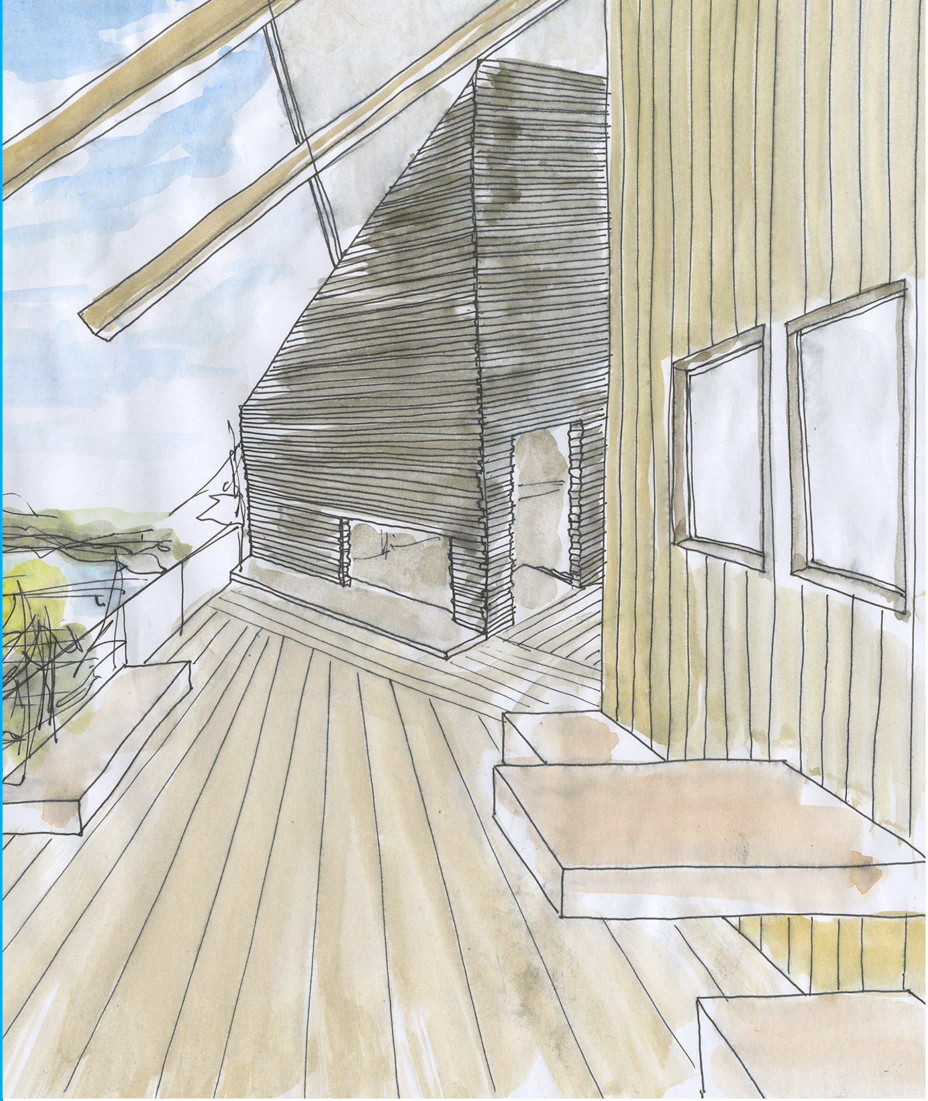


TECHNOLOGY • RESEARCH HIGHLIGHTS • VISIONS • SCIENCE •
200

# Re-use of structural elements

## Environmentally efficient recovery of building components

Petr Hradil | Asko Talja | Margareta Wahlström |
Satu Huuhka | Jukka Lahdensivu | Jussa Pikkuvirta

VTT TECHNOLOGY 200

# Re-use of structural elements

## Environmentally efficient recovery of building components

Petr Hradil, Asko Talja, Margareta Wahlström

VTT Technical Research Centre of Finland

Satu Huuhka, Jukka Lahdensivu, Jussa Pikkuvirta

Tampere University of Technology

ISBN 978-951-38-8197-9 (URL: http://www.vtt.fi/publications/index.jsp)

VTT Technology 200

ISSN-L 2242-1211
ISSN 2242-122X (Online)

JULKAISIJA – UTGIVARE – PUBLISHER

VTT
PL 1000 (Tekniikantie 4 A, Espoo)
02044 VTT
Puh. 020 722 111, faksi 020 722 7001

VTT
PB 1000 (Teknikvägen 4 A, Esbo)
FI-02044 VTT
Tfn +358 20 722 111, telefax +358 20 722 7001

VTT Technical Research Centre of Finland
P.O. Box 1000 (Tekniikantie 4 A, Espoo)
FI-02044 VTT, Finland
Tel. +358 20 722 111, fax +358 20 722 7001

Cover image: Haruka Maitani

# Preface

This publication was produced within VTT Technical Research Centre of Finland and Tampere University of Technology research project Rakennuselementtien uudelleenkäyttö (ReUSE) jointly financed by Ministry of the Environment, Finnish Wood Research, Ekokem, VTT and Tampere University of Technology. The project aims are to support C&D waste reduction, preserve natural resources and reduce overall the environmental impacts of buildings by encouraging the re-use of the building components. It is closely related to the national programme promoting resource and material efficiency, Kestävää kasvua materiaalitehokkuudella.

The aim of our research project is to contribute to reaching European policy initiatives towards a resource-efficient and low-carbon economy. It strives to create a better understanding of the end-of-life scenarios of building structures and the possible ways in which the environmental, economic and cultural values of their components can be preserved. Our goal was to approach all aspects of sustainability equally as well as all aspects of the major building materials.

It is our hope that those with the responsibility for building waste reduction and $CO_2$ governance at all levels will find useful information and inspiration in this publication.

The authors

# Contents

**Appendices**

**Abstract**
**Tiivistelmä**

# 1. Introduction

Petr Hradil

The European Parliament and Council published the revised directive on waste in 2008 [1], laying down the measures to prevent the negative effects of waste generation and to set up the overall rules for waste management.

Waste is defined in this directive as “any substance or object which the holder discards or intends or is required to discard”. Re-use means, according to the directive, “any operation by which products or components that are not waste are used again for the same purpose for which they were conceived”. Preparing for re-use means “checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing”. It should be noted that the definition of “re-use” in the directive is rather narrow and components that are not becoming waste, but are used for a different purpose are not covered by the definition. In the first case (object becoming waste), the end-of-waste criteria have to be fulfilled for successful re-use, especially that “(a) the substance or object is commonly used for specific purposes, (b) a market or demand exists for such a substance or object, (c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and (d) the use of the substance or object will not lead to overall adverse environmental or human health impacts.”

More than 4 tonnes of construction and demolition (C&D) waste per capita is generated in Finland every year. This waste contains over 75% of soil and other excavation which is normally not being accounted for. Therefore, the estimated amount of C&D waste in Finland (1 ton per capita) is below the EU-27 average of 1.1 tons per capita. Approximately 77% of this waste is recovered according to the VTT study [2], and 26% is re-used or recycled according to the BIO Intelligence Service estimation [3] based on 2009 data.

The possible reduction of C&D waste and non-renewable resources consumption by direct re-use of building elements is studied in detail in our reports [4–7] and summarized in this publication.

## 1.1 Scope and goals of this publication

The main motivation for publishing this book has been the implementation of the strategy for sustainable Europe [8] in the building sector through the reduction of construction and demolition waste. One of the most efficient ways to mitigate the environmental burden created by discarding or remanufacturing building materials is to re-use them as whole building elements. This publication focuses on structural elements that are parts of the load-carrying structure of the building or the secondary elements such as cladding and roofing panels. In this publication, re-use is defined as: *“the process when structural element is used again for the same structural purpose or another purpose in the built environment”*.

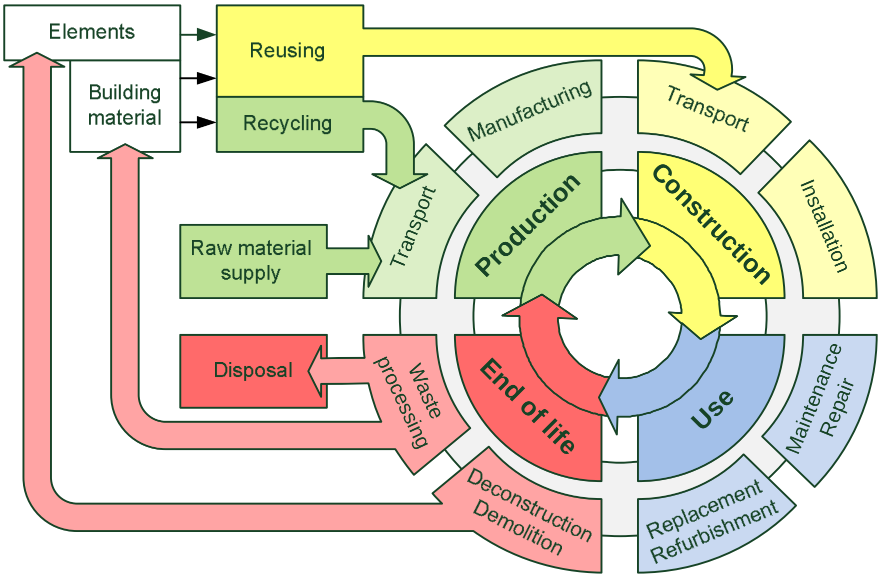


**Figure 1.** Structural elements life cycle

As can be seen from Figure 1, our definition of re-use includes building parts deconstructed especially for this purpose and the elements recovered from the demolition waste. The basic materials in the book are divided into three groups:

**Timber –** structural timber, engineered wood products (such as glulam, LVL) and wood based panels.

**Steel –** structural carbon and stainless steels, other alloys used in load-carrying structures may be also included.

**Concrete –** plain, reinforced or pre-stressed concrete elements or similar masonry products.

## 1.2 The ReUSE research project

The ReUSE project addresses the potential and challenges currently facing the re-use of elements from existing buildings and design for re-use in new buildings in order to support sustainable growth by reducing C&D waste, pollution, natural resources consumption, and the costs of manufacturing such elements. The project has a particular focus on larger structural elements in commercial, industrial and residential buildings (columns, beams, wall panels, and floor and roof elements) connected by mechanical joints and made, for instance, from steel, precast concrete, engineered timber (e.g. CLT, LVL, glulam) or timber-based materials. Many of these elements are currently difficult to re-use in new buildings. Recycling and other means of recovery or disposal thus create a considerable environmental burden. Re-use is of course different from recycling itself, for which elements will not be transformed (repaired, repainted, recoated) but sent to a recycling facility.

Re-use, an alternative solution to recycling and remanufacturing, exploits the potential of existing technologies and services, but also introduces new ones creating business opportunities for existing and newly emerging companies. The goal of re-use is to support such recovery processes that result in the same grade of product; no down-grading should occur; and the recovery should be as economical as possible in terms of money and environmental impacts. Some remanufacturing may be required even in the case of re-use, but the cost should be generally much less when compared to recycling by e.g. re-melting steel. In order for larger scale re-use to become feasible, we consider the whole life-cycle of building elements. Therefore, current technological and institutional factors as well as existing government interventions and policies that either promote or (potentially) hinder the re-use of building components are addressed within the project. Selected topics were studied, discussed and evaluated together with stakeholders in several seminars and workshops.

## 1.3 Obstacles to and opportunities for the re-use of structural elements

Returning the structural components back to service in the built environment is a rather complex process affecting all the parties involved in the life cycle. Designers have to consider the new source of materials and carefully plan for deconstruction, increased demand for coordination and flexibility in decision making will be needed during construction, and finally new business areas can be opened up to provide services for the phase between deconstruction and new building.

The process depends strongly on the size and complexity of the element or structure that is being re-used. We have proposed five categories from the smallest blocks (e.g. bricks and boards) to whole building frames (see Figure 2).

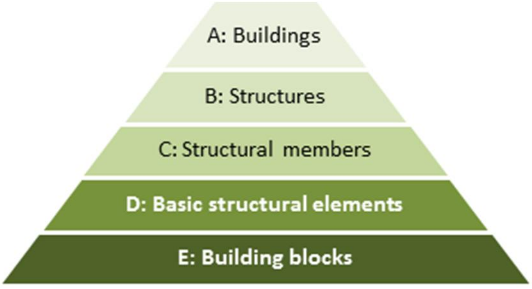


**Figure 2.** Categories of structural elements

Building elements of a higher category can often be separated into several elements of a lower category. Even though the higher category element is typically more valuable than all its parts taken together, the separation would make sense, because it may be more difficult to find a suitable application of higher category elements.

All of the possible re-use scenarios will have different impacts on sustainability, meaning society, the environment and the economy together. We have reviewed the most important issues [4] arising from the collected reports of case studies and conducted a survey to assess the importance of various obstacles to and benefits in re-use. The results of our survey show that the professionals in the building industry, administration, research and education generally have a very positive attitude towards the re-use of structural components (see Figure 3). The greatest benefit was identified in environmental aspects as much as in savings on energy, waste and raw materials (Figure 5). On the other hand, the lack of standards and legislation for building materials was evaluated as the biggest obstacle to structural elements re-use (Figure 4). Each answer was evaluated on a scale from -2 (not important at all) to +2 (very important) and the average score is represented next to the category name in Figure 4 and Figure 5.

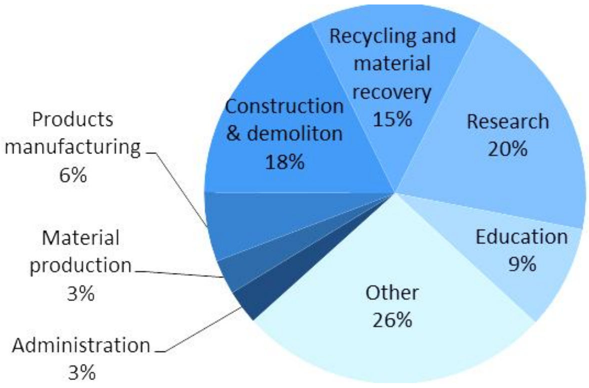


**Figure 3.** Participants in the survey

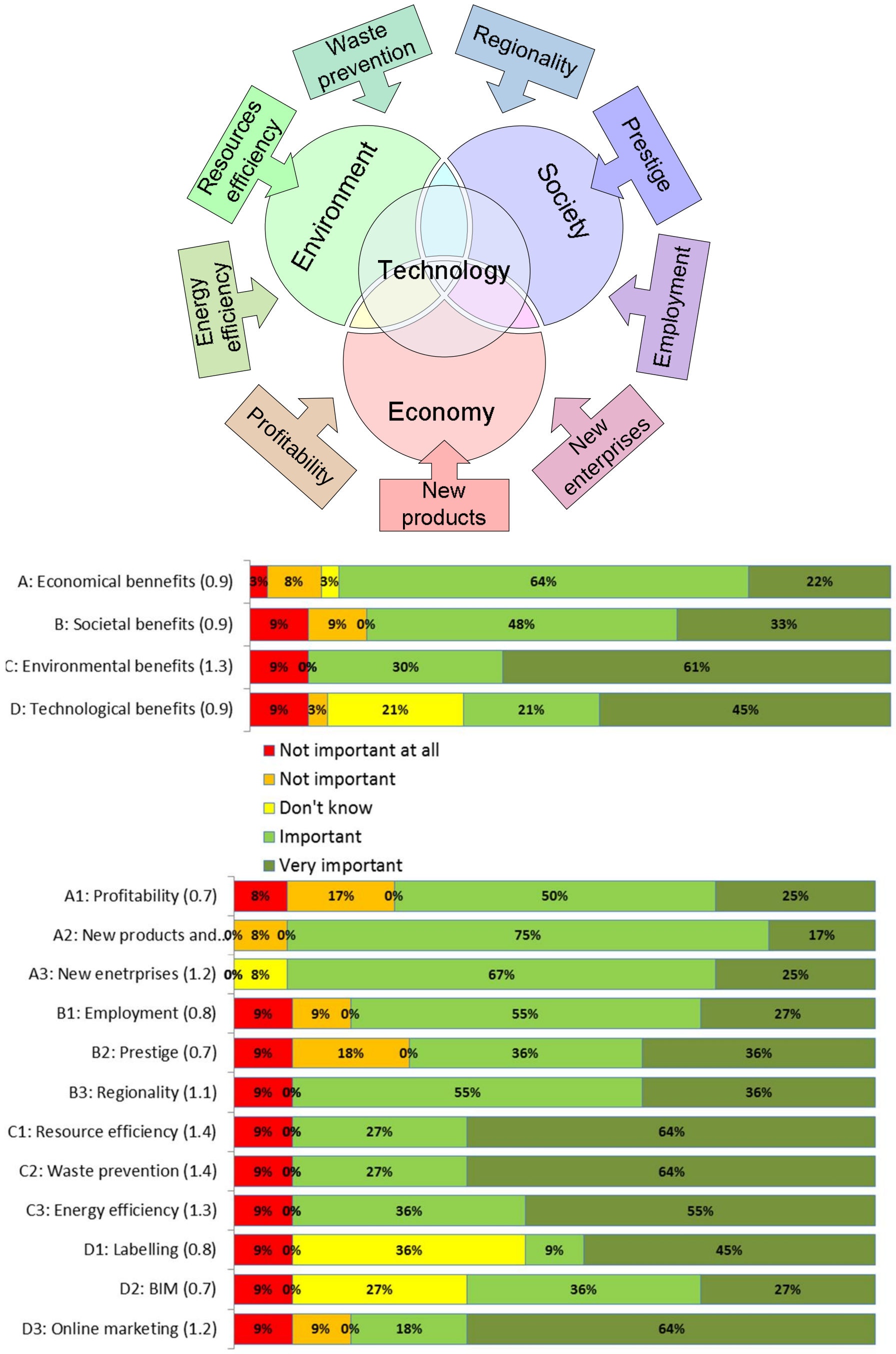


**Figure 4.** Benefits of re-use; survey results

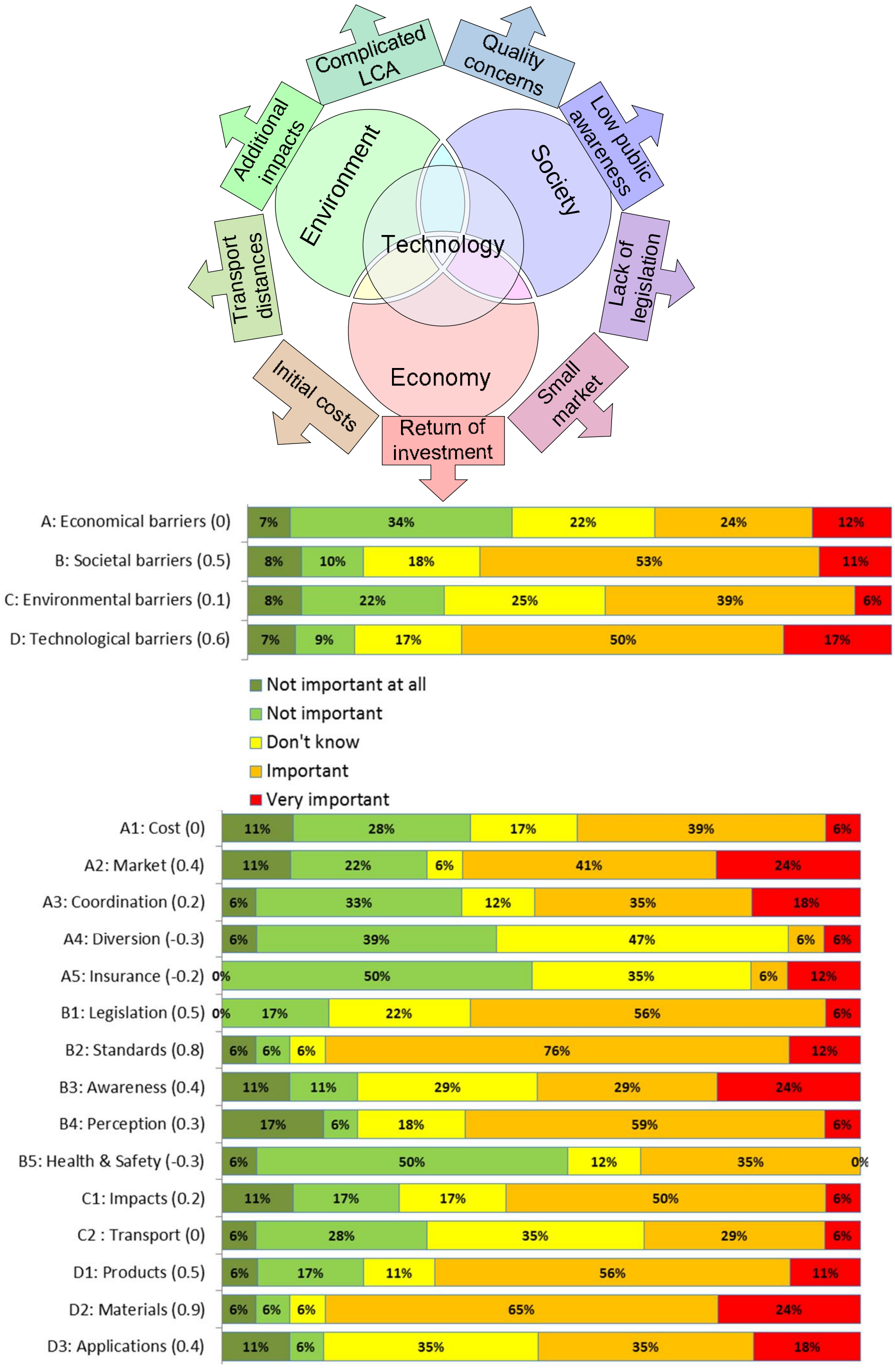


**Figure 5.** Obstacles to re-use; survey results

## 1.4 The major roles in the re-use process

Re-use of building components is a rather complex process. Many different businesses interact over a long building life. Their effect on the whole re-use cycle is described in the following glossary and Figure 6.

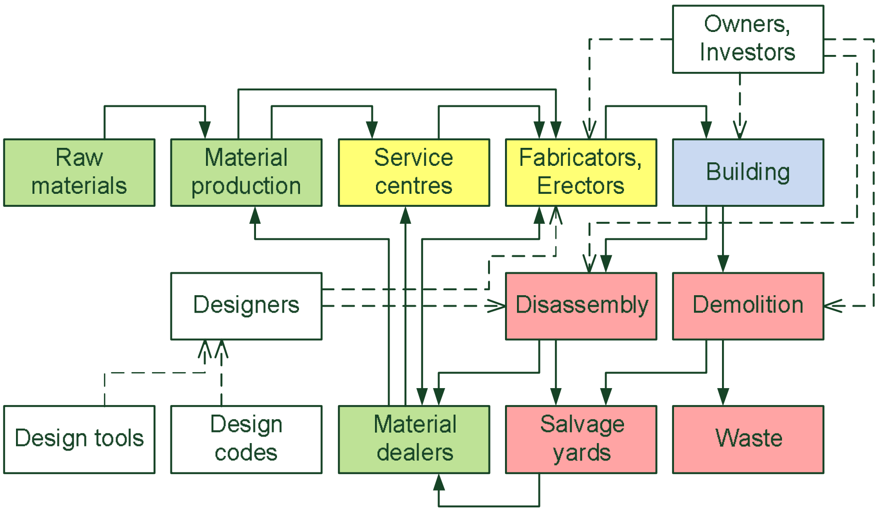


**Figure 6.** Major roles in the re-use process and their interaction

**Designers –** Designers have one of the most important roles in the re-use of structural elements. Their documentation, drawings and instructions significantly affect the effort needed in the building deconstruction. Not only selected components and technologies are important, but also the way in which the availability of final design documentation will be secured for the whole life span of the building. The maximization of environmental, cultural and financial value at the end of the building's life should be considered already in the design stage. Designers have to gain access to the information about the actual and potential supply of reclaimed components, sizes and material grades, and they need to be flexible so as to adapt to the current situation.

**Owners and investors –** A re-use project can be successful only when it is fully supported by the building owner or investor. Therefore, the building owners and investors are as important as the designers. They need to understand the process and its advantages and drawbacks. Education and the demonstration of successful cases should be the way to increase building owners' and investors' motivation.

**Raw materials –** The increasing demand for building materials is placing great pressure on natural resources. Moreover, raw materials are becoming scarce and more expensive. Material extractors will have to adapt to this change in order to avoid reducing their operations and profitability.

**Material producers (mills) –** The production process vary with the material. Raw material and in most cases also recovered waste (e.g. steel scrap) is utilized to produce new building material that is sold directly to the service centres or fabricators.

**Service centres –** Service centres are businesses that inventory and distribute materials for industrial customers and perform first-stage processing. They act as intermediaries between the producers and the fabricators, and other end users.

**Fabricators and erectors –** Fabricators purchase materials from service centres or directly from producers and fabricate the individual components that are needed to assemble a building. Some fabricators also have their own erection crews to assemble the components at the building site. Others subcontract the erection to independent organisations. Fabricators may send any waste and offcuts back to mills for recycling, usually through a dealer. Some of the fabricators will occasionally dismantle old structures and re-fabricate the reclaimed elements for new uses. A minority may have a small stock of building parts that has been reclaimed waiting for appropriate new uses.

**Buildings –** The way buildings can be assembled to maximize the usefulness and value of components at the end of a buildings life needs to be clearly demonstrated to the construction industry. The growing number of projects successfully shows how components from an old building or structure can be re-used in a new building, thus reducing the environmental impact, but the communication of such successful cases to the construction practitioners is not sufficient at the moment.

**Demolition –** Current building removal practices predominantly mean a process of destructive demolition by heavy machinery. There is a perception that manual extracting of building elements from buildings for re-use leads to additional problems and costs. However, even separation of re-usable components from the demolition waste may lead to significant recovery amounts.

**Disassembly –** The re-use of components can be maximized only when careful disassembly is carried out. Many projects have shown that disassembly is possible and should be considered. The volume of disassembled building components will increase as the demand for them increases.

**Salvage yards –** Salvage yards store building elements for re-use and recycling. A few salvage yards will extract components when they recognise the potential for re-use.

**Material dealers –** Dealers sell waste materials for recycling and re-use. Material is sorted, graded, batched, and sold back to producers for recycling. These organisations will also often buy waste materials arising during fabrication and from other sources. Material dealers will often try to sell reclaimed material directly from the demolition site.

**Design codes –** The benefits of re-use can be greatly improved if building codes emphasize the environmental aspects of the construction and give designers more opportunities for material sourcing. The immediate goal should be to enable structural elements re-use by establishing clear rules for the material grading and safety of structures designed from reclaimed components.

**Design tools –** The rapidly developing area of design software is currently able to offer many useful tools for the environmental optimization of buildings. As the buildings components are physically re-used, they can also be re-used digitally. The implementation of building information models (BIM) is essential to manage the smooth transfer of building elements between two different projects.

# 2. Assessing the potential for re-use

Satu Huuhka

Conventionally, the study of demolished buildings has focused on calculating material masses for waste statistics. However, in order to assess re-use potential in the demolished or vacant part of the building stock, a more refined approach is necessary. In the global context, appropriate data is usually not available. What is exceptional in Finland is that the same information is withheld in the official Building and Dwelling Register about existing buildings as well as vacant, abandoned and demolished buildings. In this chapter, we present our first approach to utilize this data for the benefit of reuse research.

## 2.1 Current demolition profile and simultaneous construction activity

In the first section of the study, demolished buildings were examined as constructions with intrinsic intended usages and materials and other characteristics. Special weight was given to a geographical examination of the location of the buildings. In addition, demolition was compared to simultaneous new construction. The research material was extracted from different sources of statistics as well as from the Building and Dwelling Register.

From 2000 to 2012, a total of 50,818 buildings were demolished in Finland, 3,200–4,500 buildings each year. The amount of floor area removed was a little over 9 Million square meters in total, 475,000–950,000 $m^2$ annually. 28,000 apartments were demolished; most of them were detached houses in growing municipalities. The demolition rate was on average 0.25% per annum of the existing stock, which is among the highest in Western Europe. The rate was 0.65% for non-residential buildings and 0.15% for residential buildings.

76% of demolished floor area was located in 39 functional cities, which together cover only 4.5% of Finland's area (see Figure 7). Of that floor area, nearly 60% stood in city centres which correspond to as little as 0.2% of Finland's area. It was found that the size of demolished floor area, the number of inhabitants, the demographic change (growth or shrinkage) and construction activity were all interconnected, as they correlated strongly with each other (see Figure 8).

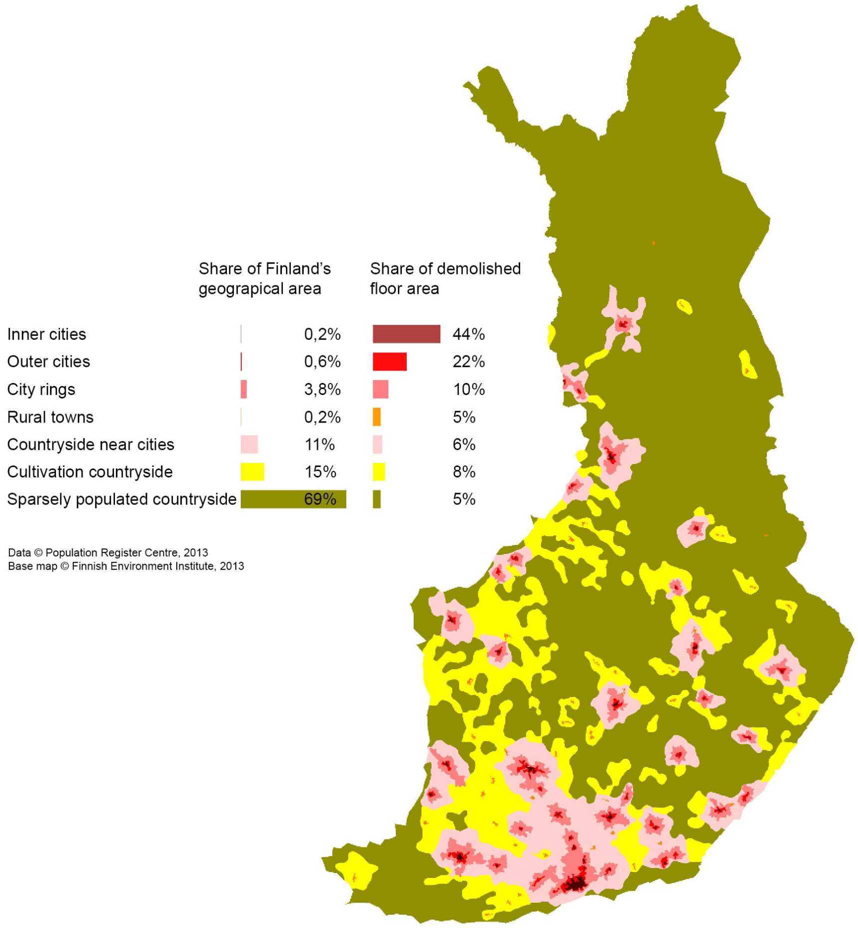


**Figure 7.** Location and amount of demolition: map of 7 area types and diagrams of their shares of Finland's geographical area and demolished floor area.

Non-residential buildings dominated the demolitions with 51% of buildings and 76% of floor area. All in all, the most significant building types were industrial buildings (1.7 Million m$^2$, average area 1,260 m$^2$, typically concrete), detached houses (1.4 Million m$^2$, average area 90 m$^2$, typically timber), public buildings (1.3 million m$^2$, average area 1,160 m$^2$, typically either concrete or timber), commercial and office buildings (1.2 million m$^2$, average area 530 m$^2$, typically concrete) and warehouses (1.1 million m$^2$, average area 710 m$^2$, typically concrete). The majority of demolished buildings and floor area was located in city centres for most building types excluding detached houses, utility buildings, holiday cottages and agricultural buildings. In the countryside, 80–90% of demolished buildings and approximately 60% of floor area belonged to the latter building types. Disappointingly, the construction method of the frame (built in-situ or prefabricated) could be tracked down for only 17% of buildings and 35% of floor area. Of these, every fourth building and every third square metre was prefabricated, typically in steel or concrete.

The demolition of floor area focused on buildings built between the 1950s and the 1980s. Detached houses dominated the demolitions prior to 1960, and their average age was the highest at the time of demolition, 64 years. For floor area in buildings manufactured during the latter half of the 20th century, industrial buildings (average age 37 years), warehouses (average age 37 years), public buildings (average age 41 years), as well as commercial and office buildings (average age 39 years), were in the majority. All in all, over 80% of the demolished floor area was located in buildings that were less than 60 years old. 47% of all buildings were reported to be demolished because of new construction, 44% because of ambiguous “other reasons” and only 9% because of destruction or decay.

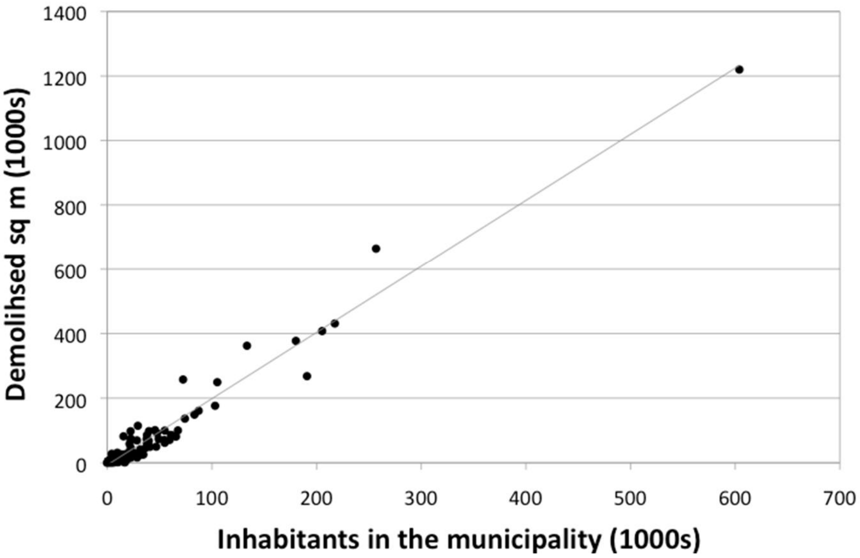


**Figure 8.** Demolished floor area, y-axis, correlates linearly (r=0,95) with the number of inhabitants in municipalities, x-axis.

The number of demolished buildings represented 22% of simultaneously built new buildings, suggesting that every fourth or fifth new building “replaced” a demolished one in the stock. The total amount of new construction exceeded demolition in all municipalities. When new construction and demolition were examined for different building types, the former exceeded the latter in 92–100% of the municipalities. Although two thirds of Finnish communities are losing inhabitants, all of them keep increasing their built area and building stock via vigorous new construction.

The summary above is a combination of two studies. One has been published as a journal article [9] and the other has been accepted for publication in the proceedings of the 5th Annual Symposium of Architectural Research ATUT2013. Both were in print during the publication of this book. A similar examination has been performed on the vacant part of the housing stock, which will possibly be demolished in the near future. The study was being finished at the time this report was published and will be offered for publication in a scientific journal.[1]

## 2.2 Future of demolition in Finland

Although ageing of materials follows the laws of physics, lengths of buildings' life cycles are not predetermined by nature. It is not even the age of the structure that has been found to determine demolition, but how people feel about it. This phenomenon is called obsolescence, and it is profoundly value-infused. Finland, as most of Western Europe, has come to a situation where annual new construction accounts for as little as 1% of the building stock. As this situation is unprecedented in history, nations are seeking for ways to shift from the paradigm of new construction to sustainable stock management. Under these circumstances, past behaviour appears to lack the predictive power for future development. Therefore, the method of mathematical extrapolation seems unreliable for predicting future demolition. Trend extrapolation also ignores the fundamental significance that changing values have for the survival of buildings. In this part of the study, a futures research method called Delphi was employed in order to survey an expert panel formed by the project’s partners representing industry and administration about demolition prospects during the 21st century. The strength of the Delphi method is in revealing the variety of possible futures, defined by different interest groups based on their own distinct values and attitudes. The respondents were asked to reply to the survey as an expert within the organization that they represent.

The majority of respondents believed that a linear increase of construction and demolition waste can be expected, resulting in 1.25 to 2.25 times the current amount by the year 2050, although half of the panel (administrators, researchers and conservationists) would prefer going under the current levels (0.25 to 0.75 times the current amount) already by 2030. The other half (mainly industry members) prefers the amount of C&D waste to keep growing or at least not to decrease, probably because their organizations are doing business from the demolition of buildings either directly (waste processing, demolition services) or indirectly (e.g. new construction on cleared plots). As the majority of the respondents did not

---

[1] Huuhka, S. Vacant buildings in Finland: Reserves for housing or building components? Unpublished manuscript

believe the waste amounts would decrease and many of them did not want them to, this may suggest that current incentives for reducing C&D waste are not very effective. However, recycling seems to be in the respondents' interests, perhaps because it offers mitigation and a certain kind of justification for the demolitions that facilitate the businesses of the organizations. Practically all the respondents considered landfill to be likely to decrease and recycling to increase already by 2030 and definitely by 2050. Although the respondents were asked to distinguish re-use from recycling, almost none of them did so. This might suggest that they do not know what to think of re-use yet. Incineration, then again, divided the respondents' opinions. Half of them proposed that it will probably be reduced while the other half believed in its increase, although no one would prefer this to happen.

When asked about the materials of the buildings to be demolished and building types, the panel gave a polarised answer, according to which either mineral materials (in practice, concrete) or wood would start to dominate over the other. Respondents believing in the increase of concrete associated this growth to the presumed upcoming demolition of 1970s mass housing, while respondents predicting the increase of timber waste proposed a set of different arguments concerning older timber housing: efforts to densify urban structure, depopulation of the countryside, moisture and mould damage as well easy demolition of timber structures. Those believing in the demolition of mass housing were industry members; their belief may be explained with the business potential that large-scale demolitions would offer. Based on respondent backgrounds, disbelief in mass demolitions may be connected to preferring the overall amount of C&D waste to decrease. Surprisingly, respondents focused almost solely on residential buildings, although this was not our original intention. As the results of the study on already demolished buildings presented in Chapter 2.1 were not complete at that time, we were not able to instruct the panel to better consider non-residential buildings.

All in all, the two options identified for the stock to be demolished were polarized in many senses: large, hard-to-demolish, hard-to-repair concrete buildings with a complex ownership structure versus small, easy-to-demolish, easy-to-repair timber houses with a simple ownership structure. As decision-making is affected by values and interests, these predictions carry the potential of becoming self-fulfilling prophecies. Material properties may not be decisive for the survival of structures when juxtaposed with human factors, including business interests.

The full-length results of the survey have been published in the proceedings of the 1st International Conference on Ageing of Materials and Structures [10].

## 2.3 Potential and obstacles for different materials

Despite the remarkable environmental benefits associated with reuse, the practice has not gained ground in Western industrialized societies such as Finland. As salvage of components is seen as labour-intensive, costs are often mentioned as the dominant obstacle to reuse in the EU. The literature also lists a variety of other obstacles: inconsistent quality, inconsistent quantity, bad perception and lack of trust, among others. However, obstacle shortlists very rarely take into account the different properties of structures. When it comes to the viability of reuse, structural steel framing, glued laminated timber as well as traditional timber framing have been assessed to possess a high potential for reuse, while precast concrete frames and steel roof trusses have in previous research shown medium potentials.

In this section of the study, the purpose was to survey members of the construction and recycling industry with regard to the potentials for and obstacles to reusing components of a specific type and material in the Finnish context. The questionnaire utilized material-component pairs in identifying which materials and components have better reuse potential and which obstacles are considered to be decisive. The research also recognized that materials and components share some obstacles while others are seen as material-specific. The questionnaire focused on prefabricated concrete, steel and timber components, which cover the majority of contemporary load-bearing structures in Finland. All material categories included four component types: two vertical (columns and wall panels) and two horizontal (beams and slabs or trusses).

In the near future, the respondents saw beams and columns made of steel or concrete as possessing the best reuse potential. In the more distant future, the highest reuse potential was associated with steel beams, columns and trusses as well as timber beams, columns and CLT. Concrete was estimated to have the lowest reuse potential of the given materials, while the potentials for steel and timber were seen as nearly equal. In the respondents' opinion, timber especially should be reused by 2050, as it held the highest preferred reuse percentages of all the materials.

Concrete beams and columns were seen to have good prerequisites for reuse per se, but their condition was seen as controversial. The obstacles affecting their reuse was a set of issues connected to the lack of an established market. For panels and slabs, the difficulty of deconstruction was seen as the first obstacle prior to the market-related issues. Construction technology was not seen to hinder the reuse of steel components, but rather the lack of an established practice, which consists of several issues. The most important single factors are the attractiveness of conventional recycling and unawareness of reuse possibilities. As for timber, its nature as a biodegradable material was evaluated as being the main obstacle to reuse. All materials shared one obstacle: demand. Other widely shared obstacles included awareness, scheduling, norms as well as material properties and damage.

In addition, the respondents provided a number of practical concerns and ideas regarding reuse. These include a suggestion that only non-weather-exposed load-bearing structures should be reused and requests for testing and standardization of reused components. As for design with salvaged components, the following issues were brought up: information on the capacity of structures is not available to the structural engineer when components are reused; designing new buildings with old spans may be challenging; old wall panels do not fulfil the current minimum room height. As for the deconstruction work, transporting components directly from the deconstruction site to the construction site would minimize the risk of damage; deconstruction work should be scheduled as loose enough; the client should be willing to pay for the time taken.

The full-length results of the survey have been presented in the 40th IAHS World Congress on Housing: Sustainable Housing Construction. The conference proceedings [11] were in print during the publication of this book. [2]

## 2.4 Potential in mass housing estates

The majority of European mass housing was built with panel technology during the 1960s and 1970s. In many countries, this stock is already being demolished or demolition is discussed due to vacancies or social problems. This may result in the creation of an unforeseeable amount of concrete waste. Simultaneously, EU has issued the Waste Framework Directive aiming at reuse (upcycling) instead of recycling (downcycling). Unlike *in situ* cast concrete, reclaimed prefabricated concrete panels from mass housing carry the potential for reuse. The purpose of this section of the study is to review the reuse potential embedded in Finland's mass housing stock from the perspective of the dimensions of the panels and spaces, *i.e.* their suitability for architectural (plan) design. The research material consists of architectural drawings of 276 blocks of flats that contain tens of thousands of prefabricated concrete panels and slabs, the dimensions of which are compared to current norms and guidelines for dimensioning living spaces. The technical prerequisites for reuse are reviewed with the help of literature. The study results in identifying an inventory of panels typical to Finnish precast concrete construction, which, in principle, should not exist because the building plans are not standardized and were supposed to be unique. The panels are found to be still usable in architectural (plan) design of detached houses, which form one third of annual residential production in Finland.

This is the abstract of a manuscript that will be offered for publication in a scientific journal.[3] For the technical prerequisites of concrete re-use see also TUT's technical report (in Finnish) [1]. For architectural design with reclaimed panels, see Chapter 4.1 and master's theses (in Finnish) by Satu Huuhka [12] and Jani Hakanen (to be released in February 2015). For the societal ambient conditions and opportunities refer to the article “Partial dismantling of 1960's to 80's neighbourhoods - a sustainable holistic solution” [13].

---

[2] For the conference paper, contact the author directly.

[3] Huuhka, S., Kaasalainen, T., Hakanen, J.H. & Lahdensivu, J. Reusing concrete panels from building for building: Potential in Finnish 1970s mass housing. Unpublished manuscript.

# 3. Environmental benefits

## 3.1 Material efficiency and eco-efficiency

Asko Talja

Material efficiency in recycling building components usually refers to the economical use of natural resources in all operations, the effective management of side streams, waste reduction, and recycling of the material at different stages of the life cycle (Figure 9). The goal in efficient material use is also to reduce the adverse environmental impacts of the products during their life cycle. Material efficiency is displayed at different stages of the value chain, as production of raw materials, processing of products, trade and consumption, as well as opportunities for the durability of re-use, recycling and recovery of waste [14]. Material efficiency is to prevent the loss of material and reduce the amount of waste generated.

If the parts of the building are crushed or smelted after demolition, this requires energy, and the energy embodied in the products in earlier manufacturing cycle is lost. Therefore, material efficiency forms a part of the eco-efficiency. The embodied energy in different materials and products varies. If the manufacturing emissions are compared with the transport-related emissions, aluminium and steel components are the most favourable for re-use (Table 1).

The European Union Directive on waste [1] obliges Member States to improve material recycling. The EU's objective is to achieve a recycling rate of 70% for construction waste by the year 2020. Re-use is one way to recycle and to achieve the objective.

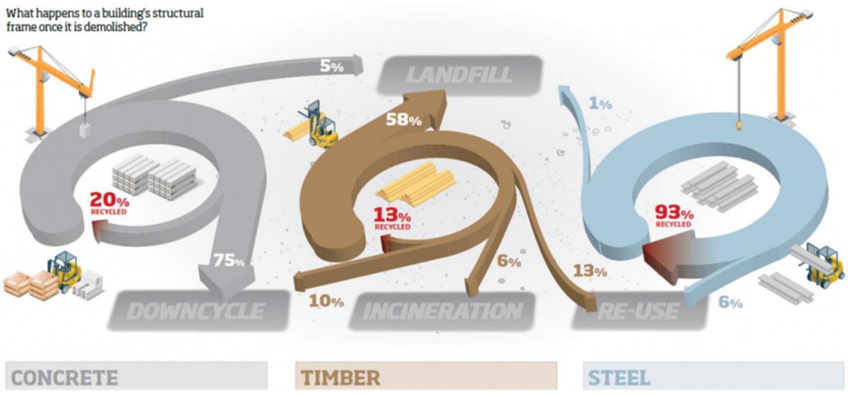


**Figure 9.** An example of end-of-life scenarios for concrete, timber and steel from buildings [15]

Eco-efficiency stands for doing more – or the same – with less. It means resource efficiency: using and re-using resources more efficiently throughout our economy. It is about eco-innovation: developing and using products, processes and other solutions that contribute to the efficient use of resources. It enhances resource productivity and generates more value from the use of resources. It means not wasting valuable materials [16].

**Table 1.** Estimated maximum transport distance of reclaimed material before the environmental advantage is lost [17]

| Material | Distance (km) |
|---|---|
| Aggregates | 150 |
| Bricks | 400 |
| Timber | 1,600 |
| Steel products | 4,000 |
| Aluminium products | 12,000 |

Eco-efficiency is also a combination of the words ecological and efficiency. Thus, eco-efficiency refers to the ratio that compares the natural resources (materials and energy) and induced (harmful) emissions and waste, which are needed in producing a product or service, with the benefits of the product or service [18].

The energy required in a building over its lifetime usually plays the major role in eco-efficiency. However, the move towards low or zero energy houses and the share of embodied energy of building materials becomes more and more important. For instance, the greenhouse gas emissions of materials of a zero-energy house in Finland (accounting for the emissions of a 50-year life cycle) are about one quarter of total greenhouse gas emissions (Figure 10). It is about half of the emissions used for heating, hot water and electricity. The share of the building materials (external and internal walls, ceilings and floors) amounts to about half of the greenhouse gas emissions of all materials.

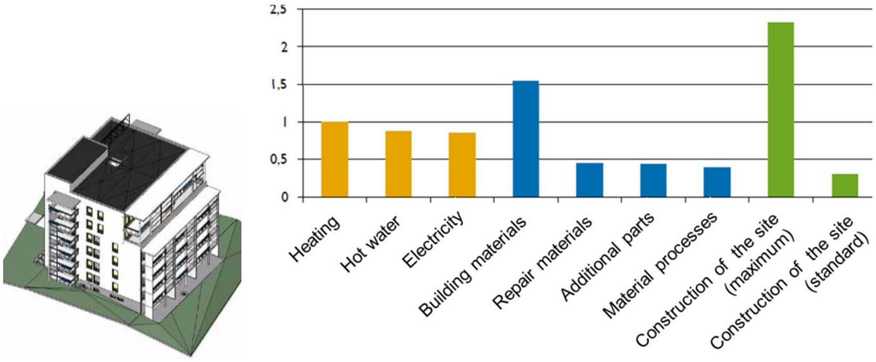


**Figure 10.** Relative greenhouse emissions ($CO_2$ equivalent normalized to heating) of a 6 storey concrete building in Helsinki [19]

## 3.2 Life-cycle impact of re-use

Margareta Wahlström

Life Cycle Assessment (LCA) is a systematic way to evaluate the environmental impact of systems, products, materials or services over the entire life cycle, from the extraction of raw resources to the waste. This approach implies the identification and quantification of emissions and material and energy consumptions which affect the environment at all stages throughout the product life cycle. This holistic perspective allows for a comparison of two or more options in order to determine which is better in terms of environmental impacts.

**Environmental impacts commonly considered in the LCA of a building product**

Depletion of abiotic resources (elements) in kg Sb equiv. and depletion of abiotic resources (fossil) in MJ

Global Warming Potential (GWP), in kg $CO_2$ equivalent

Eutrophication Potential (EP), in kg $PO_4$ equivalent

Acidification Potential (AP), in kg $SO_2$ equivalent

Ozone Depletion Potential (ODP), in kg CFC-11 equivalent

Photochemical Ozone Formation Potential (POFP), in kg ethylene equivalent

Furthermore, information about ecotoxicity and human toxicity can also be calculated in the LCA. Apart from the environmental impact categories, also information on parameters describing resource use, such as the use of energy and water consumption, is often additionally reported in life cycle studies for construction products. Information on how to calculate the environmental impacts are reported in several sources (see Nordic Innovation report [20]).

The environmental impacts from different life cycle stages are reported in relation to a functional or declared unit. The functional unit is to provide a reference by which material flows (input and output data) of the construction product's LCA results and any other information are normalized in order to produce data expressed on a common basis. An example of the functional unit is a product in a 1 m² building element over a 60-year study period.

The environmental impacts from different stages are for construction products reported typically separately for each stage (e.g. environmental impacts such as greenhouse emission during manufacturing of construction products). Especially for recycling and re-use of materials and waste materials, this sets challenges in setting the boundaries for the different flows belonging to different stages. Recycling and re-use give the benefits of avoided future use of primary materials and fuels. However, there are no clear rules or general agreement on how to handle re-use or recycling in the LCA.

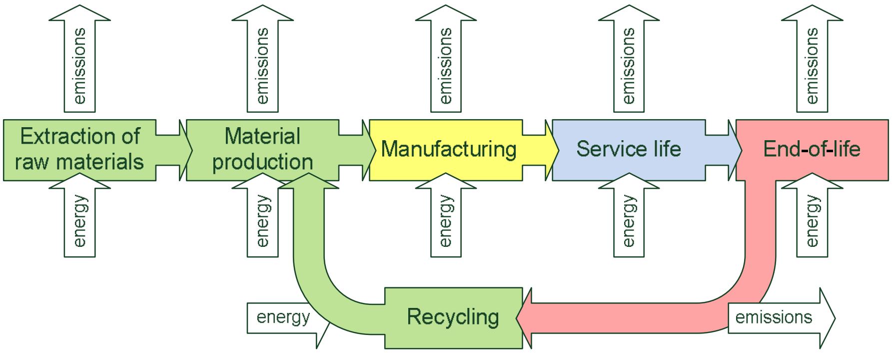


**Figure 11.** The life cycle stages for a construction product including recycling according to [21].

Ligthart and Ansems [21] distinguish the recycling/re-use process based on where and how the recycled material is used again:

- Closed loop recycling/re-use – here the material is used again in the same product system (e.g. re-use of windows)
- Open loop recycling/re-use – the material goes to another product system, the inherent product properties are changed and the material is not used in

its original use (here the material is typically down-cycled and not the focus of re-use)
- Semi-closed loop recycling/re-use – the material is used in another product system without changing the inherent materials properties (e.g. construction steel and aluminium)

Calculation of environmental impacts in the closed loop system is straightforward. Often a semi-closed loop system applies in the re-use of construction products. The key question is how to divide the impacts of recycling or re-use in stages that use this material as an input for a secondary material. This aspect is important in reporting the benefits from recycling and re-use in environmental product declarations for construction products. How to handle this recycling/re-use in Environmental product declaration is further discussed in Chapters 3.3 and 3.4.

## 3.3 Environmental product declaration

Margareta Wahlström

An Environmental Product Declaration (EPD) is a way of communicating the environmental impacts of a product, e.g. the result from an LCA, in a standardised manner and in a common format, based on common rules known as Product Category Rules (PCR). The purpose is that the format and methodology behind the environmental indicators, such as global warming potential or the use of secondary raw materials, in an EPD for a construction product should be common to all European countries and thus eliminate national declarations that act as trade obstacles. Building product EPDs are among the inputs required in most of the current environmental certification systems for sustainable buildings (e.g. BREEAM, LEED, DGNB, HQE).

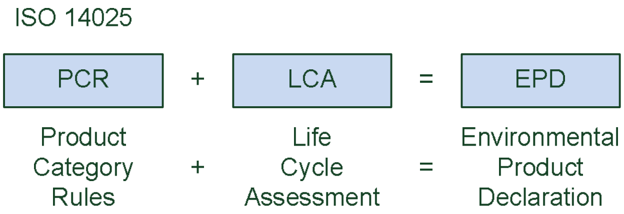


**Figure 12.** ISO 14025 (2006) procedure to develop an EPD is based on the results from an LCA and follows the methodology specifications given in the PCR.

The core PCR, EN 15804 (“Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products") describes the rules for how to develop an EPD for construction products in a common way. The life cycle of a construction product is subdivided into product stages (A-production and construction, B-usage, C-end of life, D-recycling). The standard describes the general rules about parameters to be declared, the stages of a product´s life cycle to be included and the rules for the development of scenarios. Furthermore, it includes rules for calculating the life cycle inventory and the life cycle impact assessment underlying the EPD.

More product-specific PCRs are developed by means of "an open consultation meeting" and give product specific rules and guidelines on stages (or phases) and requirements to be included in the LCA and other environmental aspects to be handled in the EPD. Apart from the product's environmental performance as given by the LCA, other significant aspects related to the product will also be declared. EPDs can only be compared when they have been elaborated based on the same PCR and all the relevant life cycle stages have been included. Products cannot be compared unless their functionality and use are considered at the building level within a system. PCRs that are product-specific have been developed in a few countries.

EPD information is expressed in information modules representing the stages of a product´s life cycle. This means that LCA data from each product stage is compiled in information modules, which are reported separately. The idea is that the LCA data for a construction project can easily be calculated based on the information given in the EPD for raw materials or elements used in the product. For example, EPDs for sawn timber or windows are used to make an LCA and EPD for a house.

The EPD includes the following information on environmental impacts (according to EN 15804):

- Parameters describing environmental impacts: the environmental impact categories are calculated from the lifecycle impact assessment (LCIA) using characterisation factors. (further Wahlström, 2014)
- Parameters describing resource use based on life cycle inventory analysis (LCI):
    - parameters describing resource use (energy, water)
    - wastes disposed
    - flows for re-use, recycling, energy recovery, etc.

The results are reported separately for different stages in the life cycle of the construction products (e.g. production). Available reports on the internet also often contain graphs about the environmental impact contribution related to the use of different stages (e.g. use of raw materials, energy (e.g. transport)). From the graphs it is possible to conclude what product stage is linked to certain environmental impacts (e.g. global warming potential).

Environmental information presented in an EPD based on EN 15804 will constitute information modules for which an LCA is performed. This modular LCA structure is illustrated below, and it is essential to make use of the EPD in practice. The product life cycle is divided into stages A to C, and module D describing recycling of the product. Figure 13 shows life cycle stages for a construction product according to EN 15804 used as modular information for construction works (including buildings as such) defined by EN 15978 (2011).

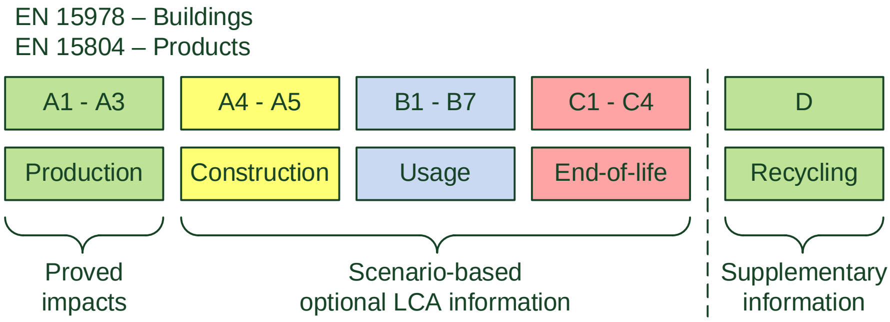


**Figure 13.** The life cycle stages of building or product

Currently, the production stage (A1–3) is the only mandatory part of the EPD, covering cradle-to-gate. The environmental impact from the production stage is then reported in relation to a declared unit, typically per kg. Apart from stages A1–3, a declaration might also include one or several additional stages. If the EPD is aimed at the comparison of products, then a functional unit (or declared unit) has to be defined in all the stages A to C in order to describe the environmental impact associated with the construction product's life cycle.

It is noticeable that the production stage (A1–3) is based on existing or historical data, and for that reason it is possible to demonstrate the impacts. However, impacts from the downstream stages have to be assessed based on assumptions (i.e. scenario based information). Normally, the use of a construction product will lead to different impacts depending on the intended use as well as the position of the product in the construction work, as well as the location of the construction work in which the product is incorporated. Therefore, the scenarios described in an EPD will always be regarded only as one specific example.

The life cycle of the product does not necessarily stop at stage C (end-of-life). The product itself or materials in it can be re-used or recycled. The goal of the information in module D is to describe potential benefits and impacts related to future recycling or reuse. The results from LCA of recycling or re-use (i.e. module D) will be reported as supplementary information to the LCA result from modules A to C.

However, the way of handling the LCA for module D on the environmental benefits and impacts from recycling of construction products is not very suitable. The most preferable level for performing a LCA would be to do it for the entire construction project instead of for a single product. In this way, it would be possible to cover all parts of the construction work and also the full life cycle.

## 3.4 Aspects of re-use and recycling in the EPD

Margareta Wahlström

The benefits of avoided future use of primary materials and fuels are addressed in module D of the Environmental Product Declaration (EPD). Module D includes the environmental benefits of re-use and recycling potentials after the end of life stage. Because the module is not mandatory according to EN 15408, there is currently limited information available about how to handle re-use or recycling in the EPD for building products. Only a few PCR documents were found that also covered module D in the EPD. For the calculation of module D, a scenario needs to be defined. An interpretation on how to include module D in EPD for recycled wastes has been presented by IVL (Sweden) in a Nordic report (Wahlström et al 2014).

**Example of a closed loop scenario –** If the product is used in the same application after a simple process ("preparation for re-use"), the "environmental gain" in module D is easy to calculate by subtracting the burden related to processing the material for re-use from the production burden. Activities include deconstruction, transport to the new site for preparation for re-use (e.g. sorting, cleaning and cutting).

**Example of semi-closed loop scenario –** If the construction product is recycled in another type of application, the calculation is more complex. An approach discussed in the Nordic report is the use of a consequential LCA. The use of the consequential LCA approach requires that a generic application scenario has been defined taking into account future recycling options. One of the challenges here is how to define the substituted product (e.g. a worst case, a realistic case or an average case). Also, the system boundaries need to be agreed (should only the life cycle analysis account for the manufacturing of the replaced material, or should the burden related to the usage also be included?).

A broader interpretation of the EPD based on the use of the consequential LCA supports the interpretation of EPD given in the Construction Products Regulation (CPR). If the EPD is to fulfil the aim given in the CPR, it is essential that the sustainable use of resources also includes the life cycle of the recycled material, which can be utilized in the construction sector or in other sectors such as the energy sector. CPR is aimed to assess the use of recycled material beyond the primary product's life cycle, or as given in preamble 55: "The basic requirement for construction works on sustainable use of natural resources should notably take into account the recyclability of construction works, their materials and parts after demolition, the durability of construction works and the use of environmentally compatible raw and secondary materials in construction works." Therefore, there is a need to specify how these environmental aspects (given above) can be accounted for with LCA methodology and within the scope of an EPD and requirements as given by i.e. EN 15804.

## 3.5 Certification systems for sustainable buildings

Petr Hradil

A great number of certification systems to assess the environmental quality of buildings have been introduced over recent decades. They have a significant impact on many project decisions worldwide. Such certification systems are being developed and promoted mostly by the national branches of the Green Building Council (GBC) or by similar organizations. Finland's own certification system, PromisE, is outdated and not used anymore. Even though there is no localization of the most common foreign certificates in Finland, it is still possible to assess the building by the international versions of several systems such as BREEAM, LEED, DGNB and HQE.

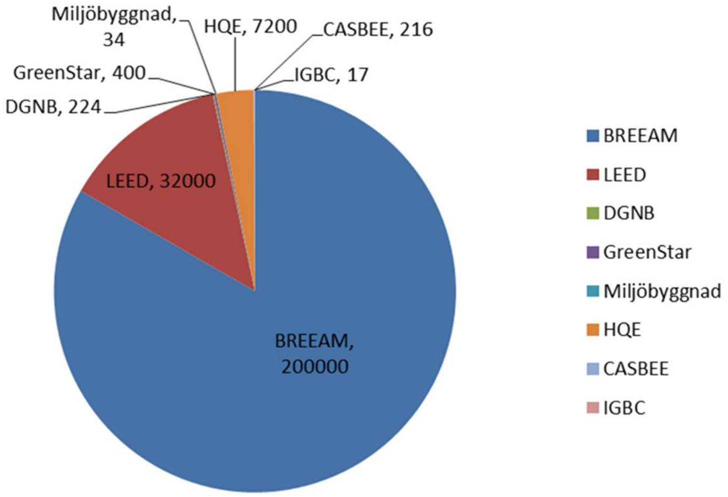


**Figure 14.** Number of certified buildings in 2012 based on data from [22]

It is likely that the common European certification system will be developed in the near future because of the strong need to measure the progress towards the strategies for sustainable Europe [8]. It may be based on the existing schemes that are already applied to thousands of buildings (see Figure 14) and are following the European and international standards. However, it would be very difficult to harmonize certification procedures in Europe, because the current methods are strongly depending on the local building practices and the climate.

The focus of certification on various environmental categories is different in each system. Some emphasize indoor air quality; others are more energy- or process-oriented. Building resource efficiency can be represented by “materials” and “waste” categories that occupy altogether less than 20% in all of the selected systems [22] as demonstrated on Figure 15.

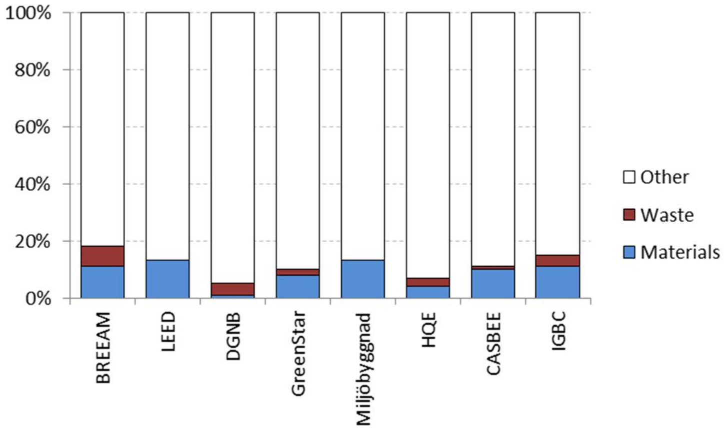


**Figure 15.** The proportion of "materials" and "waste" categories.

The findings of FORCE [23] criticized the fact that less than 5% of credits are attributed directly to the life-cycle performance of building products and materials in the four major schemes (BREEAM, LEED, DGNB and HQE), and LEED does not utilize LCA results at all. The situation has greatly improved nowadays, because the schemes (also LEED v4, GreenStar since 2013) can use quantitative measures of environmental impact (such as $CO_2e$ originating from LCA calculations).However, only DGNB and HQE are fully harmonized with international standards for LCA reporting (EN 15804, EN 15978 and ISO 14044).

# 4. Good practices in building elements reclamation

## 4.1 Architectural design with reclaimed components

Satu Huuhka

**Figure 16**. Barn siding with a weathered grey tone in the façades of an otherwise modern building.

Obstacles preventing re-use in general have been widely documented in the literature. While most obstacles are formed by economic or technical constraints, the obstacles also include issues linked to architectural design such as inconsistent quality, inconsistent quantity and difficulty of dimensional coordination. The aforementioned inherent properties of salvaged components affect massing, plan design, façade design, roof design, structural design, interior design as well as building specification, basically, the whole spectrum of architectural design. In this section of the research, an effort to simulate design from salvaged timber components was made with the help of 35 architecture students during the TUT School of Architecture course "Finnish Wood Architecture" in the spring of 2014. The analysis is based on clustering and close reading of the textual and graphical material created by the students. The identified design approaches were condensed into 10 universal design principles. One previously unknown obstacle to re-use, shortness and thinness of timber components, was identified and addressed alike. The design principles, verbalized as 'the 10 Commandments of Reuse Design', are as follows:

**Divide the spatial programme into smaller rooms or volumes –** Shortness of beams and other horizontal components such as logs is a typical challenge with re-used timber. If a spatial programme can be divided into several small rooms or volumes instead of one large space, the utilization of both shorter and thinner beams is enhanced.

**Split the structure into smaller sections –** Apart from beams, damage in deconstruction applies to vertical members, such as frame studs. Cutting off the damaged parts results in shorter studs. This challenge can be overcome by splitting the structure into smaller units. Perhaps the most obvious example of this is using a platform frame instead of a balloon frame.

**Avoid equal spans and dimensions –** Salvaged timbers typically come in varying lengths. In order to avoid leftover cuttings, a design should preferably accommodate the use of several lengths. From this point of view, a catslide roof or any other type of asymmetrical roof is better than a gable roof; in a pavilion roof, almost all the joists have different lengths as one joist length is repeated only eight times.

**Split the structure according to the function –** Nowadays, studs normally range from 150 mm to 225 mm and even up to 350 mm for passive houses because of the space needed for insulation. Studs this wide are clearly oversized from the viewpoint of loads and may be difficult to encounter in a timber waste stream. However, if the load-bearing function and the function to provide space for insulation are divided for different timber members, the necessary insulation space can be achieved by combining thinner studs. The principle can be applied to roof and floor structures as well.

**Utilize efficient forms that allow using smaller pieces for longer spans –** Some structures are more efficient than others thanks to their geometry. For example, the geodesic dome, popularized by Buckminster Fuller, is made up of equilateral triangles and has a high bearing capacity because of the space-grid action of its members. More conventional examples of structurally efficient components are roof trusses. Many types of trusses and stiff frames can be put together from planks by nailing them together.

**Define ranges instead of fixed properties –** In a normal building project; one of the architect's tasks is to define the dimensions and visual properties of the building and its parts in an exhaustive and unambiguous manner. To be able to do this with salvaged components, the parts would have to be acquired before the design begins. When pre-purchase is not a viable option, there is a need for redesign rounds as applicable components are eventually found. To avoid exhaustive redesigning, defining prefixed properties should be replaced by giving ranges. For example, the same room area can be acquired with multiple wall widths that enable different beam spans or log lengths. Respectively, the dimensions for windows and doors can be given as ranges. The principle can even be applied to the colours of cladding, for example, by allowing multiple hues of a colour or combinations of hues or colours.

**Figure 17.** Façade design exploits multiple shades of two colours.

**Rotate and repurpose –** Horizontal buildings can be used in building vertical constructions by turning beams into columns or vice versa. High glued laminated beams and wide columns from industrial and warehouse buildings can be utilized as wall panels or floor slabs in the same way as cross-laminated timber. Smaller beams and columns as well as planks and boards may be piled as if they were logs.

**Select the application according to the properties –** Sometimes it may be difficult to apply salvaged timber in a bearing frame due to the shortness of or damage to deconstructed timber members. Apart from the frame, a timber building comprises many other components for non-bearing purposes. These include stairs, claddings in the exterior as well as interior (weatherboarding, lining, flooring, ceiling, trim, screens and grilles) and a variety of rough grounds (battening, furring, sarking and pugging boards). All of these enable the use of short and variable timbers, and the latter do not even pose any requirements on the appearance. Even the shortest pieces of timbers can be utilized in built-in-place wood mosaic flooring or end grain woodblock flooring.

**Combine creatively –** Conventional timber construction already hosts design solutions that facilitate putting together cladding boards from varied sources. For example, clapboarding, staggered siding as well as board and batten cladding allow the use of weatherboards of different widths. Clapboarding also enables combining panels with different profiles or even damaged tongues and grooves. Short sections of sidings with different profiles or colours can be combined in an orderly manner by arranging them in fields separated by cover fillets. The combining strategy can be applied to windows and glazed doors as well to creating larger glassy surfaces popular in contemporary architecture.

**Let the patina speak –** The appearance that a surface develops over time is referred to as its 'patina'. The appeal of patina has been explained with a psychological experience of comfort and continuity that people associate with it. Weathered natural grey as well as faded or layered and chipped paint are aesthetic features that are difficult to reproduce plausibly in new materials. Although timber may always be painted over, stripping chipped paints from salvaged timbers can be laborious. Thus, the patina should be seen as an indigenous characteristic of reclaimed wood. Due to its nature, patina is irreparable. Therefore, patinating is a cyclic process in which the cycles of cleaning, maintenance and repair follow periods of idleness. Decorating interiors with patina brings this process to a standstill, offering vast possibilities for the use of reclaimed timber in interior design.

This is the extended abstract of a manuscript under review in a scientific journal [4]. For architectural design with reclaimed concrete panels, see master's theses (in Finnish) by Satu Huuhka [12] and Jani Hakanen (to be released in February 2015).

---

[4] Huuhka, S. Demolished lumber: Design principles for turning scrap into architecture. Manuscript submitted for publication.

## 4.2 Timber structures

Petr Hradil

The recovery of structural timber from demolition requires more manual labour than steel or concrete. Rough treatment and mixing with the other materials vastly reduces the elements' value. Separating timber from the mixed waste is very difficult and, even if it is recovered, its possible applications are limited due to its broken-up state. Chipping for particleboard or fibreboard is a good practice, but it means down-cycling the valuable solid material. Re-use is, therefore, the only option for full recovery of the structural timber potential, and deconstruction should be the clear choice over demolition.

The assessment of reclaimed timber strength should generally be the same procedure as the grading of new timber. However, several new failures can be present which makes the proper grading according to the current standards impossible. Therefore, new grading rules for re-used timber have to be developed that take into account the effects of construction & demolition, maintenance and aging of wood. The Finnish commentary on the Eurocodes [24] allows few exceptions: (1) Finnish round logs may be assumed to be of grade C30, (2) Finnish softwood sawn on site may be assumed to be of grade C18 if not graded, and (3) Finnish logs for log houses may be assumed to be of grade C24. If the original certification is available, it is generally recommended to reduce the strength grade by two steps for heavily loaded and exterior members and when the loading history is unknown. In other cases, it is recommended to reduce the strength by one grade. The summary of good practices in timber elements re-use is in the following paragraphs.

**Assess the damage –** Avoid large holes and notches in bent and tensioned members; always calculate the reduced cross-section in compression. Checks (rheological cracks) can be generally accepted within the limits of grading standards, but using elements damaged with shakes and splits is not recommended. It can be particularly difficult to distinguish different types of cracks (see Figure 18). The overview of wood damage is in Table 2.

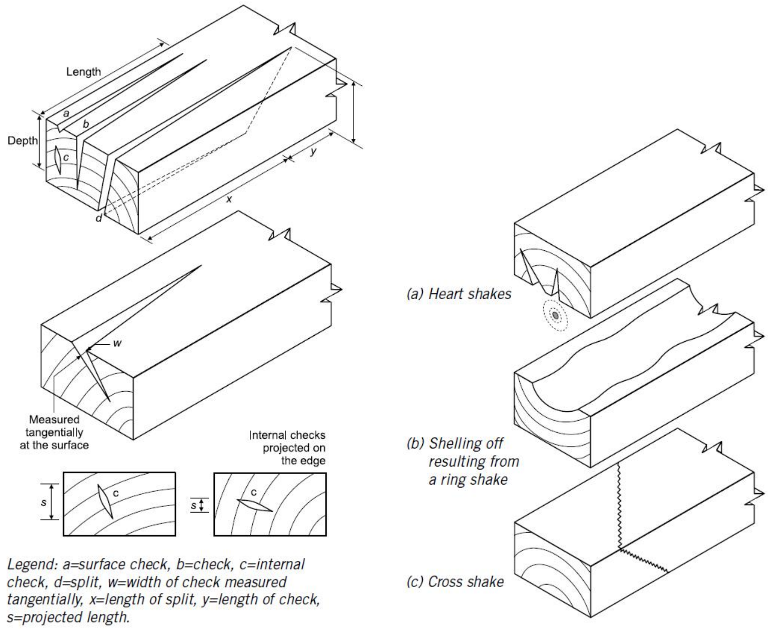


**Figure 18.** Shakes, checks and splits

**Table 2.** Damage of timber elements

| Damage | Importance | Note |
|---|---|---|
| Bolt holes | mild | reduce the cross-section |
| Notches | severe | reduce the cross-section, cause stress concentration |
| Shakes (crack from overloading) and splits | severe | require a treatment |
| Checks (rheological cracks) | mild | reduce the stiffness, increase the risk of biotic damage |
| Shape distortions | mild | difficult to fit into new structure |
| Biotic damage | mild to severe | usually requires a treatment |

**Focus on connections –** Use double headed nails to connect metal connectors and boards. Use wood screws to connect boards together. Structural connections are summarized in Table 3.

**Table 3.** Connections in timber structures

| Connections | Suitability | Note |
|---|---|---|
| Glued connections | not suitable | Cannot be separated without damaging the elements. |
| Carpentry joints | sometimes suitable | Notches can cause stress concentration if the elements are used in different configuration. |
| Nails, staples | sometimes suitable | Fail in bending, and are therefore difficult to remove without damaging the element. |
| Screws | mostly suitable | The same connector is not as effective in the same hole. |
| Bolts, dowels | suitable | The hole and the cracks should be checked. |

**Know the history –** If original grading certification is not available, a testing programme must be initiated. Treat re-used timber as unseasoned unless its moisture content is measured. The timber loses its ductility over time, and therefore the structural applications where brittle failure is likely to occur (curved members, long rows of bolts) should be avoided.

**Prepare the documentation –** Show the location and building structure from which the major engineering timber elements (such as glue-laminated beams, or panels) were salvaged, including the date of construction of the original building. Provide certification of all re-used timber to the material grade as specified on the drawings or general notes.

## 4.3 Steel structures

Petr Hradil and Asko Talja

The cost of non-renewable raw materials is critical to the sustainability of steel manufacturers. Therefore, great effort has been made in recent years to develop technologies to recover iron and carbon from the waste and to reduce fresh water consumption in the production process. Even though it is believed that steel is infinitely recyclable, about 50% of European steel production is derived from raw materials. This is mostly due to the rising demand that exceeds the scrap available for recycling [25].

Steel in building structures has a very high recovery potential because it can be roughly treated (bent, torn apart, and otherwise manhandled) and still retain its value. Even if the steel is mixed with other materials, it can be magnetically separated for recycling. Most of the steel scrap from building demolition can be used in blast or electric furnaces for new material production. This new material is functionally equivalent to the original (while concrete and timber can only be downcycled into lower grade products such as hardcore and chipboard). However, melting, rolling and forming of recycled steel products consume considerable amounts of energy and resources, and create waste and emissions. Scrap metal has to be collected and transported over relatively long distances to the steel mill. Re-use of building component is an alternative end-of-life scenario where most of the heavy industrial processes can simply be bypassed.

It takes six recycling cycles to reduce the $CO_2$ emissions of the original material by 50% [25], but the comparable savings can be achieved after a single re-use [4]. However, steel is not re-used widely in real cases. For instance, only 7% of heavy structural sections, 5% of light gauge structural steel and 10% of profiled cladding were re-used in the UK in 2012 according to a survey [26]. This could be partly attributed to the relatively high costs of re-use process, especially the deconstruction and quality control [4]. The standardized method for assessing the engineering properties of re-used steel is not available, and therefore contractors must rely on the original design documentation or perform costly material tests in certified laboratories.

Despite the fact that about 3,500 steel grades are produced worldwide, over 90% of steel production are carbon steels from which only a few strength classes are recognized in building standards. Then the determination of the element's strength class and fracture limits requires only a simple tension test of coupon or rod and the Charpy impact test of material extracted from the building element. If the designer intends to weld the recovered element, more tests may be needed to ensure weldability and to select the suitable filler material.

Recommendations for design from salvaged steel in the USA from Walter P Moore's Austin office were published in [27]. Most of them are also confirmed by the experience of European contractors. The summary of good practices in re-use of structural steel is in the following text.

**Assess the damage –** Do not use members with areas of accelerated localized corrosion or other evidence of localized section loss. Avoid elements with existing holes in locations where new holes are to be drilled in the member.

**Focus on connections –** Avoid built-up members and sections with welded, riveted, or bolted splices along the length of the member. Welded connection material may be left in place for statically loaded members, but it is a good practice to check all the existing welds in the element for cracks. The presence of bolt holes has to be evaluated according to the net section provisions in Eurocode 3. The basic types of connections (end-joints) of steel elements are presented in Table 4.

**Table 4.** Connections in steel structures

| Connections | Suitability | Note |
|---|---|---|
| Welds | not suitable | Cannot be separated without damaging the elements. |
| Rivets | sometimes suitable | Difficult to separate without damaging the elements. |
| Standard bolts & screws | mostly suitable | Bolt hole can already be damaged. |
| Slip-resistant bolts | suitable [5] | |

**Know the history –** If original drawings and specifications are not available, a testing program must be initiated. Avoid using elements from bridges or similar dynamically loaded structures because of the accumulated fatigue damage. Consider the possibility of high temperatures affecting the steel properties. Such material has always to be tested.

**Prepare the documentation –** Show the location and building structure where the members were salvaged from, including date of construction of the original building. Provide certification of all re-used steel to the section properties and material grade as specified on the drawings or general notes.

---

[5] Such connections are typically parts of structures with loading reversal and therefore the fatigue history of the elements may prevent their re-use.

## 4.4 Concrete structures

Jukka Lahdensivu

All reinforced concrete structures, such as columns, beams and slabs, are designed individually case by case, i.e. reinforcement has been calculated according to design norms and guidelines in force for design loads. Reinforced concrete structures are made either in situ or as precast concrete elements. In situ-cast concrete structures are not re-usable as whole structures or part of it. Crushed concrete is recyclable as an aggregate of new concrete, and mostly replaces natural aggregate in earth construction like roads, etc. Reinforcement is recyclable as are metals in general, but it must be separated from concrete during the crushing process. Crushing of concrete is noisy and dusty work, so concrete should first be transported to a suitable crushing places.

Concrete buildings made with girder and post frame have a very high recovery potential, because girders and columns can usually be used as such in new construction. Warehouses, industrial and office buildings as well as commercial buildings are usually made with girder and post frame. In most cases, precast columns and beams are connected together with bolts, which can usually be disassembled relatively easily. TT-slabs are connected to beams either welded or with bolt joints. Both are usually rather easy to open. Blocks of flats are also made with precast concrete panels, but the panels are connected together with reinforced and cast joints. These joints must be opened by chiselling or cut with a diamond saw. The diamond saw also cuts tie bars from the panels.

The assessment of old concrete structural members needs an accurate knowledge of the amount and situation of reinforcement as well as strength properties of used steel and concrete. Re-used reinforced concrete structural members must carry the loads demand according to the current design standards. A summary of good practices in the re-use of pre-cast concrete elements is found in the following paragraphs.

**Assess the damage –** Do not use members from areas of accelerated localized corrosion or frost-damaged concrete or where there is other evidence of localized section loss. Avoid beams with big existing holes in locations of high stress concentration. Do not use pre-stressed concrete beams or slabs with wide cracks or corroded steel.

**Focus on connections –** Avoid elements if there are wide cracks in the console area of a column or the connection area of a beam. Connecting steel must be safe and sound in all panels.

**Table 5.** Connections in concrete structures

| Connections | Suitability | Note |
|---|---|---|
| Cast and reinforced connections | sometimes suitable | Usually will damage both elements and connection steels. |
| Welds | mostly suitable | Usually can be replaced with new welds and connection steels. |
| Bolts | suitable | Usually easy to open without damaging the elements. |

**Know the history –** If original drawings and specifications are not available, a testing programme must be initiated. Avoid using elements from bridges or similar dynamically loaded structures because of the accumulated fatigue damage. Consider the possibility that high moisture levels of structure may have caused corrosion problems or even frost damage.

**Prepare the documentation –** Show the location and building structure where the members were originally in use, including the date of construction of the original building. Provide certification of all re-used concrete structures as regards to the section properties and material grade as specified on the drawings or general notes.

In addition, a comparative case study on downsizing large-panel blocks of flats and reusing the panels for new construction in four countries – Finland, Sweden, Germany and the Netherlands – was being completed at the time this report was published. The manuscript will be offered for publication in a scientific journal. [6]

---

[6] Huuhka, S., Naber, N., Asam, C. & Caldenby, C. Urban transformation through deconstruction and reuse: The international experience. Unpublished manuscript.

# 5. Quality aspects

Margareta Wahlström

## 5.1 CE marking

CE marking of construction products has been mandatory from 1st July 2013 according to the Construction Products Regulation (CPR) [28].

Discussion is still ongoing as to whether construction products already on the market before the obligation of CE-marking are subject to CE-marking. Some member states have proposed that CE marking should only be required on new construction products and not on reclaimed building materials and architectural salvage. This would mean that, for instance, products already on the market before mandatory CE-marking could be exempted from CE-marking. However, products which are further processed before recycling probably fall under the requirement for CE-marking.

Several challenges relate to CE-marking of re-usable construction products. First, the traceability of the construction products (e.g. information about manufacturing process) might create problems especially for products manufactured a long time ago with other processes. Then the quality control of the re-usable construction products (e.g. including the selection of representative samples for testing of quality properties) requires new procedures for quality control and also amendments to product standards.

## 5.2 Quality requirements

A prerequisite for use is that the material is proven to be environmentally friendly and technically suitable. This means that the construction product prepared for re-use needs to meet the requirements of potential standards or guidelines given for the specific end use and any additional requirements specified by the customer. An essential prerequisite for re-use is selective deconstruction, which ensures that the material is not damaged during deconstruction and that it does not contain excessive amounts of harmful substances or other impurities that may reduce its environmental and technical suitability or totally prevent its use. Specified quality requirements (possibly including numeric technical/environmental criteria) and a quality control system developed for the specific products give the producer the possibility of ensuring that the material is produced in conformance with the relevant environmental and technical specifications. The waste producer (or material holder or owner) must demonstrate that these technical and environmental criteria have been met. The overall aim in a quality assurance system for re-use of construction products is *"to give confidence in the material properties to ensure safe re-use"*.

**General quality requirements to be considered in the re-use of construction products**

The building material does not contain restricted compounds (due to the long lifespan of a building structure, it is possible that chemicals banned nowadays have been used in the earlier production)

The product has not been subjected to activities leading to pollution of the material.

The previous use of construction material has not endangered the technical properties (e.g. material ageing)

The deconstruction of the material has not harmed its technical properties.

The quality criteria are material-specific and depend on the type of application. In practice, the same quality requirements need to be fulfilled as for virgin products. A generic scheme for quality assurance can be developed for evaluation of the acceptance of re-usable construction products. The scheme for approval of a construction product in a specific application as well as the product quality control scheme needs to be developed in cooperation with all stakeholders involved in material handling (especially the waste producers, the end-user). Some applications may set specific pre-treatment requirements in terms of quality (e.g. cleaning, cutting).

If the material still has a waste status after the preparation for re-use, an environmental permit is needed from the environmental authorities. For CE-marking, this may lead to a situation where a third party is needed to be involved for type testing (e.g. initial testing for material approval) and product quality controls.

The description of the quality control is one of the most important parts in the quality assurance scheme. The quality control programme describes how the compliance is evaluated in practise in a continuous production of construction products (see box below).

Quality assurance is an important part of the CE-marking. The minimum requirement is that the manufacturer of a construction product has established a production control system. Current procedures for CE-marking of construction products typically do not cover re-usable construction products. Apart from the applicability of the requirement and testing procedures related to CE-marking which are described in the harmonised product standards (e.g. related to sampling and testing in type testing and factory production control), also historical data of the material use affecting the material quality needs to be taken into account.

**Elements in a quality control scheme**

Definition of the application of the material (references to existing harmonised standards, if possible)

Definition of the origin materials accepted for the application (specification on historical data needed)

Guidance for deconstruction/demolition

Guidance for visual inspection prior to deconstruction (potentially including sampling guidance)

Quality control programme (focus on key parameters including methods and action limits)

System for approval/rejection of products (for quality control)

Qualification for persons involved in the quality assurance process (links to CE-marking of new construction products)

Requirements for cleanliness, e.g. acceptable levels of impurities (e.g. nails)

Documentation system

Training of staff

# 6. Design for deconstruction and re-use

Asko Talja

Design for deconstruction (DfD) refers to the design of the building so that the parts are easily dismantled and separated from each other for re-use or recycling. Good design solutions promote further use of components and materials. Today, easy and effective constructability is the most common starting point for design, but in the future the designer will increasingly be able to judge how building parts can reasonably be repaired or dismantled without breaking them, and how the remaining lifetime of the dismantled parts can be utilized in new applications. Dismantling should be taken into account in design, and it should be a part of life cycle assessment of building parts and structures. Good design takes into account future needs, making it easy to repair the components or recycle the demolition materials. It is estimated that in 30 years half of buildings will be from this century [29].

The primary goal in recycling is to re-use the dismantled components, and the secondary goal is to recycle only the raw material (Figure 19). The primary use of the dismantled parts is to re-use them for their original purpose, and only then re-use for other purposes [30].

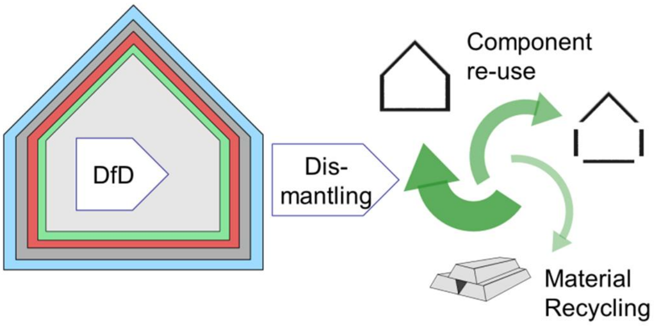


**Figure 19.** If buildings are designed for deconstruction (DfD), the components can easily be separated for further re-use and recycling.

## 6.1 DfD as a part of life-cycle management

The design related to the usage and end-of-life- stages should be a part of cycle design, which forms a part of architectural and structural design (Figure 13). However, repair, recycling and re-use is often forgotten today. The design should not be limited to the construction term benefits, but it should also take into account the entire lifecycle up to treatment of the demolition waste. The most important decisions of DfD are taken already in the project definition and general planning stage. The question of re-use and recycling arises at the stage when either the equipment or the building service life is reached, or changing the use of the land will arise. The more attention is paid to the design of building dismantlability, the better are the future benefits. Whenever the structures or technical equipment need to be repaired or replaced, simplicity of dismantling is always an advantage. Usually the service life of the parts is longer than their used life in one building. Attention should be paid to the intact dismantlability and portability of the parts. It will improve the quality and re-use opportunities of the parts.

## 6.2 Main principles of DfD

Replaceability of parts in Finland, the guidelines for design for deconstruction (DfD) have been published by the Finnish Association of Civil Engineers RIL [30] and the guidance is a part of the building's life cycle management. The main principle in DfD is that the components with different service life and with different requirements for recycling, are clearly separated (Figure 20). For example, the load-bearing frame, surface structures and installations must be clearly separated, so that each sub-assembly can be dismantled separately. This speeds up the replacement work and facilitates the re-use and recycling of building components and materials. The shorter the life span, the more easily the part should be replaceable.

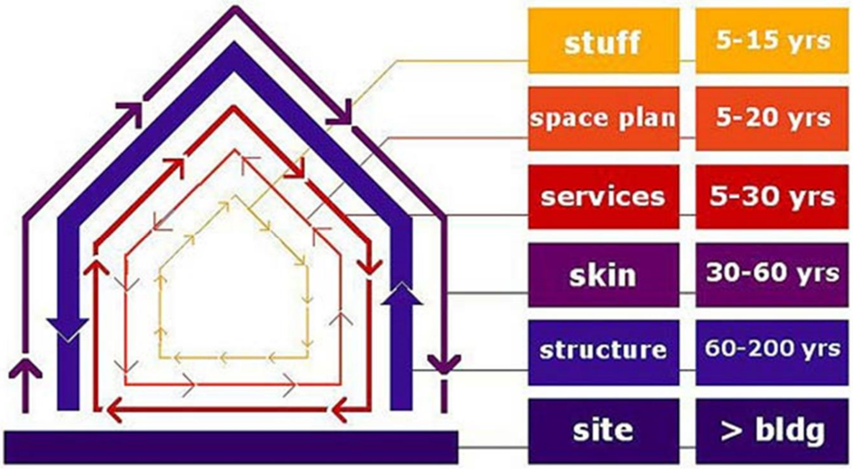


**Figure 20.** Building components grouped by different lifespans (http://www.locatearchitects.co.uk/seda-lg.htm).

**Adaptability of rooms** – The spaces should be flexibly adaptable. Buildings and rooms should be designed in advance so that splitting or merging the rooms is possible. In general, long spans allow easy adaptability of the spaces for different uses, and reduce the number of components. Load-bearing walls between apartments can also be designed so that later on openings can be made (e.g. additional reinforcement ready). When a modular system is used, it is possible to use standard scale components and materials. It should also be taken into account that the structures allow the changes in building service systems, such as renewals in electrical and plumbing systems. The equipment should be easily accessible (e.g. installation floors, installation pipes). Piping systems which are hidden in the structures are difficult to repair and sorting of materials can be complicated in demolition work.

**Dismantling of the frame** – The building frame forms the largest part of the total mass of the building. Therefore, the design for re-use and recycling of components can significantly reduce the environmental impact of building materials. The building frame should act as a self-supporting structure without the contribution of wall elements. It makes it easier in the replacement of the elements, and also in the dismantling of the whole building. Frame parts are generally massive and well protected. In many cases the components can be re-used, if desired, even several times. However, re-use requires that the structure is designed so that the parts can easily be disassembled without damage. When choosing the size of the components, the potential need for their manual removal should be considered. The lifting devices for heavy parts should be designed so that they can also be used in demolition work. The parts should be durable marked, and the specifications and standards of the materials should be well documented.

**Disassembly of the joints** – The possibility of opening the joints is particularly important in disassembly. The joints should be easily accessible and the parts should be dismantlable by non-destructive methods. The number of different types of connections and different types of fasteners in joints should be minimized. In particular, in the fastening of claddings mechanical fasteners should be used instead of adhesives and sealants. The main principle is that easy disassembly is often linked to easy assembly.

newsteelconstruction.com/wp/quicon-wins-contract-at-ikea/

http://www.peikko.com

http://www.puuinfo.fi/

**Figure 21.** Design of demountable joints is important for re-use.

**Optimized material selection** – In general, the structural members should have a long life and easy maintenance. For applications that have to be renewed such as external and internal cladding materials and coatings, easy removal and recyclable materials should be preferred. The design to standard-sized, modular and simple parts, which preferably consist of only one material, should be favoured. Also the coatings of the components should be easily removable or replaceable. The number of materials used and the number of components should be kept as low as possible. If composite components or modules are used, the potential re-use and separation of materials in the demolition should be carefully considered.

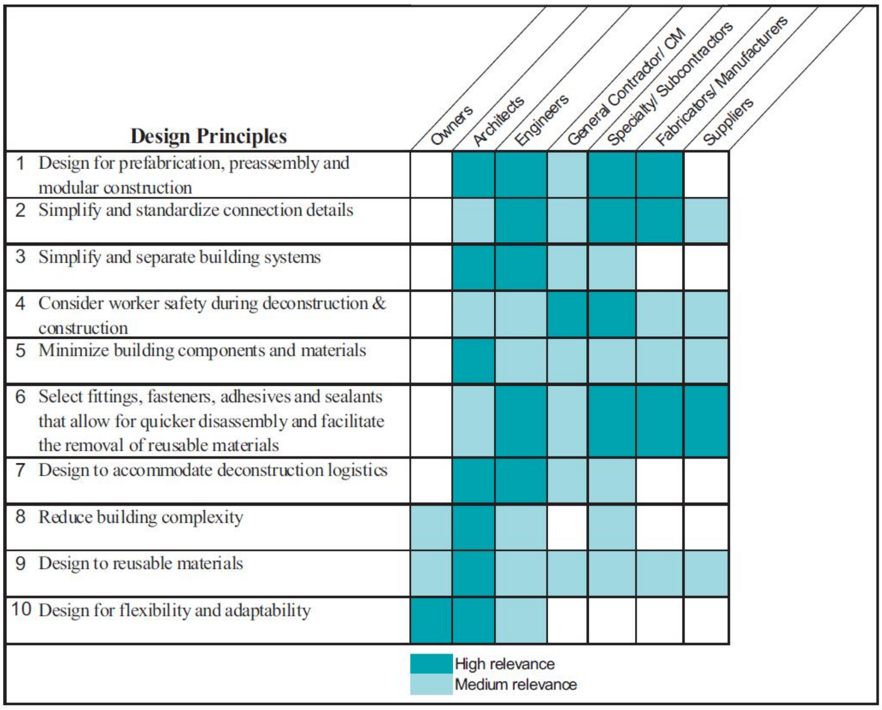
**Using non-hazardous materials** – Building products and materials that are at the end of their life cycle, and the parts that produce landfill waste or hazardous waste, should especially be avoided. It should also be kept in mind that the contaminants in coatings may prevent recycling. The choice of materials is made by following the precautionary principle; if sufficient evidence of the safety of the material does not exist, it should not be used.

**Planning demolition work** – The first use the building components and materials ends in dismantling. The future use of the components for re-use, recycling or demolition should be shown in demolition guidance, which is attached e.g. to the building maintenance book. Without advance planning, the re-use and recycling of materials is difficult and the material easily ends up in landfill waste. In addition to dismantling and safety aspects, the guidance should also include the construction drawings, material data and load data with references to the relevant standards. The information contributes to the re-use of the demolition parts in new applications. The new RFID technology-based electronic marking methods offer an additional opportunity for labelling product information.

## 6.3 Role of parties in promotion DfD

A building project involves several parties (Table 6). The main objectives of DfD are already defined at the project definition and the general design phase. Therefore the design team, led by a chief designer (often the architect), together with the client and with technical experts, has the most important impact on the outcome. Their decisions have influence on the adaptability of space and building technology, service life, energy efficiency, material choices, as well as the reparability of the building and its equipment. Also, the selected design solutions, materials and selected joint techniques have an effect on the recycling and re-use possibilities. Therefore, all architects and structural engineers should know the principles of design for deconstruction. Building product manufacturers are the key factors in development of components and product systems, including methods for fixing and jointing.

**Table 6.** The importance of various parties in design for re-use and recycling [31]



| | Design Principles | Owners | Architects | Engineers | General Contractor/ CM | Specialty/ Subcontractors | Fabricators/ Manufacturers | Suppliers |
|---|---|---|---|---|---|---|---|---|
| 1 | Design for prefabrication, preassembly and modular construction | | ■ | ■ | ▨ | ■ | ■ | |
| 2 | Simplify and standardize connection details | | ▨ | ■ | ▨ | ■ | ■ | ▨ |
| 3 | Simplify and separate building systems | | ■ | ■ | ▨ | ▨ | | |
| 4 | Consider worker safety during deconstruction & construction | | ▨ | ▨ | ■ | ■ | ▨ | ▨ |
| 5 | Minimize building components and materials | | ■ | ▨ | ▨ | ▨ | ▨ | ▨ |
| 6 | Select fittings, fasteners, adhesives and sealants that allow for quicker disassembly and facilitate the removal of reusable materials | | ▨ | ■ | ▨ | ■ | ■ | ■ |
| 7 | Design to accommodate deconstruction logistics | | ■ | ■ | ▨ | ▨ | | |
| 8 | Reduce building complexity | ▨ | ■ | ▨ | | ▨ | | |
| 9 | Design to reusable materials | ▨ | ■ | ▨ | ▨ | ▨ | ▨ | ▨ |
| 10 | Design for flexibility and adaptability | ■ | ■ | ▨ | | | | |

■ High relevance
▨ Medium relevance

## 6.4 Benefits of DfD

Planning for re-use and recycling offers a number of general benefits:

- Re-use and recycling save non-renewable resources.
- Re-use saves the energy and emissions required to manufacture new products.
- The maintenance and replacement of building elements and HVAC system is easier, reducing the costs of the future.
- Landfill waste due to repair and demolition will be reduced in the future.
- Better adaptability of the building increases the possibility to change the spaces to alternative purposes.
- Opportunities for resale and re-use of the undamaged salvage parts and objects will be greatly improved.
- A higher score can be achieved in environmental quality classification, which will improve the ecological image of the company.
- Dismantling costs and environmental impacts due to dust, noise or other harmful emissions are reduced.

- The future financial risks related to the costs of repair and demolition are reduced. Unexpected factors are e.g. changing legislation, changes in technical requirements and uncertainty of waste disposal costs.

## 6.5 Economic impacts

The benefits of design for deconstruction cannot be exploited before the demolition phase of the building or its parts. A long service life of buildings (often 50–100 years) makes it difficult to calculate the economic benefits. The residual value of the products and the costs of selective dismantling are difficult to predict. Durable materials, ease of dismantling of components and easy separation of materials often increase the costs, and economic benefits are often difficult to prove.

The future costs, discounted to the present value, are lower the later the occurrence, or the higher the discount rate (Figure 22). In socially important investments, which are based on national and state economic perspectives, the present value is often discounted by the rate level of 3–6%, but in commercial investments the assessment rate is generally higher [32]. Often, new solutions for such buildings, components or the technical equipment, which have a short life (e.g. 10–15 years) or their costs related to repair or replacement are high, are easier to prove economically viable.

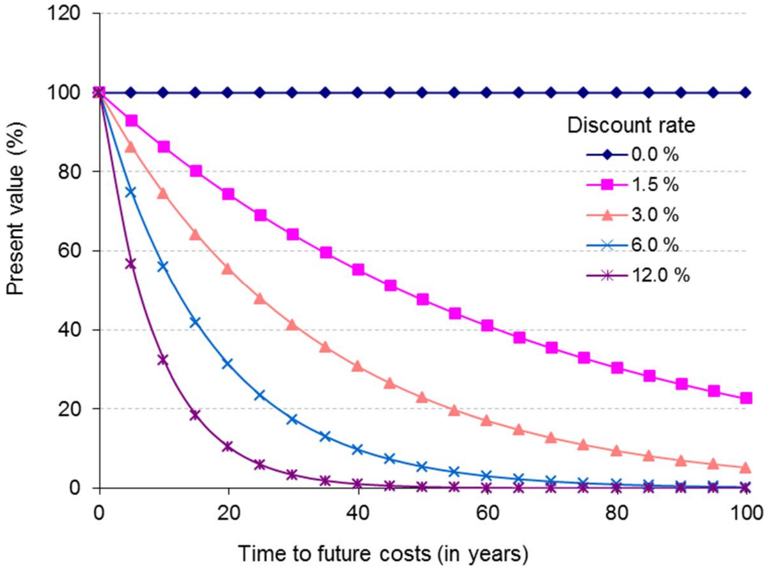


**Figure 22.** The present value of a future cost, based on different discount rates.

## 6.6 Measures to promote DfD

**Mandatory regulations for material efficiency** – Material efficiency should be part of the life cycle of the design, and it should also apply to the design of load-bearing structures. At the moment, the embodied energy of constructions or the amount of demolition waste (Table 7) is not taken into consideration in life cycle design. Consistent assessment provides clear and simple material performance indicators and evaluation methods for material efficiency and demolition recovery, which should preferably be prepared in EU cooperation. The development of guidelines requires case studies, where the needs and development opportunities should be evaluated. Cooperation with the industry ensures that the best practices and material related information (concrete, steel, wood) is transferred into practice. Public sector construction should be exemplary and show the achievable ecological, social and commercial benefits.

**Table 7.** An example of the potential demolition recovery indices of a building [33].

| Material | Normal practice | Good practice | Best practice |
|---|---|---|---|
| Concrete | 75% | 95% | 100% |
| Ceramics (e.g. masonry) | 75% | 85% | 100% |
| Metals | 95% | 100% | 100% |
| Timber | 57% | 90% | 95% |
| Inert (e.g. subsoils) | 75% | 95% | 100% |

**Guidelines and legislation to support re-use** – Although the best way to achieve a positive change in design for deconstruction is to increase knowledge, incentives also have their place. Legislation and related regulations and guidelines should be clear, and incentive bonuses encouraging re-use and recycling should be increased. Regulations and related guidelines should also encourage design of dismantling to be taken into account already at the design stage of new buildings, reducing the amount of landfill waste generated in the future. The principle should be that the new parts should be avoided if dismantled parts that meet the current requirements are available. Useful parts should not be destroyed if there is a market for them. The current Finnish Land Use and Building Act [34] requires before demolition only an inventory of quantities and qualities of the construction waste, not an inventory of re-usable building parts. Regulations and guidance should describe how the conformity of re-usable products should be shown. The Land Use and Building Act allows the compliance control by a product conformity certification given by an authorized expert, if the product does not have a CE mark. The act should also mention what kind of certification should be used in the case of dismantled products.

**Support for business development** – One of the obstacles to expanding the design of buildings for dismantling is that it is difficult to point to the new solutions being economically profitable, and sanctions to achieve the change do not exist. At the time of investment, any potential savings far in the future are often considered as unprofitable. Ecological and economic profitability of new solutions can be facilitated by examples. In the first phase, the advantages of applications with quite a short design life (hangars, petrol stations, shopping centres, schools, etc.), where the frame and foundations are designed and built to be dismountable and portable, should be shown. Such buildings designed by DfD can also be commercially profitable, but non-business economic benefits should also be taken into account. In measuring non-economic benefits by the present value method, a zero interest rate is sometimes proposed to be used [32]. The public sector should be exemplar, also in producing the case studies. The market-driven business of demolition parts should be launched by the principle that one person’s waste can be another's raw material. Such business opportunities and innovations should be supported. Profitable business of demolition parts requires that the demolition of the building is known early enough and that the conformity of the product can easily be shown. Most easily dismantled parts; such as steel and wooden glulam beams and pillars, concrete hollow core slabs and wall panels, are often most the easy to be re-used.

# 7. Case studies

## 7.1 Precast concrete hall in Kotka Harbour

Jussa Pikkuvirta

This case study concerning the carbon footprint calculation of a single concrete building was carried out as a part of the ReUSE project. The reference building in the study was a precast concrete hall building located in Kotka Harbour in Kotka, Finland. The building was originally built in 1977. A satellite picture of the building is shown in Figure 23. The aim of the study was to evaluate the potential environmental impacts of manufacturing, transporting and erecting a precast concrete framework, cast in place footings and cast in place concrete slab similar to the reference building. The second aim of the study was, from an environmental point of view, to evaluate the expediency of reusing precast concrete elements in a new building. This evaluation focused only on the product and construction stages of a building lifecycle as defined in the European standard EN 15978.

**Figure 23.** Pituuspaketointilaitos, Kotka (Image source: Google maps).

A simplified model of the reference building was created. The model included concrete framework, footings and slab. Carbon footprint calculations carried out in this study were based on a quantity analysis of material inputs for all the modelled concrete structures. The quantities were taken from the structural drawings of the reference building. The modelled precast concrete structures included three different types of beams and two different types of columns. The quantity of different concrete elements in the reference building was higher, but the differences between the elements were considered to be minor in terms of material inputs and were not taken into account.

The assessment of $CO_2$-emissions was made by using GaBi 6.0 LCA software. Materials which were used as inputs in the modelled process flowcharts included ready-mix concrete, steel rebar, and for the cast in place processes also plywood as formwork. The precast element production processes were also included an energy input. The value for the energy consumption of precast element production was based on the literature and was set to 15% of the energy used in concrete production. Construction site energy consumption related to the concrete structures was also taken into account as a separate input. Material inputs were selected from the GaBi database as “from cradle to gate”-processes as defined in the European standard. The percentages for material losses in the different processes are represented in Table 8.

**Table 8.** Material losses

| **Process** | **Loss** |
|---|---|
| Precast concrete elements | 2% |
| Cast in place, footings | 10% |
| Cast in place, slab | 5% |

The transportation distance for materials as well as for precast elements was set at 100 kilometres by default. A scenario where the transportation distance for precast elements was set at 1,000 kilometres was also studied in order to evaluate the significance of the transportation in terms of the potential environmental impacts in precast concrete production. Figure 24 shows the total potential environmental impacts of the complete concrete framework and footings as $CO_2$-equivalents. This scenario does not include the cast in place concrete slab.

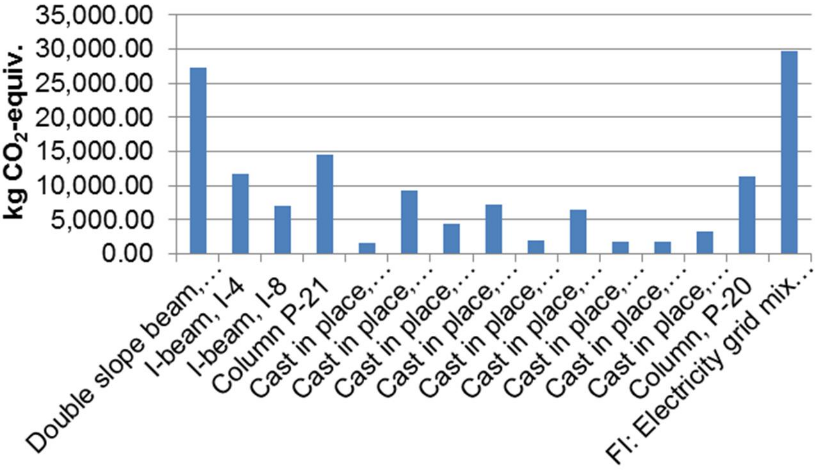


**Figure 24.** Potential environmental impacts, concrete framework and footings.

The total carbon footprint of this scenario is 140 t $CO_2$-equiv. The production of construction-related energy represents the highest single factor in terms of potential environmental impacts covering 21.1% of the total $CO_2$ emissions. The production of double slope beams represents 19.5% of the total $CO_2$ emissions and has the highest potential environmental impact among the modelled concrete structures. Together the precast element production covers 51.5% of the total potential environmental impacts in this scenario. Figure 25 represents a scenario which also includes the potential environmental impacts of the cast in place concrete slab.

The total carbon footprint of this scenario is 248 t $CO_2$-equivalent, and the cast in place concrete slab covers 43.6% of the total emissions, whereas the production of precast elements represents 29.1%. The high impact of the concrete slab on the total $CO_2$ emissions is explained by the large amount of concrete produced for the slab.

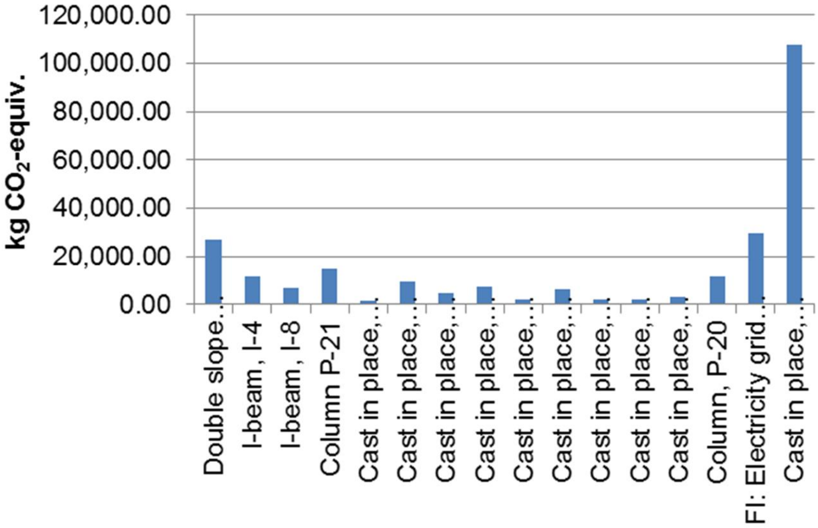


**Figure 25.** Potential environmental impacts, concrete framework, footings & slab.

The influence of the transportation distance on the total carbon footprint of a single precast element was also evaluated in this study. Every transportation distance was set at 100 kilometres by default, and in this scenario the transportation represented 2.4% of the total $CO_2$ emissions of a single double slope beam. If the transportation distance from the element factory to the construction site was set at 1,000 kilometres, the percentage of the impacts of the transportation rose to 24.4%. However, the production of ready mix concrete still remained the highest single factor in terms of potential environmental impacts, amounting to 60.8% of the total $CO_2$ emissions of a single double slope beam.

Based on this assessment, the precast element production represents a notable share of the total potential environmental impacts of the concrete structures. The transportation has a relatively minor influence, even with long transportation distances, on the total $CO_2$ emissions of a precast concrete element.

Re-using precast concrete elements reduces the need for producing new concrete, which is considered to have high potential environmental impacts. Based on this assessment, re-using precast concrete elements has potential environmental benefits due to a reduction in the concrete consumption. Also, it is probable that, on a Finnish scale, these benefits will not be negated even by longer transportation distances. However, this assessment only focuses on the environmental aspects of re-use and any other aspects such as economic or technical aspects would need their own inspection.

## 7.2 Steel beam from the industrial hall in Arad, Romania

Petr Hradil

The following case study compares the life-cycle environmental impacts and cost of a re-used steel element to the traditional “recycling” practice where the scrap is collected after demolition and melted in a furnace to produce new material. The calculation was carried out in OpenLCA software together with ELCD for steel production, transport and waste processing. The steel beam is part of an industrial building located in Arad, Romania (see Figure 26), but its components are transported from different locations. Bolts are manufactured in Dortmund, Germany, steel hot-rolled sections in Ostrava, Czech Republic, and steel hot-rolled coil in Galaţi, Romania. The beam is then assembled in the workshop in Bocşa, Romania and transported to the building site in Arad. The same workshop is also used for cleaning and remanufacturing re-used beams.

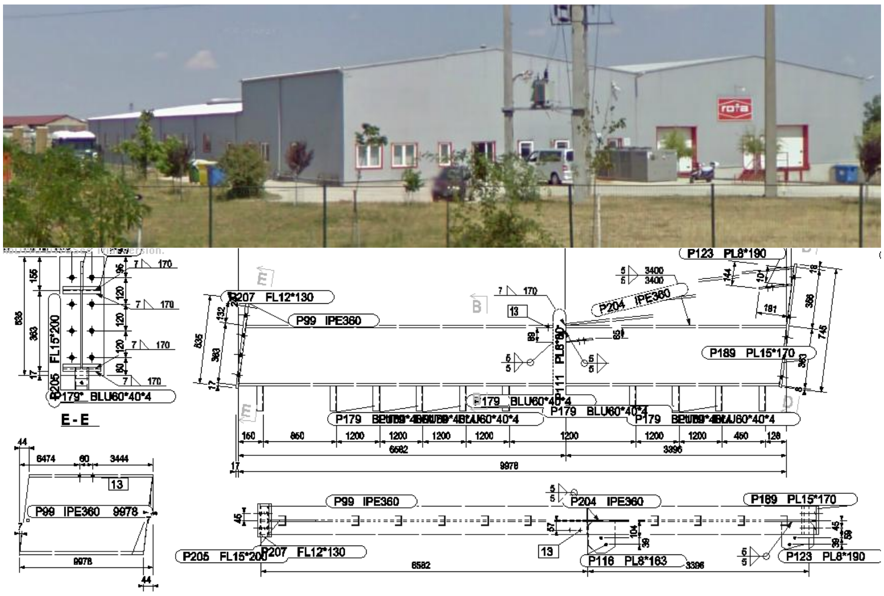


**Figure 26.** Industrial building in Arad and drawings of the beam studied

Due to the comparative nature of the results presented, the environmental impacts of construction and use stages were not calculated, and only production, manufacturing, deconstruction and end-of-life stages are included in the results. The basic flowchart of re-use and recycling scenarios is presented in Figure 27. Some of the processes were adapted from the ELCD database, and the rest is based on the literature study [4].

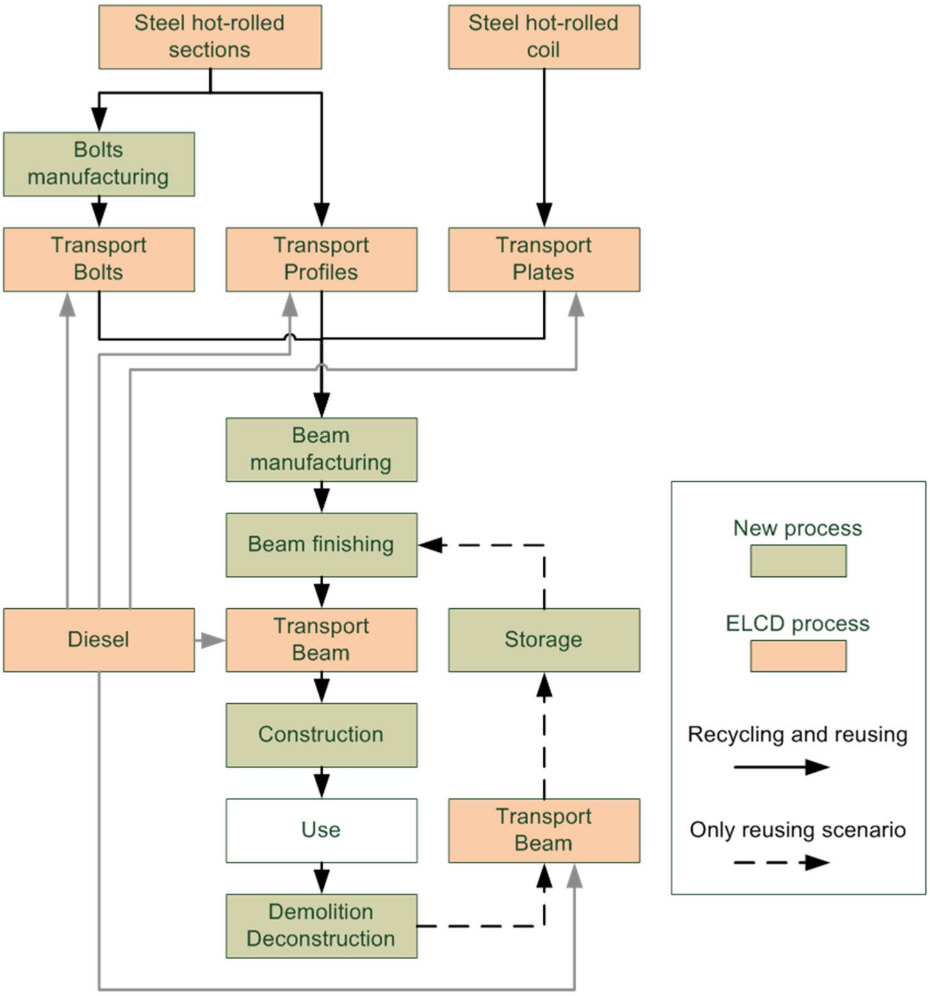


**Figure 27.** Flowchart of recycling and re-use scenarios

The recycling scenario, where all the material is turned into scrap, is basically more cost-effective because the cost of deconstruction is estimated to be double that of the construction cost and four times higher than in the case of demolition, due to the additional processes such as cleaning, sorting and quality check.

We assumed that, when the building is properly designed for re-use and all the material certificates are preserved until the deconstruction, the estimated cost can be significantly reduced. Therefore, we included the optional scenario with a reduced cost of deconstruction that was only 1.2 times higher than construction (2.4 times higher than demolition) and it turned out that such a reduction is sufficient to make the re-use process cheaper (see Table 9 and Figure 28).

**Table 9.** Results of LCA/LCCA calculation for one beam and one building life

| **LCIA category** | **units** | **no re-use** | **1x re-use** | **2x re-use** | **3x re-use** |
|---|---|---|---|---|---|
| Global warming potential (GWP100) | kg $CO_2$ eq. | 1075 | 901 | 642 | 454 |
| Stratospheric ozone depletion (ODP10) | kg CFC11 eq. x $10^{-8}$ | 4.27 | 4.44 | 3.52 | 2.78 |
| Acidification potential (AP generic) | kg $SO_2$ eq. | 3.33 | 2.90 | 2.11 | 1.53 |
| Eutrophication potential (EP generic) | kg $(PO_4)^{3-}$ eq. | 0.293 | 0.278 | 0.212 | 0.160 |
| Photochemical oxidation (POCP high NOx) | kg ethylene eq. | 0.089 | 0.046 | 0.032 | 0.025 |
| Cost | € | 1149 | 1394 | 1312 | 1270 |
| Cost (designed for re-use) | € | 1149 | 1131 | 1048 | 1007 |

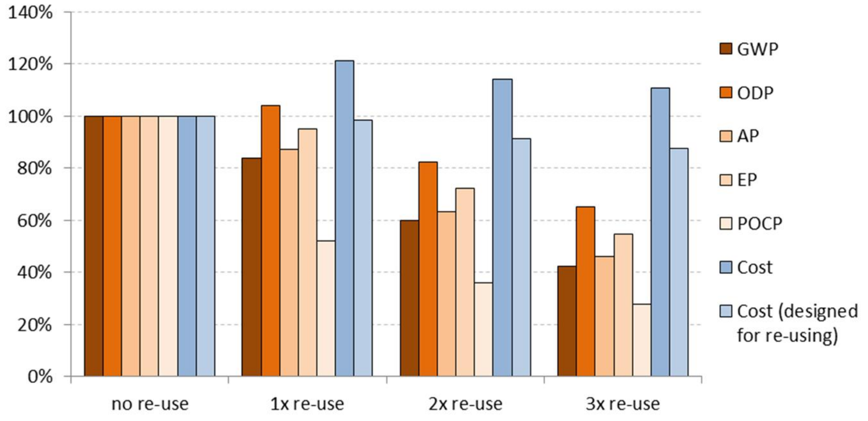


**Figure 28.** Results of LCA/LCCA normalized to the case without re-use

The basic life-cycle impact categories (GWP, ODP, AP, EP and POCP) were calculated using CML 2001 methodology. The value of the salvaged parts is not subtracted from the final results because it was already included in the manufacturing phase (no cost was allocated for the used beams).

The study showed that a significant advantage in environmental indicators can be achieved when a re-use scenario is selected. The accumulated cost of a re-used beam is higher in this basic study than the "no re-use" scenario, but the situation changes completely if we assume reduced end-of-life costs. The introduction of cheaper deconstruction, sorting and inspection technologies changes the balance between costs in both scenarios. Moreover, increasing the number of building service lives will also reduce the life cycle cost of the element.

## 7.3 Re-use policy implementation in a small neighbourhood

Petr Hradil

The aim of this case study is to demonstrate the potential of a dynamic material flow calculation in the assessment of the environmental performance of an urban district. In our artificial scenario, the district is represented by 50 wooden family houses. The houses are built from structural timber and wood-based panels. Those products are made from lumber and low-quality wood allowing for re-use and recycling when possible. Solid timber elements (framing) and wood-based panels (cladding and roofing) are studied, including their production, material recovery, extraction landfill and incineration. The structural components are supplied from a sawmill and panel production plant where the lumber and low-quality wood is either salvaged from the demolitions in the same area or extracted from the forest.

The advantage of dynamic calculation is that the inputs and outputs of the processes can be allocated within a specific time (e.g. the demolition waste is released 50 years after the building construction) or distributed in the time period such as emissions and energy associated with the building use. However, the extension of standard LCA calculation to a time domain is not simple because the characterization factors are generally not valid with dynamic outputs. Moreover, temporal variation of demand and supply may lead to negative material flows, and the processes are not fully reversible. For example, the “positive” demand for sawn wood triggers the sawmill process, but its “negative” values (the excess of sawn wood) cannot revert back to the lumber. Therefore, we have divided the system into small sub-systems with only a single demand value and boundaries carefully selected in the asymmetric flows. Those systems were solved in a given order in each time step.

The particular difficulty of the example simulation is that the system has to decide about material sourcing according to pre-defined preferences. For instance, structural timber can originate from the demolished buildings or sawmill production, but the source of the demolished buildings should be the priority. Then the accumulation of unused materials has to be handled in the model. For example, the excess of structural timber otherwise suitable for re-use can be downgraded to low-quality wood if there is no better application for it.

The simulation aims to estimate the impact of different policies/strategies to implement re-use of structural timber and wood panels in residential buildings. The target is 30% of sorted deconstructed wood elements (this means about 20% of the total material being directly re-used). The study demonstrates the effect of implementing this policy gradually until 2020, 2050 and 2100 in the selected area (see Figure 29).

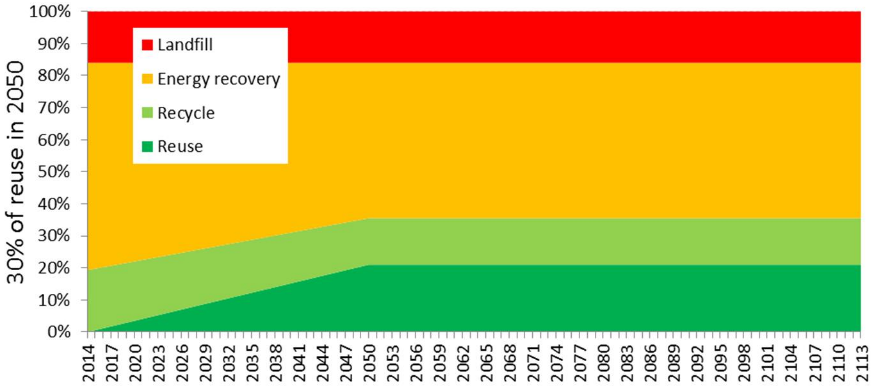


**Figure 29.** Example of implementing policy to increase re-used content to 30% of sorted wood by 2050

No LCIA methodology is used in this study because of the lack of characterization factors for dynamic effects. Therefore, the results are expressed as cumulative or yearly $CO_2$ savings in comparison to the scenario without re-use (see Figure 30).

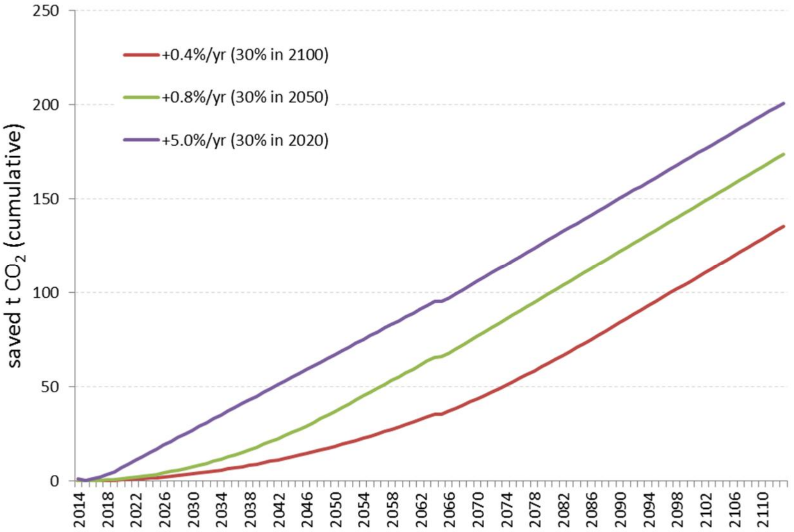


**Figure 30.** Comparison of $CO_2$ savings of three scenarios studied

As can be seen from the results presented, significant savings of $CO_2$ can be achieved when the re-use strategy is applied early. However, it should be noted that the savings are only a very small fraction of the total $CO_2$ produced in the area mostly due to the building use.

# 8. Summary and conclusions

The building element re-use practices differ with the size and complexity of the reclaimed parts. The smaller ones such as bricks, wooden boards and steel sections tend to be re-used in a more organized way, collected in the salvage yards and re-sold as basic materials in the local community. On the other hand, larger and more complex structural systems have a higher value, but lower applicability, and therefore a different approach should be selected for their re-use. Online marketing, component labelling and BIMs are the technologies that are feasible for increasing the efficiency of such components' re-use. The special category is the whole building structure. Re-use of building components is generally one of the most environmentally friendly end-of-life scenarios of the building; provided that the durability of the components extends the life of the building and that there is a suitable application for it. Re-use benefits can nowadays be declared in a standardized way according to EN 15978. Many environmental certification systems recognize re-use in their assessment process, however, the contribution of material and resource efficiency to the overall score is usually very low.

There are many other practical obstacles to the building components' re-use that should be addressed. One is the lack of strength grading rules for materials in re-used elements. This means that re-usable load-bearing components are often forced to be applied to non-structural purpose unless they are thoroughly tested in certified laboratories. Another obstacle is the difficult of deconstruction of existing buildings. The extended time and high demands on manual labour usually increases the cost of the whole process. This can be partly improved by applying standardized deconstruction practices, proper staff training and using selected technologies for deconstruction. However, the greatest impact on a building's re-usability is in its design stage. Therefore, we recommend addressing this issue in the planning of future steps towards resource efficiency.

The standardization process and the recent changes in the environmental certification systems indicate that the importance of life-cycle assessment of buildings and components will grow in the near future. However, there is a lack of reliable LCA data for the most critical stages in re-use such as deconstruction, sorting, quality check and re-distribution of materials and components. These gaps in life-cycle inventory databases have to be addressed in the future.

# Acknowledgements

This publication was created within the research project jointly funded by the Ministry of the Environment, VTT Technical Research Centre of Finland, Tampere University of Technology, Ekokem and Finnish Wood Research. The following members of the project Steering Group were appointed to supervise the implementation of the project goals:

Else Peuranen, Ministry of the Environment
Jaakko Lehto, Finnish Wood Research Oy
Toni Andersson, Ekokem Oy Ab
Harry Edelman, Tampere University of Technology
Henna Luukkonen, Association of Finnish Local and Regional Authorities
Laura Majoinen, NCC Rakennus Oy
Eila Lehmus, VTT

We wish to express our gratitude to the project sponsors and the members of the Steering and External Advisory Groups and other participant of the project seminars.

The Authors

# References

[1] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Brussels, Belgium: 2008.

[2] Meinander, M. & Mroueh, U. (eds.). Directions of future developments in waste recycling. Espoo: VTT Technical Research Centre of Finland, 2012. VTT Technology 60. ISBN 978-951-38-7893-1.

[3] ENV.G.4/FRA/2008/0112. Service contract on management of construction and demolition waste – SR1, Final report Task 2. Paris, France: Bio Intelligence Service S.A.S., 2011.

[4] Hradil, P. Barriers and opportunities of structural elements re-use. VTT-R-01364-14. Espoo, Finland: VTT Technical Research Centre of Finland, 2014.

[5] Talja, A. Rakennusten suunnittelu uudelleenkäyttöä ja kierrätystä varten. VTT-R-00736-14. Espoo, Finland: VTT Technical Research Centre of Finland, 2014.

[6] Wahlström, M., Mroueh, U. & Hradil, P. CE-marking, EPD and quality aspects related to reuse of construction products VTT-R-05736-14. Espoo, Finland: VTT Technical Research Centre of Finland, 2014.

[7] Lahdensivu, J., Annila, P., Pikkuvirta, J. & Huuhka, S. Betonielementtien uudelleenkäyttömahdollisuudet. TTY Rakennetekniikan laitos Tutkimusraportti 163. Tampere, Finland: Tampere University of Technology, 2014.

[8] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Roadmap to a Resource Efficient Europe. Brussels, Belgium: 2011.

[9] Huuhka, S. & Lahdensivu, J. A Statistical and Geographical Study on Demolished Buildings. Building Research and Information in press, doi: 10.1080/09613218.2014.980101.

[10] Huuhka, S. Future-Oriented Building Stock Studies and the Significance of Values: Addressing Demolition Behaviour with the Delphi Method. In: van Breugel, K. & Koenders, E.A.B. (eds.).Proceedings of the 1st international conference on ageing of materials and structures, AMS'14. 26–28 May, 2014. Delft, Netherlands: DCMat Ageing Centre, 2014.

[11] Huuhka, S., Hakanen, J.H. Potential and Barriers for Reusing Load-bearing Building Components in Finland. 40th IAHS World Congress proceedings, in print. Funchal, Portugal, 16–19 December 2014. 2014.

[12] Huuhka, S. Kierrätys arkkitehtuurissa: Betonielementtien ja muiden rakennusosien uudelleenkäyttö uudisrakentamisessa sekä lähiöiden energiatehokkaassa korjaus- ja täydennysrakentamisessa. MSc. thesis, Tampere, Finland: Tampere University of Technology, 2010.

[13] Huuhka, S. Partial dismantling of 1960's to 80's neighbourhoods – a sustainable holistic solution. In: da Sousa Cruz, P.J. (ed.). CRC Press, 2013. Structures and Architecture: New concepts, applications and challenges. ISBN 978-0415661959.

[14] Publication 33/2013. Sustainable growth by material efficiency. Working group proposal for a national program for material efficiency. Helsinki, Finland: Ministry of Employment and Economy of Finland, 2013.

[15] Recycling and reuse [Homepage of SteelConstruction.info], [Online] Available: www.steelconstruction.info [3.10.2014].

[16] Towards an Eco-Efficient Europe [Homepage of European Policy Centre], [Online], 2012, Available: www.epc.eu [3.10.2014].

[17] Anderson, J. & Howard, N. The Green Guide to Housing Specification, BRE Report 390. UK: BRE, 2000.

[18] Lahti, P. Evaluation and enhancement of eco-efficiency in Helsinki. Report 2:2008, Helsinki, Finland: Helsinki City Planning Department, General Department of Planning, , 2008.

[19] Ruuska, A., Häkkinen, T., Vares, S., Korhonen, M. & Myllymaa, T. Rakennusmateriaalien ympäristövaikutukset. Selvitys rakennusmateriaalien vaikutuksesta rakentamisen kasvihuonekaasupäästöihin, tiivistelmäraportti (Environmental impacts of construction materials. A report on the contribution of construction materials to greenhouse gas emissions of construction). Reports of the Ministry of the Environment 8/2013. Helsinki, Finland: Ministry of the Environment of Finland, 2013.

[20] Wahlström, M., Laine-Ylijoki, J., Järnström, H., Kaartinen, T., Erlandsson, M., Palm Cousins, A., Wik, O., Suer, P., Oberender, A., Hjelmar, O., Birgisdottir, H., Butera, S., Fruergaard Astrup, T. & Jørgensen, A. Environmentally Sustainable Construction Products and Materials – Assessment of release and emissions. Nordic Innovation Report 2014:03. Oslo, Norway: Nordic Innovation, 2014.

[21] Ligthart, T.N. & Ansems, T.M.M. Modelling of Recycling in LCA. In: Damanhuri, E. (ed.). InTech, 2012. (Post-Consumer Waste Recycling and Optimal Production.) ISBN 978-953-51-0632-6.

[22] Heincke, C. & Olsson, D. Simply Green. Kvänum, Sweden: Conny Nilsson, Swegon Air Academy, 2012. 111. ISBN 978-91-977443-5-5.

[23] Schmidt, A. Analysis of five approaches to environmental assessment of building components in a whole building context. FORCE Technology final report. Lyngby, Denmark: 2012.

[24] Rakentamismääräykset ja Eurokoodisuunnittelu (Building regulations and Eurocode design). Confederation of Finnish Construction Industries RT, 2012.

[25] Steel Recycling: scrap is a valuable raw material [Homepage of Eurofer], [Online] Available: www.eurofer.org 2014 [3.10.2014].

[26] The recycling and reuse survey [Homepage of SteelConstruction.info], [Online] Available: www.steelconstruction.info 2014 [3.10.2014].

[27] Winters-Downey, E. Reclaimed Structural Steel And Leed Credit Mr 3-Materials Reuse. Modern Steel Construction [Online]. Available: http://digital.ipcprintservices.com/ 2014 [3.10.2014].

[28] Regulation no 305/2011 of the European parliament and of the council of 9 march 2011 laying down harmonized conditions for the marketing of construction products and repealing Council directive 89/106/EEC. Brussels, Belgium: 2011.

[29] Guy, B. & Ciarimboli, N. DfD: Design for Disassembly in the built environment: a guide to closed-loop design and building [Homepage of King County], [Online], 2007, Available: http://your.kingcounty.gov/ [3.10.2014].

[30] RIL 216-2013: Rakenteiden ja rakennusten elinkaaren hallinta (Life-cycle management of buildings and structures). Tampere, Finland: Suomen Rakennusinsinöörien Liitto (Finnish Association of Civil Engineers) RIL ry, 2013. ISBN 978-951-758-556-9.

[31] Pulaski, M., Hewitt, C., Horman, M. & Guy, B. Design for deconstruction. Modern Steel Construction 2004, June 2004, pp. 33–36.

[32] Tupamäki, O. Life cycle costing – LCC in Construction New recommendations and future views. Rakennustekniikka 2003, No. 5/2003. ISSN 0033-913X.

[33] Demolition Protocol 2008. London, UK: Institute of Civil Engineers, 2008.

[34] Finnish Land Use and Building Act. Helsinki, Finland: ISBN 132/1999, amendment 222/2003 included.

# Appendix A: Authors

**Hradil, Petr,** Research scientist, Lifetime management – Infrastructure health, VTT Technical Research Centre of Finland. Main working areas: steel and timber structures, sustainable built environment. E-mail: petr.hradil@vtt.fi.

**Huuhka, Satu,** Researcher, School of Architecture – Built Environment in Transition. Main working areas: renovation, demolition and adaptive reuse of the existing building stock; recycling and component reuse; architectural construction from timber and prefabricated concrete panels. E-mail: satu.huuhka@tut.fi.

**Lahdensivu, Jukka,** Research manager, Department of Civil Engineering – Service Life Engineering of Structures. Main working areas: degradation mechanisms, condition investigation, maintenance and renovation techniques of reinforced concrete, masonry and natural stone structures; service life modelling of structures; material and energy efficiency of renovation; existing buildings' adaptation to climate change. E-mail: jukka.lahdensivu@tut.fi.

**Pikkuvirta, Jussa,** Research assistant, Department of Civil Engineering – Service Life Engineering of Structures. Main working areas: sustainability of structures, accelerated weathering tests, carbon footprint calculations and building material research. E-mail: jussa.pikkuvirta@tut.fi.

**Talja, Asko,** Senior scientist, Lifetime management – Machine health, VTT Technical Research Centre of Finland. Main working areas: design of steel and stainless steel structures, traffic-induced vibrations, building vibrations. E-mail: asko.talja@vtt.fi.

**Wahlström, Margareta,** Senior scientist, Material recycling and geotechnology, VTT Technical Research Centre of Finland. Main working areas: recovery of waste materials, value chain analysis and safe waste management and sustainable use of waste in construction. E-mail: margareta.wahlstrom@vtt.fi.

# Appendix B: Picture credits

**Cover page:** Design and illustration by Haruka Maitani
**Figure 9**: http://www.steelconstruction.info/Recycling_and_reuse
**Figure 16**: Design and illustration by Paula Tiainen.
**Figure 17**: Design and illustration by Szymon Galecki.
**Figure 18**: Interim Industry Standard Recycled Timber – Visually Graded Recycled Decorative Products, Forest&Wood products Australia, 2008
**Figure 20**: http://www.locatearchitects.co.uk/seda-lg.htm

Series title and number

VTT Technology 200

| | |
|---|---|
| Title | **Re-use of structural elements**<br>Environmentally efficient recovery of building components |
| Author(s) | Petr Hradil, Asko Talja, Margareta Wahlström, Satu Huuhka, Jukka Lahdensivu & Jussa Pikkuvirta |
| Abstract | The depletion of non-renewable natural resources and generation of waste is one of the key issues to be addressed to achieve sustainable goals of the modern society. A great amount of natural resources consumption and a significant part of waste production is contributed to the building industry and infrastructure, in particular construction, maintenance and demolition. Moreover, production of building materials (even those with a high recycled content) consumes a lot of energy and produces harmful emissions. Therefore the efficient use of resources implies that the durable building materials and elements produced from such materials should be used as long as possible regardless of the limitation of the building service life. The most challenging building parts are the load-bearing structures because they need to satisfy high quality and strength, structural safety, stability and integrity requirements. |
| ISBN, ISSN | ISBN 978-951-38-8197-9 (URL: http://www.vtt.fi/publications/index.jsp)<br>ISSN-L 2242-1211<br>ISSN 2242-122X (Online) |
| Date | December 2014 |
| Language | English, Finnish abstract |
| Pages | 69 p. + app. 1 p. |
| Name of the project | Repetitive Utilization of Structural Elements (ReUSE) |
| Commissioned by | Ministry of the Environment, Finnish Wood Research Oy, Ekokem Oy Ab, VTT Technical Research Centre of Finland and Tampere University of Technology |
| Keywords | re-use, resource efficiency, construction and demolition waste, building structures |
| Publisher | VTT Technical Research Centre of Finland<br>P.O. Box 1000, FI-02044 VTT, Finland, Tel. 020 722 111 |

Julkaisun sarja ja numero

VTT Technology 200

| | |
|---|---|
| Nimeke | **Rakennuselementtien uudelleenkäyttö**<br>Ympäristöä säästävä osien talteenotto |
| Tekijä(t) | Petr Hradil, Asko Talja, Margareta Wahlström, Satu Huuhka, Jukka Lahdensivu & Jussa Pikkuvirta |
| Tiivistelmä | Kestävän kehityksen avainkysymykset nyky-yhteiskunnassa liittyvät uusiutumattomien luonnonvarojen ehtymiseen ja jätteiden synnyn ehkäisemiseen. Suuri määrä luonnonvaroista käytetään ja huomattava määrä jätteestä syntyy kiinteistö- ja infrarakentamisen eri vaiheissa, liittyen sekä uudisrakentamiseen, korjausrakentamiseen että purkuvaiheeseen. Lisäksi rakennusmateriaalien tuotanto, myös kierrätysmateriaaleja käytettäessä, kuluttaa paljon energiaa ja tuottaa haitallisia päästöjä. Siksi rakentamisen materiaalitehokkuus merkitsee myös sitä, että rakennusmateriaalien tai niistä valmistettujen tuotteiden käyttöä ei tulisi rajoittaa vain yhden rakennuksen elinkaareen, mikäli purkutuotteet ovat edelleen käyttökelpoisia. Uudelleenkäytön suhteen vaativimpia rakennusosia ovat kantavat rakenteet, sillä niiden on täytettävä korkeat viranomaisvaatimukset, jotka koskevat sekä niiden turvallisuutta, terveellisyyttä, kestävyyttä että käyttökelpoisuutta. |
| ISBN, ISSN | ISBN 978-951-38-8197-9 (URL: http://www.vtt.fi/publications/index.jsp)<br>ISSN-L 2242-1211<br>ISSN 2242-122X (Verkkojulkaisu) |
| Julkaisuaika | Joulukuu 2014 |
| Kieli | Englanti, suomenkielinen tiivistelmä |
| Sivumäärä | 69 s. + liitt. 1 s. |
| Projektin nimi | Rakennuselementtien uudelleenkäyttö (ReUSE) |
| Rahoittajat | Ympäristöministeriö, Finnish Wood Research Oy, Ekokem Oy Ab,<br>Teknologian tutkimuskeskus VTT, Tampereen teknillinen yliopisto |
| Avainsanat | re-use, resource efficiency, construction and demolition waste, building structures |
| Julkaisija | VTT<br>PL 1000, 02044 VTT, puh. 020 722 111 |

VTT TECHNOLOGY 200

Re-use of structural elements

# Re-use of structural elements

## Environmentally efficient recovery of building components

This publication was produced within the Ministry of the Environment research project Repetitive Utilization of Structural Elements (ReUSE). The project aims are to support C&D waste reduction, preserve natural resources and reduce overall the environmental impacts of buildings by encouraging the re-use of the building components. It is closely related to the national programme promoting resource and material efficiency, Kestävää kasvua ateriaalitehokkuudella.

The aim of our research is to contribute to reaching European policy initiatives towards a resource-efficient and low-carbon economy. It strives to create a better understanding of the end-of-life scenarios of building structures and the possible ways in which the environmental, economic and cultural values of their components can be preserved. Our goal is to approach all aspects of sustainability equally as well as all aspects of the major building materials.

One of the most efficient ways to mitigate the environmental burden created by discarding or remanufacturing building materials is to re-use them as whole building elements. This publication focuses on structural elements that are parts of the load-carrying structure of the building or the secondary elements such as cladding and roofing panels.

ISBN 978-951-38-8197-9 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN-L 2242-1211
ISSN 2242-122X (Online)