in Latvia»

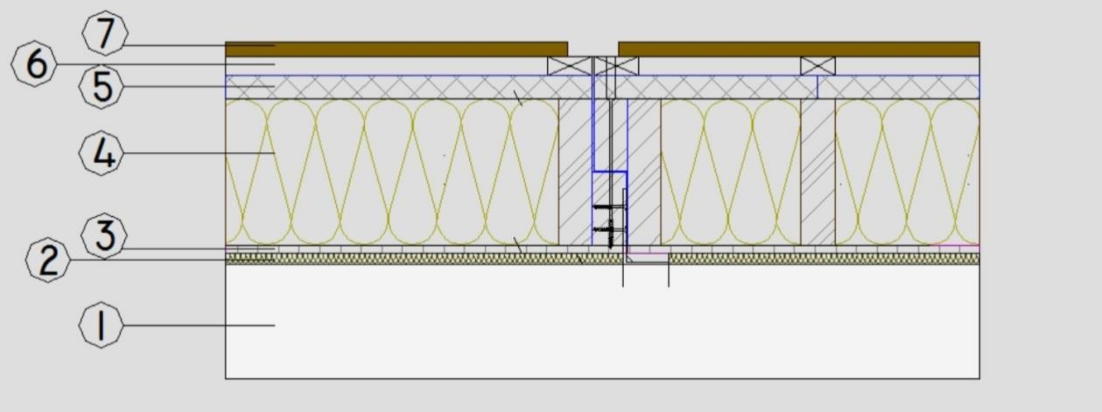

Figure 1: Thermal insulation panels for the MORE-CONNECT solution in Latvia

This illustrated solution is a basic solution, which can be easily assembled on the existing production line in Latvia. In the scope of the MORE-CONNECT project, different modifications have been evaluated.

Material options taken into consideration for the MORE-CONNECT solution and the chosen option are indicated in the following table:

<table>
<tr><th></th><th>Layer 1</th><th>Layer 2</th><th>Layer 3</th><th colspan="2">Layer 4</th><th>Layer 5</th><th>Layer 6</th><th>Layer 7</th></tr>
<tr><td></td><td>Existing wall</td><td>Connection layer between existing wall and modular panel</td><td>Frame base</td><td colspan="2">Main load bearing and thermal insulation layer</td><td>Wind protection</td><td>Ventilated air gap</td><td>External finishing</td></tr>
<tr><td rowspan="6">Materials options</td><td rowspan="6">Brick wall</td><td>Air gap</td><td rowspan="3">Oriented strand board</td><td rowspan="2">Frame</td><td>Steel frame</td><td>Mineral wool</td><td rowspan="6">-</td><td>Wood planks</td></tr>
<tr><td>Sealing tape</td><td>Wood frame</td><td>Oriented strand board</td><td>Fibro-cement board</td></tr>
<tr><td>Mineral wool</td><td colspan="2">Mineral wool thermal insulation</td><td>Wood particle board</td><td rowspan="2">Magnesite board</td></tr>
<tr><td>Soft sealing tape (mineral wool)</td><td rowspan="3">Wood particle board</td><td colspan="2">Expanded polystyrene thermal insulation</td><td>Fibrolite board</td></tr>
<tr><td rowspan="2">Loose materials</td><td colspan="2">Cellulose fibre hemp, cotton</td><td rowspan="2">Wood-fibre boards</td><td rowspan="2">Fibrolite board</td></tr>
<tr><td colspan="2">Loose materials</td></tr>
</table>

Table 1: Material options for each panel layer. The selected option is highlighted ( ).

After various evaluations a main focus has been put on the selection of optimal external finishing and the connection layer between existing wall and panels. The chosen solution is a balanced option taking into account materials' embodied energy and materials use. A more detailed description is provided below.

«Thermal insulation panels for Latvian MORE-CONNECT solution»

Figur 2: Thermal insulation panels for Latvian MORE-CONNECT solution

<u>General comments regarding opportunities and challenges for MORE-CONNECT solutions with respect to reuse</u>

Nowadays challenges for energy renovation of buildings do not just concern the reduction of final operational energy consumption, but also to question how to ensure sustainable construction with lowest possible environmental impact.

The investigated MORE-CONNECT solutions take into consideration minimization of embodied energy and use materials suitable for reuse/recycling, as further explained below. The main aim is to choose the solution with lowest environmental impact among technically and economically reasonable retrofitting solutions.

<u>Reuse of previously used materials in MORE-CONNECT solutions</u>

Opportunities

The prefabrication approach used in MORE-CONNECT is a suitable approach for the application of previously used materials. The frame construction provides options for application of materials with any density and mechanical properties. There are two main materials which can be reused in the MORE-CONNECT solution: thermal insulation and wooden beams.

The prefabricated modules are produced under controlled environment in a production line. Different types of reused building materials can be easily applied at the production line. Either loose or bulk materials can be applied. Also, combinations of both types are possible, even different bulk and loose material can be combined. The prefabricated panels have several benefits for reuse of previously used materials in comparison to typical retrofitting solution. The main benefits are:

- ✓ Existing manufacturers can make use of special warehouses to store raw material in a protected environment, which prevents negative impact of precipitation;
- ✓ Possibility to accumulate necessary amount of raw material;

- ✓ Better possibility to create material mix according to their thermodynamic properties and customer needs;
- ✓ Simultaneous production of panels with different thermal insulation materials and short-term storage for later combination with respect to the needs of a specific object;
- ✓ Production line can be easily adopted to any kind of material;
- ✓ Easier monitoring and control of properties of reused materials;

Challenges

Unfortunately, there are several practical shortcomings for mass application of previously used materials. The main shortcoming is a lack of reliable supply sources for such materials. Nowadays manufacturers offer their new products across the globe and mass production of typical products allows to offer reasonable prices. Currently the reuse of materials faces challenges in competing with the new products, the market for used materials is not stable and it isn’t able to ensure mass production. Increase of available used materials for reuse can be expected in the next 20 – 30 years. The main reason is expected to be the retrofitting of buildings built after 1990s. Such buildings already have some thermal insulation and timber elements, while buildings built before 1990s can be mainly characterized as concrete/brick buildings with concrete slabs without any thermal insulation which can be separated from load bearing element. Therefore, from buildings before 1990, there is little insulation material to be reused. Some wall examples are shown in figure 2.

«Suitability for reuse of various wall constructions»

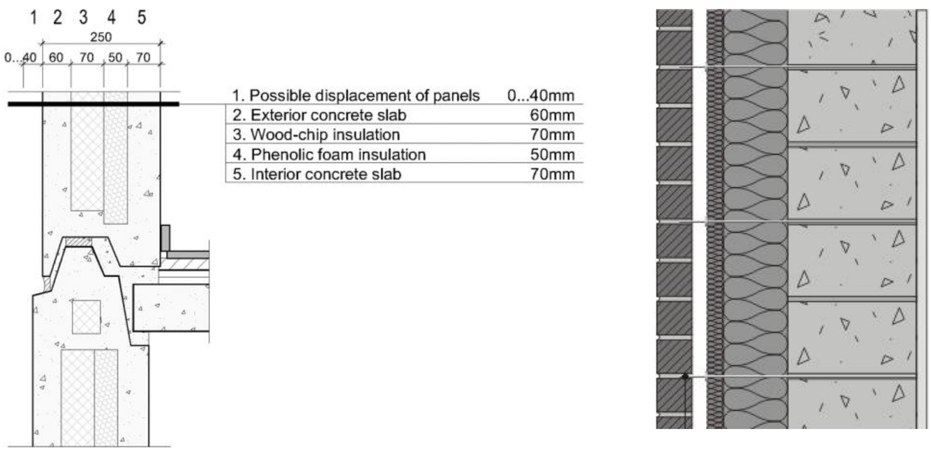

Figure 3: Wall structure in typical buildings in Estonia as used for the MORE-CONNECT pilot, for buildings built before 1990s (left), and after 1990s (right)

The demolishing process as well as the utilization and separation of construction waste of recently built constructions may require extra staff hours in order to separate external finishing out of thermal insulation and the main construction. Such a process is complicated and can cause mechanical damage of materials.

Reused materials might not have declared properties due to uncertain working conditions and a lack of information on materials' producers. Also, during the demolishing process, it is not always possible to ensure proper material storage and to prevent negative impact of precipitation. Material wetting significantly affects thermal conductivity and reduces its value for thermal insulation, which has negative impact on a building's overall energy efficiency when using affected material. Furthermore, during the transportation, materials can lose their mechanical properties due to mechanical damage.

Existing wooden elements may contain mechanical fasteners such as steel nails, screws, anchors etc. Such elements prevent reuse in mechanical production lines due to a high risk of damage to machineries. Removal of steel elements can be done only manually after careful visual inspection. Afterward timber elements can go to automated production lines.

Future reuse of material from MORE-CONNECT solutions

The main focus of MORE-CONNECT solutions is to reduce on-site installation time by using prefabricated elements. An example of a prefabricated element is shown in Figure 4.

«Installation and connection of prefabricated MORE-CONNECST panels»

Figur 4: Installation and connection of prefabricated panel; on the right hand side, Smart Connectors are shown

As it can be seen from the above-mentioned picture, proposed panels have only few connectors, which allows easy replacement of panels after the end of their service life. Compact shapes of panels are suitable for fast and safe transportation from the construction site to factory where such panels can be demolished and separated into pieces in a warehouse using special power tools. Since the panels are produced at manufacturers, more reliable information on the properties of the used materials will be available. This facilitates their reuse. The easy demolition and transportation process prevents materials from negative impact of ambient environment and reduces risk of materials mechanical damage, thus preventing moistening of materials and mechanical damages.

The MORE-CONNECT approach therefore provides opportunities for facilitating the future reuse of building materials.

The main benefits of MORE-CONNECT solutions for the future reuse of materials are:

- ✓ Initial high construction quality;
- ✓ Accurate transportation and installation of materials;
- ✓ Well documented prefabrication process, according to factories' internal quality standards;
- ✓ Reliable data on materials properties;
- ✓ Safe and fast demolishing process;
- ✓ Materials do not undergo negative impacts of precipitation during initial production, transportation, installation and later reuse;

Therefore, MORE-CONNECT solutions will have advantages for reuse/recycling at the end of their service life compared to conventional building renovation.

2.2.3 Experience in Portugal

<u>Reuse of previously used materials in MORE-CONNECT solutions</u>

The majority of end of life products are not reused in Portugal. There is an underlying energy potential and economic potential of exploring this market. To access these potentials, it is necessary to overcome some challenges and restrictions. Firstly, European and national regulations restrict the characteristics and conditions to reuse some components and materials in the production chain of new materials and products. Secondly, there is an extensive lack of knowledge among field stakeholders regarding what type of waste material is available, their characteristics and how they can use it as new products. Finally, there is also a social limitation. Users don’t perceive reuse as advantageous and generally they will not accept reused materials in their buildings.

<u>Future reuse of material from MORE-CONNECT solutions</u>

By the end of the service life of the building, the MORE-CONNECT solutions developed can still be reused in other buildings since they present a good durability. All systems components are mounted in-situ using mechanical fixings and therefore deconstruction processes at the end-of-life of the building are possible without damaging the main components of the systems: mineral wool layer and prefabricated panel. The major challenge might be the separation of elements used in the fabrication of the panel because of the polyurethane injection in the modules. In case it is not possible to separate elements, even partially, they will need to be deposited in landfills. Although that constitutes the worst solution in terms of end-of-life management of products, due the characteristics of the used materials (inert material) it is possible to mention that they will have reduced potential environmental impacts.

2.2.4 Experience in Czechia

Reuse of previously used materials in MORE-CONNECT solutions

The reuse of previously used materials was not specifically taken into account in the development of the MORE-CONNECT solutions in Czechia. However, other related aspects were taken into account. Besides reusing, an extension of service life also has a high impact on the environmental performance, as this helps to keep existing materials in use. The planned interventions of MORE-CONNECT solutions developed in Czechia have planned service life of at least 40 years for improvement of building envelopes and 15-20 years for improvements of building services.

Future reuse of material from MORE-CONNECT solutions

Current reuse of construction and demolition waste form the renovations

In the Czech renovation scenario, not much construction and demolition waste (CDW) is planned during the interventions:

- Old windows will be removed;
- In some cases window openings will be extended;
- Some soil in the perimeter of the building will be excavated in order to apply drainage systems to dry up the cellars;
- Roof tiling will be removed.

At the moment, there is no specific plan how to cope with this construction and demolition waste as whole structures or building elements, rather as materials for reuse. Probably the best available scenarios for the materials in the Czech case would be:

- Windows: Flat glass to be sent to glass factory in order to be recycled into new glass. Window frames dismounted, clean metals and plastic recycled. Wooden parts probably used for electricity/heat production by incineration.
- Bricks and mortar from the extension of the windows' openings: Mortar, when collected, would probably find use as a fill material for landscaping, but the amounts of material are so low that probably it will just be landfilled. Cleaned bricks can be re-used, probably for interior fillings and partitions, these can be offered on the second hand online market for free to anyone.
- Excavated soil will be transported to soil stock and used as filling substrate for landscaping.
- Roof tiling will probably represent the highest amount of waste material. Depending on its type, it will be either landfilled (asphalt tiles) or used as filling substrate for

landscaping (concrete or ceramic tiles). In some cases tiles were used containing asbestos, these are handled as hazardous waste which has to be landfilled with special care in airtight packing.

Future reuse of the modular retrofitting solutions

The modular retrofitting system developed for the Czech case could be theoretically reused as whole structure. It is fixed on steel anchors on the walls of existing buildings, so it would be possible to disassemble the modules and use them on another building of similar shape. But this scenario is not likely, more probably the modules will be removed from the building and disassembled into elements.

The elements consist of various materials; some materials will be easy to separate for recycling; separation of others will be complicated. Separation will be easy for the interior layer of thermal insulation, for the structural frame made of timber and its fillings from thermal insulation. Also, structural boards in the structure will be separable. On the other hand, the external layers of the panels, where the surface consists of plaster on a board or thermal insulation might be complicated to separate.

It is envisaged that the materials coming from the disassembled modules will be handled in the following way, based on today's knowledge:

- Timber elements: easily separable and could be reused as structural elements, downcycled as non-structural elements or sent to waste incineration plants for energy recovery;
- Thermal insulation:
  - Glasswool and rockwool can be reused or sent for recycling into new thermal insulation;
  - Fibre wood insulation can be reused or sent to waste incineration plants for energy recovery;
  - Vacuum insulation panels (VIPs) are hard to reuse as their dimension is fixed and cannot be accommodated. VIPs are complex products and hard to fully recycle with current technologies.
- Structural boards: Some of them may be reused, but most of them will probably be landfilled.
- External layers of plaster, glass fabric and paint are not easily separable with current technologies, they will probably be landfilled. There is a preference not to use such finishings, but at the moment other alternatives are significantly more expensive.
- Windows: Flat glass to be sent to glass factory in order to be recycled into new glass. Window frames dismounted, clean metals and plastic recycled. Wooden parts probably used for electricity/heat production by incineration.
- Metal fasteners and elements can be separated and recycled easily.

— An element has been developed which is made of textile reinforced concrete and which will be used for plinth covering. Textile reinforced concrete has advantages in terms of the reduced material input, yet in comparison with steel-reinforced concrete it has the disadvantage of being less favourable for disassembly into its components and subsequent reuse.

Regarding the use of textile reinforced concrete, a material was chosen with uncertainty for its reuse, yet which has other advantages such as reduced amount of materials input. Several studies have been developed for comparison of textile reinforced concrete (TRC) and ordinary concrete (Laiblová et al 2015, Fiala 2011, Laiblová et al. 2016). Environmental profiles show values of textile reinforced concrete are lower or similar in all categories of environmental impacts because of lower material consumption compared to the ordinary concrete. However, strength of the performance material also has to be taken into account. The ratio between the strength and the environmental impact is much more favourable for textile reinforced concrete. Potential of durable materials may go even further with different ways of lightening. It is possible to prepare elements with one side ribs or system of ribs and these elements can bring next reduction of amount of concrete in a comparison to standard solid elements (Vlach et al. 2016). The other way with similar effect is installation of foam core prisms inside of the structure (Chira et al. 2015).

2.2.5 Experience in Estonia

Overview on MORE-CONNECT solution

In the following figure, an overview is given of the MORE-CONNECT solutions developed in Estonia:

«Overview on the MORE-CONNECT solution in Estonia»

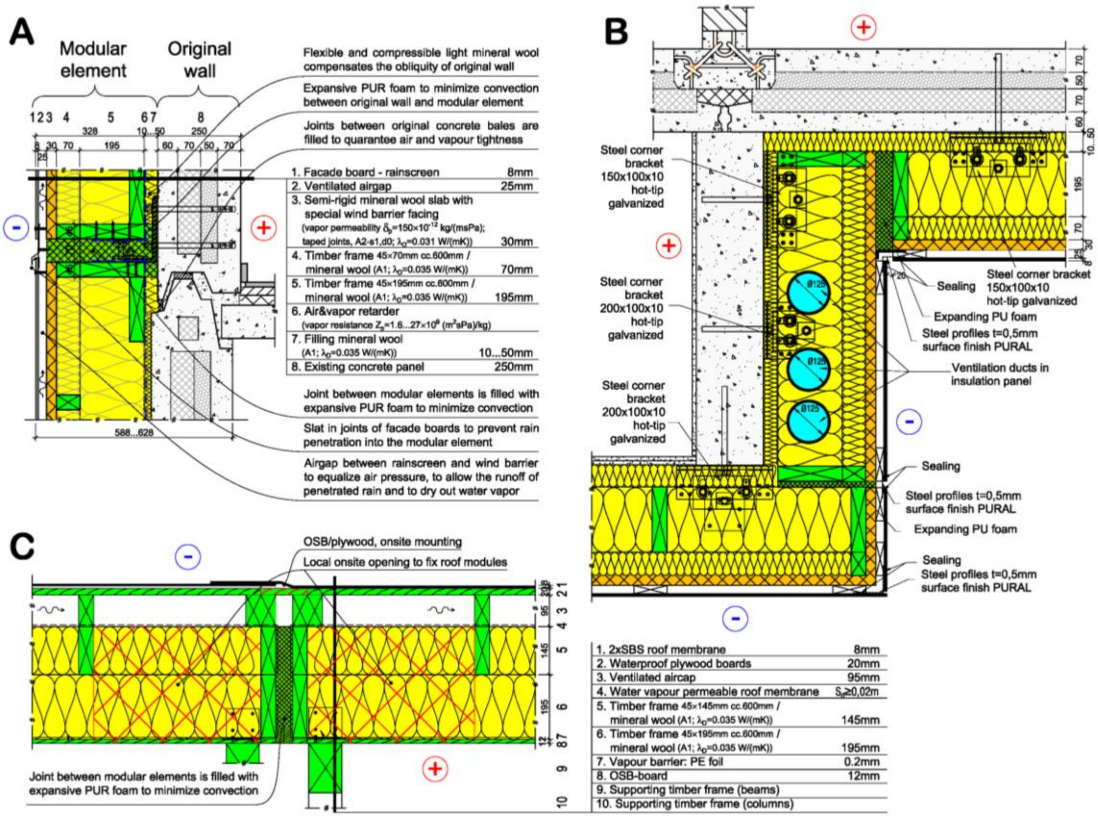

Figure 5: Designed solutions at the different structural points of the pilot building

<u>Reuse of previously used materials in MORE-CONNECT solutions</u>

MORE-CONNECT solutions help to reuse old apartment buildings in Estonia and to make them liveable. Kuusk et al (2014) showed that an existing apartment building can be renovated to meet the same energy-efficiency levels as a new building, while the demolition of an existing building and construction of a new one has at least three times higher environmental impact than low-energy renovation. This is illustrated in the following table.

Table 1. Emission of CO_2 from the production of construction materials and from energy production when comparing renovation and demolition of an old apartment building, in comparison with CO_2 emissions from district heating or electricity use. In this table, embodied energy of a renovation scenario is expressed as a sum of CO_2 emitted from the production of the construction materials and CO_2 emitted from the energy production that a building consumes during the period of 20 years.

Scenario	CO_2 emissions, t			
	Materials	District heating	Electricity	Total
Without renovation	0	2891	1717	4608
Major renovation	774	1251	2990	5015
Low-energy	1029	812	2060	3901
Low-energy (extensions)	2089	895	2283	5267
New building	9576	701	2060	12337

Modular prefabricated renovation panels developed for the MORE-CONNECT pilot in Estonia are made by timber frame. Wood is a renewable material. Timber recycling could also be possible, but high requirements to quality related to dimensions, strength, moisture safety, absence of mould or other damages probably prevent the massive reuse of recycled wood in MORE-CONNECT panels in Estonia.

Modular prefabricated renovation panels developed for the MORE-CONNECT pilot in Estonia are insulated by ISOVER glass wool. The glass wool is mainly made from sand and recycled glass. The average proportion of recycled content in the production of ISOVER glass wool is 54%. According to latest research results the reference service life of mineral wool is not limited if the material is professionally installed and used (Bau EPD GmbH 2014).

Future reuse of material from MORE-CONNECT solutions

For the pilot project of the MORE-CONNECT project in Estonia, timber frame was used because the wood can be used at the end of the service life. Reuse or recycling of glass wool products is technically feasible, but does not take place under the current ecological and economic conditions (Bau EPD GmbH 2014).

All windows in the Estonian pilot will be changed. Some of the old windows (~50%) could be reused in other similar apartment buildings.

2.2.6 Experience in the Netherlands

Reuse of previously used materials in MORE-CONNECT solutions

In the Dutch geocluster, the MORE-CONNECT solutions developed do not take into account previously used material. This simply has not been a topic as of yet. The intention is to explore this aspect more in the near future.

Future reuse of material from MORE-CONNECT solutions

In the Netherlands, the following opportunities and challenges were identified in connection with the future reuse of material used in the MORE-CONNECT pilot projects:

Opportunities

The materials that are used in the Dutch MORE-CONNECT solution are all suitable for reuse. The main material that is used is wood. This material is biobased. All the wood that is used is sourced form FSC certified forests. After the first lifecycle of the façade the wood can be used a second time when in good condition. If the wood is in poorer condition the wood can be laminated. This laminated wood can be used for production of window frames.

The façade is produced with the end of product life in mind. The composition of the façade is suitable for deconstruction. Different materials that are used in the façade are easily separated after the first lifecycle. This process is labour friendly. It is intended to work together with suppliers of raw materials to give them back their product at the end-of-life of the façade. Suppliers like Kingspan can recycle the old material into new EPS. BJW does this already with the glazing. Pilkington NL recycles the sheetglass to produce new glass for many different applications.

Challenges

The only material that is used in the Dutch solution that is not suited to deconstruct into raw materials is Fermacell. In Fermacell plates a lot of glue is used. This glue is hard to separate at the end of life.

Within the Dutch geocluster there is not enough knowledge about the recyclability of solar panels, water pumps and ventilation systems. This knowledge is expected to be gained in the near future to be able to make the Dutch solution fully recyclable.

2.2.7 Experience in Denmark

<u>Reuse of previously used materials in MORE-CONNECT solutions</u>

MORE-CONNECT solution developed by Invela

The MORE-CONNECT solution consisting of the 3D-printing of wall insulation as developed by Invela in the Danish geocluster does not take into account previously used materials.

MORE-CONNECT solution developed by Innogie

The MORE-CONNECT solution consisting of roof-integrated PV systems as developed by Innogie uses PV cells made of cadmium telluride. Cadmium is a byproduct of zinc production (Fthenakis 2004), occurring in large quantities. If it were not used in PV production, it would have to be disposed. Cadmium is toxic. However, when combined with tellurium, a substantially less toxic material is created. Furthermore, cadmium telluride is encapsulated between two sheets of glass for use as photovoltaic panels. These two aspects essentially eliminate safety concerns regarding the use of cadmium telluride in PV panels. Recycling of cadmium telluride is an important aspect of the use of these types of PV panels. On the one hand, this is necessary to contain the cadmium at the end of the life cycle of the PV panels. On the other hand, this allows to reuse the tellurium, which is a rare metalloid. Recycling of the cadmium telluride is considered to be an important source for ensuring availability of tellurium (Marwede and Reller 2012). Accordingly, in the long term, the use of recycled material in these PV panels is an important factor.

<u>Future reuse of material from MORE-CONNECT solutions</u>

MORE-CONNECT solution developed by Invela

The recyclability depends on the kind of material which is chosen for insulation material and for the finishing mortar and rendering.

For the façade insulation, various options are investigated, one of which is with a specific rock wool manufacturer. That manufacturer recycles all the insulation if during the construction process it is filled into bags, without any other materials. They deliver the bags for that purpose on site for free and they transport them back to the factory, also for free.

When using the Robot At Work solution as developed by Invela, there are specific opportunities for reuse in connection with the renovation of façades. The big benefits for recycling possibilities when using that solution is that it is thereby possible to remove the old layer of armored mortar, by milling the top 1-2 cm on the façade very accurately, and suck this material into bags. Afterwards the insulation material can be excavated and sucked into bags on site as wells. This process leaves the old facade or surface almost without any insulation on it. This process would be too expensive, if it had to be done by hand. It would also be impractical if the whole façade solution was first torn down, because then all the mortar would be mixed up with the insulation, and then the rock wool could not be reused.

This new solution has not been tested so far, yet it is considered to be possible to implement it. The process could be the same for other façade insulation solutions with mortar rendering as the finished layer, irrespective of the insulation material.

MORE-CONNECT solution developed by Innogie

The roof-integrated PV systems developed by Innogie are planned to be recycled at the end of their life-cycle. As indicated above, recycling of cadmium telluride is considered to play an important role to control the cadmium contained in the solar cells, and to ensure availability of tellurium as a raw material.

2.3 Options for materials in MORE-CONNECT solutions with respect to reuse

2.3.1 Introduction

In this chapter it is documented, which considerations have been made in the various MORE-CONNECT concepts developed in each geocluster regarding options for materials with respect to their potential for reuse. In particular, it is indicated which options for materials have been considered, what is known regarding the possibilities regarding the inclusion of reused materials or the future reuse of the materials in the MORE-CONNECT solutions, and which material options were chosen for which reasons. Factors are also taken into account which may lead to choices which do not favor the inclusion of reused material or the future reuse of material used in MORE-CONNECT solutions, for example economic considerations.

2.3.2 Experience in Latvia

The future reuse of thermal insulation components is one of the main aims of the retrofitting solutions applied by the MORE-CONNECT approach. The proposed technical solutions were evaluated in terms of possible future reuse/utilization.

The replacement of existing PVC windows is not considered in the retrofitting approach. PVC is extremely difficult to recycle, which has a negative impact on the reduction of the total environmental impact. The PVC replacement is considered to be developed further in the next 10 years.

Traditionally the majority of building materials in Latvia is recyclable. The building in the Latvian pilot case study has a relatively small area of external building envelope, which makes it more feasible to use previously used materials for retrofitting. Thus, in principle, there were opportunities for making use of reuse in the MORE-CONNECT pilot case study.

However, the inclusion of used material wasn't specifically taken into consideration due to the fact that the proposed solutions in the pilot were required to be replicable at a wide scale under current market conditions and to be produced on standardized manufacturing lines. During the preselection phase the focus was on materials which are already widely used by industrial partners and are available on the market. Furthermore, during the preselection process for the MORE-CONNECT pilots, the main target was to achieve cost optimal retrofitting solution. The reuse of building materials can potentially reduce total costs of retrofitting solutions. However, this is not sure yet. The estimation of such benefits requires additional precise economical calculations related to reuse options, beyond the scope of the MORE-CONNECT project.

The proposed concept options are based on a frame construction. Steel and timber frames were taken into consideration. As thermal insulation, mineral wool was considered as most flexible and cost optimal solution. Also EPS can be used as thermal insulation. However, it is less flexible, and joints in the carcass can reduce total energy performance of retrofitting solution.

According to Indriksone et al. 2011, a timber reuse is possible if timber can be dismantled without damage. Metal elements also are recyclable material. Both mineral wool and EPS are reusable materials. It can be concluded that available materials have a high reuse potential. However, embodied energy varies strongly for the mentioned materials.

Currently there is not any specific target which was established for the construction process with respect to reuse. The general guidance for the construction process is to use as little as possible fasteners and joins to ensure future reuse of timber materials and to facilitate the dismantling of panels' parts.

2.3.3 Experience in Portugal

Both the future reuse of MORE-CONNECT solutions as the reuse of previously used materials were active concerns during the design of the MORE-CONNECT solutions. At the end of the service life of a particular building where the MORE-CONNECT solutions are integrated, which may present higher durability than the service life of a conventionally renovated building, material used in the MORE-CONNECT solutions can be reused in other buildings or structures. The external/internal cladding of the façade modules include a recycled material which is made from waste materials from automotive industry, such as, kraft and cellulosic paper, polyurethane foam, fabrics and fibreglass.

Regarding the module structure (frame) both aluminum and wood were considered. The initial structure was considered to be in aluminum because it is a widely used material in Portugal in these types of prefabricated structures and in the construction sector in general. Although it presents a higher potential to be reused when compared to wood, its embodied energy (particularly during production), and consequently the embodied potential environmental impacts, is significantly higher than wood, which is a renewable material. At the end of the service life, wood can be easily reused for secondary materials (e.g. fibres) or used in processes of energy recovery. In addition, wood presents a higher thermal performance than aluminum, allowing avoiding thermal bridges, particularly in the connection between modules. For these reasons and in order to select an innovative solution for the prefabricated modules in the context of the MORE-CONNECT geocluster in Portgugal, it was decided to use a wood frame.

Regarding filling materials of the module, only polyurethane foam was considered, given its high thermal performance and high durability. The disadvantage is the fact that it is not mechanically recyclable. It would also be significantly difficult to separate and reuse the foam.

In the definition of the external and internal cladding of the module the materials considered were Coretech® (recycled material) and the cork slab. Cork is a natural and renewable material and its extraction is a sustainable process since it is not necessary to cut the cork oak to extract this material and its extraction is good for the life time of the oaks. Additionally it can be removed separately from the building elements, it can be reused in other structures or buildings or be recycled into new applications of thermal insulation or as an inert for lightweight concrete production. Coretech® is a recycled material made from waste components of the car industry. It presents attractive characteristics such as high durability, water and fire resistance and a very good thermal performance. It also presents a lower cost than the cork slab. Because of its properties, cork is an attractive material to be used. Nevertheless, the chosen option was to use Coretech® since it is a panel made of waste materials from the car industry, thus contributing to closing the loop of the materials life-cycle, besides of being cheaper.

In addition, all the chosen materials are non-toxic and inert when disposed in landfills, if there is no other possibility at their end-of-life.

The reuse possibility was taken into account although the final decisions to select the materials were not affected/influenced by that possibility since the reuse potentials of the materials were similar.

2.3.4 Experience in Czechia

In the Czech pilot within the MORE-CONNECT project, the possibility to recycle material at the end of the service life of the prefabricated elements was taken into account as much as possible. The focus is thereby less on direct reuse, and more on recycling in any form. Due to preference for solutions with shorter payback period, however, not all favourable solutions could be used.

In the Czech case, it has not been a specific objective during the design of the MORE-CONNECT solutions to make use of previously used materials in the prefabricated solutions, and such materials were not taken into consideration.

With respect to the construction process, external thermal insulation composite systems (ETICS) solutions are in most cases problematic for the reuse of materials as current technologies do not allow for easy separation of layers of thermal insulation and plaster and easy removal of plastic or metallic anchors and re-use of materials.

The materials for the preselection of the favorable concept to be tested in the pilot were chosen based on optimising for short payback time and low life cycle primary energy whilst maintaining long predicted service life. In some cases, biomaterials like wood fibre insulation get preference because of low embodied energy, in other cases traditional materials like glass fibre are more favorable due to lower cost or lower sensitivity to moisture.

In one case, regarding the use of textile reinforced concrete, a material was chosen which is less favourable for reuse, yet with has other advantages such as reduced amount of materials input.

2.3.5 Experience in Estonia

For the pilot of the MORE-CONNECT project in Estonia, a timber frame was chosen, as explained above, in combination with glass wool. Another material for thermal insulation would be cellulose insulation which is made of reused waste paper. The settlements of cellulose insulation, mainly during transportation, but also by changes in the ambient relative humidity and temperature, may prevent using this material. The adequate density of dry sprayed cellulose should be at least 80 kg/m^3 to minimize the settlements. This density requires twice as much material compared to typical wet sprayed cellulose and has 12% larger thermal conductivity (Smoljakova 2015).

2.3.6 Experience in the Netherlands

The future reuse at end of the service life of materials/components of the MORE-CONNECT solutions has been an objective during the design of these solutions. The patented Klik-Span solution is used to easily mount and dismount the façades on site. This mechanism replaces bolts and screws in the attachment process. The mechanism hooks and locks the façade onto the building. At the end of life of the façade, the mechanism is able to unlock the façade from the building, thereby making the separation process simple and quick. The façade is not damaged by the dismounting phase.

It has not been an objective during the design of the MORE CONNECT solutions to make use of previously used materials/components for these solutions.

As options for materials, different kinds of insulation have been considered for the MORE-CONNECT project. As a result of related evaluations, it was decided to stop using EPS, because the production of EPS causes a lot of CO_2 emissions. The alternative that is used now is more sustainable and is faster to produce. The material that is used now is Knauf Naturoll. The glass used in this material is recycled. This ensures a lower CO_2 footprint. Apart from this material, mainly wood was chosen as material for the pilot projects.

Frame/façade can easily be used two cycles. No research has been done for usage of the materials after this timeframe.

2.3.7 Experience in Denmark

The future reuse at the end of the service life of materials/components has been an objective during the design of the MORE-CONNECT solutions developed by Invela. From the start when the façade solution with robot technology was developed, it was an embedded request that the solution would have to be so flexible in its design and work capacity that a demolishing of the façade solution could be done without big changes.

It was not an objective, however, to make use of previously used materials/components in the MORE-CONNECT solution, because of the big variation of façade solutions and old materials, and to keep the focus on the new technology being developed.

The options for materials which were evaluated by Invela include:

- Spider foam, insulation spray from USA
- Foam concrete in general
- Thermosilit, insulating mortar from Salzburg
- Fixit 222, insulating mortar from Switzerland
- Multipor block insulation system from Switzerland
- Red Art Lamel Energy insulation system based on rock wool

While both the investigated Multipor block insulation system and the Red Art Lamel Energy insulation system have embedded recycling schemes for the material, the Red Art Lamel Energy insulation was considered to be economically advantageous. Furthermore, it offered to advantage of not requiring mechanical mounting of the insulation.

2.4 Intervention points in the supply chain with respect to reuse

2.4.1 Introduction

In this chapter, ideas are mentioned from the various geoclusters how the active reuse of building components and materials could be facilitated through interventions in the supply chain of MORE-CONNECT solutions.

2.4.2 Experience in Latvia

In order to promote the reuse of materials, the following is considered to be particularly important:

— It is necessary that the supply chain of MORE-CONNECT products uses national guidance and standard values on materials' environmental impact and focuses on materials produced in Latvia.

— In addition, it is important that technical data on used building materials is included in building documentation during the whole life time.

At a more detailed level, the following improvements of the MORE-CONNECT supply chain are envisaged to facilitate reuse in the future:

«Overview on reuse concept for MORE-CONNECT solutions»

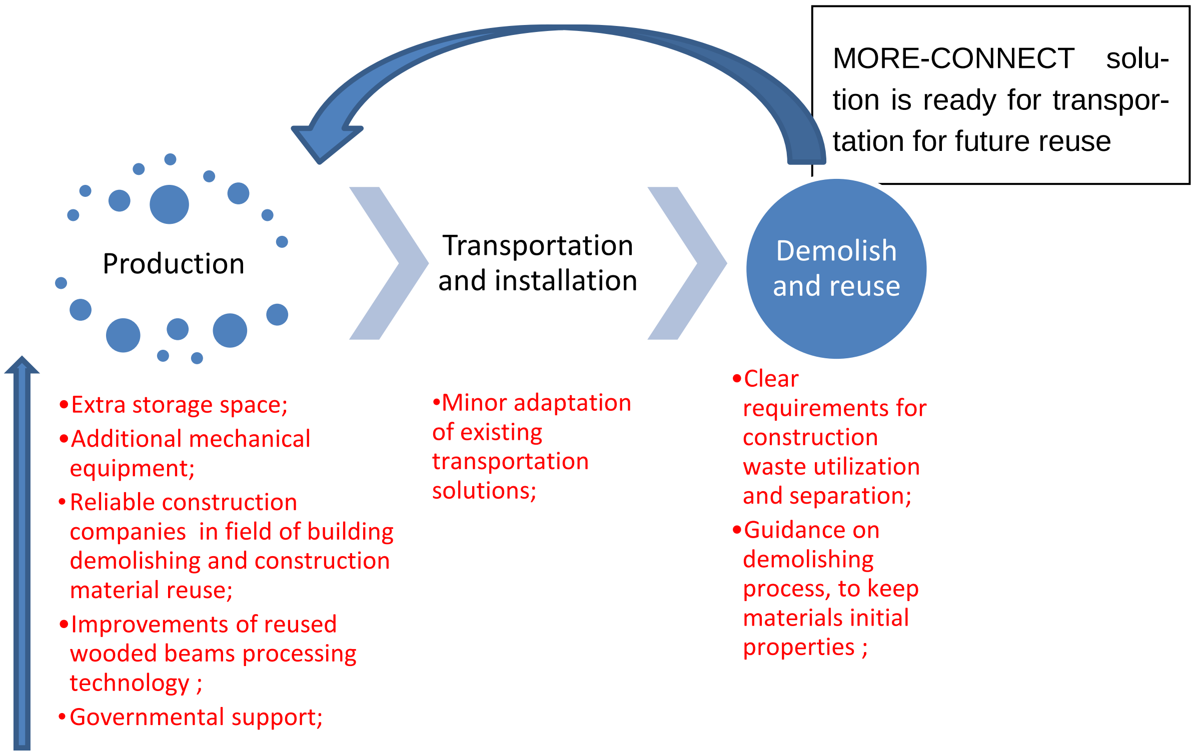

Figure 6: Overview on reuse concept for MORE-CONNECT solutions

In the figure above, in red colour the necessary improvements of the MORE-CONNECT supply chain are shown in order to implement application of reused building materials. As it can be seen, the existing supply chain can be easily adopted for use of previously used materials. MORE-CONNECT solutions facilitate future utilization of used materials as well as future separation and reuse after their life time.

2.4.3 Experience in Portugal

In Portugal there are no specialized companies for the disassembly of building components and for the characterization of materials resulting from this process. The specific amount of building components and materials resulting from the dismantling of buildings is unknown in Portugal. Additionally, the characteristics of this flow are also unknown, i.e. amount and type of materials, recycling potential, reuse potential, conformity with the pre-existing rules and standards regarding the reuse of materials in the manufacture of building products are not known. This is considered to be a main barrier in the reuse of building components and materials. While companies and procedures to foster the reuse of building components and materials do not exist, the building product companies should be responsible, to some extent, of ensuring that the different materials can be at least separated at the end of their service lives.

2.4.4 Experience in Czechia

For facilitating the active reuse of building components and materials through interventions in the supply chain of MORE-CONNECT solutions, a measure could be that producers introduce some kind of separated waste collection scheme.

2.4.5 Experience in Estonia

Reuse and recycling of demolished materials in new buildings constructed by professional companies is currently not popular in Estonia. As companies are required to guarantee quality, they do not like to take risks associated with reusing old materials. Reuse and recycling of demolished materials is popular to some extent by self-builders.

2.4.6 Experience in the Netherlands

The following possible ideas have come up regarding the question how the active reuse of building components and materials could be facilitated through interventions in the supply chain of MORE-CONNECT solutions:

- Material passports for the owner of the building: This method can help with the deconstruction of buildings. During deconstruction the building owner can then more easily decide what materials are suitable for another product.
- Design for disassembly: The MORE-CONNECT solution is already suitable for disassembly because this has been a topic during the design stage of the product.

- Patented technology: Klik-Span is a system that enables that the façade can be dis-assembled easily.
- Knowing the origin of the material: BJW has experience with EPS that was not produced properly. The EPS could not be reused again. BJW now makes sure that this does not happen again. BJW now works together with Kingspan-Unideck (NL) to ensure this.

2.4.7 Experience in Denmark

A possibility to further increase reuse of materials could be to ask suppliers of the rock wool material envisaged to be used in the pilots to reuse also the old demolished mortar in future cases.

3 Material alternatives in relation to the combined energy and materials impact of prefabricated elements

3.1 General opportunities and challenges with respect to the combined energy and materials impact

Materials differ with respect to their combined energy and materials impact. The combined energy and materials impact is considered here to refer to the combination of the impact of renovation measures due to the decrease in operational energy use for heating or cooling purposes on the one hand, and the impact of energy and emissions embodied in the materials on the other hand. Building renovation measures such as those with MORE-CONNECT solutions on the one hand reduce the operational energy use of the building, and, on the other hand, energy is necessary to produce the materials used for the MORE-CONNECT solutions, to put them into place, and to remove them at the end of their life cycle.

Here, «materials impacts» only means embodied energy and related climate change impact of the materials. There are important possible material impacts like scarcity and depletion of materials, pollution, disposal problems, etc. There are for example important scarcity/depletion reasons speaking in favour of reuse of building materials with respect to gravel, sand, and copper. There might also be strategic and geopolitical reasons for reduction of dependence of the construction industry on materials imported from far distances or unstable regions of the world.

The combined energy and material impacts are influenced both by the energetic properties of the materials in question, by reducing energy consumption and emissions, as well as the embodied energy associated with production, transport, use and disposal of the materials (Citherlet 2013). Only from a life-cycle perspective is it possible to take into account both aspects and to identify solutions which reduce the overall combined energy and material impacts most effectively.

The reuse of materials, as discussed above, is an important factor for reducing the combined energy and materials impact of renovation materials. There are also further factors beyond that.

In particular, bio-based materials play an important role in reducing the combined energy and materials impact of renovation materials, as their production often requires less energy input, causes less greenhouse gas emissions and is more sustainable than other types of materials. In its Strategy for a Bioeconomy for Europe, the European Commission calls for a partial replacement of non-renewable products by more sustainable bio-based ones in order to mitigate climate change (European Commission 2012).

Sometimes, there may even be trade-offs between the reuse of materials and the reduction of the combined energy and materials impact. Textile reinforced concrete (TRC), for example, is a composite which allows to reduce material input significantly. However, in comparison with pure concrete or steel-reinforced concrete, TRC, as composite material, can less easily be reused at the end of its service life. It is impossible to separate the fabric from the cement matrix easily. On the other hand, there are also positive sides suitable for discussion. High performance concrete is a non-absorbent material with high strength. If we crush it and replace a part of aggregates in new recycled concrete, there will be no problem with changing the amount of mixing water. This problem is currently with recycled concrete due to the water absorption of recycled aggregate using ordinary concrete. Furthermore, the effect of fibres on the mechanical parameters of the new recycled composite may be an interesting phenomenon because during crushing process of textile reinforced concrete a part of fabric will be damaged.

In countries which overall have a relatively cold climate, the application of relatively thick layers of thermal insulation is required. Thus, taking into account embodied energy is particularly important in these countries for ensuring good solutions with low total environmental impact.

3.2 Allocation of benefits associated with recycling on combined energy and materials impact

There are various approaches how the benefits in terms of reduction of greenhouse gas emissions and primary energy associated with recycling can be taken into account.

In literature, mostly two approaches are distinguished (Frischknecht 2010):

— **Recycled content approach**: According to this approach, emissions and primary energy use are allocated to a product taking into account the share of recycled material it contains. For the recycled material, only the energy use and emissions associated with the recycling are taken into account. No benefit is attributed to the material for future reuse of the material.

— **End of life recycling approach**: According to this approach, the benefit of avoiding emissions and energy use due to recycling of a product at the end of its life cycle is allocated to the primary product, not the recycled material.

As pointed out in literature, there are arguments for both approaches, and which approach is applied depends on the perspective which is taken. In the case of building renovation, the recycled content approach is considered to be appropriate. It reflects well the situation of an investor examining his or her available choices to reduce future non-renewable primary energy use and greenhouse gas emissions given the current situation, including options to make use of reused/recycled material, without the possibility of changing emissions that occurred in the past.

In the case of materials for building insulation elements, the end of life recycling approach is considered to be less suitable, because of the long service life of building elements and the related uncertainty as to whether by the end of the service life of the building elements potential benefits related to their recyclability will actually materialize. Nevertheless, it is considered to be important to take appropriate measures to facilitate the future reuse of the components of building elements at the end of their service life. The recycled content approach also has its limitations, as for example when a material is re-cycled into other product systems and the material's properties are thereby changed, the use of recycled material does not necessarily displace the use of primary materials.

Apart from the approaches indicated above there are further approaches. One of them is the resource flow approach (Rovers 2013). The starting point for that approach is the view that the original impact associated with the production of the primary material is not eliminated if something is reused or recycled. In that approach, recycling and reuse accordingly reduce the embodied impact per year of that material, yet the impact associated with the extraction of the material continues to be allocated in part also to the recycled and reused material. Accordingly, the emissions and the primary energy use associated with the extraction of a material from its environment are allocated to the related product over is primary use as well as all cycles of recycling and reuse. This approach thereby includes elements of both the recycled content approach and the end of life recycling approach.

3.3 Comparison of the combined energy and materials impact of various insulation materials

The embodied energy impact of various insulation materials is often found to be described in literature with the unit MJ/kg. An overview on related data is provided in the following table:

	Embodied energy, MJ/kg			
	Hammond and Jones (2008)	Hammond and Jones (2011)	Indriksone.et al. (2011)	Indriksone et al.,(2011a)
Stone wool	16.8	16.8	14 - 25	23.3
Glass wool	28	28	25 - 50	48.8
Sheep wool			15	
Polyurethane	72.1	102.1		
Expanded polystyrene	88.6	88.6	95 - 104	98.5
Woodwool (loose)	10.8	10.8		
Woodwool (board)	20	20		
Wool (recycled)	20.9	20.9		
Cellulose	0.94 – 3.3	0.94 – 3.3	4 – 8	7.03
Timber	8.5	10	4 – 9	3.06
Plywood	15	15		
Cork		4		
Flax		39.5		
MDF	11	11		9.32
Steel	24.4	20.1		
Steel (reused)	9.5	9.4		
Fibre cement board				13.9

Table 2: Comparison of materials' embodied energy

However, based on such numbers alone it is not straightforward to compare the material impact of various materials, as apart from the embodied energy expressed in MJ per kg of insulation material, other properties of the material play a role in determining how much embodied energy is necessary for achieving a certain thermal performance of the insulation. In particular, the density of the material and the thermal conductivity of a material influence the embodied energy impact of a material for achieving a certain energetic performance.

Furthermore, the useful life-time of a building material has an impact on the embodied emissions on an annual basis.

The following table provides an overview of some common insulation materials and indicates how much embodied energy and embodied emissions are necessary to improve a building's U-value from 1.0 to 0.1 W / (m^2 * K) with the related material, for illustration. Here, the embodied energy and embodied emissions data from Hammond and Jones (2011) have been used. The useful life-time has been assumed to be 40 years for all materials.

	Embodied energy, [MJ/kg]	Embodied greenhous gas emis-sions [kg CO_2-equiva-lent/kg]	Material density [kg/m3]	Thermal conductivity factor λ [W/(m*K)]	Embodied ener-gy to decrease U-value of wall from 1.0 to 0.1 per m^2, annual-ized over the life-time [MJ/(m^2 *a)]	Embodied greenhouse gas emissions to decrease U-value of wall from 1.0 to 0.1 per m^2, annualized over the life-time [kg CO_2-equivalent/(m^2 *a)]
	Hammond and Jones (2011),	Hammond and Jones (2011) KBOB et al. (2014)	Utochkina, E. (2014), Corklink (2016), Kymäläinen and Sjöberg (2008)	Utochkina, E. (2014), Corklink (2016), Kymä-läinen and Sjöberg (2008)		
Glass wool	28	0.36	28	0.0425	7.5	0.36
Rock wool	16.8	0.96	90	0.0425	14.5	0.96
Cellulose	2.1	0.26	45	0.04	0.9	0.11
Cork	4	0.19	105	0.04	3.8	0.18
Flax (Mat)	39.5	1.7	27.5	0.057	13.8	0.59
Polyurethane	102.1	4.1	42.5	0.0325	31.7	1.26
Expanded polysty-rene	88.6	2.6	22.5	0.0395	17.7	0.51

Table 3: Comparison of properties of various insulation materials and illustrative example of embodied energy and embodied emissions necessary to decrease U-value of the wall from 1.0 to 0.1 W / (m^2 * K) per m^2 of wall area, annualized over the lifetime of the insulation element. Here, mainly the embodied energy and emissions data mentioned above from Hammond and Jones (2011) are used. In addition, data from KBOB et al. (2014) is used for the embodied emissions of cellulose. Medium values were used when data ranges were provided.

The illustrative example shows that cellulose and cork requires the lowest amount of embodied energy to achieve a given insulation performance, followed by glass wool. Flax, rock wool and expanded polystyrene require larger amounts of embodied energy input, whereas polyurethane requires the highest amount of embodied energy input for the insulation materials listed. With respect to embodied greenhouse gas emissions, cellulose has the lowest impact, followed by cork. The third lowest impact on greenhouse gas emissions has glass wool among the materials indicated here, to achieve a given insulation performance, followed by expanded polystyrene and flax. Rock wool causes a larger amount of embodied emissions, and polyurethane has the highest impact in terms of embodied emissions.

The overview shows that bio-based materials such as cellulose and cork as well material containing a high share of recycled material such as glass wool have a particularly low impact on embodied emissions and embodied energy use for achieving a given insulation performance.

It has to be noted that life-cycle data for embodied energy use and embodied emissions depend on several assumptions in the related models, such as regarding attributions and exclusions in the models, energy sources, cultivation methods, production methods, etc. For example, in Zabalza Bribián (2011), cited in Lopez Hurtado (2016), a different allocation of embodied energy and embodied emissions regarding cellulose was carried out, taking into account the impact of the manufacture of newsprint, which represented then over 90% of overall embodied energy use attributed to cellulose. This is, however, not taken into account by other data sources applying the recycled content approach for the attribution of life cycle impacts. Zabalza Bribián (2011), cited in Lopez Hurtado (2016) nevertheless confirmed the overall low impact of bio-based materials on greenhouse gas emissions in comparison with other materials. In particular, the study concluded that wood wool has particularly low embodied greenhouse gas emissions.

Furthermore, it has to be taken into account that the embodied emissions and embodied energy use of building materials change over time. In particular, there may be changes for example because the energy system is more and more based on renewable energies or because the primary materials become scarcer and therefore more and more difficult to access.

3.4 Specific opportunities and challenges of MORE-CONNECT solutions concerning the combined energy and materials impact

3.4.1 Introduction

In this chapter, specific opportunities and challenges for MORE-CONNECT solutions with respect to the reduction of the combined energy and materials impact are documented per geocluster.

3.4.2 Experience in Latvia

Latvia has a relatively cold climate, insulation thicknesses are accordingly relatively large, which is why taking into account embodied energy is particularly important. Widely used thermal insulation materials in Latvia are mineral wool and expanded polystyrene

The specific challenge is to create a reliable network of suppliers and installers of eco-materials. Currently typical thermal insulation materials have an extended network of retailers, predictable materials properties, trained craftsmen. Materials with more favourable life cycle properties have to compete with such materials.

It is a challenge for both small companies carrying out conventional building renovation activities as well as industrial producers of prefabricated elements. Small companies offering innovative eco-materials are often not able to provide the necessary service and technical support. Producers of prefabricated houses and panels have to ensure the quality of their product at least for 35 – 50 year. This can be best done by using trusted and well know materials.

In the scope of the MORE-CONNECT project it was decided to use already well known materials with reasonably low level of embodied energy.

3.4.3 Experience in Portugal

There is a high environmental impact and embodied energy use of materials in the Portuguese construction sector. The MORE-CONNECT solutions have the opportunity of reducing the primary energy needs of the building by around 25% (84% reduction of the U-value of the exterior walls), thus reducing the potential environmental impacts of the energy used to control the buildings' indoor temperatures. Simultaneously, there is an opportunity to reduce the embodied impact of the solutions used in the energy renovation of buildings. The MORE-CONNECT solution is made of materials with lower potential environmental impacts than other similar products used in energy renovation projects, thus allowing improving the environmental life-cycle impacts of renovated buildings.

One important challenge for the dissemination of this solution might be the social acceptance of reused and recycled materials.

3.4.4 Experience in Czechia

With respect to the reduction of the combined energy and materials impact of the MORE-CONNECT solutions, a high potential is seen for biomaterials such as timber for structural elements or wood fibres as thermal insulation. In some cases, it has also already been possible to save absolute amount of used materials by using less materials of higher quality, for instance by using steel S355 instead of S235 for anchors.

3.4.5 Experience in Estonia

The challenge is considered to be mainly to decrease the price of MORE-CONNECT solutions. Less focus is therefore put on the use of materials with a small combined energy and materials impact. At the moment renovation with modular panels is still more expensive compared to external thermal insulation system (ETICS). Of course, the quality and installation speed of MORE-CONNECT solutions is better and long-term price is the same or even lower, but not all customers value that.

3.4.6 Experience in the Netherlands

In the Netherlands, the following opportunities and challenges were identified in connection with MORE-CONNECT pilot projects concerning the reduction of the combined energy and materials impact of the MORE-CONNECT solutions:

Opportunities

— When more knowledge develops in the supply chain, there is an opportunity that there is a larger demand for related solutions being developed in the MORE-CONNECT project.

— The Dutch MORE-CONNECT solution is mostly bio-based, because the main material used is wood. The share of bio-based material could be further increased by adding bio-based insulation. This, however, has a higher cost, therefore it is not used commonly.

Challenges

- This topic is at the moment not taken into account by almost anyone in decision making positions.
- There is not enough focus/knowledge on this topic in the supply chain.
- It is difficult to put economic value on this quality of the MORE-CONNECT solution.
- The price is too high at this moment for specific solutions which lower the combined energy and materials impact.

3.4.7 Experience in Denmark

In Denmark, opportunities were identified to reduce the combined energy and materials impact of materials in MORE-CONNECT solutions on the one hand with respect to the material for the wall insulation, and on the other hand with respect to the choice of the material for the photovoltaic panels.

3.5 Options for materials in MORE-CONNECT solutions with respect to the combined energy and materials impact

3.5.1 Introduction

In this chapter it is documented, which considerations have been made in the various MORE-CONNECT concepts developed in each geocluster regarding options for materials with respect to the reduction of the combined energy and materials impact. In particular, it is indicated which options for materials have been considered, what is known regarding the impacts of these materials, and which material options were chosen for which reasons. Factors are also taken into account which may lead to choices which do not minimize the combined energy and materials impact, for example economic considerations.

3.5.2 Experience in Latvia

A list of possible material alternatives which have a relatively low embodied energy use, except EPS thermal insulation material, is shown in Table 2. The precise evaluation of the embodied energy of the most relevant materials to be used in MORE-CONNECT solutions are shown in Table 2.

As it can be seen, polyurethane and polystyrene are the materials with the highest embodied energy among thermal insulation materials per kg of insulation. The materials with lowest embodied energy per kg of insulation are loose materials.

Polyurethane and polystyrene are not used in MORE-CONNECT solutions. According to existing studies the stone wool has an embodied energy value which is two times higher than wood wool. The most environment friendly material is cellulose. However, the mineral wool density varies between 50 – 120 kg/m^3 while the expanded polystyrene has a lower density range - 20kg/m^3 to 40kg/m^3, about half as high as mineral wool.

Thermal conductivity of cellulose is slightly higher in comparison to stone wool and varies in a range between 0.039 and 0.043 W/mK. Thermal conductivity of mineral wool, i.e. stone wool or glass wool, is 0.032 to 0.038 W/mK. The main reason why cellulose wasn't used in MORE-CONNECT is the absence of necessary equipment at the existing production lines. It would make sense to modify already existing production lines used by MORE-CONNECT project partners in the future to use loose materials.

It would make sense to carry out further studies which make complex comparisons between thermal insulation materials regarding their embodied energy impact taking into account the levels of density and thermal conductivity.

With respect to specific building materials, it can be noted that the application process for loose cellulose is associated with a high amount of dust. It is therefore in such cases important that the building envelope is airtight. The integration of ventilation duct can have a risk of cellulose loose dust infiltration into ducts. Special attention to ducts connection has to be paid during design and construction phase.

3.5.3 Experience in Portugal

The materials considered for the MORE-CONNECT concepts were the same as mentioned before in chapter 2.3. Both Coretech® and wood presented a lower impact on reducing heating needs in relation to the embodied energy necessary for their production in comparison with other materials, although no quantitative values are available at the moment. These materials were chosen because they were more sustainable, innovative and eco-efficient and enabled the same reduction of operational energy use. Both the selection of the wood frame instead of aluminum and the Coretech® instead of cork were based on the fact those materials have lower potential environmental impacts and their use will result in a product that has a competitive cost compared to other conventional renovation scenarios.

All the materials that constitute the MORE-CONNECT solutions are non-toxic or non-pollutant.

3.5.4 Experience in Czechia

As explained in chapter 3.2, and based on the experience from previous projects (Lupíšek et al. 2016) it was attempted to use biomaterials as much as possible. In some cases, this was feasible (timber for structural elements). In other cases the economic costs for making related improvements were significantly higher compared to traditional materials (for instance wood-fibre thermal insulation as a replacement for rock/glass wool), which disqualifies the use of materials with low environmental impact in common practice.

Furthermore, a set of variants was modelled for various targets in operational energy, taking into account embodied energy, within the framework of optimisations for the selection of the farouvable concept in WP6.

With respect to possible impacts on the indoor environment, it was recognized preference of natural materials is favourable in terms of VOCs.

3.5.5 Experience in Estonia

In Estonia, timber frames are used in the MORE-CONNECT pilot instead of light steel thermos-frame, in order to decrease the embodied energy of materials. The use of cellulose insulation was hindered because of setting during transportation, fire regulations and construction companies' small amount of experience related to working with this material.

3.5.6 Experience in the Netherlands

For the MORE-CONNECT pilot project in the Netherlands it was decided not to use EPS, due to its high embodied CO_2 emissions. Furthermore, 40% of insulation materials can come from used materials. Wood is used more efficiently because of laminating the wood that is FSC sourced. In addition, Fermacell uses 40% recycled material in their plate which is incorporated into the MORE-CONNECT design.

3.5.7 Experience in Denmark

MORE-CONNECT solution developed by Invela

For the MORE-CONNECT solution developed by Invela, there would be an opportunity to use the aerogel material Fixit 222 to lower combined energy and materials impact of the MORE-CONNECT solution. The aerogel is produced from limestone and has a particularly low amount of embodied energy. However, for the planned applications, the material was considered to be too costly. It was therefore necessary to look into other options such as multipore or rock wool. Both are similar with respect to embodied energy. After 1 to 2 years of operation of the renovated building, enough energy will have been saved to compensate for the embodied energy in the insulation material.

MORE-CONNECT solution developed by Innogie

The MORE-CONNECT solution developed by Innogie makes use of cadmium telluride (CdTe) solar cells. This type of solar cell has the specific advantage of being the PV technology with the lowest CO_2 footprint and the quickest energy recovery time. Accordingly, the choice of this material offers the opportunity to reduce the combined energy and materials impact of this MORE-CONNECT solution.

The CO_2 footprint results from the production and use of the following components:

Module:

- Glass
- semiconductor
- Laminate

Balance of System (BOS):

- Inverter
- Mounting
- Cabling

The energy recovery time is the amount of time a solar energy system has to run to generate as much energy as was required for its production. This figure is 0.79 years for CdTe in the scenario of open spaces and 1.30 years in the scenario of building roofs. The modules therefore produce a multiple of the energy used for their production over their lifetime. These values apply to the location Nuremberg for a Central European location with good irradiation values. For Southern Europe, even better values would emerge, for Northern Europe a bit less good values. In view of the fact that the PV systems are produced more and more efficiently, future energy return times can be expected to be even lower. The overall environmental impact associated with photovoltaic electricity generation is lower by a factor of 20 to 40 compared to the average electricity generation with fossil fuels.

3.6 Intervention points in the supply chain with respect to the combined energy and materials impact

3.6.1 Introduction

In this chapter, ideas are explored regarding the question how the combined energy and materials impact of building components and materials could be reduced through the MORE-CONNECT solutions by interventions in the supply chain.

3.6.2 Experience in Latvia

The MORE-CONNECT solution is based on mineral wool and similar boards. The currently existing supply chains offer the use of loose materials. As mentioned before, materials with particularly low embodied energy are mainly loose materials. However, so far, loose materials are not widely used.

MORE-CONNECT solutions offer good opportunities to make further use of materials with low energy and materials impact. MORE-CONNECT solutions can easily include environmental friendly materials such as loose fibre, hemp, cellulose. However main obstacles of implementation of such materials are not sufficient knowledge on materials properties and durability, lack of reliable supply sources as well as lack of trained craftsmen.

To make use of loose materials, the existing production lines have to be modified and staff has to be educated accordingly. All these measures require additional investments. Material with low energy and materials impact is therefore more costly. The use of natural materials with low level embodied energy can be stimulated by the reduction of local taxes and the introduction of subsidies for production line modernizations.

3.6.3 Experience in Portugal

The MORE-CONNECT solutions have the possibility to contribute to overcome some challenges of re-used/recycled materials, both on the user acceptance level and on testing new materials which are not of common application in the building sector. MORE-CONNECT solutions therefore offer the opportunity to introduce innovative materials.

3.6.4 Experience in Czechia

In order to promote the reduction of the combined energy and materials impact of building components and materials in prefabricated elements, a possible measure could be to show advantages more clearly to market actors, by making them aware of results of LCA comparisons of related good MORE-CONNECT solutions in comparison with alternatives.

3.6.5 Experience in Estonia

No specific intervention points have so far been identified in the supply chains in Estonia to reduce the combined energy and materials impact of building components and materials through the MORE-CONNECT solutions. So far, the Estonian legislation does not take this into account.

3.6.6 Experience in the Netherlands

The following ideas were gathered regarding the question how the reduction of the combined energy and materials impact of building components and materials could be promoted through intervention points in the supply chain:

- Creating demand by customers for taking into account embodied energy
- Using one standard to measure embodied energy
- Comparing products in a fair way, always according to one standard
- Governmental law: Incorporating this aspect into building regulations

3.6.7 Experience in Denmark

No specific intervention points have so far been identified in the supply chains in Denmark to reduce the combined energy and materials impact of building components and materials.

4 Conclusions

Based on the experiences obtained in the various geoclusters within the MORE-CONNECT project with respect to reuse and the combined energy and materials impact of materials, as well as on further research results taken into account, the following is concluded:

Prefabricated elements for building renovation offer interesting opportunities for increasing the reuse of materials and for using materials with low combined energy and materials impact. However, there are also various challenges involved, and as external thermal insulation composite systems they may be problematic for the reuse of materials.

There are significant synergies between the reuse of materials and the reduction of the combined energy and materials impact. The reuse of materials typically requires less energy input and causes less greenhouse gas emissions than to provide the related materials newly. However, there may occasionally also be trade-offs between the reuse of materials and the reduction of the combined energy and materials impact, as in some composite materials the amount of material input and the combined energy and materials impact is reduced at the expense of making the related material less easily reusable.

Each building material has advantages and disadvantages with respect to the combined energy and materials impact, its potential of making use of previously used materials as well as its potential for further reuse:

Wood or other bio-based materials

An attractive option for reducing the combined energy and materials impact is to make further use of wood or other bio-based materials. Such materials typically have the lowest energy and materials impact. Examples for such materials are wood beams for construction or window frames as well as cellulose, hemp and flax insulation materials, cork or wood wool. The use of related materials can be compensated by regrowing the resource, the embodied energy for processing is usually low and there are usually few problematic side effects.

Prefabricated elements offer the opportunity to make use of various types of loose materials, because the frame of those elements can provide the necessary stability to make use of such materials. In this way, particularly also loose bio-based material can be used. An interesting candidate for such a loose bio-based material is cellulose insulation. However, this material is associated with settlements, which may be caused mainly by shaking during transportation yet also by changes in the ambient relative humidity and temperature, which may prevent using this material. Another factor which is currently discouraging the use of loose bio-based materials is that lines for prefabricated insulation elements today still often lack the necessary equipment to make use of cellulose or other loose materials.

Other interesting bio-based materials are wood wool and wood wool boards. They may have the advantages associated with bio-based materials while avoiding the problem of settlements associated with loose material.

Nowadays bio-based materials are sometimes chemically treated. This may make reuse of related materials more difficult and may affect their combined energy and materials impact.

Another advantage of wood is that at the end of service life, untreated wood can easily be reused for secondary materials such as fibres. The use of timber for the frame of the prefabricated elements has the advantage that the related material is particularly well suited for reuse at the end of its service life. Wood can also be used as a renewable fuel at the end of the service life.

Cork is also an attractive natural and renewable material and its extraction is a sustainable process since it is not necessary to cut the cork oak to extract this material and its extraction is good for the life time of the oaks. Additionally it can be removed separately from the building elements, it can be reused in other structures or buildings or be recycled into new applications of thermal insulation or as an inert for lightweight concrete production. However, the availability of cork is limited.

Minerals

In general, it can be said that less treated and bulk applications have less impact, whereas processed materials have more impact. Glass wool can be made mainly from sand and recycled glass, with substantial savings in terms of embodied energy and embodied emissions. Accordingly, glass wool can be an attractive option as a material with a relatively low combined energy and materials impact.

Mineral wool is a reusable material, however, under current economic conditions such reuse occurs rarely.

Plastics

Plastics are often associated with relatively high amounts of embodied energy input. However, in cases such as polyurethane, the embodied emissions may nevertheless be smaller than in comparison with mineral based insulation materials. The reason is that in specific cases a relatively low amount of material may already provide a good insulation performance.

Some plastic materials such as EPS are reusable, while for example polyurethane foam is not. Polyurethane foam would also be difficult to separate during deconstruction. An alternative plastic material is a material made from recycled waste components of the automotive industry. It presents attractive characteristics such as high durability, water and fire resistance and a good thermal performance, at relatively low costs.

Metals

Usually, metals require a relatively large amount of energy in their production processes and have accordingly large amounts of embodied energy. Metal production processes may also have undesired side-effects.

Metals are particularly well suited for recycling; their recycling may require more energy input in comparison with the recycling of other materials, yet often the related energy input is significantly less than what is necessary for obtaining the primary materials.

5 Recommendations

5.1 Recommendations regarding material alternatives in relation to reuse

5.1.1 Recommendations for building companies

Based on experiences gathered in the MORE-CONNECT project, the following recommendations are made for building companies:

Recommendations for building companies with respect to the use of reused materials for the MORE-CONNECT solutions:

- Prefabricated elements often may facilitate the inclusion of previously used materials in building renovation processes.
- It is important that the potential of prefabricated elements for facilitating the reuse of materials is recognized and made use of.
- It is important that product companies declare the materials used for their products, provide the prerequisites to separate and reuse the components of their products and document for the building company materials used, embodied energy, separability and possibly indicate future reuse possibilities or decommissioning/disposal procedures.
- We recommend to take into consideration material reuse during development of retrofitting solutions.
- Currently simple utilization of construction waste isn’t too expensive and doesn’t require much extra effort, such as construction waste management and separation. Mandatory construction waste management and higher cost for utilization of non-separated construction waste will promote companies to provide service for construction materials' reuse.
- There is a market opportunity for specialized companies for the disassembly of building components and for the characterization of materials resulting from this process, as well as for technologies for processing construction and demolition waste into high quality recycled materials.
- A preference for external finishings other than those of the type of external thermal insulation composite systems (ETICS) would significantly improve future disassembly and recyclability.

Recommendations for building companies with respect to future reuse of parts and materials in MORE-CONNECT solutions:

- Prefabricated elements have the potential to both restrict and facilitate the reuse of building materials at the end of their life cycle. It is therefore important to take into account this topic in the design of the prefabricated solutions and in the declaration/labelling of the materials and components used, to provide the prerequisites for future reuse of components of prefabricated elements.

- The separation of elements is a specific challenge regarding the reuse of materials used in the fabrication of panels, which requires further attention.
- In particular, we recommend to ensure that prefabricated solutions are designed in a way that its components are easily dismountable and separable. We recommend to use as little as possible fasteners and joins, or at least to ensure they are easily separable, to ensure future reuse of timber materials and to facilitate the dismantling of panels' parts.
- We encourage to make use of the opportunity that industrial production of prefabricated elements offers to keep well track of materials used in the prefabricated elements and to facilitate thereby their reuse at the end of their lifecycle.
- We recommend to ensure that the design and the content of the prefabricated elements (declaration of materials used) are known and accessible to all stakeholders, to facilitate the reuse of their components.
- It would make sense to explore further a standardized approach of anchoring the prefabricated elements in a way that the modules are easily exchangeable piece by piece, without the need to replace the whole façade when a limited number of elements is at the end of their service life.

5.1.2 Recommendations for policy makers

One of the largest challenges regarding the reuse of materials is poor knowledge and lack of specific and detailed information by market actors. Traditionally, building companies do not have access to information regarding reuse/recycling of materials which enables them to choose one material instead of another. For example, there isn't systematic information regarding the type, quantity and characteristics of waste produced. In the same way, the environmental and societal benefits of using these materials and information regarding the security of using reused materials are not clearly documented. In order to reuse materials/components, it is necessary to precisely know their characteristics, and to address this through product/material declaration already in the production process and on the product. Also, there is some discomfort and scepticism in using «old» materials as new products. Provision of commonly available product information, comprising product declaration, application and performance characteristics, and trust-building projects can make an important contribution in overcoming related prejudices.

The following specific recommendations are made for policy makers to promote the reuse of materials in building renovation in connection with prefabricated elements, based on a literature review and experiences gathered in the MORE-CONNECT project (see also European Commission 2014, Dechantsreiter et al. 2015, Albrecht and Schwitalla 2014), referring both to the use of reused materials in prefabricated solutions as well as the future reuse of parts and materials:

— It makes sense to establish measures to track more systematically and to document more precisely the characteristics of materials used in construction processes, such as amount, properties and type of materials used, their recycling potential, their reuse potential, and their conformity with the pre- existing rules and standards regarding the reuse of materials in the manufacturing of building products. This is considered to be a key measure for facilitating the reuse of building components and materials. It is important that technical data on used building materials is included in building documentation during all of its life time. An important initiative in this context which we recommend to support further is a planned common framework of core indicators (European Commission 2014).We recommend to require that product companies declare the materials used for their products, provide the prerequisites to separate and reuse the components of their products and document for the building company materials used, embodied energy, separability and possibly indicate future reuse possibilities or decommissioning/disposal procedures. A measure with interesting potential to foster reuse would be the development of Environmental Product Declarations (EPDs) for building materials/components with respect to reuse. Companies could be given access to detailed information regarding the characteristics of those materials, and they could then more easily use and select the adequate material for a specific purpose.

— We recommend to pursue efforts to harmonize at European level the assessments and labeling for the environmental performance of materials with the Product Environmental Footprint method currently explored for measuring environmental performance.

— Another measure in this context could be to introduce a «building pass» which documents the materials used in the building, to facilitate further reuse at the time of renovation or destruction of a building.

— It would make sense to promote procedures for enabling reuse and recycling processes through which materials are separated directly at the deconstruction site, including if necessary also procedures to ensure that pollutants from construction materials are dealt with in an appropriate way.

— It also makes sense to gather and publish related information on an aggregated level, as a basis for providing guidance to market actors.

— We recommend in general to publish further information on the reuse of building components and materials.

— We recommend to include the topics of reuse of materials in the education and training of building professionals, to address the extensive lack of knowledge among field stakeholders regarding what type of waste material is available, their characteristics and how they can use it as new products.

— In order to promote the reuse and the recycling of construction materials it makes sense to introduce stricter requirements on construction waste utilization and separation. Building companies could be required to ensure that at least to some extent different materials used in the construction process can be separated at the end of the service life of materials, and that such waste separation is carried out. Related special legislation would allow to ensure stable supply of raw materials.

— It is important to charge disposal of building materials at least with the full overall costs for the society due to the disposal. Disposal charges or taxes higher than the costs incurred could further foster reuse of building materials. Tax revenues could be used to support information, data collection, building material collection and waste management logistics for building materials.

— It is important that demonstration projects showcase the safety and durability of reused materials, highlight the advantages of reuse as well as how to deal with related challenges, and generally increase acceptance by market actors.

— Policy makers could stimulate interest from house owners to use construction made from reused materials by giving tax incentives or subsidies to building renovations with low embodied energy. However, it is highly important to ensure that this does not counteract the insulation of building envelopes. Furthermore, it has to be taken into account that other approaches such as putting a general levy on energy use or emissions are likely to be easier to implement.

— Furthermore, economic incentives could be introduced to promote new types of business models which favour reuse of materials. The economic incentives can be direct or indirect. For instance, when the price for landfilling is increased, the re-use of materials becomes cheaper in relative terms compared to business as usual (indirect incentive). An example of a direct incentive could be subsidies by states, regions or municipalities for the collection of used materials.We recommend requiring public authorities to consider the use of reused materials in all of their building constructions and renovation activities, and to include related criteria in public tenders.

— We recommend requiring public authorities to consider the use of reused materials in all of their building constructions and renovation activities, and to include related criteria in public tend.

— We recommend to further explore a scheme for the collection of construction and demolition waste, similarly as it works for electronics now.

— We recommend to promote voluntary agreements of the construction industry with the government regarding the reuse of materials.

— We recommend to adopt regulations regarding the accountability and liability with respect to the reuse of building components and materials.

— We recommend to introduce a monitoring system for examining the progress with respect to the reuse of materials.

- European and national regulations may restrict the conditions under which re-use of some components and materials in the production chain of new materials and products are allowed; it would make sense to investigate and address related issues.
- We recommend to promote market structures for the sale and purchase of reused building components and materials, inter alia by cost-covering disposal charges etc.
- We recommend to integrate the reuse of components and materials as well as the reusability of such components and materials in labelling schemes.
- In order to promote the reuse of materials, it is necessary that the supply chain uses national guidance and standard values on materials' environmental impact and focuses on locally produced/reused materials.
- We recommend to prepare guidelines on how to maintain materials' initial properties in the demolishing process.
- We recommend to promote the generalized use of Environmental Product Declarations (EPDs).

5.2 Recommendations regarding material alternatives in relation to the combined energy and materials impact of prefabricated elements

5.2.1 Recommendations for building companies

Based on experiences gathered in the MORE-CONNECT project, the following recommendations are made for building companies regarding the combined energy and materials impact of prefabricated elements:

- For architects, engineers and other building companies we recommend to foster information and consciousness on the embodied energy of the materials applied in projects, to obtain the know-how to select products and processes that help reduce the overall energy footprint of buildings.
- The already existing production lines used by MORE-CONNECT project partners could be modified in the future in order to allow for thermal insulation the application of loose materials such as cellulose or wood fibres, which often have a particularly small overall combined energy and materials impact
- We recommend to establish a closer cooperation between panel manufacturers and producers of materials with low environmental impact to facilitate the use of such materials in panels.
- We recommend to carry out investments into production lines to increase the use of materials with low combined energy and materials impact

- We recommend to improve the knowledge of designers, engineers, planners, and production lines workers on the application of alternative materials in order to increase their capacity to make use of related opportunities.
- It is fundamental that the environmental impact of the products is taken into account in every construction company.

5.2.2 Recommendations for policy makers

The following recommendations are made for policy makers regarding the combined energy and materials impact of prefabricated elements, based on experiences gathered in the MORE-CONNECT project:

- We recommend to make databases of environmental impacts publicly available and to require that data is provided for specific products. Currently, the uncertainty in LCA data is quite high and the available databases in most countries do not provide specific data for a majority of available building materials.
- We recommend to provide a standard to measure embodied energy, and to ensure that various market products are compared in a fair way, always according to one standard.
- We recommend to make sure that embodied energy is commonly taken into account in the construction sector; this could be done by taking it up in building regulations and labels. In this context, we recommend to explore options to include embodied energy/emissions in overall targets related to energy/emissions in building construction or renovations, i.e. to specify labels and energy requirements as total energy/emission requirements, including embodied energy/emissions. Alternatively, we recommend to explore options for setting separate embodied energy targets or embodied emissions targets for building construction and renovations. In both cases it is important to make sure that there are not any unwanted negative effects such as creating obstacles for far-reaching renovations.We recommend to promote solutions based on prefabricated elements such as MORE-CONNECT solutions, as they can easily include materials with low environmental impact such as loose fibres, hemp or cellulose.
- We recommend to support the implementation of best practices regarding the materials with a low combined energy and materials impact through demonstration projects.
- We recommend to introduce a tax on energy or emissions, as it is a simple and effective solution to reduce embodied energy and embodied emissions.
- We recommend to educate and to train craftsmen, designers, engineers and planners in the topic of the combined energy and materials impact of prefabricated elements through inclusion of the topic in appropriate courses and other formation activities.

Literature

Albrecht W, Schwitalla C (2014) Rückbau, Recycling und Verwertung von WDVS. Möglichkeiten der Wiederverwertung von Bestandteilen des WDVS nach dessen Rückbau durch Zuführung in den Produktionskreislauf der Dämmstoffe bzw. Downcycling in die Produktion minderwertiger Güter bis hin zur energetischen Verwertung, Stuttgart (Deutschland), Fraunhofer IRB Verlag, https://www.baufachinformation.de/literatur/15029008835 [last accessed 2016-10-31]

AEA (2010) Green Public Procurement - Thermal Insulation Technical Background Report, mandated by the European Commission

Bau EPD GmbH 2014. Mineral insulation materials made of glass wool Saint-Gobain ISOVER Austria GmbH. Bau EPD GmbH, A-1070 Wien, Seidengasse 13/3

Zabalza Bribián I., Valero Capilla A., Aranda Usõn A. (2011) Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential, Build. Environ. 46 (2011) 1133-1140

Citherlet St., Favre D., Perriset B.(2013) Methodology to assess the environmental impacts of renovated buildings; draft paper Subtask A3, IEA Annex 56, University of applied sciences of Western Switzerland

Chira A, Kumar A, Vlach T, Laiblová L, and Hajek P (2016) Textile-reinforced concrete facade panels with rigid foam core prisms, J. Sandw. Struct. Mater., vol. 18, no. 2, pp. 200–214, Mar. 2016.

Corlink (2016) Technical data sheet – ICB Insulation Corkboard http://www.corklink.com/wp-content/uploads/2012/09/expanded-cork-technical-data.pdf [last accessed 2017-11-20]

Dechantsreiter U, Horst P, Mettke A, Schmid S, Knappe F, Reinhardt J, Theis S, Lau J (2015) Instrumente zur Wiederverwendung von Bauteilen und hochwertigen Verwertung von Baustoffen, Umweltbundesamt

de Brito M. P., Dekker R. (2003) A framework for Reverse logistics, Erasmus Research, Institute of Management, Rotterdam

European Commission (2011) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Roadmap to Resource Efficient Europe, COM(2011)571

European Commission (2012) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Innovating for Sustainable Growth: A Bioeconomy for Europe, COM(2012)11

European Commission (2014) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on Resource Efficiency Opportunities in the Building Sector, COM(2014)445

European Commission (2015) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Closing the loop – An EU action plan for the Circular Economy, COM(2015)614

Fiala C (2011), Optimalizace betonovỳch konstrukcí v environmentálních souvislostech, Nakladatelství ČVUT, 2011, ISBN 978-80-01-04663-0.

Fthenakis V. (2004) Life cycle impact analysis of cadmium in CdTe PV production, Renewable and Sustainable Energy Reviews. 8 (4): 303–334.

Frischknecht R (2010) LCI modelling approaches applied on recycling of materials in view of environmental sustainability, risk perception and eco-efficiency, The International Journal of Life Cycle Assessment, vol.15, No. 7 (2010); p. 666-671

Hammond, G. P. and C.I. Jones, 2008. “Embodied energy and carbon in construction materials,” Proc. Instn. Civil Engrs.: Energy, 161 (2): 87–98

Hammond G. and Jones C, 2011, Inventory of Carbon & Energy, (ICE) Version 2.0, Summary Tables, University of BathIndriksone D., Brēmere I., Aļeksejeva I., Grätz M., Oisalu S., Navickas K., Löfflad H. (2011) Ecology of construction materials. Ecoprint AS, Estonia 87 p.

Indriksone D., Brēmere I., Aļeksejeva I., Grätz M., Oisalu S., Navickas K., Löfflad H. (2011) Ecology of construction materials. Ecoprint AS, Estonia 87 p.

Indriksone D., Brēmere I., Aļeksejeva I., Grätz M., Oisalu S., Svirskaite J. (2011a) Using ecological construction materials in the Baltic States. Ecoprint AS, Estonia 39 p.

KBOB, eco-bau and IPB (2014) Ökobilanzdaten im Baubereich, Empfehlung Nachhaltiges Bauen 2009/1:2014, Herausgeber: KBOB Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffenetlichen Bauherren, eco-bau Nachhaltigkeit im öffentlichen Bau, IPB Interessengemeinschaft privater professioneller Bauherren, https://www.eco-bau.ch/resources/uploads/Oekobilanzdaten/kbob-Oekobilanzdaten-Empfehlung_29_07_2014.pdf [last accessed 2017-11-20]

Kim J, Rigdon B, Graves J (1998) Qualities, Use, and Examples of Sustainable Building Materials, College of Architecture and Urban Planning, University of Michigan, published by National Pollution Prevention Center for Higher Education

Künzel H., Riedl G. and Kießl K (1997) Praxisbewährung von Wärmedämmverbundsystemen. IBP-Mitteilungen 316.

Kuusk, K.; Ilomets, S.; Kalamees, T.; Tuudak, S.; Luman, A. (2014). Renovation vs. demolition of an old apartment building: energy use, economic and environmental analysis.

NSB 2014 10th Nordic Symposium on Building Physics, 15-19 June 2014, Lund, Sweden. Ed. J. Arfvidsson, L-E. Harderup, A. Kumlin, B. Rosencrantz.

Kymäläinen, H-R and Sjöberg A-M (2008) Flax and hemp fibres as raw materials for thermal insulations, Building and Environment 43 (2008) 1261-1269

Laiblová L, Vlach T, and Fiala C (2015) Fasádní panely z textilního betonu z pohledu hodnocení jejich životního cyklu LCA, Czech J. Civ. Eng., vol. 2015, no. 2, pp. 86–92.

Laiblová L, Vlach T, Kumar A, Chira A, Ženíšek M, and Hájek P (2016) Development of Lightweight TRC Panel for Sustainable Building Envelope, Cent. Eur. Sustain. Build. 2016 Innov. Sustain. Future, vol. 2016.

Lopez Hurtado P., Rouilly A., Vandenbossche V., Raynaud C. (2016) A review on the properties of cellulose fibre insulation, Building and Environment 96 (2016) 170-177

Lupíšek A, Nehasilová M, Mančík Š, Růžička J, Fiala C, Tywoniak J, Hájek P (2016) Design strategies for buildings with low embodied energy, Proceedings of the Institution of Civil Engineering

Marwede, M., and Reller, A. (2012) Future recycling flows of tellurium from cadmium telluride photovoltaic waste, Resources, Conservation and Recycling. 69: 35–49.

Neumann H (2009) Praxis-Handbuch Wärmedämm-Verbundsysteme, Verlagsgesellschaft Rudolf Müller Gmbh & Co. KG, ISBN 978-3-481-02154-2.

Ott W, Bolliger R, Ritter V, Citherlet S, Favre D, Lasvaux S, Périsset B, de Almeida M, Ferreira M (2016) Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56); Energy in Buildings and Communities Programme, http://www.iea-annex56.org

OVAM Ecolizer (2011), Ecolizer 2.0 Ecodesign Tool http://www.ecodesignlink.be/images/filelib/EcolizerEN_1180.pdf [Last accessed 2017-08-25]

Riedel W et al. (2010) Wärmedämm-Verbundsysteme: Von der Thermohaut bis zur transparenten Wärmedämmung. Baulino Verlag GmbH, Fraunhofer IRB Verlag, 2010. ISBN 978-3-938537-12-1, 978-3-8167-8235-3, 978-3-938537-01-5.

Rovers R (2013) Valuing the Impact of Recycling: Its New, unless … - a Theoretical Exploration of the Impact of Re-Use and Recycling. In Proceedings of the World Resource Forum, Davos, Switzerland, 7–9 October 2013.

Smoljakova, K. 2015, Cellulose fibers and its properties and using for the envelope insulation (Tselluvill ja selle omadused ning kasutamise võimalused välispiirete soojustamisel), Master's Thesis, (sup) Martti-Jaan Miljan; Jaan Miljan, Estonian University of Life Sciences.

U.S. Department of the Interior (2005) Environmental Considerations of Building Insulation National Park Service – Pacific West Region, https://www.doi.gov/sites/doi.gov/files/migrated/greening/buildings/upload/iEnvironmental-Considerations-of-Building-Insulation-National-Park-Service-insulation.pdf [last accessed 2016-10-31]

Utochkina, E. (2014) Heat insulation materials from environmantal aspect, Saimaa University of Applied Sciences, Bachelor thesis

Vlach T, Hájek O, Fiala C, Laiblová L, Řepka J, and Kokeš P (2016) Waffle Facade Elements from Textile Reinforced High Performance Concrete, Proc. HiPerMat 2016 - 4th Int. Symp. Ultra-High Perform. Concr. High Perform. Constr. Mater., vol. 2016, p. 10.