Towards zero-waste buildings

Building design for reuse and disassembly

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Building design for sustainability

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Preface

The topic for the thesis project emerges from my wish to learn more about the zero-waste buildings and understand how we can reduce the waste generated by the building industry.

This thesis project gave me the possibility to integrate and further broaden the skills and knowledge acquired during my studies.

I hope that my work contributes to the interest in sustainable praxis and helps to find some of the answers on how can we reduce the pressure on the environment.

Acknowledgements

I would like to thank my examiner Krystyna Pietrzyk and my supervisor Walter Unterrainer for guiding me throughout the thesis project. They both gave me a lot of helpful feedback and suggestions, that strengthened the outcome of this work. I would also like to thank my girlfriend Betina, for support and good discussions.

Academic background

2018 - 2020	Chalmers university of technology
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Oslo, 11th May 2020

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Abstract

ENG

This master thesis investigates the potentials of zero-waste buildings as one of the strategies to be used in the sustainable building environment. According to the EU Waste Framework directive, 70% of all construction and demolition waste has to be reused or recycled, by 2020. The goal of this study is to bring up some of the design challenges connected to this and increase interest for a sustainable praxis.

Participation in various events, meetings and visiting exhibitions, further helped to gain a comprehensive understanding of the topic. Some of the involved actors, such as architects, engineers and several product companies, were contacted, to get a holistic view of state of the art in the field.

Based on the investigation, a series of possible design solutions is presented in the catalogue that forms the central part of the thesis booklet. This part has the goal to give the reader an idea of how does design for disassembly might look like and inspire to carry out further investigations.

An analysis of various projects and the methods, used during the construction and dismantling of the buildings, show that there is a big potential for improvement. Building and component design that prevents a product's effective dismantling needs to be reviewed. Not producing more waste, ensuring the value preservation and simple reuse in future, shall be considered a priority.

NO

Denne masteroppgaven undersøker potensialet av avfallsfrie bygninger som en av strategiene for å oppnå et bærekraftig bygningsmiljø. I henhold til EU's avfallsrammedirektiv, skal 70% av alt bygg- og riveavfall gjenbrukes eller gjenvinnes, innen 2020. Målet av denne studien er å bringe opp noen av designutfordringene knyttet til dette og øke interessen for en bærekraftig praksis.

Deltagelse i forskjellige arrangementer, møter og besøk av utstillinger bidro ytterligere til å få en omfattende forståelse av emnet. Flere involverte aktører, som for eksempel arkitekter, ingenører og flere produkt-selskaper, ble kontaktet for å få et helhetlig syn på tilstanden i bransjen.

Designløsninger, basert på utforskningen, er presentert i katalogen som er hoveddelen av oppgaven. Dette avsnittet har som mål å gi leseren en ide om hvordan komponenter designet for demontering kan se ut og inspirere til videre undersøkelser.

En analyse av ulike prosjekter og metoder, brukt under bygging og demontering av bygningene, viser at det er et stort forbedringspotensial. Et design som hindrer en effektiv demontering må gjennomgås. Dette angår både bygningen som helhet og enkle komponenter. Å sikre verdibevaring og en enkel gjenbruk i fremtiden, uten å produsere mer avfall, bør anses som en prioritet.

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Glossary

List of important expressions

Design for deconstruction/disassembly (DfD)

is a practice that focuses on design solutions that facilitate substitution, removal and reuse of building components and materials in a building system. DfD solutions regard all levels of detail in the building, from distinct components, sub-assemblies, assemblies to the whole building systems (Fig. 1.01). A similar expression used: Reversible building design.

Design for reuse

Is intended as applying such design principles that aim for using reclaimed materials and reuse of components and materials. Design for reuse applied together with the DfD principles ensures reaching the circular economy in the built environment. (Fig. 1.02)

Recycling, Upcycling, Downcycling

Are forms of material reprocessing where recycling represents the preservation of value and quality, unlike downcycling, that is associated with a loss of these properties. The last term upcycling is represented by creative solutions where the material use results in a product with higher value, than the original, often associated with the use of waste as a resource. Commonly used symbols are shown in (Fig. 1.03).

Buildings As Material Banks

BAMB is a project developing strategies for the circular economy in the built environment by creating ways to increase the value of building materials. Major tools enabling this are the Materials Passports and Reversible Building Design. BAMB (2016). Title: About BAMB, Retrieved from www.bamb2020.eu/about-bamb/

Fig. 1.01 – **Design for disassembly,** own illustration

Fig. 1.02 – **Design for reuse,** own illustration

Fig. 1.03 – **Recycling, downcycling and upcycling symbols,** own illustration

Fig. 1.04 – **Reuse and disposal symbols,** own illustration

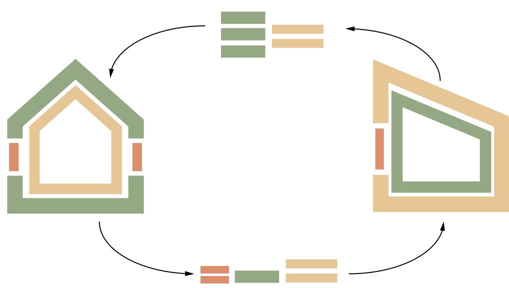


Fig. 1.05 – **Building As Material Banks,** own illustration

Theory

Introduction

Purpose/exploration

The purpose of this thesis is to explore the unused potentials of the reuse of building materials and components.

In Europe, approximately 36% of all the waste generated, come from the building industry. Reusing more and reducing the waste would diminish the pressure on the environment and the connected greenhouse gas emissions. Irresponsible use of materials and generation of a massive amount of unsorted waste is a domain of the building industry in the latest. A considerable fraction of the total waste from constructions and demolitions is still dumped into landfills or incinerated.

Background

The main subject of this thesis is, how to achieve the circular economy in the built environment and effectively manage material use after and during the whole building's life-cycle. The main strategy considered to reach this goal is the design for reuse and disassembly.

Theory

The literature references are used to re-frame the theory and analyse what the current approaches in the field are. A selection of reference projects sets the theory and practice in correlation and showcases how the theory is used in real situations and what challenges these approaches imply.

Delimitations

The thesis focuses on the theoretical aspects of the topic and reuse potentials mapping. Proposed design solutions, or reuse suggestions, are not going to be tested, and therefore their applicability in real situations has to be verified.

All the solutions have their own challenges. The purpose of this exploration is to open a discussion and invite to a broader research of these design solutions and review of dismantling methods and processes used in the built environment.

Reading instructions

The thesis is structured into five main parts, presenting both theoretical and practical aspects of the topic of reuse and design for disassembly. Each part is further described in the method on the next page.

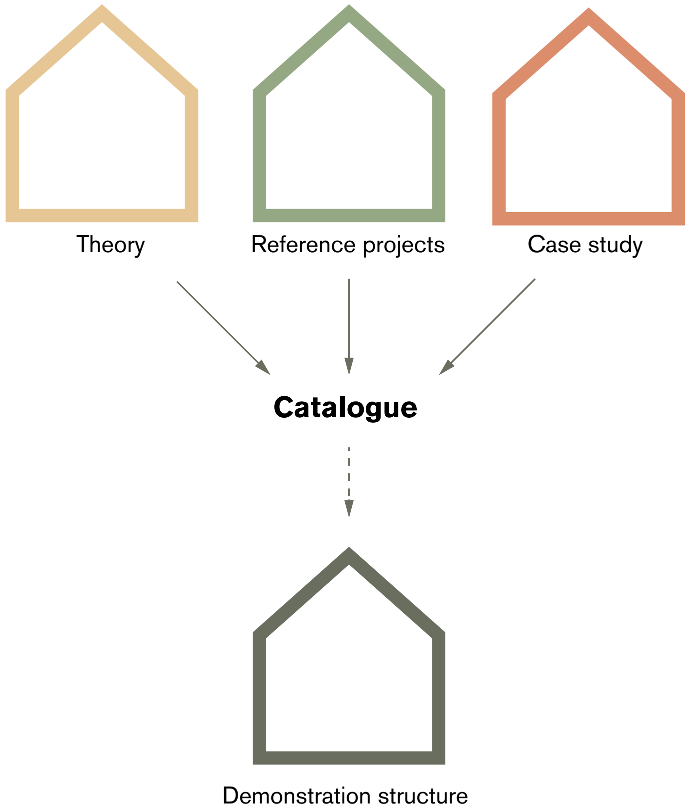
Main question and objective

> How can we ensure simple reuse of building components and materials in future, without producing more waste in the process?

"If it can't be reduced, reused, repaired, rebuilt, refurbished, refinished, resold, recycled or composted, then it should be restricted, redesigned or removed from production."

–Pete Seeger, American singer

Method



Theory

Potentials of reuse and recycling in buildings. Design principles, challenges, economical and environmental aspects.

The literature studies and participation in relevant events constitute a thorough investigation of the topic. Some of the involved actors, such as architects, engineers, entrepreneurs and several product companies, were contacted, to get a holistic view of state of the art in the field.

Reference projects

A selection of reference projects presents interesting reuse and design for disassembly strategies.

Case study

The case study presents a reuse potential mapping in a building, in Sinsenveien 53 in Oslo, that is planned to be demolished.

Catalogue

A collection of own design proposals presented together with existing solutions based on reference projects and theory.

Demonstration structure

Presents an example of a structure designed for disassembly composed of various design solutions.

Conclusion

Waste from the building industry

Economic growth contributes to increased consumption and waste production, and the building industry is the biggest source of waste all around the world. Approximately 36% of all the waste produced in Europe in 2016 comes from construction activities (Fig. 1.06). The total amount of waste produced in the EU(28) during 2017 was 2,537 bill. tons.

Statistics also show that incineration and landfill are still a considerable portion of the material treatment methods. Reuse and recycling have, therefore, still a lot of potential for improvement.

Our goal has to be to produce less waste, if any at all and use the materials most effectively and responsibly. A perfect situation is when even the waste turns into a resource.

"Waste is material without an identity."

T. M. Rau
Chairman of the Madaster Foundation

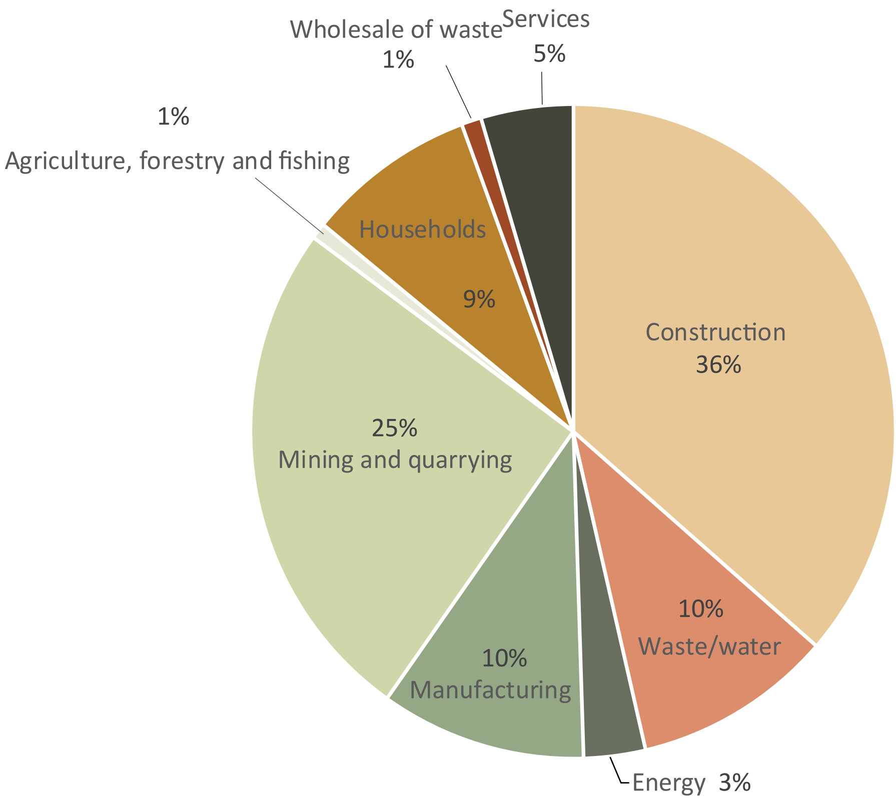


Fig. 1.06 – **Waste generation by economic activities and households, EU-28, 2016 (%)** https://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics#Total_waste_generation (6/2/2020), Adapted illustration

Waste in Europe

Waste from constructions and demolitions

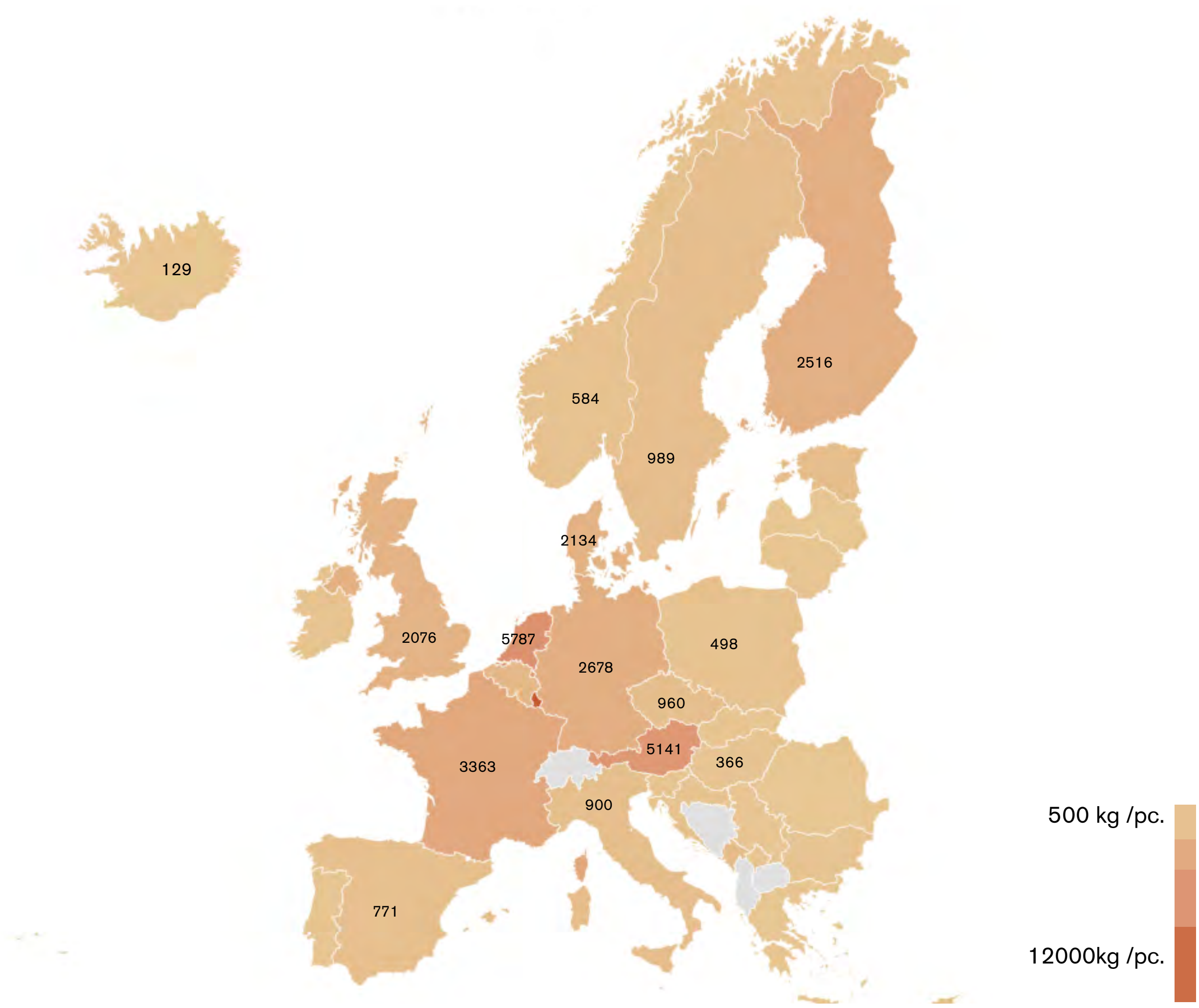


Fig. 1.07 – **Waste amount per capita from constructions in EU 2016**, Own illustration, data source Eurostat: Generation of waste by economic activity https://ec.europa.eu/environment/waste/framework/ (29/1/2020)

The waste created by the construction and demolition sector amounts to around 40% of the total waste produced. This varies from country to country. For example US 40 %, China 30 - 40 %, Norway 25 %, Sweden 40 %. The European average is about 36% which corresponds to approximately 1.8 tons of waste per person, every year. In Sweden, this corresponds to almost 1 ton of waste per person produced each year just from construction and demolition activities.(1)

According to the EU Waste Framework directive by 2020, 70% of all construction and demolition waste has to be reused or recycled.(2)

1 **Generation of waste by waste category** - https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasgen&lang=en

2 **EU Waste Framework** - https://ec.europa.eu/environment/waste/framework/

Explanation of the numbers

It needs to be clarified that some of the most significant differences in statistics, such as the example of Austria, are due to the use of own waste categories lists and national rules.

Austria uses its own Federal Waste Management Plan, that defines strict rules for excavated materials, that are not considered waste, only if used on the site from which it was excavated (FWMP 2011).

Comparing statistics regarding other types of waste, excluding soils, mineral and solidified waste, gives numbers, that are much closer to the European average.

Waste types

An obstacle to understanding, what kind of reuse potential does the waste material have, is a lack of detailed waste analysis. The waste statistics only show certain categories of waste (Fig. 1.08). A lot of waste comes from many different sources, often in the form of debris, or considerably damaged by the removal method (Fig. 1.09) and/or transport. When a component reaches the waste station, it seems it too late for it to be reused and as the earlier quotation by T. M. Rau says, it becomes a material without an identity.

A case study on an existing building that is planned to be demolished located in Sinsenveien 53, in Oslo, (presented on pg. 39) supplements this lacking information. An investigation of the building and a material mapping, gives an idea on what are the conditions and potentials for reuse.

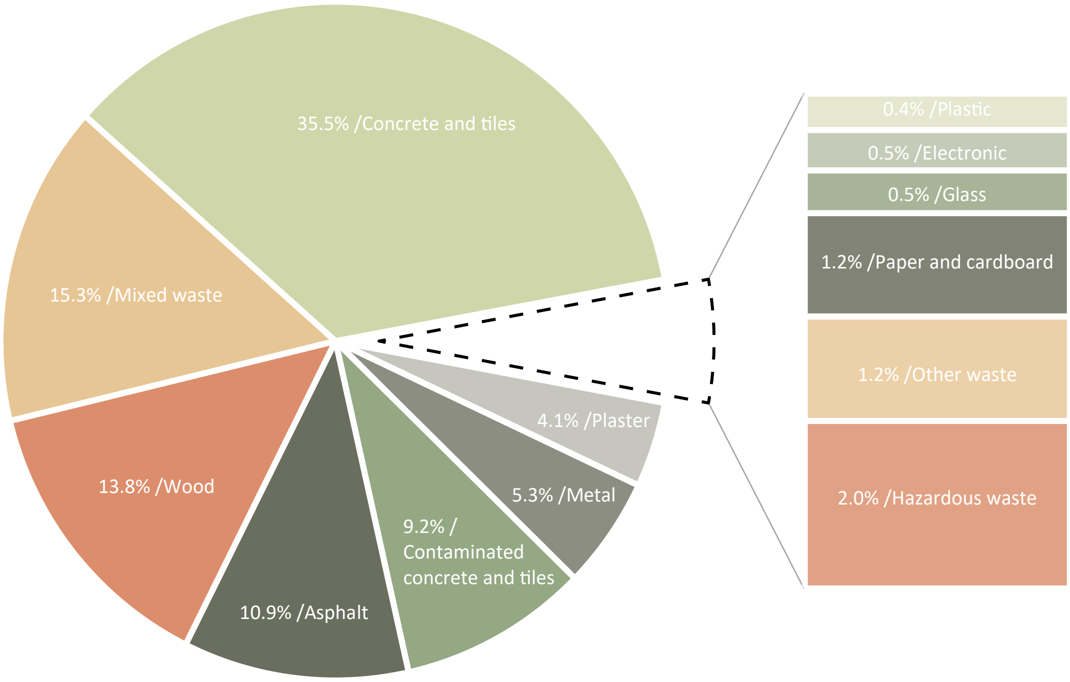


Fig. 1.08 – **Waste types in Norway,** Own illustration, Data source: https://www.ssb.no/statbank/table/09247/

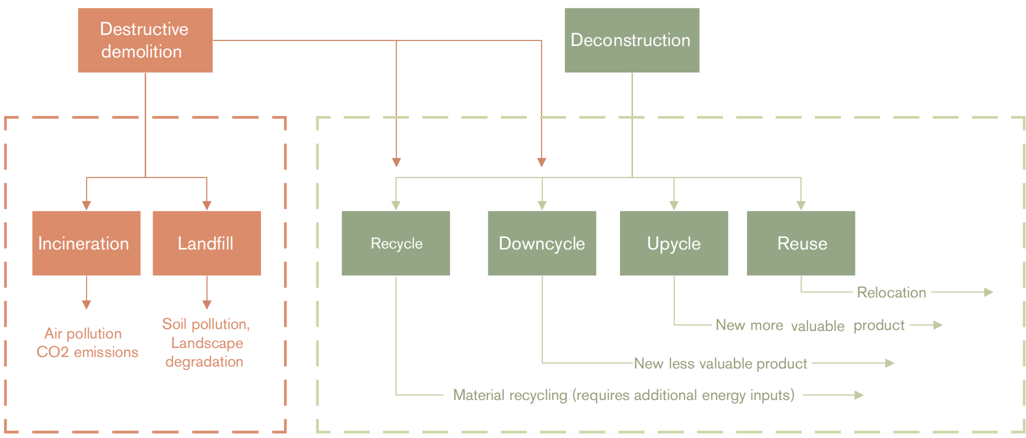


Fig. 1.09 – **Generation of waste from demolitions**, own illustration

Circular economy
Towards zero waste

Facing the problem, there is an effort to close the resource-use loops and by consequence reduce the pressure on the environment. This new model called circular economy aims at eliminating the waste and secure the availability of material resources for future generations. As described by Ellen MacArthur Foundation (2015): *“Circular economy is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.”*

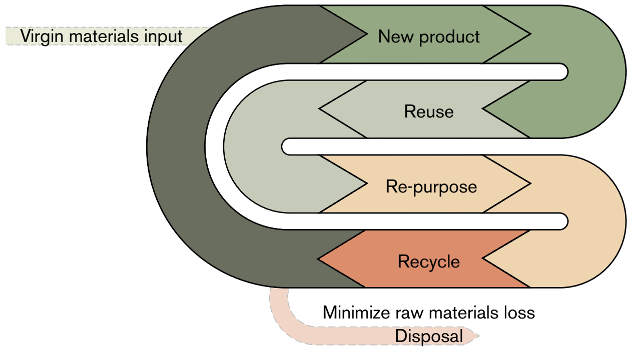


Fig. 1.10 – **Material flow - ideal situation**, Own illustration

In an ideal situation, the material flow is a closed-loop (Fig. 1.10) with maximum waste reduction and minimal input of virgin material resources, still reflecting the principles from the waste pyramid, shown on the next page. (Fig. 1.12)

In the global scale, the United Nations Sustainable Goals delineate this topic in the Goal 11 and 12, not to mention other UN sustainable goals that are closely connected.

Fig. 1.11 – **Sustainable Development Goals,** retrieved from: www.un.org/sustainabledevelopment/cities/

The Goal 11: Make cities inclusive, safe, resilient and sustainable) more in detail in the target 11.6, which focuses on the environmental impact of cities and the air quality. (Fig. 1.11)

The Goal 12: Ensure sustainable consumption and production patterns. (Fig. 1.11)

Certification for sustainable and green buildings

The requirements for the buildings to be sustainable reflect these requirements and new methods, in building design, such as design for disassembly, are applied more frequently. Various certification systems such as BREEM, LEED or the DGNB System, reward the contribution to the circular economy with extra points. The potential for reuse, recovery or recycling, is taken into account.

3

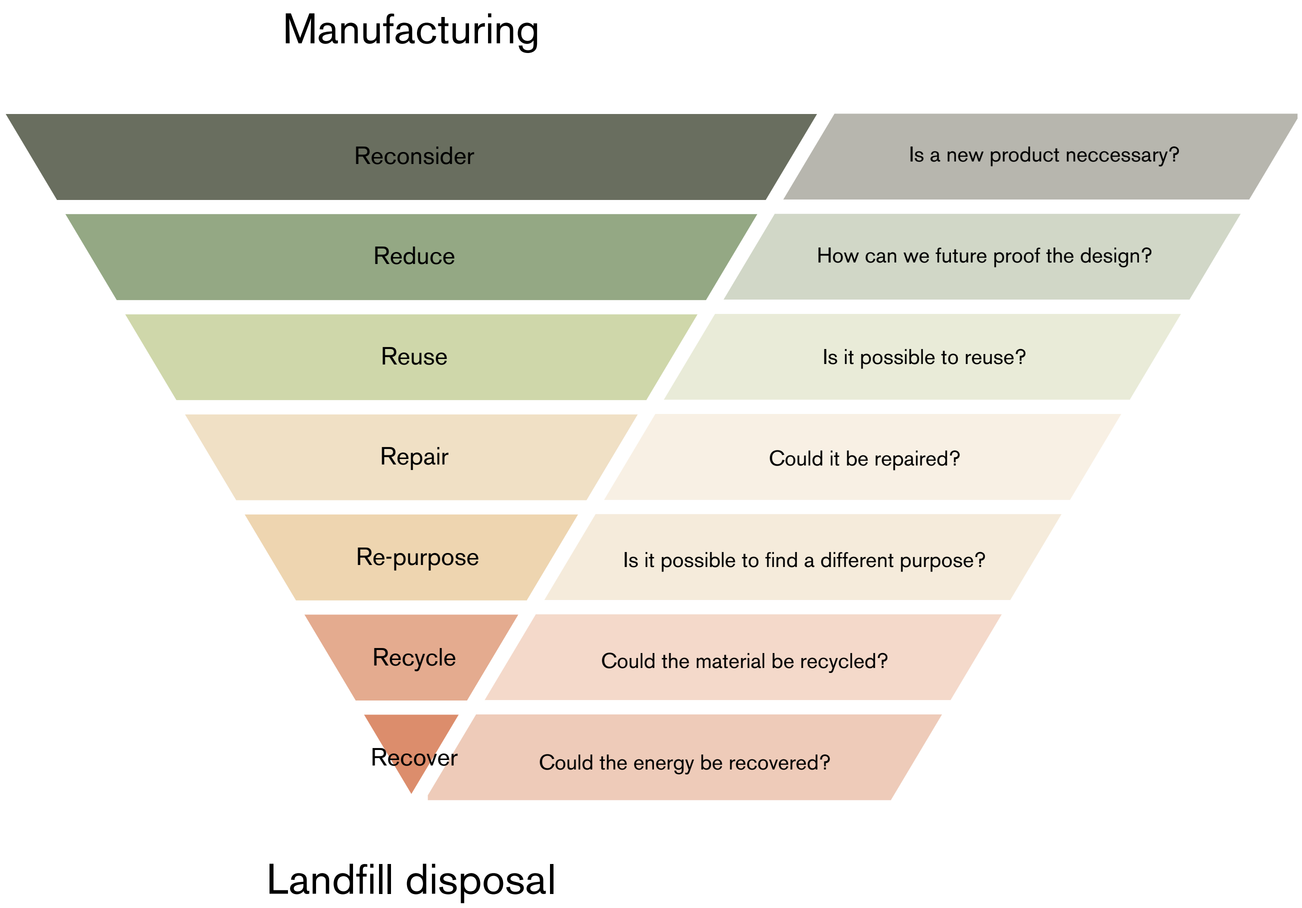


Fig. 1.12 – **7xR of the products life/cycle leading to the waste reduction**, Own illustration, based on the waste hierarchy pyramid retrieved from https://en.wikipedia.org/wiki/Waste_hierarchy

Value preservation

The diagram above is showing the life-cycle pyramid of a product. Each level represents a certain state of the value of the product in its life-cycle, in terms of both economic and environmental savings.

Each degradation into a lower level in the pyramid results in a decrease of value and therefore a least preferable option, with the disposal and almost complete loss of value in the bottom.

It is crucial to notice that recycling requires an additional amount of energy, and not all the materials are suitable for an infinite recycling loop. Recycling, from the environmental perspective, is, therefore, a less desirable option than direct reuse or re-purpose.

Between each of these steps, there is one more "R" which needs to be mentioned. There has to be a **R**eason for not repairing, reusing, etc.

Our responsibility as architects is to design the buildings and its components by keeping this in mind. At the same time, maintaining a product in a certain state should not require an exaggerated effort in terms of energy and costs.

To achieve this, a considered strategy is the design for disassembly which simplifies repair and reuse. How design for disassembly contributes to facilitates this, is discussed further in this study.

Spolia
Historical approaches

To reuse or re-purpose a building component is not a new approach in architecture. Buildings from the late antiquity are frequently compound of both new and reused fragments of stones, decorations or entire sculptures. These pieces are called *Spolia,* from Latin meaning spoils - waste material taken from other places. In some cases, there is quite a big time span between the creation and first use of the component and its re-purposed use.

Antiquity

The arch of Constantine, located in Rome built in 315 CE, is an excellent example of this. As presented by Brilliant & Kinney (2011, pg. 159)[(1)] the oldest fragments come from a time, approximately 200 years, before the construction of the arc. (Fig. 1.13)

In history, reuse has had various reasons. Brilliant & Kinney (2011, pg. 159)[(1)] identified the motives for reuse on the Arch of Constantine as emendation and manipulation of the historical records.

Japanese vernacular architecture

Japanese vernacular architecture was instead adapted to the local conditions with frequent earthquakes. High detach-ability allowed the damaged components to be easily replaced. In addition to a simple repair, the skills of traditional carpentry were maintained (Guy & Ciarimboli, 2008, p.4)[(2)].

Nowadays we face a different problem we have to adapt to. The focus today is on the environmental sustainability and preservation of the natural resources in the future. As mentioned in the previous chapters, the Circular Economy, in this case, the design for reuse and disassembly, is one of the possible strategies to face the issue.

4 **Brilliant, R., & Kinney, D.** (2011). *Reuse Value : Spolia and Appropriation in Art and Architecture from Constantine to Sherrie Levine* (1st ed.). Routledge

5 **Brad Guy, Nicholas Ciarimboli** (2008). *DfD: Design for Disassembly in the Built Environment :* a Guide to Closed-loop Design and Building, Hamer Center.

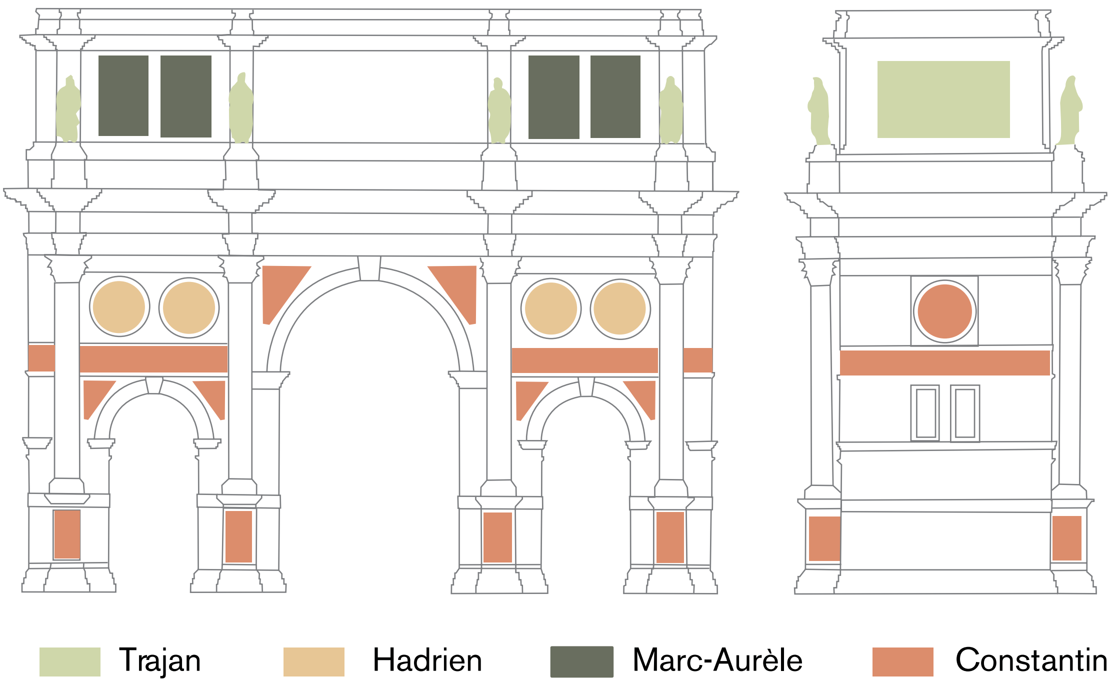


Fig. 1.13 – **Diagram of the Arch of Constantine in Rome**, Own illustration based on Brilliant, R., & Kinney, D, (2011) *Reuse Value : Spolia and Appropriation in Art and Architecture from Constantine to Sherrie Levine* (1st ed.). p.160

Fig. 1.14 – **Detail of the masonry with Spolia**, photo by Marsyas (2016), Retrieved from: https://en.wikipedia.org/wiki/Spolia#/media/File:THES-Heptapyrgion_spolia_3.jpg

追掛け大栓継ぎ
Okkake daisentsugi - beam joint

大阪城大手門柱継手
Column joint used at the gate in Osaka castle

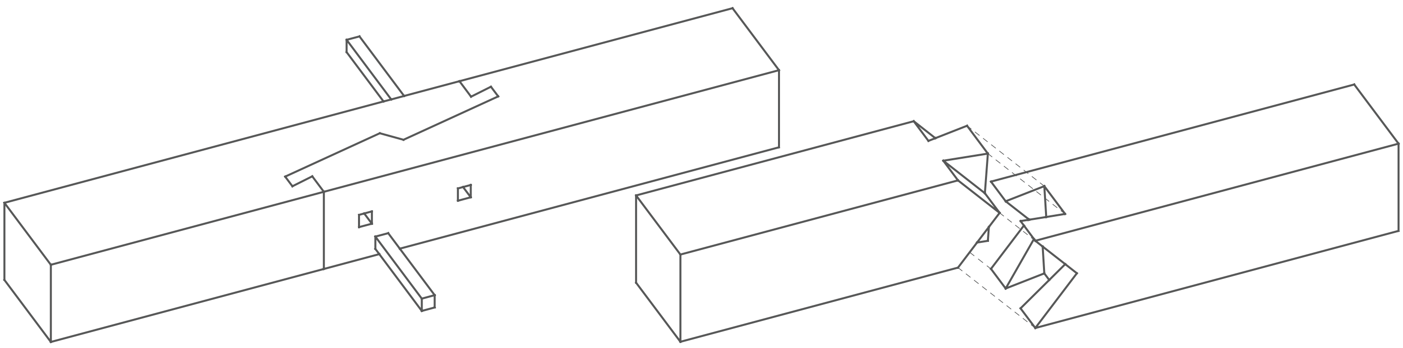


Fig. 1.15 – **Examples of traditional Japanese joinery,** own illustration

Demolition methods
Comparison

Unlike reuse, demolition is typically a destructive, dirty and high energy demanding process. In a dense urban context, it is more and more challenging and disruptive. Nowadays methods of destructive demolition create a fragmented mixture of materials. Such mixture makes it challenging to recycle, and the value of the materials diminishes (Fig. 1.16). Mixing of materials also contributes to a higher percentage of contaminated and hazardous materials.

Selective demolition

The building dismantling approaches have some variation in methods highly dependent on the estimated value of the materials present on site. If assessed correctly, a higher value of materials and components means a higher chance for recovery and salvage and a more careful dismantling.

By selective demolition approach, a part of reusable materials is recovered, and most importantly, materials are more carefully sorted and subsequently recycled.

In contrast to the traditional destructive demolition, disassembly aims at a careful, gradual removal with the goal to preserve the value of all the components with a potential to be re-purposed. Disassembly, unlike demolition, is highly planned, very little spontaneous and requires good communication between the involved actors.

Fig. 1.16 – **Demolition of Ruseløkkveien 26** - VIA Oslo - Retrieved from: https://www.instagram.com/p/BpB33f8gQzh/

The Government Quarter in Oslo

An example of an innovative approach, and a testing arena for new dismantling methods, is the Block R4 of the Government Quarter in Oslo.

In this specific demolition, at least 90%[6] of the building mass shall be sorted. Before the dismantling started, a detailed feasibility study of reuse potentials was conducted. The project done by Statsbygg explored challenges and possibilities within the reuse and re-approval of the structural elements.

Before the placement in the new location, samples of the structural elements such as the concrete slabs were tested, to ensure the properties have not changed over time.

The concrete hollow-core slabs were cut and used in another location. One of these locations is a project in Kristian Augusts gt. 13, only 500 meters from the block R4 (presented on pg. 34).

6 **Statsbygg -** https://www.statsbygg.no/Prosjekter-og-eiendommer/Byggeprosjekter/Regjeringskvartal-nytt/Miljo/

Fig. 1.17 – **Material reuse from and within the Government Quarter in Oslo,** Own illustration

Fig. 1.18 – **Dismantling of the Government Quarter in Oslo - Block R4** - (Photo: Tor Sandberg) Retrieved from: https://www.dagsavisen.no/nyheter/innenriks/na-kan-du-kjope-litt-regjeringskvartal-1.1636658

Challenges with reuse and disassembly

In the past buildings were designed, with a belief to last almost forever. Architects, designers and clients might still nowadays have this vision in their minds. In many situations, it is not the case. Some buildings built even under 50 years ago require considerable reconstructions and in some cases are torn down. Rapidly changing owners, and therefore demands, require high flexibility. The life span of the buildings became shorter than ever before. These new trends require a change in building design and dismantling methods.

Reuse possibilities of the building components are dependent on several factors, among other things, on the way a component is physically engaged in use. Also, the actual physical and chemical properties, that might have changed over time, have to be taken into consideration.

Material engagement

There is an intimidating lack of sufficient documentation or knowledge of the construction methods and materials used in older buildings.

How a building is put together is crucial in understanding how to take it apart. The scarcity of sufficient documentation makes disassembly a complex challenge, and a destructive demolition is often chosen as an easy way out.

Gradual building disassembly without a proper prior assessment is time-consuming and therefore expensive. Even with a proper on-site material study, the uncertainty of a return on the initial investment is discouraging. There is no fully established market for reused building components.

Material re-usability

There are several concerns regarding the re-usability of building components and materials. Unhealthy substances such as asbestos or heavy metals such as lead, mercury or chromium, significantly reduce the fraction of reusable materials and their possible field of application.

Physical and chemical properties or the available size are some of the obstacles. Further to this, some materials are not suitable for an infinite cycle loop. The recycling potentials of materials are thoroughly described by Riegler-Floors and Annette Hillebrandt (2019, p. 58)[7] in the Manual of recycling.

Reliability

The study of F. C. Rios et al. (2015)[8] points out some of the biggest challenges of the reuse as follows: "*The uncertainty of the quantity and quality of used materials is quite a disincentive for buyers, due to varying quality and quantity from unreliable sources.*" (p.1300). Some of the interviewed actors have also confirmed this aspect. Trond Elverum (personal communication, February 12, 2020) and Elin Hansen (personal communication, March 5, 2020).

Market

The market for reused building materials and components is not widely developed yet. There is a necessity for warehouses and a reselling platform, otherwise, the reuse is rather coincidental, provided that at the same time when a building is demolished another construction is ready to receive the component. In Norway, it is nowadays only the company Resirqel that provides such reselling service.

Legislation

Another issue that obstructs direct legal reuse is the regulations. There is a lack of legislation and methods for re-certification of the used building components. Elin Hansen (NRK, January 7, 2020)[9]. Re-approval/re-certification of the structural building components might be, therefore, problematic.

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7 **Hillebrandt, A., Riegler-Floors, P., & Rosen, A.** (2019). *Manual of recycling : buildings as sources of materials.* Detail

8 **Rios, F. C., Chong, W. K., & Grau, D.** (2015). Design for Disassembly and Deconstruction - Challenges and Opportunities. Procedia Engineering, 118, 1296–1304. https://doi.org/10.1016/j.proeng.2015.08.485

9 **NRK**, Ombruk av materialer i byggenæringen kan spare miljøet for store klimagassutslipp. Retrieved from: https://www.nrk.no/video/fcf410eb-f283-40e9-bf0e-8e917e27128b?fbclid=IwAR3MIAIHHBH-ql9_IIAkdDVuDo9ekXGsTpGkRRvqOHvTlaiCwRdbogSKzL0 (5 January 2020)

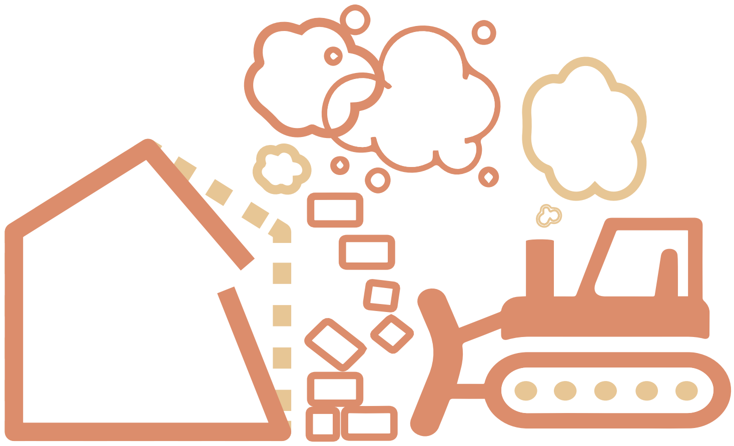

Fig. 1.19 – **Destructive demolition**, Own illustration

+ Fewer requirements on staff expertise
+ Faster and therefore often cheaper

- Mixed waste and debris creation
- Material destruction and devaluation
- High levels of dust and noise
- Waste transport requirements
- Danger for pollution and contamination

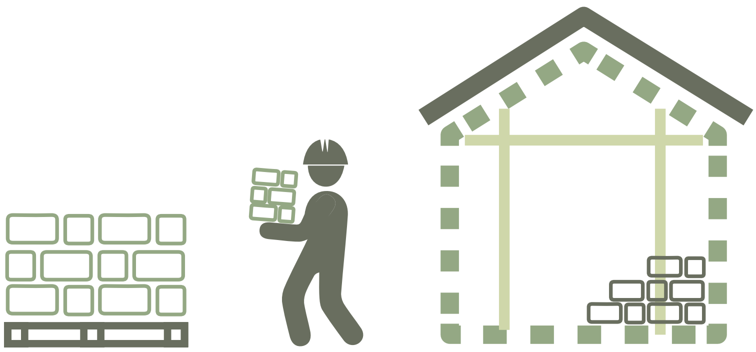

Fig. 1.20 – **Deconstruction**, Own illustration

+ Material value preservation
+ Waste reduction
+ Noise and dust reduction
+ Safer
+ Job opportunities creation
+ Material sorting control
+ On-site sorting and recycling
+ Hazardous waste control

- More expertise required
- Time-consuming
- Various special tools required
- High detail demands on documentation
- More planning required

Environmental and economical aspects

Higher demands on the building's flexibility and performance should not cause more waste. The principles of design for disassembly could solve this conflict. In this chapter, I am going to present these aspects and reflect on the benefits of reusing and designing for disassembly.

There are several arguments in favour of design for disassembly. Thormark (2007) summarises the reasons for applying design for disassembly principles as follows:

> "***Economical motives***
> *- Increased costs for waste handling*
> *- Increased costs for extraction of resources*
> *- Increased score in environmental labelling for demountable buildings*
> *- Increased terminal value for demountable buildings*
> ***Social motives***
> *- Demographic changes and changes in household structure*
> *- Buildings are demolished before the intended time*
> ***Environmental motives***
> *- Increased problems with waste production*
> *- Lack of virgin resources*
> *- Recycling and the quality of the end products*
> *- Reduced need for energy need for building operation*
> *- Climate changes*" (pg. 2)

Similarly to the mentioned increased terminal value for demountable buildings, Morgan & Stevenson (2005) observe that "*Detailing for deconstruction makes any property more attractive as an investment opportunity.*" (pg. 4)

Advantages of detachable connections

The main benefit of the design for disassembly is the high flexibility and adaptability of the building. Repair and replacement or the floor-plan solution adaptation are made easier.

Hillebrandt (2019, pg. 42)(12) point out that there are advantages in all the phases of the buildings life-cycle:

- Efficient and quick assembly during the construction phase.
- Easier maintenance and component replacement during the utilization phase and modernization.
- More efficient disassembly allows as well the component reuse and therefore reduce disposal costs.

A building designed in a way that destructive demolition means are not needed provides a series of additional advantages.

Health and safety

Disassembly reduces the amount of dust and noise in the process. Especially in high-density urban areas, a gradual deconstruction should be a requirement. Hazardous materials are easier to control and separate from the rest. This reduces the risk of contamination.

Resources vs. waste

Disassembly preserves the value of the materials. Both reuse and recycling is made possible by careful sorting and storing. Even a component not designed for disassembly could be reused.

Environment

Salvage of building materials and components and the subsequent reuse or re-purpose, reduces the need for new products and diminishes the pressure on the environment.

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10 **Chris Morgan, Fionn Stevenson,** (2005). Design for Deconstruction - SEDA Design Guide for Scotland: No.1, pg. 4

11 **Thormark, C.** (2007). Motives for design for disassembly in building construction. Portugal SB 2007 - Sustainable Construction, Materials and Practices: Challenge of the Industry for the New Millennium, pg. 2

12 **Hillebrandt, A., Riegler-Floors, P., & Rosen, A.** (2019). *Manual of recycling : buildings as sources of materials.* Detail

13 **Thormark, C.** (2001). Recycling Potential and Design for Disassembly in Buildings. Lund Institute of Technology, pg. 42

Possible solutions

Waste prevention methods

Digitalization

Some of the latest requirements in the building industry are facing the problem by using BIM, which facilitates an eventual future disassembly. This comprehensive documentation, including any information about the building its components properties, instructions for maintenance as well as indications and guidelines for disassembly allows to simulate the disassembly process and avoid unnecessary damage. Also called As-built Documentation updated after the completion of the building, including all the successive changes, encourages disassembly. (Fig. 1.21)

Buildings As Material Banks

BAMB is a project that develops strategies for a circular economy in the built environment. These strategies have the goal to increase the value of building materials. "*Instead of being to-be waste, buildings will function as banks of valuable materials"* The tools to achieve this are the Materials Passports and Reversible Building Design.[14]

Concerns

Previously mentioned strategies are not yet widely used. Most of the existing buildings do not have such documentation, and a high level of uncertainty is a big obstacle for reuse.

To fully implement principles of the circular economy, there is a need for mapping of reuse potential and digitalization of the existing building stock. Digitalization could provide enough information for the process and therefore increase reuse potential.

An example of digitalization of an existing building is presented later in the case study.

14 **BAMB (2016).** About BAMB, www.bamb2020.eu/about-bamb/

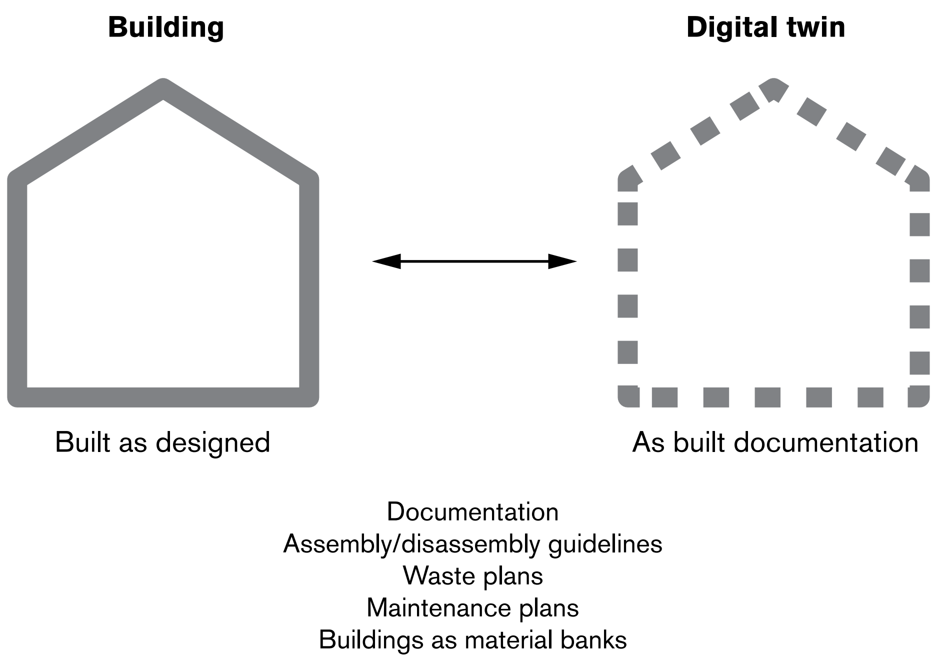

Fig. 1.21 – **As built documentation** - digital twin, own illustration

Building parts
Lifetime and dependency

Each part of the building has a different lifetime and requires a different amount of maintenance and upgrades. The changes of purpose, energy efficiency and fashion requirements put high demands on the flexibility of various building parts. Parts requiring high flexibility are the most desirable to be designed for disassembly. The expected lifetime of each layer of the building is illustrated in a diagram by S.Brand (1995)[15] (Fig. 1.22).

For the purposes of the design for disassembly, it is necessary to split these layers into subdivisions (Fig. 1.23) and observe how these layers are interdependent. The interdependency defines the overall flexibility and adaptability of the building parts (Fig. 1.24).

Changes in the building's program require high adaptability of the internal partitions and floor to ceiling height. The capacity to accommodate new functions and systems such as HVAC, facilitates the transformation.

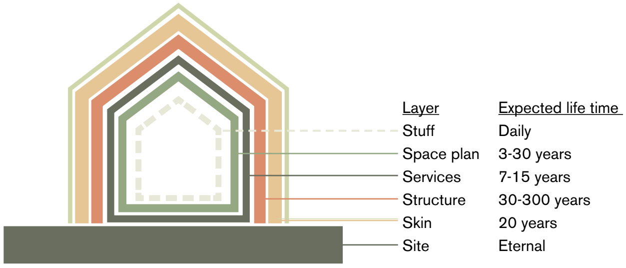

Fig. 1.22 – Building layers diagram (Brand, S. 1995), Adapted illustration.

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15 **Brand, Stewart.** (1995). *How buildings learn: What happens after they're built.* Penguin, p. 35

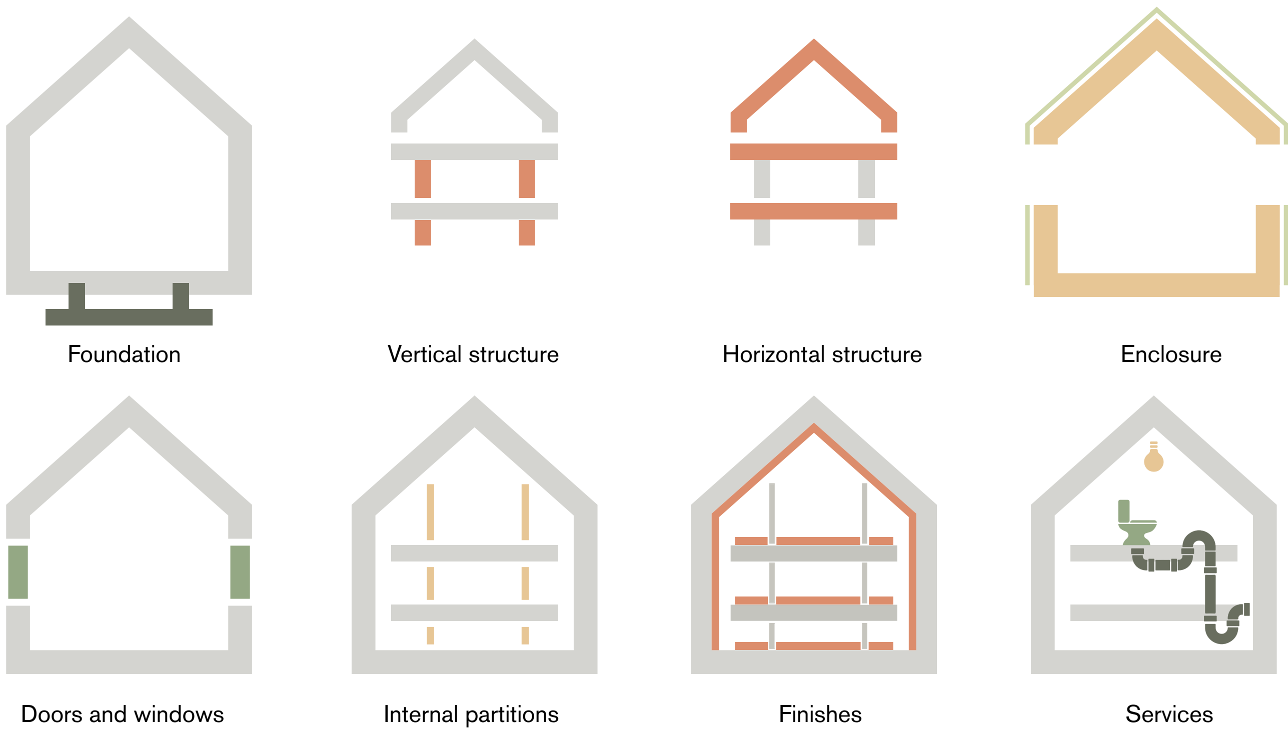


Fig. 1.23 – **Building parts,** own illustration

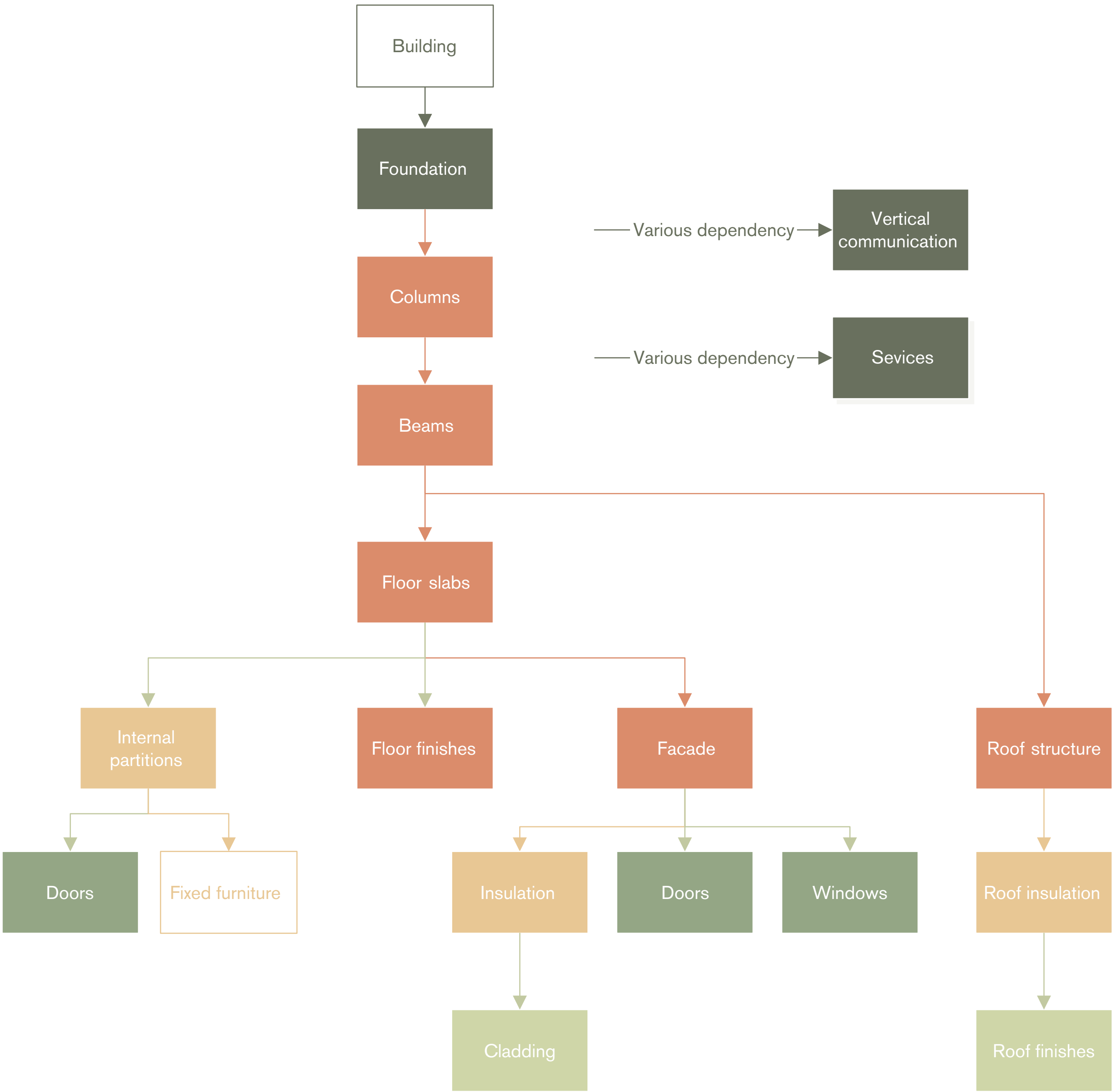


Fig. 1.24 – **Building parts dependencies** (colours relate to Fig. 1.23)**,** Own illustration

Reuse and disassembly

Design principles

There are many ways how to reuse and make building components reusable. Some of them are very creative, and there are no limits to this. Some of the most typical are illustrated in this chapter. Such principles are a base tool-kit for the design for reuse and disassembly.

Design for reuse and disassembly requires close attention to both functional, technical and aesthetically aspects. Overall aesthetically poor or compromising detailing is less likely to succeed.

Good balance between complexity, durability and time of assembly and disassembly is also a key component in a good design. A design solution that tends excessively into being too quick to assemble and disassemble, risks compromises on the durability.

General principles, characteristic for Design for disassembly, are prefabrication standardization and modularity.(16) These aspects highly reduce waste and maximize re-usability.

Prefabrication

Reduces the amount of on-site waste, and the effectiveness and possibility for direct recycling of the material increases.

Modularity

Makes it easier to replace, manage and reorganize various parts of the building.

Standardization

Increases the re-usability of a building component. Elements with varying sizes have reduced compatibility and are less likely to be reused.

Standard sizes of building materials, especially board materials, are using multiples of 1220 mm, in the metric system, corresponding to 4 feet in the imperial system.

For an easy recyclability, homogeneous or easily separable materials are favourable. Composite materials might be an option if the whole component is easily reusable. Materials need to be healthy to be reused or recycled.

An element, designed to be easily replaceable and removable, needs to be independent from other components.

There is a consensus on eliminating glued or nailed connections and replace them with screws or bolts. These connections are often easily accessible. Nevertheless, especially an easily accessible joint has to be placed correctly, keeping the safety in mind.

Apparently unimportant details in the design choices could have a significant effect on the result. In a business context, it might even seem embarrassing using such simple solutions. However, it is even more embarrassing to oversee the opportunity they offer.

Intrinsic characteristics affect how components and materials are involved in the construction, and therefore how likely these are going to be upgraded or reused. These principles could be adapted and applied to any part of the building.

16 **Brad Guy, Nicholas Ciarimboli** (2008). *DfD: Design for Disassembly in the Built Environment :* a Guide to Closed-loop Design and Building, Hamer Center. p.6

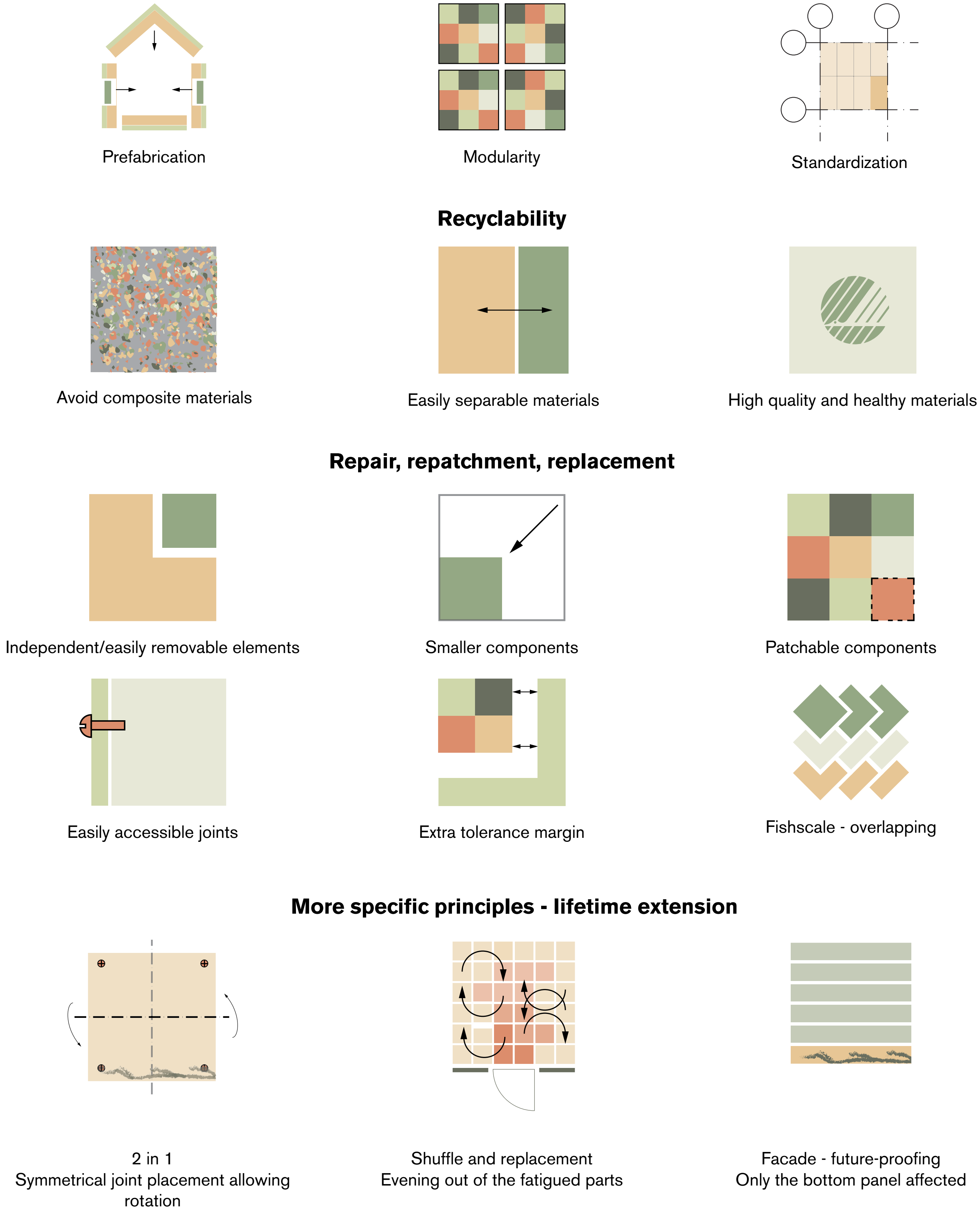


Fig. 1.25 – **Design characteristics and principles**, own illustrations

Design process

Phases

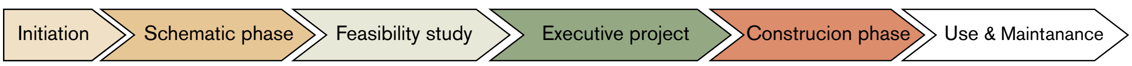
Different approaches in material use reflect in the project phases and the time necessary. In different countries, the overall phases and the denomination varies, based on the national laws and regulations.

A general comparison of the project phasing and connected actions helps to understand what needs to be adjusted during the design process for a successful implementation of material and component reuse into a project.

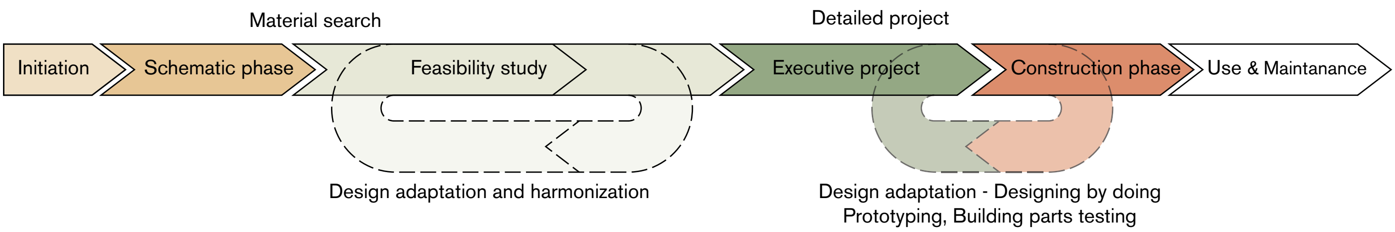
Compared to a conventional project, a reuse project requires more adaptability in the design phase. The biggest complication is a non-reliable availability of components. The design has to be harmonized accordingly.

The design process needs to be further adapted to the situation on-site and in the nearest context. Illustrations on the following page are showing different scenarios.

Standard project



Project with material reuse approaches



Dismantling project

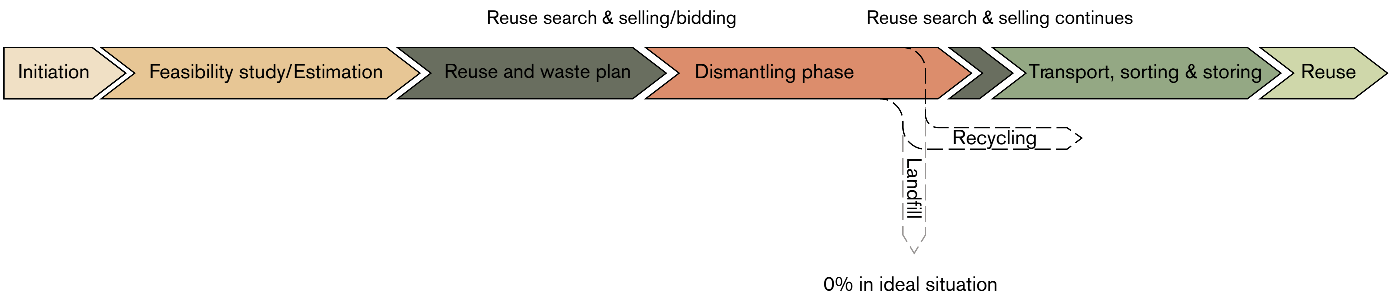


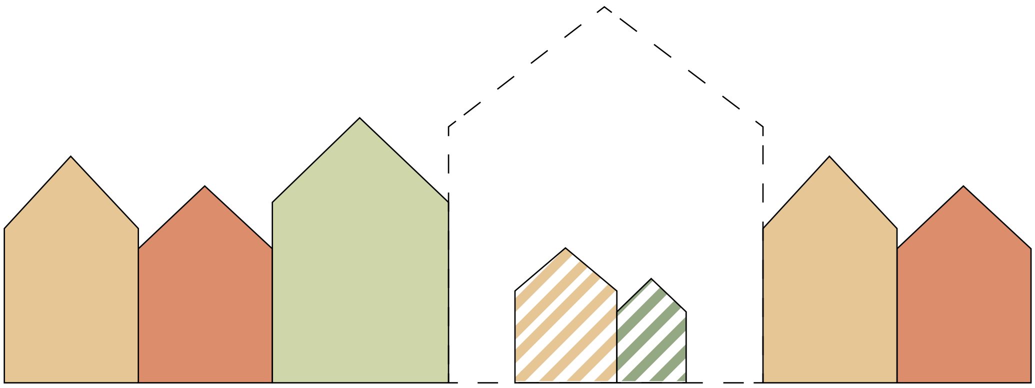
Fig. 1.28 – **Diagram of building phases**, own illustration

Design process

Reconstruction, Re-purposing, Reuse

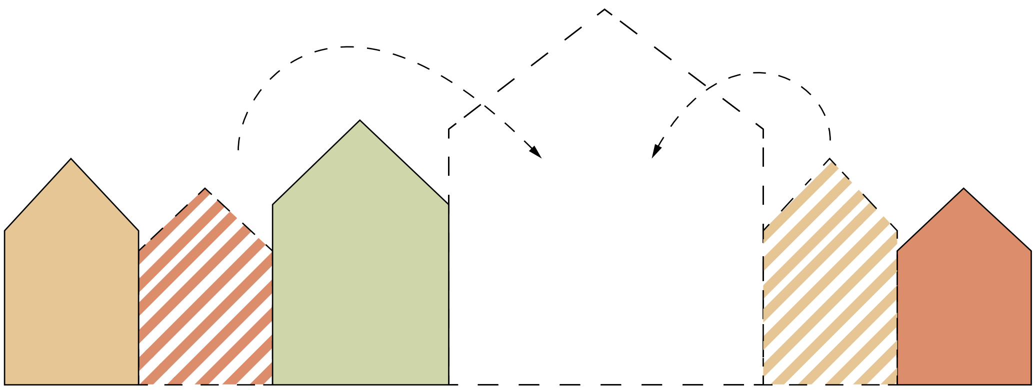
An existing building/s on-site

Assessment of the existing on-site materials, components and building volumes.



Empty building site

Assessment of the available and reusable materials and components



Reconstruction or demolition

Assessment of the possibilities of local components or material reuse and re-purpose

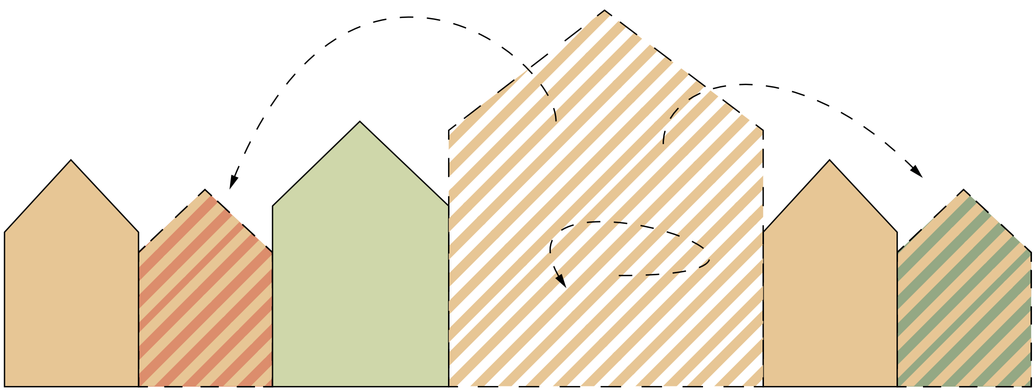


Fig. 1.29 – **Illustration of design process and material flow,** own illustration

Conclusion
Theory

In order to successfully apply strategies of design for disassembly and reuse, several things have to be changed, on different levels of the project design. These changes regard both the design process and the output itself, starting from the component level, up to the assemblies and the system as a whole.

From the research and communication with involved actors, there are several issues connected to the approach of reuse and re-purpose discussed in the chapter about Challenges with reuse and disassembly.

Process

When reusing components or designing the building assemblies to be reusable, material sourcing process changes. Moreover, the design choices have to be harmonized with the available resources.

Waste

It needs to be mentioned that waste is generated by the instant of throwing the object into the container, where together with other stuff, it loses its value and undergoes further damage. Proper mapping and evaluation of both the building and the market, done before the dismantling, is crucial for any potential reuse.

As discussed on pg. 20 the material reusability also needs to be taken in consideration. Not all materials are suitable for an infinite cycle loop.

Unreliability

The biggest challenge is the unreliability of the sources, transport and storage and the uncertainty of future benefits and a return on investment. Feasibility study in the case of both transformation and new building construction with the circular economy approaches requires more time for planning and assessing.

Motivations

There are potential investment savings when compared to the acquisition of new building components and a decisively lower environmental impact. Nevertheless, also to get used to reuse more would enhance, how we take care of our historical heritage and social values.

Sustainable building certifications

Depending on the environmental ambitions implementing DfD and reuse approaches into a project contributes to the circular economy. Various certification systems such as BREEM, LEED or the DGNB System, reward the project's contribution to the circular economy with extra points and potentials for reuse recovery or recycling are taken into account.

Fig. 1.30 – **Materials from disassembly vs. material from demolitions,** own illustration

Reference projects

Lilleakerbyen

Oslo

Architects: Lendager arkitekter, LPO arkitekter
Client: Mustad eiendom
Location: Oslo, Norway
Design features: Waste salvage
Project type: Urban development

Lilleaker is an industrial area located in Oslo just on its western border. The area is currently (2020) undergoing a big re-development. New public facilities together with over 2300 housing units will be built.

An important concept behind the development was the goal to salvage materials from the existing structures. The total estimated value of the assessed materials with the potential to be reused on-site is 1.5 bill. NOK

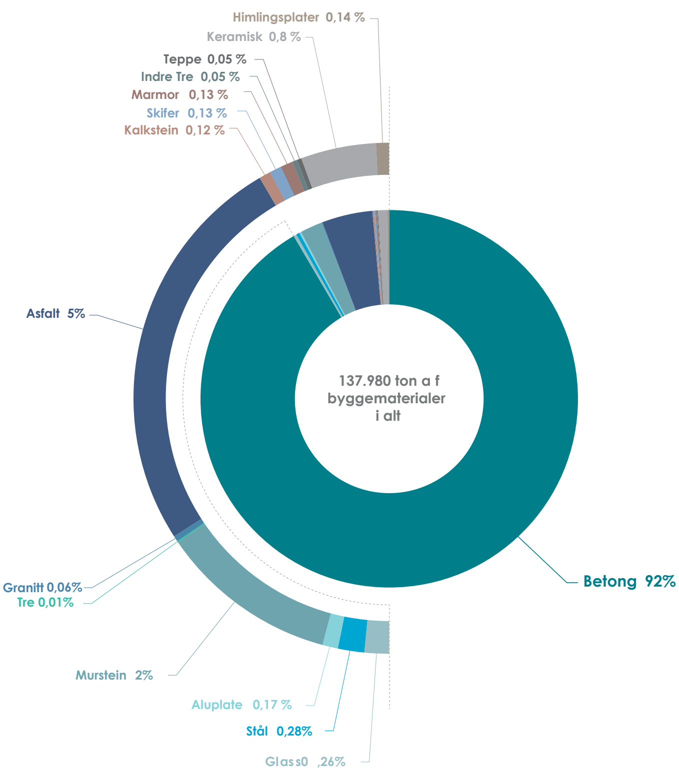


Fig. 2.01 – **Waste - from expenses to possibility**, source: https://lendager.com/strategi/byggeaffald-fra-omkostning-til-mulighed/

Fig. 2.02 – **Lilleakerbyen LPO arkitekter**, retrieved from: lpo.no/prosjekter/lilleakerbyen

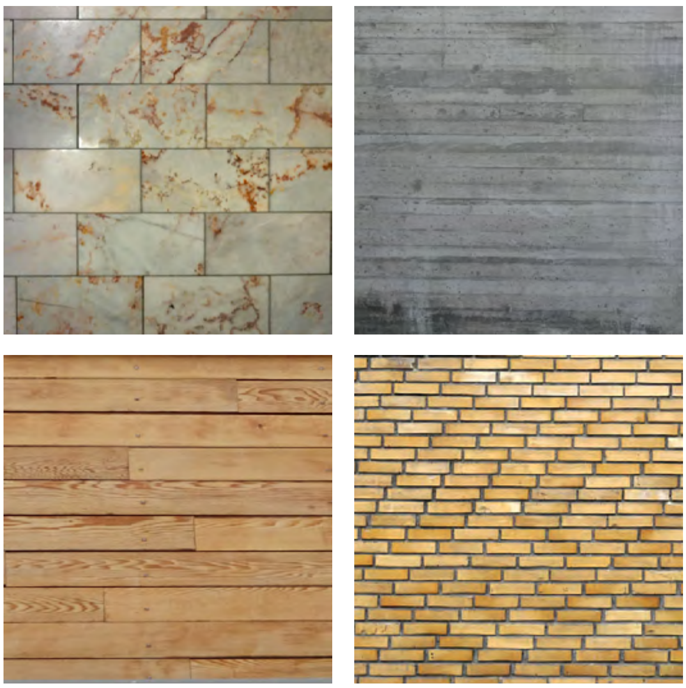


Fig. 2.03 – **Materialekartlegning** - Lilleakerbyen - Lendager arkitekter, source: mercell.com/en/tender/103310058/forsvarlig-ombruk-tender.aspx

Kristian Augusts gt. 13

Oslo

Architects:
MAD arkitekter
Client:
Entra
Location:
Oslo, Norway
Environmental ambitions:
Circular building, reuse and recycling, reuse of the existing building volume and transformation
Project type:
Extension and rehabilitation of the existing building.

Early phases

Transformation and reuse potentials were carefully assessed, and the decision, of keeping the existing structure and reuse a considerable amount of elements, was taken. Compared to a standard project, more time was dedicated to the feasibility study and material search.

Reuse and recycling

This project is an excellent example of several used strategies. There are reused materials, both on-site and from other buildings. And even a small amount of materials removed from the building were sold and used elsewhere.

In the new building extension, approximately 1/3 of the projects concrete hollow-core slabs, used for the structural floor elements, were reused from the nearby Government Quarter.

Challenges

The new design had to deal with a limited floor to ceiling height and the required HVAC system placement.

Transformation

Most of the reused components are placed in a detachable manner, which makes the elements such as the fish scale facade cladding reusable also in future.

Fig. 2.04 – **Kristian August gate 13** - MAD arkitekter, Image source: https://mad.no/projects/kristian-august-gate-13/

Fig. 2.05 – **On-site reused doors - MAD arkitekter**, Image source: https://mad.no/projects/kristian-august-gate-13/

Fig. 2.06 – **Tiles rehabilitation - MAD arkitekter**, Image source: https://mad.no/projects/kristian-august-gate-13/

Circular house GXN

Copenhagen

Architects:
3XN Architect, Lendager Group, Vandkunsten
Client:
Realdania and The Danish
Environmental Protection Agency
Location:
Copenhagen, Denmark
Environmental ambitions:
Circular Sustainability
Project type:
Prototype

The circular house is a demonstration structure that promotes applications of sustainable and circular principles, by using design for disassembly and Cradle to Cradle. This exhibition space shows solutions in 1:1 scale and demonstrates, that applying the circular principles into the built environment is possible and educates the visitors in circular economy. A catalogue published together with the construction shows available solutions, GXN - 3XN (2018)

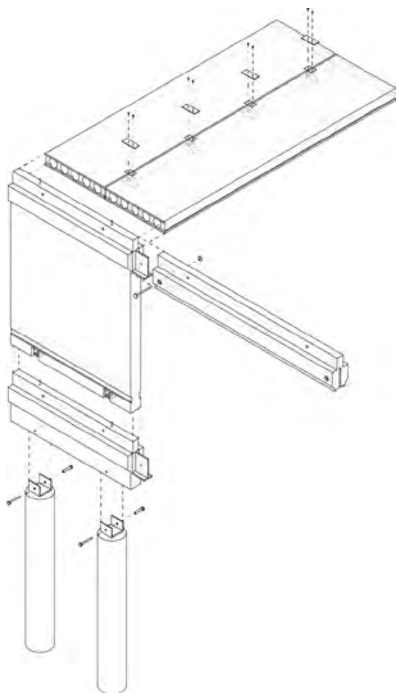


Fig. 2.07 – **Detail of the structural system** of the Circle House Demonstrator - GXN, Retrieved from: gxn.3xn.com/project/circle-house-demonstrator

Fig. 2.08 – **Circle House Demonstrator** - GXN, Retrieved from: gxn.3xn.com/project/circle-house-demonstrator

Fig. 2.09 – **Facade detail** - GXN, Retrieved from: gxn.3xn.com/project/circle-house-demonstrator

EU - Headquarters
Brussels

Architects:
Philippe SAMYN and PARTNERS architects & engineers, LEAD and DESIGN PARTNER. With Studio Valle Progettazioni architects, Buro Happold engineers.

Client:
Council of the EU

Location:
Brussels, Belgium

Environmental Ambitions:
Sustainable development, window frames reuse

Project type:
Public services

With this project the European Council wished to stand as an example of sustainable development facade of the building is made of a patchwork of reused window frames, completed with a new single sheet glass panes.

Fig. 2.11 – **Facade** - Philippe SAMYN and PARTNERS architects & engineers, LEAD and DESIGN PARTNER

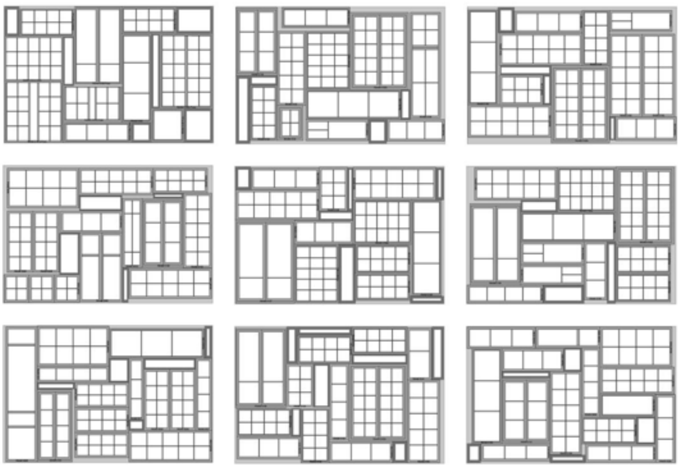


Fig. 2.10 – **Facade panels** - Philippe SAMYN and PARTNERS architects & engineers, LEAD and DESIGN PARTNER.

Fig. 2.12 – **Facade module** - Philippe SAMYN and PARTNERS architects & engineers, LEAD and DESIGN PARTNER.

Ressourcerækkerne

Ørestad

Architects:
Lendager Group, AG Gruppen, MOE
Client:
NREP A/S
Location:
Ørestad, Denmark
Environmental Ambitions:
Material reuse, circular economy
Project type:
New construction

The project designed by Lendager architects called Ressourcerækkerne located in Ørestad in Denmark is an excellent example of innovative use of recycled bricks. A new design of the upcycled brick facade introduces a patchwork appearance which turns into an exciting design motive. According to the Lendager architects, the reuse of a variety of materials from demolished buildings, contributed with up to 70% CO_2 emission reduction in the construction.

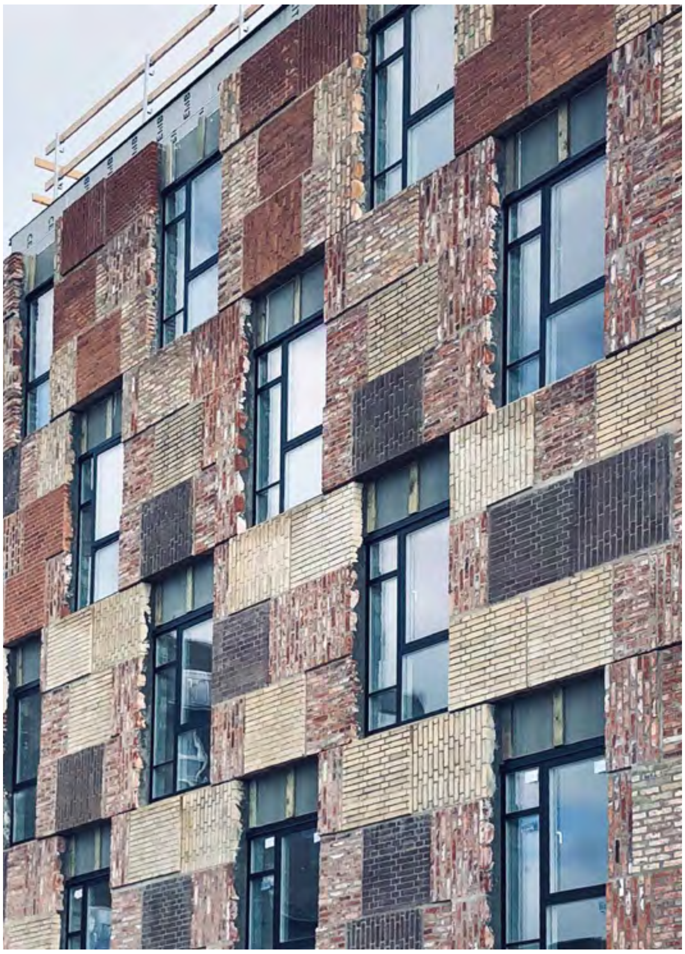


Fig. 2.14 – **Ressourcerækkerne** - Ørestad, Retrieved from: lendager.com/arkitektur/ressourceraekkerne/

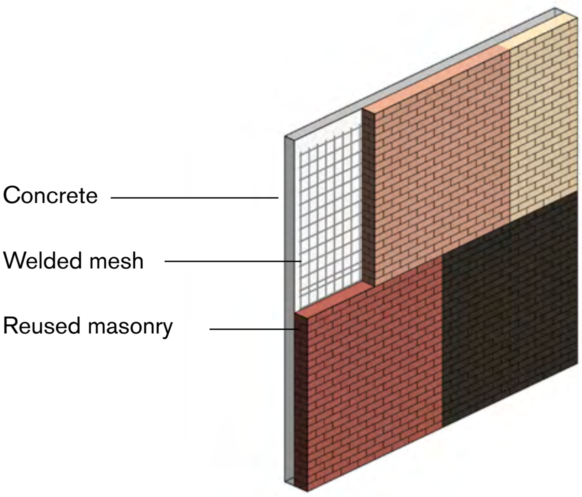


Fig. 2.13 – **Facade module layers**, Own illustration

Fig. 2.15 – **Ressourcerækkerne** - Ørestad, Retrieved from: lendager.com/arkitektur/ressourceraekkerne/

Systimber

Architects:
Systimber
Location:
De Pinte, Belgium
Environmental ambitions:
Design for disassembly, circular economy
Project type:
Housing, recreation

Systimber is a solid wood construction system designed for quick and simple assembly and eventual disassembly. Specially designed profiles are fabricated on a CNC machine, ensuring high precision. The profiles are fitted with seals ensuring the water and air-tightness.

Fig. 2.17 – **Tiny house - Systimber** Photo by: PULSAR fotografie, Retrieved from: https://www.systimber.com/

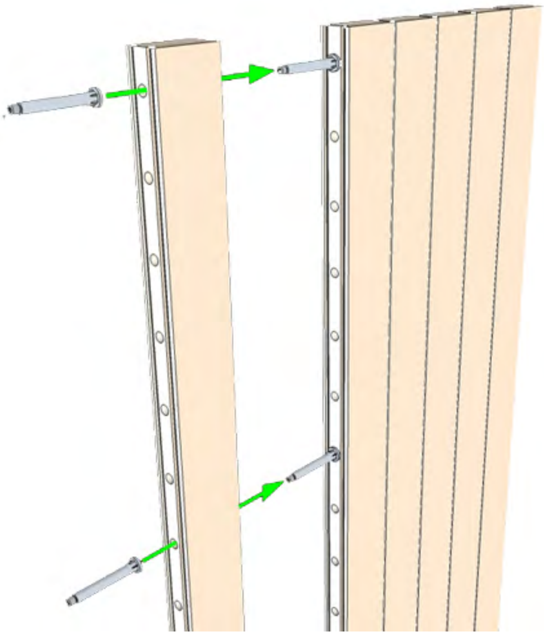


Fig. 2.16 – **Montage system - Systimber,** Retrieved from: https://www.systimber.com/

Fig. 2.18 – **Montage system - Systimber,** Retrieved from: https://www.systimber.com/

Reflections

Reference projects

The previously presented projects are shown below in a comparative table with a set of criteria, comparing on-site material reuse, design for disassembly, innovation, prefabrication and waste strategy.

Some of the study cases show an exceptional application of reuse and recycling strategies. Nevertheless, it is important to point out, that not in all the cases a simple future component disassembly is taken into consideration.

In an ideal situation, a reused or recycled component is also easily removable in the future. Such a principle makes possible a full implementation of the circular design principles.

	On site reuse	Recycling	DfD	Innovation	Prefabrication	Waste strategy
	Assessed value of materials with reuse potential.			Material mapping		The waste is considered a resource
	Reuse of building components on-site		Facade cladding and other components are easily demountable	Combination of transformation and new construction. New processes	Prefabricated structural elements reused from the Governmental quarter	Some materials sold as a resource to other projects
		Recycled plastic facade components	Fully detachable joints	Circular economy	High level of prefabrication	
	Facade materials from a close-by demolition site	Masonry upcycling	Modular facade panels	Facade patchwork	Prefabricated facade modules	
			Quick assembly and disassembly	Construction system	Prefabricated modules	
		Window frame reusing			Prefabricated facade modules	

Case study - Sinsenveien 53

Reuse potential mapping

Introduction

As mentioned earlier, the complexity, uncertainty and lack of sufficient documentation, especially in the case of an older building, is a challenge to the reuse topic.

This case study illustrates what kind of materials, in a building, have the potential for reuse. It makes the reuse process to be seen as more realistic and tempting. This is done through a material mapping, based on available documentation and non-invasive investigation of the building located in Sinsenveien 53, Oslo.

The building is located in an industrial area, that is currently transforming, and is planned to be demolished, to make space for new apartment buildings. A new zoning plan is under development. Adjacent buildings, in nearby Peter Møllers vei, are already being demolished (Illustrated on pg. 51) New construction has the goal to get the BREEAM certification. Reuse is, therefore, highly considered.

The interesting current situation, together with a good condition of the building, determined the case study selection.

Location:

Sinsenveien 53, Oslo, Norway

Original building use:

Office and warehouse

Owner:

Skanska AS

Area:

Approximately 11600 m2

Fig. 3.01 – **Sinsenveien 53,** Own photo

Sinsenveien 53

Buildings history overview

1982 | Construction started

1986 | Completion

1987 | Building elevation extension completion

2001 | New technical instalations
2005 | Plumbing and piping upgrade

2010 | New side entrance in the facade

2013 | Elevators upgrade

2015 | HVAC systems upgrade

(2021) | Demolition

Fig. 3.01 – **Sinsenveien 53 - Main entrance**, Own photo

Fig. 3.02 – **Sinsenveien 53 - South west facade**, Own photo

Fig. 3.03 – **Sinsenveien 53 - North east facade**, Own photo

Available documentation

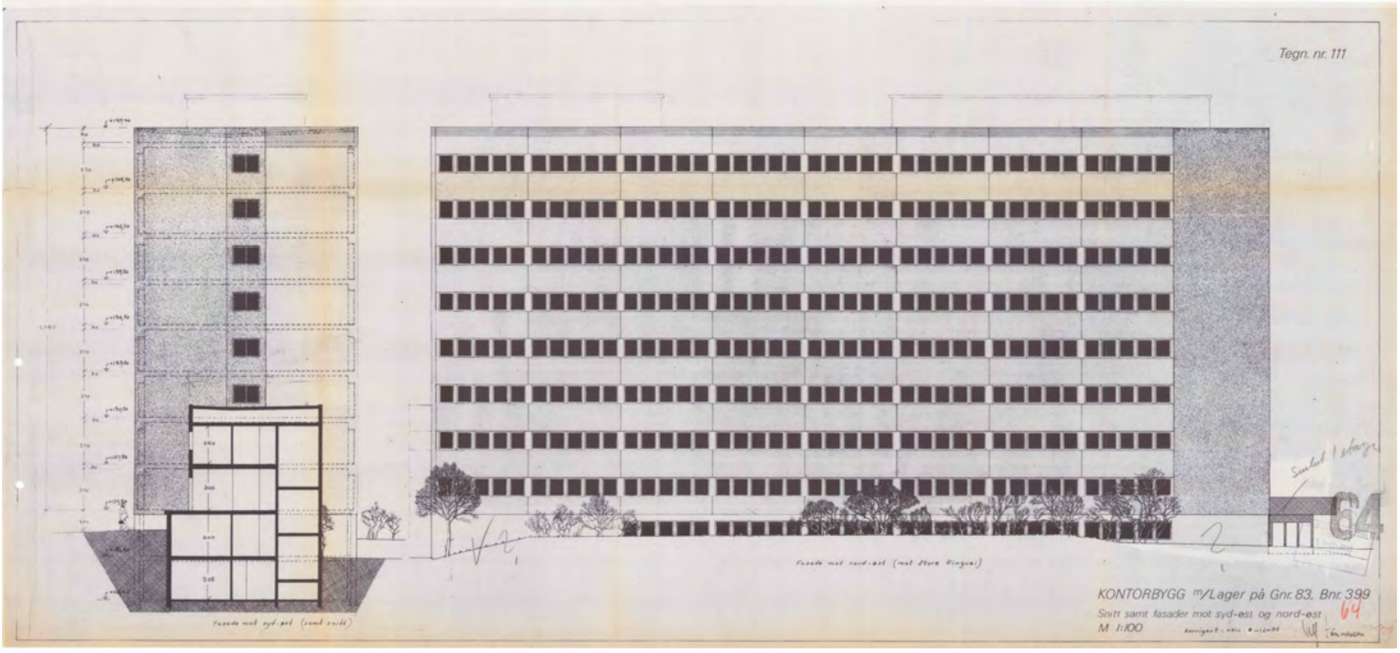


Fig. 3.04 – **Sinsenveien 53 - Nord-east and south west facade,** Plan- og bygningsetaten, Retrieved from: innsyn.pbe.oslo.kommune.no/saksinnsyn/main.asp?text=Sinsenveien+53

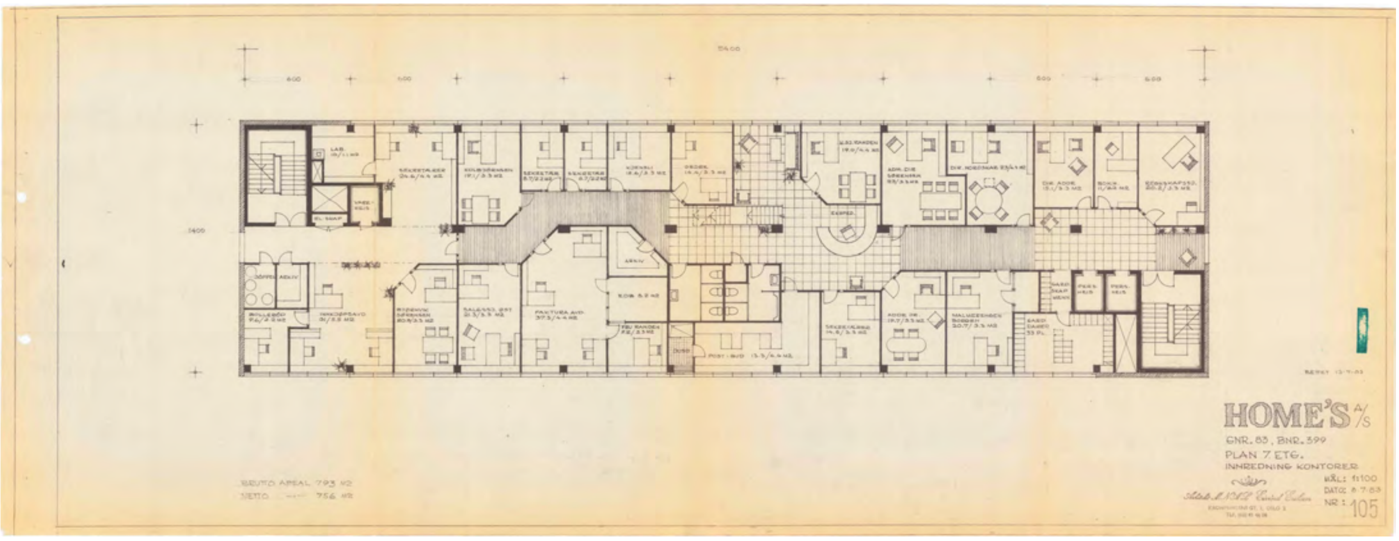


Fig. 3.05 – **Sinsenveien 53 - Interior plan,** Plan- og bygningsetaten, Retrieved from: innsyn.pbe.oslo.kommune.no/saksinnsyn/main.asp?text=Sinsenveien+53

Photogallery

Fig. 3.06 – **Sinsenveien 53 - South west facade,** Own photo

Fig. 3.09 – **Sinsenveien 53 - Interior,** Own photo

Fig. 3.07 – **Sinsenveien 53 - South west facade,** Own photo

Fig. 3.10 – **Sinsenveien 53 - Office partitions,** Own photo

Fig. 3.08 – **Sinsenveien 53 - Facade detail**, Own photo

Fig. 3.11 – **Sinsenveien 53 - Stairs,** Own photo

Material mapping

The table below presents a mapping of various components present in the building. Together with an estimation of quantities, it gives an overview and an idea of the reuse potentials. Each component is listed with information about the material it consists of, an approximate quantity, placement in the building, reuse potential and a photo.

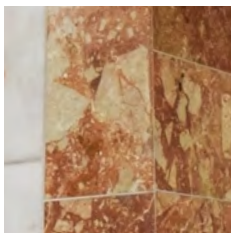
The reuse potential includes consideration of value and possible applications, but also possible obstacles for reuse. Even though it is not a subject of this thesis, to thoroughly analyse the hazardous material contents, the origin of the building from the 1980s suggests some possible challenges. Material safety has to be accepted as a prerequisite for any reuse.

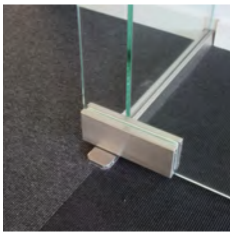
For easy orientation, the table is organized into distinct building layers, presented earlier on the pg. 24. I would like to emphasise, that regardless of the original placement in the building, there are practically no limits to creative reuse and ways of re-purpose.

Quantities are approximative, based on consultations of available documentation and observation during a short visit inside the building. These vales serve to illustrate at least a partial image of the building and are not suppose to be used as a basis for exact calculations.

Layer	Element	Material	Qty	Unit	Placement	Reuse potential	Photo
Envelope	**Facade masonry**	Masonry	~2700	m2	Facade all floors	The facade consists of sandwich elements with a high reuse potential. Sealant material in the expansion joint has to be removed because of hazardous substances.	
	Wall first floor	Concrete	140	m2	Basement	Wall in the basement is cast in situ and has, therefore, limited reuse application. Crushed could be used as added aggregate in new concrete.	
Windows and doors 	**Windows**	Glass and aluminum	990	pcs	All floors	Originating from 80s, high probability for hazardous substances. Have to be handled as hazardous waste. Reuse possibilities are therefore limited.	
	Window blinds - Hüppe ARS 80 Set length 5.5m (2.2 m + 3.3 m)	Alluminium	116	set	SW and SW facade	Reusable if handled with care. Aluminium sheets could easily get damaged during disassembly.	

Layer	Element	Material	Qty	Unit	Placement	Reuse potential	Photo
	Entrance door	Glass and aluminum	1	pc	1st floor	Uncertain origin, if from 80s, same rule as for the windows applies	
Vertical structure	**Column 400x400 mm**	Concrete	128	pcs	All floors	Prefabricated concrete columns, potential for reuse. The reapproval could be challenging.	
	Column 700x700 mm	Concrete	6	pcs	Basement		
	Column 400x500 mm	Concrete	64	pcs	All floors		
Horizontal structure	**Beam 500x400**	Concrete	168	pcs	All floors	Same as previous.	
	Hollow-core slab 200 mm	Concrete	~240	m2	Core slabs	Viz. The Government Quarter in Oslo on page 19	
	Hollow-core slab 300 mm	Concrete	~5200	m2	All floors		
	Hollow-core slab 400 mm	Concrete	~400	m2	Ground fl.		
Services	**Elevators**	Composite	4	pcs	All floors	Reuse potentials are uncertain.	
	Lighting fixture	Electronics	6	pcs	Entrance areas	Easily removable. Light-bulbs are changeable for more energy efficient ones.	
	Lighting fixture Glamox	Electronics	>20	pcs	All floors	Easily removable. Upgradeable with new T5 Led Light-bulbs. Indicative price of a new equivalent product 3670,-	

Layer	Element	Material	Qty	Unit	Placement	Reuse potential	Photo
Services 	**Heating panels Glamox**	Electronics	>40	pcs	6th-8th floor	Easily removable. Energy efficiency has to be assessed. Indicative price of a new equivalent product 900,-	
	Ventilation ducts	Steel			All floors	Direct reuse could be difficult, the profitability of such use is limited. Alternative use viz. pg. pg. 60-59	
	Emergency stairs	Steel	1	pcs	S-E Facade	The stairs have a suitable standard distance between landings. Eventual adaptation is possible by segment removal.	
Finishes 	**Carpets**	Nylon	~5200	m2	All floors	Carpets in the building are in various conditions, quantity and quality of each have to be assessed.	
	Ceiling panels	Glass fiber	~5200	m2	All floors	Easily removable, big part is surely reusable. Soft material that has to be handled and stored carefully.	
	Wall coating	Marble	x	m2	Stairs area, entrance area	Removal could be difficult. Alternatively, crushed marble can be used as aggregate in terrazzo flooring. Viz. pg. 71	
	Flooring	Stone	~ 47	m2	Main entrance area		

Layer	Element	Material	Qty	Unit	Placement	Reuse potential	Photo
Internal partitions	**Movable partition wall**	Composite	1	pc	6th floor	Most suitable for a structure with the same floor-to-cieling height (2.7m)	
	Frame-less office partition	Glass			6th floor	Partitions have a modern style. Reuse application should have same height (2.7m) Security glass cutting might be problematic.	
	Office partition	Glass, wooden frame			8th floor	Door blades are in good conditions.	
	Toilet Partition	CDF board			6th floor Toilets	Easily removable.	
	Fixed composite partition	Composite			1st - 3rd floor	Height 2.7 m, The value of the component is limited.	

Facade element

Produced by:
Norcem Betong AS, Fredrikstad
1982 - 1987

Component size:
5988x1800x245

Compound of following layers:
25 mm brick cladding,
60 mm concrete
100 mm fibre insulation
60 mm concrete

Weight:
~3.9 tons each

The facade is composed of prefabricated sandwich elements. For reaching the energy efficiency requirements (TEK 17) an additional layer of insulation has to be added when reused. Considering that the insulation capability has diminished, approximately 15-20 cm of insulation could satisfy the current requirements.

Based on the estimations from various companies, delivering prefabricated facade products, an equivalent new facade element would each cost between 24000-34500 NOK (2200-3200,-/m^2).

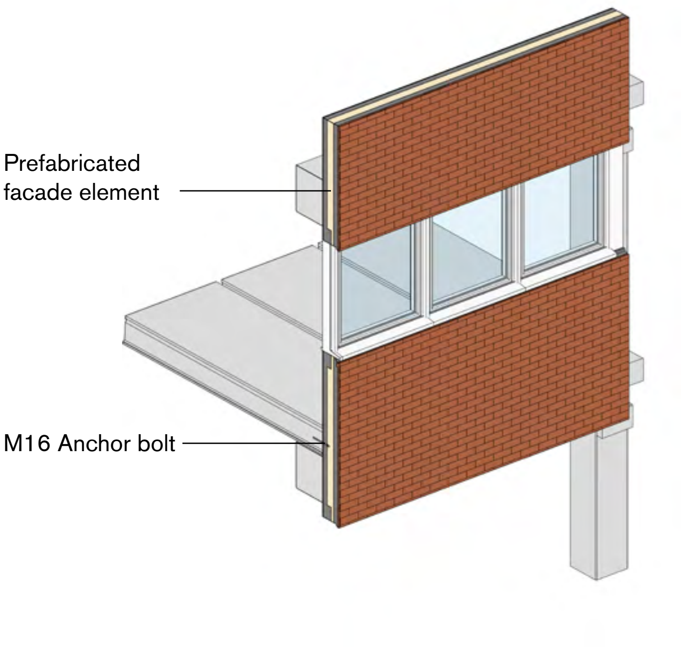


Fig. 3.13 – **Facade element - layers**, Own illustration

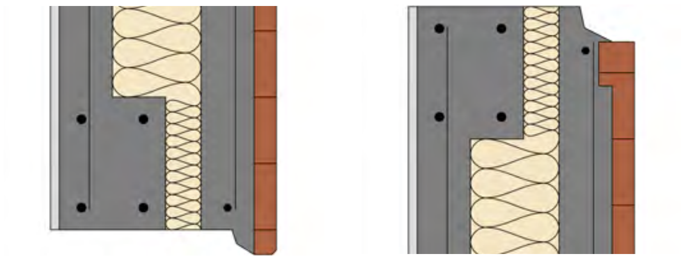


Fig. 3.14 – **Facade element detail,** Own illustration

Fig. 3.12 – **Sinsenveien 53 - Facade**, Own photo

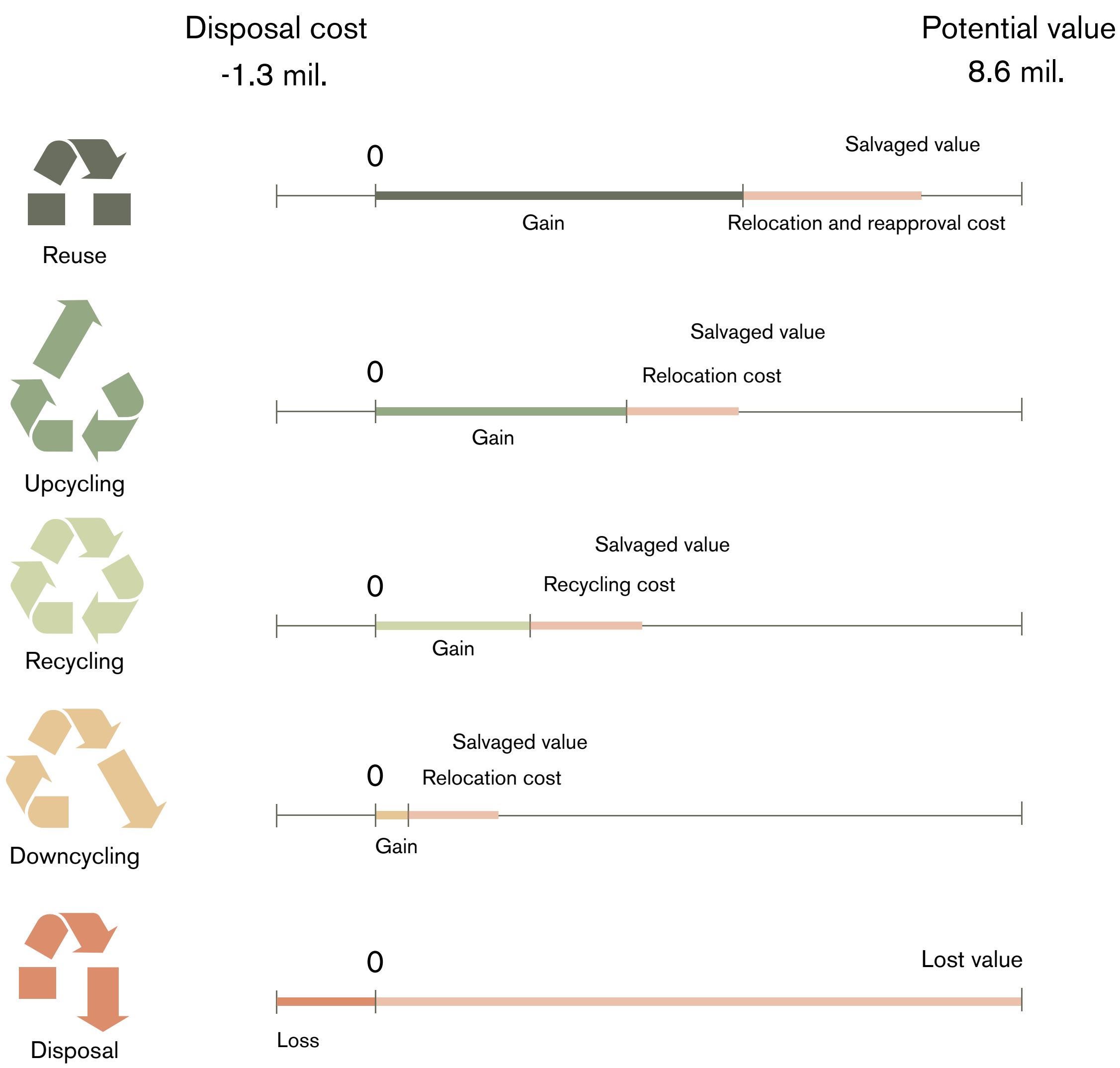
Fig. 3.15 – **Sinsenveien 53 - Facade detail**, Own photo

Facade element

Possible scenarios

The reuse value could be expressed in quite concrete numbers, based on prices for the waste disposal and a price for an equivalent new product. These values are the starting point and the initial driving force for any material or component to be reused. The following figure compares different possible approaches and the resulting value.

The best possible scenario would be, if the facade components were reused on one of the new structures on the same site, avoiding excessive transport.



Reflections

Reuse potentials

A closer look at the structure uncovers some opportunities for relatively simple reuse. For example, the facade consists of prefabricated modular sandwich elements. The brickwork of these modules shows no sign of remarkable deterioration. These entire units, each weighing about 3.9 tons, are possibly detachable and have certainly high chances for being reused. Considering the amount and the total weight of the facade, which is approximately 960 tons, the potential savings of the expenses for waste disposal is significant.

Efficient reuse

The structure uses 6.0x6.0 meters for the structural grid dimension and 2.7 meters for the floor-to-ceiling height. Same, or compatible dimension, in the new structure receiving any components, would facilitate the reuse.

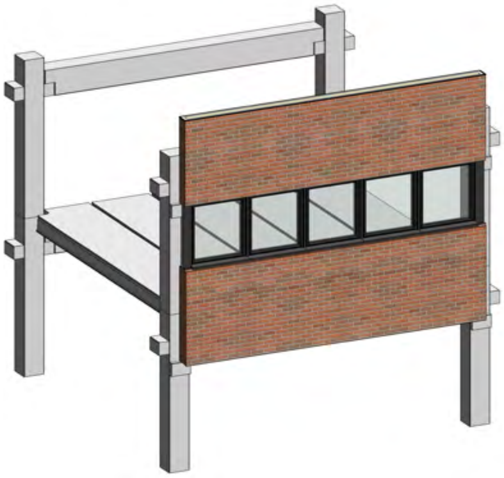
Digitalisation

A digital model based on the available drawings and on the building investigation was used to get an overview of the quantities and visualize how various components are dependent on each other. However, a digital model could be used for eventual planning of a gradual disassembly. The chapter on Possible solutions presented earlier on page 23, discusses the advantages of such a method.

Feasibility study

This case study shows a quick estimation of reuse potentials. In order to fully uncover and analyse the reuse potentials, a more detailed mapping, along with several more visits of the interior of the building, would be necessary.

If none of the building parts is going to be reused the same situation as on the neighbouring site, illustrated on the next page, could be expected.



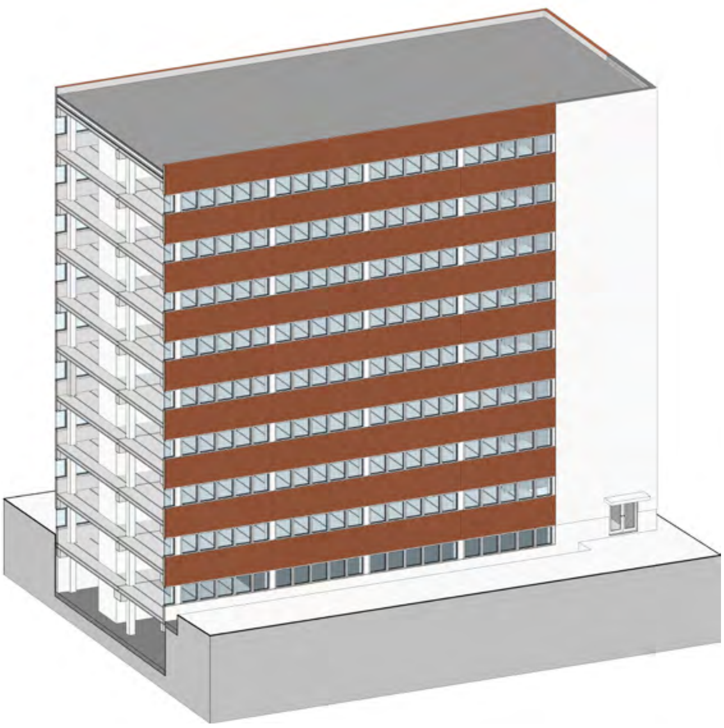


Fig. 3.01 – **Sinsenveien 53 - Digital model**, Own illustration

Sinsenengen industry area
Nearby demolition - Peter Møllers vei

Fig. 3.02 – **Demolition in Peter Møllers vei,** Own photo

Fig. 3.03 – **Demolition in Peter Møllers vei,** Own photo

Fig. 3.04 – **Demolition in Peter Møllers vei**, Own photo

Catalogue

Introduction

The catalogue establishes a tool-kit that provides an overview of various design solutions. It has as the goal to give an idea of practical applications and how does design for disassembly and reuse might look like, and most importantly inspire to carry out further investigations.

The catalogue is divided into eight chapters about each building layer identified. Each chapter presents outstanding design solutions in use, as well as some of my own proposals (marked).

Some of the existing design solutions are taken from the previously presented reference projects and presented in detail.

There are differences in the availability of various design solutions. Structural elements are an example of this. Detachable or reused products are not widely developed. This is undeniably due to lacking re-approval possibilities.

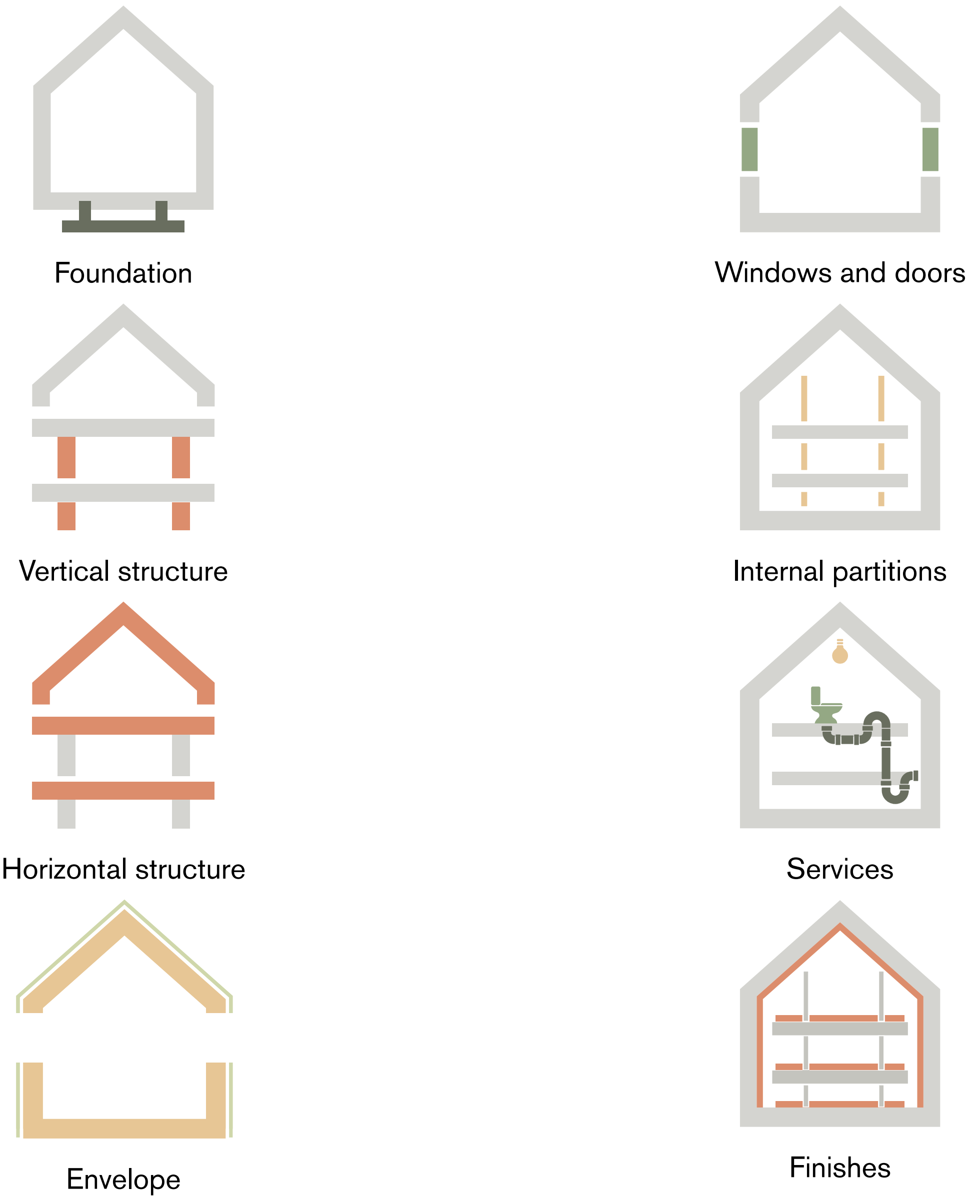
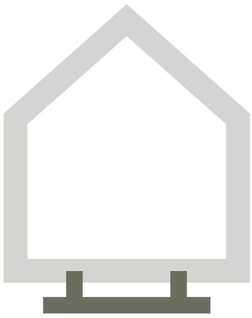
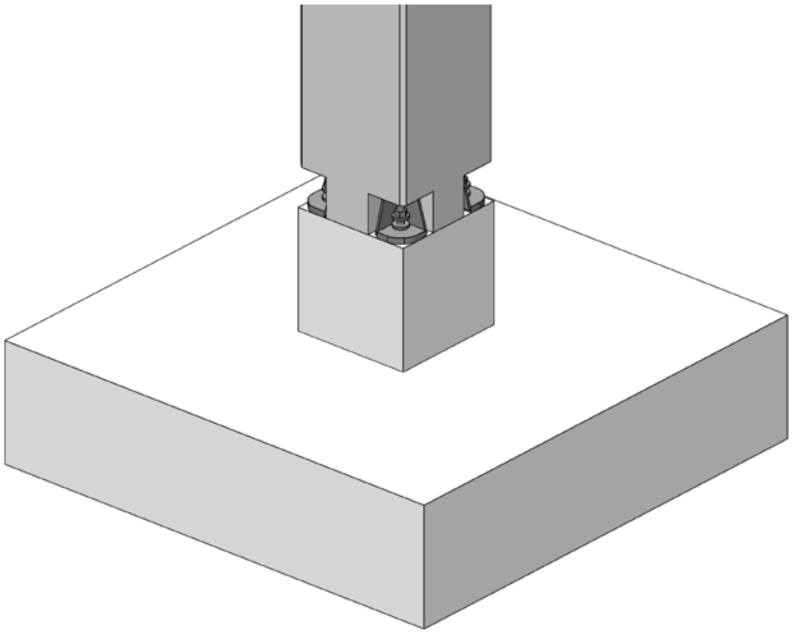


Fig. 4.01 – **Building parts,** own illustration

Foundation





The foundation is rarely designed for disassembly. Nevertheless, there are some examples where reuse of the foundation is at least partially possible. Prefabricated foundations combined with bolted connections are an example of such a solution.

Fig. 4.02 – **Prefabricated foundation with bolted connection** - Own illustration

For maintaining the reusability, a lime mortar has to be used. Unilke cement mortar, lime mortar is removable (Fig. 4.10)

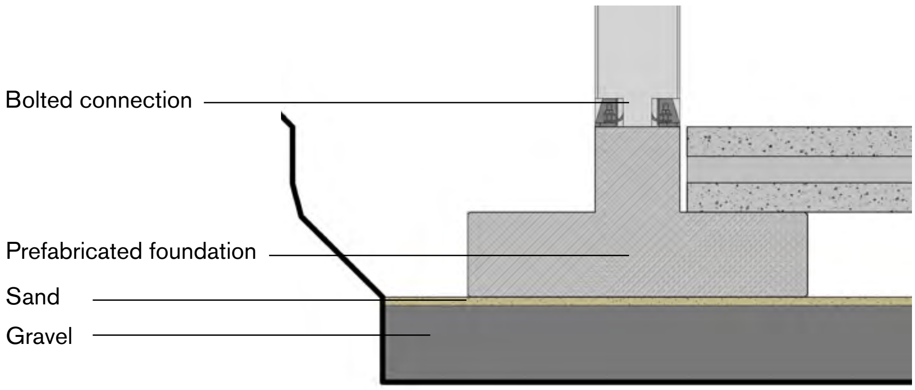
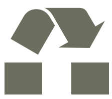


Fig. 4.03 – **Prefabricated foundation section detail**, Own illustration



Reusable

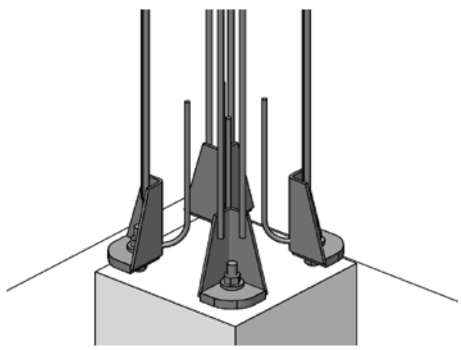


Fig. 4.04 – **Bolted connection - rebars** - Own illustration

Existing design

Screw piles

Screw piles (Fig. 4.05) are an example of a removable and reusable foundation. These are typically used for smaller structures. Nevertheless, some of the latest types of screw piles could withstand loads above 200 tons, depending on the soil loading capacity.

Fig. 4.05 – **Helical anchors** - Photo by: Argyriou, Retrieved from: https://en.wikipedia.org/wiki/Screw_piles

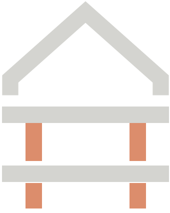
Prefabricated foundation

Prefabricated concrete elements have a reuse potential if the bolted connections are covered with removable materials. This is also illustrated on page 57 (Fig. 4.10)

Fig. 4.06 – **Prefabricated foundation**

Vertical structure

Columns

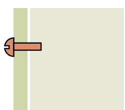


On the structural level, there is a high demand on durability and safety. Therefore a structure designed for a simple disassembly might seam as an incorrect option. However, design for disassembly typically reduces also the assembly time, that is highly desirable.

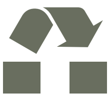
There are several examples of steel joinery for wood, as well as prefabricated concrete structures, that are demountable.

Double forked column

The proposed column is inspired by joinery originally used in furniture manufacturing. This double forked connection together with a steel connection element makes a simple compound column with no wasted material



Easily accessible joints



Reusable

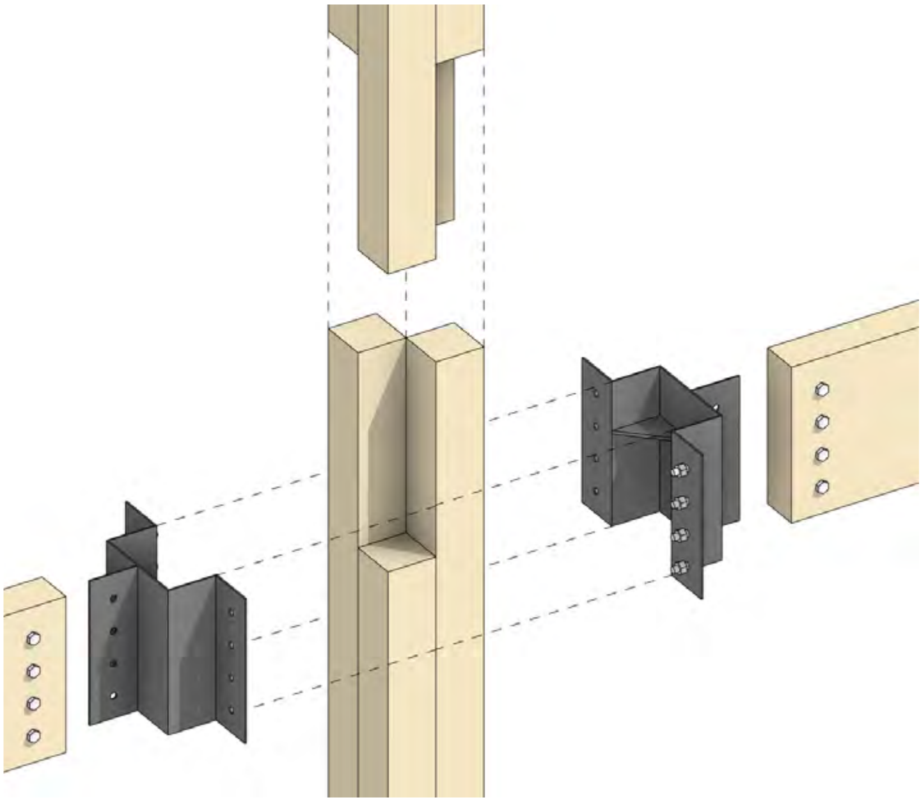
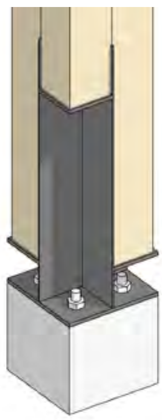


Fig. 4.07 – **Double forked column**, own illustration



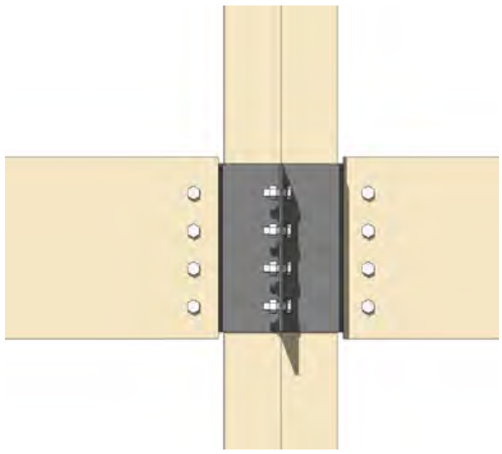


Fig. 4.08 – **Double forked column - base**, own illustration

Fig. 4.09 – **Double forked column - connection detail,** own illustration

Existing design

Precast bolted connections Peikko and GXN

Precast bolted connections Peikko and GXN. Peikko, together with GXN, are developing bolted connections on previously existing prefabricated Peikko products. These new connections make disassembly and reuse easier. Bolted connections are covered with mortar, that could be blasted out with high-pressure water blasting. (Fig. 4.10)

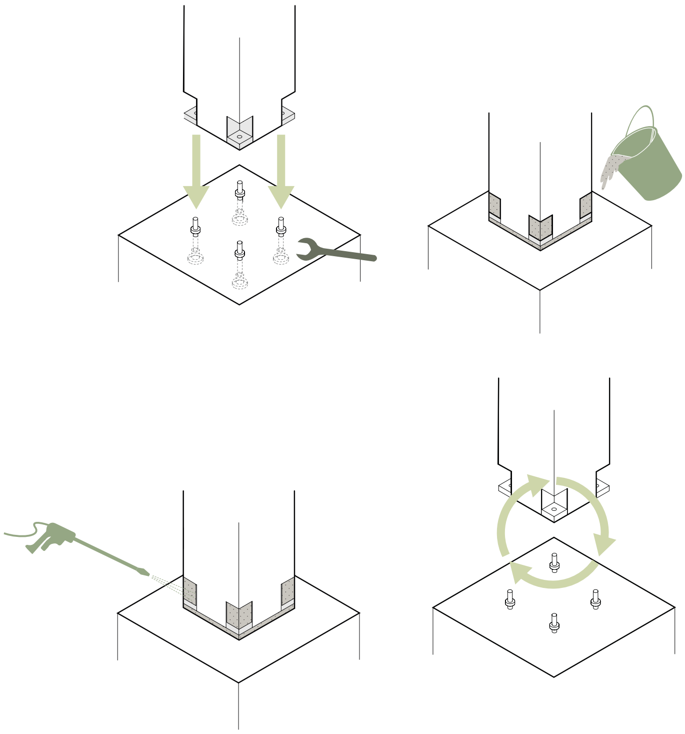


Fig. 4.10 – **Peikko prefabricated column** designed for disassembly and reuse, PEIKKO White Paper - Adapted illustration

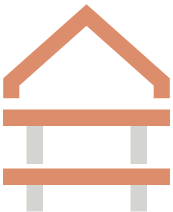
Timber connections in steel

There is a wide spectre of timber joints in steel, making disassembly, without damaging the timber material, possible. The connection shown in (Fig. 4.11) is a heavy timber joint designed by Acton Ostry Architects.

Fig. 4.11 – **Heavy timber joint - Acton Ostry Architects** Retrieved from: https://www.actonostry.ca/project/mount-currie-health-care-day-care/

Horizontal structure

Beams and floors



As mentioned in the introduction, detachable or reused structural components are not widely developed.

In this proposal, I would like to show alternative reuse of a structural beam transformed into landscaping elements.

Upcycled beams

In this proposal, beams from the building of the case study in Sinsenveien 53 are upcycled into retaining walls. The beam also has an optimal hight ideal for seating hight.

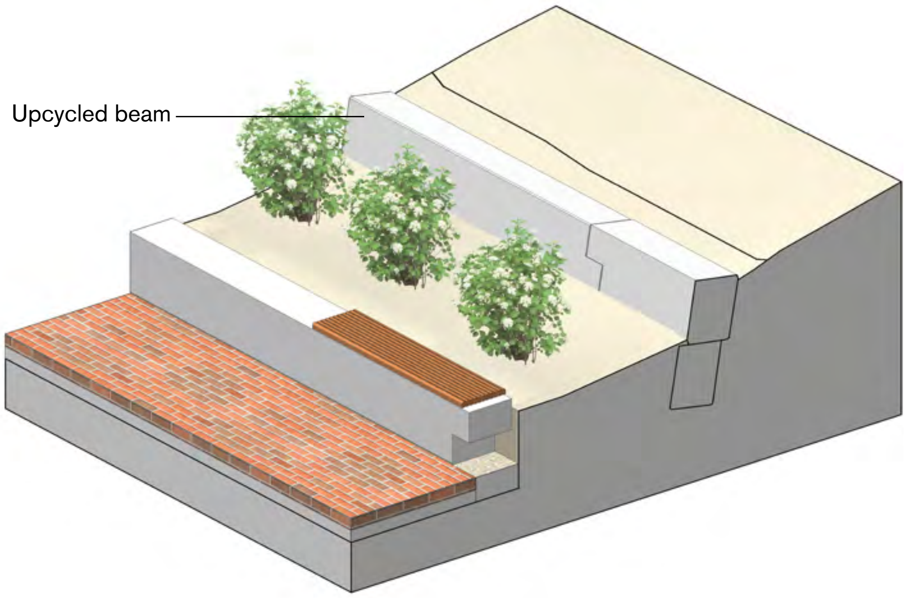


Fig. 4.12 – **Retaining wall - upcycled concrete beam,** own illustration

Waste product upcycling

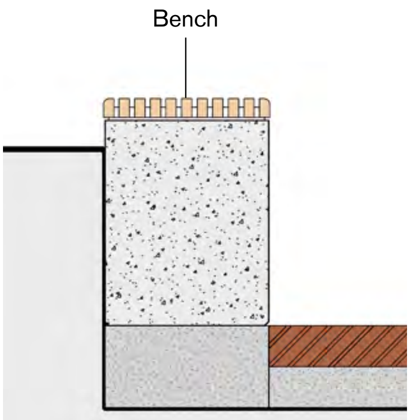


Fig. 4.13 – **Upcycled beam - section with bench,** own illustration

Fig. 4.14 – **Concrete beam - Case study Sinsenveien 53,** own photo

Existing design

Woodsol system

Woodsol is a research project that has the goal to develop wooden structural solutions. The system is being developed for quick assembly of high-rise timber structures. The connection design, therefore, allows for disassembly as well.

Fig. 4.15 – **Woodsol**- Timber structure, Retrieved from: http://www.woodsol.no/

Rounded Dovetail/ Swallowtail connection

With nowadays technology, it is easy to manufacture almost any possible geometric connection.
The connection is easy to assemble and disassemble, and there is no need for metal fasteners, which makes it a very sustainable option.

Fig. 4.16 – **Geometric connection** – Swallow tail - Walter Unterrainer

Stairs Kirribilli House

An interesting new design of stairs by MCK architects allows disassembly of the stair treads. Such design allows for an adaptation to the dimensions of the structure when reused.

It worth mentioning that in this specific case, a lot of steel is involved. An adapted version of this stair design could further enhance the environmental impact of the product.

Fig. 4.17 – **Stairs – MCK architects**, retrieved from: www.mckarchitects.com/site/projects/show/40/Kirribilli-House/

Envelope

Facade and roof sheeting

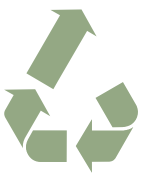
The building envelope is often subject to change for reasons as energy efficiency improvements of the building or aesthetic reasons.

Upcycled air duct shingles

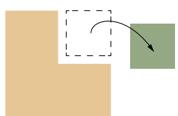
In this proposal, an upcycled tube material is folded and cut into new metal shingles. The length is used in the most effective way mirroring the cut angle. Resulting folded shingle has one part for attachment and minimum overlapping.

This proposal is inspired by the facade, made of the same type of air duct, designed by Vandkunsten architects (Fig. 4.19)

Proposal characteristics



Waste product upcycling



Easily removable components

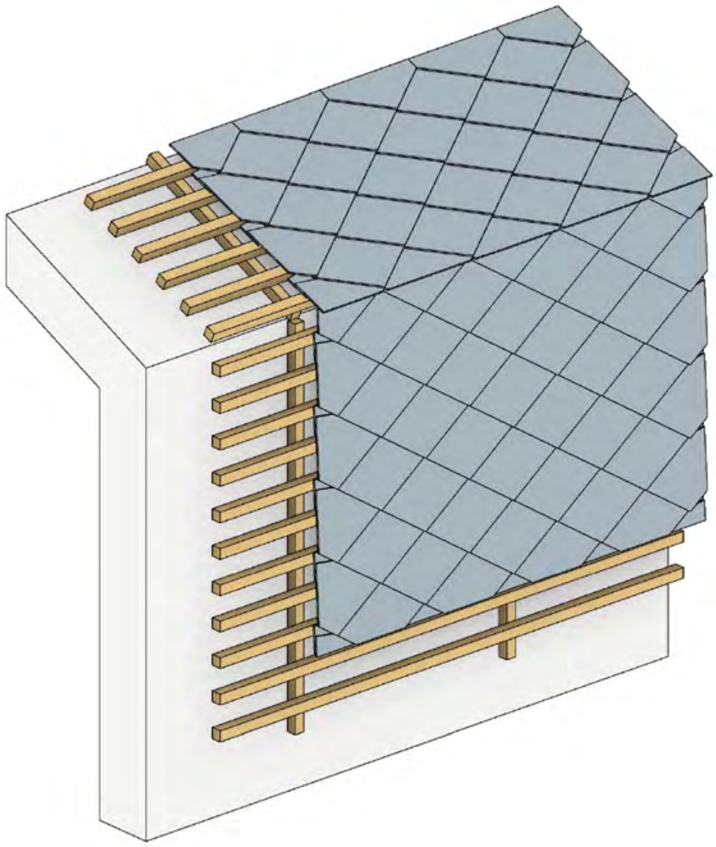


Fig. 4.18 – **Cladding use example**, Own illustration

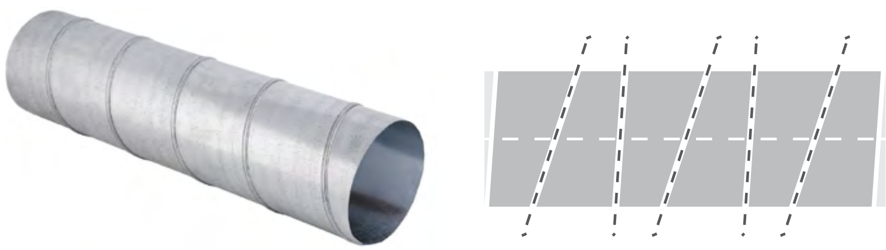


Fig. 4.19 – **Upcycling of used air duct** - cutting angle and folding

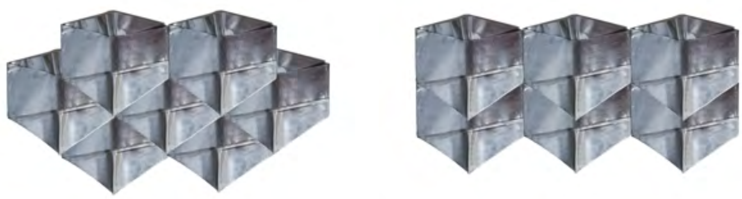


Fig. 4.20 – **Pattern alternatives**, Own illustration

Fig. 4.21 – **Facade shingle** - Upcycled airduct, Own illustration

Fig. 4.22 – **Facade shingle** - Type 2, Different metal tube, Own illustration

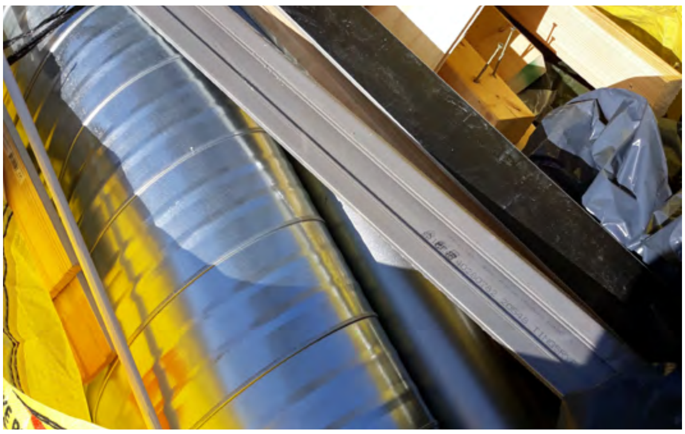


Fig. 4.23 – **Wasted tube materials**, Own illustration

Fig. 4.24 – **Wasted tube materials**, Own illustration

Existing design

PrettyPlastic©

Facade tiles from recycled plastic household waste, used on the People's Pavilion in Eindhoven (NL).

The tiles are detachable, screwed onto the supporting structure.

Same facade cladding was also used in the reference project in Kristian Augusts gate 13 in Oslo presented on pg. 33.

Fig. 4.25 – **Facade detail - People's Pavilion** by bureau SLA and Overtreders W., Photo by Jeroen van der Wielen

Vandkunsten

The Danish office Vandkunsten explored the possibilities of reuse of air ducts. With the use of fasteners, the flat sheets are attached to the supporting structure.

Fig. 4.26 – **Facade detail - Vandkunsten**, Retrieved from: vandkunsten.com/en/projects/component-reuse

Potato Head Beach Club

Is located on Bali in Indonesia, The facade is made of re-purposed window shutters.

Fig. 4.27 – **Facade detail** - Potato Head Beach Club - Indonesia, Photo: Walter Unterrainer

Existing design

Upcycle Mursten

The project called Ressourcerækkerne by Lendager architects (pg. 36) shows an innovative way of reusing brick walls, turning them into a new facade. The brick walls are cut into one by one meter pieces and assembled on facade panels. (Fig. 4.29)

Experimental House in Muuratsalo

Was designed by Elissa and Alvar Aalto as their own summer atelier and summer residence, Alvar Aalto Foundation (2017). The house is a composition of various experiments together with brick façades compound of various types and textures with an inspiring appearance. (Fig. 4.30)

CASA REX / FGMF Arquitetos

FGMF architects, in a project for their own office, realized an interesting design of the main facade, facing the entrance area, made of gabions. The gabions were filled with material from demolition, grey gravel and red sandstone. FGMF Arquitetos (2012) (Fig. 4.28) and (Fig. 4.31).

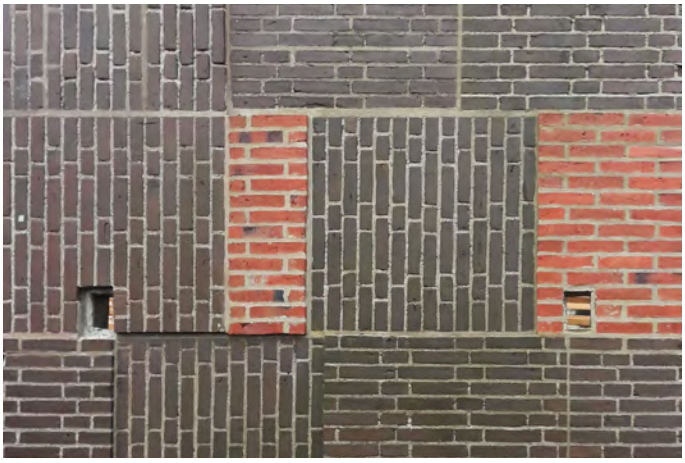


Fig. 4.29 – **Facade detail - Wasteland,** Own picture

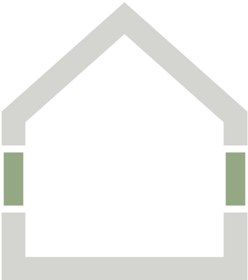
Fig. 4.30 – **Experimental House in Muuratsalo,** Photo by Moritz Bernoully, Retrieved from: https://www.flickr.com/photos/moritzbernoully/4887069419

Fig. 4.28 – **Facade detail** - CASA REX / FGMF Arquitetos - Brazil, Photo: Gabriel Mota, Retrieved from: https://www.archdaily.com/378491/casa-rex-fgmf-arquitetos?ad_medium=gallery

Fig. 4.31 – **Facade detail** - CASA REX / FGMF Arquitetos - Brazil, Photo: Rafaela Netto, Retrieved from https://www.archdaily.com/378491/casa-rex-fgmf-arquitetos?ad_medium=gallery

Windows and doors

Windows



There is an obstacle for the reuse of windows and doors. A big part of potentially reusable windows contains hazardous contents in sealants. This makes it impossible to reuse legally most of the windows produced before 2005.

It even seems that dismount of old windows is not a big problem (Fig. 4.33). If there were no hazardous materials, the window would be perfectly reusable.

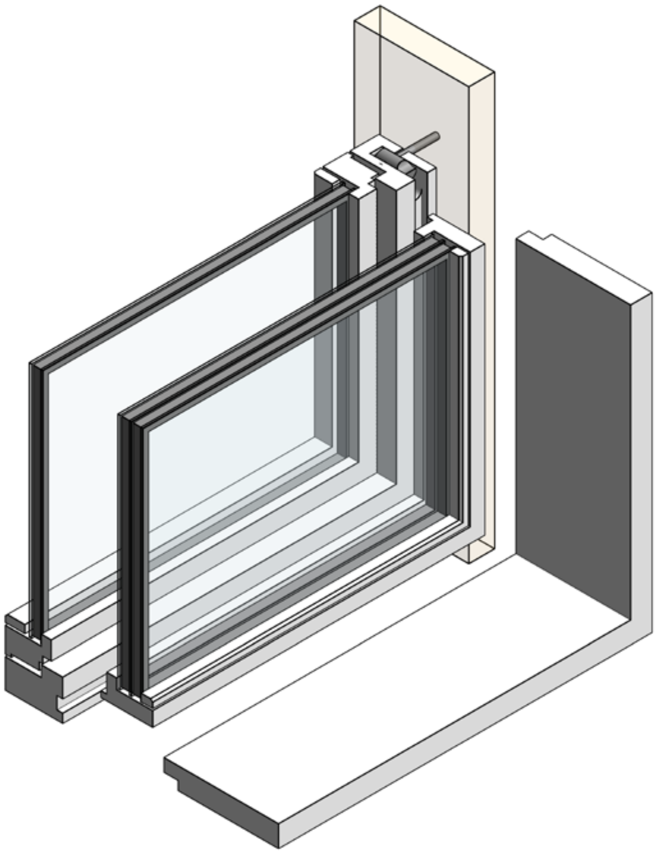


Fig. 4.32 – **Window upgrade with new insulating window panes,** Own illustration

High quality and healthy materials

1 from 2

Additional insulation

Fig. 4.33 – **Demounted windows from a demolition,** Own photo

Fig. 4.34 – **Disassembled window,** Own photo

Existing design

Upcycle Windows

Design by Lendager architects is another example of how reuse of windows of various sizes could look like. A patchwork of reused windows was presented on the Wasteland exhibition in Lilleakerbyen in Oslo. Similarly, partial reuse of window frames is shown it the project of European Council headquarters presented on pg. 35.

Fig. 4.35 – **Upcycled Windows** - Wasteland, Own picture

Upcycle Windows - 1 from 2

On the same exhibition, Lendager architects also presented a simple solution of reusing two entire windows turning it into one “new” window fulfilling the energy efficiency requirements. A similar principle is also used in old listed buildings.

Fig. 4.36 – **Upcycled Windows** - Wasteland, Own picture

VELFAC 200 ENERGY

This window, by Velfac company, is designed to be disassembled and make it easier to separate and reuse or recycle single parts.

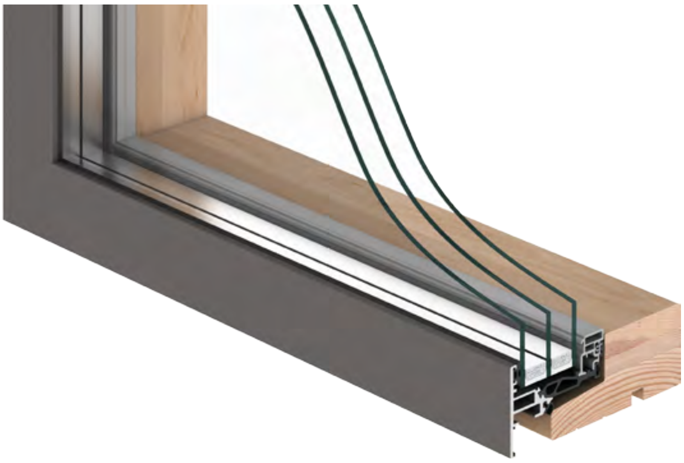


Fig. 4.37 – **VELFAC 200 ENERGY**- Retrieved from: velfac.co.uk/domestic/technical/velfac-200-energy/

Internal partitions

The internal partitions are often necessary to move or remove responding to the changes in use and changes in floor plan distribution. There are several types of movable partitions available on the market that respond to demands on flexibility.

Internal partitions do not necessarily need to be waterproof or provide good thermal insulation. Relatively low demands on performance are making the internal partitions a suitable field for various types of material recycling and upcycling.

In terms of disassembly, internal partitions do not seem to be the most critical component. A big part of the internal partitions, present in the material mapping of the case study seems to be easily removable and reusable.

Recycled materials

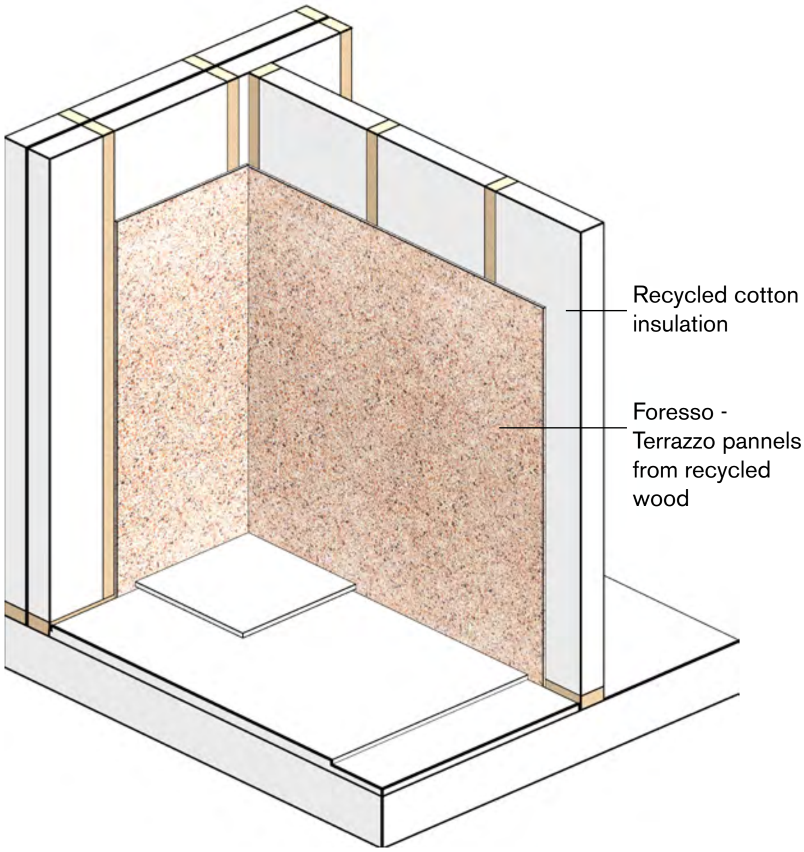


Fig. 4.38 – **Internal wall partition,** Own illustration

Internal partition made from recycled materials, sound insulation made of recycled cotton from textile and wooden terrazzo (illustrated below)

Fig. 4.39 – **Quiet Batt™** - Retrieved from: https://www.soundproofcow.com/product/quiet-batt-30-soundproofing-insulation/

Fig. 4.40 – **Foresso - timber terrazzo,** Retrieved from: https://foresso.co.uk/londoncollection

Existing design

New Nordic Wall

Is a design developed by Vandkunsten inspired by the Norwegian Stavneblokka, by Gaia Trondheim (stavneblokka.blogspot.no). The wall is made of modules that are easily assembled in partitions. Modules are made of reclaimed scrap wood.

Fig. 4.41 – **New Nordic Wall** - Vandkunsten, Retrieved from: vandkunsten.com/en/projects/component-reuse

Vacuwall

Is an internal partition wall, using a vacuum system installation. It is quick to install and remove. The panels are connected with an interlocking system without anchoring to the floor or ceiling. The modules can be handled by two people.

Fig. 4.42 – **Vacuwall** - Vacuum system Retrieved from: https://www.liko-partitions.com/en/vacuwall-movable-walls

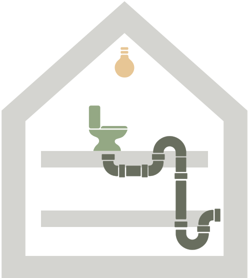
Internal partition - security glass

There is approximately 10% of tempered glass produced with wrong measurements. Unfortunately, tempered glass cannot be easily cut without heating it, after which it needs to be re-temper. An easy way to use the glass with open measurements is to overlap these sheets and make a fish-scale pattern.

Fig. 4.43 – **Upcycled security glass**, Photo: Walter Unterrainer

Services

Devices



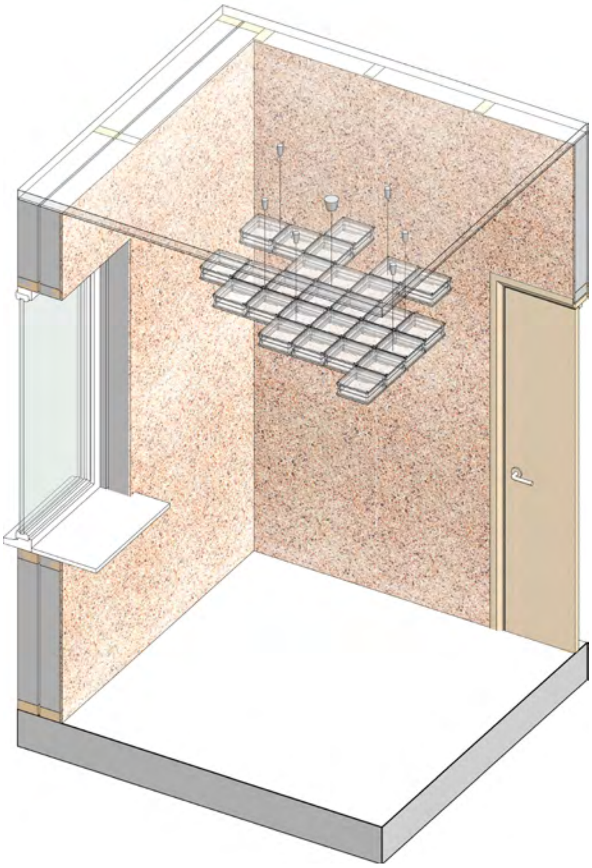
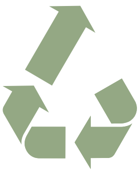


Fig. 4.44 – **Lighting fixture application,** Own illustration

The buildings services are usually not the issue in terms of disassembly. However, it remains an issue regarding the waste quantity generated. Norway and Sweden are leading the statistics in quantities of discarded equipment. It is even more evident in the construction sector.[1]

Upcycled glass blocks



Waste product upcycling

Fig. 4.45 – **Wasted glass blocks,** Own illustration

Fig. 4.46 – **Lighting fixture prototype,** Own illustration

1 **Eurostat** - Generation of waste by waste category https://ec.europa.eu/eurostat/web/products-datasets/-/ten00108

Existing design

Services conduit - Martini Hospital

The Martini Hospital was designed with several adaptability features. Among other features, the conduits were designed in a way that "*it is possible to move supply points for electricity, medical gases and water,...*" Arnold Burger (2007)

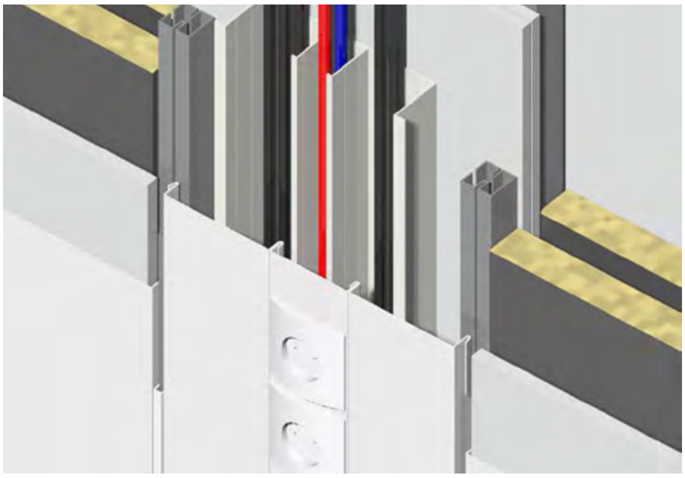


Fig. 4.47 – **Services conduit - Martini Hospital** - Retrieved from: seedarchitects.nl/en/projects/martini-hospital/

Systimber

An interesting solution in a timber structure is the profile designed by Systimber. The channel hidden behind a wooden panel accommodates the wires with the possibility for upgrade.

Fig. 4.48 – **Electrical installations - Systimber -** Retrieved from: www.systimber.com/

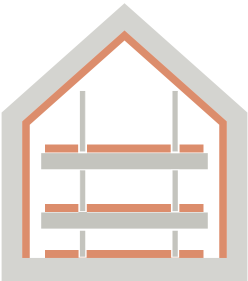
Fischer Lighting

Is a company based in Copenhagen that works with renewing of old light fittings, upgrading them into more energy-efficient products.

Fig. 4.49 – **Fischer Lighting -** GXN innovations, Retrieved from: gxn.3xn.com/project/lighting-circular-economy

Finishes

Floor and wall coatings



Finishes are subject to changing trends and aesthetic requirements. Unlike other parts of the building, finishes are changed even several times during the building's life-cycle.

Demountable ceramic tiles

The proposal suggests a new design of ceramic tiles that are attached without adhesives or glues, by screwing them in place, making the removal possible.

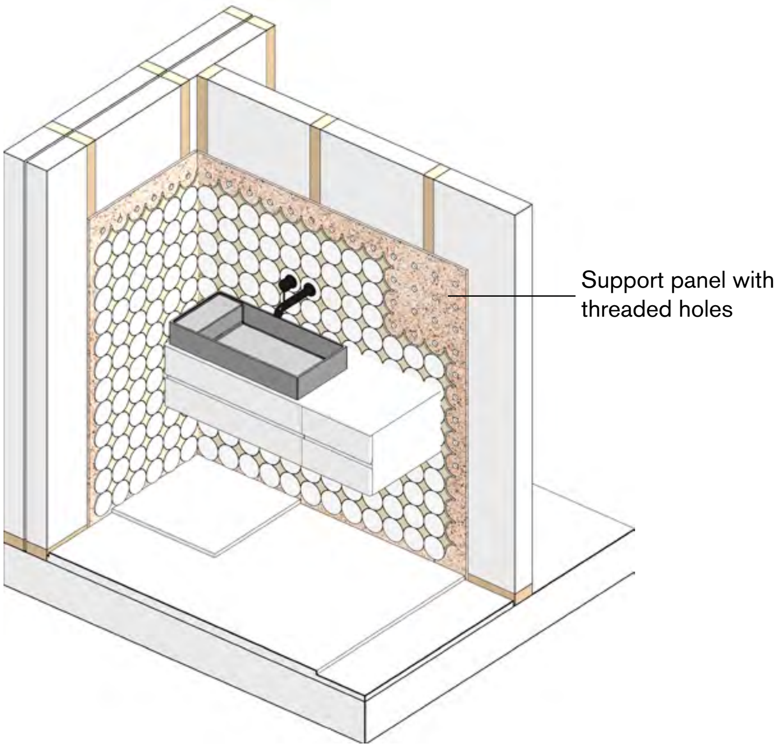
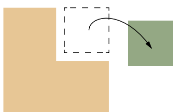
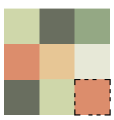


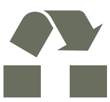
Fig. 4.50 – **Demountable ceramic tiles - application**, Own illustration



Easily removable components



Patchable components



Reusable

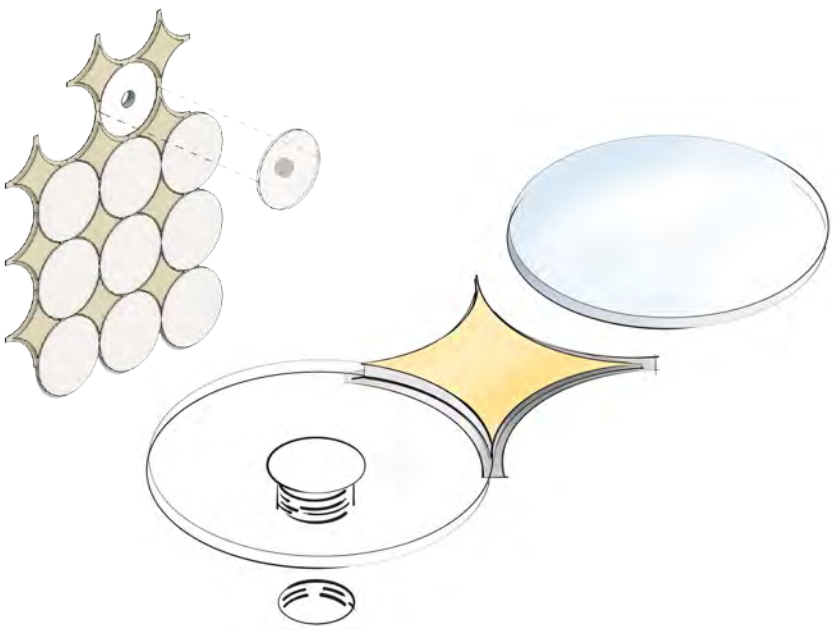


Fig. 4.51 – **Demountable ceramic tiles - sketch**, Own illustration

Existing design

Patchable carpet

The carpet tiles, as shown earlier (Fig. 1.25) on page 27, are a patchable solution, allowing for lifetime extension by shuffling or removing the fatigued parts.

Fig. 4.52 – **Carpet tiles** - Retrieved from: https://site.cycle-up.fr/wp-content/uploads/2019/08/cycleup-blog-image-la-moquette-peut-sortir-de-la-benne.jpg

Modular flooring

A similar principle with wooden flooring offers various types of the floating floor, using the click system, that are available on the market. The re-usability is relatively high. Similarly, as the carpet tiles, re-patchment or removal of fatigued parts is possible.

Fig. 4.53 – **Modular parquet** - Retrieved from: https://en.decorexpro.com/parket/hudozhestvennyj/

Reusing valuable stone material

Various finishes, such as flooring or wall coating, made of stone, are difficult to remove and get damaged during the removal. Nevertheless, the material could be alternatively recycled and used in terrazzo flooring as the aggregate. This solution relates to the marble wall coating present in the case study. Such a job can be performed, for example, by the company Respo Terrazzo AS.

Fig. 4.54 – **Terrazzo flooring** - Marble from Sinsenveien 53, Own illustration

Existing solutions

There are several existing design solution allowing for disassembly and reuse. In some cases, there is very little necessary to be done. Fully applying these solutions is often depending on minor choices. A good example are the bolted connections developed by Peikko and GXN presented on pg. 57. These connections are based on previously existing Peikko products, which makes the implementation easily acceptable by all the involved actors.

Glued or mortar binding

Masonry and tiles are widely used, but a simple reuse is difficult because of the binding material. Applications involving glue or mortar binding might be used if these are applied in modules that are possible to disassemble. An example of reuse of bricks combined with this principle is the facade designed by Lendager architects on pg. 63.

In some cases, a step back in material use is necessary. Nowadays, the cement mortar is widely used for binding materials. Unlike lime mortar, it binds the material too strongly together and is difficult to remove.[(17)]

A new mortar called VITRUV©, developed by KALK A/S, allows for separation and reuse of the masonry. The company aims to get the first Cradle to Cradle certified mortar.[(17)] The same mortar was also used in the bolted connections by Peikko and GXN (pg. 57).

17 NEW C2C LIME MORTAR https://kalk.com/build-lasting-culture/new-c2c-lime-mortar

Demonstration structure

Design for disassembly

Criteria

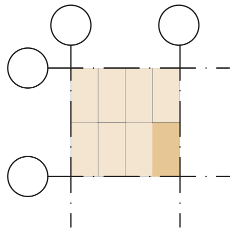
This last part of the thesis presents a demonstration structure, composed of various design solutions, shown previously in the catalogue. Its purpose is to showcase these solutions in correlation to other principles and illustrate how these proposals work on a building scale.

The structure is de-contextualised and does not have any specific program.

Standardisation

There are some components, such as the facade element and hollow-core slabs taken from the case study and placed in this demonstration structure. Use of these demonstrates, that nevertheless, the structural dimensions of these two structures are different, considering that both are using a standard size module, there might be still some compatible element.

The dimensions applied to the structural grid derive from standard sizes of building materials (discussed on page 25). If there is a known resource of reused building components, this measure might be further adapted to the dimensions of the original donating structure or reused component.



Used grid 3660x3660

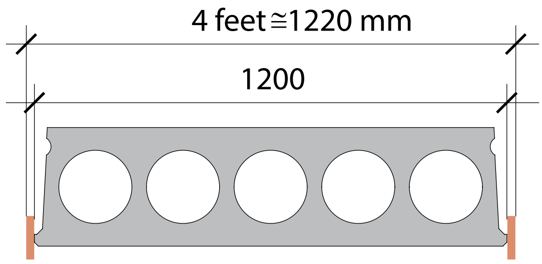


Fig. 5.01 – **Standard product dimensions with tolerance margins,** Own illustration

Multi-material construction

Fig. 5.02 – **Demonstration structure characteristics,** Own illustration

Demonstration structure

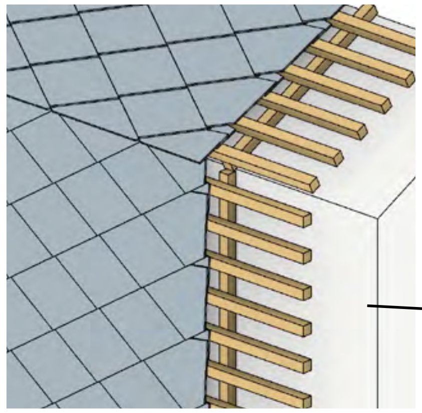


Fig. 5.03 – **Reused air duct cladding**

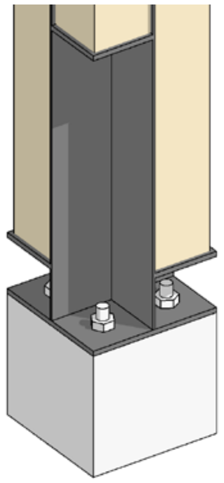


Fig. 5.04 – **Double forked column** - base

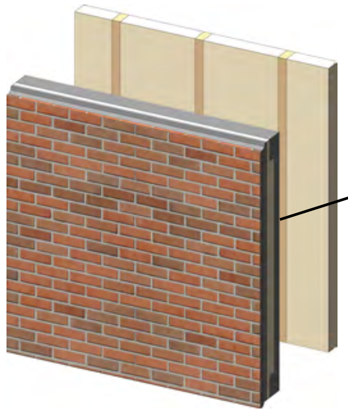


Fig. 5.05 – **Facade element from Sinsenveien 53**

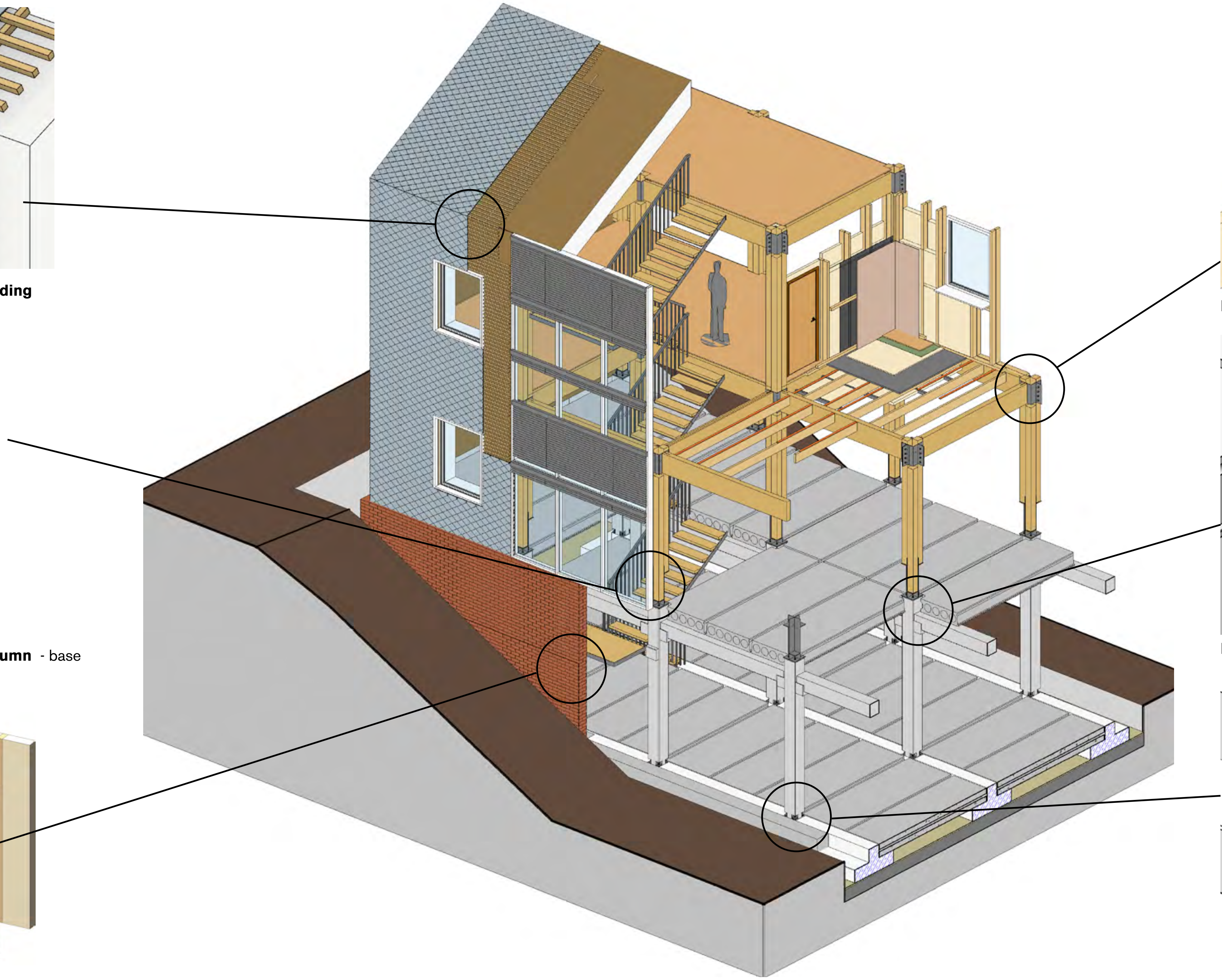


Fig. 5.09 – **Demonstration structure**

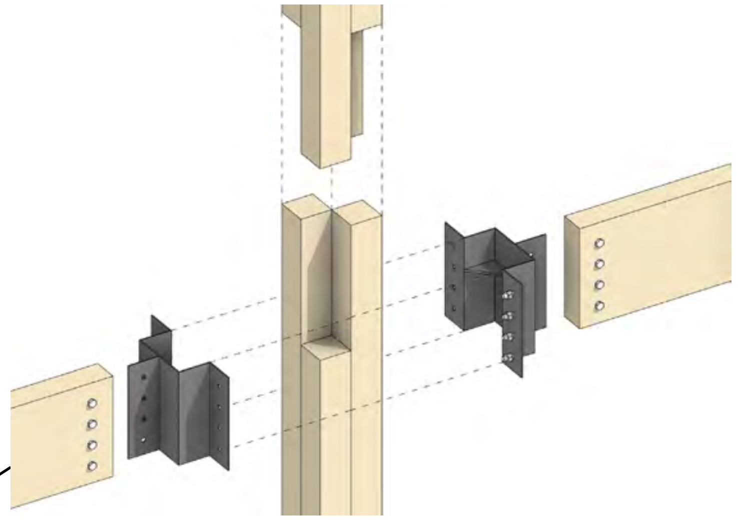


Fig. 5.06 – **Double forked column**

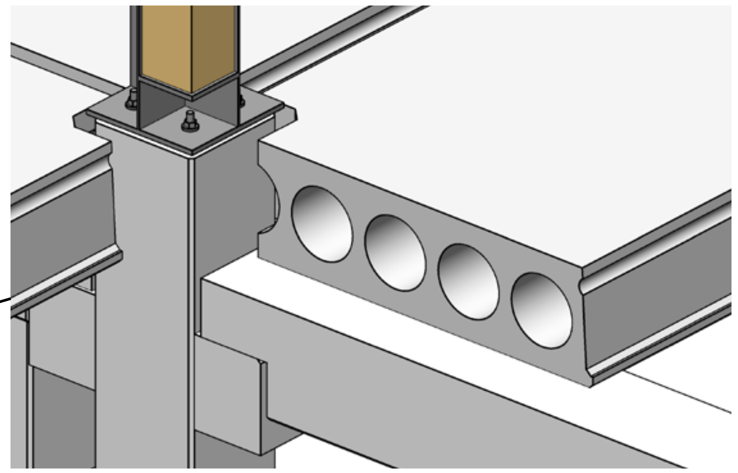


Fig. 5.07 – **Prefabricated concrete column**

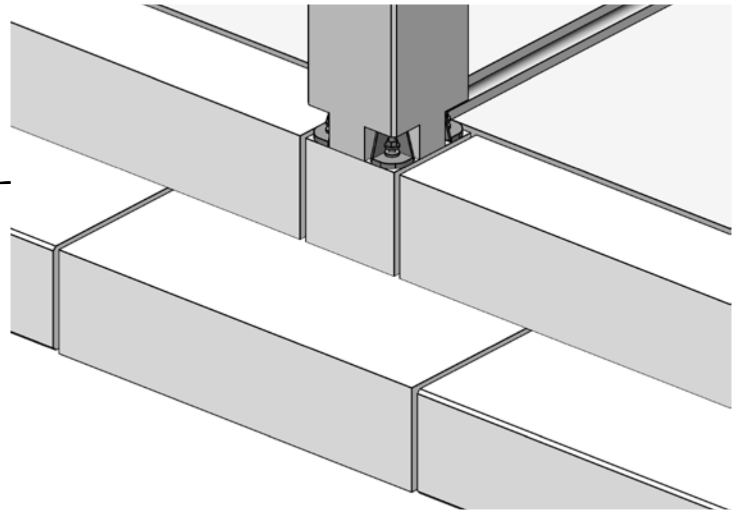


Fig. 5.08 – **Prefabricated concrete column**

Discussion

Discussion

Main question and objective

> How can we ensure simple reuse of building components and materials in future without producing more waste in the process?

What has been done to answer this

1. Through the theory, I have answered, what defines the issue.
2. A material mapping in the case study that uncovers some of the reuse potentials in a building.
3. An example of digitalization of an existing building, as a tool that facilitates reuse.
4. The catalogue, presenting my own design proposals, together with existing solutions that establishes a tool-kit for use in a project.

I believe that reusing is possible with the right set of values on all the levels; environmental, economical and social. On each of these, some values need to be re-discovered and promoted. A holistic view of different aspect regarding these values has been given in this thesis.

Social values

Stereotypically purchasing a new product is associated with high social status and expectation of something better than the previous product. This is highly reflected in how close the economic growth is connected to the generation of waste. This mindset has to be changed. A real growth is to make more from what we already have.

I believe, that by showing aesthetically pleasing design, this is possible. Re-inventing, inventing new, but also promoting existing solutions, gives more trust and encourages to accept new approaches. I believe that this thesis will inspire others to search for new creative ways to reach sustainability in the built environment.

Environmental value

It is undoubtedly beneficial for the environment, to reuse as much as possible without producing more and generating more waste. This reduces the pressure on the environment and gives it time to catch up and recover. There are studies, such as the Element Recovery and Sustainability Hunt, A. J. (2013), that reveal how many years are remaining until depletion of known resources. Regarding some materials, it might be soon, that not-recycling is not even an option, if we still want to use the same material.

Economical values

The case study uncovered some of the reuse potentials and challenges connected to the dismantling of a building.

It is clear that reversible design increases the building's value and makes the investment more attractive. It facilitates the adaptation to the changes of purpose, energy efficiency and fashion requirements.

Conclusion

An analysis of various projects and the methods used during the construction and dismantling show that there is a big potential for improvement. Design that prevents a product's effective dismantling needs to be reviewed. This regards both building as a whole and its singular components. To ensure simple reuse in future, preserve the value of products and reduce the waste quantity, shall be considered a priority.

List of figures

Theory

Reference projects

Case study

Catalogue

Demonstration structure

References

Listed in alphabetical order

Nr.	Description
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Nr.	Description
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3	**Eurostat** https://ec.europa.eu/eurostat/web/products-datasets/-/ten00110
4	**Statsbygg -** https://www.statsbygg.no/Prosjekter-og-eiendommer/Byggeprosjekter/Regjeringskvartal-nytt/Miljo/
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