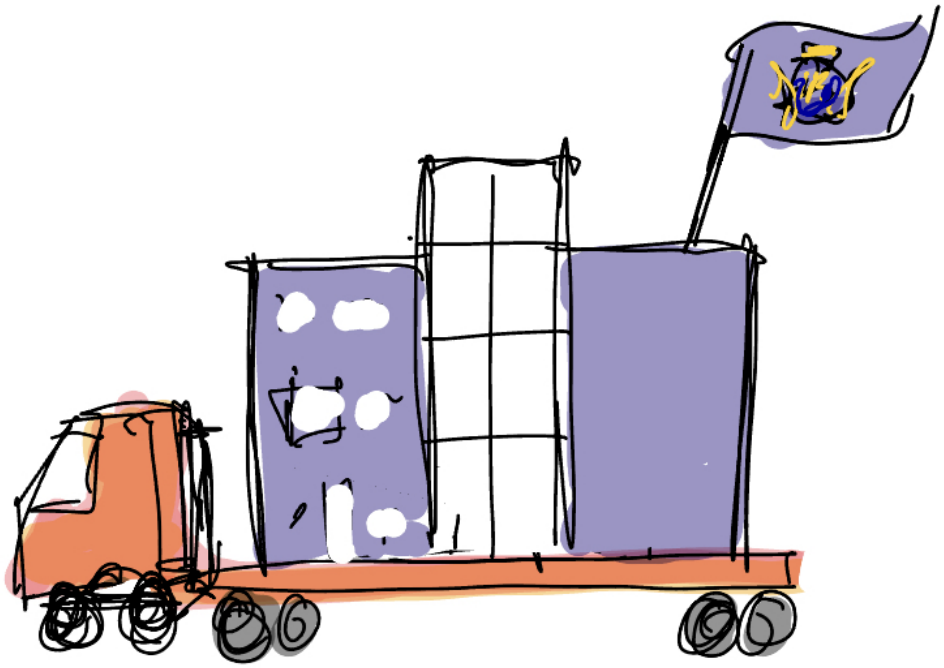
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Moving HSB Living Lab

A Reuse Evaluation Framework for a Preliminary Assessment of the Reuse Potential of Building Products

Degree project report in Industrial Ecology

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Abstract

This thesis investigates how to make a preliminary reuse evaluation of used building components, decoupled from a receiving project. In order to test the evaluation a modular residential building is used as a case study. The objectives of the project are to define how different parameters affect the reuse potential of the building products, and to use this knowledge to compare reuse scenarios. Due to existing research gaps on how to evaluate relevant reuse parameters, a framework is developed, suggesting what parameters are relevant, how to evaluate them and how to aggregate the results.

The project highlights the great complexities of evaluating and reusing building components, drawing insights from both literature and stakeholder interviews. The first part of the outcome of this project include the first iteration of a preliminary Reuse Evaluation Framework, designed to guide future reuse practices. The evaluation is based on grading various product properties to acquire scores for the key criteria *Recovery potential*, *Environmental impact* and *Market readiness*. Thereafter weights are assigned to each criteria, based on the preferences of the decision maker, giving a final reuse potential. The second part of the outcome include an inventory of the case study, as well as the application of the framework through the evaluation of selected building components in two different reuse scenarios. The studied scenarios are: 1. reusing the whole modules of the building (relocating the building); 2. reusing the individual building products. Based on the assumptions made in the study, the results show that reusing individual building products give higher reuse potential for most evaluated products, as compared with reusing them as part of the modules. This is in part due to the low market readiness and adaptability of the modules. Ultimately, which scenario is preferable also depends on circumstances that are outside of the scope of the evaluation framework, such as site-based building regulations. However, the results can indicate what to consider and what direction to take in a reuse project.

Acknowledgements

This thesis would not have been possible without the support of many people and we are truly grateful to everyone who has been part of this journey.

First and foremost, we would like to thank our supervisor, Elena Malakhatka, for her guidance, patience and continuous support throughout this project. Her feedback and advice helped us move forward whenever we faced challenges and she always encouraged us to think critically and look at the problems from different perspectives. We would also like to thank our examiner, Holger Wallbaum, for his valuable guidance and encouragement.

A special thank you to everyone at HSB Living Lab for welcoming us and giving us access to the data and knowledge needed to carry out this project. We truly appreciated your openness and willingness to help whenever we had questions.

We are also grateful to each of the 23 interview participants who took the time to share their experiences and perspectives. Although we cannot mention you by name to preserve your anonymity we want to express that your contributions were essential and invaluable to this thesis.

Finally, we would like to thank our families and friends for their patience, encouragement and constant support throughout our studies. Your belief in us has meant more than words can express. Alexanda would like to especially thank her partner Ignacio who spent many hours listening to and giving feedback on the project during his work hours.

Use of Generative AI

We would like to acknowledge the use of generative AI tools, including ChatGPT and Grammarly, in this thesis to improve the text's clarity and to correct grammatical errors. These tools were also used to better understand various complex concepts and terminology. The authors of this thesis take full responsibility for the presented content, analysis and discussions.

Alexandra Bäckström and Zainab Al Shara , Gothenburg, July 2027

List of Acronyms

Below is the list of acronyms that have been used in this thesis, listed in alphabetical order:

AEC	Architecture, Engineering, and Construction
BBR	Boverkets Byggregler / National Building Regulations
BIM	Building Information Model
BoM	Bill of Materials
BRG	Business Region Göteborg
CDW	Construction and Demolition Waste
CE	Circular Economy
CO2	Carbon Dioxide
CO2eq.	Carbon Dioxide equivalents
GHG	Greenhouse Gases
DDP	Detailed Development Plan
DfD	Design for Disassembly
DfAD	Design for Adaptability and Deconstruction
DP	Disassembly Potential
EC	Embodied Carbon
EoL	End-of-Life
EPD	Environmental Product Declaration
EU	European Union
EPR	Extended Producer Responsibility

GWP	Global Warming Potential
HSB	Hyresgästernas sparkasse- och byggnadsförening
HSB LL	HSB Living Lab
HVAC	Heating, Ventilation, and Air Conditioning
LCA	Life Cycle Analysis
LCC	Life Cycle Costing
MCDA	Multi-Criteria Decision Analysis
MIPS	Material Input Per Service unit
MP	Material Passport
NPS	Non-Product Specific
OOS	Out Of Scope
PBL	Plan och Bygglagen / (Swedish) Planning and Building Act
PV	Photovoltaics
RP	Recovery Potential
SIS	Svenska Institutet för Standarder / The Swedish Institute for Standards
SKR	Sveriges Kommuner och Regioner / Sweden's Municipalities and Regions
SotA	State of the Art
U/R/D	Upcycle/Recycle/Downcycle

Glossary

Term	Definition
Active product	A product that relies on a source of energy, other than that generated by the human body or gravity, in order to function as intended.
Building component	A product manufactured as a distinct unit to serve a specific function or functions, as defined by ISO 20887:2020 (Design for disassembly and adaptability).
Building element	A major functional part of a building (e.g. foundation, floor, roof, services), as defined by ISO 6707-1:2020.
Building material	Any material used in construction, such as steel, concrete, brick, masonry, glass, wood, etc, as defined by General Multilingual Environmental Thesaurus (GEMET), 2021.
Building product	In this thesis, this term is defined to encompass building materials, components and modules.
Downcycling	Transforming a product to give it a lower quality/value.
Modular building	Composed of modules for easy construction or arrangement and adaptation or disassembly, as defined by ISO 20887:2020.
Module	A set of standardized parts or independent units, as defined by ISO 20887:2020.
Preparing for reuse	According to the EU waste hierarchy - checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be reused without any other pre-processing.
Recycle	Any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original or other purposes, as defined by Directive 2008/98/EC, Article 3.
Refurbishment	The process of restoring a product to its original specifications.

Repair	Correcting damage to a product in order for it to perform its intended function.
Reusable	In this thesis it is defined as a component, material or product that can undergo reuse, in its current condition or after it has been prepared for reuse.
Reuse	The use of products or components more than once for the same, or other purposes without reprocessing. However, in this thesis the broader concept of reuse that includes the terms refurbishment and repair, as preparations for reuse, are also included, as defined by ISO 20887 (2020).
Shearing layers	A method developed by Stewart Brand of categorising building products into different layers of a building according to their function and/or lifespan. The layers include *Site, Structure, Skin, Service, Space plan* and *Stuff*.
Upcycling	Transforming a product to give it a higher quality/value.

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1

Introduction

The construction industry of today continues to follow a linear economic model that relies on continuous extraction of natural resources and leads to continuous waste creation. This inevitably causes resource depletion and continued emissions of Greenhouse Gases (GHG) and other harmful pollutants such as microplastics and heavy metals. The current model also encourages the production of building products that are often disposed of before their full potential has been utilised [Moscati et al., 2023].

According to *Boverket - the Swedish National Board of Housing, Buildings and Planning* - 13,6 million tons of Construction and Demolition Waste (CDW) was produced in Sweden in 2022. This corresponds to about 39 percent of all generated waste in the Country, and 20 percent of all hazardous waste. The recycling rate for non-hazardous building waste was estimated to be 55 percent with some uncertainty [Boverket, 2024a], but when it comes to reuse rates there are gaps in the statistics [Nordic Council of Ministers, 2023]. According to a study from 2024, the reuse rate in Europe is estimated to be <15 percent [Pristerà et al., 2024], and according to Abu-Ghaida et al. [2024] the reuse rate worldwide is less than 1%. More precise data does not exist as of now.

When it comes to the environmental footprint, GHG emissions from the Swedish construction and real estate industry accounted for 21% of the country's total GHG emissions in 2022. Out of these new construction accounted for approximately 21 %, heating for 28 %, property management for 24 % and renovation and extensions for 28 % [Boverket, 2025]. Previous studies have shown that out of the emissions emitted during new construction, renovations and extensions, the largest part comes from material extraction and manufacturing - around 85% for the average residential building [Erlandsson et al., 2021]

These numbers show that shifting to a circular model that reduces the extraction of

raw materials, new manufacturing and waste generation could have great environmental benefits. Circular practices include extending product lifespan, simplifying repair and refurbishment, reusing, (or, where reuse is not possible) recycling or energy recovery.

This thesis explores challenges and opportunities of reuse in different End-of-Life (EoL) scenarios using a case study. A first iteration of a framework for the preliminary reuse evaluation of building products is developed and tested. The results are analysed and suggestions for improvement of the framework are discussed.

In this report the word *Building product* is used as a general word for building parts, including building material, components and modules. A *building component* is defined as a "product manufactured as a distinct unit to serve a specific function or functions", according to ISO 20887:2020 (Design for disassembly and adaptability). A *building material* is defined as "any material used in construction, such as steel, concrete, brick, masonry, glass, wood, etc." , according to General Multilingual Environmental Thesaurus (GEMET), 2021. A *building module* is here defined (according to ISO 20887:2020) as a "set of standardized parts or independent units", and *modular* as "composed of modules for easy construction or arrangement and adaptation or disassembly"

The introductory chapter sets the stage of the study and introduces the background, aim, research questions, limitations, methods and case study of this thesis. At the end we state our contribution to theory and practice.

1.1 Background

Circular Economy (CE) is defined as an "economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles", according to ISO 20887:2020 (Design for disassembly and adaptability).

In this context, the EU Waste Directive (2008/98/EC) is a general framework for waste management that establishes basic definitions and requirements. For example, the directive facilitates the official description of the 'waste hierarchy' (Figure 1.1), which suggest which waste management practices should be prioritised. The first priority is "Prevention", followed by "Preparation for re-use" (through refurbishment or repair), "Recycling", "Recovery", and lastly conventional "Disposal".

Prevention refers to strategies and products that try to decrease waste generation. *Reuse* is defined as the "use of products or components more than once for the same or other purposes without reprocessing" (Note 1 to entry: "Reprocessing does not include

preparation for re-use, such as removal of connectors, cleaning, trimming, stripping of coatings, packaging, etc.") (ISO 20887:2020). *Recycling* is defined as a process in which discarded materials are reprocessed into raw materials for the production of new products Iacovidou and Purnell [2016]. *Recovery* refers to energy recovery through combustion, and *Disposal* as e.g. land filling.

Regarding waste from the construction sector, the member states of the EU were required to increase their reuse, recycling and other material recovery (excluding energy recovery) of non-hazardous Construction and Demolition Waste (CDW) to 70 percent by 2020 [European Commission, 2024]. The EU countries have largely met the target, with most already having exceeded it in 2016. However, the high recovery rates are mostly achieved through down-cycling, e.g. backfilling and low-grade recovery applications, such as using recycled aggregates as road sub-bases. With these open-loop practices the inherent value of materials are lost [European Environment Agency, 2024], and this cannot be considered truly circular or sustainable.

Recycling is considered the circular practice that has been applied to the greatest extent, however, evidence suggests that it is less beneficial than Prevention and Reuse practices. This is due to the fact that in most recycling processes some material is inevitably wasted and/or contaminated [Minunno et al., 2020]. Additionally, while the reuse process of some elements may involve some reprocessing/fabrication, the energy requirement for this is still considerably than for recycling. For example the reuse of steel and glass can result in savings of more than 60% of the carbon required for recycling [Iacovidou and Purnell, 2016].



Figure 1.1: EU Waste Hierarchy [European Commission, 2024]

The interest in circularity and reuse is growing through an increased societal awareness of climate change and other environmental impacts, as well as an increased pressure from governments. With the help of studies, reports and pilot projects the transition towards circular economies has slowly begun. However, the reuse rates are still estimated to be

low Abu-Ghaida et al. [2024] and it is clear that to increase the reuse rates there is a need for a large-scale adoption of a variety of new circular practices and business models in the construction sector [Boverket, 2024b].

1.1.1 An Overview of the Reuse Process

In order to better understand reuse, as it is practised today, we provide a short description of the steps that make up the reuse process starting from the EoL of a building. While the conventional building process is well established and looks more of less the same in all construction projects, the reuse process is less so and might be different from case to case. The differences may be what steps are included as well as when and how many times they occur [Lindborg et al., 2024]. The steps included in the reuse process are based on three different reports, Lindborg et al. [2024], Sveriges Kommuner och Regioner (SKR) [2024] and Fastighetsägarna Stockholm [2024]. The original phrasing has been edited without changing the meaning to better fit the context. The reuse process generally contains more steps than the conventional EoL process, however, Lindborg et al. [2024] highlights that many of the steps are similar to standard procedures and could be incorporated into the conventional project planning.

The reuse process begins with a *Reuse inventory*, where all the building components comprising the building are documented. Here an initial *Reuse evaluation* is conducted, where an assessment of the reusability, environmental impacts and economic value for each type of component is made. Based on this *Reuse goals* and *Action plans* can be made, detailing what amount of reuse should be achieved in the project, and what should be recycled or energy recovered instead. Here the process of finding other projects in which to reuse the recovered components should be started. The receiving projects could be internal, or external. Following this a more detailed inventory might be conducted to plan the disassembly procedure before the *Disassembly* starts. After disassembly the recovered components need to be *Transported* to a *Storage* facility. Some components need *Quality assurance* and some might also need *Refurbishment* before they can be reused in a new location. After this step the components can either be resold on the market or plans for reuse in another internal project can be made. The components are thereafter *Reassembled* according to their function and need. A follow up evaluation of results and assessment of the avoided emissions of reuse is recommended. The building is then *Used and maintained*. Ideally information on the condition of the component is kept and updated to simplify future reparation and reuse.

1.1.2 Barriers and Drivers

Many of the barriers and drivers of circularity in Sweden and Europe have been identified by stakeholders in the building sector. However, there seems to be no obvious starting

point to achieving a functional reuse market, since all factors and all stakeholders are connected and dependent on each other. One of the main barriers to action is a lack of economic incentives [Ericsson et al., 2024, Nordic Council of Ministers, 2023, Fastighetsägarna Stockholm, 2024]. If introducing reuse into a project leads to an economic loss, then few companies are willing to invest. The continued high cost of reuse compared to the use of new materials can be said to be partly due to inadequate policies on reuse [Ericsson et al., 2024, Nordic Council of Ministers, 2023, Fastighetsägarna Stockholm, 2024]. The environmental and societal costs of carbon emissions from the production of new materials are not yet influencing the market prices. Therefore an increase in regulations, taxation and subsidies could help create the economic incentives that are needed. Increased demands for the inclusion of reused components in public procurements is also an important driver [Nordic Council of Ministers, 2023, IVL Swedish Environmental Research Institute, 2021]. On the other hand, a greater flexibility of legislations around reuse could also facilitate necessary variability in e.g. the aesthetical condition of a product [Nordic Council of Ministers, 2023].

Due to insufficient economic incentives, a professional reuse market has not yet been fully established [Ericsson et al., 2024, Fastighetsägarna Stockholm, 2024, IVL Swedish Environmental Research Institute, 2021]. One example of a platform/business that has been developed to function as such is CCBuild (Centrum för Cirkulärt Byggande/Centre for Circular Construction) [CCBuild, 2025]. It is functional and growing, but it is not yet offering enough products to satisfy the need of the industry. For this to change many pieces need to fall into place. Looking at the first phase of a new project, it is necessary to introduce circular thinking and design early in the building's life-cycle, to develop new and improved project management methods [Ericsson et al., 2024, IVL Swedish Environmental Research Institute, 2021] and to unify the way that the whole industry works with terminology and tools in order to standardise the process [Nordic Council of Ministers, 2023]. New and changed roles need to be established, specifically focused on circularity. An example of this is extended producer responsibility, mandating producers to ensure the continued function and quality of their products throughout its life-cycle, which could span multiple uses in different buildings [Ericsson et al., 2024, Fastighetsägarna Stockholm, 2024, Nordic Council of Ministers, 2023].

At the end-of-life of a building, or at the start of a renovation project, it is necessary to make it standard practice to conduct a reuse inventory and a reuse evaluation of the building products. This is necessary to inform a decision on what can be reused, and what should be recycled or energy recovered [Nordic Council of Ministers, 2023]. Utilising digital tools in order to store information about each building's components and systems is an important key to optimising the reuse rates [Nordic Council of Ministers, 2023, IVL Swedish Environmental Research Institute, 2021]. Today modelling tools that store

information about building components, such as Building Information Models (BIM), are not fully adapted for circular projects, which poses a problem to stakeholders [Lindborg et al., 2024]. An issue related to this is the uncertainty around the performance of used materials, which could be said to be due to a lack of relevant information and difficulties in transferring data between projects. In order to ensure adequate performance there is therefore a need for digital tools such as BIM and Material Passports (MP) to grow and adapt to circular practices [Ericsson et al., 2024, Fastighetsägarna Stockholm, 2024, IVL Swedish Environmental Research Institute, 2021].

Other challenges that arise when the decision to reuse building components is made are related to logistics and an uncertain market demand. Today there is an insufficient amount of storage facilities for material that is awaiting a second use [Fastighetsägarna Stockholm, 2024, IVL Swedish Environmental Research Institute, 2021]. This means that the products need to be reused in a new project immediately after disassembly, severely limiting the ease of circularity. Due to the current lack of demand on the market and lack of specifications in building projects for reused components, finding a project that could receive the used products also poses a great challenge [IVL Swedish Environmental Research Institute, 2021, Halling and Johansson, 2023]. New business models that offer temporary storage for used building products while awaiting instalment in a new project would provide an important service [Blixt and Fischer, 2023, Harala et al., 2023], and an increased certainty of what products are in supply and demand on the market would reduce the risk that is currently associated with professional large-scale reuse [IVL Swedish Environmental Research Institute, 2021, Halling and Johansson, 2023].

Summary of drivers and barriers:

- High cost of reuse (-)
- Low cost of new material (-)
- Reuse policies:
  - Increased economic incentives (+)
  - Extended producer responsibility (+)
  - Stricter public procurement requirements (+)
- Circular design, e.g. Design for Disassembly (+)
- New project management methods (+)
- Standardised reuse processes (+)
- New/changed roles (+)
- More digitalisation (+)
- Lack of quality assurance (-)
- Lack of logistics and storage solutions (-)
- Low market demand (-)
- Lack of specifications for reuse (-)
- Circular business models (+)

1.2 Goal and Scope

1.2.1 Aim

The focus of this thesis is on reuse practices at the EoL of buildings and the aim is to investigate how to make a preliminary evaluation of the reuse potential of different types of building products. A modular residential building is used as a case study. The main objective is to examine two different reuse scenarios and evaluate which of the scenarios result in more reuse and why.

The intended outcomes of the project include:

- A State of the Art summary of current knowledge on reuse evaluation based on a literature review and stakeholder interviews.
- A proposed framework for evaluating the reuse potential of building products before a receiving project is known.
- An inventory of all the building products that comprise the case study.
- A Reuse evaluation of a selection of the building products for two different reuse scenarios.

1.2.2 Research Questions

Building upon the previously established aims this investigation will address the following key research questions, divided into a *theoretical* part and a *practical* applied part:

Theoretical research question:
RQ1. How can a preliminary evaluation, decoupled from a receiving project, of the reuse potential of building products be structured, and what parameters should be considered?

Practical research question:
RQ2. Which of the examined building products can be considered reusable in the case study, and what factors affect their reuse potential?

1.2.3 Scope & Limitations

The scope and limitations of the project are as follows:

- The project is based in Sweden and follows the national building regulations of Sweden.
- The answers to the research questions builds upon current knowledge from past or ongoing reuse practices, and is likely to be subject to change as knowledge increases.

- Only the reuse of the type of building products that are present in the case study are evaluated.
- No social impacts are assessed in this project.
- Due to a lack of available data and time constraints assumptions are made regarding certain properties of the evaluated building products. These are described more in detail in section 3.4.
- The number of studies included in the literature review are relatively few, which influences the reliability of the results.

1.3 Methods

1.3.1 Research Design

The research method of this thesis follows a qualitative approach based on literature studies and interviews with stakeholders from various fields and with different expertise. Due to large knowledge gaps in this topic the framework development is highly explorative and therefore the evaluation results uncertain. An iterative process of framework design and results analysis was carried out within the time limits of the project to improve the results.

1.3.1.1 Double Diamond

The overarching methodological work can be divided into three unique phases overlapped by four different steps that are spanning the project, see figure 1.2. The steps are based on the concept of the *Double Diamond* [Council, n.d.]. In the first phase, *State of the Art*, we *Discover* the subject by studying current knowledge and then *Define* the goal and scope of the thesis. In the second phase, *Scenario, framework & inventory development*, we move into practice and *Develop* the inventory of the building through data collection and management. In the third and last phase, *Reuse evaluation & Scenario Assessment*, we *Deliver* a sustainability evaluation of the selected reuse scenarios.

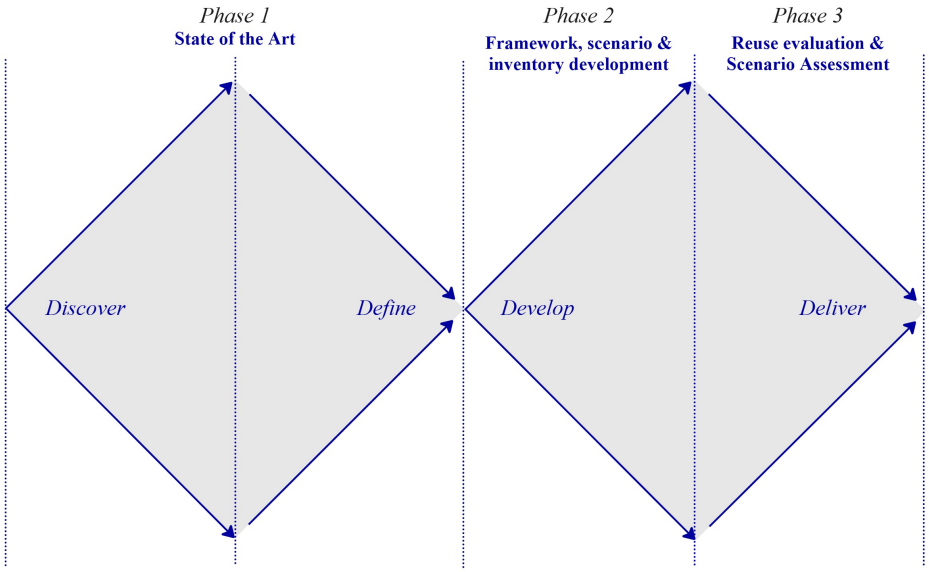


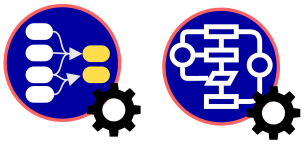
Figure 1.2: The phases and methodological steps of the thesis

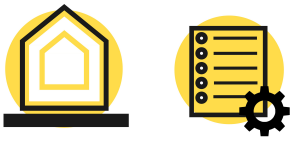
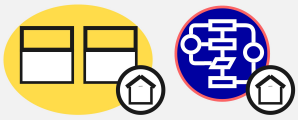
1.3.2 Summary of methods and tools

Below is a summary of all the methods used in the thesis, see table 1.1. The phase in which each method is used can be seen, and a brief description of what each method is used for is given in the table.

Table 1.1: The methods used in the project

Phase	Method	Description
State of the Art, step 1 *Discover*	Literature Review with Heat-map visualisation 	A literature review is conducted to gain insights on suggested reuse evaluation methods, and a heat-map is created to help identify research gaps.

Phase	Method	Description
	Semi-structured Interviews I 	Interviews are conducted to attain direct and up-to-date stakeholder insight. The interviewees are actors from academia, consultancy, industry and government with knowledge on different aspects of the reuse process.
State of the Art, step 2 *Define*	Network analysis 	A complex network represented by a network graph is created with the reuse evaluation parameters mentioned in the literature review. Relationships between parameters, their dependencies and hierarchy, are examined to provide an overview of the complex network.
Scenario, framework & inventory development , step 3 *Develop*	Scenario development through Semi-structured Interviews II 	Different reuse scenarios are developed based on brainstorming with the real estate owner and further evolved through insights gained from a second round of interviews with HSB partners and other industry actors experienced in reuse.
	Reuse evaluation framework development: Parameter categorisation & Algorithm design 	A *Reuse evaluation framework* is developed based on the Network analysis that concludes the *State of the Art*-phase. The framework offers a holistic way to make a preliminary evaluation of the reusability of building products when the receiving project/-s is still unknown. Parameter categorisation and algorithm design are used to support the design of the framework and enable a logical system of evaluation.

Phase	Method	Description
	Reuse inventory using Shearing layers 	*Shearing layers of change* is used to effectively organise and categorise the extensive data that has been collected and managed. As part of this process, a reuse inventory of the building is conducted to compile a comprehensive list of its building elements.
Reuse evaluation & Scenario Assessment step 4 *Deliver*	Reusability Framework application 	A reuse evaluation of the building elements of the case study is conducted, based on the reuse evaluation criteria, in order to make a preliminary assessment of the reuse potential in the different reuse scenarios.

1.3.2.1 Literature Review

The literature review is conducted based on the keywords *reuse, circularity, construction, buildings, Nordics, reuse evaluation, reusability, case study, design for disassembly* and *modular buildings* to gain knowledge on current theory and practical applications of reuse evaluation as described in scientific papers and reports. *Chalmers library, Google Scholar, Science direct, Research gate, Connected papers* and *Perplexity* were used to find the literature. Snowballing was used to further expand the literature set. Certain papers suggested to us during interviews were also included. The relevant papers and reports used for the review all included clear suggestions of important parameters that determine the reuse potential of a building product.

1.3.2.2 Semi-structured Interviews I & II

Two types of different semi-structured interviews were conducted in this thesis, both types lasting around one hour. The first group of interviews took place in the beginning of the project and focused on gaining a general understanding of current reuse practices, the possible developments of reuse, as well as the opinions of actors in the industry, consultancy, academia, and government. The second group of interviews involved manufacturers, resellers, reuse firms, consultants, and other participants who had practical

experience in the reuse of building products. These were conducted in order to develop the case study scenarios, learn more about the particular building products found in the case study, as well as what type of products they considered reusable or not. The manufacturers in interview group II were selected because of their collaboration/ connection with the case study. Both interview types were used to inform and strengthen the development of the Reuse evaluation framework. It is important to note that the participants were not asked directly to specify which parameters should be included in a reuse evaluation, however, the general topic was related to reusability. The questions asked in interview I and II can be found in Appendix C

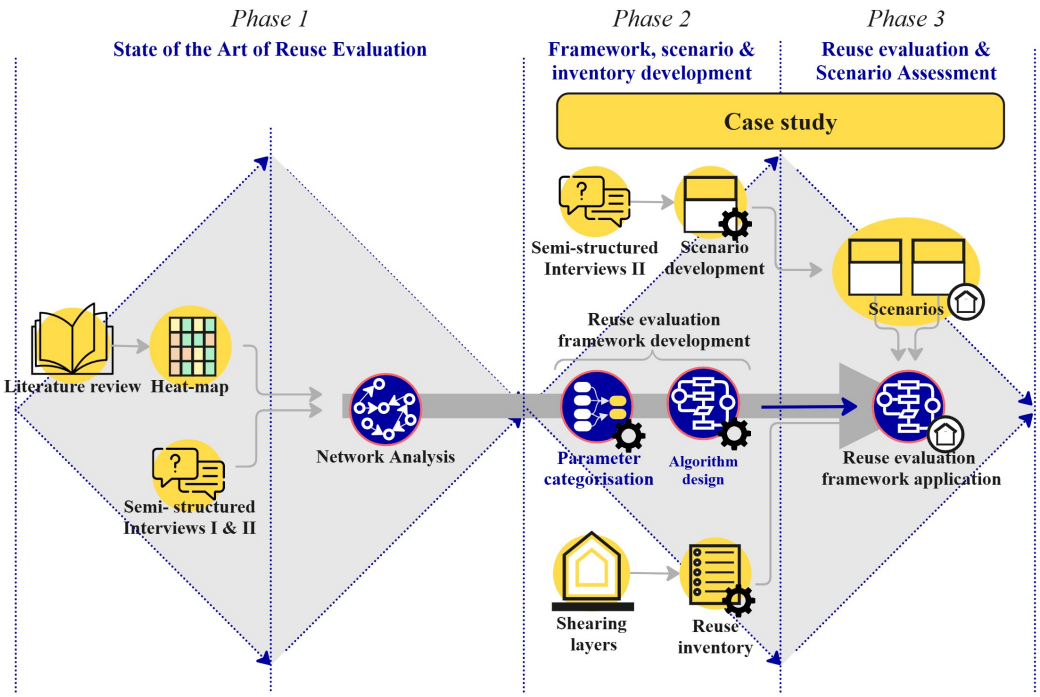


Figure 1.3: The methods applied in the thesis

1.4 The Case Study

The case study of this project is the HSB Living Lab (HSB LL), which is a modular residential building located on Chalmers' campus Johanneberg, Göteborg, owned by HSB (Hyresgästernas sparkasse- och byggnadsförening).



Figure 1.4: HSB Living Lab west facade

The HSB LL is a so-called *Living Lab*, which is a type of building following a methodology that promotes stakeholder collaborations and testing new ways of living and building in a real-world environment [RISE Research Institutes of Sweden, 2024]. Funding for the research comes from the various partners of HSB, which include companies, government organisations and Chalmers University of Technology. The research that has been conducted since the building's completion in 2016 has involved various aspects of residential construction, building systems and human behaviour, including energy use, water use, waste management, reuse of building elements, and social interactions.

The HSB LL was built as a modular building due to the short building permit it was given (10 years, with a maximum extension of 5 years). HSB, together with some of its partners and its leading architects, saw it as an opportunity to design the building for disassembly, so that it could be moved to another location when the permit expired. It is as of now scheduled to be removed in 2027. The potential reuse of the Living Lab is something that HSB, in collaboration with Chalmers, wants to explore. This project assesses the reuse potential of a selection of building products from the case study in two different reuse scenarios - reusing the modules as a whole by disassembling and moving the whole building to a new location, or reusing individual products in other reuse projects.

The building consists of 44 modules, each measuring approximately 13.35 meters and weighing around 20 tons, including pre-installed furnishings. Together the modules create a five-story building with a total gross floor area of around 2000 m^2, See figure

1.5 for a section of the building made by the architects at *Tengbom*. The assembly process involved lifting each module into place using a crane, with an average of five modules raised daily over the course of about 10 days. After all the modules were lifted into place, the interior connections of the modules and installations required some additional months to complete [MedicSolution Nordic AB, 2016]. A summary of general information on the building is provided in table 1.2.



Figure 1.5: HSB LL Section, by *Tengbom*

Table 1.2: General description of the building

Property	Data
Type	Housing on floors 2,3 and 4; Office on floor 1
Location	Chalmers Campus Johanneberg, Gothenburg, Sweden
Property Owner	Hyresgästernas Sparkasse- och Byggnadsförening (HSB)

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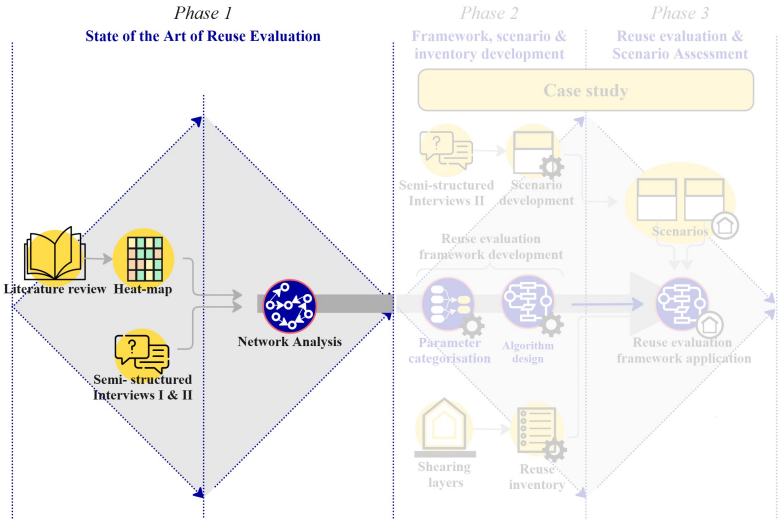
Property	Data
Total building area	around 2000 m^2
Floors	5 Floors (of which 4 are full floors)
Apartments	24 Student rooms with shared kitchen, living space and bathrooms, as well as 5 regular apartments of varying sizes.
Modules	Size: 13,35 meters long
	Weight: around 20 tons each, including furnishings
Construction completion	2015
Building permit expiration	2027

1.5 Contribution to theory and practice

This Master's Thesis contributes to theory and practice by proposing a detailed framework for evaluating the reuse potential of a building product (material, component or module), before its disassembly, and before a receiving project has been identified. The framework is based on an extensive literature review, reinforced by stakeholder interviews. The aim is to define what properties and other parameters are relevant to evaluate, how they can be evaluated, and how the results can be aggregated into a final score. The first iteration of the framework is applied on a case study and then analysed for improvements.

2

The State of the Art of Reuse Evaluation



To investigate current proposals for evaluating the reuse potential of building products, 14 different papers and reports that explicitly formulate reuse evaluation methods and mention relevant parameters have been analysed. Most of these have been created in a Nordic context, however, a few studies from other parts of the world have also been included to add specific knowledge, such as on modular buildings. Some of the literature is written in conjunction with a case study that was used to support of confirm the evaluation. A few of the methods are specifically focused on certain types of building products, such as structural components. The scope of the analysis is presented in more

detail below, after which a table with relevant characteristics of the studies are given, see table 2.1, followed by a short description of each study. In Appendix A, tables with the individual proposals from each study can be found. In table 2.2, a heat-map with all parameters selected as relevant for the scope of this thesis is presented, showing the occurrence of parameters in different studies as well as to what extent each parameter has been defined and graded by the authors. Parameters that share the same definition have been aggregated into one to reduce the amount of parameters. How this was conducted can be seen in Appendix B. Interview insights from Interview I and II are thereafter presented, beginning with a description and key citations from each interviewee. The questions for each interview can be found in Appendix C.1 and C.2 respectively. Based on the parameters found in the studies, the occurrence and suggested connections between these, as mentioned by the interviewees, are presented in table 2.4. In order to understand the relationships between the parameters, such as dependencies and influence, a network analysis of the parameter connections is conducted. Finally, identified research gaps are presented and the positioning of this study is given, describing which gaps this thesis attempts to fill.

2.1 Parameter analysis scope

The scope of the analysed evaluation methods and their proposed parameters is guided by certain considerations related to the research scope of the thesis. Parameters for which the following conditions are true are out of the scope of the analysis:

- There already exist regulations for this aspect of a building product/building that determine reusability. This includes such parameters as:
  - Material toxicity
  - Cultural heritage classification or similar classifications enforcing reuse
  - Products that are under Extended Producer Responsibility (EPR)
- It is not possible or relevant to assess this aspect in a preliminary reuse evaluation decoupled from a receiving project. This includes:
  - Available quantities of product types. This should be assessed in a subsequent assessment after a preliminary reuse potential has been established.
  - Logistics and storage details.
  - Future use. The intended use is assumed to be the same as the products current use, i.e. up-cycling or down-cycling is not included.
  - Time-wise availability of the product.
  - Specific recovery methods.

2.2 Current proposals of reuse evaluation parameters from literature

Table 2.1: Reuse evaluation studies

Study	Origin	Case study	Application
1. *Bellini et al. [2024]*	Nordic	EoL of residential building	General
2. *Iacovidou and Purnell [2016]*	Europe	-	Structural components
3. *Lindborg et al. [2024]*	Sweden	-	General
4. *Janson et al. [2022]*	Sweden	EoL of 5 adjacent hospital buildings	General
5. *Sveriges Kommuner och Regioner (SKR) [2024]*	Sweden	-	General
6. *Linus Brander [2021]*	Sweden	EoL of two buildings: a 19th century commercial/restaurant facility; a 1980s office/storage facility	Heavy structural elements
7. *White [2021]*	Sweden	A number of previous reuse inventories conducted in the research project *ReCirculate*	General
8. *Karin Hedén [2022]*	Sweden	EoL of office building	General
9. *Geldermans [2016]*	Europe	-	General
10. *Fastighetsägarna Stockholm [2024]*	Sweden	-	General
11. *Sandra Moberg [2022]*	Sweden	-	General
12. *Abu-Ghaida et al. [2024]*	Sweden	-	General
13. *Business Region Göteborg [2025]*	Sweden	-	Products suited for circulation to other property owners or reuse-hubs
14. *Yang et al. [2025]*	World	Relocation of a modular building	Modular buildings (with steel structure)

2.2.1 General evaluation methods

Descriptions of the analysed studies are given below, where each study is represented by the number it has been assigned in table 2.1 above.

2.2.1.1 Study 1. *Bellini et al. [2024]*

The data for the report by Bellini et al. [2024] was gathered by conducting semi-structured interviews with experts and participants of a reuse project, as well as through workshops. The reuse parameters were defined based on existing standards and regulations, such as *TEK17* (Building technical regulations of Norway), LCA according to ISO 14044:2006, Risk management according to ISO 31000:2018, etcetera, as well as the input from the interviewees. The case study involved an existing industrial/office building set to be disassembled and reused in in a new residential building on the same site. The reuse evaluation was applied to a few selected building components (internal wall, ceiling panels and wood flooring), and included considering "environmental" aspects, "technical requirements", "quality", "life expectancy", "possibility for disassembly", "costs" and "risks". However, some of the parameters, such as environmental, risk, and cost, could not be evaluated due to a lack of available information at such an early stage of the project. The grading of the parameters was either a qualitative assignment of a number between 1-5, or a yes/no by assigning 1 or 0.

2.2.1.2 Study 2. *Iacovidou and Purnell [2016]*

In the paper by Iacovidou and Purnell [2016] the focus is on developing a classification system for structural components to guide their reuse evaluation. The authors highlight some findings from their literature review, including two overarching indicators that are considered important for reuse evaluation. The first one being "Reuse potential", which is more focused on the technical feasibility of reusing a product. It considers factors such as "market maturity", type and quality of "material", "residual" value, "dimensions", "connections", "exposure", and "generation" of use. The second indicator is "Embodied carbon reuse efficiency", which is described as the amount of conserved embodied carbon through reuse. No way of grading the parameters were suggested by the authors.

2.2.1.3 Study 3. *Lindborg et al. [2024]*

The report by Lindborg et al. [2024] aims at providing a practical guide for circular design and planning in construction projects. The report is based on a literature review, interviews, workshops and case studies located in Sweden. It offers examples of parameters that should be digitally documented for a building product, as well as how this information can be structured. The authors recommend developing digital workflows

and integrations between different platforms such as inventory apps and BIM programs to make the reuse process smoother. The suggested parameters include "dimensions", "material", "functional requirements", "level of product information", "condition", "total climate savings" and "total amount". A way of grading the parameters was suggested for some of the parameters, but not all, in which they are assigned a number between 0-5.

2.2.1.4 Study 4. *Janson et al. [2022]*

Janson et al. [2022] aims to provide practical guidance on when to demolish, renovate, or build new, as well as how to reuse building products in Sweden. The report is based on a case study in which five buildings were to be either demolished or renovated. The authors sought assistance from a reuse consultancy for building products (*Kompanjonen*) and suggest their parameters for the reuse evaluation. *Kompanjonen* places importance on three main criteria: "demand" for the product, "disassembly potential" and "commercial volume". They state that a building product must achieve a high grade in these three criteria to be considered reusable. The grading system is based on assigning a number between 1-5, however, for most of the parameters definitions are missing.

2.2.1.5 Study 5. *Sveriges Kommuner och Regioner (SKR) [2024]*

The report by Sveriges Kommuner och Regioner (SKR) [2024] discusses strategies for promoting reuse in the building sector in Sweden to support real estate owners. It is based on practical experience and knowledge from networks and ongoing industry work. The report identifies eleven key parameters, but three parameter are highlighted: market demand, disassembly potential and the commercial volume of the component. However, the report lacks a detailed explanation of how these parameters could be evaluated. Note that some authors of this report are from the reuse consultancy firm, *Kompanjonen* who were also collaborators in report by Janson et al. [2022]. This explains the similarity of the parameters suggested in these two reports.

2.2.1.6 Study 6. *Linus Brander [2021]*

The report by Linus Brander [2021] aims to give practical criteria to assess the reuse of heavy structural elements before and after disassembly, implementing these criteria on two different structural components as examples. The suggested parameters can be used to evaluate other kinds of building products besides structural ones, however, the exact translation of their evaluation for other types of products is not given by the authors. The parameters include "assembly type", "dimensions", "length", "product type", "age", "condition", "previous use", "exposure" "disassembly potential" and "handling possibilities. A grading method is suggested for a few parameters, such as disassembly potential - easy, medium, difficult, uncertain - and condition - Ok, poor, surface rust, uncertain.

2.2.1.7 Study 7. *White [2021]*

The report by White [2021] has a focus on the reuse inventory methodology. The authors provide a simple tool for evaluating building components, and suggests prioritising what to salvage based on "disassembly potential", "environmental impact" and "economy". It is meant to be used for an early assessment before making a deeper analysis. The authors provide an overall evaluation with a grading from A to C for these three parameters. A, B and C are defined differently depending on the parameter. For example, for "Economy" A=high new purchase cost and long remaining service life, and C=low new purchase cost and short remaining service life. They do not explicitly explain how to combine the grades to acquire a final score, however, from the examples provided, it can be inferred, with some uncertainty, that if any of the criteria receives a grade of C, then the overall evaluation will also be C and if none of the criteria receive a C, the overall evaluation will be based on the average of the three criteria.

2.2.1.8 Study 8. *Karin Hedén [2022]*

In the report by Karin Hedén [2022], the office building *Kromet* in Gothenburg, Sweden, was treated as a material bank; product- and material-specific reuse potential was assessed using six main parameters: "reduced climate impact", "ease of disassembly", "potential for reuse", "raw materials with limited availability", "economic value versus new product", "quantity" and "disassembly potential". In the first reuse inventory they used construction drawings and made two site visits. This was followed by product-specific detailed inventories (recording "condition", "material", "function", and "dimensions"). After assessing the six parameters, workshops were conducted to identify the project's goals, which resulted in prioritising the following criteria: "reduced climate impact", "ease of disassembly", and "quantity" when determining what building products to reuse. The parameters are graded by assigning a grade of low, medium or high. No further explanations of what constitutes a "low" or a "high" is given.

2.2.1.9 Study 9. *[Geldermans, 2016]*

The paper by [Geldermans, 2016], which is set in the Dutch context, proposes seven reuse parameters for building products. The parameters were determined during 4 workshops with a core group of researchers, architects and consultants from Delft University of Technology, University of Applied Sciences Rotterdam, Briqs Foundation, and Knowledge Platform for Sustainable Resource Management. They differentiate between intrinsic properties and relational properties, and argue that "the real value of a product is at the intersection [of the two properties]". The *intrinsic properties* include high "functional quality", "sustainable origin", "ability to be reincarnated sustainably after every iteration", "non-toxic" and "consistent with biological cycles and cascade" (or one or more technical cycles). The *relational properties*, which concern anticipation

of unknown future use scenarios, include "dimensions" (considering dynamic capacity-demand), "connections" (dry and logical) and "performance time" (defining the lifespan). To apply these in practice, the authors use seven assessment data categories. The authors mention that by considering both the intrinsic and relational properties, one can make informed decisions regarding the circularity potential of a building product. The evaluation was not tested on a specific building case study and no grading method is provided.

2.2.1.10 Study 10. *Fastighetsägarna Stockholm [2024]*

The reuse evaluation method provided by Fastighetsägarna Stockholm [2024] aims at being an easy and straightforward guide for Swedish real estate owners. The guide is based on a mix of reports, prior research, and interviews with practitioners in the building sector. They present a simple two-axis graph where one axis represents the effectiveness of reuse in regards to "climate effect", ranging from low impact (indicating a low reduction in "climate footprint" and a short "remaining service life") to high impact (indicating a high reduction in "climate footprint" and a long "remaining service life"). The other axis measures the "economic effort" involved in regards to "time of reuse" and "costs", from low effort (requiring little time and cost) to high effort (being highly time-consuming and expensive to reuse). By placing a building product on the graph, it becomes easy to identify which ones are worth reusing (those that score high in impact and low in effort) and which ones are less worth reusing (products that score low in impact and high in effort). The report provides some examples of where to place different building materials and products, but the criteria are not applied on an actual case study in the report and the method of placement is based on rough estimation and experience rather than clear guidelines.

2.2.2 Further exploration into specific reuse parameters

2.2.2.1 Study 11. *[Sandra Moberg, 2022]*, Environmental impact

The main focus of the report [Sandra Moberg, 2022] is on evaluating the environmental impact of reused building products. It presents the products that are suitable for reuse based on current flows of used materials at reuse firms, previous experiences from studies and case studies, materials that are being reused today in the city of Stockholm, and the product categories with the largest flows that are registered on the platform CCBuild. The report mention three general parameters that should be prioritised when looking at the climate effect of reuse. These include building products with high "embodied emissions", "large" components/"heavy" materials, and high "flow rate" (often replaced or sold in large amounts). No grading method is provided.

2.2.2.2 Study 12. *Abu-Ghaida et al. [2024]*, Recovery Potential

In the paper by Abu-Ghaida et al. [2024] a method for assessing a product's "Recovery Potential" (RP) is developed and suggested for use in LCA. The method involves estimating the RP through the parameters "Disassembly Potential" (DP) and material-specific properties, such as how "fragile" a material is. The DP in turn, originally proposed by Cottafava and Ritzen [2021], depends on "connection types" between products, "connection access", "form containment" and "crossings". It is important to note that these parameters are based on the scenario in which a building part will be removed and replaced, and not on the scenario that the whole building will be disassembled. The grading method used by the authors, which is based on previous studies, consists in assigning a grade from 0.1-1 using fuzzy numbers, meaning that a certain connection type is assigned a "suitable" number between 0.1 and 1. In the case study of the paper a cut-off was made if a product was assigned the lowest grade (0.1) for any parameter, in order to exclude unlikely reuse scenarios.

2.2.2.3 Study 13. *Business Region Göteborg [2025]*, Market readiness

In an online seminar in April 2025 by *Handslaget för cirkulärt byggande* (a Gothenburg based initiative with the aim of increasing the reuse of building elements and establishing a large scale reuse market) the *Research Institutes of Sweden* (RISE), and *Business Region Göteborg* (BRG), presented a selection of the building products with the highest potential for large scale reuse on the market [Business Region Göteborg, 2025]. The focus was on the products that should circulate to other property owners or be received by local reuse firms. This was a stepwise assessment that resulted in identifying 18 building components considered mature enough for large-scale reuse. This selection was done first with the help of data from property owners identifying the product with the largest flow and selecting products based on supply and demand. This selection was then thinned and clustered according to internal feedback. Finally an analysis based on the three parameters "Economic profit", "Technical feasibility" and "Market demand" was done and the products considered to be at the intersection of the three parameters were chosen as suitable for a large scale reuse market. No specific grading method was suggested.

2.2.2.4 Study 14. *[Yang et al., 2025]*, Assembly type/Modular design

The report presented by [Yang et al., 2025] examines a demountable modular housing system. The case study featured in the report focuses on a four-story building constructed with 68 modules made of structural steel frames and precast slabs, located in Hong Kong, China. The aim was to disassemble, relocate and reuse the building. The references the authors used were from semi-structured interviews with structural engineers, site observations, and archival documents of the building. They identify practical parameters

relevant for reuse evaluation, such as "ease of disassembly", existence of "take-back mechanisms","technology-driven traceability" and "value retention" process.

2.2.3 Parameter heat-map

A heat-map of the mentioned parameters can be seen in table 2.2. The studies are numbered from 1-14 in columns, and the occurrence of a parameter in a study is marked with an x. A Green colour signifies that a clear definition and grading method has been provided; yellow signifies that only a definition has been provided; red signifies that only the parameter name has been given. In some cases the definition of a parameter is explained by its name, such as with *Weight* and *Dimensions*, in which case a yellow colour has been assigned to the table cell. As previously stated, parameters with similar definitions have been grouped for simplification. How this grouping has been performed can be found in appendix B.

Table 2.2: Heat-map of reuse evaluation parameters from literature

Reusability parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Environmental impact	x	-	x	x	x	-	x	x	-	x	x	-	-	-
Embodied carbon	x	-	x	-	-	-	x	x	-	x	x	-	-	-
Economic profit	-	-	-	-	-	-	x	-	-	-	-	-	x	-
Costs	x	-	-	-	-	-	-	-	-	x	-	-	-	-
Value of eq. new product	-	-	-	-	-	-	x	x	-	-	-	-	-	-
Quality & Life expectancy	x	x	-	x	x	x	x	-	x	x	-	-	-	-
Condition	x	x	x	x	x	x	-	x	-	-	-	-	-	-
Technical feasibility	x	x	x	-	-	-	-	-	-	-	-	-	x	-
Technical properties	x	x	x	-	-	-	-	-	-	-	-	-	-	-
Recovery potential	-	-	-	-	-	-	-	-	-	-	-	x	-	-
Disassembly potential	x	-	-	x	x	x	x	x	-	-	-	x	-	x
Handling possibilities	-	-	-	-	-	x	-	-	-	-	-	-	-	-
Assembly type	-	-	-	-	-	x	-	-	-	-	-	-	-	x
Risk	x	-	-	-	-	-	-	-	-	-	-	-	-	-
Function	-	-	-	-	x	x	-	x	-	-	-	-	-	-
Dimensions	-	x	x	x	x	x	-	x	x	-	-	-	-	-
Part of large product flow	-	-	-	-	-	-	-	-	-	-	x	-	-	-
Weight	-	-	x	-	-	-	-	-	-	-	x	-	-	-
Market readiness	-	x	-	-	-	-	-	-	-	-	-	-	x	-
Market demand (internal or external)	-	-	-	x	x	-	-	-	-	-	-	-	x	-
Previous use	-	x	-	-	-	x	-	-	-	-	-	-	-	-
Previous physio- mechanical use	-	x	-	-	-	-	-	-	-	-	-	-	-	-

Reuse evaluation parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Maintenance history	x	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of previous uses	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Material	-	x	x	-	-	x	-	x	x	-	-	x	-	x
Consistency with biological or technical cycles and cascade	-	-	-	-	-	-	-	-	x	-	-	-	-	-
Raw materials with limited availability	-	-	-	-	-	-	-	x	-	-	-	-	-	-
Time of reuse process	-	-	-	x	x	-	-	-	-	x	-	-	-	-
Exposure	x	x	-	-	-	x	-	-	-	-	-	-	-	-
Indoor/outdoor placement	-	x	-	-	-	x	-	-	-	-	-	-	-	-
Weather exposure	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Chemical exposure	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Temperature exposure	-	x	-	-	-	x	-	-	-	-	-	-	-	-
Moisture exposure	-	-	-	-	-	x	-	-	-	-	-	-	-	-
Loading	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Static loading	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Fatigue loading	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Impact transient loading	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Connections	-	x	-	-	-	x	-	-	x	-	-	x	-	x
Connection access	-	-	-	-	-	-	-	-	-	-	-	x	-	-
Crossings	-	-	-	-	-	-	-	-	-	-	-	x	-	-
Level of product information	x	-	x	-	-	-	-	-	x	-	-	-	-	-
Busniness models	-	-	-	-	-	-	-	-	-	-	-	-	-	x

1. Bellini et al. [2024], 2. Iacovidou and Purnell [2016], 3. Lindborg et al. [2024], 4. Sveriges Kommuner och Regioner (SKR) [2024], 5. Janson et al. [2022], 6. Linus Brander [2021], 7. White [2021], 8. Karin Hedén [2022], 9. Geldermans [2016], 10. Fastighetsägarna Stockholm [2024], 11. Sandra Moberg [2022], 12. Abu-Ghaida et al. [2024], 13. Business Region Göteborg [2025], 14 Yang et al. [2025]

2.3 Interview insights into reuse evaluation parameters

In this chapter, insights from interviews are added to the parameters influencing reuse evaluations, which were collected from the literature review in the previous chapter. The interview insights are meant to strengthen the parameters and also to help add more understanding of connections between the parameters.

Table 2.3: Interview participants by sector and role

Interview Participants

Academia		
Participant A1	Researcher	Interview I
Participant A2	Architect and Researcher	Interview I
Participant A3	University professor	Interview I
Consultancy		
Participant C1	Architect	Interview I
Participant C2	Environmental Consultant	Interview I
Participant C3	Project Manager	Interview I & II
Participant C4	Architect	Interview I
Participant C5	Architect and reuse specialist	Interview I
Participant C6	Reuse consultancy firm	Interview II
Participant C7	Reuse consultancy firm	Interview II
Participant C8	Reuse hub/service provider	Interview II
Government		
Participant G1	Project Manager	Interview I
Participant G2	Project Manager	Interview I
Industry		
Participant I1	Project Manager	Interview I
Participant I2	CEO of a building product manufacturing company	Interview I
Participant I3	Research and Innovation Coordinator	Interview II
Participant I4	Property manager	Interview I & II
Participant I5	Team leader in a building product manufacturing company	Interview II
Participant I6	Construction and civil engineering company	Interview II
Participant I7	CTO and head of projects in a company focused on prefabricated modules	Interview II
Participant I8	Demolition and remediation contractor	Interview II
Participant I9	Head of Sales, Project Logistics in a distribution company	Interview II
Participant I10	Head of Circular Economy and Sustainable Innovations at a home appliance manufacturer	Interviw II

2.3.1 Interview insights

2.3.1.1 A1. Researcher

Researcher A1 is an experienced civil engineer with a background as an HVAC consultant, currently engaged in the coordination of circular construction initiatives alongside their research endeavours. They emphasize several critical factors necessary for the effective implementation of reuse within the construction sector. A key point raised is the demand for high-quality, modular building products that facilitate successful reuse.

"The modularity and quality level [of building components] needs to be high if we are to succeed with reuse [in the industry]"

They also advocate for the construction of installations in layered configurations to enable ease of disassembly, thereby enhancing the potential for material recovery and reuse.

"Make it possible to disassemble installations by, for example, building in layers."

Additionally, they mention that current Detailed Development Plans (DDPs) in Sweden are not adapted to the new thinking on reuse. Planned areas are described in such detail, in regards to materials and aesthetics, that it leaves no room for used products that deviate from the descriptions.

"I would like to do more research on the role of Detailed Development Plans in the circular [economy]...They are not adapted to the new thinking around reuse."

A notable quote from A1 is their comment on reuse and circularity:

"In the industry, one now thinks that reuse should work , but what happens next time a component is going to be reused? It has to be able to continue indefinitely, otherwise it isn't really circularity."

They also highlight the importance of accountability for reused products and propose that the manufacturer should bear the primary responsibility for them.

"Both the product owners and the building owners want the building components dismantled, but no one wants to do the work...Who takes responsibility for products and their reuse? It should be the producer's responsibility."

2.3.1.2 A2. Architect and Researcher

Besides their work as a researcher, A2 has worked as an architect for 14 years and as a professor for 7 years. They highlight the need for instructions on assembling and disassembling building products, thereby simplifying the practical aspects of the reuse process.

"There should be a tool that creates an instruction for how to assemble and disassemble."

They also note the current gaps in integrating reuse during the early stages of design and the lack of guidelines on how to achieve this.

"What is missing is a connection between reuse and the early [design] stages."

They believe that it is crucial to maintain an open system of digital tools that is accessible, thereby facilitating seamless collaboration among various software and reuse marketplaces. In a conversation regarding modularity and reuse, they said:

"A brick is a small building component that is very flexible and allows for creative design. It can be risky to commit to larger components."

2.3.1.3 A3. Researcher and Professor

A3 is a senior researcher in sustainable building and circularity. In their work they collaborate across multiple municipalities and industries to help build and coordinate research networks on circularity in cities. A3 says that new construction isn't necessarily the most economical option and that renovations can create more jobs.

"With renovation work, job opportunities are created...It is not correct that building new is best from an economic point of view."

They also mention the circular-economy metric Material Input per Service unit (MIPS) (i.e. the material required to deliver one unit of service) as a helpful lens for shaping a reuse business model.

2.3.1.4 C1. Architect

Architect C1 is a sustainability specialist, working with circularity in the industry for more than 30 years. Regarding the environmental benefit of reuse, they bring up the importance of preserving a building's load-bearing structure, which usually has a high EC:

"The building structure is one of the most important parts to preserve, not just the old aesthetically pleasing windows."

Meanwhile they mention that it is important to be able to build beautiful buildings that are resilient and can be kept in good condition for a long period. They propose that building product manufacturers should drive the reuse market because of their extensive knowledge of their building materials:

"The building material industry must tackle [the reuse market] challenge. The experts should do this, they know their material."

2.3.1.5 C2. Environmental Consultant

C2 is an environmental consultant with experience working with reused building materials and re-framing the thinking around reuse in business. They recommend prioritising commonly used and easily reusable materials for the reuse inventory, and emphasise the importance of quality assurance before a building product is reused.

"[Ask yourself]: which materials are used the most?"

In their ongoing work with reuse they were part of organising the creation of an internal reuse hub for a construction company. They explain that the motivation behind this is the benefit of having a stock of reusable material at one's disposal, instead of having to search for external material for each new project.

"Start building up the inventory of reusable material before there is an end costumer - what materials might be needed? One can't just focus on delivering for one 'end costumer'"

C2 also argue that precision around the definition and requirements of reuse is important, and suggests that a large barrier to increased circularity is the lack of specification for reuse in procurement documents.

2.3.1.6 C3. Project manager

Project manager C3 has worked and conducted research in building services engineering. They say that, if possible, preserving a building's structure is important for shortening the reuse process and thereby reducing costs.

"Preserving the building structure can save a lot of time, and therefore also money."

According to C3, many building products are easier to reuse if they are disassembled and cut into standard dimensions. For example:

"When [installations] are disassembled, do it (cut them) in standard dimensions so that it's easier to reuse later."

For reuse practices to grow, they think there needs to be a shift away from the current reliance on buyer–seller matchmaking in the reuse market. They also add that:

"It is important to find [the right] business models... What needs to happen is that reuse is no longer be self organised. It is preferable for customers not to have to visit several places [to find material]."

Additionally they mention green loans as a tool that could help lower the cost of capital for reuse initiatives.

"Green loans could be a way to finance reuse."

Another way to reduce costs, according to C3, is to use wholesalers' existing logistics system to distribute reclaimed materials alongside regular deliveries.

"The wholesaler could drive back used material after they have delivered [new or reusable] material to the building site."

2.3.1.7 C4. Architect

C4 has worked for several years as an architect. They suggest that digitally storing information on the building product and keeping it up to date can simplify the reuse process. C4 articulate this by saying:

"I encourage the use of 'True BIM'. If you work in BIM, you can follow the building throughout its entire life cycle."

However, they stress that there is a need for better coordination between the different software used in the industry.

2.3.1.8 C5. Architect and reuse specialist

C5 has worked as an architect and reuse specialist for over three years. C5 highlights strategies that facilitate reuse, noting that the assembly type affects recovery potential, with prefabricated components being easier to disassemble.

"The more prefab [is used], the easier it will be to disassemble."

They also observe that the type of connection significantly influences reuse outcomes:

"When it comes to design for disassembly, using mechanical connections plays an important part. For example, instead of glue, prescribe screws or glue that is easy to remove."

Furthermore, C5 highlighted that irrespective of how effectively a design accommodates reuse, evolving technical requirements as well as newly implemented fire and acoustics standards can render building products unsuitable for reuse.

"Today, there are new standards compared with just five years ago, for example, new fire-safety and acoustic requirements.[. . .]No matter how much you plan for reuse, you don't know what requirements will be in place in the future."

C5 notes that effective reuse in the building sector hinges on strong business models:

"Working with the product development of waste is important - the so called 'productification of waste' (produktifieringen av avfall), which is an expression coined by Sweco."

2.3.1.9 C6. Reuse consultancy firm

C6 works at a reuse consultancy firm and confirms that:

"Recycling materials has a higher environmental impact and cost than reusing"

They note the importance of ensuring that reusing building products provides both economic and environmental value:

"[Regarding] inventory methods, [first] check if there is an economic or environmental value"

Furthermore, C6 emphasises that handling costs contribute substantially to the overall expenses involved in the reuse process and that it is important to choose the right product to reuse:

"Used [building products] are never more expensive than new if you choose the right things to reuse![. . .] The value of reused items is often low on the reuse market [. . .] It's too cheap to buy new installations, which makes reuse too expensive."

C6 adds that it's important that there is a demand for the reused product and that, based on their experience, some items are reusable only internally within real estate companies, while others can enter external markets.

"The value of used material in the market is often low"

C6 also notes that new regulations and technical requirements can hinder the reuse of building products, such as elevators. On the topic of of modular buildings, they say that while it can be environmentally beneficial to move a building if the alternative is demolition, finding suitable locations where the local detail plan permits the particular use, dimensions and aesthetics of the used modular building is challenging. C6 suggests increasing demolition and waste costs to improve project economics by promoting reuse and recovery. They also proposes economic incentives to stimulate the market demand for used products.

"It is [for example] too cheap to buy new installations, which makes them too expensive to reuse."

2.3.1.10 C7. Reuse Consultancy firm

C7 owns a reuse consultancy firm and says that the reuse process is generally costly and that there is no guarantee that the used products will be sold after recovery. They point out that:

"The matter of storage is problematic. [While] it's easy to fill a storage space for used material, emptying it is far more challenging [...] Retrieved building products are kept no longer than three months [by the firm] before being considered unprofitable."

Furthermore, they criticise many current reuse marketplaces for not being user friendly enough. C7 suggest establishing multiple reuse hubs instead of depending solely on traditional building material retailers.

"I believe that [establishing] more reuse hubs could replace the standard building material retailers."

They also note that when examining the financial aspects of reuse, it is important to consider the costs associated with disassembly:

"The disassembly costs money [...] We are paid by the real estate owner to perform the disassembly, but afterwards we buy (back) what we consider to be reusable components. The total cost is therefore [usually] plus-minus zero, ±0 [...] What

remains are logistical costs."

C7 point out that the ratio of reusable products in a building often depends on the building type and age - older buildings are usually easier to disassemble and almost all building products can be reused, as opposed to modern buildings where many different materials are often glued together or otherwise irreversibly integrated.

"How much can be reused depends on the type and age of the building [...] Older buildings are easier to disassemble [and] it is possible to reuse almost everything."

C7 says that there is a risk of damaging the building products when they are moved and talks about the differences in handling possibilities for different building materials or components:

"When it comes to for example, gypsum boards. the focus is on-site reuse at the same location because they are fragile therefore difficult to move without causing damage [...] It is [in general] easy to damage components during recovery."

2.3.1.11 C8. Reuse hub/service provider

C8 works at a reuse hub and collaborates with partners in the construction industry to provide support throughout the reuse process. They note that how building components are fitted together greatly influences their potential for reuse.

"How a material is installed greatly affects its future potential for reuse."

C8 explains that:

"[We] work in accordance with industry standards and product performance requirements in order to ensure product quality."

When it comes to what kind of building product they prioritise for reuse, they say:

"[We] want to focus on collecting and reusing [products with high climate impact per unit of weight]."

C8 adds that:

"[We] are still looking for a more sustainable business model to attain better financial results."

2.3.1.12 G1. Project Manager

G1 works as a project manager and has experience running reuse projects in the building industry. Speaking of a past project in which they goal was to reuse structural elements, G1 states:

"[It is] hard to know whether the product is safe to reuse, the manufacturer was engaged because they want someone knowledgeable to assess [the glulam beams]. The property owners want to involve the material manufacturers to ensure quality."

They also mention a project run at Chalmers University of Technology titled *CREATE*, in which a tool ("CREATE tool") was developed.

"In the project 'Create' buildings are considered material banks. The aim is to map what materials we have available in our cities, and to be able to predict what types and amount of material will be made available when a building is scheduled for demolition."

2.3.1.13 G2. Project Manager

G2 is a strategy manager for circular construction at the city property management and part of *Klimatgruppen* (The climate group), which has the aim to support the industry transition from a linear to a circular economy. They explain that the primary aim should be to preserve what is already there and to prioritise the repairability of buildings.

"While the whole building does not necessarily need to have an extended service life, its components should be easy to replace."

G2 adds that:

"To preserve is the highest priority, but if something needs to be disassembled it's better to do it in larger parts."

However, G2 gives an example of a case study in which they attempted to repurpose a modular preschool, stating that:

"The designer [of the modular preschool] had planned to reuse it at the modular level, but it turned out not to be possible [...] There was no demand nor site to move it to."

G2 adds that this case study shows the importance of long-term planning to ensure circularity.

2.3.1.14 I1. Project Manager

Project manager I1 is working on a project that is ambitious with its utilisation of used building products.

"In [an ongoing reuse project] the [developer] is demanding that the project does not emit more than 280 tons of CO2."

They emphasise that the reuse market needs to grow and improve to allow for large scale reuse, and the market actors need to understand what materials are available:

"To make it possible to work on a large scale [with reuse], better and faster access to used products is needed[...] A good learning process for the whole industry is to really understand what materials are available in a building."

Regarding how to make the reuse of building products easier in general, they suggest that:

"[Research should focus more on] flexibility and modularity at an appropriate scale."

I1 notes that heavier structural materials are more interesting to reuse from an environmental perspective:

"The [building] structure has the highest environmental impact [...] Heavier materials are the most interesting from an environmental point of view."

2.3.1.15 I2. CEO of a building product manufacturing company

I2 has been the CEO of a product manufacturing company for more than 15 years. I2 says that today:

"There is a lot of discussion around resource use [...] There are only x amount of resources."

They stress that a successful circular business model requires knowledge on which materials can be circulated and reused more effectively. They add that the amount of the building product circulating in the industry matters and that:

"[A] large-scale system must be created, with quick sorting, cleaning and quality control."

They also emphasise the importance of initially testing and validating the business model within a targeted niche before expanding to additional materials and services.

"Reuse hubs are too small-scale [...] there is no market for private reuse, it's too small-scale [...] A market begins with a niche, starting with something small and later expand."

I2 mentions bricks as a good example of a building product to test this reuse model. This is mainly because used bricks can be CE-marked and quality-assured. However, when it comes to disassembly of brick walls the type of mortar used plays a role for reusability.

"Swedish mortar that is cement based is hard to disassemble, [whereas] the Danish [limestone] mortar is easier to take apart."

When it comes to reusing existing building stock, I2 urges us to:

"Take care of [the] heavy concrete structures that [we] already have."

2.3.1.16 I3. Research and Innovation Coordinator

I3 is a researcher and innovations coordinator at a construction company with experience related to the financing of circular projects. I3 points out that there needs to first be a quality check of the building product before refurbishing it.

"Some building components can be quality assured on-site, others need to be sent away [to another location]."

Besides that, it is also important to consider the remaining service life of the products and the price of an equivalent new one before deciding to reuse a building product.

"Some products, such as used bricks, can be compared with a 'premium product' [...] It is important to ask yourself: 'what would be costly if you bought it new, and is there a lot of life left in the building product?'"

I3 also says that:

"[I] don't believe in peer-to-peer [business], but in some type of intermediator."

2.3.1.17 I4. Property manager

I4 has several years of experience working as a property manager. I4 states that:

"The time required to demolish [a building] is very different from that required for careful disassembly"

They also explain that it takes too long to find reusable material:

"Today there is a lack of labelling of reusable goods, and it [therefore] takes too long to find material."

Regarding the type of building product that has higher reuse potential, I4 mentions indoor products such as doors, kitchen, toilets, etc. that have a higher level of modularity and exchangeability.

"Create better conditions for reuse - more modularity!"

I4 remarks that some products, such as windows, are today harder to reuse due to their custom-made dimensions.

"In the past windows [tended to be] manufactured according to standard dimensions. Today they are custom-made because the price difference is not very large, but that makes reuse harder."

In regards to the the reuse process and extra costs of reuse, I4 states that:

"We should come up with new market systems that are as simple and streamlined as the current [construction] system. You can't always keep doing reuse projects with 'extra resources' just to make it work."

2.3.1.18 I5. Team leader in a building product manufacturing company

I5 states that in their company they are currently piloting circular strategies with a service-based offering: a long-term service contract based on an expected 20-year product life.

"We would like to offer a 'reuse service' with a 25 year contract [...] It is unlikely that [we] will buy back [our] products, however, we can offer free take-back."

The idea is to handle maintenance rather than doing one-off sales. They also mention they have no plan to buy products back, but they're open to taking returns at no cost and bundling a deal on replacements. I5 believes that Environmental Product Declarations are important for the advancement of the circular economy:

"It's only when the use of EPDs is established that reuse will get going."

They also mention that the function of a product can affect its reusability, giving an example:

"Porcelain itself has no mechanics, so it is fairly easy to reuse [compared to active components]."

2.3.1.19 I6. Construction and civil engineering company

I6 works at a construction company that has been involved in projects focusing on reuse of building materials.

"It is important to gather large enough amounts of material for large-scale reuse."

They find some items easier to transport than others and say they have the most experience in reusing bricks. Regarding quality assurance they comment that:

"Quality assurance is best performed by manufacturers if, for example, [the component] is load-bearing."

I6 expresses criticism of modular buildings due to the increased material use compared to traditional construction. They argue that simply having a shorter construction time on site is not a sufficient reason to choose a modular design, they say:

"The major disadvantage of modular construction is the large amount of extra material (double walls) and many joints[...] Perhaps it is more important to save material than to build faster."

2.3.1.20 I7. CTO and head of projects in a company focused on prefabricated modules

I7 started working with modular construction many years ago, mostly providing for medical care, pharmaceutical factories and data centres. They highlights the advantage of modular buildings, noting that besides the faster construction time they also allow for an entire building to be relocated if needed, stating:

"Now the advantage of modularity is starting to be understood in Sweden. If you build modularly, you can then move the whole building [if needed]."

When describing their reuse business model, they say that:

"[We] offer both leasing and selling of our modules"

2.3.1.21 I8. Demolition and remediation contractor

I8 has been involved in demolition work for over 22 years. In regards to the disassembly of buildings they say that it's challenging:

"Much has to be taken down by hand [rather than mechanically]. [Resulting in] more steps, more physical work and more logistics which make it more expensive [...] In Sweden, labour hours are more expensive which is why it's especially challenging here."

"[Either] it takes a long time to disassemble, which makes it costly, or [a product] is fastened in a way that makes it impossible [to do it]."

I8 points out that reusing building products like windows and doors is not easy due to the need to match their acoustic and fire properties with current demands.

"To meet [today's] sound and fire regulations is hard. That usually makes it problematic to reuse [for example] doors and windows."

I8 also underline that a strong understanding of structural components is needed to ensure safe reuse of these building products.

2.3.1.22 I9. Head of Sales, Project Logistics in a retail and distribution company

I9 is head of sales in a large retail and distribution company and they agree that many actors working with reuse experience issues with logistics.

"One is very dependent on one another. Everyone has to get in there and take risks"

I9 explains that because of pressure from society they and other companies have started working more with reuse. They are now trying to acquire experience working with basic reuse flows and different business models. They note that economic profit is closely related to the quality of building products for reuse:

"You have to put in something of value to get value back."

I9 adds that determining product ownership is a common issue in reuse, with different business models under discussion.

“Who owns the product [in the value chain]? [...] How will the supplier make money? Everyone [in the value chain] has to gain something”

2.3.1.23 I10. Head of Circular Economy and Sustainable Innovations at home appliance manufacturer

I10 explains that they worked extensively with developing their products to be more sustainable. First and foremost this includes efforts to make them more repairable and modular. I10 also addresses the complexity of determining or assigning a lifespan to a product, saying:

"No data makes sense when it comes to lifespan and reusability of specific products. Compare it with cars, how long is a car considered usable, for example?"

2.3.2 Parameter strengthening and inputs

Below, in table 2.4, the parameters that were mentioned in the interviews as relevant for evaluating reuse potential are listed. Relevant connected parameters, *parameter inputs*, that influence another parameter are also listed.

Table 2.4: Parameter strengthening and inputs from interviews

Parameter	Mentioned by	Parameter input	Mentioned by
Environmental impact	C6, I1	Weight	I1
		Raw materials with limited availability	I2
Embodied Carbon	C8, I5		
Economic profit	C6	Value of eq. new product	C6, I3
		Quality and Life expectancy	I9
		Costs	C7
Costs	C6	Handling possibilities	C6, I8
		Time of reuse process	C3, C7, I8
Quality and Life expectancy	A1, C2, C7, G1, I3, I10		
Technical feasibility	A1, C6	Technical properties	C5, I8
		Function	C6
		Dimensions	C6
		Quality and Life expectancy	C8
		Assembly type	G2
Recovery potential	C7	Assembly type	C5
Disassembly potential	C6, C7	Level of product information	A2
		Connection access	A1
		Crossings	A1
		Connection	C8, I8
Handling possibilities	C7	Material	C7
Assembly type	A1, I4, I6, I7		
Material	C2		
Function	C1, C7, I4, I5		

Interview insight of parameter inputs

Parameter	Mentioned by	Parameter input	Mentioned by
Dimensions	A2, C3, G2, I1, I4		
Part of large product	I2, I6		
Weight	I2		
Market readiness	C1, C3, C7, I1, I4		
Market demand (internal or external)	C6	Economic aspects	I4
		Technical feasibility	I4
Potential for reuse multiple times	A1, G2	Material	C7, I2
Raw materials with limited availability		Material	I2
Time of reuse process	C6, C7, I2, I4	Level of product information	I4
Connections	C5, I2		
Level of product information	A2, C4, G1, I1		
Business models	A1, A3, C3, C3, C5, C6, C7, C8, I2, I3, I5, I6, I7, I9		

2.4 Network graph of reuse evaluation parameters

The reuse evaluation parameters mentioned in the literature, as well as the parameter inputs (connections between parameters) mentioned in the literature and interviews, together form a complex network of relationships. An analysis of this network could give a deeper understanding of the hierarchical structure of the parameters, and ways of evaluating them.

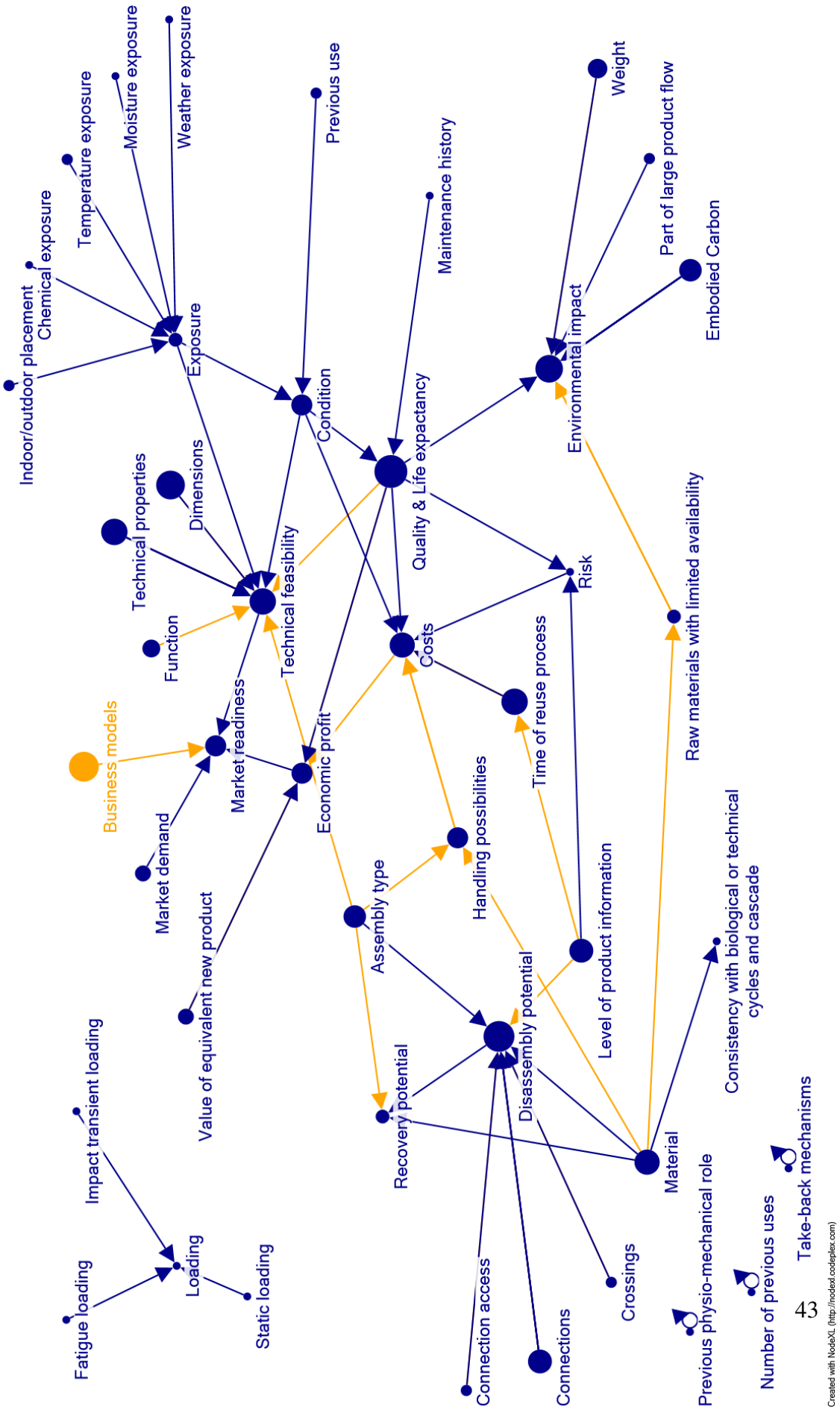


Figure 2.1: Network graph of reuse evaluation parameters

2.4.1 Network graph analysis

The complex network formed by the parameters and their connections can be seen in the network graph in figure 2.1. Important characteristics of the network graph include:

- The network is *directed*, meaning that the parameter that has an arrow pointing towards it is affected by the parameter that the arrow is pointing from. For example, as can be observed in the graph, *Environmental impact* is influenced by/dependent on *Embodied Carbon*.
- The size of the parameters, represented as nodes, is proportional to how many times is has been mentioned in the studies and interviews.
- Some nodes, such as *Recovery potential* is a so called "sink-node", which only has inputs and no outputs. This is a probable sign of special significance.
- A few nodes are not connected to any other node, but only to themselves in a so called "self-loop". These parameters were not mentioned as having any input or being an input to another parameter. This fact does not directly mean that they are not significant, and it might be a result of connections not having been mentioned explicitly.

Note that the yellow links (arrows) in the graph were only mentioned by interviewees and not found in the included literature.

In figure 2.2 the nodes with the most mentions (>5) can be seen. Below, in figure 2.3, the nodes with an in-degree ≥ 3 can be seen, meaning that their number of parameter inputs/parameters that affect them is equal to or greater than three. In contrast, figure 2.4 shows the nodes with the highest out-degree (≥ 3), meaning that the number of parameters that they affect is equal to or greater than three.

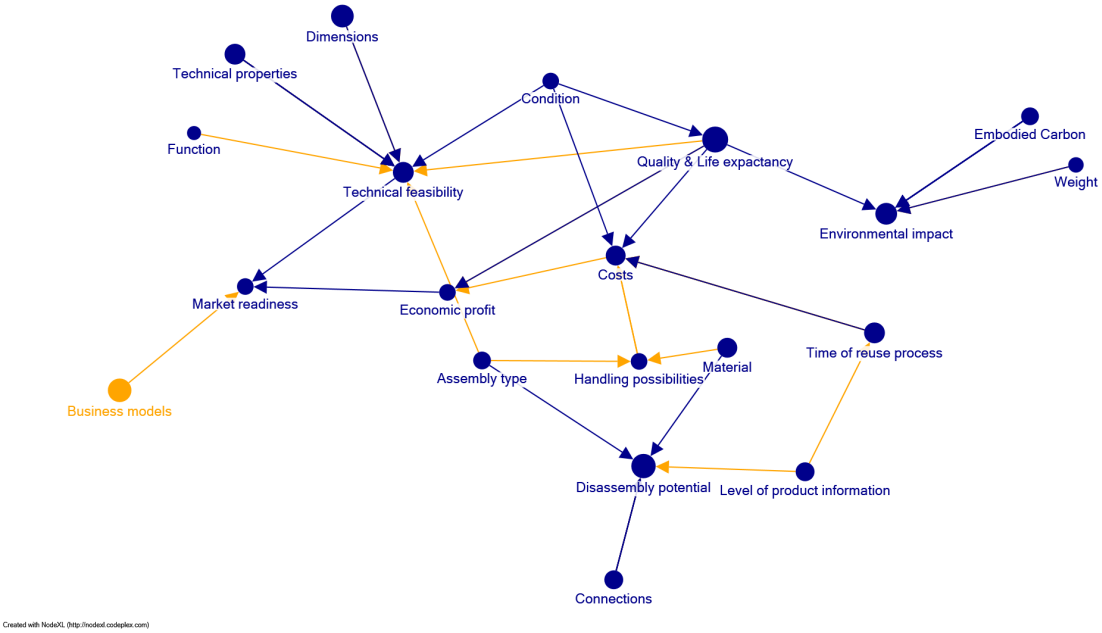


Figure 2.2: Node size (number of times mentioned) equal or larger than 5

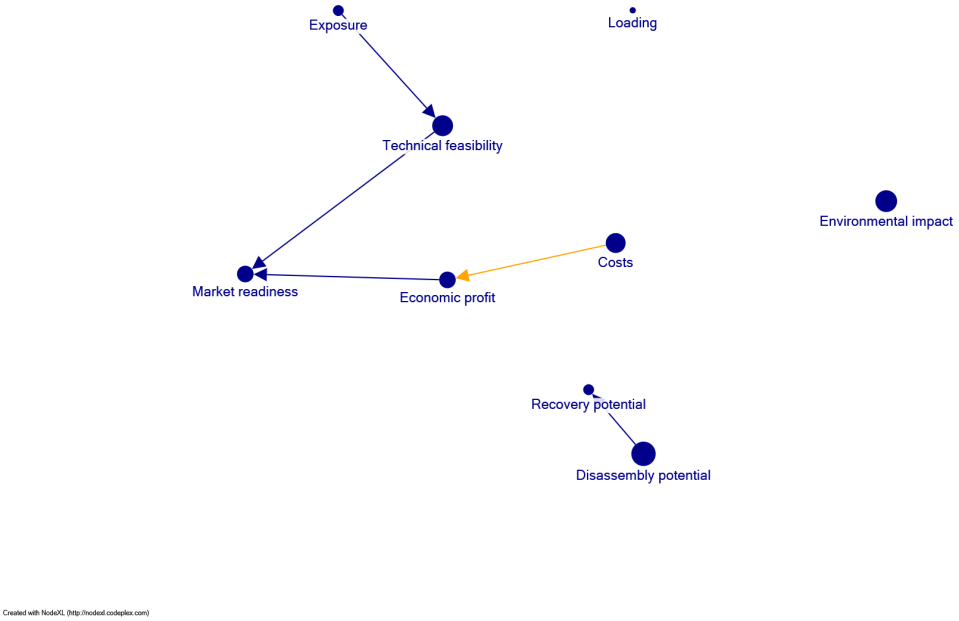


Figure 2.3: Input (in-degree) equal to or greater than 3

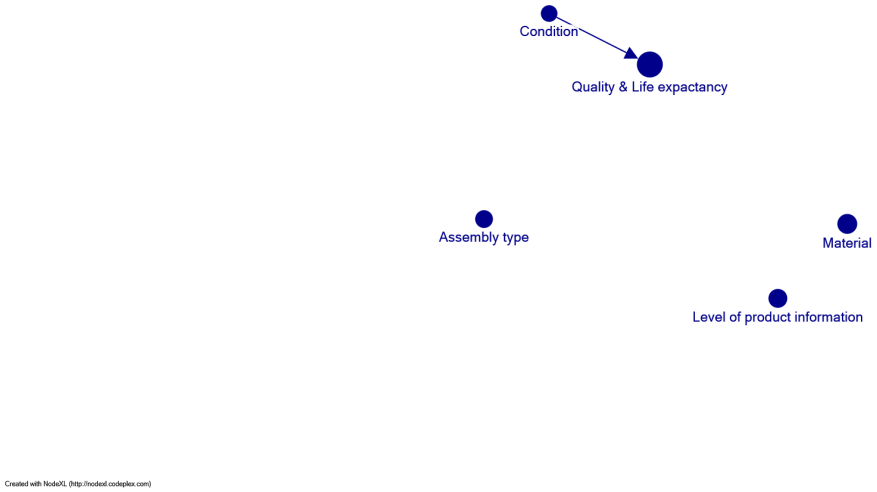


Figure 2.4: Output (out-degree) equal to or greater than 3

2.5 Gaps in existing research

While the barriers and drivers of reuse are relatively well known and there are many proposals for what parameters to take into account when evaluating the reuse potential of used building elements, there are few examples of well-defined and easily applicable methods or frameworks for reuse evaluation that are decoupled from a receiving project and result in a reuse potential.

Out of the studied evaluation methods, the reusability matrix from Bellini et al. [2024] is arguably the most clear to follow, but it is dependent on project-specific information regarding the receiving project/-s. In their case study they could not acquire evaluation results at an early stage due to insufficient information. In contrast the suggested methods from Lindborg et al. [2024], Sveriges Kommuner och Regioner (SKR) [2024], Janson et al. [2022], White [2021] and Karin Hedén [2022] are decoupled from project-specific information, however, the definitions and grading methods of the parameters are vague. The evaluation methods from Iacovidou and Purnell [2016] and Linus Brander [2021] are specifically focused on structural components and technical aspects, making their scope narrow. Similarly, the methods from Sandra Moberg [2022], Abu-Ghaida et al. [2024], Business Region Göteborg [2025] and Yang et al. [2025] are focused on one specific aspect of reuse and can not be used to acquire holistic results. Lastly, Geldermans [2016]

and Fastighetsägarna Stockholm [2024] provide parameters that are well defined, but no detailed guidance on how to grade them.

Comparing the suggested parameters from the literature review with the barriers and drivers mentioned by stakeholders in section 1.1.2, we can see that most of the barriers/-drivers are either Non-product specific (NPS), i.e. apply to all products equally, or Out Of Scope (OOS) of this thesis, see table 2.5. The barriers/drivers relevant for this study include *High cost of reuse*, *Low cost of new material*, *Circular design* (*Connections, Connection access, Crossings, Assembly type, Material*), *Lack of quality assurance*,*Low market demand* and *Circular business models*. Most of these can be found in the studied evaluation methods of the literature review, in the same words or in variations, as described in the table. The existence of *Circular business models* for specific building products is not mentioned as a parameter, except by Yang et al. [2025] in the form of *Take-back scheme* for modular products. We consider this to be a gap in the current evaluation methods, as this parameter is mentioned in other literature on reuse as well as in the conducted interviews of this thesis, and as the existence of a circular business model for a specific product type could greatly increase the reuse potential of that product.

Table 2.5: Comparison with barriers and drivers

Barrier/Driver	Mentioned parameter
High cost of reuse	Mentioned as *Economic aspects*
Low cost of new material	Mentioned as *Value of equivalent new product*
Increased economic incentives	[NPS]
Extended producer responsibility	[OOS]
Stricter public procurement requirements	[OOS]
Circular design	Mentioned as *Connections, Connection access, Crossings, Assembly type* and *Material*
New project management methods	[NPS]
Standardised reuse processes	[NPS]
New/changed roles	[NPS]
More digitalisation	[NPS]

Continued on next page

Barrier/Driver	Mentioned parameter
Lack of quality assurance	Mentioned as *Level of product information, Risk, Quality & Life expectancy* and *Technical feasibility*
Lack of logistics and storage solutions	[OOS]
Low market demand	Mentioned as *Market demand*, *Market maturity*
Lack of specifications for reuse	[OOS]
Circular business models	Mentioned as *Take-back schemes*

Non-Product Specific (NPS), Out Of Scope (OOS)

To conclude, the following gaps have been observed after conducting a literature review on the reuse evaluation of building products.

The Reuse evaluation methods lack:

- Clear definitions for many parameters
- Applicable grading methods
- Sufficient suggestion on how to aggregate the grades of all parameters into a final decision-supporting score
- Inclusion of *Circular business models* as an important parameter.

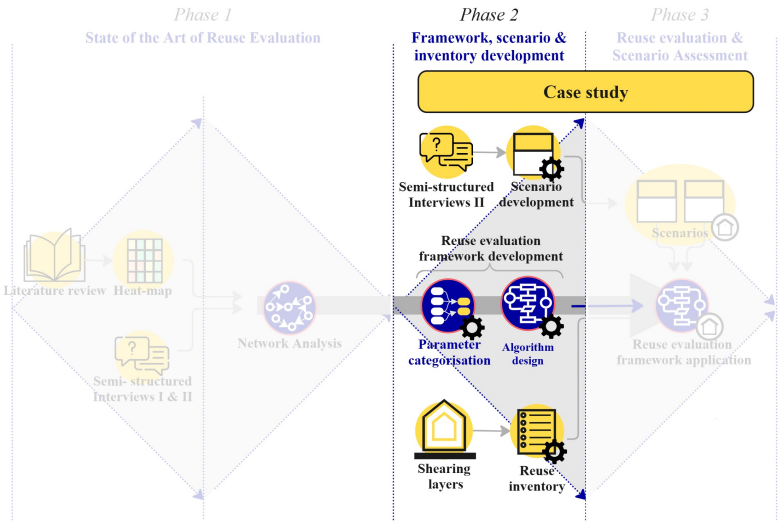
2.6 Positioning of this study

Drawing upon the identified research gaps and our synthesis of proposed reuse evaluation parameters, in the form of the reuse parameter heat-map (see table 2.2), and the network graph (see figure 2.1), the aim of the next part of this thesis becomes to formulate a well defined and practically applicable framework for reuse - a *Reuse evaluation framework*. It should be applicable to projects in their preliminary evaluation phase and be decoupled from the requirements of a receiving project.

The focus of this thesis is on developing a method for grading building products that can be aggregated into a single score which represents its reuse potential. Furthermore, it includes the application of the method on the case study of the thesis, enabling a comparison of the reuse potential in the two reuse scenarios.

3

Framework, scenario & inventory development



3.1 RQ 1. How can a preliminary evaluation of reuse potential be structured, and what parameters should be considered?

With knowledge gained from the conducted literature review and interviews, a foundation has been made on which to develop a first iteration of a *Reuse evaluation framework*. The

framework is meant to be applicable to all types of building products, except furniture and other lose items (*Stuff*). It is meant to be used for making a preliminary decision on what products in a building have a high potential for reuse when conducting a reuse project without any known receiving projects. The reuse evaluation should be followed by a deeper environmental impact assessment, for example an LCA, and a cost assessment, for example through Life Cycle Costing (LCC), in order to build a better foundation on which to make a final decision. However, we believe that in order to conduct an LCA or LCC a first estimate of the reuse potential of the inventoried building products needs to be made. In this chapter we suggest how such an estimate could be made by studying building products' properties and by utilising a grading system that relate the properties to reuse criteria. The parameters have been retrieved from the literature review and strengthened by interviews presented in the previous chapter. Some modifications have been made to the structure of the connections between the parameters, which is motivated and described in detail in the following section.

3.1.1 Categorising the proposed reuse evaluation parameters

To begin with the proposed reuse evaluation parameters have been divided into five different categories to gain a better overview of their different characteristics, from left to right:

- Product History
- Product Properties
- Reuse Process
- Reuse Indicators
- Key Reuse Criteria

The *Product History*, which is the previous use and exposure of the product, affects the *Product properties*, which include innate properties (such as material and function) and the current condition (such as quality & life expectancy). The *Product properties* in turn affect the *Reuse process*, which include time and handling, the *Reuse Indicators*, which involve more abstract parameters such as costs and risk, and finally the *Key Reuse Criteria*, which are the key parameters used to assess reuse potential, see figure 3.1.

The rightmost parameters, *Key Reuse Criteria*, represent the "sink nodes", as identified through the network analysis. These are selected as the key criteria on which to base the reuse evaluation. They include *Recovery potential*, *Environmental impact* and *Market readiness*.

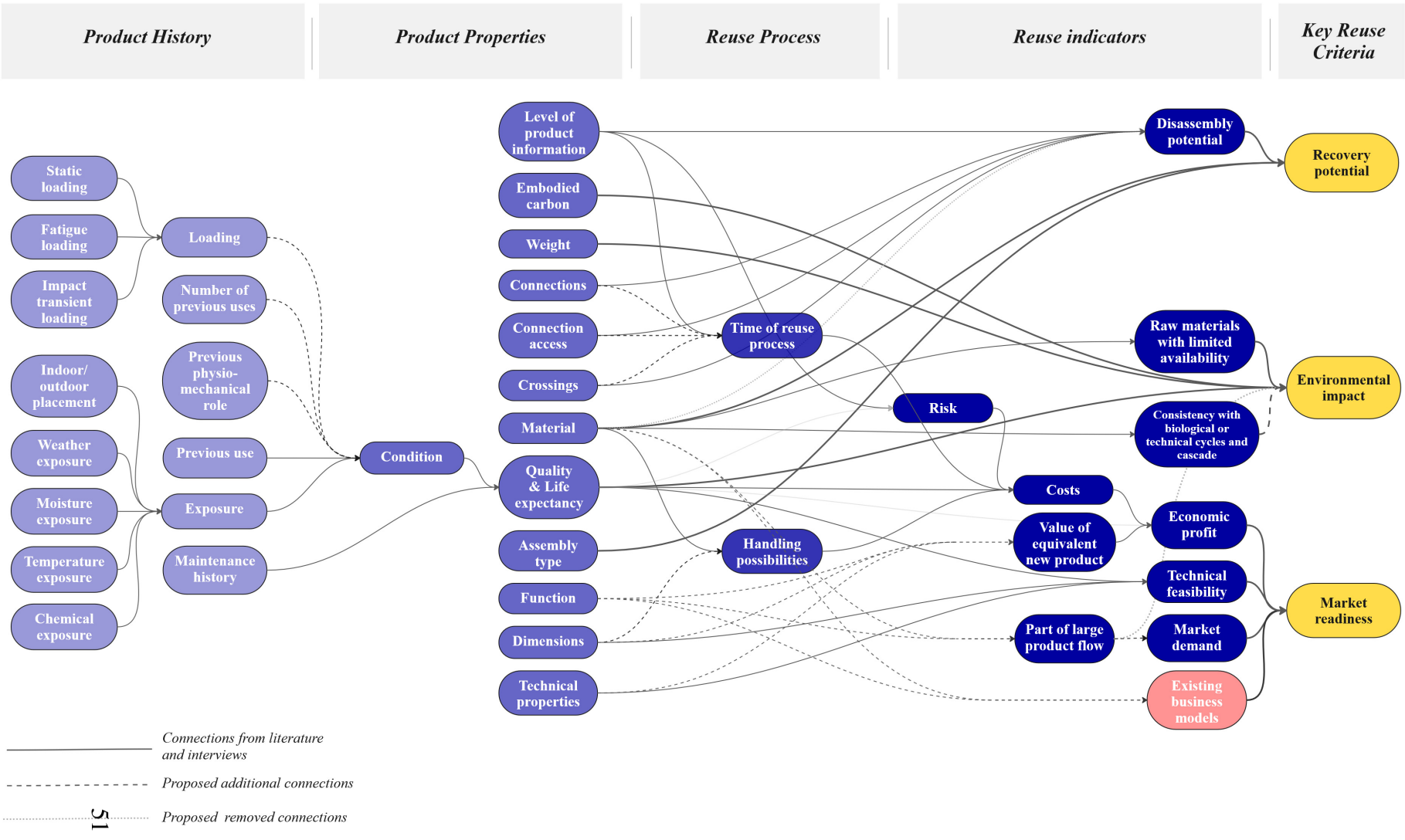


Figure 3.1: Categorisation of reuse evaluation parameters

3.1.1.1 Simplifications and adjustments

Changes that have been made to the parameter connections include:

- Removing connections going directly between *Product History* and *Time or reuse process/Reuse Criteria*, as these should be linked only through the *Product properties*. We base this on the reasoning that unless the history of a product affect its properties, it is irrelevant to its reuse potential.
- The connection suggested by Sandra Moberg [2022] between *Part of large product flow –> Environmental impact* has been changed to *Part of large product flow –> Market demand*, as the reasoning of the authors is that if the market demand of the product is high, there is a greater practical chance at reuse, leading to more avoided emissions. In order to differentiate the different criteria in a meaningful way, *Environmental impact* should mainly be concerned with the theoretical potential for avoided impacts, and not practical aspects.
- The connection between *Quality & Life expectancy* and *Risk*, as suggested by Bellini et al. [2024], has been removed, as any risk related to uncertainty in performance is assumed to be evaluated through the parameter *Level of product information*, in which the degree of uncertainty is evaluated.
- The parameters *Loading*, *Previous physio-mechanical role*, and *Number of previous uses* (mentioned by Iacovidou and Purnell [2016] as especially relevant for structural components) have been connected to the parameter *Condition*, as they are assumed to have a potential affect on the condition of a building product.
- The parameters *Connections*, *Connection access* and *Crossings* (mentioned by Abu-Ghaida et al. [2024] and others), have been connected to *Time of reuse process*. It is assumed that a product that is harder to disassemble adds to the time of disassembly.
- The parameter *Dimensions* have been connected to *Handling possibilities*, as it is assumed that the larger the size of a building product, the more difficult it is to handle.
- The parameters *Function*, *Dimensions* and *Technical properties*, have been connected to the parameter *Value of equivalent new product*. This is based on the assumption that it is primarily the functional role, dimensions and technical performance of a product that are compared when determining the value of an equivalent new product.
- The parameters *Material* and *Function* have been connected to *Part of large product flow*, as these are assumed to be the parameters determining whether a product belongs to a product type found in large volumes on the market.
- The connection between *Material* and *Disassembly potential* has been removed. Instead, *Material* is only connected directly to *Recovery potential*, to which *Disassembly potential* is also connected. This is to avoid double-counting the influence of material on *Recovery potential*, which would otherwise be represented both directly and indirectly via *Disassembly potential*.
- The connection between *Quality & Life expectancy* and *Economic profit* has been

removed, and only its connection to *Cost* is kept, as *Cost* is already connected to *Economic profit*. This is done to avoid double-counting its influence on economic profit.
- The parameter *Consistency with biological or technical cycles and cascade* has been connected to *Environmental impact*, as the choice of appropriate cycle and cascading strategy is assumed to influence the potential for avoided environmental impacts.
- The parameters *Material* and *Function* have been connected to *Existing business models*. This is based on the observation that existing reuse-related business models are typically developed for specific combinations of material and function, e.g. steel beams, clay bricks or porcelain sanitary ware.

3.1.2 Information on Product History

The history of a building product can have an effect on its current condition, quality and life expectancy. The properties, capacities, and expected service life as described in the original product documentation of a new product can have been altered by factors such as weather exposure, number of previous uses and performed maintenance. It is therefore important to study this information, if available, in conjunction with making visual inspections, if possible. The parameters in figure 3.2 are proposals from the literature review of important parameters related to the history of a building product. Some parameters are relevant only for structural components, such as *Loading*. Other parameters, such as *Maintenance history*, is especially relevant for products with a short life expectancy or active products. The *Product History* is not in itself graded or evaluated, but used as data to inform the (current) *Product Properties*

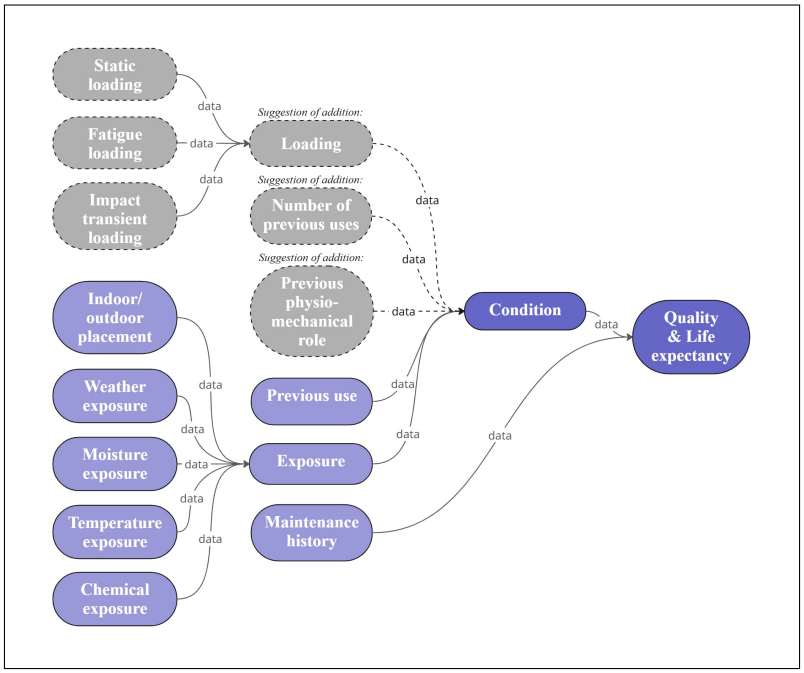


Figure 3.2: Product History parameters

3.1.3 Defining the product properties and grading system

In this section we attempt to define and suggest a grading method for each *Product property*. In the State of the Art analysis of the previous chapter, it was noted that most of the parameters relevant for reuse are poorly defined and lack clear grading methods. Using the studied literature and conducted interviews as a starting point, we attempt to derive what definitions could be proper and relevant, and how each product property could be graded in such a way that it connects well with subsequent parameters related to the *Reuse process*, *Reuse Indicators* and, ultimately, the *Key Reuse Criteria*. In certain cases the evaluation of some properties, such as *Function* and *Material* in relation to *Existing business models*, is interdependent and need to be evaluated jointly. In such cases, the description of the grading method can be found under the first of the interdependent properties.

To link the parameters in a correct and useful way, a common grading system for all parameters will be utilised is this study. Suggestions from literature include hard-easy, low-high, A-B-C, 1-5, 0-1, 0.1-1, etc., with the former ones being more simple/coarse, and the latter ones being more precise.

For example, in the paper by Abu-Ghaida et al. [2024] a grading system ranging from 0.1-1, with a step of one decimal point (0.1), is used. Their assessment enables assigning

a numerical value to parameters, by using fuzzy number logic. Fuzzy number logic is a way of modelling imprecise or vague quantities using real numbers. It acknowledges a degree of uncertainty between the completely true (1) and the completely false (0) [Delgado et al., 1994]. The score between 0 and 1 can be interpreted as a percentage from 0% to 100%. Due to the large uncertainties in a preliminary assessment, adding more precision with more decimal points would only provide a false sense of certainty. Abu-Ghaida et al. [2024] divide the grades into varying intervals depending on the nature of the parameter, e.g. {0.1, 0.4, 0.8, 1} or {0.1, 0.4, 1}, which allows for some freedom of translation. It is, however, unclear how the varying intervals were chosen in their cases as it was not motivated directly in the paper. Additionally a cut-off was made at 0.1 for all parameters related to *Disassembly potential*, to dismiss cases with unrealistically low potential.

In the paper by Bellini et al. [2024] a system of both 1-5 and 0 or 1, was used depending on the nature of the parameter. For example, *Environmental impact* was graded with the gradual increase from 1 to 5, whereas *Technical requirement* was graded based on if the requirements were fulfilled (1) or not (0).

Based on the literature we propose a flexible system that allows for both precision and imprecision through adjustment in grading intervals. For example, in a system ranging from 0-1, a precise evaluation could comprise 11 different grades: {0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1}. Whereas an imprecise evaluation (low-medium-high) could comprise three different grades, for example: {0.1, 0.5, 0.9}, by changing the interval between grades. In the case of imprecise evaluation, the two extremes 0 and 1 should be avoided to mirror the uncertainty of the evaluation. When evaluating parameters that include a criteria that needs to be fulfilled in order to allow for reuse, a binary grading of "Met" or Not met" can be given. This grade will determine whether or not the evaluation process can continue.

In regards to methods for aggregating the grades, few references were found. Abu-Ghaida et al. [2024] and White [2021] suggest using the average of the grades to acquire a final score, where Abu-Ghaida et al. [2024] uses a weighted average approach. In other literature references the aggregation methods are unclear or not discussed. In this study the average will be calculated using the arithmetic mean, giving equal importance to low and high grades. No weights will be assigned to individual product properties due to a lack of information on the relative importance of each property.

Grading system:

- Grading system total range: 0-1
- Minimum step: 0.1

- The amount of grading steps and their interval is based on the possible precision of the evaluation of each parameter
- For parameters that are evaluated based on whether they fulfil a criteria, a binary grading of "Met" or "Not met", or similar, is given.
- Aggregation method: arithmetic mean

Below we explore each *Product Property* in more detail and suggest a definition and grading method.

3.1.3.1 Level of product information

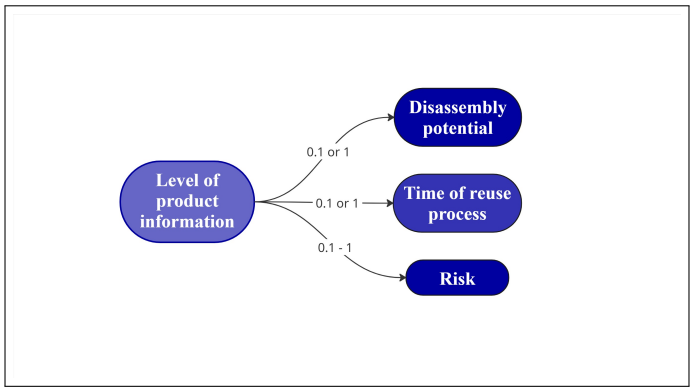


Figure 3.3: Parameter connections of Level of product information

Level of product information is mentioned as "Level of information and data" by Bellini et al. [2024], who describes it as affecting the level of *Risk* in a reuse project. It is also mentioned as "Level of product information" by Lindborg et al. [2024]. This parameter is not a product property per se, but rather assesses the level of available and attainable information on the product properties. Lack of information on used building products is a known barrier to reuse, and researchers and stakeholders emphasise the importance of an increased use of digital tools to record the history and current condition of a product. Interviewee I4 states that due to a lack of initial information the *Time of the reuse process* might be longer. Interviewee A2 adds that the *Disassembly potential* might increase if there was more available information in the form of precise instructions for the disassembly procedure.

Proposed definition

The level at which information on the history and properties of a building product is available.

Proposed grading

- In regards to *Disassembly potential*, if information on disassembly procedures is available grade 1 is given, if information is not available grade 0.1 is given.
- In regards to *Time of reuse process*, if all essential information on the product properties is available though documents and visual inspection, grade 1 is given. If some essential information necessitates expert consultation and/or further on-site tests, grade *0.1* is given.
- In regards to *Risk*, if all essential information on the product can be acquired during the inventory phase, grade 1 is given. If some essential information cannot be acquired until after disassembly, grade *0.2* is given. If some essential information cannot be acquired until after disassembly and need further off-site testing, grade *0.1* is given.

Table 3.1: Grading of Level of product information to Disassembly potential

1	0.1
Information on disassembly procedures is available.	No information on disassembly procedures is available.

Table 3.2: Grading of Level of product information to Time of reuse process

1	0.1
All essential information on the properties of the building product is available through documentation and visual inspection.	Some essential information is not readily available, necessitating expert consultation and/or further on-site tests.

Table 3.3: Grading Level of product information to Risk

1	0.2	0.1
All essential information on the building product can be acquired during the reuse inventory phase.	Some essential information can only be acquired after disassembly.	Some essential information can only be acquired after disassembly and necessitates further off-site testing.

3.1.3.2 Embodied carbon

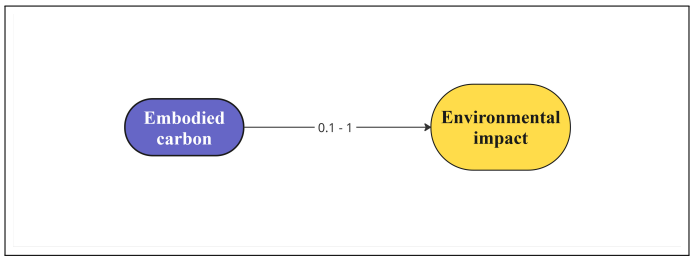


Figure 3.4: parameter connections of Embodied carbon

Embodied carbon is mentioned by Bellini et al. [2024], Lindborg et al. [2024], Janson et al. [2022], Sveriges Kommuner och Regioner (SKR) [2024], White [2021], Karin Hedén [2022], Fastighetsägarna Stockholm [2024] and Sandra Moberg [2022] as an important parameter to include when evaluating the *Environmental impact* of a building product. It is referred to as the "climate footprint of [an] equivalent new product", "reduced climate impact", "measure of carbon savings potential", etc. The Embodied Carbon (EC) can be acquired either through Environmental Product Declarations (EPDs) of equivalent new products or using a climate database. It is measured in [kg CO_2eq./unit], where the unit could be represented by a kilogram of the product, or by the total weight of the product.

While the definition of EC is known, no suggestion of what constitutes a high or a low EC has been proposed due to the relativity of the values. The grading could be based on the highest and lowest EC of the products present in the reuse project itself, or the spread of values between all types of building products used in the industry. There is as of now no correct or incorrect approach, however, the results will vary with the choice of grading method.

As the *Act on Climate Declarations* introduce stricter limit values for carbon emissions from the building life cycle, benchmarks with which to compare will emerge and could inform the grading of these properties. However, since the limit values will apply to whole buildings and not individual products, there will still be a need for knowing which products represent the greatest potential for avoided emissions.

Proposed definition

The amount of *Embodied Carbon* per kilogram [kg CO_2eq./kg].

Proposed grading

We suggest grading the *Embodied Carbon* of materials based on the distribution of values of building materials used in the industry. Climate databases such as *Boverkets Klimatdatabas* and *co2data - construction* from the *Finish Environment Institute*, can be used to find the EC of the most common building materials as well as some common components (such as doors, windows, studs, pipes, etc.). The spread of EC in *Boverkets Klimatdatabas* is around 0.06 - 10 [kg CO_2eq./kg].

For these parameters the grading method is quantitative, where the result is directly translated into a grade between 0.1 and 1 with a 0.1 step in between. See Appendix D for a more detailed explanation of the grading used in this thesis.

Table 3.4: Grading Embodied Carbon to Environmental impact

1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
10	2.7	2.00	1.28	0.65	0.40	0.24	0.19	0.16	≤ 0.12

3.1.3.3 Weight

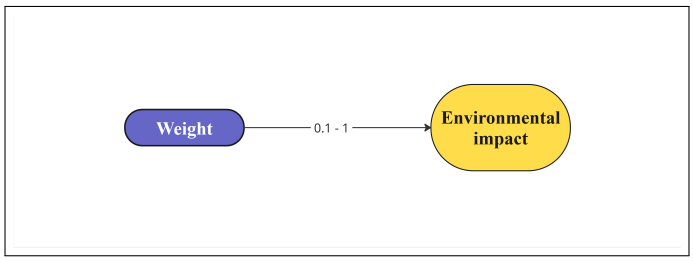


Figure 3.5: parameter connections of Weight

Weight is mentioned by Lindborg et al. [2024] and Sandra Moberg [2022] as an important parameter. Sandra Moberg [2022] and interviewee C1 (see section 2.3.1) connects it to *Environmental impact*. Interviewee C1 states that it is important to focus on heavy building products if the aim is to reduce emissions, as they contain high EC per volume due to their weight. One example is concrete elements, which have a low EC per kilogram, but high EC per volume.

Proposed definition

Weight per volume/square meters [kg/m^3] / [kg/m^2] or weight per building specific Gross Floor Area [kg/m^2 GFA].

Proposed grading

We suggest to chose from two alternatives of grading the parameter *Weight*. It can either be based on the distribution and frequency of values of building materials used in the industry. Climate databases such as *Boverkets Klimatdatabas* and *co2data - construction* from the *Finish Environment Institute*, can be used to find the weight of the most common building materials as well as some common components (such as doors, windows, studs, pipes, etc.).

The second alternative is that, if there is an inventory conducted for the building, you can compare the weight of the building's components and materials in relation to its Gross Floor Area (GFA) measured in kilograms per square meter (kg/m^2 GFA). This method allows for a more accurate comparison of the existing components within the building which is the reason this alternative was selected in this project. For these parameters the grading method is quantitative, where the result is directly translated into a grade between 0.1 and 1 with a 0.1 step in between. See Appendix D for a more detailed explanation of the grading used in this thesis.

Table 3.5: Weight to Environmental impact. Weight per building specific Gross Floor Area [kg/m^2 GFA]

1 - 0.1
Distribution of the weight per volume/square meters [kg/m^3] / [kg/m^2] or of building materials and components in the studied building per its specific gross floor area [kg/m^2 GFA].

3.1.3.4 Connections

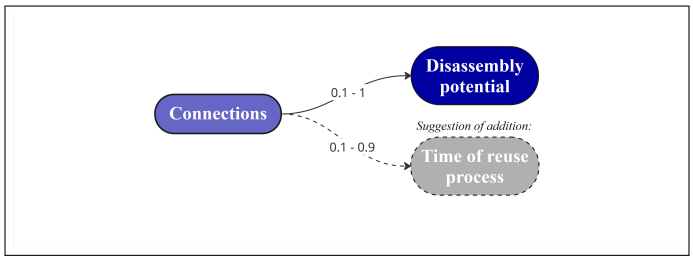


Figure 3.6: Parameter connections of Connections

Connections between building products is mentioned as an important parameter to include when assessing the *Disassembly potential*. It is highlighted by Iacovidou and Purnell [2016], Linus Brander [2021] (who focuses on structural components), Geldermans [2016], Abu-Ghaida et al. [2024] and Yang et al. [2025] (who focuses on modules), as well as by interviewees C5 and I2. Abu-Ghaida et al. [2024] also include the parameters *Connection access* and *Crossings* as part of correctly evaluating the *Disassembly potential* of a product. In their paper, which focuses on accounting for recovery potential in building LCA, a method for constructing and evaluating a disassembly network is mentioned. Different types of connections, connection access and crossings are defined and graded. The definitions and grading system of Abu-Ghaida et al. [2024], originally proposed by Cottafava and Ritzen [2021], is used in this thesis, since it is well developed and builds upon previous studies.

We also propose adding the parameter *Time of reuse process* as being affected by the *Connections*, *Connection access* and *Crossings*. This relationship was not directly stated in the studies or conducted interviews, however, it is implied that the reuse process takes more time if the building product takes longer to extract due to their connections.

Proposed definitions

The type of connections that are present between the building product and other building products/elements

Proposed grading

- In regards to *Disassembly potential* the *Connection* is graded based on the extent to which the connections between building products allow for disassembly without

damage.

- In regards to *Time of reuse process* the *Connection* is graded based on the time it takes to disassemble the connections.

Table 3.6: Grading Connections to Disassembly potential

1	0.8	0.6	0.2	0.1
Dry connection Click connection Velcro connection Magnetic connection	Connection with added elements Ferry connection Corner connection Screw connection Bolt and nut connection	Direct integral connection Pin connection Nail connection	Soft chemical compound Kit connection Foam connection	Hard chemical connection Glue connection Pitch connection Weld connection Cement bond Chemical anchors

Table 3.7: Grading Connections to Time of reuse process

0.9	0.5	0.1
The connection is fast to disassemble, involving little preparation and few steps.	The connection is slower to disassemble, involving some preparation and/or more steps.	The connection is very slow to disassemble, involving extensive preparation and/or many steps.

3.1.3.5 Connection access

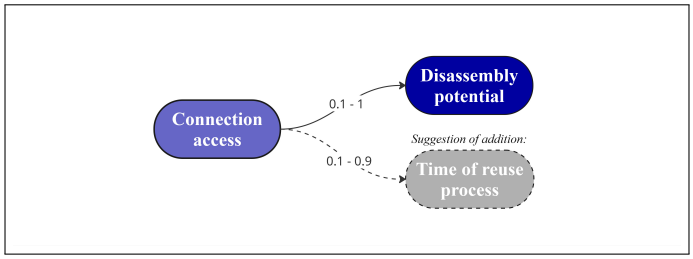


Figure 3.7: Parameter connections of Connections access

See the above description of *Connections* for references.

Proposed definitions

The accessibility to the connections for disassembly purposes.

Proposed grading

- In regards to *Disassembly potential* the *Connection access* is graded based on the extent to which the connection is accessible without damage to the product itself or other products.
- In regards to *Time of reuse process* the *Connection access* is graded based on the time it takes to access the connections.

Table 3.8: Grading Connection access to Disassembly potential

1	0.8	0.4	0.1	Not met
Freely accessible	Accessibility with additional actions that do not cause damage	Accessibility with additional actions with repairable damage	Not accessible, irreparable damage to other products	Not accessible, irreparable damage to the product itself

Table 3.9: Grading Connection access to Time of reuse process

0.9	0.5	0.1
The connection is fast to access, involving little preparation and few steps.	The connection is slower to access, involving some preparation and/or more steps.	The connection is very slow to access, involving extensive preparation and/or many steps.

3.1.3.6 Crossings

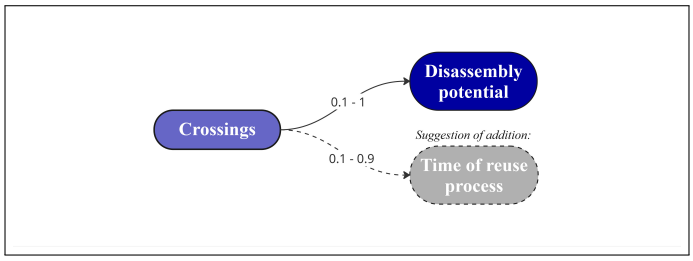


Figure 3.8: Parameter connections of Crossings

See the above description of *Connections* for references.

Proposed definitions

The crossing or integration of other building products/elements around or in the evaluated product

Proposed grading

- In regards to *Disassembly potential*, *Crossings* is graded based on the extent to which obstructions of other crossing or integrated products/elements allow for disassembly without damage.
- In regards to *Time of reuse process*, *Crossings* is graded based on the time it takes to extract the product from the building.

Table 3.10: Grading Crossings to Disassembly potential

1	0.4	0.1
Modular zoning	Crossings between one or more objects	Full integration of objects

Table 3.11: Grading Crossings to Time of reuse process

0.9	0.5	0.1
The product is fast to extract, involving little preparation and few steps.	The product is slower to extract, involving some preparation and/or more steps to remove surrounding elements.	The product is very slow to extract, involving extensive preparation and/or many steps to remove surrounding elements.

3.1.3.7 Quality & Life expectancy

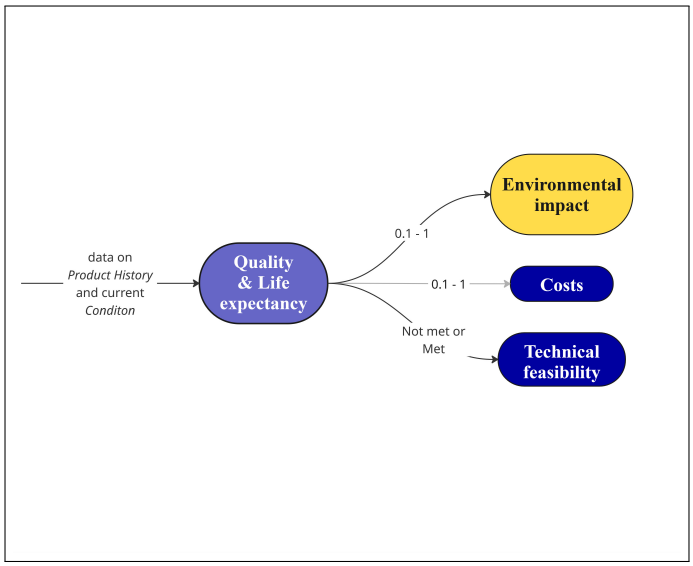


Figure 3.9: Parameter connections of Quality & Life expectancy

Quality & Life expectancy are important parameters mentioned in several references. Bellini et al. [2024] combines them into one parameter, whereas Iacovidou and Purnell [2016] and Geldermans [2016] mention "quality" and "performance quality" separately, and Janson et al. [2022], Sveriges Kommuner och Regioner (SKR) [2024], Linus Brander [2021], White [2021], Geldermans [2016], and Fastighetsägarna Stockholm [2024] mention "age", "year", "remaining service life" and "performance time" separately. The *Quality & Life expectancy* is informed by the *Condition*, which includes both physical/-functional and aesthetic condition. To assess the *Quality & Life expectancy* of a building product, as noted by Bellini et al. [2024], it is beneficial to have access to documented maintenance history, as-built documentation, and product specifications. Fastighetsägarna Stockholm [2024] links the life expectancy with *Environmental impact*, and White [2021] and Bellini et al. [2024] links it to *Economic profit* and *Costs* respectively. Interviewee C8 (owner of a reuse firm) comments that "[We] work...based on industry standards and performance requirements", highlighting the fact that used products are not exempt from quality and service life requirements included in *Technical feasibility*. Interviewee I9 links to *Economic profit*, stressing that "one has to send in [for reuse] things of value in order to receive value in return".

Interviewees G1 and I10 states that determining the quality of a product and linking the remaining lifespan to its potential for reuse can be challenging. Interviewee I10 saying that "No data makes sense when it comes to lifespan and reusability of specific products.

Compare it with cars - how long is a car considered usable for example? [Take] washing machines, ovens, etc. [They have] 10 years of official lifespan. [But that presupposes] 8 hours of use a day, around 13 000 hours, [which is usually not the case]". Despite this difficulty, the reviewed papers and reports, along with interviewees C7, A1, I3, C2, and G1 agree that it is important to consider the quality and life expectancy. Interviewee A1 thinks that "the quality will have to be high if we are going to succeed with reuse".

A few grading methods have been proposed for this parameter. Bellini et al. [2024] suggests a scale from 1 to 5, where 1 indicates an item is old and worn out, and 5 indicates a good condition, assessed through visual inspection. Janson et al. [2022] highlights that building products aged between 5 and 15 years generally have good reuse potential. Fastighetsägarna Stockholm [2024] and White [2021] suggest looking at a "Break-even point" for active products in regards to *Environmental impacts* and *Costs* respectively. A break-even point is the point in time at which the product intended for reuse and a new product will have caused the same environmental impacts (in this case carbon emissions) or resulted in the same cost. This means that up until the break-even point a used product will be more environmentally/economically beneficial. When calculating the break-even point, White [2021] suggests looking at both the one-off impact/cost and the yearly impact/cost which they define as follows:

- One-off impact/cost:
  - New product: production emission and purchase price
  - Product for reuse: reconditioning/transport emission and purchase price.
- Annual impact/cost from the usage of the products e.g energy/water use multiplied by how much the product is used.

The calculations for each product are performed simply by adding the one-off impact/cost and the cumulative total impact/cost over time based on the yearly impact/cost. Plotting the emissions and costs over time using the formula below, the break-even point is the point at which the lines cross.

$$t^* = \frac{\text{One-off}_{\text{new}} - \text{One-off}_{\text{reused}}}{\text{Annual}_{\text{reused}} - \text{Annual}_{\text{new}}}.$$

where t^* is the year of the break-even point.

No suggested grading method for *Quality & Life expectancy* is sufficient to inform a comprehensive system that takes all aspects of the property into account. The grading from 1-5 by Bellini et al. [2024] does not include any assessment of the remaining service life, but can be used to evaluate the quality. The "thumb-rule" given by Janson et al. [2022] - suggesting that products below 15 years of use normally have a "good"

reuse potential - is vague, as no indications of which types of building products it applies to are given. Finally, the calculation of a break-even point for active products in regards to costs and environmental impacts is useful, however, the resulting t* (years) needs to be evaluated further (i.e. how is a large t* and a low t* evaluated?).

Proposed definition

The product's functional and aesthetic condition, as well as its expected remaining service life.

Proposed grading

- When grading *Quality & Life expectancy* against *Environmental impact* and *Costs*, we suggest splitting up the parameter into an evaluation of the *Quality* of the product, i.e. to what extent it is in need of repair or refurbishment before reuse, and the evaluation of the estimated life expectancy. The quality can be evaluated in five steps from 0.2-1, as suggested by Bellini et al. [2024], whereas the life expectancy, as it is numerical, might be evaluated by assessing the percentage of remaining service life and directly assigning the corresponding grade from 0-1 (rounding off to one decimal). For active products, the break-even point (environmental and economic respectively) is assessed as the remaining service life. The average of the two grades is calculated to acquire the grade for *Quality & Life expectancy* in regards to *Environmental impact* and *Costs*.
- In regards to *Technical feasibility*, if the product is in good condition or repairable and/or possible to refurbish to extend the service life, grade *Met* is given. If the product is damaged or worn out but not repairable or possible to refurbish, grade *Not met* is given.

Table 3.12: Grading Quality to Environmental impact and Costs

0.9	0.7	0.5	0.3	0.1
The product is in good condition.	The product is in acceptable condition.	The product requires thorough cleaning.	The product shows some wear and needs some light to moderate refurbishment.	The product is worn out and in need of moderate to heavy repair or refurbishment.

Table 3.13: Grading Life expectancy to Environmental impact and Costs

1 - 0
The remaining percentage of the initial service life.

Table 3.14: Grading Quality & Life expectancy to Technical feasibility

Met	Not met
The product is in good condition, or repairable and/or possible to refurbish to extend the guaranteed service life.	The product is damaged or worn out, and not considered repairable or possible to refurbish.

3.1.3.8 Function

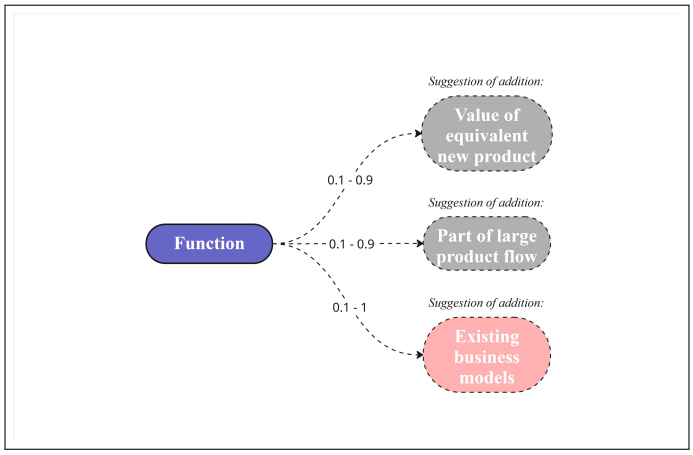


Figure 3.10: Parameter connections of Function

The *Function* of building product is a parameter that has been mentioned by Sveriges Kommuner och Regioner (SKR) [2024], Karin Hedén [2022], Linus Brander [2021], and the interviewees C1, C7, and I5, as important to consider. In our findings, the definition of *Function* has not been clearly stated, nor what it links to or how to grade it.

We propose that the parameter *Function*, along with *Dimensions* and *Technical properties*, is linked to *Value of equivalent new product* as it is the same functionality,

dimensions and technical properties that needs to be met when comparing the value of two or more products. If the value of a certain type of building product is high on the market, it is likely that the value of the used product of the same type (if in good condition) will also be high.

Additionally, we propose that *Function*, as well as *Material*, is connected to *Part of large product flow* (the type of used building products that circulate the most in the industry). Considering the function and material of the product one can compare with the size of the flow on the market for that type of product and assess if it is likely to be in demand.

Furthermore, we connect *Function* with *Existing business models*, on the grounds that a circular business model is built around products with certain *Functions*, and of certain *Material*s. It is important to know to what extent the supply chain and circular services of a product are existent. For example, is the product part of a take-back scheme offered by the manufacturer/reseller that secures the whole supply chain, or does the reuse process involve disconnected actors?

Proposed definitions

The *Function* of the building product is defined as the purpose it is intended to serve in a building.

Proposed grading

- In relation to *Value of equivalent new product* the *Function*, *Dimensions* and *Technical properties* of the product are assessed based on the market value of the same type of product. A high value gives a high score and vice versa.
- In relation to *Part of large product flow* the *Function* and *Material* is assessed based on how "generic" a product is and the ease with which it can be replaced with an equivalent product. A high grade indicates a product with a high generic function, allowing for easy substitutions.
- In relation to *Existing business models* the *Function* and *Material* are assessed based on if circular business models exist to support the reuse of the product, as well as to what extend they are part of a supply chain.

Due to a lack of precision in the evaluation, the grades are divided into three approximate scores: 0.9, 0.5, 0.1.

Table 3.15: Grading Function, Dimensions and Technical properties to Value of equivalent new product

0.9	0.5	0.1
The value of an equivalent new product of the same function, dimensions and technical properties is high.	The value of an equivalent new product of the same function, dimensions and technical properties is moderate.	The value of an equivalent new product of the same function, dimensions and technical properties is low.

Table 3.16: Grading Function and Material to Part of large product flows

0.9	0.5	0.1
The product is commonly used and commonly found in bulk as identical modular units that follow universal standards, e.g. bricks, sanitary porcelain or cable trays.	The product is commonly or moderately used, but subject to different regulatory standards that are project-dependent, e.g windows, radiators or insulation.	The product is typically found in small amounts or few units and need to follow project-specific requirements, e.g elevators or central heat pumps sized to the building.

Table 3.17: Grading Function and Material to Existing business models

1	0.7	0.5	0.1
A circular supply chain exists for the product type, involving disassembly, transport, storage, refurbishment, quality assurance and reselling.	The supply chain for the product type is only partly established, but separate reuse services exists. This necessitates contacting some individual actors to secure the reuse process.	The supply chain for the product type is not established, but separate reuse services exists. This necessitates contacting all individual actors to secure the reuse process.	One or more essential reuse services are currently not offered for the product type, such as storage or quality assurance, making it difficult to reuse through the market. Further development of business models are needed.

3.1.3.9 Dimensions

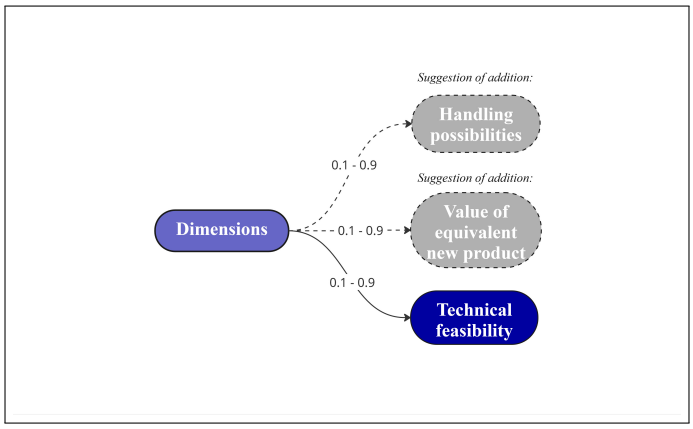


Figure 3.11: Parameter connections of Dimensions

The *Dimensions* of a building product is mentioned as "Dimensions" by Iacovidou and Purnell [2016], Lindborg et al. [2024], Linus Brander [2021] (focusing on the cross-section and length of structural components), Karin Hedén [2022] and Geldermans [2016], as well as "Form" by Janson et al. [2022] and Sveriges Kommuner och Regioner (SKR) [2024]. It is considered an important parameter by several studies, and though it is simple to define a method for grading it has not been suggested. In the conducted interviews the influence of dimensions on reuse potential was discussed: Interviewee A2 points out that small and flexible components such as bricks allow for more creative design when used in reuse projects, as opposed to larger components; interviewee G2, on the other hand, stresses that if anything needs to be disassembled it should be done in larger parts; interviewee I1 thinks that there should be more research into what could be considered a good scale of flexibility and modularity; interviewee I4 mentions that in the past windows were built according to standard dimensions whereas today they are often custom-made to fit specific projects, which makes them harder to reuse in other projects; interviewee C3 promotes cutting installations such as pipes and ducts, into standard dimensions during the reuse process in order to make the reuse process easier, as different sizes of installations are harder to include in new designs.

We propose that the dimensions of a product is connected to *Technical feasibility* as a common technical problem with reusing products is the variation in size. We also suggest that the dimensions have an effect on the *Handling possibilities* of the building product during the reuse process, as well as the assessment of the *Value of an equivalent new product*. Larger components are more difficult to handle, requiring more planning and heavier machines. When comparing with an equivalent new product the dimensions,

together with function and technical properties, need to match in order for the products to be considered equivalent.

Proposed definitions

The dimensions of the building product; height, width and length [m].

Proposed grading

- In regards to *Technical feasibility* the *Dimension* of the product is assessed based on to what extent the product allows for easy integration into a new project or site, i.e. if it is of standard dimensions.
- In regards to *Handling possibilities* the *Dimension* of the product is assessed based on to what extent it allows for easy handling during the reuse process.
- In regards to *Value of equivalent new product* see table 3.15 in section 3.1.3.8.

Due to a lack of precision in the evaluation, the grades are divided into three approximate scores: 0.9, 0.5, 0.1.

Table 3.18: Grading Dimensions to Technical feasibility

0.9	0.5	0.1
The product is of a dimension that is available as a standard stock-item.	The product can be adjusted to the size of a standard stock-item with repairable damage or moderate refurbishments.	The product cannot be adjusted to the size of a standard stock-item without irreparable damage or extensive refurbishments.

Table 3.19: Grading Dimensions to Handling possibilities

1	0.7	0.5	0.1
The product can be handled by one or two people.	The product needs to be handled by medium sized machinery.	The product needs to be handled by heavy machinery, such as a crane.	The product cannot be handled by crane and/or transported safely without size adjustments.

3.1.3.10 Technical properties

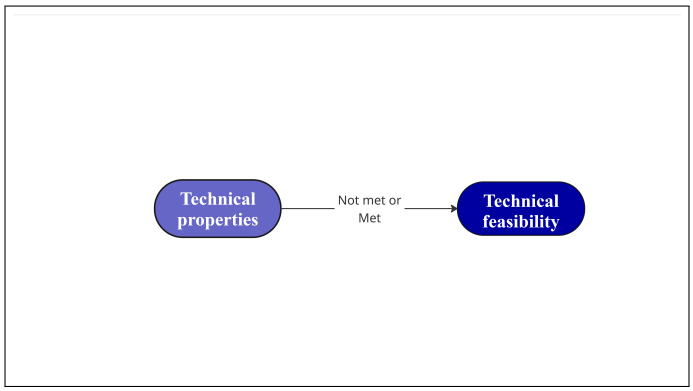


Figure 3.12: Parameter connections of Technical properties

Technical properties include such properties as structural capacity, fire resistance, thermal conductivity, sound transmission and protection class. These are mentioned in studies and interviews as key parameters for certain types of building products. Bellini et al. [2024] connects structural, fire resistant, acoustic and thermal properties to *Technical feasibility*, ensuring that the product meets the standard and regulatory requirements of its type. Lindborg et al. [2024] also connects fire resistant and acoustic properties to *Technical feasibility*, and adds protection class as also being relevant. Interviewee C5 and C8 brings up the difficulty of matching the properties of used products with new stricter requirements: "Today there are new standards as compared to just five years ago, for example, new fire resistance and acoustic requirements...No matter how much one plans for reuse, one doesn't know what the new requirements will be"; "To match acoustic and fire resistance requirements is hard. [It] often complicates the reuse of doors and windows".

The definitions of structural properties, fire resistant properties, thermal properties, acoustic properties and protection class are standardised and standard units of measurement exist. A grading system proposed by Bellini et al. [2024] involves ensuring that national standards, such as *TEK17* (standards for energy efficiency and energy consumption of buildings in Norway) or *NS standards* (main standard organisation in Norway) are met, where grade 1 indicates that the standards are met and grade 0 that they are not met. A challenge lies in the uncertainty of the future requirements that will be placed on the building products. It is dependent on the overall development of stricter requirements, as well as the future deployment and use of a product. Decoupling the properties of the product from the requirements of a receiving projects, necessitates making estimations of what could be expected of the product.

We also propose that *Technical properties* are related to the assessment of the *Value of an equivalent new product*. When comparing with an equivalent new product the technical properties, together with function and dimensions, need to match in order for the products to be considered equivalent.

Proposed definitions

In the Swedish context *Boverket* sets legal requirements for products properties through the *National building regulations* (Boverkets Byggregler, BBR), whereas *Swedish Institute for Standards* (SIS), sets the standards for how to test, classify and calculate the properties. Regarding Protection class, insurance companies sets requirements via *Stöldskyddsföreningen* (SSF).

- The structural properties includes the strength, stability, serviceability, durability, fatigue, and robustness of a structural component.
- The fire resistant properties include R (Resistance, load-bearing capacity), E (Integrity), I (Insulation) classes and reactions to fire.
- The thermal properties include maximum U-value [W/m^{2}K] for walls, roofs, floors, windows and walls.
- The acoustic properties include sound insulation and noise levels.
- The protection class includes resistance to intrusion, burglary and vandalism for e.g. doors and locks.

Proposed grading

- In regards to *Technical feasibility* the properties are graded according to the requirements of *BBR* and *SSF*. If the expected requirement is met, grade 1 is given, if not, the grade *Not met* is given and the product needs to be downcycled, upcycled or recycled.
- In regards to *Value of equivalent new product* see table 3.15 in section 3.1.3.8.

Table 3.20: Grading - Technical properties to Technical feasibility

Met	Not met
The building product meets the minimum requirements relevant for its specific product type.	The building product does not meet the relevant requirements for its specific product type and needs to be downcycled, upcycled or recycled.

3.1.3.11 Material

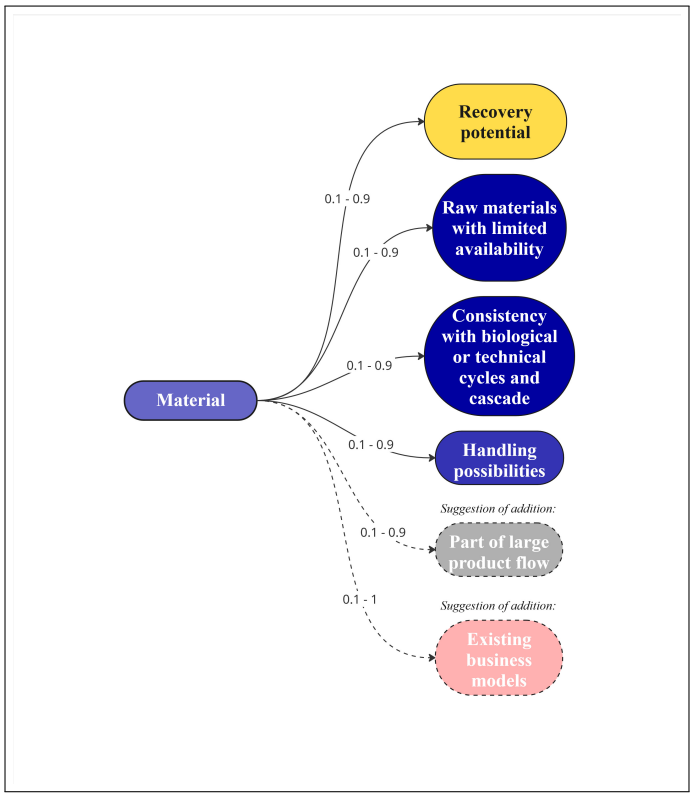


Figure 3.13: Parameter connections of Material

The *Material* of the building products is mentioned by Iacovidou and Purnell [2016], Lindborg et al. [2024], Linus Brander [2021], Karin Hedén [2022], Yang et al. [2025], Geldermans [2016], Abu-Ghaida et al. [2024], as well as interviewees C2, C6 ,C7 and I2. Geldermans [2016] links the type of *Material* to *Consistency with biological cycles and cascade*, and interviewee I2 connects *Material* with *Raw materials with limited availability*, highlighting the importance to consider material scarcity and the negative environmental impact associated with continuous material extraction.

Material is also relevant when it comes to the *Recovery potential* and the *Handling possibilities* of a building product. Abu-Ghaida et al. [2024] explicitly mentions the "fragility" of a material as an important aspect to consider when assessing the *Recovery potential*, however, no suggestion of how to define or grade the fragility is given. Yang et al. [2025] mention that the *Material* affects the ability to disconnect the building components: *"Various technical factors can affect the extent to which a structure can be easily disassembled and reused, including the types of materials used..."*. Interviewee

C7 comments that "[When it comes to] e.g. gypsum boards [one focuses on] internal reuse on the same location due their fragility and difficulty in transporting them without inflicting damage", and says that in general it is "easy to damage things while moving them".

Regarding *Raw materials with limited availability* the evaluation might be based on assessing the resource availability of a certain material. If a material is scarce as a natural resource, or hard to extract, the priority to reuse or recycle products containing that material should be high.

The material's *Consistency with biological or technical cycles and cascade* relates to whether the material is renewable or non-renewable, as well as whether is classified as biodegradable or not. Manufactured materials that are non-renewable and non-biodegradable should be circulated within the technical cycle. In contrast, renewable and biodegradable materials could be composted or incinerated with marginal environmental impacts.

The fragility of a material, as it relates to *Recovery potential* and *Handling possibilities*, is hard to quantify and grade, as there is no standard measurement for it. Arguably the fragility of a building product during the reuse process is not only related to material properties but also the dimensions and shape of the product. However, this is not part of the evaluation of this parameter. Some standards of measurement that could be used to evaluate material fragility might include:

- Impact resistance (for drops)
- Fracture toughness (resistance to breaking after cracking)
- Tensile strength (withstanding tension)
- Vibration resistance (for transportation)
- Compression/stacking durability (for storage)

These are all related to different stages of the reuse process, such as disassembly, on-site handling, transportation, storage and reassembly.

In regards to *Recovery potential*, i.e. the ease of damage-free recovery from a project, fracture toughness and tensile strength might be relevant to assess. In regards to *Handling possibilities* the impact resistance, vibration resistance and compression/stacking durability might be relevant.

Apart from the parameter connections above, we also suggest that *Material* is related to *Part of large product flow* and *Existing business models*. When assessing to what extent a product is part of a large product flow both the functionality and material of a

product should be taken into account. This reasoning also applies to the assessment of the extent to which business models and supply chains exist to support the reuse of a certain product type.

Proposed definitions

The physical substance that the building product is made from.

Proposed grading

- In regards to *Raw materials with limited availability* the *Material* is graded based on its scarcity as a natural resource.
- In regards to *Consistency with biological or technical cycles and cascade* the *Material* is graded based on its biodegradability and renewability.
- In regards to *Recovery potential* the *Material* is graded based on its fracture toughness and tensile strength.
- In regards to *Handling possibilities* the *Material* is graded based on its impact resistance, vibration resistance and compression/stacking durability.
- In regards to *Part of large product flow* see table 3.16 in section 3.1.3.8.
- In regards to *Existing business models* see table 3.17 in section 3.1.3.8.

Due to a lack of precision in the evaluation, the grades are divided into three approximate scores: 0.9, 0.5, 0.1.

Table 3.21: Grading of Material to Raw materials with limited availability

0.9	0.5	0.1
The material is naturally scarce or hard to mine. Additionally the supply of recycled material is limited or non-existent, and it is hard to substitute with other materials.	The material is available in moderate amounts in nature or in a recycled form. It is possible to to substitute with other materials, but with some trade-off.	The material is abundantly available in nature or in a recycled form, or easy to substitute with other materials.

Table 3.22: Grading of Material to Consistency with biological or technical cycles and cascade

0.9	0.5	0.1
The material is non-renewable or non-biodegradable, and should therefore be circulated within the technosphere through reuse or recycling.	The material is renewable but not biodegradable, and should therefore be circulated within the technosphere through reuse, recycling or energy recovery.	The material is renewable and biodegradable and could circulate in the biosphere through composting.

Table 3.23: Grading of Material to Recovery potential

0.9	0.5	0.1
The average of the material's fracture toughness and tensile strength is high.	The average of the material's fracture toughness and tensile strength is moderately high.	The average of the material's fracture toughness and tensile strength is low.

Table 3.24: Grading of Material to Handling possibilities

0.9	0.5	0.1
The average of the material's impact resistance, vibration resistance and compression/stacking durability is high.	The average of the material's impact resistance, vibration resistance and compression/stacking durability is moderately high.	The average of the material's impact resistance, vibration resistance and compression/stacking durability is low.

3.1.3.12 Assembly type

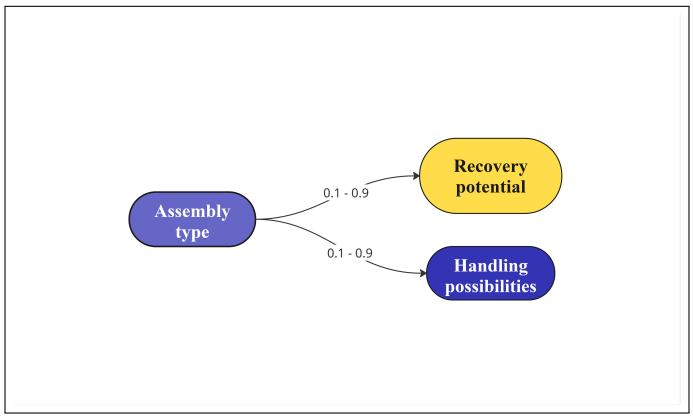


Figure 3.14: Parameter connections of Assembly type

Assembly type is mentioned by Linus Brander [2021] as "Assembly type", who defines it as "whether the building product is site-built or pre-manufactured", and by Yang et al. [2025] as "Modular design". Interviewee A1 comments that "the degree of modularity will need to be high...if we are to succeed with reuse", and interviewee C5, linking to *Recovery potential*, adds that "the more pre-fab, the easier it will be to recover [building products]". Interviewee I7 insists that "if one builds modularly one can move whole buildings", and interviewee C6, linking to *Handling possibilities*, adds that "[Modules] are...easy to move". Interviewee I6, on the other hand, states that "[there is] a great disadvantage to modular building - a lot of extra material (double) [and] many seams. Maybe [it is] more important to save on material [than] building quickly".

Assembly type refers to whether the product is site-built or pre-manufactured, and to the level of modularity of the building product. A brick or a gypsum board is a simple modular unit, whereas walls, floors and whole building modules are more complicated units of modularity, fulfilling more functions per product. The opinions on whether a simple or complicated level of modularity is "better" from a circularity or a sustainability perspective differs. However, we argue that the pre-manufactured product have a higher *Recovery potential* and greater *Handling possibilities* than site-built products, as site-built often implies custom made dimensions, shapes and connections. For example, cast in-situ concrete elements need to be cut with powerful machines into smaller blocks, which is time consuming and necessitates the instalment of new connections before reuse. Similarly site-built walls, floors and roofs are normally not made to be cut into reusable components. Attempts have been made, such as with exterior walls in the case study by Göteborgs Stad, Stadsfastighetsförvaltningen [2023]. However, the wall elements required size adjustment on location and extensive refurbishment before they

were acceptable for reuse, negatively affecting the *Recovery potential*.

Proposed definition

The method of assembly of the product, i.e. site-built or pre-fabricated, as well as its level of modularity.

Proposed grading

The extent to which the product is pre-fabricated and modular as opposed to site-built and customised. The connected parameters, *Recovery potential* and *Handling possibilities*, could arguably be graded according to the same conditions, as the assembly type affects the extraction and transportation of the product similarly. Due to a lack of precision in the evaluation, the grades are divided into three approximate scores: 0.9, 0.5, 0.1.

Table 3.25: Grading of Assembly type to Recovery potential and Handling possibilities

0.9	0.5	0.1
The product is modular and pre-fabricated with the intention of easy replacement or recovery for reuse.	The product is custom built but pre-fabricated, suggesting a high probability of successful recovery and handling, but potential difficulties in replacing other products.	The product is non-modular and custom built on site, with no intention of replacement or reuse.

3.1.4 Subsequent grading of the Reuse Process, Reuse Indicators and Key Reuse Criteria

Based on the grading of the *Product properties*, the *Reuse process* and *Reuse indicators* can be evaluated by calculating the average of the score of the parameter inputs related to each parameter, see figures 3.15-3.17. The procedure for evaluating each *Key reuse criteria* is different and include certain conditions, these are presented in the following section on *Reuse evaluation algorithms*.

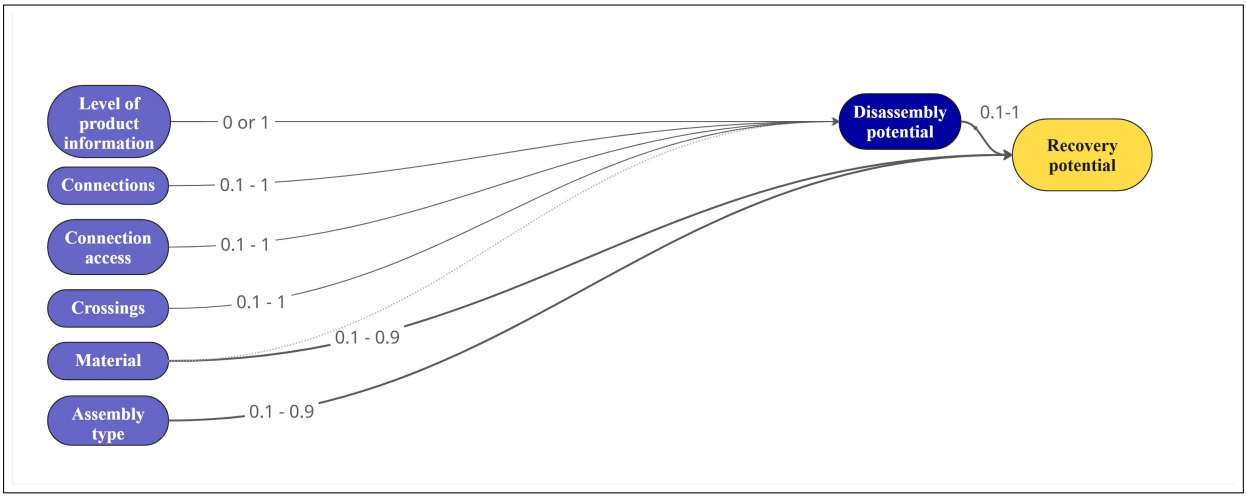


Figure 3.15: Parameter connections to Recovery potential

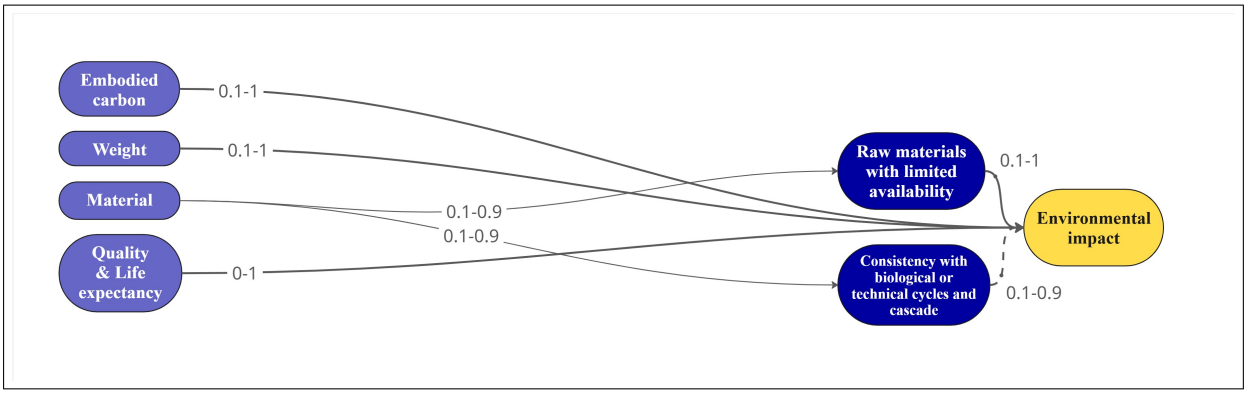


Figure 3.16: Parameter connections to Environmental impact

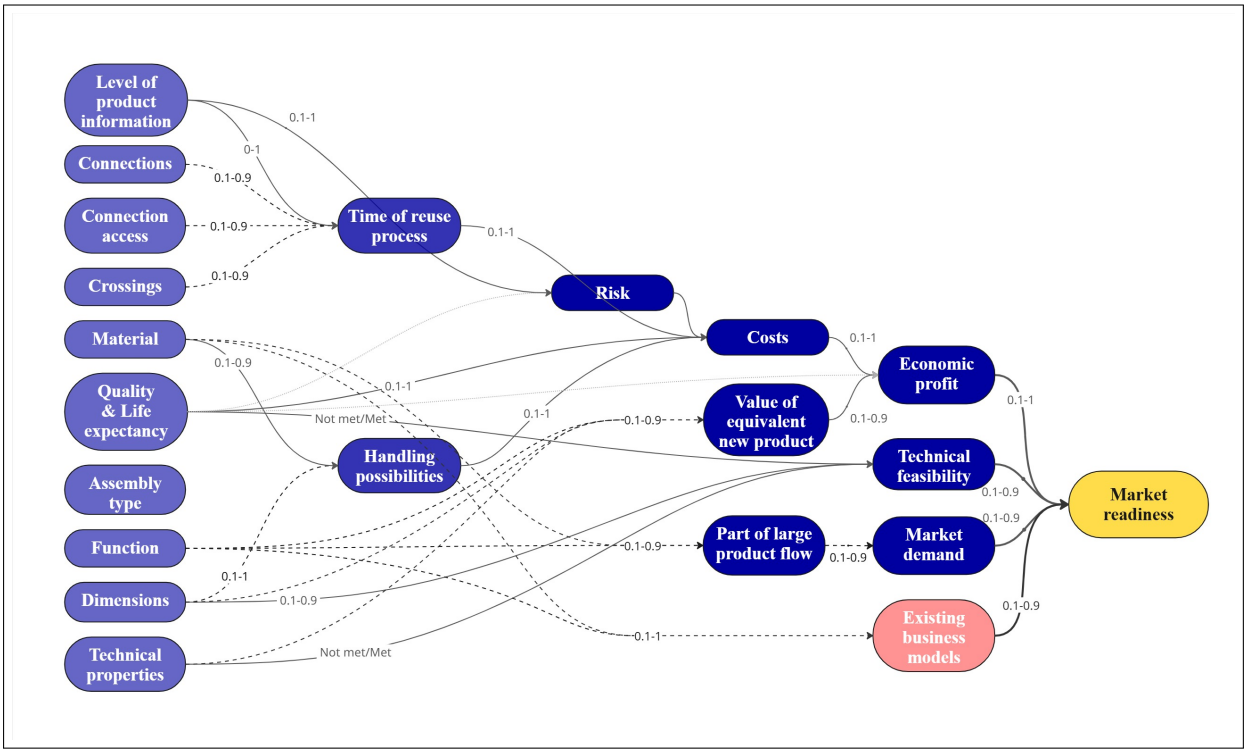


Figure 3.17: Parameter connections to Market readiness

3.1.5 Reuse evaluation algorithms

In this section the Reuse evaluation algorithm of each *Key reuse criteria* is presented. Each criteria has specific conditions that need to be met in order for a product to receive a reuse potential. If a condition is not met the score Upcycling/Recycling/Downcycling (U/R/D) is given, meaning that reuse of the product as such is not recommended. The product can instead be directed to upcycling, recycling or downcycling to be materially circulated in another form.

3.1.5.1 Recovery potential

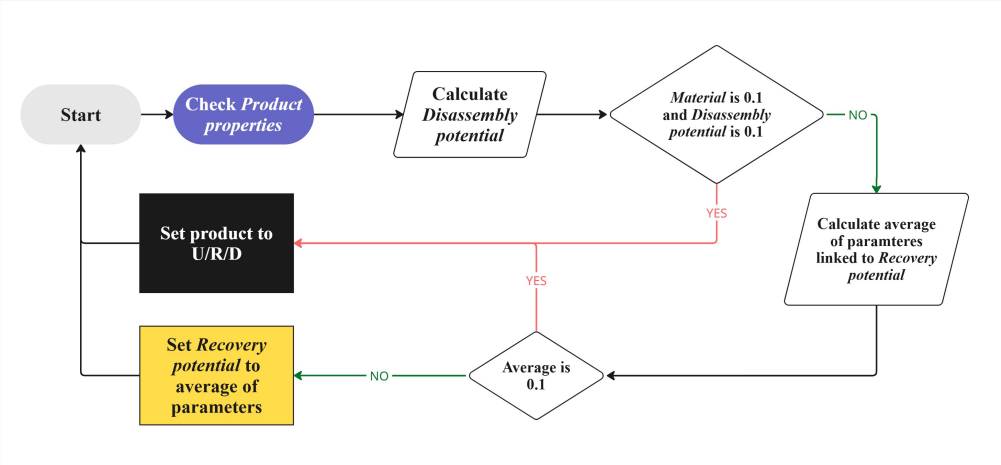


Figure 3.18: Recovery potential evaluation algorithm

For *Recovery potential* the *product properties* are first checked and the *Disassembly potential* is calculated. *Material fragility* and *Disassembly potential* are evaluated against a cut-off threshold of 0.1. This threshold is established because fragile materials, combined with difficult disassembly procedures, increase the risk of product damage. If *Material fragility* and *Disassembly potential* are both (≤ 0.1), the evaluation procedure continues and the average of all parameters linked to *Recovery potential* is calculated. This average is then assessed against a cut-off. If the average grade is low (≤ 0.1) the product is set to *U/R/D* due to a high probability of irreparable damage inflicted during the disassembly process. If the average is higher than 0.1, this value becomes the final score of the *Recovery potential*.

3.1.5.2 Environmental impact

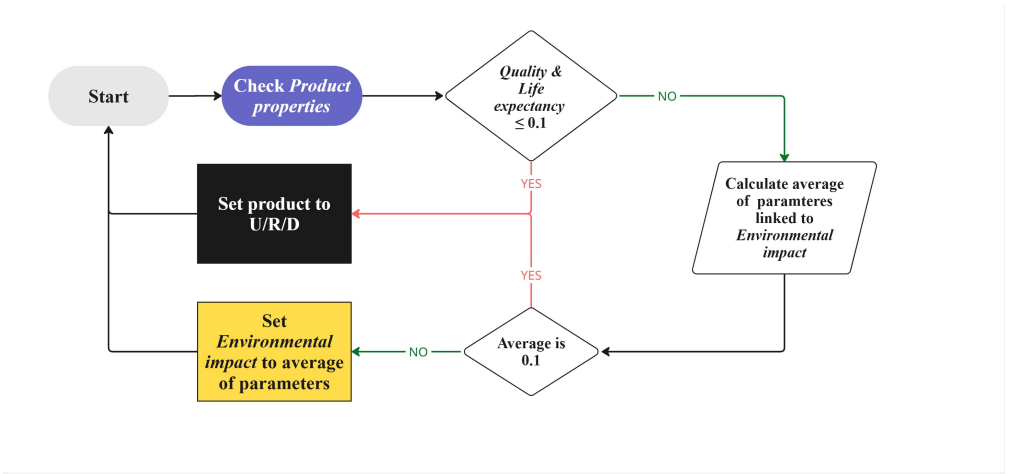


Figure 3.19: Environmental impact evaluation algorithm

For *Environmental impact* the *product properties* are first checked. A cut-off at grade 0.1 for *Quality & Life expectancy* is made to avoid unrealistic scenarios, such that if *Quality & Life expectancy* is graded low (≤ 0.1) the product is set to *U/R/D*. If this condition is false, the average of all parameters linked to *Environmental impact* is calculated. This average is then assessed against a cut-off, such that if the average grade is low (≤ 0.1) the product is set to *U/R/D*. If the average is higher than 0.1, this value becomes the final score of the *Environmental impact*.

3.1.5.3 Market readiness

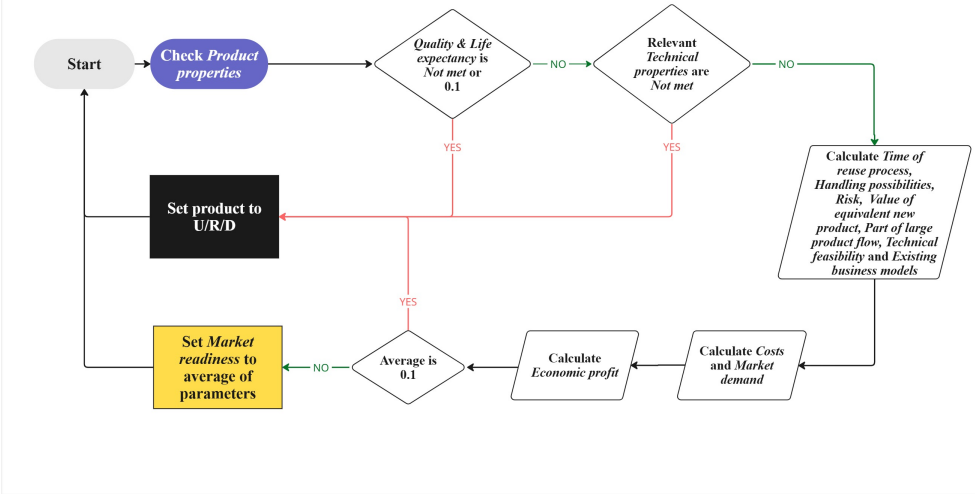


Figure 3.20: Market readiness evaluation algorithm

For *Market readiness* the *product properties* are first checked. A cut-off at grade 0.1 for *Quality & Life expectancy* is made to avoid unrealistic scenarios. If *Quality & Life expectancy* is not met or graded low ($\leq$ 0.1), the product is set to *U/R/D*. If this condition is not true, the relevant technical properties *Structural properties*, *Fire resistant properties*, *Thermal properties*, *Acoustic properties* and *Protection class* have to be "Met"; otherwise the product is set to *U/R/D*. If both *Quality & Life expectancy* and the relevant technical properties are fulfilled, the parameters *Time of reuse process*, *Handling possibilities*, *Risk*, *Value of equivalent new product*, *Part of large product flow*, *Technical feasibility* and *Existing business models* are calculated, followed by *Costs Market demand* and, finally, *Economic profit*. Thereafter, the average of all parameters linked to *Market readiness* is calculated and assessed against a cut-off at 0.1, such that if the average grade is low ($\leq$ 0.1) the product is set to *U/R/D*. If the average is higher than 0.1, this value becomes the final score of the *Market readiness*.

3.1.6 A proposal for aggregation into a final score

When the *Key Reuse Criteria* have been assigned a score it is possible to either use the results and make a decision with no further aggregation, or, if the project contains a large amount of different types of building products, to aggregate the results into a final score that represents the overall reuse potential. This implies prioritising and/or deciding on cut-off values for the criteria. For example, *Economic aspect* and *Market*

readiness might be a priority if the project has a small budget, and a cut-off at 0.7 might be appropriate to ensure profitability. How one or several criteria can be prioritised is described below.

3.1.6.1 Weighted grading

Depending on the particular goals and resources of a reuse project, the importance of different criteria will vary. This can be reflected in the results by using Multi-Criteria Decision Analysis (MCDA), in which the criteria are assigned different weights of importance in order to provide a more customised result/advice. If the focus of the project is to reuse as much as possible, then the *Recovery potential* might be assigned a heavy weight. If the focus is on avoiding emissions and environmental aspects, the *Environmental impact*, *Consistency with biological or technical cycles and cascade* and *Potential for reuse multiple times* might be assigned heavy weights. If the project has a tight budget the *Economic aspect* and *Market readiness* might be assigned a heavy weight. The weight can be set directly by the decision-maker, or decided using a method such as surveys, ranking or pairwise comparison (AHP) [Munir, 2017].

The common practical steps of weighted grading, which are followed in this framework, are:

- Assign each criterion a weight $w_i \geq 0$ based on a chosen method of prioritisation.
- Normalise the weights so that
$$\sum_{i=1}^{n} w_i = 1$$
In order for the weight to be interpreted as percentages.
- Calculate the weighted score for each criterion:
$$\text{Weighted score}_i = s_i \cdot w_i$$
- Calculate the final score for the overall evaluation:
$$\text{Total score} = \sum_{i=1}^{n} s_i \cdot w_i$$

[Dodgson et al., 2009].

3.1.6.2 Interpreting the final score: Reuse Potential

The weighted grading of the ultimate *Reuse Criteria* will result in a final score, which will be in the form of a Reuse potential with a value between 0-1. It can also be interpreted as a percentage between 0-100%. This potential can be used to inform the

decision-makers or stakeholders of the potential for reuse. However, since uncertainties around the reuse process are relatively high, no definitive answer can be given (with a few exceptions related to legal regulations and technical aspects).

3.2 Reuse Scenarios

This section begins by outlining the two scenarios that have been explored for the case study and the assumptions made for each scenario. In this thesis, the focus is on evaluating whether the building element can be reused, and does not consider transport distances or if storage is needed and/or available.

3.2.1 Descriptions of Scenarios

In this project two main reuse scenarios were explored, see figure 3.21 below. The first scenario involves disassembly of the modules and reassembly on another location, keeping the same configuration but possibly performing renovations of the interior. The second scenario proposes disassembling the entire building and reusing its components and materials individually in other building projects. Both scenarios present uncertainties due to an immature reuse market for most building elements, as circular business models are still underdeveloped or non-existent. The market value of these building elements significantly influences their potential for reuse, both for external and internal demand. No consideration of the ownership of the building elements has been made, nor who pays for the costs or benefits from reuse.

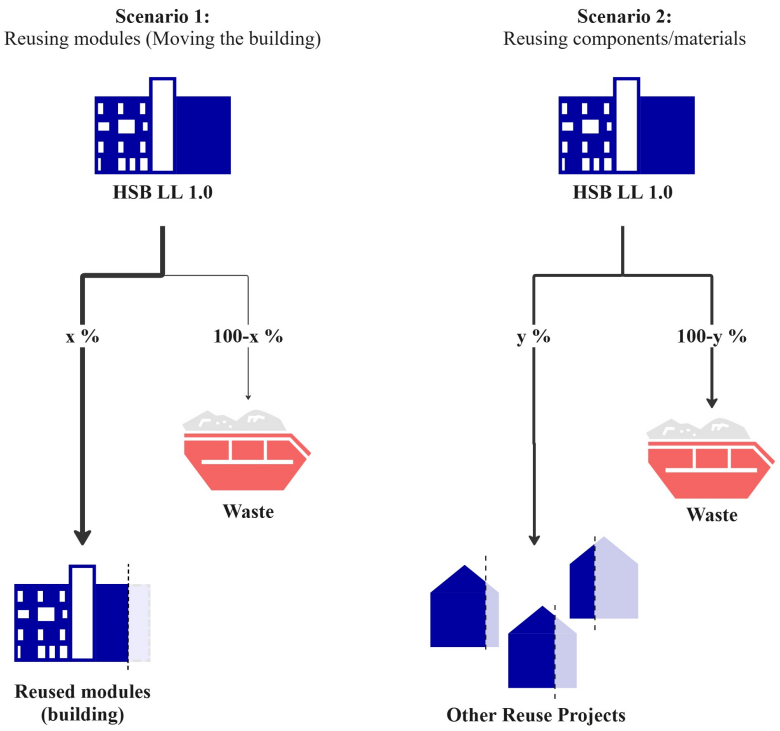


Figure 3.21: Overview of the analysed scenarios

3.2.1.1 Scenario 1: Reusing modules (Moving the building)

In scenario 1, see fig. 3.22 the reusability of the modules are explored. The building is disassembled similarly to how it was assembled, that is, the modules are prepared for separation by removing seams, overlapping components, the roof and the large glass panes. Some parts of the modules which has low service life left are changed to newer ones, otherwise, most of the components in the modules are kept as they are. Furthermore, additional interior supports are added to ensure the structural stability of the modules during transport. After this preparatory step the modules are lifted by cranes, one by one, on to trucks (one module per truck) and transported to temporary storage (if needed) before moving the modules to a new location. The building is thereafter reassembled and some light renovations performed may be performed. These are however not taken into consideration in the carbon emission analysis. The modules were custom made for the function and layout of the building, and the specific load, and are assumed to be too expensive to arrange in a different configuration. It is possible to add one or two stories, but this has not been further explored in this scenario.

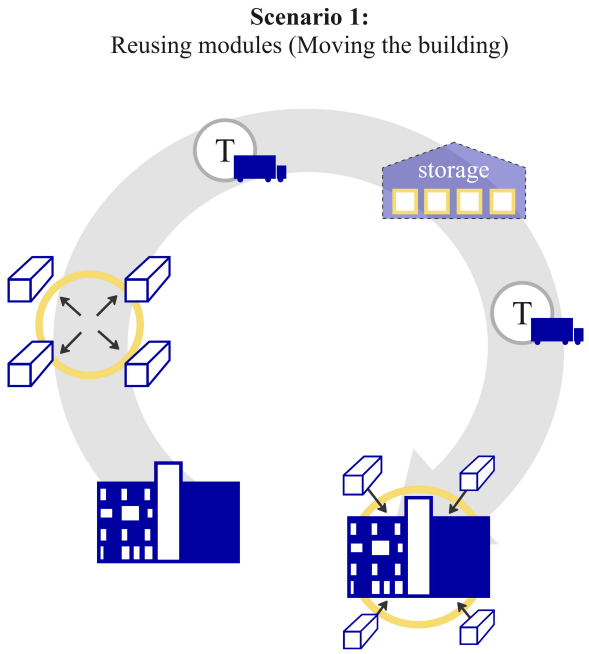


Figure 3.22: Reuse scenario 1: Moving the building

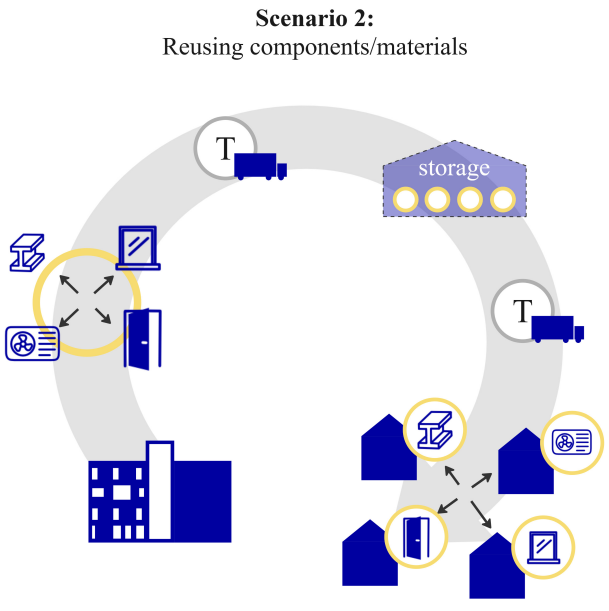


Figure 3.23: Reuse scenario 2: Selling components

3.2.1.2 Scenario 2: Reusing components/materials

In Scenario 2, the focus is on the reusability of building components and materials, as illustrated in figure 3.23. All building elements are disassembled and assessed individually, some as material and some as components. Not all building elements are kept in the same dimensions, for instance, some components, such as ducts, are assumed to be cut to standard sizes to ensure more uniform properties. This is done to simplify their reuse in new construction projects where they may be suitable.

3.3 Reuse Inventory

In this section the methods and tools used for making an inventory of the building products in the case study are described. Thereafter a description of the building is given, including its construction and types of material per shearing layer. Finally, the inventory is summarised by showing the total amounts of building products, as well as the distribution of the known weight and EC of each shearing layer.

3.3.1 Inventory data collection and quality

The inventory data was primarily gathered from a BIM model built by PEAB during the planning process, accessed through StreamBIM [StreamBIM, 2026], a BIM-based collaboration platform used in the Architecture, Engineering, and Construction (AEC) industry. When specific information was not available in the BIM model, alternative sources found in NAVET (HSB's central platform for managing, storing and organising documents) such as as-built drawings, construction drawings, and Bills of Materials (BoM) were used. Additional details, including component weights, were obtained from product documentation available on manufacturers' websites. An example of all the mentioned examples of the data can be seen in figure 3.24 and the data collection sources, along with how they were used, are summarised in table 3.26.

Table 3.26: Data collection Sources

Source	Use	Product type
BIM	Dimensions, locations, and types of components	Dimensions and types of most elements.
2D drawings	Layout, assembly, and design details	Steel type, weight and dimensions of steel modules,

Continued on next page

Source	Use	Product type
BoM	Material specifications and quantities	Materials in walls, floors, roof, windows and doors.
Product Documents	Component weights and technical specifications	Home appliances, weight of installations in *Service* layer.
Semi-structured interviews II	Additional information on products and disassembly procedures	Steel modules, cabinets, installations, home appliances and sanitary components.

3.3.2 Data management

All the components in the BIM model were extracted and organised into a list using *Solibri* [Solibri Inc., 2026] where the components were sorted by type, dimensions and quantity. This list was then transferred to the spread sheet, where the components were categorised by their Shearing Layers. Additional information such as their weight, material and manufacturer was calculated and/or added.

Table 3.27: Data management tools

Tool	Use
Solibri	Extracting and managing data from the BIM model
Excel	Organising, processing and analysing collected data

3.3.3 Shearing layers

This chapter provides a detailed description of the building by dividing it into its shearing layers. The *Site* and *Stuff* layers have been excluded. The *Site* layer is not relevant for reuse and the *Stuff* layer has been omitted due to lack of documented information and the time constraints of this thesis.

3.3.3.1 Structure

The Structure of the HSB LL is made up of the foundation, made of cast in-situ concrete, and 44 self supporting steel modules, weighting in total around 210 tons. The steel

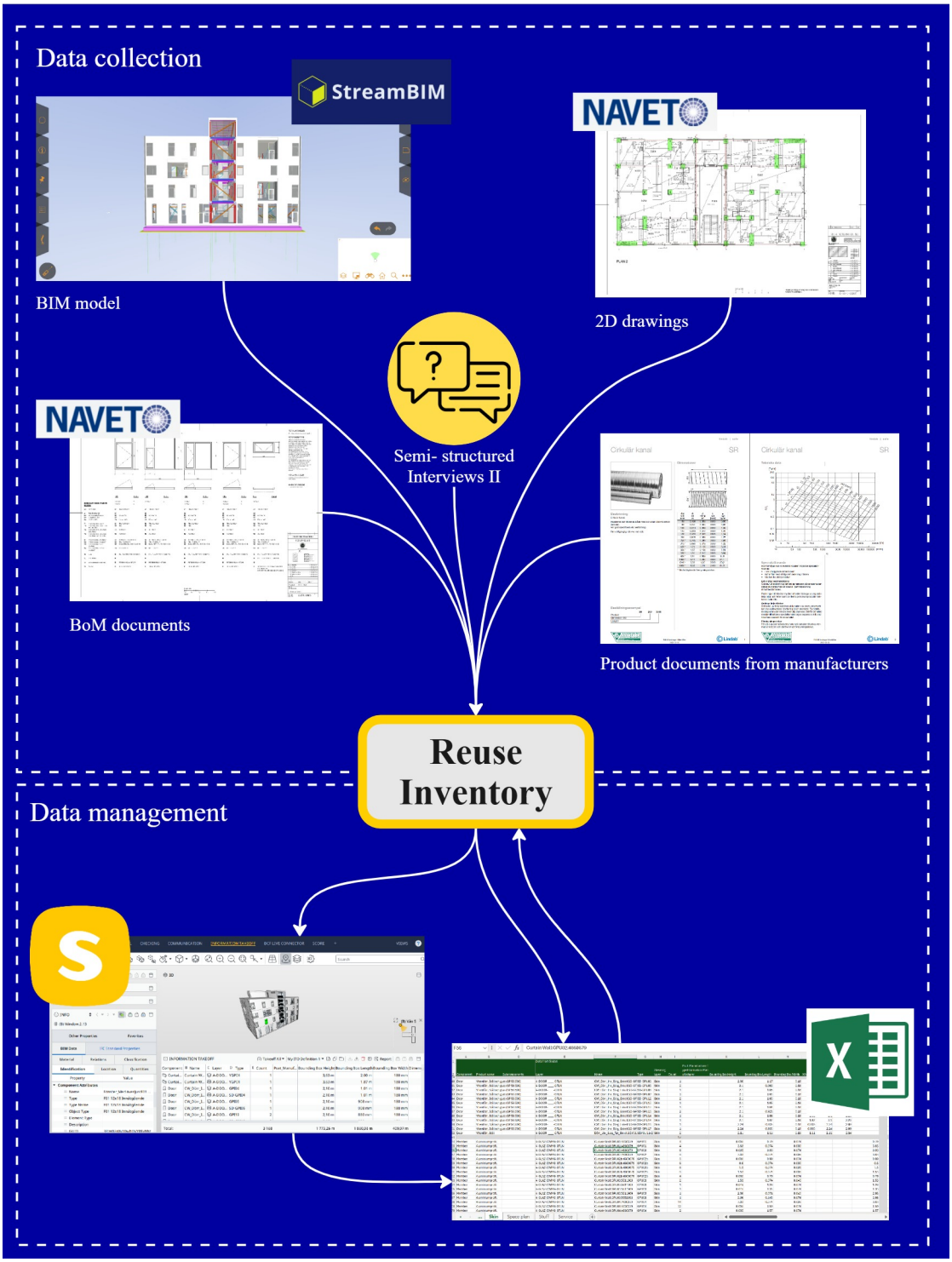


Figure 3.24: Reuse inventory data collection and management

modules have a length of around 12 meters and a height varying between 3.5 meters and 4.2 meters, depending on which floor of the building they are on. An example on how one such module looks like can be seen in figure 3.25. The modules are custom-made to work with the desired design and function of the building and work best in the configuration that they are in currently. It is possible to reconfigure the modules, but that was not the initial intention, and would result in higher costs and environmental impacts according to the manufacturer. They were, however, dimensioned to be able to carry 1-2 additional floors of similar steel modules.

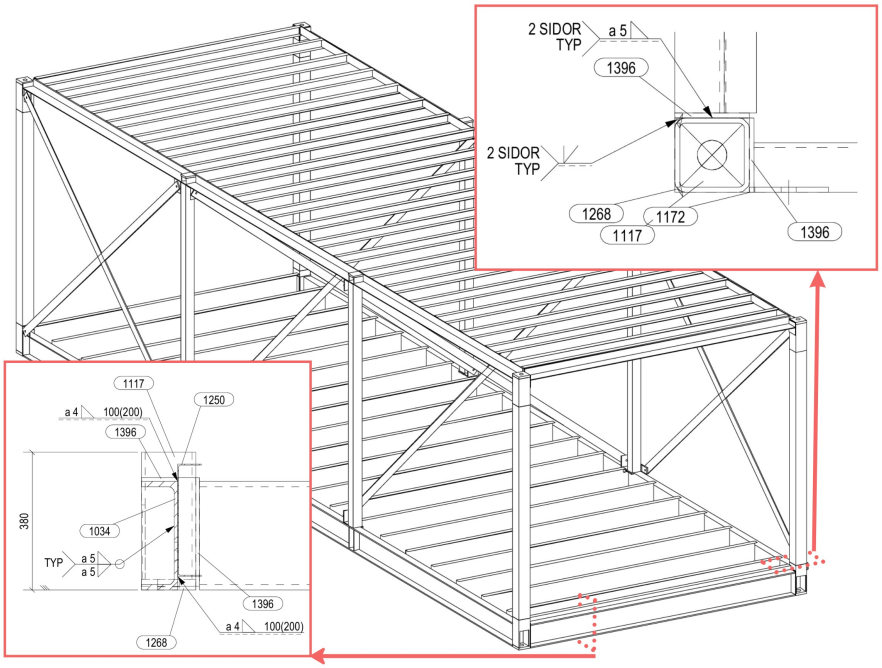


Figure 3.25: An example of one steel module

3.3.3.2 Skin

The skin consists of high pressure laminates made of impregnated natural wood-based fibres that are exchangeable. This enables testing of different types of facade systems. Both small openable aluminium windows and large float glass panels (safety glass) with aluminium frames can be found in the facade. Most of the large glass panes are located on the first floor, which is designed to be more open to the public, and along the metal stairs that run through the centre of the building. The exterior doors are mostly made of steel and glass. The balconies on floors 2, 3 and 4 have metal and glass railings, and large curtain walls with laminated glass separate the apartments from the balcony.

The exterior walls have a regular wood framed structure with a mix of stone wool and polyurethane insulation. The interior layer consists of two gypsum boards. The roof has a metal structure and its outer layer is made of bitumen roofing felt.

3.3.3.3 Space plan

The HSB LL is made up of 5 floors, out of which floors 2-4 are apartments, the first floor is a multi-functional space containing offices, a conference room, a staff kitchen, a laundry area and spaces for exchanging belongings and sharing tools, and the 5th floor holds the HVAC system and most of the rooftop. The apartments on the 2nd and 3rd floor are so called "clusters", each containing 6 rooms of 13 m^2 (47 m^3) where each resident has a small living room, loft, kitchenette and toilet. Besides these there is a large shared kitchen, living room, bathrooms and a balcony. There are 4 clusters in total with 24 rooms. On the 3rd floor are regular apartments of varying sizes.

One important feature of the student rooms is that they are not built according to the accessibility requirements set by SIS (The Swedish Institute for Standards). Because of the temporary building permit and the fact that the rooms are classified as "student apartments", an exception was made. This could influence the reusability of the building in its current design, due to the difficulty in finding similar exceptional conditions on another location. If such a location is not found, the manufacturer of the modules suggest that light renovations of the building could turn it into medical facilities, such as a health centre with patient and staff rooms, or laboratories.

The interior walls mostly have a metal framed structure with stone wool insulation and gypsum boards on either side. The floors also have a metal structure (U profiles), stone wool insulation and gypsum boards on either side. The floor material varies depending on the floor and the space. The apartment and bathroom doors are wooden, whereas the doors in the common spaces are either steel or steel and glass. The interior glass planes (mostly on the first floor) are made of laminated safety glass with aluminium frames.

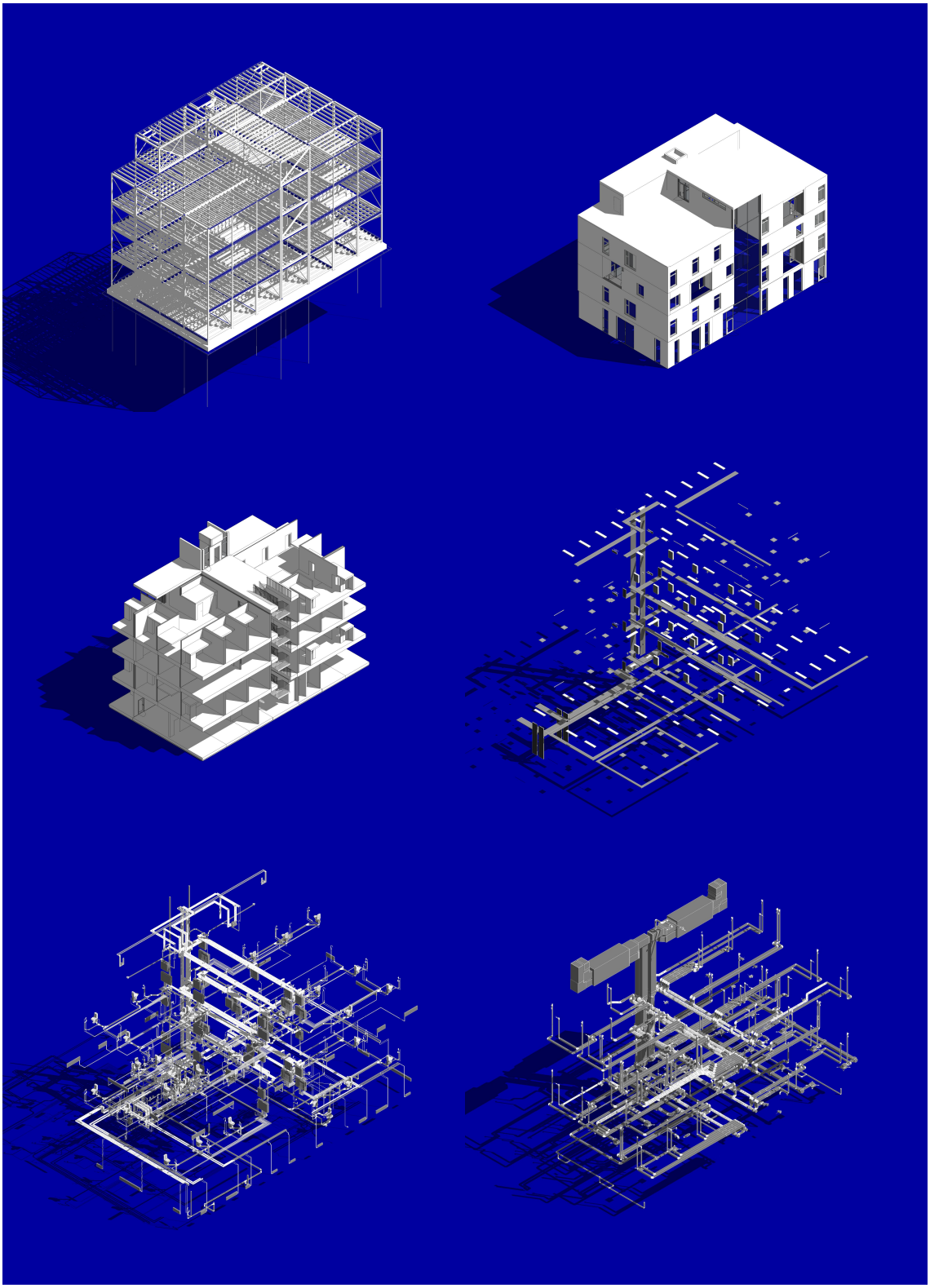
The kitchen cabinets consist of wood fibre boards and the kitchen tops of solid wood.

3.3.3.4 Service

One of the fundamental ideas behind the living lab was to make all installations accessible and easy to modify so that changes could easily be made and tested. This concept is well displayed in the building, as it is possible to see many of the installations through glass doors and windows. Due to the building having a modular structure and being a research facility, there are some differences in the installations compared to conventional

housing. In an interview with the consulting company responsible for planning most of the installations in the building, they noted that because the building is modular, it features two air handling units, which is unusual for a building of this size. They also mention that the installations have been adapted to fit the modular design, resulting in a greater number of systems than typically required, almost twice as much in this case. The fact that the small rooms in the shared clusters each have their own toilet, washing station and kitchen sink also contributes to the greater number of components in the *service* layer.

Most of the elements in the *service* layer have not been replaced or repaired since the construction in 2015, such as ducts, diffusers, and pipes. However, some of the changes that have been made include: the addition of an air-source heat pump in 2019/2020, the replacement of 8 bathroom tap mixers 2021/2022, the addition of two water accumulation tanks and fire detectors and the addition of building integrated solar panels installed on the west and east facade in the years 2016-2018, where the west facade is most extensively covered (140 m^2 of panels), along with the installation of roof top PV panels (50 m^2). The change of the mixers and fire detectors have not been taken into account in the evaluation.



3.3.4 Summary of the collected reuse inventory data

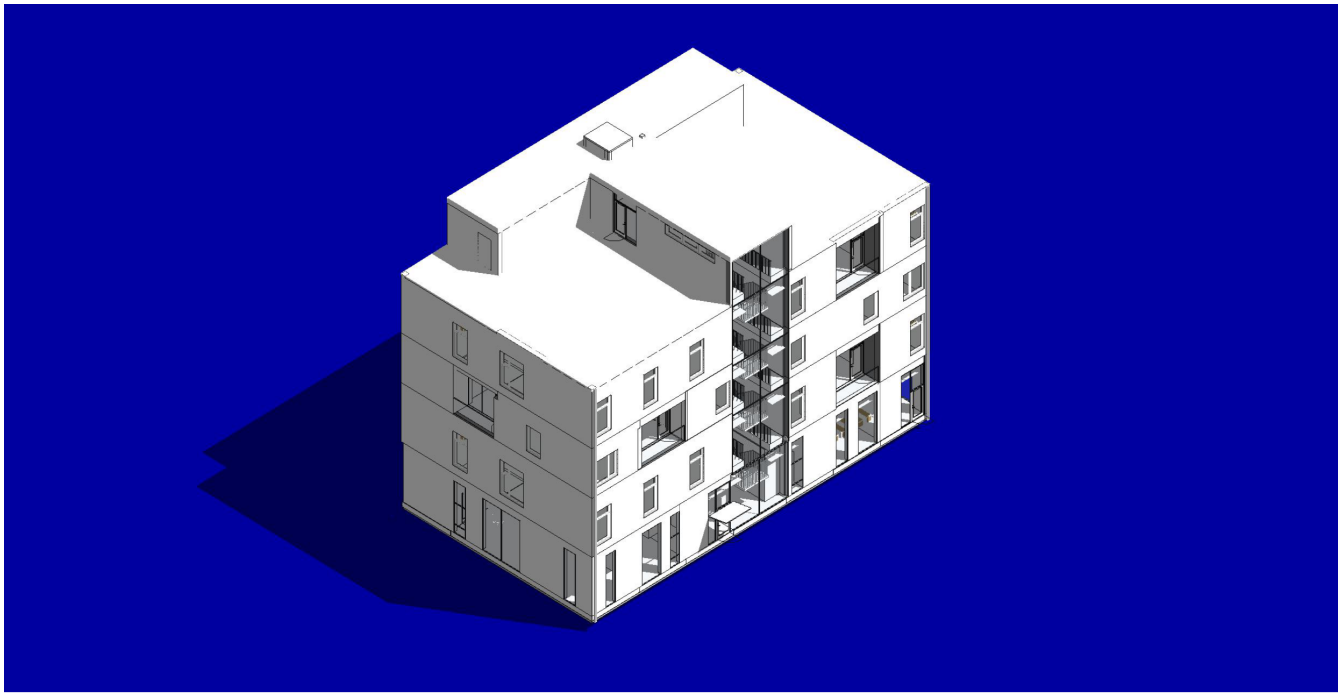
Here the results of the reuse inventory are presented. They include a summary of all documented building elements of the case study, sorted according to the shearing layers. The total weight of the building is compared with the weight of the inventoried elements to assess the ratio of the unknown, undocumented products. The distribution of the known weight as well as the known EC among the studied shearing layers is also included. Lastly we dive deeper into the distribution of weight and EC of different types of products in each shearing layer. This distribution has informed the decision of which products to select for reuse evaluation in the scenario assessment.

The building elements documented through the conducted reuse inventory are presented in figure 3.26. The elements are divided according to their respective shearing layers and the amount presented in various units. These results are based on data from available building documents, 3D-models, interviews and visual inspections. However, the weight could not be attained for all elements, due to time constraints and lack of data. In figure 3.27 the ratio of the known and unknown weight can be seen. The known weight is around 70% of the estimated total weight, which should be taken into account when observing the subsequent results.

The estimated total weight of the building is around 1020 tonnes. Each module, according to the manufacturer *Medic Solution*, weighs approximately 20 tonnes, including furnishings. With a total of 44 modules, along with the roof and concrete slab, this estimation accounts for the entire HSB LL weight.

It can be observed in figure 3.28 that out of the known weight *structure*, which includes the steel structure and the concrete foundation, make out almost half (48%), followed by *space plan* (31%), *skin* (17%) and *services* (3%). In figure 3.29 it can be observed that *Structure* makes out an even greater part of the total known EC at 61%, followed by *Space plan* (19%), *Skin* (15%) and *Service* (5%).

The diagrams in figure 3.30-3.33 show the relative contributions of each product type weight and embodied carbon for the products analysed within each layer. Steel components such as the modular structure in *structure* and the U-section beams in the floor slabs in *space plan* stand out. The gypsum boards in both *skin* and *space plan* contribute significantly, as well as the stone wool insulation and glass panes (including frames). The polyurethane insulation, facade panel and fibre cement boards are notable in the *skin* layer. In the *service* layer we can see that the duct insulation, elevator system, solar panels and radiators stand out.



Elements in the building:

Structure

44 pcs
/ 210 tons.. Steel modules

459 m²..... Concrete Foundation

Service

- 193,5 m²....PV panels
- 16 000 m...Cable
- 326 meter..Cable trays/ladders
- 24 pcs..... Distribution board
- 1 pcs..... Elevator

- 1018 m.....Ventilation ducts
- 4606 kg.....Duct insulation
- 2 pcs..... Air handling units
- 1 pcs..... Heat pump

- 39 pcs..... WC
- 3280 m.....Water pipes
- 520 m..... Waste water pipes
- 873 kg.....Pipe insulation
- 41 pcs..... Sink
- 91 pcs..... Tap mixer
- 2 pcs..... Accumulator tank
- 35 pcs..... Radiators

- 13 pcs..... Dishwasher
- 3 pcs..... Washing machine
- 3 pcs..... Tumble dryer/ drying cabinet
- 13 pcs..... Fridge/freezer
- 24 pcs..... Fridge
- 13 pcs..... Stove
- 10 pcs..... Oven/microwave

Skin

1170 m²..... Exterior wall

798 m²	Facade panel
228 m²	Sheet metal
228 m²	Rubber sheet
228 m²	Plywood
1553 m	V section lath (steel) 45 mm
1553 m	Wood lath 70 mm
400 m	Wood lath 22 mm
1170 m²	Windscreen
85,6 m³	Stone wool board
942 m²	Fibre cement board
140 m³	Polyurethane insulation
1170 m²	Plastic membrane
70,6 m³	Stone wool insulation
1953 m	Wood studs 120 mm
1553 m	Wood studs 45 mm
400 m	Steel studs 120 mm
2340 m²	Gypsum board

474 m²..... Roof

474 m²	Roof cover
474 m²	Plywood
792 m	C section 220 mm (steel)
269 m³	Insulation
474 m²	Plastic membrane
792 m	Hat section 25 mm (steel)
948 m²	Gypsum board

47 pcs.....Windows

- 343 m².....Glass panes
- 0,7 m³.....Aluminium

15 pcs..... Steel and glass doors

2 pcs..... Steel doors

32 m².....Glass railing

Space plan

xxx m²..... Interior wall

5717 m²	Gypsum board
306 m²	Fibre cement board
3936 m	Steel stud 95 mm
216 m²	Insulation
617 m²	Gypsum and glass fibre board

xxx m².....Floor

509 m²	Textile mat
6217 m²	Gypsum board
1805 m²	Food fibre board
335 m	Wood lath 28 mm
3015 m	Wood lath 70 mm
267 m³	Stone wool insulation
1296 m²	Non-woven fabric
1296 m	U section 200 mm (steel)
1296 m²	Underlay roofing felt
1296 m³	Oriented Strand Board (OSB)
509 m	Hat section 25 mm (steel)
609 m²	Plastic membrane
200 m³	Plywood
335 m	Wood stud 145 mm

432 m²..... Suspended ceiling (metal)

76 pcs.....Wooden doors

14 pcs..... Steel and glass doors

1 pcs.....Steel doors

- 89 m².....Glass panes
- 1,3 m³.....Aluminium

- 8 flights.. Metal stairs
- 11 m².....Landing

128 m.....Steel railing

- 8,4 m³.....Kitchen fittings (wood fibre)
- 2,2 m³.....Kitchen counter (massive wood)

4,6 m³.....Wardrobe (wood fibre)

Figure 3.26: Reuse inventory results

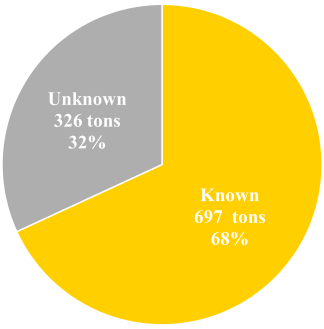


Figure 3.27: The ratio of known and unknown weights of building elements

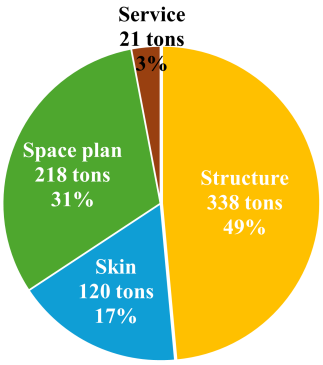


Figure 3.28: The distribution of known weight in the shearing layers

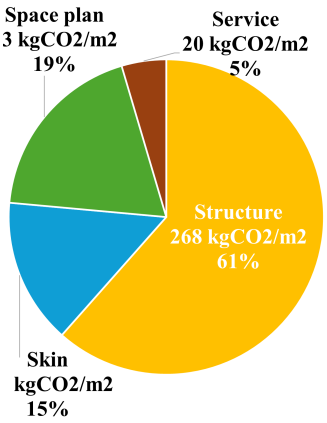


Figure 3.29: The distribution of known EC in the shearing layers

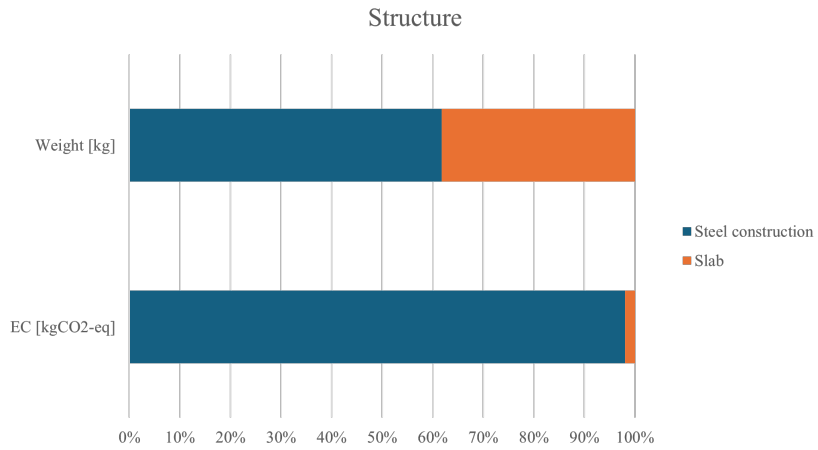


Figure 3.30: Weight and embodied carbon distribution of studied products in the Structural layer

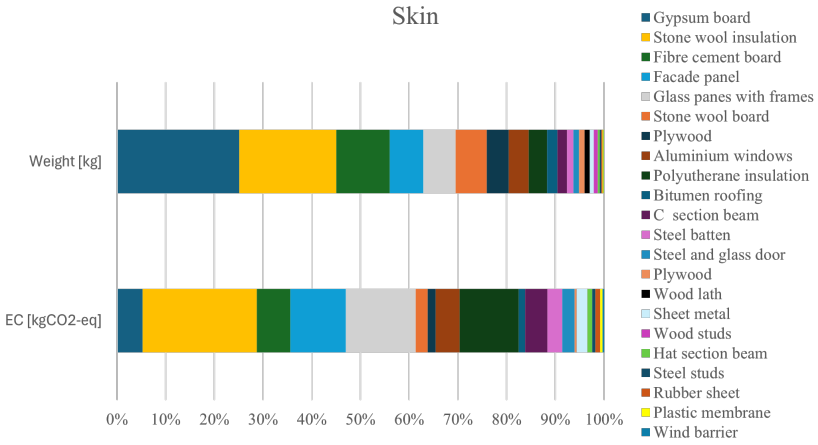


Figure 3.31: Weight and embodied carbon distribution of studied products in the Skin layer

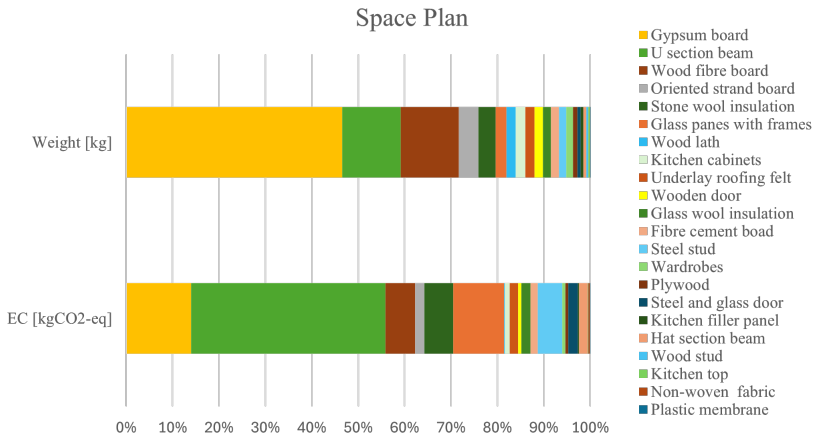


Figure 3.32: Weight and embodied carbon distribution of studied products in the Space plan layer

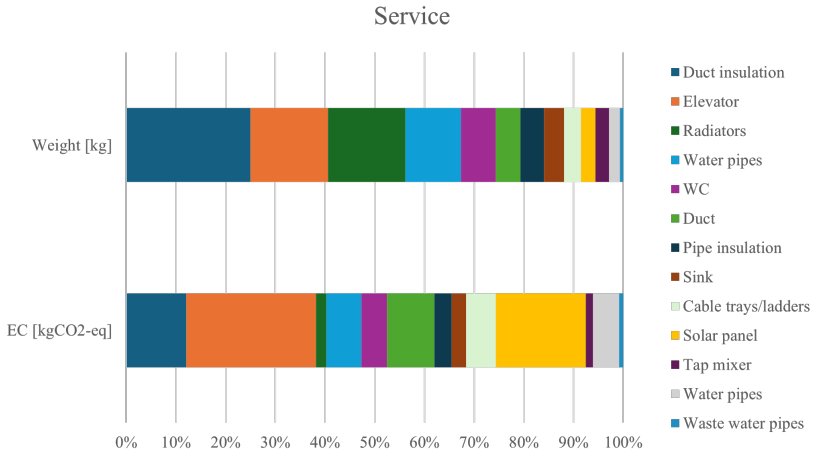


Figure 3.33: Weight and embodied carbon distribution of studied products in the Service layer

3.4 How we apply the framework to the case study

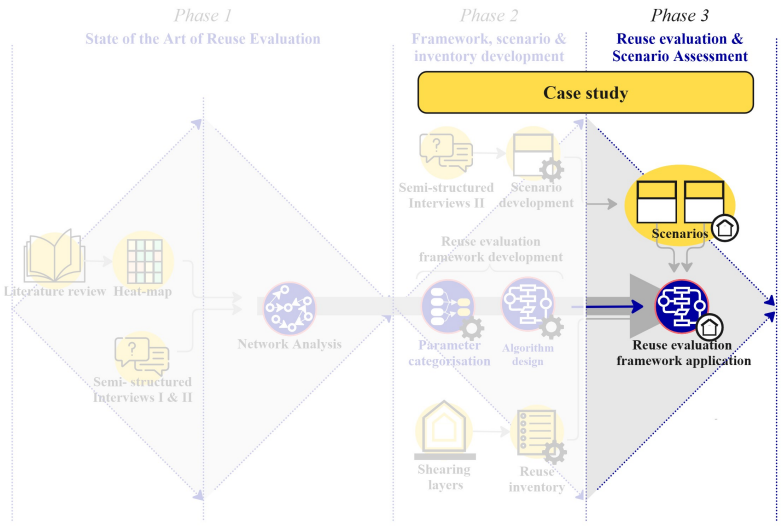
When applying the developed *Reuse evaluation framework* to the case study a number of simplifications and assumptions have been made, these are:

- Due to a lack of time to examine all building products, the three products with the highest EC from each shearing layers have been selected for evaluation.

- The physical and aesthetic condition of all elements is assumed to be of grade 1. This may overestimate reusability.
- When evaluating the reuse potential of the modules, overlapping elements, such as walls or facade panels, have not been considered. Parts of these elements need to be removed during disassembly and might not be reused. The weight of these parts are assumed to be negligible, but never the less this may result in an overestimation of reusability.
- When evaluating the reuse potential of the modules, the remaining service life of elements in the modules are not considered as they are assumed to remain within the modules during the relocation and continue to be used until they need to be repaired or replaced.
- When evaluating the modules, it is assumed that the foundation, elevator, stairs, glass panes spanning multiple modules and roof are not part of the modules themselves and need to be disassembled, transported and reassembled separately. These elements are therefore evaluated separately but without including the *Market demand*, as they are assumed to be used with the modules and therefore have the same demand as the modules.

4

Reuse evaluation & Scenario Assessment



4.1 RQ 2. Which type of building products can be considered reusable in the case study, and what factors affect their reusability?

The developed *Reuse evaluation framework* has been applied to selected building products considering the particular conditions of the two scenarios. In scenario 1 the modules

have been evaluated as one type of building product, whereas in scenario 2 components and materials within the modules have been evaluated. As the wall and floor elements of the case study are not modular and difficult to cut into modular units due to installations and connections, the individual material and component layers of the elements have been evaluated.

4.1.1 Selected building products

The selection of building products for reuse evaluation is based on the inventory results, where the product types with the highest EC per square meters (weight [kg/m^2] multiplied by EC [kg CO_2eq/kg]) from each shearing layer were chosen. 3 products from the layers *skin*, *space plan* and *service* were selected, and 2 products from the *structure* layer (as there are only two types of products in the structure layer - steel structure and foundation slab). For scenario 1, the modules are evaluated as a product that contains the selected components from the different layers. Out of the selected products it is assumed that all components, expect for the foundation slab and the elevator, are integrated into the modules and will simply be disassembled and transported as parts of a module. The reuse potential of these components therefore corresponds to the reuse potential of a module. For scenario 2 all the selected components are instead evaluated as individual products. See table 4.1.1 for a summary of the weight and EC of all evaluated products.

Table 4.1: Selected products for evaluation

Product	Shearing layer	Weight [kg/m^2]	EC [kg CO_2eq/kg]
Module (scenario 1)	all layers	308	1.48
Steel construction	structure	104	2.52
Foundation slab	structure	65	0.08
Gypsum board	space plan	21	0.227
U-section beam	space plan	14	2.55
Wood fibre board	space plan	14	0.39
Stone wool insulation	skin	12	1.28
Glass panes (including frame)	skin	4	1.32
Fibre cement board	skin	7	0.679

Continued on next page

Product	Shearing layer	Weight	EC
Elevator	service	1	2.97
Duct insulation	service	2	3.9
Radiator	service	1	4.1

4.1.2 Evaluation examples from each scenario

Here we show two examples of how the reuse potential of one product from each scenario has been estimated, see table 4.1.2. From scenario 1 the modules are evaluated as a product, and from scenario 2 the steel structure is evaluated as a product. The product properties of each product are described and then graded according to the grading system of the reuse evaluation framework. In table 4.1.2, "Parameter" is the product property being evaluated, "Parameter Connection" is the parameter that the property is being evaluated against, "type" is the characteristics of the property, and "grade" is the grade that the product is given for that particular property. In Appendix E the reuse evaluation of all selected products from the two scenarios can be found.

Table 4.2: Scenario 1: Evaluation example

		Module (scenario 1)		Steel structure (scenario 2)	
Parameter	Parameter Connection	*type*	*grade*	*type*	*grade*
Level of product information	Disassembly potential	info is available	1	info is available	1
	Time of reuse process	info is available	1	info is available	1
	Risk	info is available	1	info is available	1
Embodied carbon	Environmental impact	1.48 kg CO_2eq/kg (based on known EC)	0.7	2.52 kg CO_2eq/kg	0.9
Weight	Environmental impact	308 kg/m^2	1	104 kg/m^2	0.9
Connections	Disassembly potential	bolt/sealants	0.8	welded	0.1
	Time of reuse process	relatively fast	0.9	slow	0.1

Continued on next page

		Module (scenario 1)		Steel structure (scenario 2)	
Connection access	Disassembly potential	additional actions required, repairable damage	0.4	accessible, assuming all components are disassembled	1
	Time of reuse process	medium	0.5	slow	0.1
Crossings	Disassembly potential	Not relevant, assuming all components are disassembled	-	not relevant, assuming all components are disassembled	-
	Time of reuse process	medium	0.5	slow	0.1
Quality & Life expectancy	Environmental impact & Cost	assumed good condition, on average >38 out of 50 years	0.9	assumed good condition, >38 out of 50 years	0.9
	Technical feasibility	assumed good condition	Met	assumed good condition	Met
Dimensions	Technical feasibility	extensive renovations required to adjust	0.1	can be adjusted to standard dimensions	0.5
	Handling possibilities	needs to be handled with a crane	0.5	needs to be handled by medium sized machinery after having been cut	0.7
Technical properties	Technical feasibility	assuming that it follows the regulations of the new site*	Met	follows regulations	Met
Material	Raw materials with limited availability	mix of materials; mostly abundant	0.1	iron, carbon; abundant	0.1
	Consistency with biological or technical cycles and cascade	majority of weight non-renewable and non-biodegradable (techno-sphere)	0.9	iron, carbon; non-renewable and non-biodegradable (techno-sphere)	0.9

Continued on next page

		Module (scenario 1)		Steel structure (scenario 2)	
	Recovery potential	fracture toughness and tensile strength of the structure is high	0.9	high fracture toughness and tensile strength	0.9
	Handling possibilities	impact resistance, vibration resistance, compres-sion/stacking durability of the structure is high	0.9	high impact resistance, vibration resistance and compres-sion/stacking durability	0.9
Assembly type	Recovery potential	modular and pre-fabricated	0.9	non-modular, pre-fabricated	0.5
Function & Material	Existing business models	supply chain not established, but separate reuse services exist	0.5	established supply chain	1
	Part of large product flows	few products on the market, follow project specific requirements	0.1	commonly used but subject to different standards	0.5
Function, Dimensions & Technical properties	Value of equivalent new product	assuming high value	0.9	assuming high value	0.9
Reuse Potential		66%		73%	

* In the evaluation of the reuse potential of the modules it is assumed that the modular building, without any large changes (reconfigurations or renovations), follows the specific building regulations of the site of relocation. The existence or cost of such a location is not taken into account in the evaluation.

4.1.3 Evaluation results

In figures 4.1 - 4.8 below, the reuse potential of the evaluated products from both scenarios can be seen side by side. Each figure shows the results for the products of a specific shearing layer and scenario. For each product the grading in each of the three reuse criteria *Recovery potential*, *Environmental impact* and *Market readiness* is presented, as well as the aggregated final score, the reuse potential. The final score is given with equal weights to all three reuse criteria. If the product is not considered reusable, it is recommended for Upcycling/Recycling/Downcycling (U/R/D).

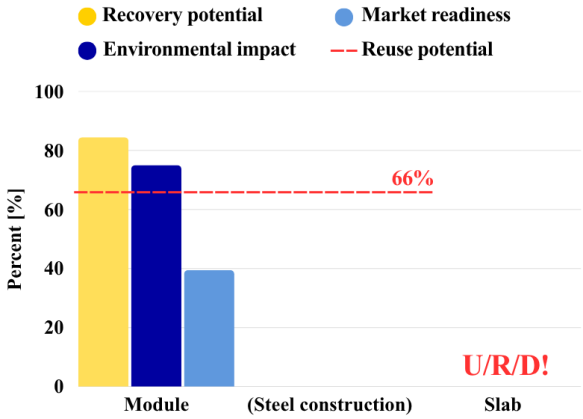


Figure 4.1: Scenario 1: *Structure layer*

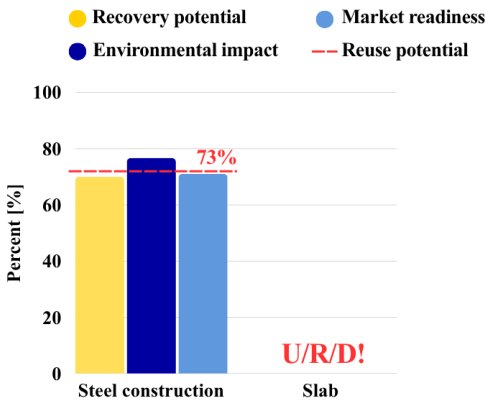


Figure 4.2: Scenario 2: *Structure layer*

4.1.3.1 Structure

In scenario 1 it can be observed that the modules (which contain components from all shearing layers) have been given the reuse potential of 66%. The modules are designed for disassembly and reassembly, which increases their reuse potential. However, difficulties in adapting the modules to the building regulations of a new site as well as renovating for a change of use, reduces the reuse potential considerably. The steel construction that is part of the modules also receive a score of 66% as they are integrated into the modules. The foundation slab is not part of the modules and considered non-reusable (U/R/D) due to its connections, being cast into the ground, as well as its dimensions, making it too difficult to handle as one unit.

In scenario 2 the steel construction is given a score of 73%. The steel members of the structure are welded, however, as they can be cut into standard dimensions and a local reuse service for steel is established, the reuse potential for the steel construction is higher in scenario 2 than in scenario 1. The foundation slab is given the same score in both scenarios as it is extracted in the same way. The connections and dimensions of the concrete slab make it non-reusable.

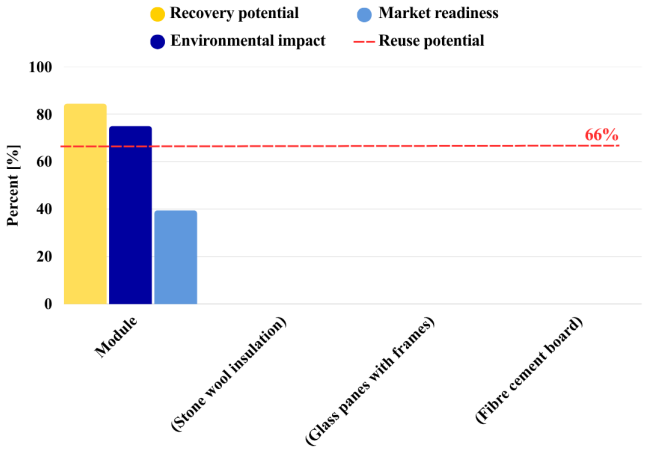


Figure 4.3: Scenario 1: *Skin layer*

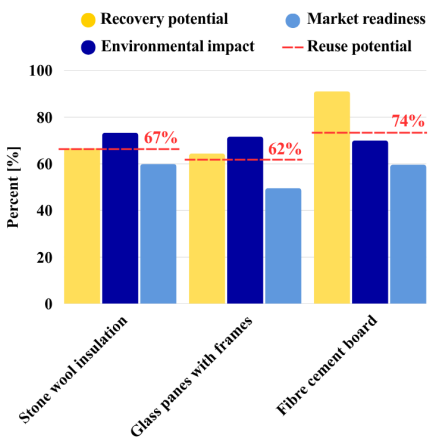


Figure 4.4: Scenario 2: *Skin layer*

4.1.3.2 Skin

In scenario 1 all the evaluated products in the *Skin*-layer are integrated into the modules, giving them an estimated reuse potential of 66%.

In scenario 2 the reuse potential of the three evaluated products differ slightly. For all of the three, the *Environmental impact* is 70% or slightly higher. The easiest product to recover is the fibre cement board, with a score of 91%, which can be found in the exterior wall connected with screws. The glass panes with frames and stone wool insulation are given the scores 64% and 67% respectively in regards to *Recovery potential*. Both are possible to extract without damage, but fragile during the handling process. In regards to *Market readiness* both the stone wool insulation and fibre cement board receive a score of 60%. They are of standard dimensions, but no specialised local reuse service for these types of products exist at this moment. The *Market readiness* of the glass panes with frames is estimated to be 50%. This is due to their large size and non-standardised dimensions.

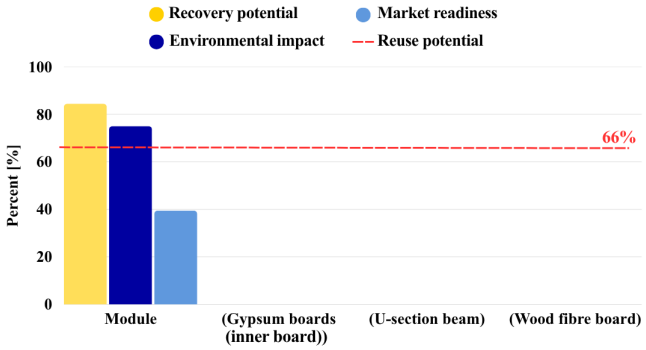


Figure 4.5: Scenario 1: *Space plan*

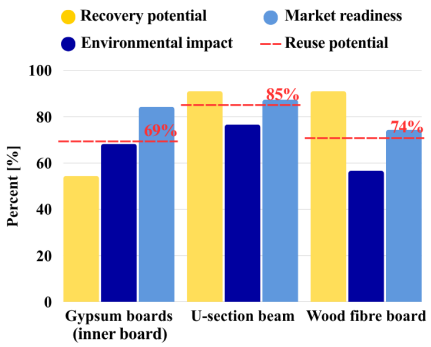


Figure 4.6: Scenario 2: *Space plan*

4.1.3.3 Space plan

In scenario 1 all the evaluated products in the *Space plan*-layer are integrated into the modules, giving them an estimated reuse potential of 66%.

In scenario 2 the reuse potential of the steel u-section beam (which is part the floor) is the highest at 84%. The gypsum board and wood fibre board, which are part of the interior walls, are estimated to have a reuse potential 69% and 74% respectively. The screw connection and durability of the steel give the u-section beam and Wood fibre board the highest *Recovery potential*, 91%, whereas the gypsum board receives a relatively low score, 54%, due to its material fragility. The *Environmental impact* of steel is also the highest, followed by gypsum and wood fibre. The market readiness for the three products are all relatively high. The u-section beam has the highest score as it can be handled by a local reuse service. The gypsum and wood fibre boards are part of large products flows and used in standard dimensions, which increase their market readiness.

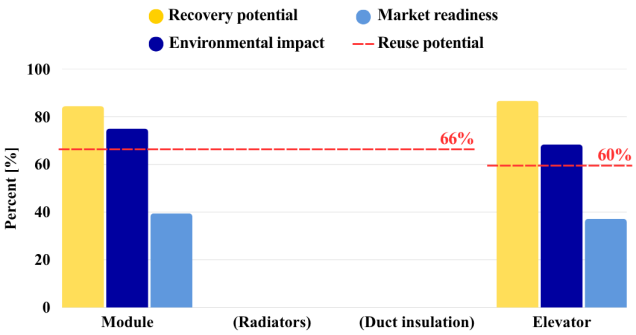


Figure 4.7: Scenario 1: *Service layer*

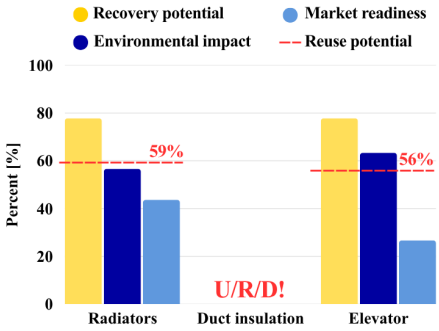


Figure 4.8: Scenario 2: *Service layer*

4.1.3.4 Service

In scenario 1, two of the evaluated products in the *service* layer - the radiators and duct insulation - are considered to be integrated into the modules, and therefore they are given the same estimated reuse potential as the modules, 66%. The elevator spans several modules vertically and therefore needs to be disassembled individually. It has a high *recovery potential* as it is assumed that most of the connections are screws/bolt, and relatively high *environmental impact* as it is largely made of steel. The *market readiness* is estimated to be the same as that of the modules as the elevator will be installed into the modules again after relocation. The estimated reuse potential of the elevator is slightly lower than that of the modules, 64% as compared with 66%, due to the assumptions that it takes longer to disassemble per mass of material and that the embodied carbon is less per volume.

In scenario 2, the radiators are estimated to have the highest reuse potential, 59%, of the selected products in the *service* layer, followed by the elevator, 56%. The duct insulation is not considered reusable as it is assumed that it will be irreversibly damaged in the disassembly process due to being glued. The radiators are relatively easy to recover, however, due to being an active component its efficiency reduces with time, lowering its *market readiness*. The elevator has a high *recovery potential* and *environmental impact* in both scenarios, but in scenario 2 the difficulties in adjusting the dimensions of the elevator to fit another building limits its *market readiness*.

4.1.4 Scenario assessment

In the evaluation results it can be observed that for some products their reuse potential is estimated to be higher if they are reused as a part of the modules, for example, the radiators and duct insulation. In these cases the short remaining service life and

low disassembly potential are irrelevant, which raises their potential for reuse. For many other products the estimated reuse potential is higher if they are disassembled and reused separately, for example, the steel construction, stone wool insulation and wood fibre board. This is because they are estimated to perform better on the reuse market in the form of separate components rather than as a part of a used modular system. For some products, such as the foundation slab, the estimated reuse potential is the same in both scenarios as it has to be disassembled separately and is limited by its low recovery potential.

The evaluated products are too few to point at a definite result in the scenario comparison. However, out of the evaluated products, the majority of the weight and embodied carbon has a slightly higher estimated reuse potential in scenario 2 as compared with scenario 1.

5

Discussion

5.1 Framework development

The reuse evaluation framework presented in this thesis represents the first iteration of a more systematic approach to reuse evaluation than has been previously suggested. This proposal has many flaws and the results should not be taken as absolutes. Here we will discuss in more detail which parts of the framework should/could be improved or reworked.

5.1.1 Data quality

The literature review and semi-structured interviews offered valuable insights into the factors influencing the reuse potential of building products. This understanding helped identify the parameters that were included in the framework, as well as how they influence each other. However, the literature review included only 14 studies, which may have resulted in some parameters being overlooked. Nevertheless, the approximately 50 parameters examined might be enough to provide a solid overview of the commonly used reuse parameters in the industry. The interviews were conducted as open-ended dialogues about reuse in the construction industry and were not directed towards discussing reuse parameters as such. This could be considered a limitation. If the interviews were conducted again with this specific purpose in mind the results might differ. Furthermore, while the number of times certain parameters were mentioned might suggest their importance, this factor was not taken into account when forming the reuse evaluation framework.

5.1.2 Grading system

The grading system used in this iteration of the framework is based on calculating the arithmetic mean of all related parameters. Another method of calculation could be the

geometric mean. The arithmetic mean is calculated by the summation of all the values (grades) and division of the total count (n) of parameters, whereas the geometric mean is calculated by multiplying all values and taking the nth root. When using the arithmetic mean we obtain the average of all grades, giving both the high and low scores equal weight. Conversely, when using the geometric mean a low grade has a much larger influence on the final score. In some cases, the geometric mean might give a more realistic result as, for certain parameters, a low grade would most likely prevent the reuse of the product. For example, a low grade for *Quality & life expectancy*. However, in other cases a low grade for one parameter might be compensated for by a high grade for another parameter. For example, a low grade for *Material* (durability) might be compensated for by a high grade for *Connections*, as a fragile product could be easy to reuse if it is easy to extract. In this case the arithmetic mean might give a more realistic result. Both methods of calculation could be useful for different combinations of parameters.

Another aspect of the grading system is the weight (importance) given to each parameter. In this iteration of the framework all parameters are given the same weight, with the exception of the *Key reuse criteria* (*Recovery potential*, *Environmental impact* and *Market readiness*). Due to a lack of knowledge on the relative importance of each parameter, no attempt was made at assigning weights for the numeric grading. However, for some parameters a product needs to fulfil certain standards in order to be considered feasible to reuse, such as technical requirements, in which case the grade "Met" or "Not met" is assigned. This could arguably be considered a more "important" parameter with higher weight. Apart from this, weighting could/should be further explored.

5.1.3 How to interpret the Reuse potential

The estimated reuse potential of a product is presented as a percentage, where close to 0% potential signifies a low chance of successful reuse and close to 100% signifies a high chance. For results closer to 50%, the percentage might be hard to interpret. What does it mean if the estimated reuse potential of a product is 50%? Is 50% of the product reusable? Is the product reusable 50% of the time? When deciding whether or not to attempt to reuse a product, is a 50% reuse potential a "yes" or a "no"? The answer is not clear, and it will be up to the user of the framework to decide at what estimated reuse potential reuse is feasible. In a comparison of two types of products or two different scenarios, the "winner" is whatever product/scenario gives the higher potential. However, when deciding whether or nor to pursue reuse when the percentage is low in both cases necessitates weighting and comparing the grades of the *Recovery potential*, *Environmental impact* and *Market readiness*. A low *Recovery potential* might require more funding, a low *Environmental impact* might require high market demand, and low *Market readiness* might require internal reuse or a predetermined receiving

project.

5.2 Implications for the case study

What do the reuse evaluation results imply in regards to the best reuse approach for the case study? As observed, the unweighted reuse potential for the majority of the sample of evaluated products are higher in scenario 2 (reusing products individually). However, if we observe the reuse potential of the modules in scenario 1 in more detail it can be seen that, while both *Recovery potential* and *Environmental impact* are relatively high, the low *Market readiness* reduces the potential significantly. This implies that internal reuse could be a good approach. As *Costs* and *Technical feasibility* are still relevant parameters for internal reuse, despite being connected to *Market readiness*, these still need to be assessed. In the assessment of *technical feasibility* it is assumed that the modular building follows the technical and aesthetic building regulations at the relocation site. Furthermore, it is noted that to change the layout of the modules extensive renovations are required, resulting in high costs. Therefore, a successful reuse in scenario 1 hinges on finding a site with suitable regulations and that the need for renovations is minimised. If these conditions cannot be met, full disassembly and reuse of individual products (or product types) is recommended.

6

Conclusion

6.1 Research Findings

Through this study, involving the development of a framework for preliminary reuse evaluation and the implementation of the framework on a case study, the following research findings, divided into theoretical and practical findings, were made:

Theoretical findings

- The literature review has revealed large knowledge gaps regarding methods for evaluating the reuse potential of used building products.
- The network analysis has shown the complex relationships between different reuse evaluation parameters.
- Assigning precise grades for certain product properties is challenging due to a lack of knowledge and practice of reuse.

Practical findings

- The framework implies that, based on the evaluation of the sampled building products, scenario 2 (reuse of individual products) offers greater overall reuse potential than scenario 1 (reuse of modules/building). However, if the modules were to be reused internally, assuming that the building follows the regulations of the site of relocation and does not need to be renovated extensively, scenario 1 would give the highest reuse potential.
- Products of higher complexity are often less adaptable and therefore result in fewer reuse opportunities.
- Comparing the Reuse potential of individual building components and whole building modules is difficult due to differences in complexity. Here the unit of comparison needs to be based on provided utility (economic, environmental and/or social).

6.2 Future research

To improve the suggested *Reuse evaluation framework* and further assess the environmental and economic impacts of the case study, the following future research is suggested:

- Further analysis of the outcomes of past and future case studies on reuse needs to be made in order to better define and grade the reuse evaluation parameters.
- Conduct interviews more targeted at defining reuse evaluation parameters as such.
- Instead of using *Reuse potential* as the result of the evaluation, research on how to provide more practical and easy to interpret suggestions, based on the combination of grades of different parameters, could be useful.
- In order to acquire more representative results for the scenarios of the case study, a full evaluation of all product types in the building needs to be conducted.
- Combine the preliminary results of the reuse evaluation with an LCA and LCC.
- Research how to include social impact as reuse evaluation parameter(s).

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A

Reuse evaluation parameters from literature

In the following tables key properties and criteria for reuse of building products, according to different studies, are presented. The *Parameter* (property or criteria) is given, followed by an indication of "Out of scope" (OOS), if the parameter was not included in our analysis due to being outside of the scope of this thesis. The proposed *Grading* system, as well as the *Definition* and suggested *Parameter input* (what other parameters influence this parameter) are also stated if given by the authors. The *Parameter input* are marked with [OOS] to indicate if they are outside of the scope.

Table A.1: Key parameters for reuse of building products according to Bellini et al. [2024]

Parameters	OOS	Grading	Definition	Parameter input
Environmental evaluation (GHG emissions)		1–5, with 1 indicating low carbon saving potential	Measures carbon saving potential of reusing products compared to using a new product. Suggests using LCA or ISO 14044:2006 (Specifies LCA requirements and guidelines).	• Logistics and storage (e.g. transport distance and storage requirements) [OOS] • Embodied carbon (through EPDs) • Quantity [OOS]*

Technical requirement		0–1, indicates whether the requirements are met, with a value of 1 indicating 'yes' and 0 indicating 'no'.	To ensure that the products meet the standard and relevant regulatory requirements (e.g. TEK17, NS standards or CE marking).	• CE-marking (if available) • Condition • Exposure • Future use [OOS] • Structural, fire, acoustic and thermal properties
Quality and life expectancy		1–5, The grading is based on the following: 1=old and worn out 2=some wear 3=cleaning required 4=acceptable 5=good.	This criteria is first assessed with a visual inspection, and it is suggested that further tests should be performed before reuse.	• CE marking (if available) • Condition (visual inspection) • Maintenance history
Possibility for disassembly		0–1, graded as 0 if dismantling is not possible and 1 if it can be disassembled	The possibility to disassemble a product. Measured through visual inspection. This assessment is based on ISO 20887:2020 (Design for Disassembly and Adaptability).	-
Logistics and storage	[X]	0–1, rated as 1 if the product needs to be stored before reuse	Is assessed based on if storage is needed before instalment in a new project. This criterion depends on the receiving project.	• Risk evaluation • Quantity • Storage area • Transport
Location in the project	[X]	0–1, evaluated as 1 if the product is possible to include in a new design/project	Is assessed based on if the building product fits into a particular receiving project.	• Quantity • Project plan • Placement suitability & compliance

Risk evaluation	1–5, where a rating of 5 signifies low risk, indicating a high potential for reuse.	This criterion is affected by multiple factors, and the paper highlights the necessity of employing a consistent and organised method for this measurement. One recommendation is to follow the ISO 31000:2018 (Risk Management).	• Quantity* [OOS] • Storage duration & condition (risk of degradation and added uncertainty/cost if items must be stored) [OOS] • Life expectancy • Future use [OOS] • Accountability (defined as responsibility for approvals and warranty on reused products) [OOS] • Level of information and data
Cost evaluation	1–5, where a rating of 5 signifies low cost, indicating a high potential for reuse.	Costs can be affected by a range of factors, such as logistics and condition of the product, and there is therefore a need for a standardised measurement approach. One method to consider is life Cycle Costing (LCC). A low cost is assigned a higher grade.	• Quantity* [OOS] • Storage duration, conditions and handling [OOS] • Logistics [OOS] • Availability [OOS] • Budget [OOS] • Condition • Quality • Life expectancy • Risk-related factors • Future use [OOS]

*Quantity isn't relevant in the preliminary evaluation. It matters in later stages and once there's a receiving project.

Table A.2: Key parameters for reuse of building products according to Iacovidou and Purnell [2016]

Parameters	OOS	Grading	Definition	Parameter input
Action		-	The component's physio-mechanical role in its earlier use: structural, semi-structural, modular or functional.	
Material & Quality		-	The components material, for example concrete, steel, timber, glass, etc. and material quality, such as strength grade for structural components.	• Material • Quality
Deployment		-	The type of building the components was used in. e.g. domestic housing, high-rise housing, commercial, industrial or infrastructure.	-
Exposure		-	The environmental conditions the component has been exposed to e.g. outdoor, indoor, marine, chemical/corrosive, high temperature. They suggest determining this classification with the help of, for example, weather records, details of chemical environments, and Eurocode EN1992* exposure classes.	• Indoor or outdoor placement • Weather exposure • Chemical exposure • Temperature exposure
Loading		-	The physical loading the component has had e.g. Static loading, fatigue loading or impact/transient loading	• Static loading • Fatigue loading • Impact transient loading
Recovery	[X]	-	How the component is recovered, e.g. general demolition, component-specific recovery, DfD process, and what is the risk of damage/ contamination.	• Recovery method • Risk of damage • Risk of contamination

Residual		-	The component's preserved structural and functional features, such as dimensions, structural capacity, and functional capacity. The source of this information should be identified, e.g. if on-site tests have been made, or if the assumptions are based on loading conditions, environmental exposure and remaining service life.	• Structural capacity • Functional capacity • Dimensions
Connections		-	How easily the component can be connected to other projects, such as through standard connections like bolts, or if there is no connector because the component was cut from a non-reversible connection.	-
Availability	[X]	-	Details about the time-wise availability, location, and quantity of components for other projects as well as the market maturity of these components.	• Time arising • Place arising • Amount arising • Market maturity for the specific building product
Generation		-	How many times the component has been reused, and whether the new application qualifies as upcycling, recycling or down-cycling/cascading.	• Number of times the component has been reused • If the component will be upcycled, recycled or down-cycled/cascaded** [OOS]

*European design standards for concrete structures [European Commission, Joint Research Centre]
**Upcycling/recycling/down-cycling is out of scope. The reuse evaluation exists to decide that, so it can't be an input when assessing reuse potential.

Table A.3: Key parameters for reuse of building products according to Lindborg et al. [2024]

Parameters	OOS	Grading	Definition	Parameter input
Dimensions		-	-	-
Material and colour		-	-	-
Functional requirements		-	Including, fire, acoustic and protection requirements	• Fire resistant properties • Acoustic properties • Protection class
Level of product information		0 to 5 stars	-	-
Aesthetic condition		0 to 5 stars	-	-
Functional condition		0 to 5 stars	-	-
Time-wise availability		-	-	-
Total climate savings		-	Given as kg CO_2eq/component	• Embodied Carbon
Total quantity*	[X]	-	Total quantity of the product, measured in number of units, area or volume.	-
Total amount		-	The total weight of the product, measured in kilograms	-

*Refer to the comment in table A.1 regarding *Quantity*, the same rationale applies here.

Table A.4: Key parameters for reuse of building products according to Janson et al. [2022]

Parameters	OOS	Grading	Definition	Parameter input
Demand (internal or external)		1–5	-	-

Disassembly potential		1–5	-	-
Commercial volume*	[X]	1–5	-	-
Age		1–5	According to the authors reusable building products are typically between 5 and 15 years old, with some exceptions.	-
Climate impact		1–5	-	-
Form		1–5	-	-
Function		1–5	-	-
Condition		1–5	-	-
Time		1–5	-	-

*Refer to the comment in table A.1 regarding *Quantity*, the same rationale applies here.

Table A.5: Key parameters for reuse of building products according to Sveriges Kommuner och Regioner (SKR) [2024]

Parameters	OOS	Grading	Definition	Parameter input
Market demand (internal or external)		-	-	-
Disassembly potential		-	-	-
Commercial volume*	[X]	-	-	-
Age		-	-	-
Climate impact		-	-	-
Form		-	-	-
Function		-	-	-
Condition		-	-	-
Time		-	-	-

Unique value		-	-	-
Waste hierarchy	[X]	-	-	-

*Refer to the comment in table A.1 regarding *Quantity*, the same rationale applies here.

Table A.6: Key parameters for reuse of building products according to Linus Brander [2021]

Parameters	OOS	Grading	Definition	Parameter input
Assembly type		-	If the building product is site-built or pre-manufactured	-
Dimensions		-	Cross section dimensions	-
Length		-	The length of the component.	-
Type of product		-	Material or component type (e.g I-beam)	• Material • Dimensions
Quantity*	[X]	-	The available amount of the building product.	-
Age/Year		-	Age of the building product to help estimate remaining service life. Could be used to acquire information on building norms at the time of installation or the risk of there being hazardous materials in the building part	-
Condition		OK, poor, surface rust or uncertain	Ocular evaluation of damage (if present) that affects the structural integrity. This is further examined through different tests to assure quality.	• Physical condition (as assessed through visual appearance and then further testing) • Previous use • Exposure

Previous use	From low to high physical impact on the product: Offices/ Housing, Restaurants/ Storage/ Shops, Industry/ Garage/ Workshop/ Swimming hall/ Animal facilities	The previous use can affect the condition of the product.	-
Exposure	-	Exposure to factors such as moisture and temperature variations, indoor or outdoor conditions, etc. These factors could affect the condition of the product.	• Indoor or outdoor conditions • moisture levels • temperature
Disassembly potential	easy, medium, difficult, uncertain	The possibility to disassemble or extract the component	• Connections
Handling possibilities	-	The ease of handling the product without risks. Handling heavy building components is risky and must be evaluated to maintain a safe environment.	-

*Refer to the comment in table A.1, the same rationale applies here.

Table A.7: Key parameters for reuse of building products according to White [2021]

Parameters	OOS	Grading	Definition	Parameter input
BSAB code	[X]	-	Standardised Swedish codes. Each building part and type of construction work is given a common code used to structure data and help communication [Svensk Byggtjänst, 2025]	-
Environmental impact		A= large climate footprint, C= low	The climate footprint (for installations, includes use-phase impacts) of the product.	• Embodied Carbon

Disassembly potential	A=easy, C=complicated	Grades if the disassembly and reassembly of the component is easy or complicated.	-
Economy	A = high new-purchase cost & long remaining life, C = low cost + short remaining life.	Assessed by considering both the cost of a new equivalent product and the estimated remaining service life of the used product.	• Value of equivalent new product • Remaining service life

Table A.8: Key parameters for reuse of building products according to Karin Hedén [2022]

Parameters	OOS	Grading*	Definition	Parameter input
Reduced climate impact		Low, Medium, High	Calculated as if reused items replace new products. Suggests using climate data from Boverket's climate database or co2data.fi, and EPDs when needed (impacts from any reconditioning, storage and transport were excluded)	• EPDs of equivalent new products
Potential for reuse		Low, Medium, High	-	-
Raw materials with limited availability		Low, Medium, High	-	-
Quantity**	[X]	Low, Medium, High	-	-
Economic value vs new product		Low, Medium, High	-	-
Disassembly potential		Low, Medium, High	Ease of removing the product intact for reuse, based on inventory, trial disassembly, and simple function tests during the reuse-demolition.	-
Condition		-	-	-
Material		-	-	-

Function	-	-	-
Dimensions	-	-	-

*The report does not define a scale for the grading, it presents them qualitatively in a value wheel
**Refer to the comment in table A.1, the same rationale applies here.

Table A.9: Key parameters for reuse of building products according to Geldermans [2016]

Parameters	OOS	Grading	Definition	Parameter input
Exact composition of material or product		-	-	-
Sustainable origin; ability of the material or product to be "re-incarnated" through many iterations		-	The material composition, presence of toxic substances	• Material • Toxicity
Non-toxic	[X]	-	-	-
Consistency with biological cycles and cascade (or one or more technical cycles)		-	-	• Material
Performance quality of the material or product		-	-	-
Intended (re) use path of the material or product	[X]	-	For a material to be reused again and again in high-grade cycles the intended lifespan and use within a building needs to be anticipated.	• Intended Lifespan • Intended use
Performance time of the material, product, component or service		-	Defining the lifespan/service life.	-

Connections applied between materials, products or components		-	-	-
Dimensioning of material, product or components		-	-	-
Quality of the registration system and process	[X]	-	Assessment of the quality control of the data and how it is managed.	-

Table A.10: Key parameters for reuse of building products according to Fastighetsägarna Stockholm [2024]

Parameters	OOS	Grading	Definition	Parameter input
Climate effect		an axis from low to high	Depends on the climate footprint/ embodied carbon of the equivalent new building product, as well as the remaining service life of the used product.	• Climate footprint of equivalent new product • Remaining service life of the product
Economic effort		an axis from low to high	Depends on the time required for the reuse process of a building product, as well as the cost of the reuse process	• Time of reuse process • Cost of reuse process

Table A.11: Key parameters for reuse of building products according to Sandra Moberg [2022]

Parameters	OOS	Grading	Definition	Parameter input
High climate effect		-	The authors identify building products with high embodied emissions, large volumes, and those that have a high flow rate as the products with the greatest potential for avoided carbon emissions.	• Building product with high embodied emissions (extraction/manufacture) • Large volumes/heavy materials • High flow products (often replaced or available in large numbers)

Table A.12: Key parameters for reuse of building products according to Abu-Ghaida et al. [2024]

Parameters	OOS	Grading	Definition	Parameter input
Recovery Potential				• Disassembly potential • Material fragility
Disassembly Potential		0.1-1		• Connection types • Connection access • Form containment • Crossings
Connection type		0.1-1		-
Connection access		0.1-1		-
Form containment		0.1-1		-
Crossings		0.1-1		-

Table A.13: Key parameters for reuse of building products according to Business Region Göteborg [2025]

Parameters	OOS	Grading	Definition	Parameter input
Market readiness		Highest potential, higher potential, or high potential	Indicate how ready a building product category is for a large-scale reuse market.	• Economic profit • Market demand • Technical feasibility

Table A.14: Key parameters for reuse of building products according to [Yang et al., 2025]

Parameters	OOS	Grading	Definition	Parameter input
Ease of disassembly		-	The ability to disconnect building components.	• Modular design • Material • Connection type
Take-back mechanisms		-	Ownership remains with the client, and the products are returned to a new contractor for reuse.	-
Technology-driven traceability	[X]	-	It is important to have some sort of tracing (e.g QR code) of the building product during the reuse process (disassembly, transport, reassembly)	
Ease of value retention		-	The ability and ease to implement a value retention process, including repairing, replacing and refurbishing building products for them to be reused.	-

B

Aggregation of the parameters

Parameter	Similar parameters	Reference
Environmental impact	Env. evaluation	*1.Bellini*
	Climate impact	*4.Janson*
	Climate impact	*5.SKR*
	Env. impact	*7.White*
	Reduced climate impact	*8.Heden*
	Climate effect	*10.Fastighetsägarna*
	High climate effect	*11.Moberg*
	Total climate savings	*3.Lindborg*
Embodied Carbon	Embodied Carbon	*1.Bellini*
	Embodied Carbon	*3.Lindborg*
	Embodied Carbon	*7.White*
	Climate footprint of eq. new product	*10.Fastighetsägarna*
	High embodied carbon	*11.Moberg*
	EPD of eq. new product	*8.Heden*
Economic profit	Economy	*7.White*
	Economic profit	*13.BRG*
Costs	Economic Effort	*10.Fastighetsägarna*
	Cost evaluation	*1.Bellini*
	Cost of reuse process	*10.Fastighetsägarna*
	Costs	*10.Fastighetsägarna*
Value of eq. new product	Value of eq. new product	*7.White*
	Economic value vs. new product	*8.Heden*

Quality & Life expectancy	Quality & Life expectancy	*1.Bellini*
	Quality	*2.Iacovidou*
	Performance quality/performance time	*9.Geldermans*
	Age	*4.Janson*
	Age	*5.SKR*
	Age/year	*6.Brander*
	Remaining service life	*7.White*
	Remaining service life	*10.Fastighetsägarna*
Condition	Condition	*4.Janson*
	Condition	*5.SKR*
	Condition/physical condition	*6.Brander*
	Condition	*8.Heden*
	Condition	*1.Bellini*
	Functional condition/aesthetic condition	*3.Lindborg*
	Functional capacity	*2.Iacovidou*
Technical feasibility	Technical requirement	*1.Bellini*
	Technical feasibility	*13.BRG*
	Functional requirement	*3.Lindborg*
	Residual	*2.Iacovidou*
Technical properties	Structural capacity	*2.Iacovidou*
	Structural properties	*1.Bellini*
	Fire properties	*1.Bellini*
	Fire resistant properites	*3.Lindborg*
	Acoustic properties	*1.Bellini*
	Acoustic properties	*3.Lindborg*
	Protection class	*3.Lindborg*
	Thermal properties	*1.Bellini*
Recovery potential	Recovery potential	*12.Abu-Ghaida*

Disassembly potential	Possibility for disassembly	*1.Bellini*
	Disassembly potential	*4.Janson*
	Disassembly potential	*5.SKR*
	Disassembly potential	*6.Brander*
	Disassembly potential	*7.White*
	Disassembly potential	*8.Heden*
	Disassembly potential	*12.Abu-Ghaida*
	Ease of disassembly	*14.Yang*
Handling possibilities	Handling possibilities	*6.Brander*
Assembly type	Assembly type	*6.Brander*
	Modular design	*14.Yang*
Risk	Risk evaluation	*1.Bellini*
Function	Function	*5.SKR*
	Function/type of product	*6.Brander*
	Function	*8.Heden*
Dimensions	Dimensions	*3.Lindborg*
	Form	*4.Janson*
	Form	*5.SKR*
	Dimensions	*6.Brander*
	Dimensions	*8.Heden*
	Dimensioning	*9.Geldermans*
	Dimensions	*2.Iacovidou*
Part of large product flow	Large product flow	*11.Moberg*
Weight	Weight/Total amount	*3.Lindborg*
	Heavy materials	*11.Moberg*
Market readiness	Market maturity	*2.Iacovidou*
	Market maturity	*13.BRG*

Market demand (internal or external)	Demand (Internal or external)	*4.Janson*
	Market demand (internal or external)	*5.SKR*
	Demand	*13.BRG*
Previous use	Previous use	*6.Brander*
	Deployment	*2.Iacovidou*
	Generation/number of uses	*2.Iacovidou*
Previous physio- mechanical use	Previous physio-mechanical role	*2.Iacovidou*
Maintenance history	Maintenance history	*1.Bellini*
Number of previous uses	Ability of the material or product to be reinc	*9.Geldermans*
	Ease of value retention	*14.Yang*
Material	Material	*2.Iacovidou*
	Material, colour	*3.Lindborg*
	Material	*6.Brander*
	Material	*8.Heden*
	Material/Exact composition of material or pr	*9.Geldermans*
	Material	*14.Yang*
	Material fragility	*12.Abu-Ghaida*
Consistency with biological or techn	Consistency with biological or technical cycl	*9.Geldermans*
Raw materials with limited availabil	Raw materials with limited availability	*8.Heden*
Time of reuse process	Time of reuse process	*10.Fastighetsägarna*
	Time	*4.Janson*
	Time	*5.SKR*
Exposure	Exposure	*2.Iacovidou*
	Exposure	*6.Brander*
	Exposure	*1.Bellini*

Wheather exposure	Wheather exposure	*2.Iacovidou*
Chemical exposure	Chemical exposure	*2.Iacovidou*
Moisture exposure	Moisture exposure	*6.Brander*
Indoor/outdoor placement	Indoor/outdoor	*2.Iacovidou*
	Indoor/outdoor	*6.Brander*
Temperarure exposure	Temperarure exposure	*2.Iacovidou*
	Temperature	*6.Brander*
Loading	Loading	*2.Iacovidou*
Static loading	Static loading	*2.Iacovidou*
Fatigue loading	Fatigue loading	*2.Iacovidou*
Impact transient loading	Impact transient loading	*2.Iacovidou*
Connections	Connections	*2.Iacovidou*
	Connections	*6.Brander*
	Connections applied	*9.Geldermans*
	Connection types	*12.Abu-Ghaida*
	Connection type	*14.Yang*
Connection access	Connection access	*12.Abu-Ghaida*
Crossings	Crossings	*12.Abu-Ghaida*
Level of product information	Level of product information	*3.Lindborg*
	Level of information and data	*1.Bellini*
	CE-marking	*1.Bellini*
Business models	Take-back mechanisms	*14.Yang*

C

Interview questions

C.1 Semi-structured interview I questions

Interview I addressed current reuse practices within the Swedish building industry. All interviewees were asked the same questions. However, adjustments were made to the questions after insights gained from the interviewee. This resulted in the reformulation of certain questions and the inclusion of additional examples to enhance clarity and relevance. Below are the original questions in Swedish, followed by their English translations.

Samtal om Återbruk [Swedish]

1. Introduktion
   (a) Vilka är vi?
   (b) Vad är ”Moving HSB Living Lab”?
   (c) Målet med projektet
      i. Våra nuvarande forskningsfrågor:
2. Om dig
   (a) Kort om dig och din bakgrund
   (b) Din roll i din organisation/ditt företag
   (c) Vad är din koppling till cirkularitet?
3. Cirkularitet i byggindustrin
   Berätta lite om . . .
   (a) Vilken fas i byggnadens livscykel arbetar du mest med?
   (b) Fallstudier och erfarenheter
   (c) Vad skulle du vilja undersöka mer i framtida fallstudier?
4. Framtiden för återbruk?
   (a) Vad är en **viktig oklarhet** kring utvecklingen av cirkularitet?

Exempel: grad av modularitet, krav på kvalitet, vad mer?

5. Cirkularitet i byggindustrin
   Berätta . . .
   (a) Vad skulle ni vilja att man undersökte i ett forskningsarbete kring återbruk?
   (b) . . . med avstamp i ”Moving HSB Living Lab”?
6. Praktiska metoder – Berätta lite om era arbetssätt och verktyg
   (a) Design, t.ex. Design for Deconstruction, Design for Reuse och ?
   (b) Digitala verktyg
      i. Inventeringsverktyg, t.ex. BIM, Excel, Material Passports, CCBuild, Dacke, Loopfront, Palats och ?
      ii. Projekteringsverktyg, t.ex. BIM och ?
      iii. Marknadsverktyg, t.ex. Rebygg, Palats, CCBuild, Återbruksbyrån.
   (c) Beräkningsverktyg (ekonomiskt, miljömässigt), t.ex. LCA, LCC, CMA och ?

   Tack för samtalet!

Conversation on Reuse [English]

1. Introduction
   (a) Who are we?
   (b) What is “Moving HSB Living Lab”?
   (c) The goal of the project
      i. Our current research questions:
2. More about you
   (a) Briefly about you and your background
   (b) Your role in your organisation/company
   (c) What is your connection to circularity?
3. Circularity in the construction industry
   Tell us a bit about . . .
   (a) Which phase of the building life cycle do you work with the most?
   (b) Case studies and experiences
   (c) What would you like to investigate further in future case studies?
4. The future of reuse?
   (a) What is an **important uncertainty** in the development of circularity?
      Examples: degree of modularity, quality requirements, what else?
5. Circularity in the construction industry
   Tell us . . .
   (a) What would you like to see investigated in research on reuse?
   (b) . . . starting from “Moving HSB Living Lab”?
6. Practical methods – Tell us a bit about your ways of working and your tools

(a) Design, e.g., Design for Deconstruction, Design for Reuse, and ?
(b) Digital tools
    i. Inventory tools, e.g., BIM, Excel, Material Passports, CCBuild, Dacke, Loopfront, Palats, and ?
    ii. Design/planning tools, e.g., BIM and ?
    iii. Market platforms, e.g., Rebygg, Palats, CCBuild, Återbruksbyrån.
(c) Calculation tools (economic, environmental), e.g., LCA, LCC, CMA, and ?

Thank you for the conversation!

C.2 Semi-structured interview II questions

Interview II was more adjusted to the interviewee's expertise. The purpose is to understand methods of working, obstacles and opportunities related to the reuse of building products and modular building. Below are the questions asked in interviews II depending on the manufacturers, resellers, reuse firms, consultants or the interviewees' practical experience in the reuse of building products.

Interview II questions [Swedish]

1. Bakgrund och roll
    (a) Hur länge och i vilka typer av projekt/produkter har du arbetat med cirkularitet/återbruk/modulärt byggande?
    (b) Hur arbetar du med återbruk?
    (c) Vilka delar i projektet har ni varit med och projekterat/levererat? (t.ex. HVAC, vatten, avlopp)
    (d) Har du arbetat med HSB Living Lab?
2. Praxis & verktyg
    (a) Vilka branschplattformar/riktlinjer/verktyg för miljödata och återbruk känner ni till och använder?
    (b) Vilka fungerar bäst och varför? Vilka hinder ser ni för bredare användning?
    (c) Känner du till branschens miljödataplattformar och skulle du rekommendera dem för vårt projekt?
    (d) Cirkulära certifieringar, planer på andrahands sortiment eller fokus på återvinning? Är det pantsystem eller tar ni in utan ersättning?
    (e) Hur arbetar ni med återbruk i era initiativ/projekt? Tar ni emot alla typer av byggnadskomponenter/material? Finns tidsgräns i lager?
    (f) Samarbeten med demonterings-/rivningsaktörer: hur uppstod de och vad motiverade er?
3. Modulärt byggande & teknisk genomförbarhet

(a) Hur modulära är modulerna i sig? Hur modulära är övriga komponenter?
(b) Erfarenhet av liknande modulära projekt, vilka funktioner har de använts för och var ser ni störst behov?
(c) Återtagningssystem, skulle ni vara villiga att ta tillbaka modulerna, och till vilket pris?
(d) Vilka återbruksscenarier ser ni som mest rimliga för modulerna och för LL?
(e) Vad kunde ha gjorts bättre tekniskt?
(f) Skulle byggnadskomponenter som golv och tak kunna återbrukas i framtiden? Hur, genom vem och i vilka dimensioner?
(g) Hur unika är installationerna i LL?
(h) Vilka dimensioner/längder på rör/kanaler/radiatorer är återbrukbara? (t.ex. ventilationskanaler 3 m raka, radiatorlängder)

4. Montering, demontering och tid/kostnad
   (a) Montering/demontering av LL,[Hur är] processen?
      i. Tidsåtgång?
      ii. Kostnad?
   (b) Metallstänger som användes vid montering , var finns de nu?
   (c) Skulle demontering ta ungefär lika lång tid som montering? Hur lång tid tar en ”standard” rivning idag?
   (d) Hur går demontering/rivning till i praktiken? Vad gör ni först? Vem bedömer vad som ska återbrukas?
   (e) Skillnad tids- och kostnadsmässigt mellan rivning och demontering?
   (f) Vad kostar transport till deponi och deponiavgifter?
   (g) Vilka maskiner används? Vilken typ av fordon och bränsle bör vi räkna med?
   (h) Vad gör att det är dyrt att flytta HSB LL jämfört med andra modulhus?
5. Inventering, spårbarhet och kvalitet
   (a) Hur är er procedur vid inventering?
   (b) Hur lagrar ni information om material?
   (c) Hur planerar ni demonteringsprocessen?
   (d) Hur kvalitets säkrar ni varor/komponenter?
   (e) Har rivare/demontörer kunskap om varsam demontering av olika komponenter?
   (f) Lista över rörtyper/installationer i byggnaden? Har installationer bytts ut under de senaste 10 åren, vilka och när?
6. Lager och logistik
   (a) Hur länge lagrar ni varor som längst? Behöver ni kassera mycket?
   (b) Geografisk spridning? Erbjuder ni upphämtning?
   (c) Lagring av återbrukade varor: egna lager eller externa? Hur hittar ni bra lagringsplatser?
   (d) Vad vore optimalt logistikmässigt för ökat återbruk?

(e) Vilket bränsle används i transporter?
(f) Fordonstyper att räkna med i analyser.

7. Marknad
   (a) Skalan på försäljningen, mest privatkunder eller företag/hela byggnader?
   (b) Letar ni aktivt kunder/projekt som kan ta emot varor? Vad säljer ni mest och vad är svårast att sälja?
   (c) Hur ofta efterfrågas återbruk av byggnadskomponenter idag? Vem betalar vem och för vad?
   (d) Hur kan vi modellera marknadsscenarier?
   (e) Vilket scenario lutar det åt nu? Om byggnaden säljs, hur går ni tillväga?
   (f) Tror ni på återbruk via tillverkare/grossister eller via återbrukshubbar?
8. Livslängd, reparerbarhet och värde
   (a) Hur länge håller era produkter? Vad bestämmer livslängden (t.ex. sanitetsprodukter, blandare, vitvaror)?
   (b) Kan man reparera/byta delar istället för hela produkten? Beaktas detta i designfasen?
   (c) Värde efter 12 år, ser ni fortsatt liv i LL:s produkter efter flytt/återbruk?
   (d) Information om livslängder på olika produkter, var får vi bäst tag på det?
   (e) Hur förändras värdet på installationer över tid? Finns data/formel?
9. Miljö, LCA, EPD
   (a) Hur bör vi lägga upp LCA-analyserna? (inkl. demonterbarhet som parameter)
   (b) EPD:er för installationer och komponenter.
   (c) Kan vi få tillgång till EPD:er för era produkter?
   (d) Är återbruk alltid miljömässigt värt? Finns en avståndsgräns. var går den?
10. Ekonomi
    (a) Hur kan vi uppskatta kostnader och priser på komponenter?
    (b) Intäkter kopplade till forskning/utrednin, hur lönsamt och hur bör det drivas?
    (c) Hur mycket av tidigare rapporter/underlag får användas? Hur ska ersättning hanteras?
    (d) Transport- och deponikostnader; typisk kostnad per ton*km.
    (e) Kostnader för flytt/omkonfigurering, pris vid återtag.
    (f) Affärsflöden i återbruk: vem betalar vem och för vad?
11. Framtid
    (a) Hur tror ni att framtiden för återbruksmarknaden ser ut?
    (b) Planer på andrahands sortiment kontra återvinning, vad krävs för skala?
    (c) Är planerat åldrande fortfarande starkt eller ifrågasätts det mer?
    (d) Syn på framtida återbruk av större byggnadselement (t.ex. golv/tak) i större skala.
    (e) Kommentar till skepsis mot flyttbara hus, finns goda skäl att fortsätta bygga

modulärt och flyttbart?

Interview II questions [Engslish]

1. Background and role
   (a) How long and in what types of project/-s, have you worked with circularity/reuse/modular construction ?
   (b) How do you work with reuse?
   (c) Which parts of the project have you designed/delivered? (e.g., HVAC, water, wastewater)
   (d) Have you worked with HSB Living Lab?
2. Practice & tools
   (a) Which industry platforms/guidelines/tools for environmental data and reuse do you know and use?
   (b) Which work best and why? What barriers do you see to broader adoption?
   (c) Are you familiar with the industry's environmental data platforms, and would you recommend them for our project?
   (d) Circular certifications, plans for second-hand assortments, or a focus on recycling? Do you operate a deposit-return scheme, or do you accept materials without compensation?
   (e) How do you work with reuse in your initiatives/projects? Do you accept all types of building components/materials? Do you have a specific time limit for how long items can be stored?
   (f) Regarding your collaboration with deconstruction/demolition contractors: how did these partnerships arise and what motivated them?
3. Modular construction & technical feasibility
   (a) Regarding the case study HSB LL: How modular are the modules themselves? How modular are the other components?
   (b) What experience do you have from similar modular projects, what functions have they served and where do you see the greatest need?
   (c) Take-back systems: would you be willing to take back the modules , and at what price?
   (d) Which reuse scenarios do you consider most realistic for the modules and for HSB LL?
   (e) What could have been done better technically?
   (f) Could building components such as floors and roofs be reused in the future? How, by whom, and in what dimensions?
   (g) How unique are the installations in HSB LL?
   (h) What dimensions/lengths of pipes/ducts/radiators are reusable? (e.g., straight ventilation ducts 3 m, radiator lengths)

4. Assembly, deconstruction and time/cost
    (a) [Regarding the] reassembly/deconstruction of HSB LL,[what is the] process?
        i. Time required?
        ii. Cost?
    (b) [Regarding] the metal rods used during assembly, where are they now?
    (c) Would the deconstruction take approximately as long as the assembly? How long does a "standard" demolition take today?
    (d) How does deconstruction/demolition work in practice? What do you do first? Who determines what will be reused?
    (e) Time and cost differences between demolition and deconstruction?
    (f) What does transport to landfill cost, and what are the tipping fees?
    (g) Which machines are used? What vehicle types and fuels should we assume?
    (h) What makes moving HSB LL more expensive than other modular buildings?
5. Inventory, traceability & quality
    (a) What is your procedure for materials inventory/audit?
    (b) How do you store information about materials?
    (c) How do you plan the deconstruction process?
    (d) How do you assure the quality of goods/components?
    (e) Do demolition/deconstruction crews have skills for careful disassembly of different components?
    (f) List of pipe types or intallations in the building. Have installations been replaced in the last 10 years, which ones and when?
6. Storage & logistics
    (a) What is your maximum storage duration for goods? Do you need to discard much?
    (b) Geographic coverage? Do you offer pickup?
    (c) Storage of reused goods: in-house warehouses or external? How do you find suitable storage locations?
    (d) What would be logistically optimal to increase reuse?
    (e) What fuels are used in transport?
    (f) Vehicle types to include in analyses.
7. Market
    (a) Scale of sales, mostly private customers or businesses/entire buildings?
    (b) Do you actively seek customers/projects to take materials? What do you sell most, and what is hardest to sell?
    (c) How often are reused building components requested today? Who pays whom, and for what?
    (d) How can we model market scenarios?
    (e) Which scenario seems most likely now? If the building is sold, how do you proceed?

(f) Do you foresee reuse via manufacturers/wholesalers or via reuse hubs?

8. Service life, repairability & value
   (a) How long do your products last? What determines service life (e.g., sanitaryware, faucets/mixers, appliances)?
   (b) Can parts be repaired/replaced instead of the whole product? Is this considered in the design phase?
   (c) Value after 12 years, do you see continued life in LL's products after relocation/reuse?
   (d) Information on service lives for different products, where is the best source?
   (e) How does the value of installations change over time? Is there data or a formula?
9. Environment impact, LCA & EPDs
   (a) How should we structure the LCA analyses? (including disassemblability as a parameter)
   (b) EPDs for installations and components.
   (c) Can we access EPDs for your products?
   (d) Is reuse always environmentally beneficial? Is there a distance threshold, where is it?
10. Economics
   (a) How can we estimate costs and prices of components?
   (b) Revenues linked to research/feasibility studies, how profitable is this and how should it be run?
   (c) How much of previous reports/supporting material can be used? How should compensation be handled?
   (d) Transport and landfill costs; typical cost per ton-km.
   (e) Costs for relocation/reconfiguration; buy-back price.
   (f) Business flows in reuse: who pays whom, and for what?
11. Future
   (a) How do you see the future of the reuse market?
   (b) Plans for second-hand assortments versus recycling, what's required to scale?
   (c) Is planned obsolescence still prevalent or increasingly questioned?
   (d) Views on future reuse of larger building elements (e.g., floors/roofs) at scale.
   (e) Comment on scepticism toward relocatable buildings, are there good reasons to continue building modular and movable structures?

D

Distribution Analysis of Embodied Carbon and Weight

The data we are analysing is skewed, and we want to establish definitions and determine what values are considered low, medium, and high based on the reference values. The empirical cumulative distribution function (ECDF) was used because it is easy to interpret and transparent, allowing you to easily determine, in percentiles, what a value is considered low or high relative to the reference data, and to see, in deciles, the distribution of the reference data. Figure D.1 and figure D.2 shows the ECDF of embodied carbon (modules A1-A3) for building products found in the Boverket climate database. The second figure provides a closer look at the 0-50% range for a clearer visualisation. Figure D.3 displays the weight distribution (ECDF) of the building products found in the HSB LL inventory, allowing us to compare the weights of different building products within the building. The result is summarised in table D.1. Note that the graphs were created with the assistance of an AI program to generate MATLAB code.

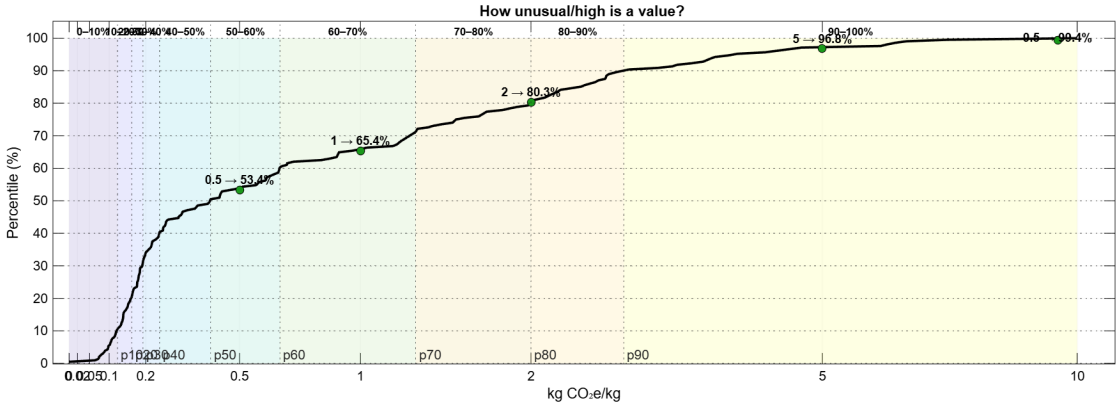


Figure D.1: ECDF showing the distribution of embodied carbon (modules A1–A3) for building products listed in the Boverket climate database

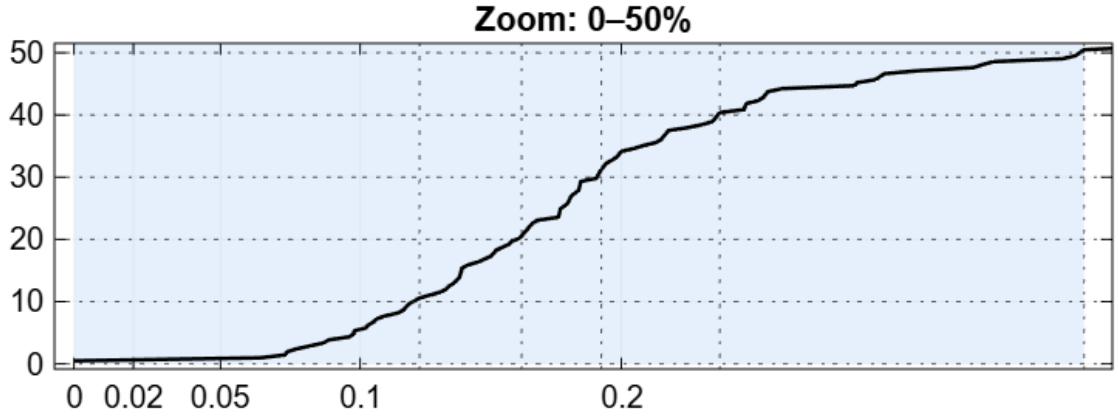


Figure D.2: EC-boverket Zoom in on 0-50%

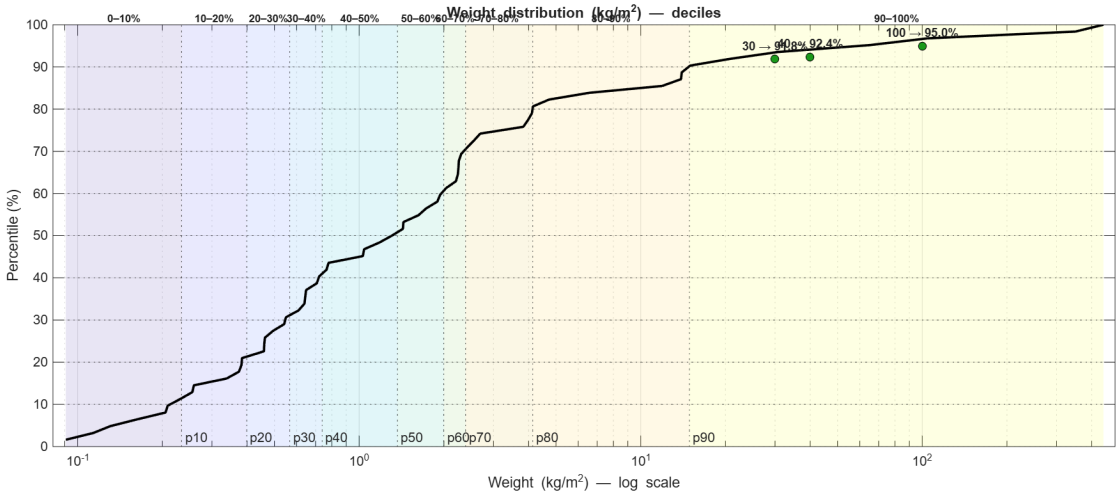


Figure D.3: Weight distribution (ECDF) of building products for HSB LL.

Table D.1: Weight to Environmental impact. Weight per building specific Gross Floor Area [kg/m^2 GFA]

1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
440	14.9	4.1	2.4	2	1.4	0.7	0.6	0.4	≤ 0.2

E

Reuse evaluation of selected products

E.1 Scenario 1

E.1.1 Structure

Table E.1: Scenario 1: Evaluation of the Structure layer

		Module		Foundation slab	
Parameter	**Connection**	*type*	*grade*	*type*	*grade*
Level of product information	Disassembly potential	info is available	1	info is not available	0.1
	Time of reuse process	info is available	1	info is available	1
	Risk	info is available	1	info is available	1
Embodied carbon	Environmental impact	1.48 kg CO_2eq/kg (based on known EC)	0.7	0.08 kg CO_2eq/kg	0.1
Weight	Environmental impact	308 kg/m^2	1	65 kg/m^2	0.9
Connections	Disassembly potential	bolt/sealants	0.8	cement bond	0.1
	Time of reuse process	fast	0.9	slow	0.1
Connection access	Disassembly potential	additional actions required, no damage	0.4	irreparable damage	Not met
	Time of reuse process	medium	0.5	slow	0.1
Crossings	Disassembly potential	not relevant*	-	not relevant*	-

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		Module		Foundation slab	
	Time of reuse process	medium because of the crossing walls between modules	0.5	slow	0.1
Quality & Life expectancy	Environmental impact & Cost	assumed good condition, >38 out of 50 years	0.9	assumed good condition, >38 out of 50 years	0.9
	Technical feasibility	assumed good condition	Met	assumed good condition	Met
Dimensions	Technical feasibility	extensive re-furbishments required to adjust	0.1	cannot be adjusted	0.1
	Handling possibilities	needs to be handled with a crane	0.5	cannot be handled without size adjustment	0.1
Technical properties	Technical feasibility	assuming that it follows the regulations of the new site*	Met	follows regulations	Met
Material	Raw materials with limited availability	mix of materials; mostly abundant	0.1	sand, gravel, limestone; abundant	0.1
	Consistency with biological or technical cycles and cascade	majority of weight non-renewable and non-biodegradable (techno-sphere)	0.9	non-renewable and non-biodegradable (techno-sphere)	0.9
	Recovery potential	fracture toughness and tensile strength of structural steel is high	0.9	high fracture toughness and tensile strength	0.9
	Handling possibilities	impact resistance, vibration resistance, compres-sion/stacking durability of structural steel is high	0.9	impact resistance, vibration resistance, compres-sion/stacking durability is high	0.9
Assembly type	Recovery potential	modular and pre-fabricated	0.9	site-built	0.1

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		Module		Foundation slab	
Function & Material	Existing business models	supply chain not established, but separate reuse services exist	0.5	essential services not available	0.1
	Part of large product flows	few products on the market, follow project specific requirements	0.1	heavy use, but project specific	0.5
Function, Dimensions & Technical properties	Value of equivalent new product	assuming high value	0.9	medium value	0.5
Reuse Potential		66%		U/R/D	

*Not relevant as it is assumed that all modules will be disassembled.

E.1.2 Service

Table E.2: Scenario 1: Evaluation of the Service layer

		Elevator	
Parameter	**Connection**	*type*	*grade*
Level of product information	Disassembly potential	info is available	1
	Time of reuse process	info is available	1
	Risk	info is available	1
Embodied carbon	Environmental impact	2.97 kg CO_2eq/kg	0.9
Weight	Environmental impact	1 kg/m^2	0.4
Connections	Disassembly potential	bolts/screws	0.8
	Time of reuse process	medium	0.5
Connection access	Disassembly potential	additional actions required, no damage	0.8
	Time of reuse process	slow	0.1
Crossings	Disassembly potential	not relevant	-

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Elevator			
	Time of reuse process	medium	0.5
Quality & Life expectancy	Environmental impact & Cost	assumed good condition, 13 out of 25 years	0.8
	Technical feasibility	assumed good condition	Met
Dimensions	Technical feasibility	assuming that it can only be adjusted in height	0.1
	Handling possibilities	needs to be handled with a crane	0.5
Technical properties	Technical feasibility	follows regulations	Met
Material	Raw materials with limited availability	mostly iron, carbon; abundant	0.1
	Consistency with biological or technical cycles and cascade	mostly iron, carbon; non-renewable and non-biodegradable (technosphere)	0.9
	Recovery potential	high fracture toughness and tensile strength	0.9
	Handling possibilities	high impact resistance, vibration resistance and compression/stacking durability	0.9
Assembly type	Recovery potential	The assembly type is pre-manufactured and modular, designed with replaceable subsystems, yet tailored to specific project requirements.	0.9
Function & Material	Existing business models	assumed to be the same as the modules; no supply chain, but services exists	0.5
	Part of large product flows	used in small amounts and follow project specific requirements	0.1
Function, Dimensions & Technical properties	Value of equivalent new product	high value	0.9
Reuse Potential		64%	

E.2 Scenario 2

E.2.1 Structure

Table E.3: Scenario 2: Evaluation of products in the Structure layer

		Steel structure		Foundation slab	
Parameter	**Connection**	*type*	*grade*	*type*	*grade*
Level of product information	Disassembly potential	info is available	1	info is not available	0.1
	Time of reuse process	info is available	1	info is available	1
	Risk	info is available	1	info is available	1
Embodied carbon	Environmental impact	2.52 kg CO_2eq/kg	0.9	0.08 kg CO_2eq/kg	0.1
Weight	Environmental impact	104 kg/m^2	0.9	65 kg/m^2	0.9
Connections	Disassembly potential	welded	0.1	cement bond	0.1
	Time of reuse process	slow	0.1	slow	0.1
Connection access	Disassembly potential	accessible	1	irreparable damage	Not met
	Time of reuse process	slow	0.1	slow	0.1
Crossings	Disassembly potential	not relevant*	-	not relevant*	-
	Time of reuse process	slow	0.1	slow	0.1
Quality & Life expectancy	Environmental impact & Cost	assumed good condition, >38 out of 50 years	0.9	assumed good condition, >38 out of 50 years	0.9
	Technical feasibility	assumed good condition	Met	assumed good condition	Met
Dimensions	Technical feasibility	can be adjusted to standard dimensions	0.5	cannot be adjusted	0.1
	Handling possibilities	needs to be handled by medium sized machinery after having been cut	0.7	cannot be handled without size adjustment	0.1
Technical properties	Technical feasibility	follows regulations	Met	follows regulations	Met
Material	Raw materials with limited availability	iron, carbon; abundant	0.1	sand, gravel, limestone; abundant	0.1

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		Steel structure		Foundation slab	
	Consistency with biological or technical cycles and cascade	iron, carbon; non-renewable and non-biodegradable (techno-sphere)	0.9	sand, gravel, limestone; non-renewable and non-biodegradable (techno-sphere)	0.9
	Recovery potential	structural steel; high fracture toughness and tensile strength	0.9	reinforced concrete; high fracture toughness and tensile strength	0.9
	Handling possibilities	structural steel; high impact resistance, vibration resistance, compres-sion/stacking durability	0.9	reinforced concrete; medium impact resistance, high vibration resistance and compres-sion/stacking durability	0.9
Assembly type	Recovery potential	non-modular, pre-fabricated	0.5	non-modular, site-built	0.1
Function & Material	Existing business models	established supply chain	1	essential service not available	0.1
	Part of large product flows	subject to different standards	0.5	subject to different standards	0.5
Function, Dimensions & Technical properties	Value of equivalent new product	assuming high value	0.9	assuming medium value	0.5
Reuse Potential		73%		U/R/D	

*Not relevant as it is assumed that everything will be disassembled.

E.2.2 Skin

Table E.4: Scenario 2: Evaluation of products in the Skin layer

		Stone wool insulation		Glass panes with aluminium frames		Fibre cement boards	
Parameter	**Connection**	*type*	*grade*	*type*	*grade*	*type*	*grade*
Level of product information	Disassembly potential	info is available	1	info is available	1	info is available	1
	Time of reuse process	info is available	1	info is available	1	info is available	1
	Risk	info is available	1	info is available	1	info is available	1
Embodied carbon	Environmental impact	1.28 kg CO_2eq/kg (based on known EC)	0.7	1.32 kg CO_2eq/kg	0.7	0.68 kg CO_2eq/kg	0.6
Weight	Environmental impact	12 kg/m^2	0.9	4 kg/m^2	0.8	7 kg/m^2	0.8
Connections	Disassembly potential	dry connection	1	screws	0.8	screws	0.8
	Time of reuse process	fast	0.9	fast	0.9	fast	0.9
Connection access	Disassembly potential	accessible	1	accessible	1	accessible	1
	Time of reuse process	medium	0.5	fast	0.9	fast	0.9
Crossings	Disassembly potential	not relevant*	-	not relevant*	-	not relevant*	-
	Time of reuse process	medium	0.5	fast	0.9	medium	0.5
Quality & Life expectancy	Environmental impact & Cost	assumed good condition, >38 out of 50 years	0.9	assumed good condition, >38 out of 50 years	0.9	assumed good condition, >38 out of 50 years	0.9
	Technical feasibility	assumed good condition	Met	assumed good condition	Met	assumed good condition	Met
Dimensions	Technical feasibility	stock-item	0.9	not of standard dimensions, cannot be adjusted due to properties of safety glass	0.1	stock-item	0.9
	Handling possibilities	can be handled by one or two people	1	needs to be handled by medium sized machinery	0.7	can be handled by one or two people	1

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		Stone wool insulation		Glass panes with aluminium frames		Fibre cement boards	
Technical properties	Technical feasibility	assuming that it follows the regulations of the new site	Met	follows regulations	Met	follows regulations	Met
Material	Raw materials with limited availability	stone; abundant	0.1	sand, soda ash, limestone, aluminium; abundant	0.1	cement, sand, cellulose fibres; abundant	0.1
	Consistency with biological or technical cycles and cascade	stone/minerals; non-renewable and non-biodegradable (techno-sphere)	0.9	sand, soda ash, limestone, aluminium; non-renewable and non-biodegradable (techno-sphere)	0.9	cement, sand, cellulose fibres; mostly non-renewable and non-biodegradable (techno-sphere)	0.9
	Recovery potential	low fracture toughness and tensile strength	0.1	low fracture toughness, high tensile strength	0.5	medium fracture toughness, high tensile strength	0.9
	Handling possibilities	medium impact resistance, high vibration resistance, low compression/stacking durability	0.5	low impact resistance, medium vibration resistance, high compression/stacking durability	0.5	medium impact resistance, medium vibration resistance, high compression/stacking durability	0.5
Assembly type	Recovery potential	modular and pre-fabricated boards	0.9	non-modular, pre-fabricated	0.5	modular and pre-fabricated	0.9
Function & Material	Existing business models	essential services missing	0.1	partly established through general reuse hubs	0.7	essential services missing	0.1
	Part of large product flows	Commonly used but has project-specific dimensions	0.5	Commonly used but has project-specific dimensions	0.5	Commonly used and of standard dimensions	0.9
Function, Dimensions & Technical properties	Value of equivalent new product	assuming low value	0.1	assuming medium value	0.5	assuming low value	0.1
Reuse Potential		67%		62%		74%	

E.2.3 Space plan

Table E.5: Scenario 2: Evaluation of products in the Space plan layer

		Gypsum boards		U-section beams		Wood fibre boards	
Parameter	**Connection**	*type*	*grade*	*type*	*grade*	*type*	*grade*
Level of product information	Disassembly potential	info is available	1	info is available	1	info is available	1
	Time of reuse process	info is available	1	info is available	1	info is available	1
	Risk	info is available	1	info is available	1	info is available	1
Embodied carbon	Environmental impact	0.227 kg CO_2eq/kg	0.4	2.55 kg CO_2eq/kg	0.9	0.39 kg CO_2eq/kg	0.5
Weight	Environmental impact	21 kg/m^2	0.9	14 kg/m^2	0.9	14 kg/m^2	0.9
Connections	Disassembly potential	screws and filler/putty on outer boards	0.5	screws	0.8	screws	0.8
	Time of reuse process	medium	0.5	fast	0.9	fast	0.9
Connection access	Disassembly potential	accessible with additional actions with repairable damage	0.4	accessible	1	accessible	1
	Time of reuse process	slow	0.1	medium	0.5	medium	0.5
Crossings	Disassembly potential	not relevant	-	not relevant	-	not relevant	-
	Time of reuse process	medium (the studied component is the inner gypsum board)	0.5	medium	0.5	medium	0.5
Quality & Life expectancy	Environmental impact & Cost	assumed good condition, >38 out of 50 years	0.9	assumed good condition, >38 out of 50 years	0.9	assumed good condition, >38 out of 50 years	0.9
	Technical feasibility	assumed good condition	Met	assumed good condition	Met	assumed good condition	Met
Dimensions	Technical feasibility	available as standard stock-item	0.9	available as standard stock-item	0.9	available as standard stock-item	0.9

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		Gypsum boards		U-section beams		Wood fibre boards	
	Handling possibilities	can be handled by one or two people	1	can be handled by one or two people	1	can be handled by one or two people	1
Technical properties	Technical feasibility	follows regulations	Met	follows regulations	Met	follows regulations	Met
Material	Raw materials with limited availability	gypsum, paper; mostly abundant	0.1	iron, carbon; abundant	0.1	wood fibre (from softwood waste); abundant	0.1
	Consistency with biological or technical cycles and cascade	majority of weight non-renewable and non-biodegradable (techno-sphere)	0.9	non-renewable and non-biodegradable (techno-sphere)	0.9	renewable and biodegradable (biosphere)	0.1
	Recovery potential	low fracture toughness and tensile strength	0.1	high fracture toughness and tensile strength	0.9	low fracture toughness and tensile strength	0.9
	Handling possibilities	low impact resistance, low vibration resistance, high compression/stacking durability	0.5	high impact resistance, vibration resistance and compression/stacking durability	0.9	low impact resistance, medium vibration resistance, high compression/stacking durability is high	0.5
Assembly type	Recovery potential	modular and pre-fabricated	0.9	modular and pre-fabricated	0.9	modular and pre-fabricated	0.9
Function & Material	Existing business models	partly established though reuse firms	0.7	established through manufacturer	1	partly established through reuse firm	0.7
	Part of large product flows	commonly used and found in similar dimensions	0.9	commonly used and found in similar dimensions	0.9	commonly used and found in similar dimensions	0.9
Function, Dimensions & Technical properties	Value of equivalent new product	assuming low value	0.1	assumed medium value	0.5	assumed low value	0.1
Reuse Potential		69%		85%		74%	

E.2.4 Service

Table E.6: Scenario 2: Evaluation of products in the Service layer

		Radiators		Duct insulation		Elevator	
Parameter	**Connection**	*type*	*grade*	*type*	*grade*	*type*	*grade*
Level of product information	Disassembly potential	info is available	1	info is not available	0.1	info is available	1
	Time of reuse process	info is available	1	info is available	1	info is available	1
	Risk	info is available	1	info on condition only available after disassembly	0.2	info is available	1
Embodied carbon	Environmental impact	4.1 kg CO_2eq/kg	0.9	3.9 kg CO_2eq/kg	0.9	2.97 kg CO_2eq/kg	0.9
Weight	Environmental impact	1 kg/m^2	0.4	2 kg/m^2	0.6	1 kg/m^2	0.4
Connections	Disassembly potential	bolt/sealants	0.8	wire mesh/glue	0.2	bolts/screws	0.8
	Time of reuse process	fast	0.9	fast	0.9	medium	0.5
Connection access	Disassembly potential	accessible	1	irreparable damage to the product itself	Not met	accessible	1
	Time of reuse process	fast	0.9	slow	0.1	slow	0.1
Crossings	Disassembly potential	not relevant	-	not relevant	-	not relevant	-
	Time of reuse process	fast	0.9	medium	0.5	slow	0.1
Quality & Life expectancy	Environmental impact & Cost	assumed good condition, 3 out of 15 years	0.6	assumed good condition, 48 out of 60 years	1	assumed good condition, 13 out of 25 years	0.8
	Technical feasibility	assumed good condition	Met	assumed good condition	Met	assumed good condition	Met
Dimensions	Technical feasibility	not all components are similar to stock items, cannot be adjusted in size	0.1	available as a standard stock-item	0.9	not available as a stock-item and can only be adjusted in height	0.1
	Handling possibilities	can be handles by one or two people	1	can be handles by one or two people	1	needs to be handled with a crane	0.5

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		Radiators		Duct insulation		Elevator	
Technical properties	Technical feasibility	assuming that it follows the regulations of the new site	Met	follows regulations	Met	follows regulations	Met
Material	Raw materials with limited availability	iron, carbon; abundant	0.1	stone (basalt); abundant	0.1	mostly iron, carbon; abundant	0.1
	Consistency with biological or technical cycles and cascade	iron, carbon; non-renewable and non-biodegradable (techno-sphere)	0.9	stone (basalt); non-renewable and non-biodegradable (techno-sphere)	0.9	mostly iron, carbon; non-renewable and non-biodegradable (techno-sphere)	0.9
	Recovery potential	high fracture toughness and tensile strength	0.9	Low fracture toughness and tensile strength	0.1	high fracture toughness and tensile strength	0.9
	Handling possibilities	high impact resistance, vibration resistance and compres-sion/stacking durability	0.9	low impact resistance, high vibration resistance, low compres-sion/stacking durability	0.1	high impact resistance, vibration resistance and compres-sion/stacking durability	0.9
Assembly type	Recovery potential	pre-manufactured and modular assembly type , designed with replaceable subsystems, yet tailored to specific project requirements	0.5	pre-manufactured and modular assembly type , designed with replaceable subsystems, yet tailored to specific project requirements	0.5	custom built but pre-fabricated, with replaceable subsystems	0.5
Function & Material	Existing business models	partly established through reuse firms	0.7	essential services not available	0.1	essential services not available	0.1
	Part of large product flows	commonly used but has project specific dimensions	0.5	commonly used but has project specific dimensions	0.5	few units per project, follows project specific requirements	0.1
Function, Dimensions & Technical properties	Value of equivalent new product	low value	0.1	low value	0.1	high value	0.9
Reuse Potential		59%		U/R/D		56%	