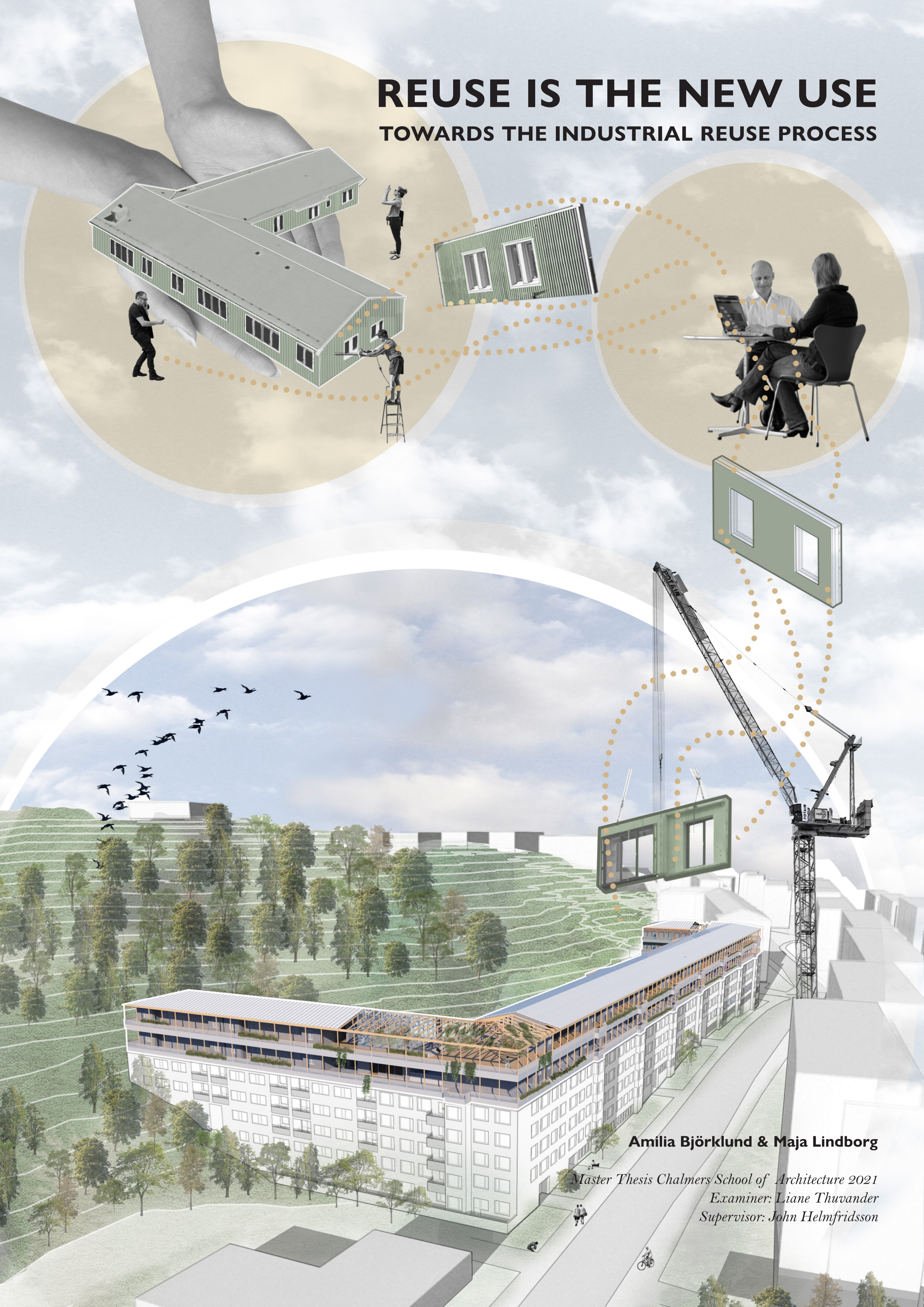
REUSE IS THE NEW USE

TOWARDS THE INDUSTRIAL REUSE PROCESS



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Master Thesis Chalmers School of Architecture 2021
Examiner: Liane Thuvander
Supervisor: John Helmfridsson

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Reuse is the new Use
Towards the industrial reuse process

Chalmers University of Technology
Department of Architecture & Civil Engineering
Architecture & Planning Beyond Sustainability
Gothenburg, Sweden 2021

Examiner: Liane Thuvander
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ABSTRACT

Working towards a circular building industry is one of the prerequisites for solving the issues on large amounts of demolition waste and emissions from new construction projects. This includes the circulation and reuse of existing building materials and components. What is lacking are established processes for designing with reused building parts on an industrial scale. The aim of this thesis is therefore to explore how inventories and information management can facilitate a reuse design process on an industrial scale.

The first part of this thesis uses literature studies on current research, reference reuse projects and semi-structured interviews with actors in the building industry to get an understanding of the reuse process of today. It identifies different types of inventories and how they could be used further in the design process through the connection with BIM.

The second part of this thesis is a pilot project in collaboration with an ongoing pre-study by Familjebostäder to add housing on top of an existing apartment building from the 70's in central Gothenburg. The pilot project implements the findings from the first part in a rooftop design proposal with reused timber-frame wall elements. The elements are sourced from two preschools in Gothenburg set to be demolished within the coming year, through a collaboration with Lokalförvaltningen.

As a conclusion, this thesis proposes an interconnected inventory process to make the information flow more efficient. The key to a successful inventory relies on visibility (how to visualise the content of your inventory) and compatibility (how to connect your inventory data to further usage).The architect's reuse design process would benefit from integrating the inventory data directly into the BIM software. In this thesis, a concept toolchain and workflow for connecting a reuse database to the BIM model was developed and tested.

Furthermore, analysis of cost comparisons, carbon emissions and disassembly feasibility in the pilot project showed that element reuse is more feasible than material reuse on an industrial scale, and that element reuse of timber frame buildings provides an interesting business model for prefab factories.

Key words
reuse, circular economy, circular building industry, material inventories, information management, BIM

AUTHORS

The starting point for this thesis was a shared interest and passion for a circular construction industry - Amilia from a more practical point of view and Maja from a more digital point of view, which has proven to complement each other well.

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* * *

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* * *

This thesis is built upon the knowledge and experience from people all across the building sector.

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It is because you took your time and patience to explain the most trivial of things to us, that this thesis exist. Let it be a reminder that the only way towards a circular built environment, is together.

* * *

Last but not least, thank you to family and friends for the continuous discussions and feedback, and for the times you just provided dinner and a conversation about something entirely different.

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GLOSSARY

Building part
The general word for a part from a building at any scale used in this thesis.

Building elements see page 34.
Building materials see page 34.
Building components see page 34.
Building interior see page 34.

BIM see page 41.
BIM software see page 41.
BIM model see page 41.
BIM object see page 41.

Briefing document Programhandling
Stage 0-1 according to RIBA stages.

Project planning document Systemhandling
Stage 2-3 according to RIBA stages.

Construction document Bygghandling
Stage 4 according to RIBA stages.

Environmental inventory Miljöinventering
Also called *waste audit* or *pre-demolition audit.*

Colour codes

Reuse/ Supply

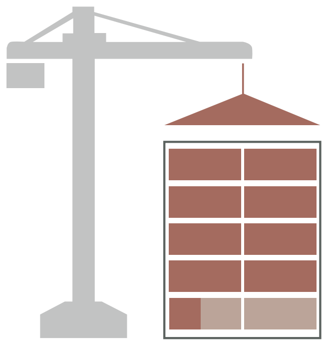
New construction/ Demand

Inventory

INTRODUCTION

The idea of a circular building industry is quickly moving from a theoretical utopia to a concrete vision and reality. This includes the circulation and reuse of existing, pre-used building materials and components.

WHY REUSING MATERIALS?



DECREASE USE OF VIRGIN MATERIALS

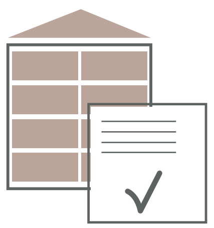
About 10% of Swedish carbon emissions comes from new constructions, with the largest contributing factor being the use of virgin materials. 84% of emissions from new constructions are coming from materials (Boverket 2021) (IVL 2015, 38).

The construction industry's goal is to have net zero emissions by 2045 (Fossilfritt Sverige n.d.).

MINIMIZE CONSTRUCTION WASTE AT DEMOLITION SITES

Each year, Sweden produces over 12 million tons of construction waste (Naturvårdsverket 2020).

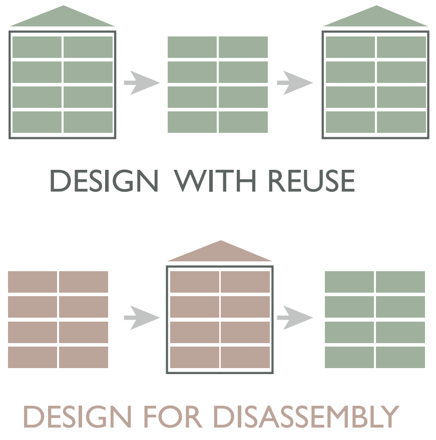
By 2020, the goal was a 70% reuse/recycling rate (Regeringskansliet 2019). As a reference, about 52% was estimated as recycled in 2018 (Boverket 2021).



CLIMATE DECLARATIONS FOR NEW CONSTRUCTIONS

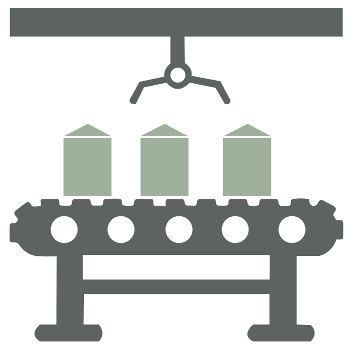
Starting in 2022, all new construction projects need a climate declaration of the building frame and envelope, including a life cycle assessment, LCA. According to current ISO standards, reused materials score better than virgin materials in life cycle calculations (IVL 2021).

HOW REUSING MATERIALS?



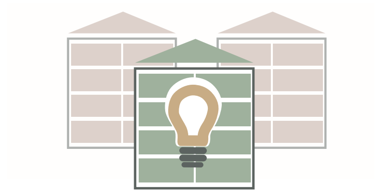
(RE)USING WHAT WE HAVE

There is a lot of talk about design *for* reuse, called "design for disassembly", and that is great - but we need to start designing not only for future reuse, but design *with* reuse already today.



MAKE IT INDUSTRIAL

Reuse needs to be implemented on an industrial scale to reach higher quantities and better profitability. This means we need to find efficient and smart workflows for how reuse can be integrated into the design process, but it also means understanding what kind of building parts are most feasible to reuse in the first place.



MORE PILOT PROJECTS!

To be able to develop industrial, circular business models, more pilot projects are needed to test and implement ideas and share them with the rest of the industry.

BACKGROUND

SUPPLY AND DEMAND

In a circular building economy, demolitions and new constructions can be seen as *supply* and *demand* projects, as described by Rose and Stegemann (2018, 7) (see figure 1). If the reuse market could reach this kind of balance, it has large potentials to success as a business model, since supply and demand form the most fundamental concepts of a market economy (Investopedia 2020).

When looking more specifically at the reuse process, it can be defined as a constant and indefinite relationship between supply projects and demand projects (Rose & Stegemann 2018, 7). The process might be circular, but time is linear. As shown in the illustration below, a construction starts as a demand project - indicates red colour - and is by the time of deconstruction switched to be seen as a supply project - indicates the gradient switch to green.

The yellow connection in the diagram is describing the flow of materials and information between the supply and demand project. The owners of this information include all stakeholders in the building industry - from architects, reuse consultants and property developers to second hand market places, recondition companies and storage companies. As such, methods and tools for efficient communication between all these actors are one of the most important prerequisites for a working industrial reuse industry.

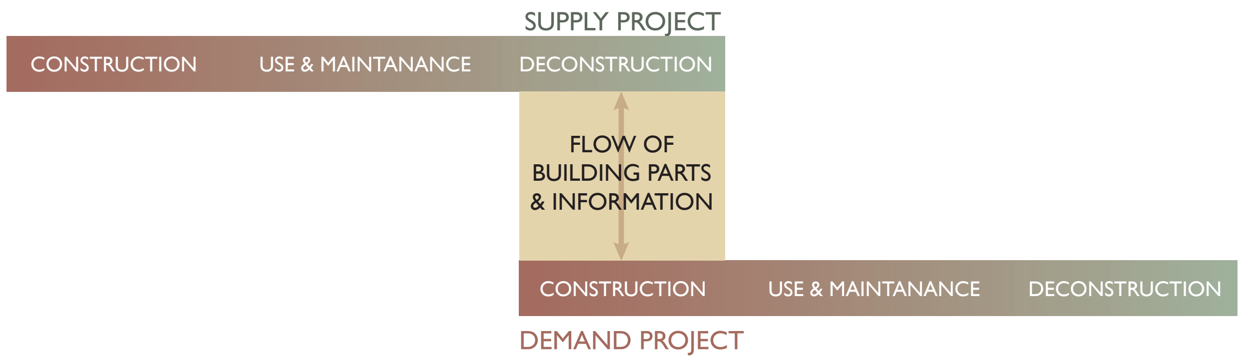


Figure 1. The relationship between a supply and demand project (adopted illustration, Rose and Stegemann 2018).

CIRCULAR PRECONDITIONS

To reach a circular building industry, including the usage of reused materials, the city of Gothenburg together with Kaminsky architects have developed a diagram summarising the ten most important preconditions (see figure 2). Two of them have a clear relation to methods and tools for efficient communication - *inventories* and *information management.*

Inventory - a complete list of items such as property, goods in stock, or the contents of a building (Oxford dictionairy).

Information management - the process of collecting, organizing, storing and providing information within a company or organization (Cambridge dictionary).

1. Material inventories

• Knowledge on material inventories needs to be developed.
• More time is needed in the pre-study phase to allow for material inventories and analysis.
• Classification of materials according to reuse potential should be an obvious part of the material inventory.
• The result of the material inventories need to be connected to digital databases to enable the information to be used during planning and project planning.
(Göteborgs stad 2020, 17)

2. Information management

• Business models for digital information management need to be established.
• Regulations and agreements around how to log and store information on building parts need to be established.
• There is a need for digital tool development, to be able to store and update information about building parts and their position. The tools need to work both during project planning, construction, maintenance and demolition.
• There is a need for database models for public access to information on building parts, such as material composition and assembly and disassembly guidelines. These databases need to be integrated in the tools for project planning and management.
(Göteborgs stad 2020, 17)

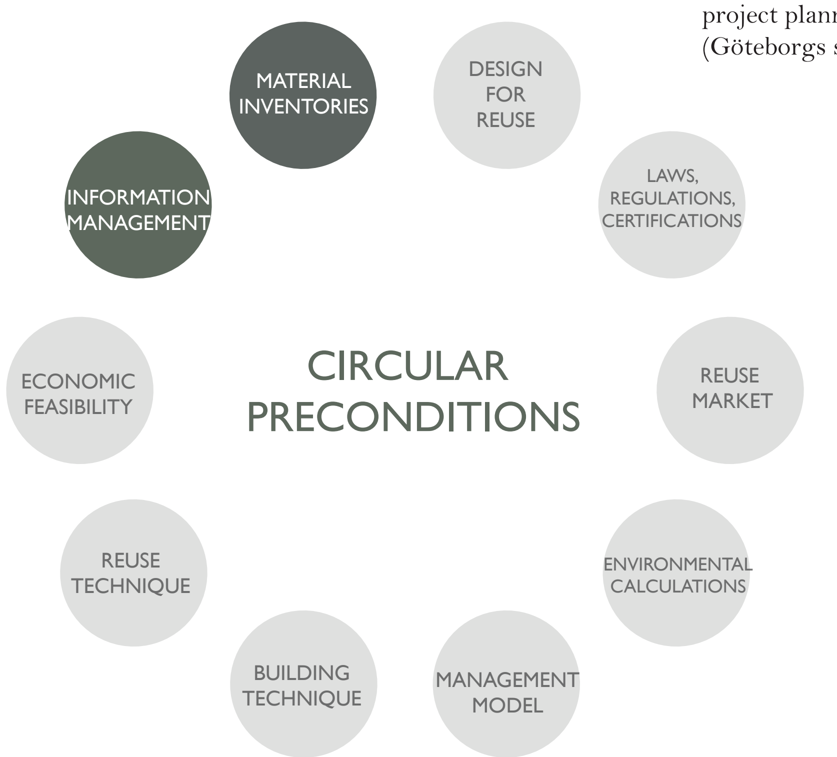


Figure 2. Circular preconditions (adopted illustration, Göteborgs stad 2020).

WORKING IN NETWORKS

There are several organisations, national as well as international, working towards a circular economy. *Centrum för cirkulärt byggande* (Center for circular construction, short: CCbuild) is a Swedish innovation project and organisation run by IVL Svenska Miljöinstitutet. Since 2015, they have been working towards industrial reuse and circular material flows through a number of services:

• a multi-disciplinary network and sharing platform through seminars and events
• a library of know-how: research articles, guidebooks, reference projects et cetera
• digital services such as an inventory database and a market place for reused building parts
• providing guidelines on working methods and processes
(CCbuild, n.d.)

To date, CCbuild is connecting around 30 different companies and organisations within the Swedish building industry (Loh Lindholm, personal communication, May 10, 2021).

A CURIOUS CLIENT

Familjebostäder i Göteborg is a property owner and developer with over 18500 rental apartments. They are a part of the real estate group Förvaltnings AB Framtiden, owned by the municipality of Gothenburg (Familjebostäder i Göteborg n.d.).

In January 2021, Familjebostäder i Göteborg released a report describing their current work and future vision on circular material flows. It references Framtiden's guideline of "always considering reuse of materials in renovation projects", and analyzes their two REUSE pilot projects which mainly addressed building interiors and components (Franker, Lunneblad, Wilson 2021, 3). In the report, Familjebostäder states that during 2021 they will continue their work on reuse, including more implementations. They also conclude that there is a need for easier and more comprehensive ways of communicating costs and climate savings in relation to reuse (Franker, Lunneblad, Wilson 2021, 24).

The site

During the spring of 2021, Familjebostäder is conducting a pre-study for the renovation of a four-storey apartment block in Linnéstaden in central Gothenburg, along with a two-storey rooftop addition. The rooftop addition will work as the case study for this thesis, but the renovation of the existing building will not be considered as its extents are still undetermined.

Overview of the existing building with the possible rooftop addition marked in red.

View from the courtyard of the existing building at Jungmansgatan.

RESEARCH QUESTIONS

How can **designing with reused building parts** become feasible on an **industrial scale**?

How can **material inventories** develop to facilitate reuse on an industrial scale?

How can **information management** facilitate the implementation of reused building parts in the architect's design process?

AIMS & OBJECTIVES

The aim of this thesis is to propose solutions on **how to reach reuse of building parts on an industrial scale**. The focus lies on contributing to the challenges that have a direct connection to the architect's design process: **inventories** and **information management**.

The aim is further to be able to contribute and implement reuse principles in our future careers.

The objectives of this thesis are:

• to compile and analyse current parallell reuse processes to identify common methods.

• to explore how inventories can develop to facilitate the reuse of building parts on an industrial scale.

• to explore how information management can contribute to facilitate the reuse of building parts on an industrial scale.

• to explore how and what building parts to reuse on an industrial scale.

• to explore these findings in a real case pilot project in central Gothenburg.

AUDIENCE

The target group for this thesis is stakeholders in the building industry, to explain and highlight the benefits and possibilities with actively working with reuse in their building projects.

Architects are provided with a guide with process steps to follow when working with reused building parts, and how these steps relate to the phases in a standard design process. Furthermore, it can provide them with insights into some of the aesthetic design consequences that the implementation of some reused building parts can have.

Property developers can gain knowledge on the benefits as well as challenges that exist when deciding to apply reused building parts in a project.

Computational design consultants and BIM developers can get an understanding of how the feasibility on reusing building parts heavily relies on a way to make inventories compatible with a BIM tool, and how this could be done on a conceptual level.

Environmental inventory specialists and reuse consultants can get an understanding on how interconnected inventories can help to make the inventory process more efficient and increase the feasibility of reusing building parts.

Product suppliers, prefab manufacturers and demolition firms can get an understanding on how circular economy will change the building sector and how they can develop to adapt to a new kind of business.

Building permit department at municipalities can get an understanding on how circular economy will change the building sector and how they can develop to adapt to new kind of conditions that requires a larger extent of flexibility.

METHOD

This thesis uses **research by design** through an iterative process with a pilot project connecting theory and practice.

The theoretical framework
A **literature review** of research papers and reference projects to understand the basis of the current reuse industry today

Semi-structured interviews with around 25 different stakeholders in the building sector, either providing their experience on the current reuse industry and/or finding out ways to improve it.
• Architects
• Reuse consultants
• Deconstruction firm
• Property owners/developers
• Timber prefab company
• Researchers
• Construction engineers

Seven of the actors share experience from seven real case processes and in total, ten material inventories could be collected and analysed.

The practical process
Three **site survey inventories** to strengthen the understanding of the theoretical investigations within this field.
• Roof of Jungmansgatan
• Biskopsgatan's preschool
• Östra Palmgrensgatan's preschool

The **design of a pilot project** with reused building parts on Jungmansgatan with a design process following the phases from a standard Swedish construction process (see Glossary page 7). This included life cycle assessment and estimated cost calculations.

The **BIM compatibility development** including practical investigtions in Revit and Grasshopper.Inside. Revit to develop a method to design with reused building parts in a BIM software. The investigations included:
• Workflow concept
• Toolchain concept
• Test scripts to confirm feasibility

DELIMITATIONS

The pilot project is a rooftop addition and a housing project creating the following delimitations:
• Building interiors are not considered.
• A rooftop addition requires a light-weight construction. This excludes concrete and brick reuse.

Focus is on the building frame and envelope. This includes exterior walls (including doors and windows) and roofs.

The focus is on designing with reused building parts. As per the circular conditions diagram (see figure 2 on p. 11), this includes "Material inventories" and "Information management".

The focus in this thesis is on industrial reuse processes. As per the circular preconditions diagram, this includes "Economic feasibility".

As such, the other seven preconditions are outside the scope of this thesis.

THEORETICAL FRAMEWORK

None of the previous Chalmers theses within the field of building reuse have had a specific focus on industrial reuse and the conditions that follows (Wilder 2017, Josefsson 2019, Andersson & Nilsson 2020, Jörlén 2020, Grmela 2020). The main starting points for this thesis has therefore been the *Circular preconditions* report with an industrial focus, published by the city of Gothenburg in 2020. It describes the needs to be able to reach reuse on an industrial scale through ten categories, of which this thesis is focusing on *Inventories* and *Information management* (see Background chapter). Additionally, Josefsson's thesis *Form follows availability* from 2019 provided a great basis for understanding the current reuse industry in a larger context, along with its possibilities and obstacles (Josefsson, 2019).

Terminology
The concept of describing reuse processes through supply and demand projects comes from Rose & Stegemann (2018, 7). To divide supply projects into *on site* supplies or *off site* supplies was defined by Wilder in her thesis *Constant Change* (Wilder 2017, 58).

Methodology
Jörlén (2020) is using semi-structured interviews to understand the reuse process in reality, which resulted in a realistic thesis and inspired this thesis to do the same, however with a more specific focus on inventories and information management. Andersson & Nilsson (2020) used a real pilot project and client to practically test the reuse process. This thesis uses the same method but in a larger, industrial scale and not all the way through construction.

Inventories
Jörlén concludes her thesis by stating the need to establish structures and routines for doing inventories, such as what to include, what paramters to log and how to make the inventories further accessible (Jörlén 2020, 33). This is analysed further in this thesis.

Information management
Josefsson states the importance of increased transparency and availability of information to support informed decision-making (2019, 100). This is further mentioned by one of the interviewees in Andersson & Nilsson's thesis, calling out for a documented design program to make the reuse vision visible for stakeholders throughout the project (2020, 34). In a similar way, Sweco architects specifically claims BIM tools as a way of dealing with this type of circular information management (Eriksson 2019, 87).

The architect's design process
Grmela (2020) proposes reuse of facade elements which is further discussed and analysed in this thesis as a way towards industrial reuse. Andersson & Nilsson (2020) propose making window intervals on building permit drawings to allow for a flexible design, a method used in the pilot project of this thesis.

PART I

REUSE TODAY

Investigating current practices for reuse.

1.SUPPLY AND DEMAND

Understanding the overall process and status of today's reuse industry.

INVENTORY IN PRACTICE

To understand how the reuse process works in reality, seven ongoing reuse projects have been analysed through semi-structured interviews with one of the stakeholders in the project. These reuse projects are shortly introduced here.

Stadskvarteret
Demolition of existing apartment buildings to build new housing blocks in Helsingborg.
PROPERTY DEVELOPER Helsingborgshem
ARCHITECT Jaennecke Arkitekter
REUSE CONSULTANT Helsingborgshem (internal)
CONTRACTOR Serneke
GROSS AREA 6300 m²

Bromma Sjukhus
Remodeling project of a hospital in Stockholm.
PROPERTY DEVELOPER Vectura fastigheter
ARCHITECT White Arkitekter
REUSE CONSULTANT Kaminsky Arkitekter
CONTRACTOR Skanska
GROSS AREA 25 000 m²

Kromet/Kaj 16
Demolition of an office building (Kromet) to build a new mixed-use building (Kaj 16) in Gothenburg.
PROPERTY DEVELOPER Vasakronan
ARCHITECT Dorte Mandrup
REUSE CONSULTANT White Arkitekter
CONTRACTOR Ramboll
GROSS AREA 37 500 m²

Europahuset
Remodeling project of an office building into housing in Mölndal.
PROPERTY DEVELOPER Balder fastigheter
ARCHITECT White Arkitekter
REUSE CONSULTANT White Arkitekter
CONTRACTOR not decided
GROSS AREA 42 000 m²

Kustgatan
Remodeling project of an office building into housing in Gothenburg.
PROPERTY DEVELOPER Familjebostäder
ARCHITECT Sunnerö Arkitekter + Unit Arkitektur
REUSE CONSULTANT Reclaimd
CONTRACTOR RO-gruppen
GROSS AREA 5926 m²

Panncentralen Högsbo
Demolition of a boiler room in Gothenburg.
PROPERTY DEVELOPER Familjebostäder
ARCHITECT -
REUSE CONSULTANT Reclaimd
CONTRACTOR Hål i Betong
GROSS AREA 450 m²

Onsala Rymdobservatorium
Remodeling project of a space observatory at Råö in Halland.
PROPERTY DEVELOPER Chalmersfastigheter
ARCHITECT White Arkitekter
REUSE CONSULTANT Reclaimd
CONTRACTOR NCC
GROSS AREA 500 m²

DEVELOPING THE PROCESS DIAGRAM

This chapter uses the supply and demand diagram by Rose and Stegemann (introduced in the Background chapter) as a base for illustrating the flow of information and building parts between a supply and demand project. Based on semi-structured interviews of actors from the seven ongoing reuse projects introduced on the previous page, the diagram has been adapted to show how inventories and information management play a role at different stages throughout the reuse process.

The diagram can be extended by specifying the standard procedure steps for the supply and demand project respectively. In this thesis, the supply project is divided into a demolition procurement - the time when the demolition permits are approved and procurements are done (Boverket, 2021) - and the actual deconstruction. The demand project is divided into the three standard building phases in Sweden (Johansson 2018, 10) - *programhandling, systemhandling* and *bygghandling* - as well as the construction phase (see figure 3). The diagram indicates that the flow of information is occuring before and during the demolition procurement in a supply project, and during the three first phases in a demand project. The flow of building parts happens between the deconstruction phase in the supply project and the construction phase in the demand project.

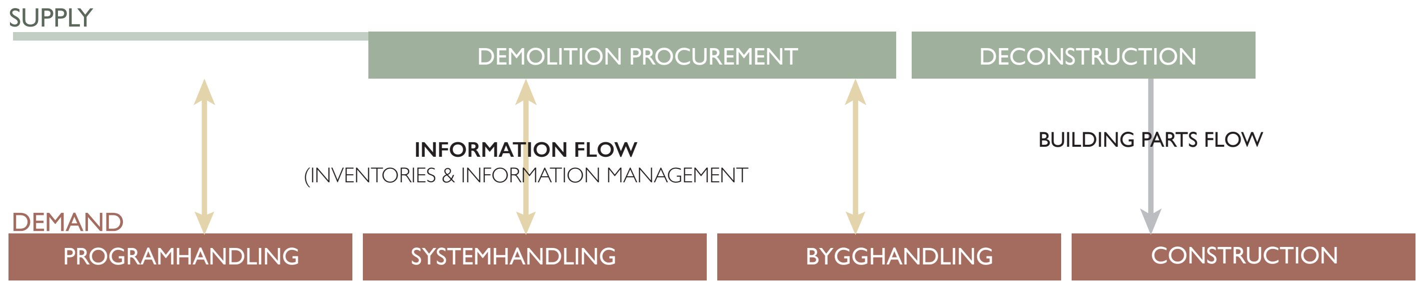


Figure 3. Supply and demand project in relation to each other showing how information flow as well as flow of building parts are happening in the process (adopted illustration based on Rose & Stegeman 2018 and summary of analysis of reuse projects).

The time aspect

Completing a building project can vary between 2-15 years, while the time between the decision to demolish and the start of the demolition is much shorter - in a smooth process as short as ten weeks (Fiedler, personal communication, February 17, 2021).

The fact that the demolition procurement is proceeding quickly can be a big problem when it comes to taking care of building parts. Sometimes, there is not time to save anything at all, and what has not managed to get a new owner before the demolition will go to waste (Holmberg, personal communication, January 28, 2021). This is confirmed by one of the reuse consultants interviewed, who admits that building parts that have not found new owners before the demolition starts gets thrown away due to the lack of a viable intermediate storage business model and actor (Håkansson, personal communication, January 22, 2021).

Several of the interviewees in this thesis have indicated the same experience, adding to the importance of starting as early as possible with an inventory process to make sure there is enough time to save as much as possible. In an interview with a reuse consultant at White architects about the ongoing reuse project Kromet in Gothenburg, it is explained that the inventory has been performed at an early stage to identify building parts with a reuse potential. As a result, clear instructions could be given already in the demolition procurement on what and how to deconstruct.

After a first inventory, several of the actors from the interviews have set some kind of targets on what to reuse. Apart from being used as instructions for the demolition firm, as in the case of Kromet, it has further led to the planning and designing with these building parts. In combination with additional inventories performed it has been possible to settle a final design already in the systemhandling (see figure 4).

Off site vs on site supply

6 out of 7 reuse projects in this thesis were remodeling projects. The reuse implemented in the design was mainly the same building parts that already existed on the same site - a so called *on site* supply as defined by Wilder (Wilder 2017, 20). This meant that the deconstruction could be matched with the new construction. Additionally, the storing of the

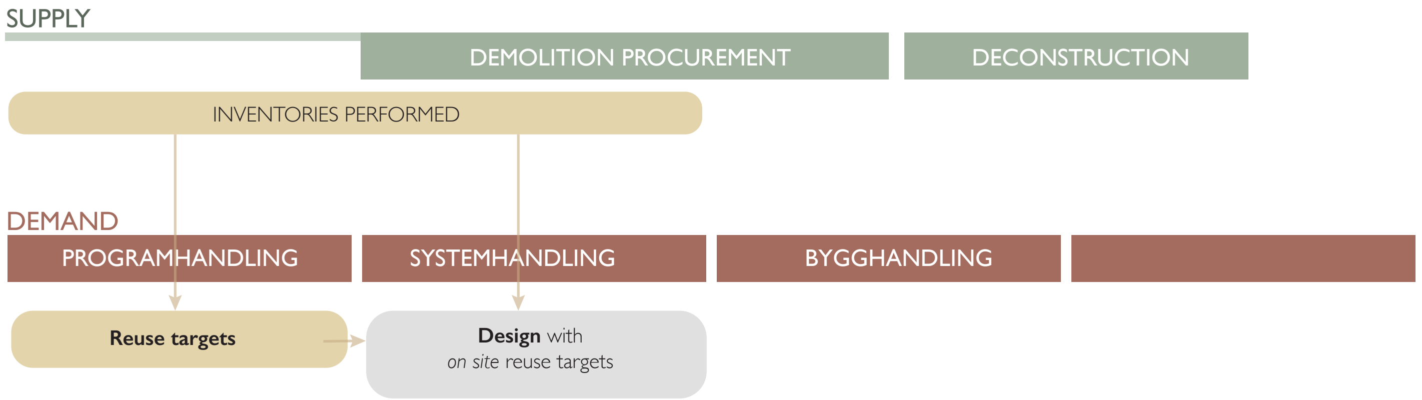


Figure 4. How inventories of the supply project are performed at an early stage in the building process to be able to plan for the building parts in the design before it gets demolished (summary from analyse of several reuse processes).

deconstructed building parts could in most cases be solved by storing it on the same site until the construction started. Conclusively, although the inventories still had to be done in an early stage to have time to implement it in the design, the logistics when working with an on site supply are less complex than if the supply project would have been another building, at another site, with another owner.

One reuse project that did not have an on site supply as its primary supply is Onsala Rymdobservatorium, developed by Chalmersfastigheter. They were instead looking for building parts from so called *off site* supplies as defined by Wilder (2017, 20). The project leader explains that they initially planned the building as in any conventional design process, but designed with flexible principles according to their reuse targets, as they did not know from the start what building parts they would find. Along with the design process they had to scout for building parts and store them until the time of the construction.

When working with an off site supply, one of the challenges is to set reuse targets without knowing what building parts that will exist at the time of the construction. The project leader at Onsala Rymdobservatorium mentions that in the programhandling phase, they based their reuse targets on a statistical estimation, meaning they investigated what reused building parts are available today and have a high possibility to also be available in the future. This is represented as an *Urban mining* in figure 5. The inventories of the building parts from the off site supply were performed by the owner of the off site supply, after which Chalmersfastigheter could get hold of this information to make a choice on whether to use it or not. The reuse targets from the urban mining could in this way be matched with the information from the off site supply in the bygghandling phase, and with this they could finalise their design (see figure 5).

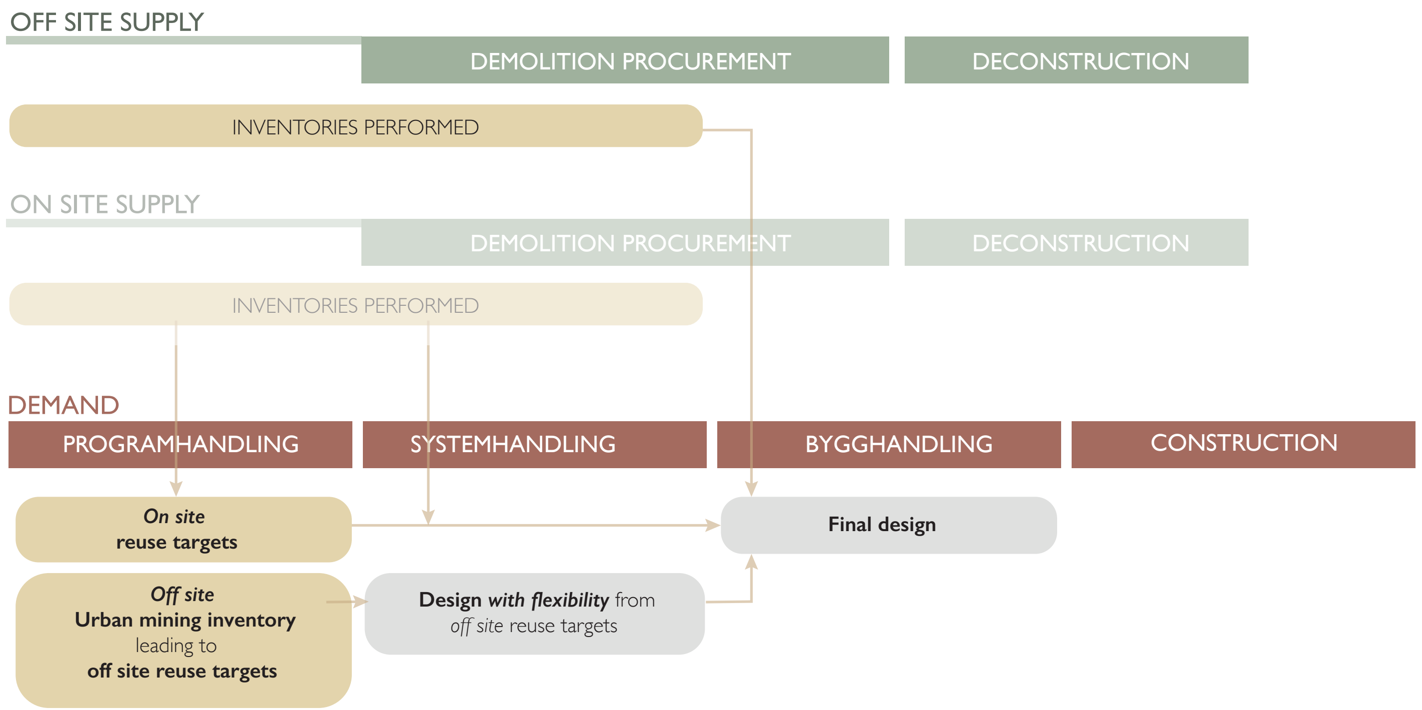


Figure 5. When working with an off site supply, an urban mining is done by the demand project to implement in a flexible design. The urban mining reuse targets are matched with information from inventories from the off site supply in the bygghandlingsphase to set the final design (summary of analysis of reuse processes).

In the case of Chalmersfastigheter, they had an on site supply from a smaller building needed to be taken down to make way for the new building. As for the off site supplies, they had several. To illustrate that, the diagram could be complemented with several off site supplies. For the on site supply however, there can of course never be more than one.

The final diagram (see figure 5) shows the complexity of the relationship between supply and demand projects. The communication between them heavily relies on the inventories and especially how the information from the off site supplies are managed further in the reuse process. These two themes - *inventories* and *information management* - will be further analysed and discussed in chapter 2 and 3 respectively.

Industrialising the reuse process

What prevents demand projects from buying the off site supply earlier in the design process? The interviews in this thesis indicates that the storing of reused building parts is an unavoidable issue and a challenge from many aspects. Buying reused building parts early in the process of a new construction requires storage for a longer and at times uncertain period of time, which is both a logistical, judicial and economical issue. It raises questions on who owns the building parts in-between usage and thus who pays for it. Additionally, because of the uncertainties of the time frame of a new construction - pro-longed building permit procedures and unexpected appeals among many - buying and storing a reused building part too early could end up long and expensive (Dahlstrand, personal communication, Mars 19, 2021).

A comparison can be drawn to the prefabrication industry and the production of new building elements. One example is Derome, one of Sweden's major prefab timber companies. When their productions are planned there are automatic reservations of amount of materials needed, and automatic purchase orders done to their suppliers (Carlsson, personal communication, February 1, 2021). An industrial process builds upon smooth transitions where administration and working hours are minimised, and materials arrive just-in-time.

"If it is not documented,
it doesn't exist."

- Louise Fried

2. INVENTORIES

Investigating the purpose and methods for doing different kinds of reuse inventories, with a focus on how they relate to the architect's design process and reuse on an industrial scale.

WHAT & WHY INVENTORY?

Inventories can be performed by many different stakeholders using very different methods, but they all have a similar purpose. This chapter analyses ten different reuse inventories and seven ongoing reuse projects along with practical site survey inventories to understand how and why an efficient inventory process can be performed.

An inventory is not directly connected to a reuse purpose. In any business or organisation holding a physical stock, the inventory is considered one of the most important assets to understand and monitor your business (Unleashed 2015). Stores, warehouses and companies are obliged by law to perform inventories of their stock each year to account for their total value (Skatteverket 2021).

One of the main reasons for making an inventory is to get an overview of what you own - a way of realising the actual value of your stock. When it comes to reuse inventories, large amount of resources could be saved if doing inventories of the existing building stock, as the information contributes to making it available to a larger extent (Håkansson, personal communication January 22, 2021). Furthermore, inventories are needed to be able to plan for the reused building parts in the new construction projects (Göteborgs stad 2020, 10).

"In the same way that daylight, terrain, infrastructure and soil conditions are mapped and analyzed at the beginning of a project, an inventory of the conditions for reuse on the site must be a natural part of every analysis to identify existing and potential qualities and values."
(Andersson & Nilsson 2020, 33)

LEVELS OF INVENTORIES

The inventories analysed in this thesis have shown a large variation in detailing. Some of the inventories were only using an estimated grading on the reuse potentials of the building parts, while some had detailed information such as measurements or building code requirements. The level of detailing is mainly determined by:

• the purpose of the inventory
• the size of the project
• in which phase of the project the inventory was made

What differed differed one inventory from another was whether it led to a reuse target or not (see chapter 1). Some of the inventories were made to identify the reuse potential of a certain building part, as a base for a decision to set reuse targets. Other inventories were made after such a decision already had been taken, and in those cases the purpose was to collect all the additional information needed to be able to implement it in a design.

Another important aspect is the size of the project, as it determines how focused the inventory needs to be. In a smaller project, it might be possible to inventory all building parts with a high level of detailing throughout the building, but in a larger project there is a need to limit the focus to a certain type of building part. In the reuse process of Kromet, the detailed inventory took a very long time since they did not limit themselves to any specific materials or products (Hedén, personal communication February 11, 2021). In another project - Panncentralen in Högsbo - the building was small enough to be able to inventory the detailed information from the start (Reclaimd 2020).

INVENTORY METHODS

The analysis showed that the inventory methods differed in the same ways as the inventories themselves.

Lendager Group calls the method of collecting most of the inventory information from drawings a *desktop mapping* (Lendager Group 2019, 17). To visit the demolition site to collect information is defined as a *site survey* by Rose and Stegemann (2018, 5). According to Lendager Group, a desktop mapping should always proceed an actual site survey. Depending on the amount of information that can be gathered from the desktop mapping, a site survey is simply a way of verifying that the gathered information was corrent and up-to-date (Lendager 2019, 17). This was confirmed during the practical site surveys made in this thesis, where a lot of time could be saved by mapping the type and amount of windows by using as-built facade drawings prior to the site survey, and only using the site survey to check on the condition of the windows. It was however noted that the possibility of doing a desktop mapping depends on what building part to inventory, as building interiors generally are not shown in as-built documents to the same extent and therefore might need more time on the site survey.

One of the reuse consultants interviewed used a pre-decessor to the digital tool *CCbuild Produktbanken* (see chapter 3 on *Logging and storing inventories*) to perform an inventory. Quite soon, it became obvious that the level of detailing in the tool was too extensive for the purpose of the inventory, and they ended up using a conventional spread sheet, customising the inventory after their own needs (Stenberg, personal communication January 25, 2021).

Conclusively, the analysis showed that inventories can be performed on a scale depending on its purpose and its level of detailing, and that the inventory methods differ accordingly. In this thesis, four different types of inventories were identified (see figure 6).

LIST OF INVENTORIES

To understand how the inventory process works in reality, ten inventories have been analysed and are presented below.

Hoppet inventory
TYPE OF INVENTORY Reuse potential inventory
REUSE CONSULTANT Lendager group
PROPERTY OWNER Lokalförvaltningen

Kromet inventory I
TYPE OF INVENTORY Reuse potential inventory
REUSE CONSULTANT White Arkitekter
PROPERTY OWNER Vasakronan

Kromet inventory II
TYPE OF INVENTORY Detail inventory
REUSE CONSULTANT White Arkitekter
PROPERTY OWNER Vasakronan

Bromma Sjukhus inventory
TYPE OF INVENTORY Reuse potential inventory
REUSE CONSULTANT Kaminsky Arkitekter
PROPERTY OWNER Vectura fastigheter

Kustgatan inventory
TYPE OF INVENTORY Reuse potential + Detail inventory
REUSE CONSULTANT Reclaimd
PROPERTY OWNER Familjebostäder

Panncentralen Högsbo inventory
TYPE OF INVENTORY Reuse potential + Detail inventory
REUSE CONSULTANT Reclaimd
PROPERTY OWNER Familjebostäder

Stadskvarteret inventory
TYPE OF INVENTORY Reuse potential inventory
REUSE CONSULTANT Helsingborgshem
PROPERTY OWNER Helsingborgshem

Eriksboskolan inventory
TYPE OF INVENTORY Environmental inventory
ENVIRONMENTAL CONSULTANT Relement
PROPERTY OWNER Lokalförvaltningen

***Form follows availability* inventory**
TYPE OF INVENTORY Reuse potential + detail inventory
REUSE CONSULTANT Taleen Josefsson
PROPERTY OWNER -

***Towards zero-waste buildings* inventory**
TYPE OF INVENTORY Reuse potential inventory
REUSE CONSULTANT Václav Grmela
PROPERTY OWNER -

INITIAL INVENTORIES

DETAILED INVENTORIES

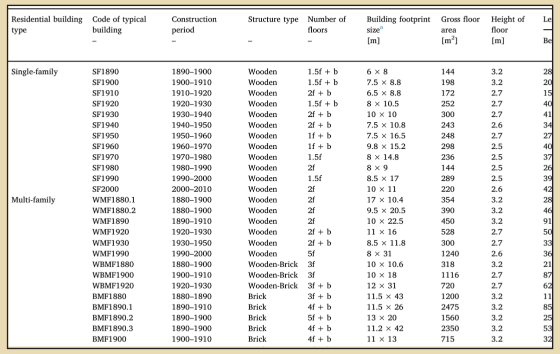
URBAN MINING

An inventory to understand ***what exists*** *to reuse*

Purpose:
To get a broad picture of what building typologies or building parts exist in the society and what is frequently demolished to be able to get an expectation of a future supply.

Typical inventory parameters:
- Construction type/building part
- Construction/manufacturing period
- Quantity

Real case example:



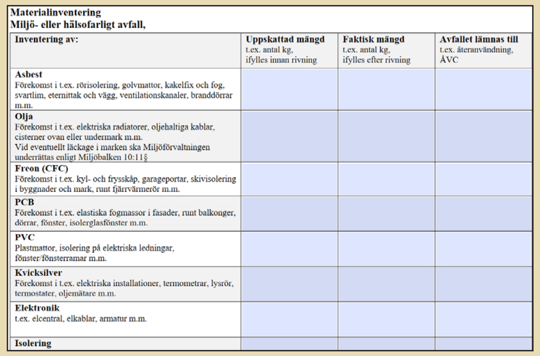
ENVIRONMENTAL INVENTORY

An inventory to sift out ***what is possible*** *to reuse*

Purpose:
To create a basis for the waste management by identifying if and where hazardous substances exist in a building before a demolition. The methods used are ocular inspections as well as taking samples.

Typical inventory parameters:
- Type of hazardous substance
- Location
- Quantity/extent

Real case example:



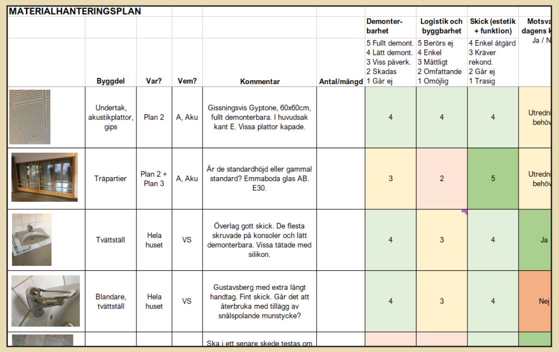
REUSE POTENTIAL INVENTORY

An inventory to sift out ***what is feasible*** *to reuse*

Purpose:
To get an idea of the reuse potential of building parts where the final decision of the potential depends on the sum of several parameters. The economic and environmental aspects has shown to be the most decisive ones.

Typical inventory parameters:
- Economical value
- Environmental savings
- Quantity
- Disassembly feasibility
- Condition
- Aesthetics
- Future applications

Real case example:



DETAIL INVENTORY

Inventories to collect ***further information after a decision on what to reuse*** *has been taken*

Purpose:
To collect the additional information needed to be able to implement the building components in a new design.

Typical inventory parameters:
- Exact measures
- Classifications: fire, sound, construction
- Upcycling propositions

Real case example:

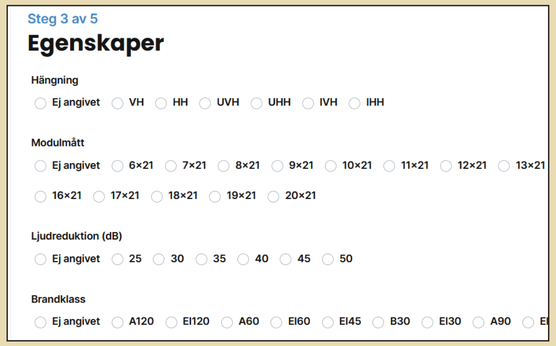


Figure 6. Summary of the four types of inventories identified in this thesis (Gontia P. et al. 2018, Göteborgs stad n.d., Kaminsky 2020, CCbuild Produktbanken 2021).

URBAN MINING

Building with reused materials on an industrial scale requires a constant and large supply and circulation of these materials. To understand the supply, one can look at what generally is being demolished in our cities today.

Most demolitions are of course occurring because the in-going materials have worn out or are toxic. In such a case, the general reuse potentials are quite low (Holmberg, personal communication, January 28, 2021). However, there are two other major reasons for demolitions. The first one is that the building no longer serves a purpose or function - that there no longer is a need for it. Such is the case of a lot of apartment buildings in rural areas, where the effect of the ongoing urbanisation leaves the buildings empty and thus expensive to heat and maintain (Eklund et al. 2003, 2). The other reason is that the building does not meet the government's or city's requirements for energy performance or plot ratio. If a renovation or addition to the building is not considered possible or good enough, the only remaining option is to demolish it and replace it with a new building meeting today's standards (Karlsson, personal communication, February 16, 2021). Both of these reasons mean that the building potentially is demolished long before the in-going materials reach the end of their technical life cycle (Eklund et al. 2003, 1). This is where the general reuse potentials becomes higher.

Urban mining can be considered an inventory method in a large scale, mapping what materials can be found in supply projects throughout the city, and which of them are most common. As mentioned in chapter 1, in an early stage of a demand project it might be too early to find a specific off site supply project. In such a case, urban mining can be a way of securing a generic supply of building parts. This means that it is possible to understand what type of building parts most likely will be available when the project is in the construction phase, and therefore can plan ahead for them (Dahlstrand, personal communication, Mars 19, 2021). Conclusively, what differentiates the urban mining from the other types of inventory is that it is performed by the demand project rather than the supply project. Furthermore, it is a method allowing generic projections of future supply and as such, it does not provide information detailed enough for a practical application at the project level (Rose and Stegemann 2018, 3).

Urban mining methods

There are several ways of finding out what reused building parts are going to be available. These have been summarised and analysed by Rose and Stegemann, but are a list of more or less efficient examples and as such more or less industrial. As an example, SuperUse studios coined the term *harvest mapping*, which is a process where the area around the site is scouted for available waste streams. This is a time-consuming process well outside the scope of the architect and as such far from realistic in a mainstream construction procedure (Rose and Stegemann 2018, 4).

One of the more promising processes could be to develop and communicate the existing, mandatory pre-demolition audits that needs to be submitted to the municipality prior to a demoliton. These documents need to include estimated amounts of the in-going materials and are public records, but as of today they are usually hard to find and get an overview of. These records could benefit from being collated in a public platform accessible for the demand side of the project (Rose and Stegemann 2018, 5).

Dnr	Ärendemening	Objekt
BN 2019-00885	Rivningslov för industri-, lager- och kontorsbyggna	GAMLESTADEN 22:14 (GAMLESTADSVÄGEN 18A)
BN 2019-01040(	Rivningslov för rivning av del av Nilsericsontermina	GULLBERGSVASS 17:1
BN 2020-00150	Rivningslov för rivning av affärsbyggnad	RUD 4:1 (GITARRGATAN 2)
BN 2020-0020(	Rivningslov för rivning av lokal	GAMLESTADEN 28:21 (MARIEHOLMSGATAN 50)
BN 2020-00204	Rivningslov för rivning av industribyggnad 742, 744	SKÅR 40:17
BN 2020-00235	Rivningslov för rivning av enbostadshus	HÄSTEVIK 2:420 (LÅNGE JANS VÄG 27)
BN 2020-00449	Rivningslov för rivning av Torslandaskolan	TORSLANDA 96:1 (RUNSKRIFTSGATAN 8)
BN 2020-00477	Rivningslov för rivning av del av skola	RAMBERGSSTADEN 54:5 (BLACKEVÄGEN 1)
BN 2020-00554	Rivningslov för rivning av fd båtverkstad	MASTHUGGET 712:41 (TREDJE LÅNGGATAN 24)
BN 2020-00691	Rivningslov för rivning av enbostadshus och förråd	NÄSET 101:8 (BARRIÄRVÄGEN 8)
BN 2020-01066	Rivningslov för rivning av lager	BRÄNNÖ S:6
BN 2020-01083	Rivningslov för rivning av byggnader inom nöjespar	HEDEN 40:38
BN 2020-010741	Rivningslov för rivning av glaskupoler för nedgång t	GULLBERGSVASS 703:7
BN 2020-01049	Rivningslov för rivning av fritidshus	HÄSTEVIK 1:165 (LILLETUMMENS VÄG 41)
BN 2020-01015	Rivningslov för rivning av komplementbyggnad	VRÅNGÖ 1:79 (MITTVIKSVÄGEN 12)
BN 2020-00953	Rivningslov för rivning av lokal	KORTEDALA 49:5 (FÖRSTAMAJGATAN 8)
BN 2020-00947	Rivningslov för rivning av industribyggnad	GULLBERGSVASS 703:17 (BERGSLAGSGATAN 6)
BN 2020-00934	Rivningslov för rivning av carport	KYRKBYN 118:13 (NORRA SÄLÖFJORDSGATAN 39)

Materialinventering
Avfall som inte är miljö- eller hälsofarligt

Inventering av:	Uppskattad mängd t.ex. antal kg, ifylles innan rivning	Faktisk mängd t.ex. antal kg, ifylles efter rivning	Avfallet lämnas till t.ex. återanvändning, ÅVC
Trä			
Mineral som består av betong, tegel, klinker eller keramik			
Metall			
Glas .			
Plast			
Gips			
Övrigt			

Figure 7. Extract of pre-demolition audits submitted to the city of Gothenburg. To retrieve more detailed information, documents for each building needs to be ordered seperately from the municipality (Stadsbyggnadskontoret, personal communication, January 21, 2021) (Göteborgs Stad 2021).

ENVIRONMENTAL INVENTORY

An environmental inventory is required by law to precede all remodeling and demolition projects to identify potential hazardous substances (Johansson 2018, 15). Furthermore, it aims to be the basis of the tender documents for the procurement of a demolition firm.

The outcome of the inventory is an extensive document containing an overview and analysis of all the materials in the building. The document contains images, building history and building drawings to visualise and locate the materials (Holmberg, personal communication, January 28 2021).

There is currently no focus on the reuse aspect within the environmental inventory profession, according to an interview with an environmental inventory specialist (Holmberg, personal communication, January 28 2021). Since July 2020, however, a new law requires the 'kontrollplan' that is established together with the material inventory to include what building components that could be reused, and how they should be deconstructed to preserve their value, see figure 11 (Boverket 2020). This idea is also mentioned by the city of Gothenburg, stating that an environmental inventory also could decide on a reuse potential to save time in the next stage of the inventory process (Göteborgs stad 2020, 10). In an interview with an environmental inventory specialist, it is agreed that this would be possible on a basic level - such as grading the condition and take initial measuremeants - but would require up to 25% more time as an estimation (Holmberg, personal communication, January 28 2021).

Material/produkter att återanvända

Ifyllda produktgrupper är identifierade som de vanligaste för återanvändning. Ta bort det som inte är relevant och lägg till om andra produktgrupper kan vara relevanta.

Fylls i av materialinventerare, byggherre eller återbruksaktör		Fylls i av återbruksaktör eller entreprenör						
Avfallsslag/ fraktion	Bedömd mängd	Hantering/ förvaring	Borttagen mängd	Transportör	Mottagare	Mottagen mängd	Verifiering	Kommentar
Dörrpartier								
Innerväggar och tak (glaspartier och akustikskivor)								
VVS, t.ex. handfat och toaletter								
Beslag och dörrautomatik, t.ex. dörrhandtag, dörrbeslag och dörrstängare								
Belysning								
Galler och smide, t.ex. spiraltrappor, tillgänglighetsramper, förrådsgaller								

Figure 8. The "kontrollplan" is required to be filled in since July 2020 when doing an environmental inventory (Göteborgs Stad 2020).

REUSE POTENTIAL INVENTORY

As stated in the introduction of this chapter, the reuse potential inventory is the inventory that decides whether the building part is worth reusing or not.

The reuse potential has to be done after (or together with) an environmental inventory. In september 2019, Danish architecture firm Lendager Group performed an extensive reuse potential inventory on four preschools for Lokalförvaltningen in Gothenburg. These inventories were not preceded by environmental inventories but rather worked as inspiration for the municipality as what to do with all the in-going materials and components of the buildings. This included desktop mapping as well as site surveys, visualised in an extensive reuse report calculating environmental savings and showing possible future application of the building parts in an idea catalogue (Lendager 2020). It was first after the environmental inventories were done that it was found out that several of the buildings contained large amounts of hazardous substances, which extensively limited the reuse potentials (Karlsson, personal communication, February 16, 2021). Although the idea catalogue contributed as an thorough inspiration source, it was a shame that a lot of time was spent when finally nothing could be reused.

Reuse potential parameters

Five of the ten inventories analysed in this thesis used a set of parameters to decide on the reuse potential of each building part. From these five inventories, along with input from *CCbuild Produktbanken*, the most frequently used parameters could be categorised into six types of reuse potential parameters (see figure 9).

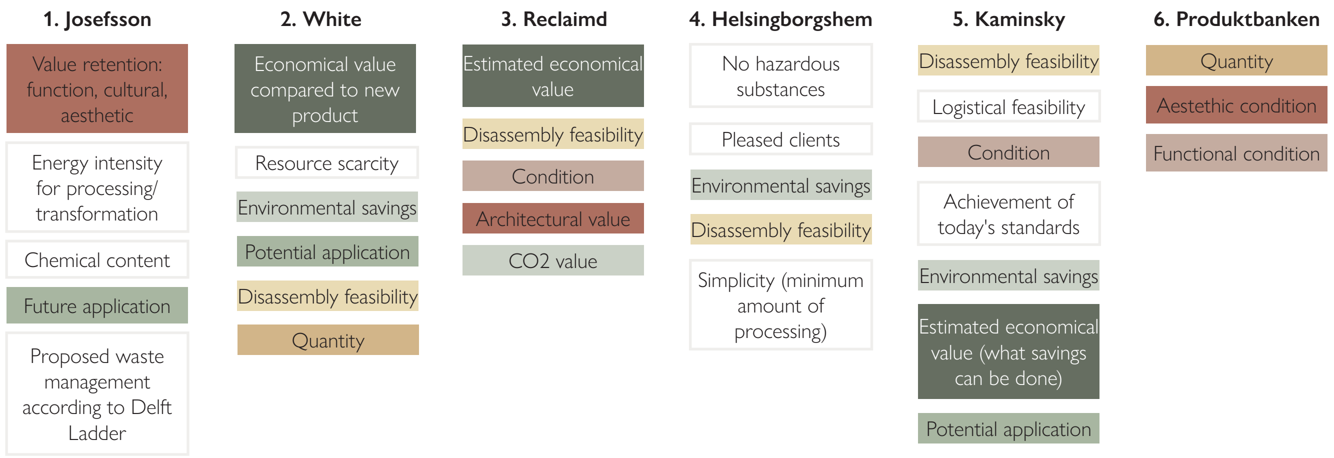
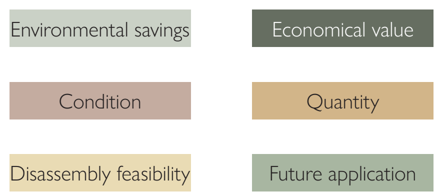


Figure 9. Mapping of all parameters connected to the reuse potential of a building part.

As stated in the introduction, *reuse needs to be implemented on an industrial scale to reach higher quantities and better profitability* and that *it is needed to understand what kind of building parts are most feasible to reuse.* The reuse potential parameters therefore has to be looked at through an industrial lens and always from an economical point of view, since economy is what powers a successful business.

One of the seven parameters that could not be directly connected to an economical aspect is the architectural value. The architectural value is important, but it is not discussed further in this chapter as it is a parameter connected to the demand project rather than the supply project - it is up to the demand project to decide what aesthetically fits the new construction. The other six parameters are explained briefly in the following section.



The six most common reuse potential parameters.

ENVIRONMENTAL SAVINGS

The environmental savings does not have a direct connection to economical aspects, but as this is the main reason for reusing building parts anyway, large environmental savings is a very strong driving force. According to several interviews, the environmental savings have been the starting point to decide on what to prioritise in further investigations on what to reuse. An example is in Europahuset, where one of the architects in the projects mentions that the concrete frame and foundation was set as the main reuse focus due to its large climate impact and economical value (Landenberg, personal communication, January 29, 2021).

Environmental savings is referring to the emissions produced in the A1-A3 phase in a life cycle assessment (LCA). Transportation of building parts (phase A4) is a small emission in comparison (BM 1.0).

ECONOMICAL VALUE

This is referring to the actual built-in economical value compared to a similar new building part.

CONDITION

The condition is a parameter strongly connected to both the environmental and economical parameters, since reconditioning requires both cost and energy. The main economical expenditures are working hours for reconditioning (Lendager 2021, 39).

An aspect to consider when looking at the condition is whether the building part meets today's standards, such as fire or energy requirements (Stenberg, personal communication, January 25, 2021).

As stated in the introction of this chapter, this parameter can only be evaluated through a site survey.

QUANTITY

There is a larger reuse potential in larger quantities (CCbuild, seminar 22/3). This is confirmed by the project leader at Onsala Rymdobservatorium, dreaming to find one big supply project to find all building parts from, as every transportation is a cost connected to increased working hours and increased emissions (Dahlstrand, personal communication, Mars 19, 2021).

FUTURE APPLICATIONS

Two purposes for the future application parameter were identified: location and function.

The location could be on site, such as interior products being reused within the renovation project (Lunneblad, personal communication, February 3, 2021). The location could also be off site, such as suspended ceiling tiles moved from one office building to another (Hedén, personal communication, February 11, 2021). If no demand project has been found within the time before deconstruction, the future location could also be set to a reuse material supplier (Lunneblad, personal communication, February 3, 2021). The function proposes in what ways the building part could be reused apart from direct reuse. These includes examples of upcycling, such as skirting boards turned into acoustic wall panels (Lendager 2019, 75), or downcycling, such as concrete wall elements turned into entrance benches (Stenberg, personal communication, January 25, 2021) or broken bricks used as foundation aggregate (Josefsson 2019, 58).

DISASSEMBLY FEASIBILITY

The disassembly feasibility has to be taken into consideration because the cost of labour is so much higher than the cost of materials and products (Andersson and Nilsson 2020, 22).

The disassembly feasibility varies a lot depending on the type of building part. To evaluate this parameter further, four different categories of building parts have been identified in relation to their disassembly feasibility (see figure 10).

Building interior
Loose furnishings that need little to no disassembly.

EXAMPLES chairs, tables, shelving systems.

Building components
Individual components including fixed furnishings, that already are designed for disassembly.

EXAMPLES windows, doors, toilets, kitchens, light fixtures.

Building materials
Single materials that also include the separated, individual materials of a building element.

EXAMPLES bricks, mineral wool boards, wooden joists, concrete roof tiles.

Building elements
Walls, floors, ceilings. The main construction parts of the building. Usually layered and consisting of several building materials.

EXAMPLES timber frame walls, cut-out brick partitions, prefab concrete slabs with integrated insulation.

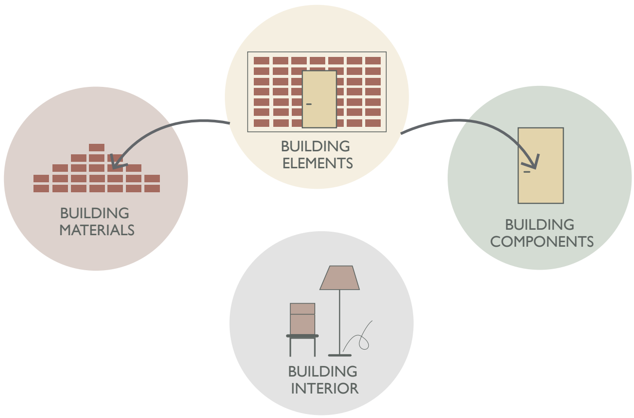


Figure 10. Building part categories.

Interiors & components

The existing industrial reuse in the building sector today is mainly working with building interiors, as they need little to no disassembly and are smaller and easier to transport and store. An office space is generally refurbished every 3-5 years as the tenants change, making their in-going parts important to reuse from an environmental point of view (Håkansson, personal communication January 22, 2021). Procedures for reuse of building interiors have gone fairly far, with around 15 projects presented at the webpage of CCbuild (CCbuild n.d.). An example is Selma Lagerlöf Center, a cultural public building in north Gothenburg, where reused building interiors were used throughout the 6200 square meter building (White 2019).

A building component is also one of the easiest building parts to reuse. According to the sales manager at Dacke App, both interiors and components constitutes "the low hanging fruits" of the reuse market (Axlund, personal communication, January 22, 2021). Kompanjonen is a reuse consultant company focusing on the reuse of building interiors and components (Håkansson, personal communication, January 22, 2021).

Materials vs elements

With industrial reuse systems for building interiors and building components in place, the challenges mainly lie in the industrial reuse of building materials and building elements.

The building stock we have today has not been built with methods that facilitates the disassembly of each material in an element. Because of the use of nails, glue and other non-reversible attachments, the disassembly is a time-consuming and thus costly work (Österberg, personal communication, February 28, 2021). Furthermore, the economical value of the element does not lie in each, single material but rather in the assembly of them. A comparison in *Sektionsfakta*, a reference book comparing the cost of material and labour for different building parts, shows that the material costs of a standard timber frame wall only is about 30% of the total cost (Sektionsfakta 2020, [7.023]). Similarly, the material costs of a steel stud wall is about 40% of the total cost (Sektionsfakta 2020, [7.060]).

What can be seen is that the cost of the materials themselves are quite small in comparison to the cost of assembling them. With the same logic, this means that the cost of disassembling the wall material by material would simply would be too time-consuming and thus too costly. Conclusively, to reach industrial reuse of large scale building parts, the focus should be on the reuse of whole building elements rather than building materials. This is confirmed by several sources. The head of Research & Development at prefab timber company Derome examplifies this with a planar element, which costs around 70-80 000 Swedish kronor a piece and include a lot of expensive man hours (Carlsson, personal communication February 1, 2021). In an interview with a project leader at a property developer, it is claimed that the reuse of whole walls and elements is where reuse actually could start become profitable (Lunneblad, personal communication February 3, 2021). Finally, *The Delft Ladder* is a waste management hierarchy developed in the Netherlands, where element reuse is considered of higher priority than material reuse (see figure 11) (Gorgolewski 2017, 37).

There are methods for reusing building elements today. In North America, RE-USE Consulting are working with the de- and reconstruction of large building elements, mainly focusing on single house buildings with timber structures. The company is not working with systematised solutions nor on an industrial scale, but they are experienced around the principles of deconstructing building elements (Benninck, personal communication, Mars 11, 2021).

An ongoing research project is Återhus, a collaboration between the architecture office CoDesign, research institute Rise and building contractors NCC. They focus on element reuse of heavy structures in concrete and steel, since these emit high carbon emissions during production and have a long life span (Svensk Byggtidning 2021). The reuse of heavy structures is however outside the scope of this thesis.

An issue with element reuse is to manage the element size. The size is a balance between "as few cuts as possible" and "manageable" concerning the weight (Österberg, personal communication February 28, 2021).

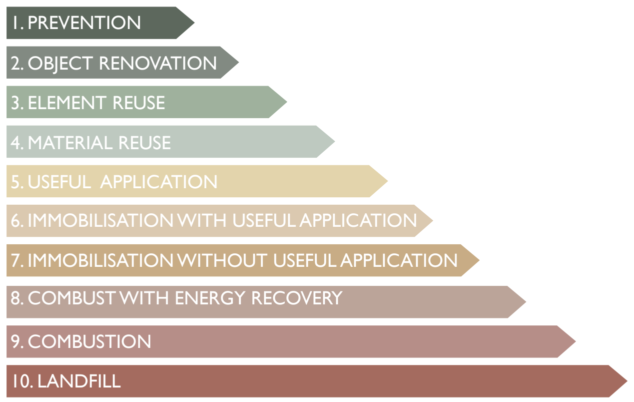


Figure 11. The Delft Ladder (Gorgolewski 2017).

THE REUSE REPORT

VISUALISING THE DATA

When a reuse potential inventory has been done, it needs to be summarised and visualised towards the different actors of the project; mainly the client, so that he or she can make an informed decision in how to proceed with the reuse process in the project, such as setting reuse targets (CCbuild n.d.). In 7 of the 10 inventories analysed in this thesis, this has been done in the form of a reuse report.

An important element of the reuse report is to visualise the inventory in a way that makes it easy to comprehend. This is done by using different visualisation methods to highlight different kinds of data (see figure 13, 14 & 15). From the inventory analysis, eight types of visualisation elements have been identified (see figure 12). If the inventory had a reuse report connected to it, the visualisation elements of the report was analysed. If no report was attached to the inventory, the visualisation elements of the inventory itself was analysed.

One of the visualisation elements is to use a table with scores where the different reuse potential parameters are rated. The rating of the parameters were done in two ways, either one of the ways or in a combination:

- An estimated numerous value with a minumum scale of 1 to 3 and a maximum scale of 1 to 10, with 1 being the lowest.
- A written comment by the different stakeholders in the project - the reuse consultant, the property developer and the architect. These kind of comments were deemed essential to determine the reuse potential, as they can get more nuanced than a single number.

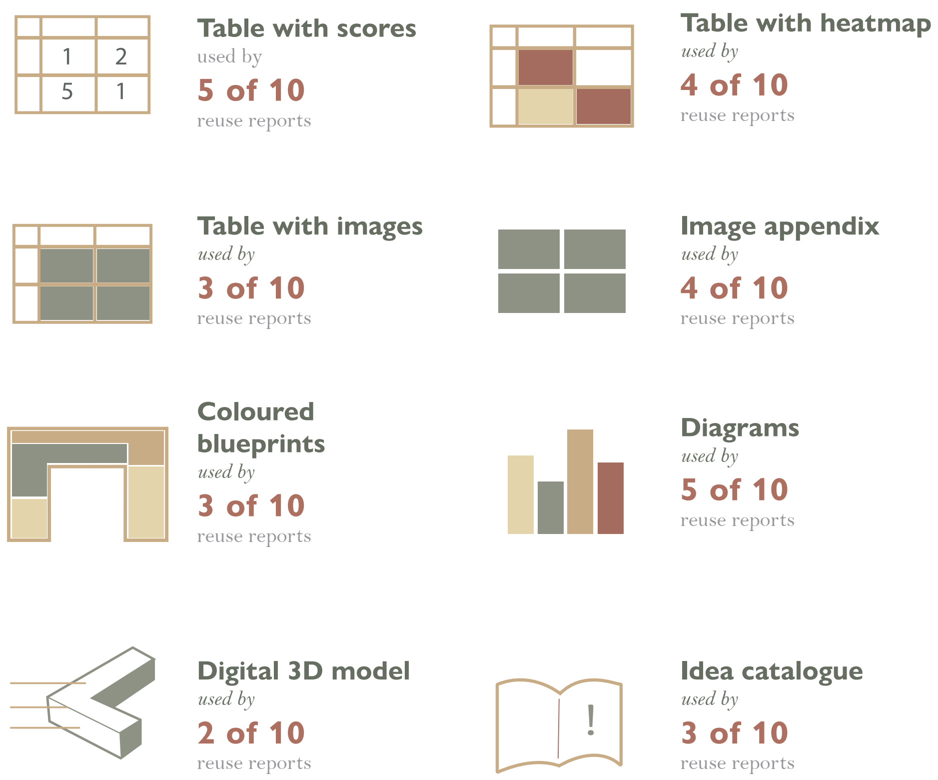


Figure 12. Summary of visualisation elements in the reuse reports analysed.

SETTING REUSE TARGETS

The visualisation elements are an important way of summarising and comparing the reuse potentials of different buildings parts and as such, important to be able to set reuse targets. A reuse target is an overall generic goal for the amount of reuse in the project. This was used by all six reuse projects analysed in this thesis.

Three types of reuse targets were identified, based on either:

- a percentage, such as "85% reused building parts, measured in volume units" (Dahlstrand, personal communication, Mars 19, 2021)
- a specific building part, such as "Reuse of brick facade, concrete floor elements, stainless steel sinks and steel staircase railings" (Delander-Eksten, personal communication, February 3, 2021)
- a combination, such as "100% reused surface layers in one apartment" (Lunneblad, personal communication, February 3, 2021)

Reuse targets can be set by both the supply and the demand project. Supply projects set targets on the amount of building parts they want to deconstruct and find further usage for. Demand projects set targets on the amount of reused building parts they want to include in their new construction.

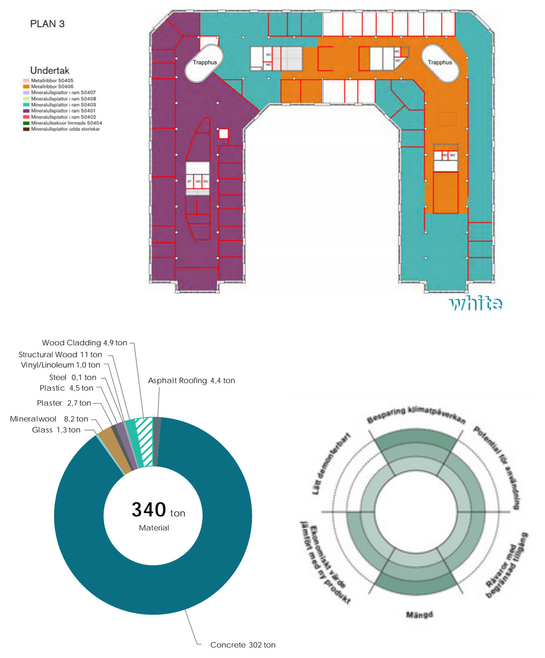


Figure 13, 14 & 15. Visualisation examples from the reuse reports analysed (White 2019, Lendager 2019, White 2019.

DETAIL INVENTORY

After the reuse targets are set, a detail inventory is needed to complete the previous inventories with the information needed to be able to be plan the reused building parts into a new construction.

This informaton is different for each type of building part but at least includes detailed measurements, as well as different certifications regarding fire, noise and energy standards. Which detail parameters are needed to be able to design with the reused building part is further investigated in chapter 5 (see page 81 on *Design with off site supply*). This is to be able to generate BIM objects based on the inventory data (see chapter 3 on *Information management*).

It is important to have set reuse targets based on the reuse potentials as a basis in the detail inventory, as it can be a time-consuming process if the focus is not sharp enough (Stenberg, personal communication, January 25, 2021).

"The most valuable commodity I know of is information."

- Gordon Gekko, *Wall Street*

3. INFORMATION MANAGEMENT

Investigating the purpose and methods for working with information management within reuse projects, and how they relate to the architect's design process.

SYNCHRONIZING THE DATA

One of the prerequisites for a circular building industry, as stated in the introduction, is that information about built-in materials and products can be stored in an accessible way. By putting the information from the inventories in standardised database systems, the data can be synchronized between stakeholders within the project as well as between projects (Göteborgs stad 2020, 17).

This type of infrastructure is called a digital ecosystem, which can be described as a collaborative exchange of information (IVL 2021, 18). There are several benefits to creating digital ecosystems within the reuse process:

• A better reuse market, by creating an overview of available materials and products for all buildings, at all scales and in all phases, making it easier to source components for a demand project (Andersson & Nilsson 2020, 94).
• A possibility to connect with other types of information, such as product specifications and material compositions (Göteborgs stad 2020, 17).
• Enabling further usage of the built-in components during property management, such as through a digital twin (IVL 2021, 4).
• Enabling further usage of the data in the design process, for example by connecting it to a BIM model (Stenberg, personal communication, January 25, 2021).

The overall benefit is that less time is needed for hunting down information, making it more efficient and thus more industrial (Andersson och Nilsson 2020, 94).

This thesis has delimited itself from the reuse market and property management, and rather focus on the architect's process in relation to reuse. As such, this chapter will delve more into the last point - the integration of the inventory into the architect's design process using information management.

CONNECTING REUSE TO THE DESIGN PROCESS

There are several examples of projects using information about reused building parts as a part of the design process. This chapter uses semi-structured interviews and literature review of previous theses to analyse a selection of building projects connecting the architect's design process to the reuse of building parts.

In a reuse project by Danish architecture firm Vandkunsten, the architects placed all existing and found construction elements in a 3D model from which they continuously adjusted the design (Josefsson 2019, 140). This is a common method when working with on site reuse, where the existing building and its constituting building parts need to modeled any way (Westin, personal communication, April 23, 2021). When working with large scale off site supplies however, this method of manually modeling 3D model objects that might or might not be included in the final design would be too time-consuming to be economically feasible.

In their project Upcycle studios, Danish architecture firm Lendager Group developed a new product called *Upcycle windows*, where reused window panes were mounted together in a new frame to form a curtain wall system. As a part of the project, an algorithm was developed that took the dimensions from the inventory data of the available reused window panes and optimised the amount of them in the curtain wall system by looking for the most efficient pattern (see figure 16) (Lendager 2020, 164). This kind of tool provides a strong connection between the inventory data and the design process, and is more efficient because of the algorithm. It is however customised to solve one very specific problem of the reuse design process.

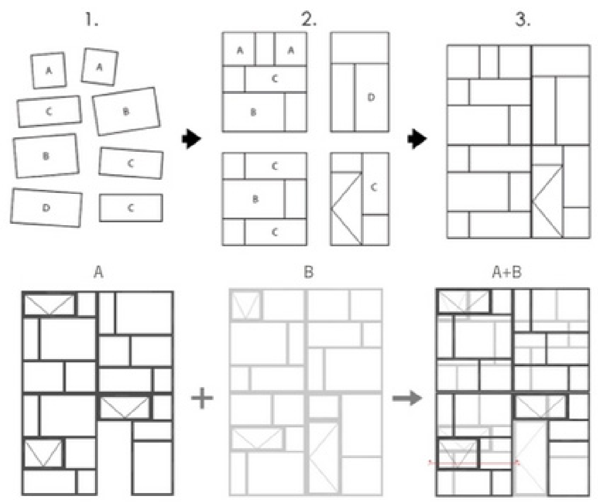


Figure 16. Pattern algorithm for Upcycle windows (Lendager 2020).

CONNECTING REUSE TO BIM

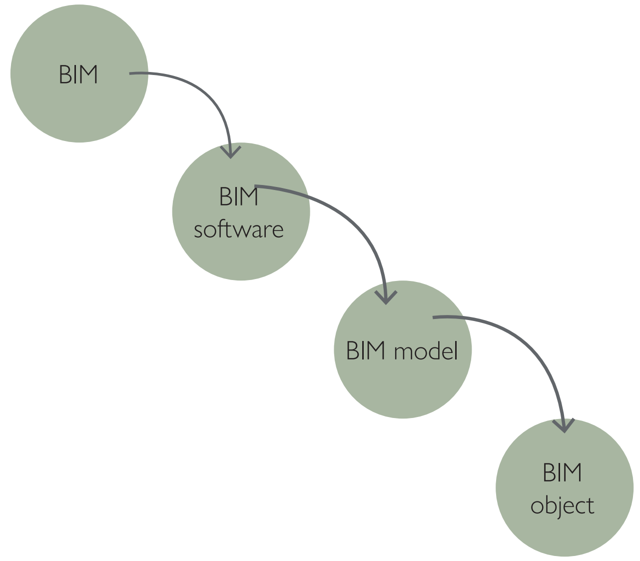
There are lot of research papers and pilot project connecting reuse of building parts to building information modeling. These have been found via the semi-structured interviews and by searching for "reuse + BIM" in research database systems.

BIM stands for Building Information Modeling and is the process of creating and managing information in a construction project through a digital representation of the building (NBS n.d.).

BIM software is a software that enables the use of BIM, such as Revit or ArchiCad (BIM wiki n.d.).

BIM model is all the 3D geometry of the building, and its associated information, within the BIM software.

BIM object is a digital 3D representation of a specific building part in the BIM model. It is a combination of the actual object geometry and the associated information such as material and manufacturer properties (Break with an architect n.d.).



The relationship between different BIM definitions.

The pilot project *The Circular Building* was as a prototype collaboration between Arup, Frener & Reifer, BAM Construction and The Built Environment Trust. The small house was designed using a BIM model which uploaded the material and component information to a database. Each material was given a so-called *material passport* in the form of a physical qr code, containing the information required to facilitate future circulation of the materials. The materials themselves, however, were new (Gorgolewski 2017, 57).

In their project *ACE - Arkitektur för cirkulär ekonomi*, Sweco looked at the tools and methods needed to create architecture for a circular economy on an industrial scale (Eriksson 2019). One of their main themes is the use of BIM to include information related to circular economy, by developing a list of property sets in Revit. The property sets contain both boolean properties (yes/no), such as *ComponentPrefabricated* and *ModularComponent*, indicating if the building part is prefabricated or modular, as well as percentage-based parameters, such as *ReusePotential* (Eriksson 2019, 65-66). Furthermore, they connected the values from the property sets to a 3D heatmap to see which objects are connected to high or low values, meaning to visualise potential climate thieves (Eriksson 2019, 73). Similar to *The Circular Building*, however, this project also worked with virgin materials, and as such focus on design *for* reuse rather than design *with* reuse. This means that:

• they design using virgin materials rather than reused materials
• they focus on the export of data *from* the BIM model, rather than the import of data *to* the BIM model

There are a few research papers that approaches the integration of existing, preused building parts into a BIM model.

Cai and Waldmann propose a material and component bank to make the reuse of building parts in old building into new buildings more efficient. The research paper is however assuming that a BIM model of the old building already is existing (Cai & Waldmann 2019, 9). This is generally not the case with older buildings.

In a 2020 research paper, Bertin et al. creates a BIM-based toolchain and database for the reuse of load-bearing steel columns and beams. In their database, BIM objects of the reused structural elements are stored along with information on the more structural properties. These reuse BIM objects can then be imported and replace new elements in the BIM model (Bertin et al. 2020, 15). The information is stored in two ways in BIM: through *phasing* and through *shared parameters* (Bertin et al. 2020, 12-13). Similarly to Cai and Waldmann, however, Bertin et al assumes that the reuse BIM objects need to be modeled manually prior to the integration into the new BIM project.

One of the reuse projects analysed in this thesis is the ongoing remodeling project of Bromma Hospital in Stockholm. As a part of the renovation, a 2-year long research project led by IVL Svenska Miljöinstitutet and Kaminsky architects is investigating how to plan for and coordinate the reuse of building parts (Vectura 2020). The goal in Bromma Hospital is to try to and use the inventory data to generate BIM objects of at least some of the building parts planning to be reused, starting with some storage cabinets (Stenberg, personal communication, January 25 2021).

Similarly, Sweco claims that within BIM softwares today, there are no simple ways of importing or cross-referencing information about materials - neither virgin nor reused - from and to a material database (Eriksson 2019, 80).

Conclusively, what is lacking is a simple way of importing the inventory data into a BIM software to generate BIM objects that the designer can use as a part of her design process. To enable this type of function, a further analysis is needed of:

- in what ways current material inventories are logged and stored
- in what ways BIM software organise and visualise data
- in what ways BIM objects can be generated through the import of data

"In the next step of processing the inventory, compatibility with a BIM software is essential. This is nothing that is possible today, but the possibility is widely asked for from several actors in the building sector. It is a way to simplify the designing, planning and integration of reused materials in the project for the architect."

(Stenberg, personal communication, January 25, 2021)

Figure 17. 3D scanning as a way of logging and storing inventory data, using White Recapture (White ReCapture n.d.).

LOGGING AND STORING INVENTORY DATA

To understand in what ways inventory data can be used further in the design process, an analysis of how the data of current material inventories are logged and stored is needed. From the inventories analysed in this thesis, as well as the answers from the semi-strucutred interviews, four tools for logging and storing the inventories were found.

CCbuild Produktbanken

As mentioned in the background chapter, CCbuild is an innovation project run by IVL Svenska Miljöinstitutet. They are providing a digital platform consisting of an inventory software and a market place for reused building parts. These two services are connected and synchronized through *Produktbanken*, which is a database with a user interface where users can upload the information from their inventories using a set list of parameters (see figure 18). Each inventory is connected to a specific project with a specific project owner, but the information can be shared with other project owners if needed. The inventory data can also be downloaded as an Excel sheet (CCbuild n.d.). The consequence when working with this kind of tool is to have to work with a set list of parameters, and not be able to customise the tool according to project-specific parameters. This aside, *Produktbanken* is providing the tool the closest to the idea of a standardised database system where inventory information can be shared between projects. To date, they have around 85 different companies and 160 projects using the database (Loh Lindholm, personal communication, May 10, 2021).

Dacke App

Dacke App is a private company offering an inventory software and database, with an associated phone application. The software is still under development and no testing have been possible during the time of this thesis. It does however have an API in progress to be able to connect to other platforms (read more on API on p. 45). Jan Axlund, CEO of *Dacke App*, deems this as essential to be able to success as an inventory tool. 'API in' is to be able to reach the information in the BIM software to see the available components in the inventory database, 'API out' is to be able to forward that information back to the original source, to "reserve" the component in the inventory database (Axlund, personal communication, January 22, 2021). As the tool is still under development, however, no further analysis or usage of *Dacke App* is made in this thesis.

White ReCapture

White ReCapture is an inventory service developed by White Architects, where the building is 3D-scanned, imported to a BIM software and converted into BIM objects (see figure 17). This makes it possible to store the building geometry directly in the BIM software and save further information directly to each BIM object, thus creating a direct integration between the inventory and the BIM model (White ReCapture n.d.). However, this type of inventory becomes very project-specific, and there is still a need for a database to upload the BIM objects to if further usage of the objects in other projects are to happen. Because the service still is very new, no further analysis or usage of *White Recapture* is made in this thesis.

Spread sheets

Using a spread sheet service, such as Microsoft Excel or Google Sheets, is a simple and accessible way of logging the data from an inventory. The parameters for each inventoried object could easily be customised by adding and deleting columns, and by using several worksheets. The spread sheet formats, such as .txt and .csv, are compatible with most tools, softwares and programming languages (Guru99 n.d.). However, it might be difficult to secure that the information is logged in the same way throughout different projects, thus decreasing the compatibility chances.

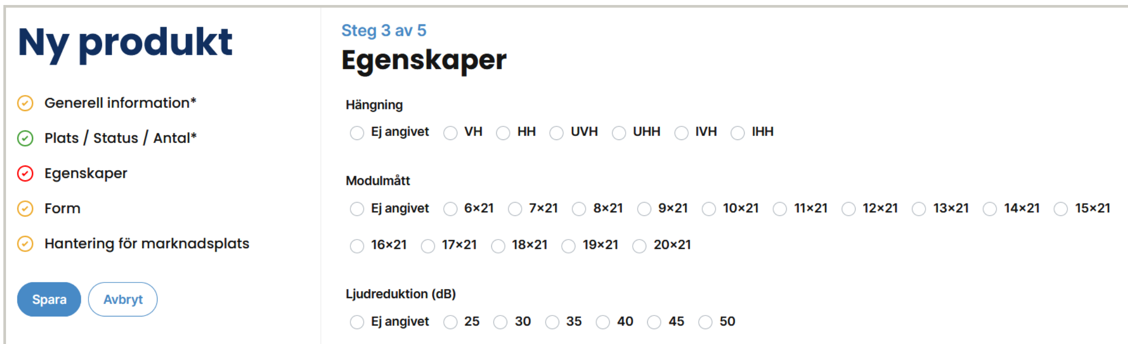


Figure 18. Screen shot from one of the logging stages of an inventory in CCbuild *Produktbanken* (CCbuild n.d.).

ORGANISING AND VISUALISING BIM OBJECT DATA

To understand in what ways data connected to BIM objects is organised and can be visualised, a summary of the most essential and commonly used functions were made using Revit documentation.

IN WHAT WAYS CAN WE ORGANISE DIFFERENT DATA?

Phasing
Most building projects proceed in phases, each representing a distinct time period in the life of the project (Autodesk n.d.). In a typical renovation project, the phases would at least consist of "Existing", "Demolition" and "New construction" (Westin, personal communication, April 23, 2021). Revit tracks the phase in which views or elements are created or demolished. Phase filters can then be used to produce phase-specific project documentation, controlling what elements are visible in what phases (Autodesk n.d.).

Families
A family is a group of elements with a common set of properties (family parameters). Different elements belonging to a family may have different values for some or all of their parameters, but the set of parameters (their names and meanings) is the same. These variations within the family are called family types or types (Autodesk n.d.).

Parameters
Parameters store and communicate information and properties about all elements in a model. They are used to define and modify elements. There are four types of parameters:

Project parameters specific to a single project file, usually used to categorise views.
Family parameters specific to a family, such as the dimension of a door.
Shared parameters can be used in any project or family because it is saved in a separate file.
Global parameters specific to a single project file, usually used to set specific values or dimensions between elements.
(Autodesk n.d.)

IN WHAT WAYS CAN WE VISUALISE DIFFERENT DATA?

Tags
A tag is an annotation for identifying elements in a drawing. When a tag is created, labels are added to display the value of desired element parameters (Autodesk n.d.).

Schedules
Schedules are tables that can be used to quantify and analyse the amount of components and materials in your BIM model. They can be filtered to only show BIM objects with certain parameters or parameter values. The schedules can also be exported in various standardised formats such as .txt or .csv (Autodesk n.d.).

View filters
A view filter can be used to override the graphic display and visibility of selected elements that share common parameters (Autodesk n.d.).

BIM COMPATIBILITY TOOLS AND METHODS

This chapter looks at what different types of tools or methods that can be used to generate BIM objects from imported data.

The foundation of a digital eco-system relies on interoperability, meaning that two or more systems can both share and use the information they give and receive (IVL 2021, 21). One of the fundamental services for a well-functioning digital ecosystem is a well-functioning API (SnapLogic 2019). An API is the piece of programming defining how two or more software programs can interact. One software can call the other software's API to get access to their data, and the other way around (RapidAPI n.d.).

Revit API
The Revit API can be used to create software extensions or plug-ins that provide further functions than the original software. The plug-ins are a part of the Revit interface. These plug-ins can be written using a variety of programming languages, such as C# and Visual Basic. The Revit API documentations is a manual providing all the information and code references needed for the developer to create a plug-in (Autodesk n.d.). However, to work with the Revit API means that the developer of the plug-in needs to have programming skills, making it less accessible and prone to updates, changes and development by the actual plug-in users - professionals in the construction industry.

Visual programming
Visual programming is a type of programming language that lets the user describe the programming processes using illustrations and flow charts, where each illustration represent an already defined piece of code (OutSystems 2019). This type of programming requires less text-based programming experience, meaning it is a lower threshold for a professional in the construction industry to go in and develop the functions of the plug-in according to her preferences. There are two visual programming languages compatible with Revit: Dynamo and GrasshopperInside.Revit. Both of these can create and edit a majority of the Revit elements, including families, family types and their associated parameters (Rhino.Inside.Revit n.d.).

Existing plug-ins
In the AutoDesk App Store, Revit users can browse through thousands of existing plug-ins. There are several plug-ins enabling the user to download and thus generate BIM objects directly into the model from the plug-in's database of BIM objects. One of the most popular examples is NBS National BIM Library, a British company that has developed a BIM object standard for product manufacturers to follow to ensure compatibility and consistency for the user (NBS National BIM library n.d.). Another example is bimproject.cloud, a web-based catalog of BIM objects where the user can create and customise their own objects by changing the parameters before downloading the objects, see figure 19. A customised object is always based on an existing family type in the database, which the plugin duplicates and changes the properties according to your settings (bimproject.cloud, n.d.). There are also plug-ins allowing the user to import and export data in various format into Revit. The AutoDesk App Store review does however not show any plug-ins allowing the combination - to generate BIM objects based on imported data, and upload the altered object back.

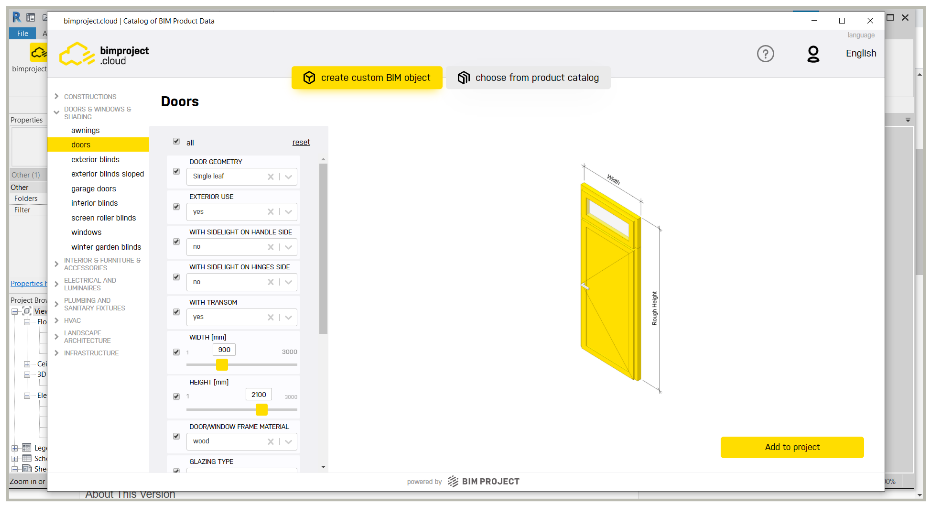


Figure 19. Screen shot from bimproject.cloud, where the user can customise their BIM object before downloading it (bimproject.cloud, n.d.).

"If you want to be a good archeologist, you gotta get out of the library!"

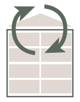
- Indiana Jones

4. DISCUSSION

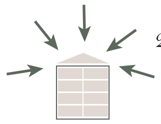
Summarising and discussing the findings from chapter 1, 2 and 3.

ON SITE & OFF SITE SUPPLY

The analysis of ongoing reuse projects shows that the reuse process has to be performed differently depending on two different scenarios connected to the orgin of the supply.



1. The project is a remodelling project where building parts can be reused from the same project, meaning an **on site supply**.



2. The project is a new construction and has to search for reused building parts from an **off site supply**.

If the project has an on site supply, it means that the building parts are known from the start and can be planned into the project as soon as all necessary inventories have been performed.

When using one or several off site supplies, an Urban mining is done to get a first understanding of the general availability of certain building parts. The Urban mining is done at an early stage in the project and consequently, the design have to be planned with flexibility. The specific building parts from off site are settled later in the project to avoid unnecessary storing.

DOING THE RIGHT THING AT THE RIGHT TIME

The analysis of reuse projects and inventories shows the importance of starting at an early stage in the building process, but more importantly to do the right thing at the right time.

An early and clear priority of what building parts to reuse makes the process more efficient and simplifies further work. Here, we can compare the reuse projects Stadskvarteret and Bromma Sjukhus. At Stadskvarteret, a reuse potential inventory quickly narrowed down the reuse targets to brick, stainless steel kitchen sinks and staircase railings. These were then successfully detail-inventoried, deconstructed and reused (Delander-Eksten, personal communication, February 3, 2021). At Bromma Sjukhus, the detail inventory was done too early, meaning that the reuse consultant put a week just on inventoring doors, without even knowing if they were going to reuse them (Stenberg, personal communication, January 25, 2021).

The conclusion from the Hoppet inventory shows the importance of starting the reuse process with an environmental inventory, to avoid unnecessary work. An analysis of the reuse projects show that only 3 of 7 actively used the environmental inventory in their reuse process.

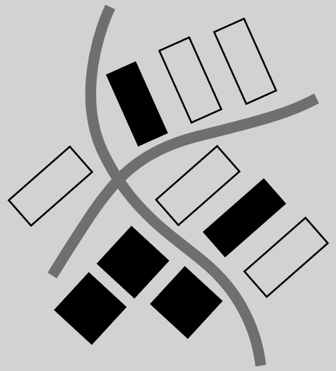
Furthermore, a reuse project could benefit from performing the environmental and reuse potential inventory at the same time. There is no point for both an environmental consultant (using quantitative/objective methods) and a reuse consultant (using qualitative/subjective methods) to count windows - this should be done by one of them, and then the information could be shared with the other. As an example, the environmental inventory consultant counts windows and check their asbestos level, while the reuse consultant check the quality, disassembly feasibility etc.

To summarise these findings, the four different steps of doing inventories can be combined into an *inventory funnel* (see figure 20) where inventories are performed in a specific order depending on the scale and phase of the project. The funnel highlights the importance of doing the right type of inventory in the right order and at the right time, to make the process more efficient and less time-consuming.

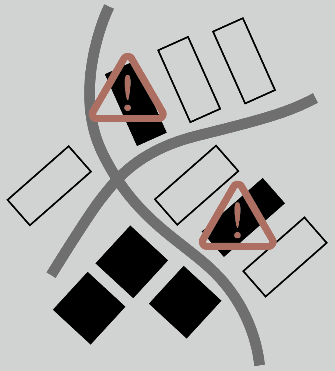
How "initial" or "detailed" an inventory is, as described in figure 8 on page 28-29, is mainly based on:
- the number of inventory data parameters
- the detailing of each inventory data parameter (e.g. quantity is a less detailed parameter than measurements)

How detailed an inventory *can* be, is mainly based on:
- the project scale
- the reuse priorities (many different types of building parts = less detailed inventory)

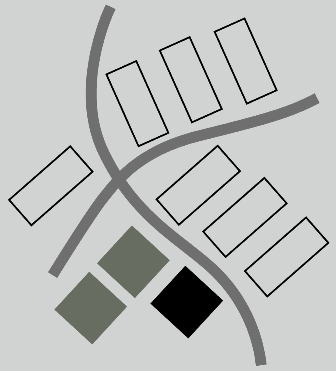
Figure 20. The inventory funnel.



Urban mining
- An inventory to understand *what exists* to reuse



Environmental inventory
- An inventory to sift out *what is possible* to reuse



Reuse potential inventory
- An inventory to sift out *what is feasible* to reuse

Detail inventory
- Inventories to collect *further information after a decision on what to reuse* has been taken

VISIBILITY & COMPATIBILITY

The research made in chapter 1 and 2 highlighted two key words that can be used to summarise the most important functions of inventories and information management: **visibility** *and* **compatibility**.

An inventory contains a lot of information that can be difficult to get an overview of in its raw format. A reuse report summarising the most important findings from the inventory, including the use of visualisation elements, has proven efficient to keep the different stakeholders in the project informed. As mentioned in chapter 3 on *Information management*, this type of visibility would be useful to incorporate in a BIM model for a continous and updated version of the information, available at all times.

One of the prerequisites identified to make the reuse process more industrial is the need to connect the information from the inventories. The information needs to be connected in-between the inventories themselves - to save time and work hours - but also connected to further usage in the building project. This requires compatibility - a standardised way of logging, organising and storing the data as well as an API for uploading and downloading the data. The development of an API is outside the scope of this thesis, but for the pilot project in the next chapter, ways of testing and developing both the visibility and the compatibility of the inventory data will be done through the use of a BIM software.

PART II

REUSE TOMORROW

Implementing our vision on the future of industrial reuse.

5. PILOT PROJECT

Based on the theory from part I, this chapter implements the findings in a design proposal at a rooftop addition at Jungmansgatan in Gothenburg.

Southeast corner of Jungmansgatan with the rooftop design proposal.

BRIEFING DOCUMENTS

The briefing document phase introduces the commission of the project on Jungmansgatan. Design constraints are evaluated according to the detail plan and the client demands, from where general design strategies can be settled.

What concerns the reuse process, inventories of what is available to reuse on site are performed, following the steps of the inventory funnel. From this, it will be possible to set *On site reuse targets* to see what building parts need to complement with in an Urban mining. Conclusively, *Final reuse targets* can be settled for Jungmansgatan. For a reuse process summary, see figure 21.

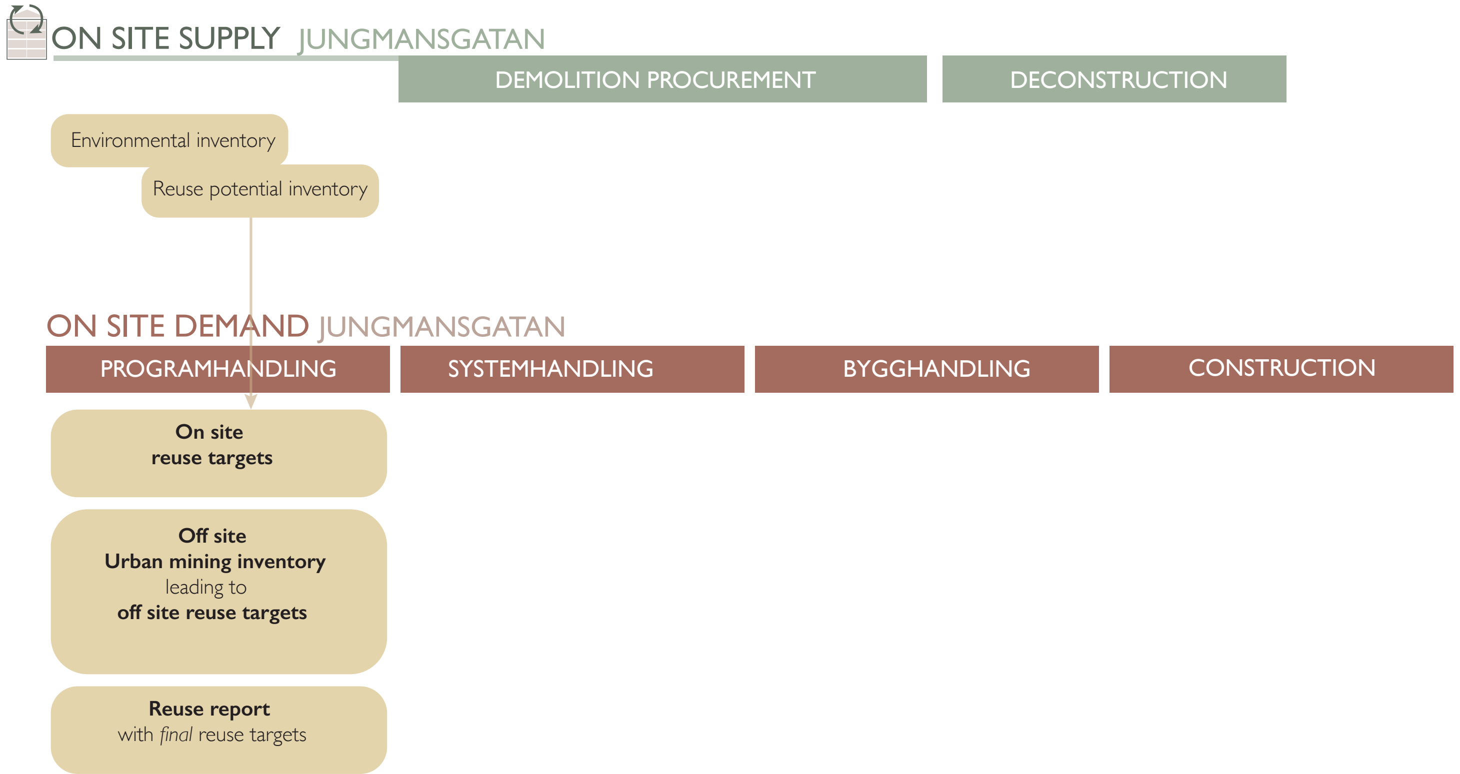


Figure 21. The reuse process performed in the Briefing document phase.

THE COMMISSION

Building information

Jungmansgatan 41-63 (Olivedal 27:12) was built in 1966 and is located in Linné in central Gothenburg. It is a four-storey concrete building with brick facades containing a mix of housing, offices and a preschool. The housing consists of a smaller number of studio apartments and 4 bedroom apartments, and a majority of 2 bedroom apartments. There is also a parking garage underneath the building and its courtyard.

A more in-depth site analysis has been done outside the scope of this thesis and will be published seperately as a part of Familjebostäder's pre study.

Site plan, 1:2000.

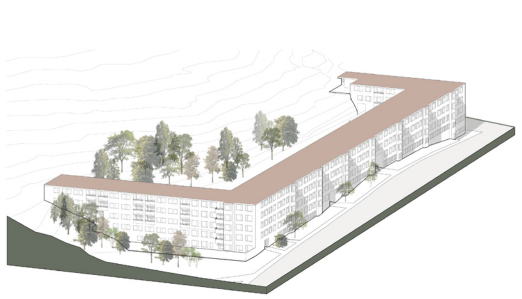
Perspective overview of the existing building at Jungmansgatan.

PROJECT INFORMATION

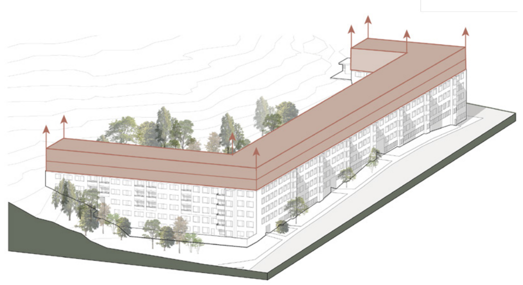
The project means to create two additional rooftop storeys containing housing and shared spaces.

EXISTING GROSS AREA Approx. 10 000 m2 (excl. garage)
ADDITIONAL GROSS AREA Approx. 5000 m2

DETAIL PLAN CONSTRAINTS

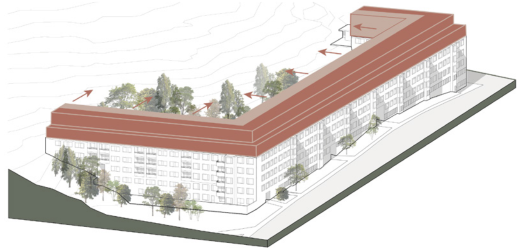


1. THE EXISTING BUILDING
becomes the foundation for the rooftop extension.



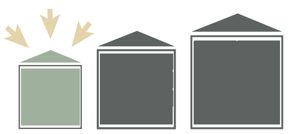
2. TWO STOREY ROOFTOP ADDITION ALLOWED.

3. TOP STOREY RETRACTED ON STREET SIDE
to minimize the height impression for walkers-by. Two meters retraction on long side and three meters on short sides.

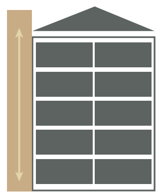


4. BEDROOMS ON COURTYARD SIDE
to cope with noise limits.

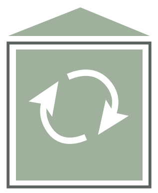
CLIENT DEMANDS



SMALL APARTMENTS EMPHASIS
The rooftop apartments should be of mixed size but with an emphasis on studios and 1 bedroom apartments.



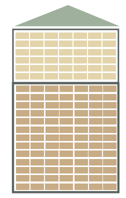
EXTERNAL ELEVATORS
to minimise the interventions in the existing buildings.



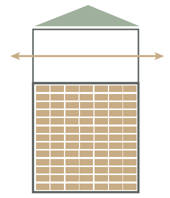
REUSE DECISION
Reused building parts should be included and integrated in the design. Focus is on roof and exterior walls including windows and doors as per thesis delimitations.

DESIGN STRATEGIES

ARCHITECTURAL EXPRESSION

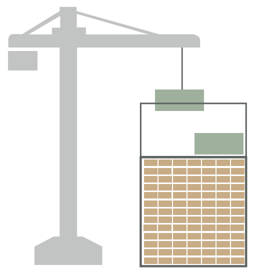


A COHERENT FACADE
Especially on the courtyard side, the facade of the rooftop addition and the existing building should create a harmonic and coherent expression.



SIGHTLINES
The rooftop additions should allow for openings to create connections between the courtyard and the street.

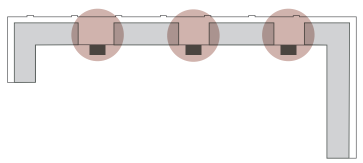
CONSTRUCTION



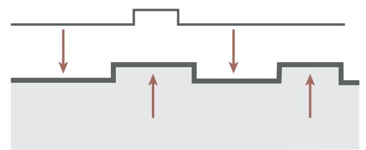
MAXIMISE OFF SITE CONSTRUCTION
The rooftop additions should be constructed through planar elements to maximise off site construction.

MODULARITY & STANDARDISATION
The rooftop apartments should strive for modularity and standardised measures to enable future reuse.

SPATIAL FUNCTIONS



TURNING UNUSABLE TO USABLE
Left-over unusable spaces should aim to be positioned next to the staircases, where people usually pass, and include shared spaces and functions to create active areas.



ACCESS BALCONIES
The access balcony facade should work with nisches and extrusions to pick up the existing building volume, and include functions beyond entrances to minimise a monotonous corridor effect.

ON SITE SUPPLY

In order to make a rooftop addition possible, the existing roof needs to be removed. The on site inventory is therefore a way to investigate the possibilities of reusing the roof construction.

ENVIRONMENTAL INVENTORY

An environmental inventory has not yet been performed at Jungmansgatan and will not be done within the time of this thesis. If an environmental inventory had been performed, it would have determined whether any parts of the roof construction contain hazardous substances and thus have no reuse potential.

To be able to test the idea of an interconnected inventory process, a principle of how the logging of materials during an environmental inventory would look like was developed. For that example, it was assumed to be no hazardous substances.

To get an understanding of the roof construction and an estimated quantity, a desktop mapping was performed (see figure 22 & 23).

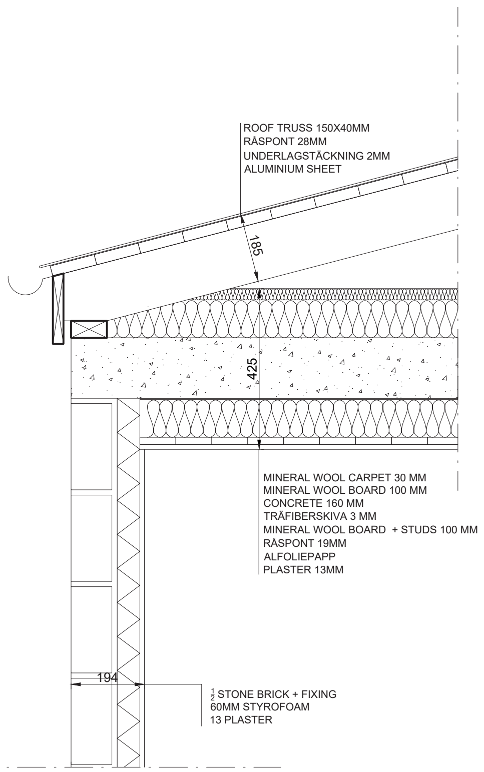


Figure 22. Detail section of existing roof-exterior wall, 1:20.

REUSE POTENTIAL INVENTORY

The reuse potential inventory is logged using the same table as the environmental inventory, hence, the environmental inventory can work as a filter to see what should be further focused on. The inventory (see page 58-59) is logged with a score and comment that becomes the basis for the reuse targets summarised in the reuse report (see page 60).

The estimated environmental savings were calculated using BM 1.0, for input assumptions and calculations see appendix B and C. The estimated economical value was calculated using *Sektionsfakta*, for input assumptions and calculations see appendix D.

A combined environmental and reuse potential inventory.

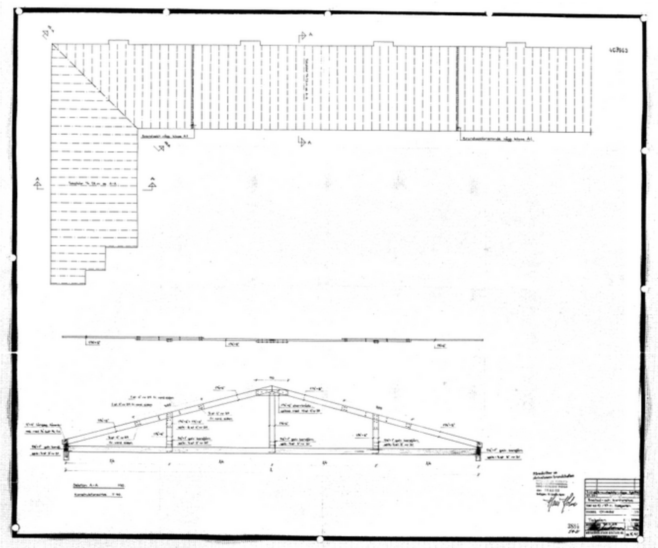


Figure 23. Existing blueprints of roof construction (Göteborgs stad, Stadsbyggnadskontoret, 2021).

OFF SITE SUPPLY

URBAN MINING

During 2019, Lokalförvaltningen together with Danish architecture firm Lendager Group performed a building material mapping, consisting of four preschools in Gothenburg planned to be demolished within the coming years (Lendager 2019). When analysing the ongoing demolition projects in the city of Gothenburg, an additional four schools could be identified (Stadsbyggnadskontoret 2021). All of them are one-story timber-frame buildings.

In dialogue with Angélica Karlsson, project leader at Lokalförvaltningen, this building typology is deemed interesting from a reuse point of view as they are demolished before they reach the end of their potential life cycle. Instead, they are usually demolished to make place for new, two-story preschools to meet an increased number of children (Karlsson, personal communication, April 14, 2021).

A further investigation of the construction of these preschools led to an identification of a standardised building method that has been used since the 60's, constructing buildings with prefabricated timber-frame elements. The elements are constructed in standard length sizes between approximately 3,2-4,8 meters, with a standard measure chain of 600 mm intervals, fixed next to each other by screw and bolt (Fiedler, personal communication, February 22, 2021).

The urban mining of doors was done through a dialogue with reuse material supplier Återbruket Alelyckan in Gothenburg, confirming a steady flow of doors, however with a higher flow of interior doors than exterior doors (Återbruket Alelyckan, personal communication, May 6, 2021).

An Urban mining was done as a first stage of finding supply projects.

Figure 24. Four preschools about to be demolished (Relement 2020, Göteborgs stad n.d., Lendager 2019, & Olden Bygg o Miljö 2020).

LOGGING THE INVENTORY DATA

The information from the environmental inventory and reuse potential inventory can be logged and organised using the same table, which can be uploaded to the reuse database, and used to fill in further information during a detail inventory.

The building parts are logged both as the actual element and as the components and materials that the element consists of. This is to be able to decide in what scale or form the building part has its largest reuse potential. Each reuse potential parameter has a column for a comment and a grading and in the end there is a column for attachments.

Building part	Building part name	Position	Quantity	Unit	Score	Condition	Score	Environmental savings	Score
BUILDING ELEMENTS	Roof construction	Jungmansgatan	Same as for the new construction.		5	Visual inspection shows great condition.	5	54 037 kg CO2e (see appendix D).	5
BUILDING COMPONENTS	Wooden rafters	Roof construction	210	pcs	5	no hazardous substances	5	574 kg CO2e (see appendix D).	1
BUILDING MATERIALS	Insulation boards	Roof construction	2550	m²	4	no hazardous substances but risk of mold	5	16 664 kg CO2e (see appendix D).	4
BUILDING MATERIALS	Tongue and groove boards	Roof construction	2700	m²	5	no hazardous substances	5	2067 kg CO2e (see appendix D).	2
BUILDING MATERIALS	Roof felt paper	Roof construction	2700	m²	5	no hazardous substances	5	8749 kg CO2e (see appendix D).	3
BUILDING MATERIALS	Roof tin sheets	Roof construction	2700	m²	5	no hazardous substances	5	25 984 kg CO2e (see appendix D).	5

These fields are filled in by the environmental inventory specialist and handed over to the reuse consultant.

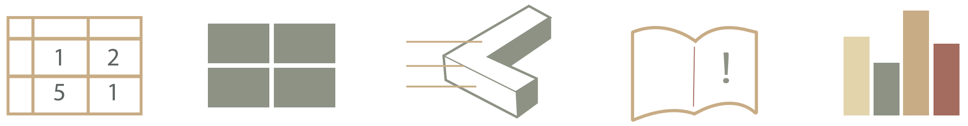
More columns with information can be added, choosing from a set list of parameters to ensure compatibility.

Building part name	Economical value	Score	Disassembly feasibility	Score	Future application	Score	Total score	Attach-ments	+
Roof construction	4 187 153 SEK incl. construction costs (see appendix C).	5	Cut into elements, lift off roof and onto new construction.	3	Direct reuse.	5	28		
Wooden rafters	2 227 500 SEK incl. construction costs (see appendix C).	4	Saw from concrete flooring.	4	Direct reuse.	4	23		
Insulation boards	71 280 SEK, material costs only (see appendix C).	2	Loose boards.	5	Direct reuse.	5	25		
Tongue and groove boards	242 460 SEK, material costs only (see appendix C).	3	Attached with nails to roof felt paper, will have to be sawn into pieces.	1	Several upcycling examples exist.	3	19		
Roof felt paper	18 041 SEK, material costs only (see appendix C).	1	Attached with nails, will break into pieces.	1	Energy recycling.	1	17		
Roof tin sheets	179 818 SEK, material costs only (see appendix C).	3	Attached with nails, will break into pieces.	1	Several upcycling examples exist.	1	20		

The attachments to each building part can be used to automatically generate an image appendix, where each photo is given the name of the building part along with a unique number (littera).

Table 1. Environmental and reuse potential inventory for the existing roof at Jungmansgatan, scored from 1 to 5 with 1 being the lowest and 5 the highest (see p. 36 on *Visualising the data*).

REUSE REPORT



A summary of the visualisation elements used in this reuse report: table with numbers, image appendix, 3D model, idea catalogue, diagram.

The reuse potential matrix (see table 2) shows that the element reuse potential is much higher than the component and material reuse potential. This led to the on site reuse target for the roof construction in the form of element reuse.

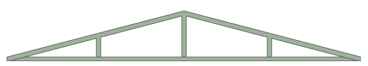
The built-in economical value compared to a new roof construction of the same kind has been calculated and is deemed high. For full calculations, see appendix D.

The environmental savings parameter shows that the roof tin sheets and roof felt paper are most important to reuse. As the disassembly feasibility is very low for the roof tin sheets and the roof felt paper on a material level, it strengthens the argument for element reuse.

Furthermore, the roof is considered in a very good condition and would as such not need any additional materials apart from at element joints.

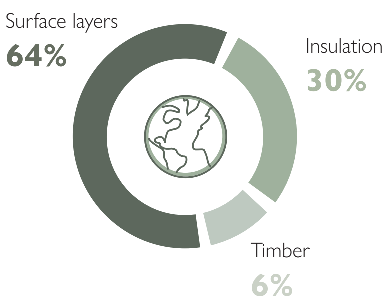
Building part	Building part name	Position	Total score
Building elements	Roof construction	Jungmansgatan	28
Building components	Wooden rafters	Roof construction	23
Building materials	Insulation boards	Roof construction	25
Building materials	Tongue and groove boards	Roof construction	19
Building materials	Roof felt paper	Roof construction	17
Building materials	Roof tin sheets	Roof construction	20

Table 2. Summary of inventories in a reuse potential matrix.



built-in economical value in the roof construction

4,2 million SEK



built-in carbon emissions in the roof construction

56 ton CO2e

GWP distribution of existing roof (BM 1.0).

Roof tin sheets on the existing roof.

FINAL REUSE TARGETS

On site reuse targets

ELEMENT REUSE Roof construction 100%

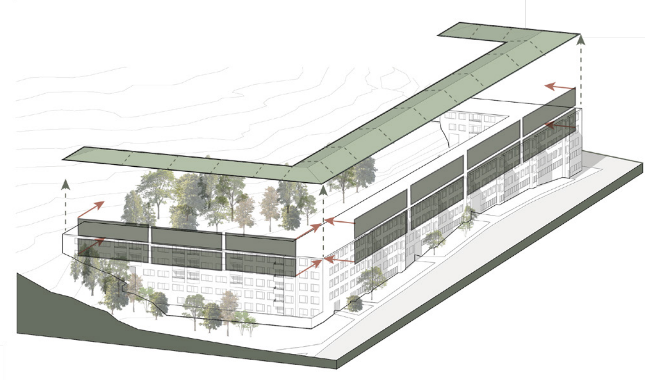
Cut and reuse as a roof for the new construction.

Off site reuse targets

ELEMENT REUSE Exterior timber frame element walls with reused windows 100%

COMPONENT REUSE Doors 50%

Find as many exterior walls and doors as possible to cover the need of the new construction.



Future application on Jungmansgatan.

DESIGN CONSEQUENCES & CONSTRAINTS

Element reuse of the roof construction would mean that the deconstruction of the roof would have to time with the start of the rooftop construction, to minimize the need for intermediate storage.

Furthermore, the reuse of the entire roof construction means that the access balcony towards the street side will have an overhang (see figure 25).

Element reuse of timber frame wall elements have two immediate affects on the design:

- fixed window positions in the walls
- maximum element height is usually 2,7 meters

Designing with flexibility

By designing with interval measurements rather than precise dimensions for the windows, the chances increase of finding a wall element with windows that will fit within the intervals. This process is described by Andersson & Nilsson, see figure 26 (2020, 35).

The element height will have to be taken into consideration when designing the load-bearing construction and the connection between the walls and the inter-mediate flooring, to maximise the roof height in the apartments.

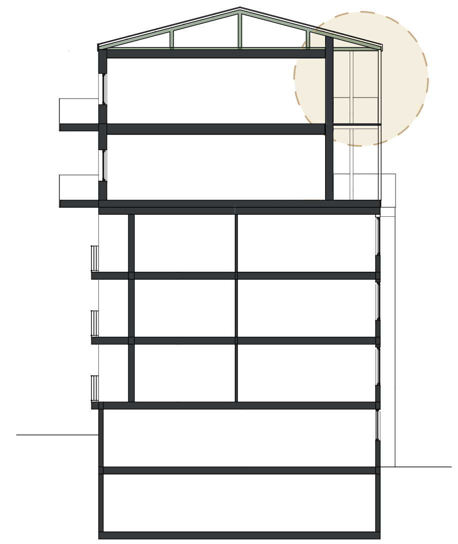


Figure 25. Reused roof will create an overhang over the access balconies.

NEXT STEPS

The necessary information about the roof is deemed complete by the desktop mapping and reuse potential inventory. It is not expected to be necessary to perform a detail inventory.

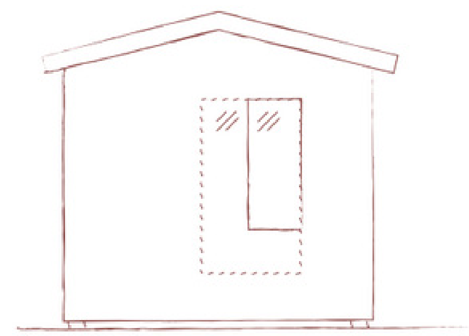


Figure 26. Window intervals for building permit drawings (Andersson & Nilsson 2020).

PROJECT PLANNING DOCUMENTS

During the Project planning document phase the actual design process starts, and the constraints and conditions are processed to generate building concepts (see page 63) and a final building layout (see page 64).

The information collected during the environmental and reuse potential inventory together with the data from a desktop mapping has completed the information from the on site supply. The roof trusses can then be modeled in BIM.

The *Off site reuse targets* that were set based on the Urban mining in the Briefing document phase are also implemented in the design and in the BIM model by setting measure intervals on the windows. As such, the final building permit drawings will have to visualise the partly flexible design.

The final reuse targets will be a part of the deconstruction and construction procurements (not further discussed during this phase). For a reuse process summary, see figure 27.

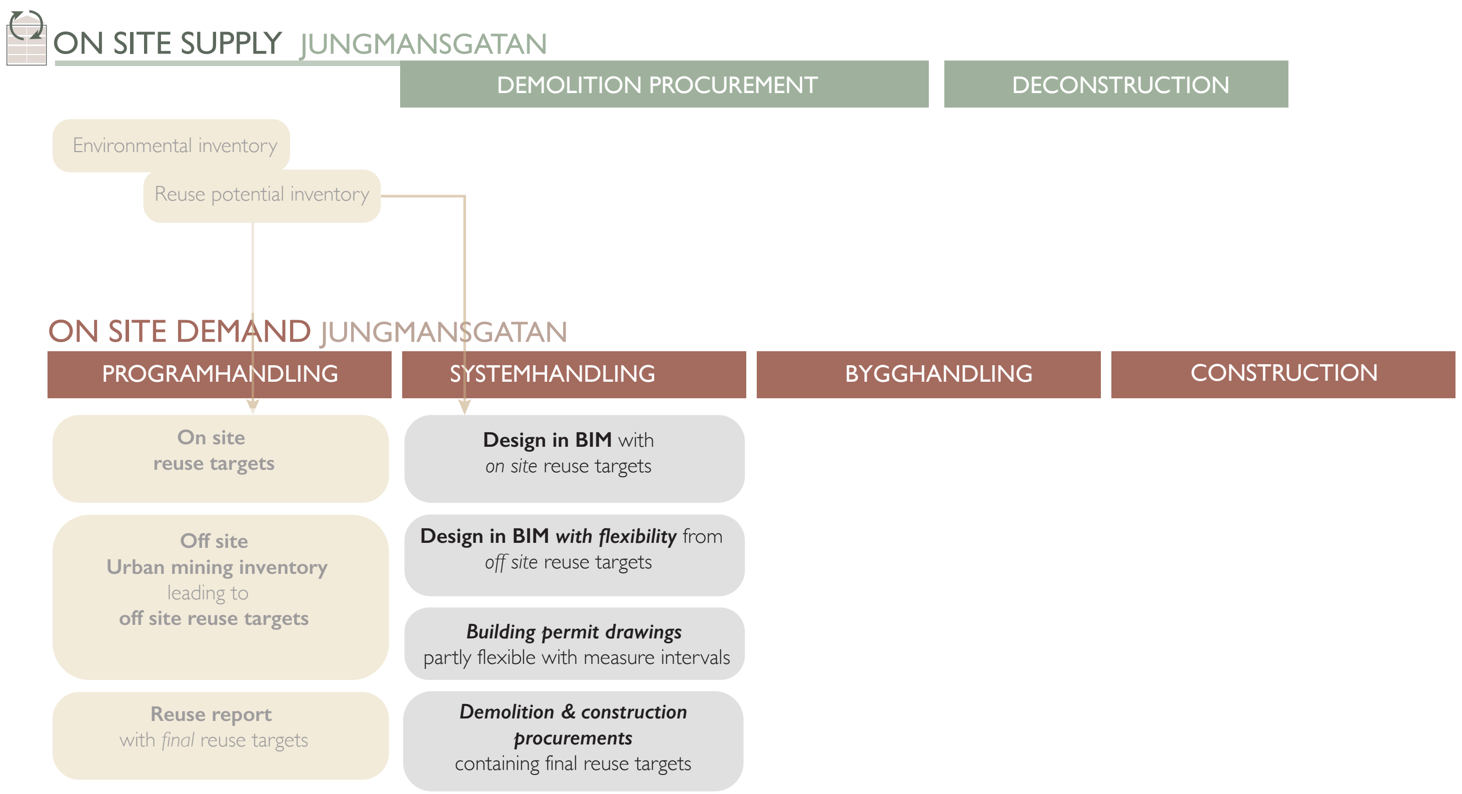
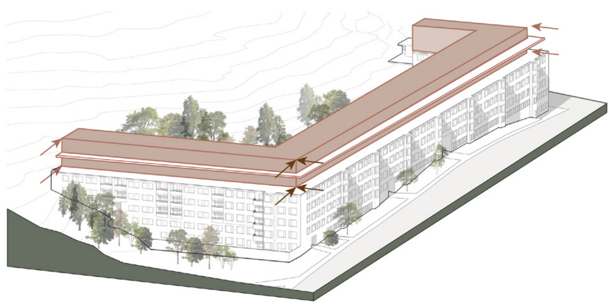
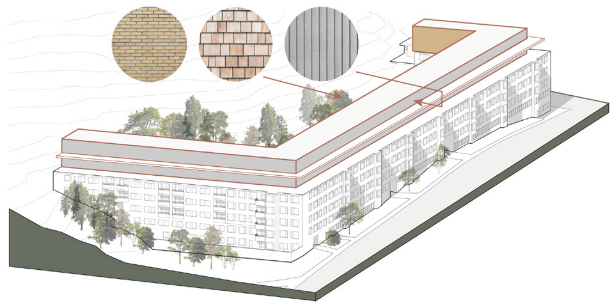


Figure 27. The reuse process performed in the Project planning document phase.

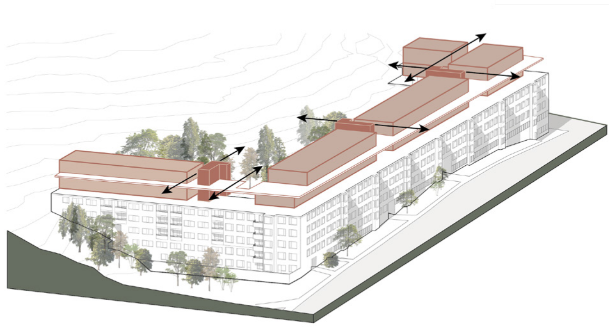
BUILDING CONCEPTS



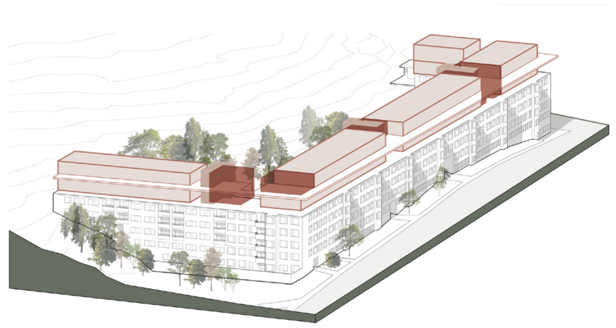
VOLUME
Both storeys are pushed in to make space for the access balconies towards the street side.



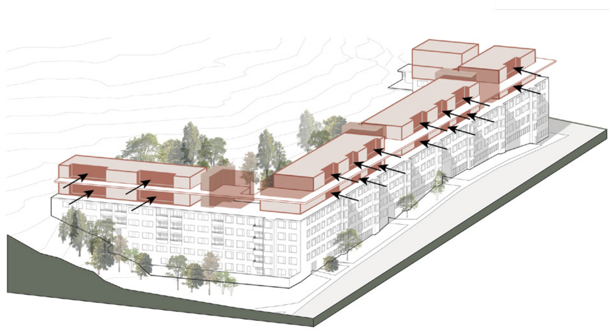
A COHERENT FACADE
Where the new facade aligns with the existing yellow brick wall, the facade gets a cladding of wooden cedar shingles to be coherent. The pushed in walls towards the street gets a grey wooden panel facade, a design decision based on a reuse consequence.



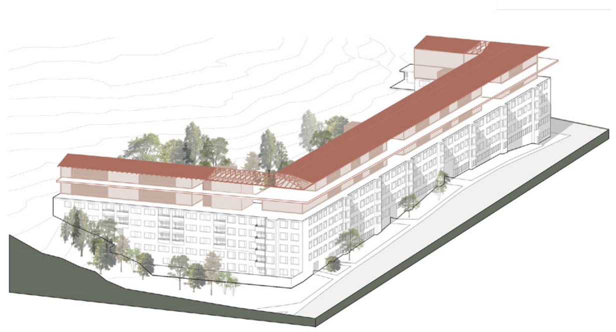
COMMUNICATION
Three elevator shafts are built on the side of the courtyard and divides the apartment volumes in four parts. One additional opening is made to provide daylight and sightlines in the north corner.



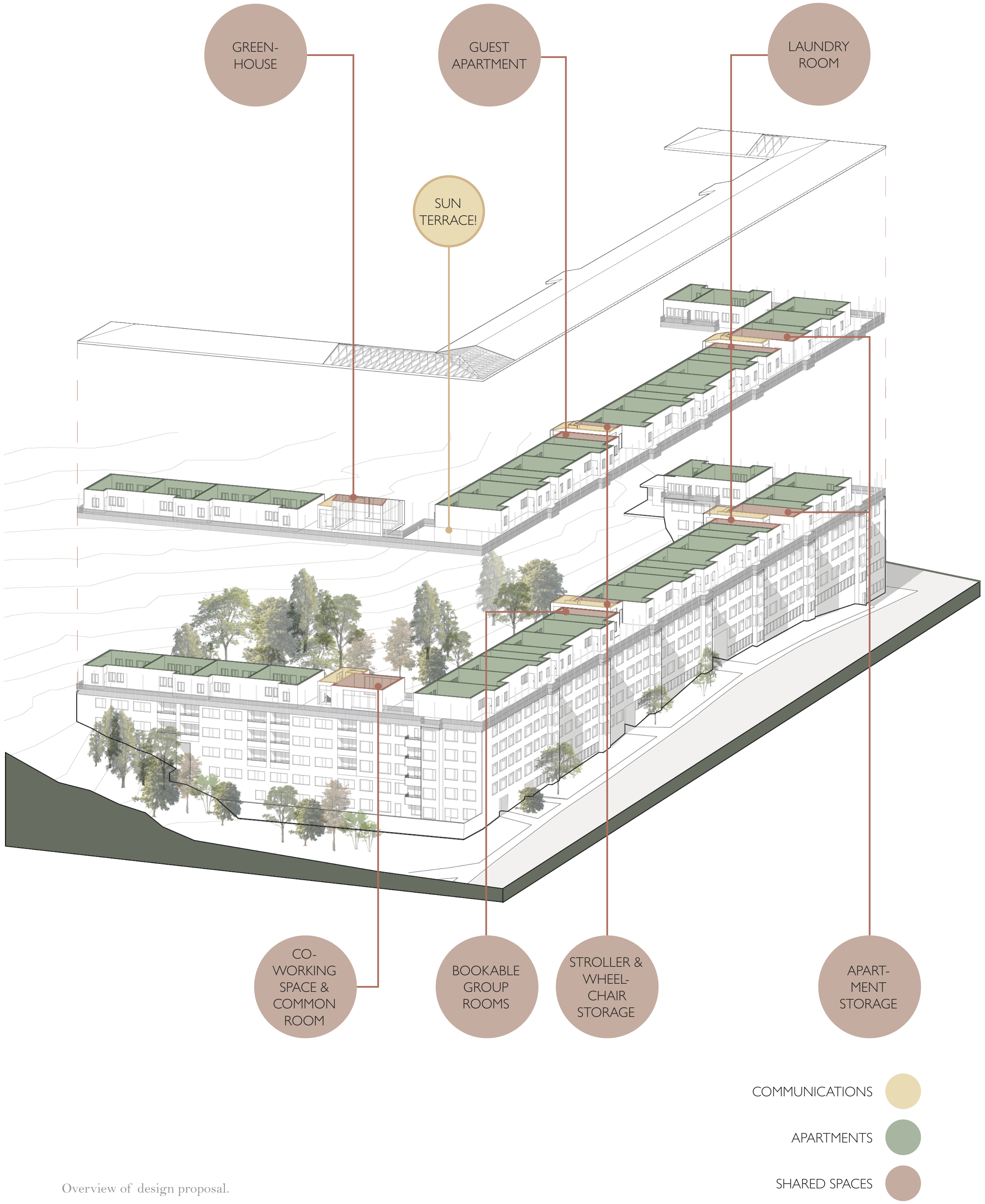
SOCIAL SHARED SPACES
The leftover space that could not be apartments are positioned together with the stairwells to activate those further as social shared spaces.



APARTMENT LAYOUT
The apartments entrances towards the street are retracted to provide a semi-private space, and each apartment has a balcony towards the quiet courtyard.



ROOF DEFINING SPACES
The reused roof trusses contributes to the expression of one connected volume and stretches along the access balcony either as a pergola or solid weather protection.



Overview of design proposal.

DESIGN WITH ON SITE SUPPLY

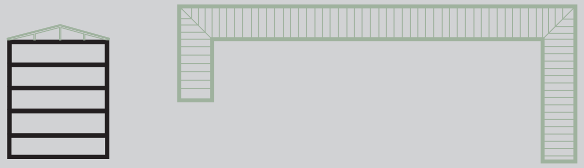
When working with an on site inventory, the building parts to be reused will in most cases already be modeled in the BIM software, as a part of the existing building. As such, there will be no need to download nor upload any information from and to the reuse database. Instead, the design process will be using the *Phasing* function of the BIM software to inform the project *when* certain building parts are supposed to be at certain positions (see page 44 on *organising & visualising BIM object data*).

In the case of Jungmansgatan, there are three phases which are similar to most renovation projects:

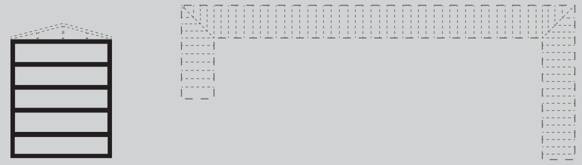
EXISTING the existing building
DECONSTRUCTION highlighting what needs to be deconstructed to make way for new rooftop addition
NEW CONSTRUCTION the new rooftop addition

By creating a project parameter called *On site reuse target* (Yes/No) that can be applied to any kind of object in the model, the on site reuse targets from the reuse report can be stored directly in BIM, making it accessible for all stakeholders in the project at any time. All BIM objects in the existing building planning to be reused on site are marked "Yes". The *On site reuse target* parameter can then be used as a graphical filter in the BIM software to colour-code the on site reuse target BIM objects to make it clear and visual what is to be reused. Finally, when a reused building parts is in its new position, a project parameter called *Reused* (Yes/No) is informing everyone that this is a reused building part.

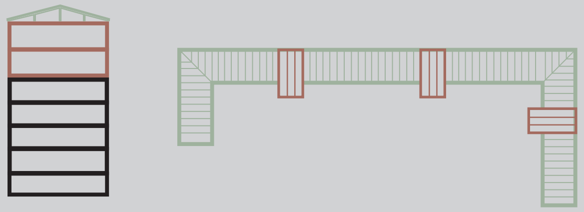
For the roof, this means that in the first two phases, the roof is in its existing position marked *On site reuse target* = Yes. In the New construction phase, however, a copy of the roof is made and moved to its new position. The old version is marked "demolished" in this phase, and the copy of the roof is marked *Reused* = Yes.



Phase: Existing
• The existing roof and rafters are in their original position.
• *On site reuse target* = Yes, colour-coded in green.



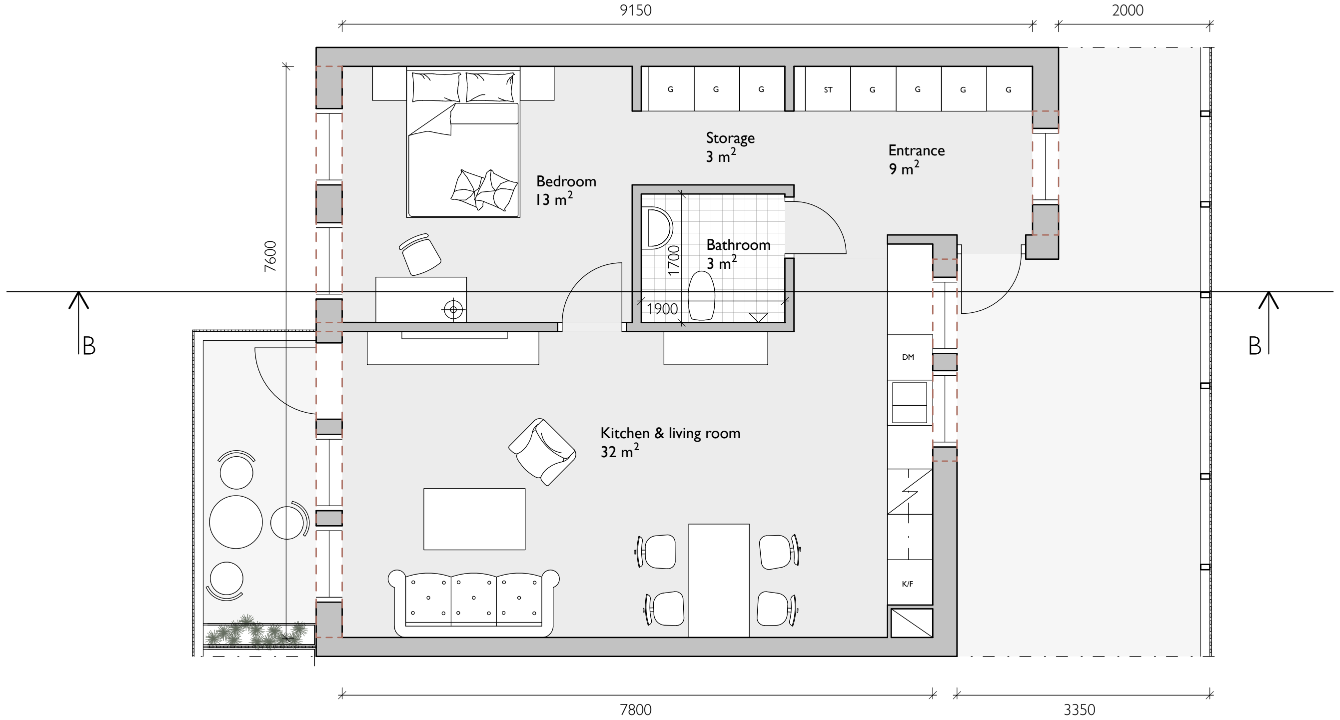
Phase: Deconstruction
• The existing roof and rafters are in their original position, visualised with dashed lines to show that they are to be deconstructed.



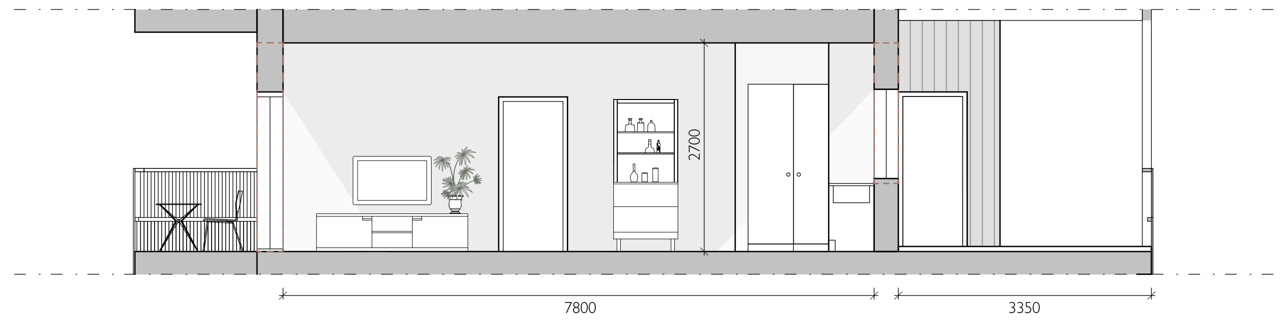
Phase: New construction
• The existing roof and rafters are marked as "demolished" and does not show in drawings.
• A copy of the existing roof and rafters are in their new position where *Reused* = Yes, colour-coded in green.
• Additional roofing needed is added, where *Reused* = No, colour-coded in red.

DESIGN WITH OFF SITE SUPPLY

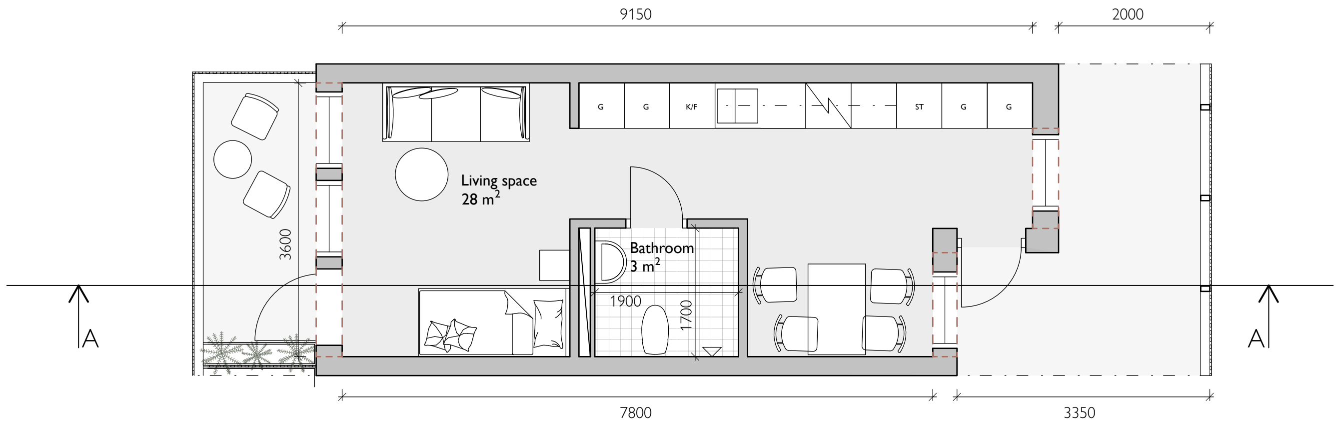
As a result of the client demand, a one bedroom apartment and a studio apartment has been designed. One of the design strategies for the access balconies was to create a variated space that would favour the apartments. This resulted in niches by each entrance, a way for the tenants to get a small semi-private space between their apartment and the access balcony. In the interior space, this gives both apartments a proper hallway set aside from the living areas.



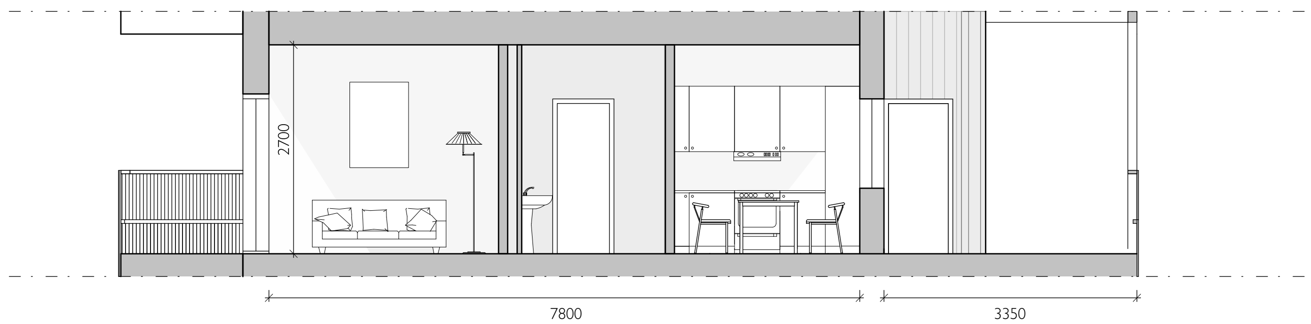
1 bedroom apartment,
BOA 62 m²



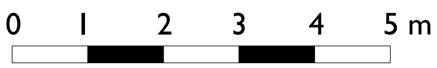
Section B-B



Studio apartment,
BOA 31 m²



Section A-A



Plan and section, 1:100, for the type apartments.

OFF SITE REUSE TARGETS

By creating a project parameter called *Off site reuse target* (Yes/No) that can be applied to any kind of BIM object in the model, the off site reuse targets from the reuse report can be stored directly in BIM, making it accessible for all stakeholders in the project at any time. All BIM objects planning to be constructed out of reused building parts are marked "Yes".

The *Off site reuse target* parameter can then be used as a graphical filter in the BIM software to create a *reuse target plan* (see figure 28) and a *reuse target schedule* (see table 3).

REUSE TARGET DRAWINGS

To be able to go more into depth and focus on certain functions and workflows in the pilot project of this thesis, a section of four apartments over two floors - four studio apartments and four 1 bedroom apartments - have been chosen (see figure 29).

In the reuse target plan, all BIM objects that have *Off site reuse target* marked as "Yes" are colour-coded in green. This gives a clear overview on the reuse focus and scope of the project, and connects to the importance of visibility of reuse targets (see chapter 4 under *Visibility & Compatibility*).

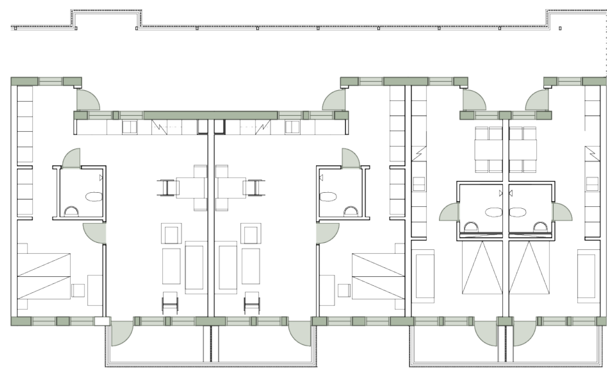


Figure 28. Reuse target plan, 1:300, showing the *Off site reuse target* building parts marked in green.

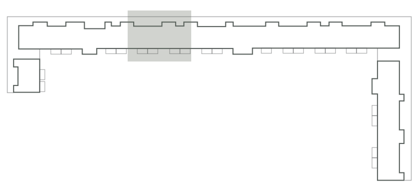


Figure 29. Marking out the section of 4 apartments x 2 floors that is chosen for a closer study in this thesis.

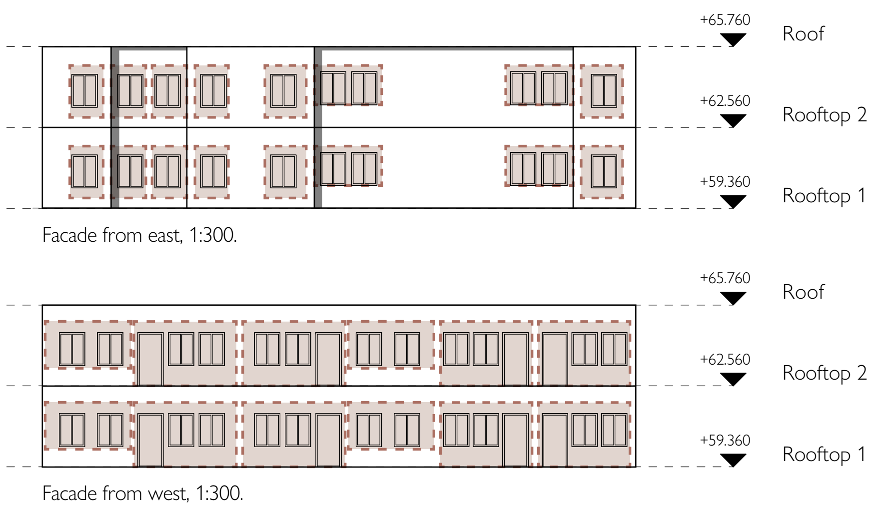


Figure 30. Facade drawings of the chosen section, 1:300, showing the window intervals marked in red.

REUSE TARGET SCHEDULES

By creating reuse target schedules, we get a clear overview and idea on the amount and type of reused building parts needed from the supply projects. The schedules are created per building part. They show how many meters of wall that needs to be found for Jungmansgatan, and how many doors of different types (see table 3).

As can be read from the reuse target schedules, the BIM objects in this phase are generic BIM objects that later can be replaced by the specific reused building parts from the reuse database (see the chapter *Design with off site supply* on page 81).

Wall schedule [Off site reuse target: Yes]

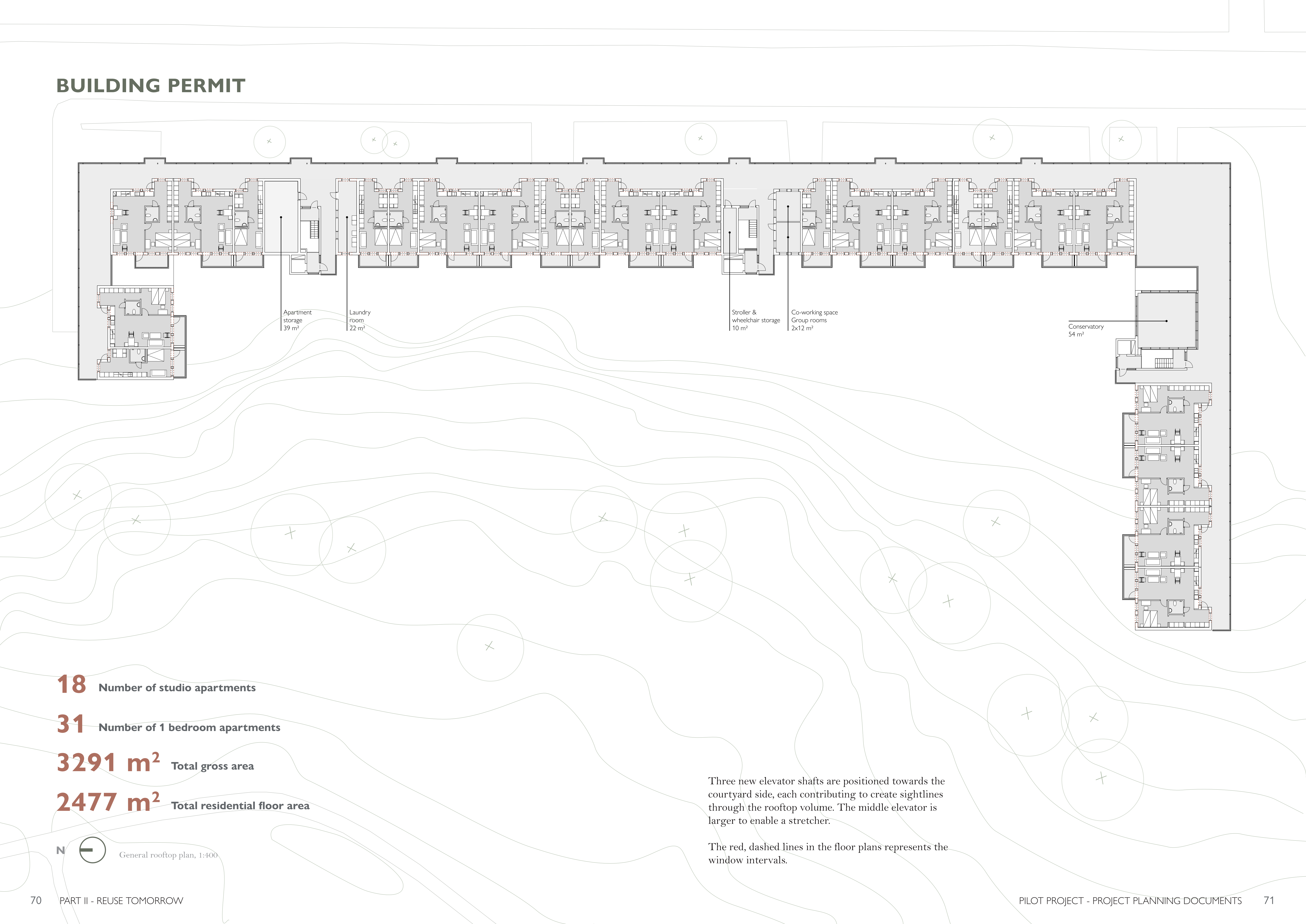
Quantity	Family type	Length [mm]	Height [mm]
2	Basic wall: Exterior wall street side	5050	2700
2	Basic wall: Exterior wall street side	3600	2700
2	Basic wall: Exterior wall street side	2400	2700
2	Basic wall: Exterior wall street side	10900	2700
2	Basic wall: Exterior wall street side	2700	2700
4	Basic wall: Exterior wall courtyard side	3600	2700
4	Basic wall: Exterior wall courtyard side	7800	2700

Door schedule [Off site reuse target: Yes]

Quantity	Family type	Littera	Width [mm]
8	Generic exterior door 9x21	GED-09-X	900
8	Generic patio door 9x21	GPD-09-X	900
12	Generic interior door 8x21	GID-08-X	800

Table 3. Off site reuse target schedules for the walls and doors.

BUILDING PERMIT



General rooftop plan, 1:400

18 Number of studio apartments

31 Number of 1 bedroom apartments

3291 m² Total gross area

2477 m² Total residential floor area

Three new elevator shafts are positioned towards the courtyard side, each contributing to create sightlines through the rooftop volume. The middle elevator is larger to enable a stretcher.

The red, dashed lines in the floor plans represents the window intervals.

To create a coherent expression for the rooftop addition, the access balcony railing is wrapping the new storeys in wooden ribs made from reclaimed timber. It is solid up to a height of 450 mm, to create a private space for the tenants and to cover the intermediate flooring constructions.

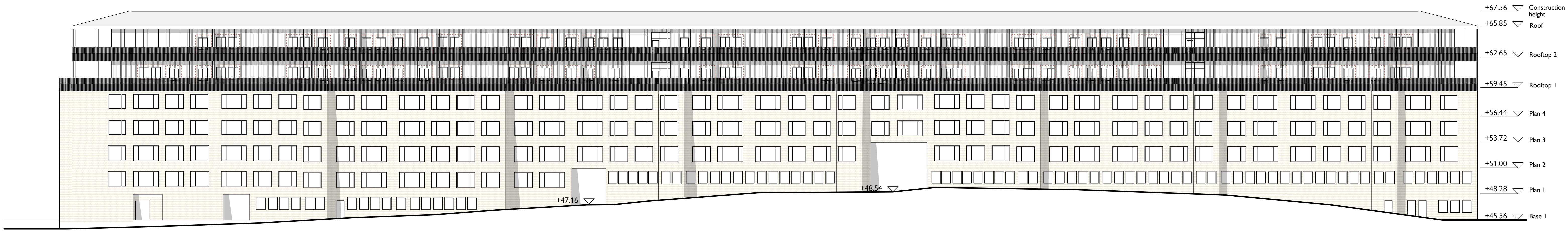
The east and west facades have different expressions, as stated in the design strategies and building concepts. On the courtyard side, the facade is cladded with shingles to match the brick facade. The inserted facade on the street side has a reconditioned wooden panel from the reused walls, painted in grey to match the mineral-based facade materials on the surrounding buildings.

EXTERIOR MATERIALS & COLORING

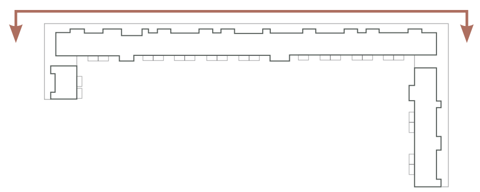
EXISTING
Facade: Yellow brick
Railing: Red tin sheet

ADDITION East
Roof: Grey tin sheet
Facade: Grey painted timber panel
Railing: Grey painted timber laths

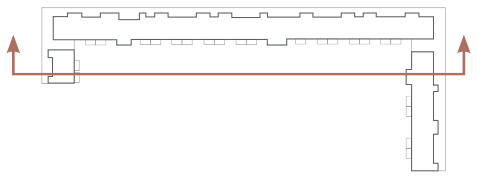
ADDITION West
Roof: Grey tin sheet
Facade: Cedar shingles
Railing: Grey painted timber laths



Elevation from east, 1:400.



Elevation from west, 1:400.



CONSTRUCTION DOCUMENTS

The Off site supply inventories are performed by the Off site supply project, independent from the demand project. For the purpose of this thesis, it is shown how the inventories of Off site supply 1 are done, see page 75-79.

In the demand project, the building permit is approved and it is finally time to start searching for a specific *Off site supply* in the reuse database to finalise the design. The thesis explores and proposes how the reuse database could be compatible with BIM through the development of a concept toolchain and workflow. This means that the reuse database can be reached directly from BIM and automatically generate BIM objects based on the parameters logged in the inventory. The design process can then proceed as usual, and the final choice of reused building parts can be uploaded back to the reuse database to "reserve" them. At this time, information from BIM on potential reconditioning could also be used for the upcycling procurement. This type of information management would facilitate the design process of the reused building parts. For a summary of the reuse process, see figure 31.

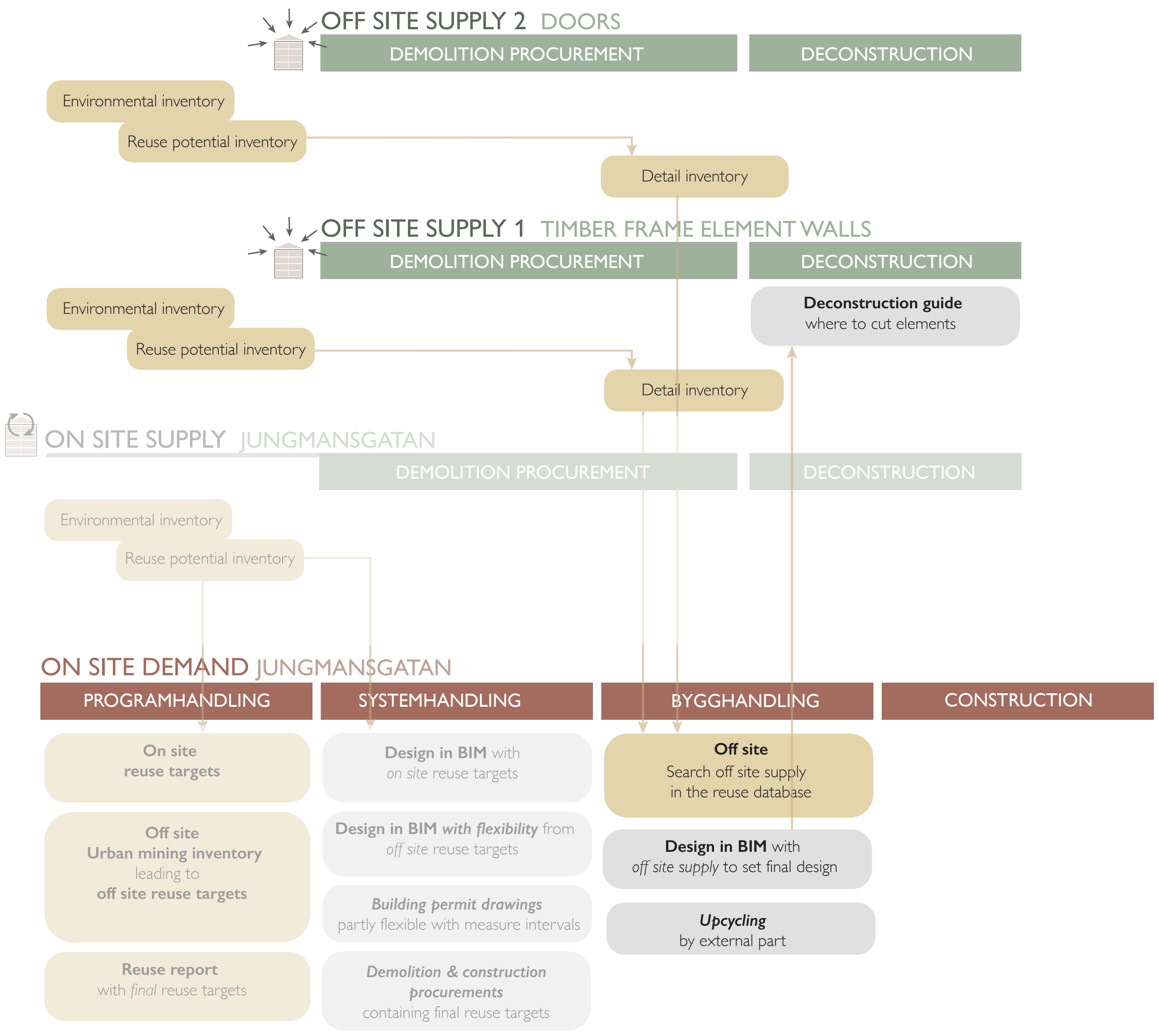


Figure 31. The reuse process performed in the Construction document phase.

OFF SITE SUPPLY 1: TIMBER FRAME WALLS

According to the Urban mining, several preschools are to be demolished within the coming years and could provide the supply of timber frame element walls. Because of the limitation of time for this thesis, two preschools were chosen. These preschools were found through dialogue with Lokalförvaltningen.

DESKTOP MAPPING

ERIKSBOSKOLAN

Eriksboskolan is situated near Hjällbo in the eastern part of Gothenburg. It is being demolished to make way for a new two-story pre-school at the same site, to handle the increasing amount of children in the area (Karlsson, personal communication, April 22, 2021).

Figure 32 & 33. Aerial view of Eriksboskolan building A, B and C & facade building C (Relement 2020).

WALL COMPOSITION
2x22 Facade "Lockpanel"
70x22 nailing battens cc 600
7 board
9 windboard
45x45 timber joists cc 600
45 mineral wool
120x45 timber studs cc 600
120 mineral wool
vapor layer
2x13 gypsum board

WALL COMPOSITION
2x22 facade "Lockpanel"
34x70 nailing battens cc 600
9 Asfaboard
145x45 timber studs cc 600
145 stone wool
vapor layer
2x13 gypsum board

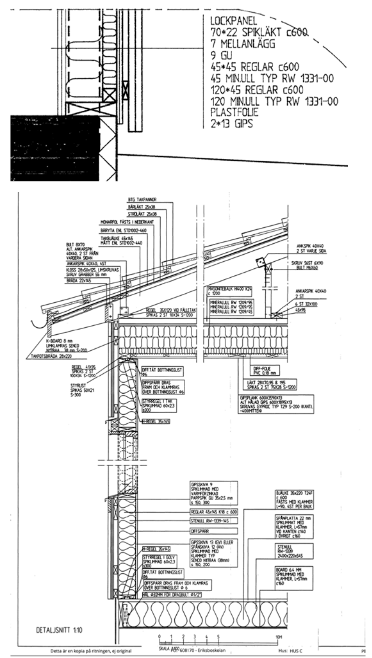


Figure 34 & 35. Blueprints of the wall constructions (Göteborgs stad, Stadsbyggnadskontoret, 2021).

Building A & B
CONSTRUCTION YEAR 1969-70, extended at several places from year 1990 and forward
GROSS AREA 3500 m²
CONSTRUCTION TYPE timber frame construction
CONSTRUCTION HEIGHT lowest height 2,8 m
GROSS WALL LENGTH 460 m
DEMOLITION PLANNED 2021

Building C
CONSTRUCTION YEAR 2010
GROSS AREA 750 m²
CONSTRUCTION TYPE timber frame construction
CONSTRUCTION HEIGHT 2,7 m
GROSS WALL LENGTH 153 m
DEMOLITION PLANNED 2021

Facade of Biskopsgatan 8.

BISKOPSGATAN 8

Biskopsgatan's preschool is situated in Bräcke on Hisingen island in north Gothenburg. It is being demolished to make way for a new two-story pre-school at the same site, to handle the increasing amount of children in the area (Karlsson, personal communication, April 22, 2021).

WALL COMPOSITION
40 facade "Lockläkt"
34x70 nailing battens cc 600
9 windboard
145x45 vertical timber joists cc 600
145 stone wool insulation
13 gypsum board

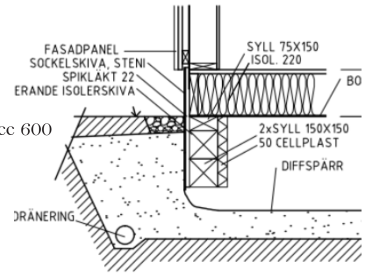


Figure 36. Blueprints of the wall construction (Göteborgs stad, Stadsbyggnadskontoret, 2021)

CONSTRUCTION YEAR 2013
GROSS AREA 687 m²
CONSTRUCTION TYPE timber frame construction
CONSTRUCTION HEIGHT 2,7 m
GROSS WALL LENGTH 137 m
DEMOLITION PLANNED 2021

ENVIRONMENTAL INVENTORY

An environmental inventory has been done for both Eriksboskolan and Biskopsgatan. They show that all buildings have pressure-impregnated sills that have to handled as "hazardous waste". They also show that building A and B at Eriksboskolan have Eternit facade elements containing asbestos, as well as Internit wind boards containing asbestos. As such, the whole facades will have to be dealt with as "hazardous waste".

Conclusively, the environmental inventory has worked as a filter according to the inventory funnel, where we do not have to do any further inventories on building A and B at Eriksboskolan but continue with building C at Eriksboskolan and Biskopsgatan 8.

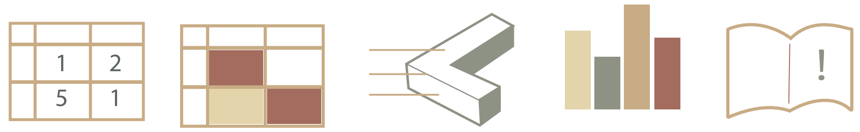
REUSE POTENTIAL INVENTORY

The estimated environmental savings were calculated using BM 1.0 (see appendix C). The estimated economical value was calculated using standard type data from *Sektionsfakta*, which might vary slightly from the actual walls and windows (see appendix D).

See table 5 for the combined data from the environmental and reuse potential inventory for Biskopsgatan 8.

The inventory funnel - environmental inventory should preceed the reuse potential inventory.

REUSE REPORT



Visualisation elements used in the reuse report: table with scores, table with colour legend, 3D model, diagram, idea catalogue.

Building part	Building part name	Position	Total score
	Exterior walls	Biskopsgatan 8	28
	Exterior walls	Eriksboskolan building C	28

Table 4. Summary of inventories through a reuse potential matrix.

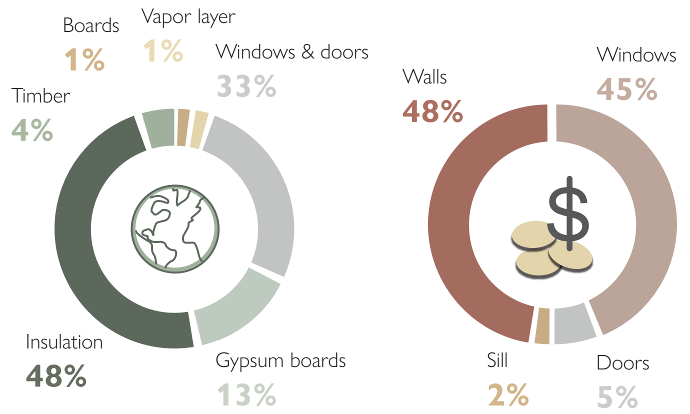
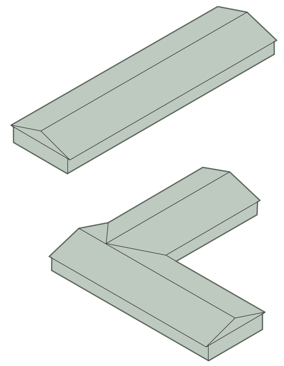


Figure 37 & 38. GWP (BM 1.0) and cost distribution for Biskopsgatan 8.

As seen in the summarizing reuse potential matrix (see table 4), the reuse potentials are similar for both schools and as such, both can be reused.

Figure 37 shows there is a large environmental saving in reusing the insulation and the windows and doors from Eriksboskolan building C and Biskopsgatan 8.

Figure 38 shows that there is also a large economical value built into the exterior walls of these buildings, specially the walls and windows. This supports and confirms the previously set off site reuse target to work with element reuse of these walls.



Total built-in carbon for the exterior walls in Biskopsgatan 8 & Eriksboskolan building C

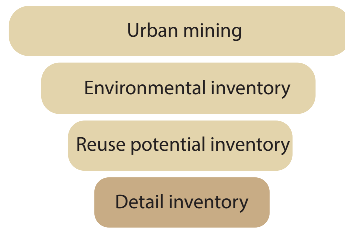
21 ton CO2e

Total built-in economical value for the exterior walls in Biskopsgatan 8 & Eriksboskolan building C

2,45 million SEK

NEXT STEPS

The information from the environmental and reuse potential inventories should be uploaded to a reuse database to enable further usage and compatibility in the design process. What further information is needed from a detail inventory on the walls, to be able integrate them into the design, is explained in the *Design with off site supply* chapter on page 81.



The inventory funnel - detail inventory.

LOGGING THE INVENTORY DATA

The information from the environmental inventory and reuse potential inventory can be logged and organised using the same table, which can be uploaded to the reuse database, and used to fill in further information during a detail inventory.

The building parts are logged both as the actual element and as the components and materials that the element consists of. This is to be able to decide in what scale or form the building part has its largest reuse potential. Each reuse potential parameter has a column for a comment and a grading and in the end there is a column for attachments.

More columns with information can be added, choosing from a set list of parameters to ensure compatibility.

Building part	Building part name	Position	Quantity	Unit	Score	Condition	Score	Environmental savings	Score	Economical value	Score	Disassembly feasibility	Score	Future application	Score	Total score	Attach-ments	+
BUILDING ELEMENTS	Exterior walls	Biskopsgatan 8	277	m^2	5	Overall good condition.	5	9747 kg CO2e (see appendix D).	5	1 194 135 SEK incl. construction costs (see appendix C).	5	See appendix E.	4	Upcycled wall elements.	4	28		
BUILDING COMPONENTS	Windows 3-glazing	Exterior wall	57	pcs	5	no hazardous substances	5	3211 kg CO2e (see appendix D).	5	354 877 SEK, material costs only (see appendix C).	4	Taken out from wall.	4	Direct reuse.	4	27		
BUILDING MATERIALS	Wooden facade panel	Exterior wall	277	m^2	5	no hazardous substances	5	159 kg CO2e (see appendix D).	2	56 259 SEK, material costs only (see appendix C).	3	Sawn into pieces.	2	Several upcycling examples exist.	5	22		
BUILDING MATERIALS	Nailing battens	Exterior wall	617	m	5	no hazardous substances	5	31 kg CO2e (see appendix D).	1	18 125 SEK, material costs only (see appendix C).	2	Sawn into pieces.	2	Several upcycling examples exist.	3	18		
BUILDING MATERIALS	Windboard	Exterior wall	277	m^2	5	no hazardous substances	5	126 kg CO2e (see appendix D).	2	11 523 SEK, material costs only (see appendix C).	2	Attached with screws or nails.	3	Direct reuse.	3	20		
BUILDING MATERIALS	Studs	Exterior wall	617	m	5	no hazardous substances	5	105 kg CO2e (see appendix D).	2	44 665 SEK, material costs only (see appendix C).	3	Sawn into pieces.	2	Several upcycling examples exist.	3	20		
BUILDING MATERIALS	Insulation board	Exterior wall	277	m^2	5	no hazardous substances	5	4790 kg CO2e (see appendix D).	5	19 556 SEK, material costs only (see appendix C).	2	Loose boards.	4	Direct reuse.	4	25		
BUILDING MATERIALS	Vapor layer	Exterior wall	277	m^2	5	no hazardous substances	5	100 kg CO2e (see appendix D).	2	2022 SEK, material costs only (see appendix C).	1	Waterproofing function will break during deconstruction.	1	Energy recycling.	1	15		
BUILDING MATERIALS	Gypsum board	Exterior wall	277	m^2	5	no hazardous substances	5	1225 kg CO2e (see appendix D).	3	16 952 SEK, material costs only (see appendix C).	2	Porous, will break into pieces.	1	Material recycling.	1	17		
BUILDING MATERIALS	Sill	Exterior wall	137	m		pressure-impregnated												

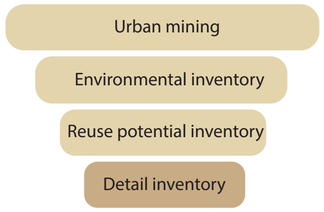
These fields are filled in by the environmental inventory specialist and handed over to the reuse consultant. As the sill is pressure-impregnated and thus have no reuse potential, there is no need to gather further inventory data about the sill.

The attachments to each building part can be used to automatically generate an image appendix, where each photo is given the name of the building part along with a unique number (littera).

Table 5. Environmental and reuse potential inventory for Biskopsgatan 8's preschool, scored from 1 to 5 with 1 being the lowest and 5 the highest (see p. 36 on *Visualising the data*).

OFF SITE SUPPLY 2: DOORS

Ideally when looking for reused building parts, everything would be uploaded to the same reuse database, making it easier and more efficient to find them. As this is not yet the case, in this thesis, doors were scouted at the web shops of three different reuse material suppliers: *CCbuild Produktbanken*, *Brattöns Återbruk* and *Kompanjonen*. As all these doors have already been deemed to have reuse potential by a reuse consultant, no reuse potential or environmental inventory is needed. All that is needed is a detail inventory to collect their respective information and upload to the reuse database, to have it all collected in one place (see more on p. 81).



A detail inventory could be done directly.

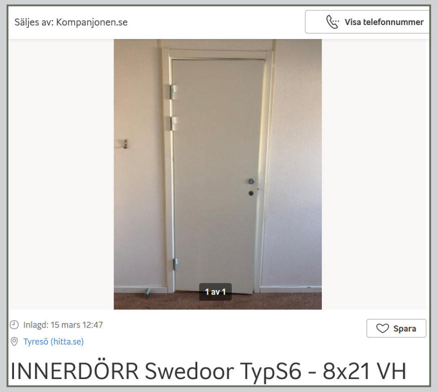
Figure 39, 40 & 41. Ads from the reuse material suppliers (Brattöns Återbruk 2021, Blocket Kompanjonen 2021 & Brattöns Återbruk 2021).

DETAIL INVENTORY

EXTERIOR DOORS Brattöns återbruk

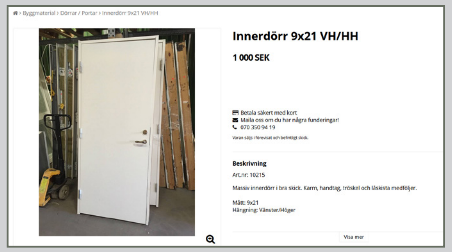
QUANTITY 20 pcs
MODULE MEASURE 9x21
MATERIAL & COLOUR wood, brown glazing
PRICE 400 SEK/pcs excl. VAT and transport

INTERIOR DOORS Kompanjonen



QUANTITY 2 pcs
MODULE MEASURE 8x21
COLOUR white
PRICE 1490 SEK/pcs excl. VAT and transport

INTERIOR DOORS Brattöns återbruk



QUANTITY 2 pcs
MODULE MEASURE 9x21
COLOUR white
PRICE 1000 SEK/pcs excl. VAT and transport

PATIO DOORS

No patio doors were found.

DESIGN WITH OFF SITE SUPPLY

As concluded in chapter 3 on Information Management, there are several benefits from making the information from the inventories compatible with other kinds of processes and functions in the building industry. This chapter looks at how the data from the inventories related to Jungmansgatan can be imported into a BIM software to generate 3D components, so called BIM objects. This means that the architect could design with the actual reused building parts, to make sure they are integrated in a good way in the new construction (demand) project, in this case the rooftop addition at Jungmansgatan.

Toolchain and workflow

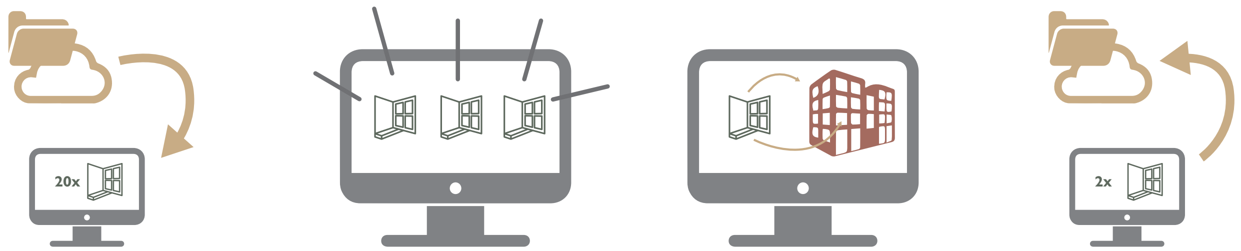
To be able to import the inventory data from the reuse database and generate BIM objects, a concept toolchain was developed to describe the development of such a function, along with a workflow on how it would be used by the designer. The main idea of the toolchain is to provide a communication platform between the reuse database and the BIM model (see figure 42).

In this thesis, Revit was chosen as BIM software and *CCbuild Produktbanken* was chosen as the reuse database. Each part of the toolchain was tested using Grasshopper.Inside.Revit as a proof of concept (see appendix F). The methodology described should however apply to any other BIM software, programming language or database.

Levels of complexity

The process for BIM compatibility looks very different depending on if it can be modeled as a single component or BIM family type, or needs to consist of several components forming an element or an assembly. In this case, the doors from the off site supply can be modeled as a single components while the walls with windows from the off site supply has to be modeled as several components. For this thesis, it was chosen to focus on the BIM compatibility of the doors. As such, the procedure for designing with wall elements including windows will not be discussed in relation to BIM but rather on a more generic design workflow level.

PREREQUISITE.
Upload information to the existing reuse database, based on inventories.



STEP 1. SYNC WITH THE REUSE DATABASE
Filter what type of reused building parts you want to integrate in your design, and download the object information from the existing reuse database to your BIM model. These building parts then gets 'reserved' for 48 hours to prevent other users from downloading them. (API in)

STEP 2. BIM OBJECT GENERATION
Based on existing BIM model information from the off site reuse targets, and the downloaded object information from the reuse database, BIM objects are automatically generated.

STEP 3. DESIGN PROCESS
Design, test and iterate your building with the reused BIM objects by moving them and changing their appearance.

STEP 4. SYNC BACK TO THE REUSE DATABASE
Book/buy the reused building parts you wish to use by uploading the updated position and owner (saved in the littera) to the reuse database. (API out)

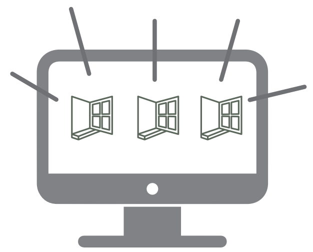
Figure 42. Concept workflow for integrating inventoty data into BIM model.

OFF SITE SUPPLY 2: THE DOORS

COMPONENT REUSE

In the system document phase, generic doors components were positioned at each door, with an *Off site reuse target* parameter set to 'Yes' to store the reuse targets in the BIM model. This generated a reuse target plan (see figure 28 page 68) and a reuse target schedule (see table 3 page 69) for the doors. These visualisations give an idea on the amount and type of doors needed to be found in the reuse database.

For the following detailed process description of the BIM compatibility, the exterior doors are chosen as an example.



STEP 1. SYNC WITH THE REUSE DATABASE
Use constraints to filter objects from the reuse database:
Doors -> Exterior doors -> Module measures 9x21

When syncing with the reuse database, every parameter can act as a filter, such as material or minimum amount.

Download object information from the reuse database:
In this case the filter is set to the existing family type of Generic exterior doors in the BIM model along with their width of 900 mm. Only information on these type of reused building parts are downloaded from the reuse database.

STEP 2. BIM OBJECT GENERATION
Reuse objects are generated automatically in the BIM model:
The process of creating BIM objects of the reused doors in the database can be automated by duplicating and changing the parameters of the generic doors from the system document phase, see figure 43. To understand what parameter from the reuse database that feeds what family type parameter in Revit, see page 84.

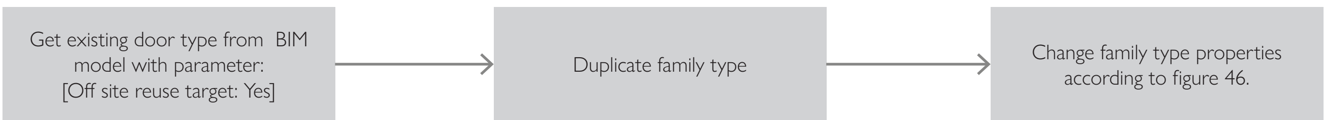


Figure 43. Flow diagram explaining how the reused component can be generated automatically.

Replacing existing generic doors

One of the limitations of the chosen BIM software is the inability to set a maximum amount of instances to each family type. This is part of a larger discussion (see chapter 6 on *Compatibility*), but in this example it has been solved by letting the plugin place out the correct amount of reused doors in the model, rather than letting the designer place them herself. This is done by replacing the generic doors with the amount of reused doors available in the reuse database (see figure 44).

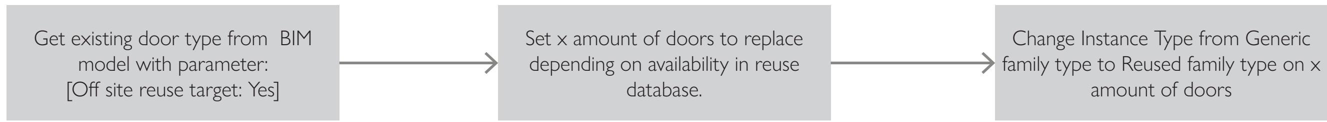


Figure 44. Flow diagram explaining how to automatically replace the generic components with the reused components.

Creating materials

The difficulty in creating a material in the BIM software based on a text-based string from the reuse database - as it is logged and stored today - lies in that materials and colours can be described in very different ways. To solve this, it is proposed to create a set list of materials to choose from when uploading your inventory data in the reuse database, which can be read by the plug-in to create the right hatches and textures:

- wood
- metal
- concrete/stone
- glass
- brick
- solid colour

As for the colour, apart from a string-based name, it is proposed to specify the colour in the reuse database using the RGB system, which then can be translated into a colour in the BIM software (see figure 45).

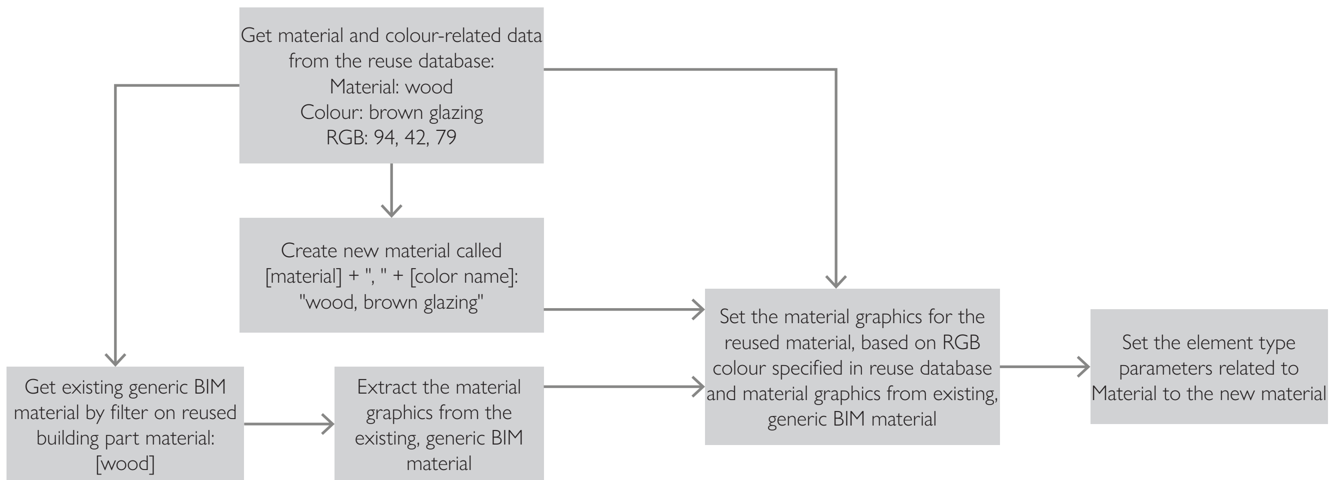


Figure 45. Flow diagram explaining how to automatically generate a material for the specific reuse BIM object.

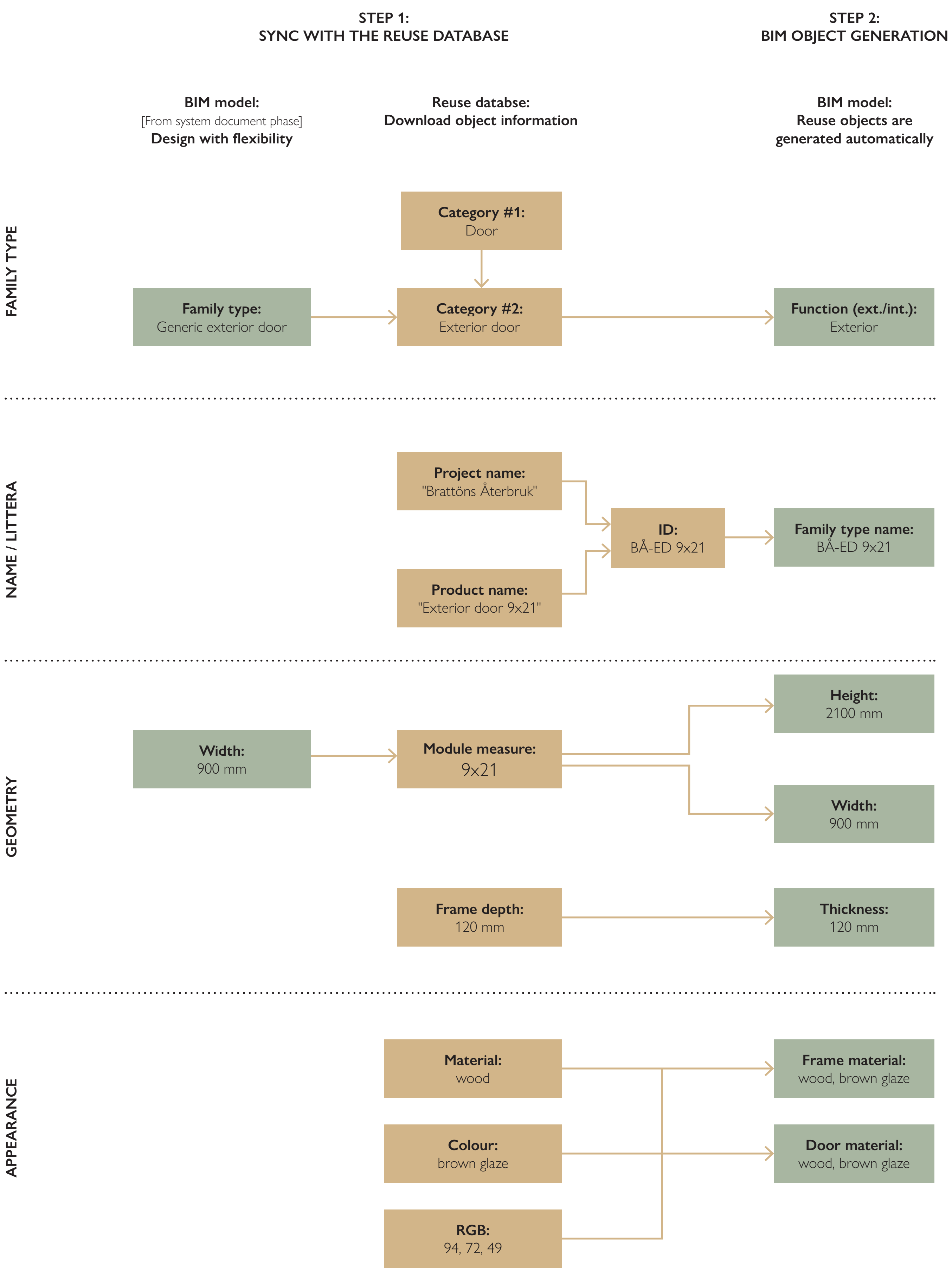
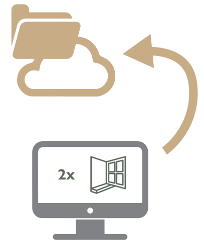


Figure 46. Flow diagram explaining what parameters from the reuse database that feeds what parameters in the BIM software for a specific door type.



STEP 3. DESIGN PROCESS
1. Move around the doors after they have been placed in the model to adjust position.
2. Change the colour of the door to match the walls at Jungmansgatan.

STEP 4. SYNC BACK TO THE REUSE DATABASE
In this case, 8 out of 20 doors from the reuse database are used and the status is updated accordingly (see figure 47).

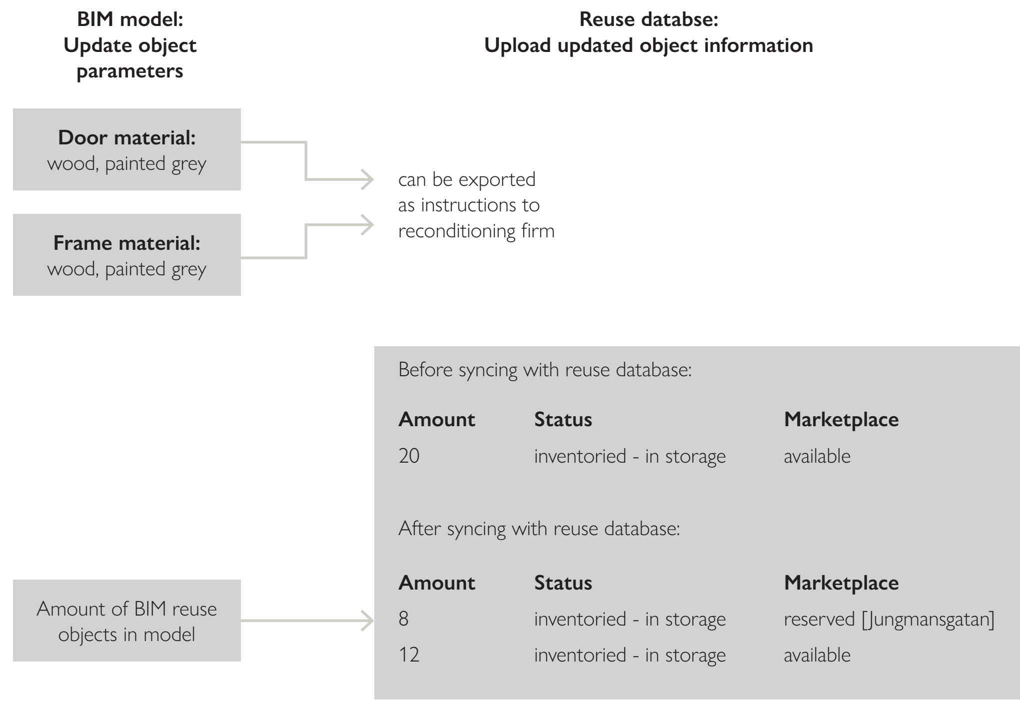


Figure 47. Flow diagram explaining how the status in the reuse database is updated.

Visibility in the design process

The same process as just described can happen for the interior doors, where we found two from Brattöns Återbruk and another two from Kompanjonen (see page 80). This, however, still means that there will be eight new interior doors needed. Similarly, for patio doors, none was found in the reuse database and they will all have to be new. This is summarised and reflected in the door tags (see figure 48) and the updated door schedule (see table 6). These can work as a base for the tender documents, so that the contractor knows how many doors to get from where.

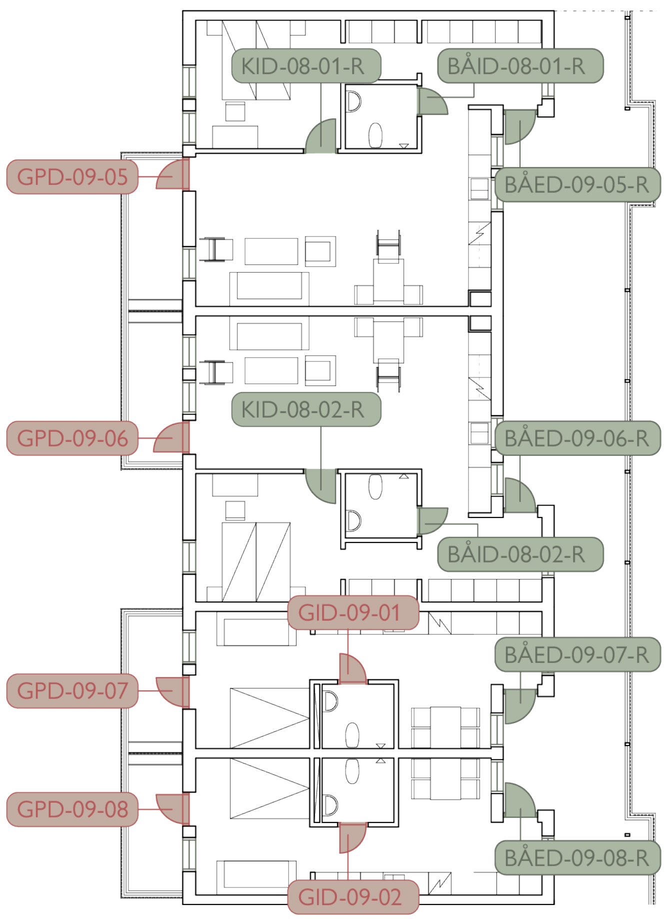


Figure 48. Updated floor plan, 1:200, with corresponding door tags, colour-coded depending on if they are reused or new.

Door schedule

Quantity	Family type	Littera	Width [mm]	Condition
8	Brattöns Återbruk Exterior Door 9x21	BÅED-09-X-R	900	**Reused**
8	Generic patio door 9x21	GPD-09-X	900	**New**
8	Generic interior door 8x21	GID-08-X	800	**New**
2	Kompanjonen Interior Door 8x21	KID-08-X-R	800	**Reused**
2	Brattöns Återbruk Interior Door 8x21	BÅID-08-X-R	800	**Reused**

Table 6. Updated door schedule marking which doors are reused (from the reuse database) and which ones have to be new.

OFF SITE SUPPLY 2: TIMBER FRAME WALLS WITH WINDOWS

ELEMENT REUSE

The system document phase of the demand project resulted in a BIM model with marked intervals for where windows can be placed (see figure 30 on page 68). Facade drawings are provided from the supply project of the existing preschools (see figure 49), which can be loaded into the BIM model and matched with the wall lengths and window intervals.

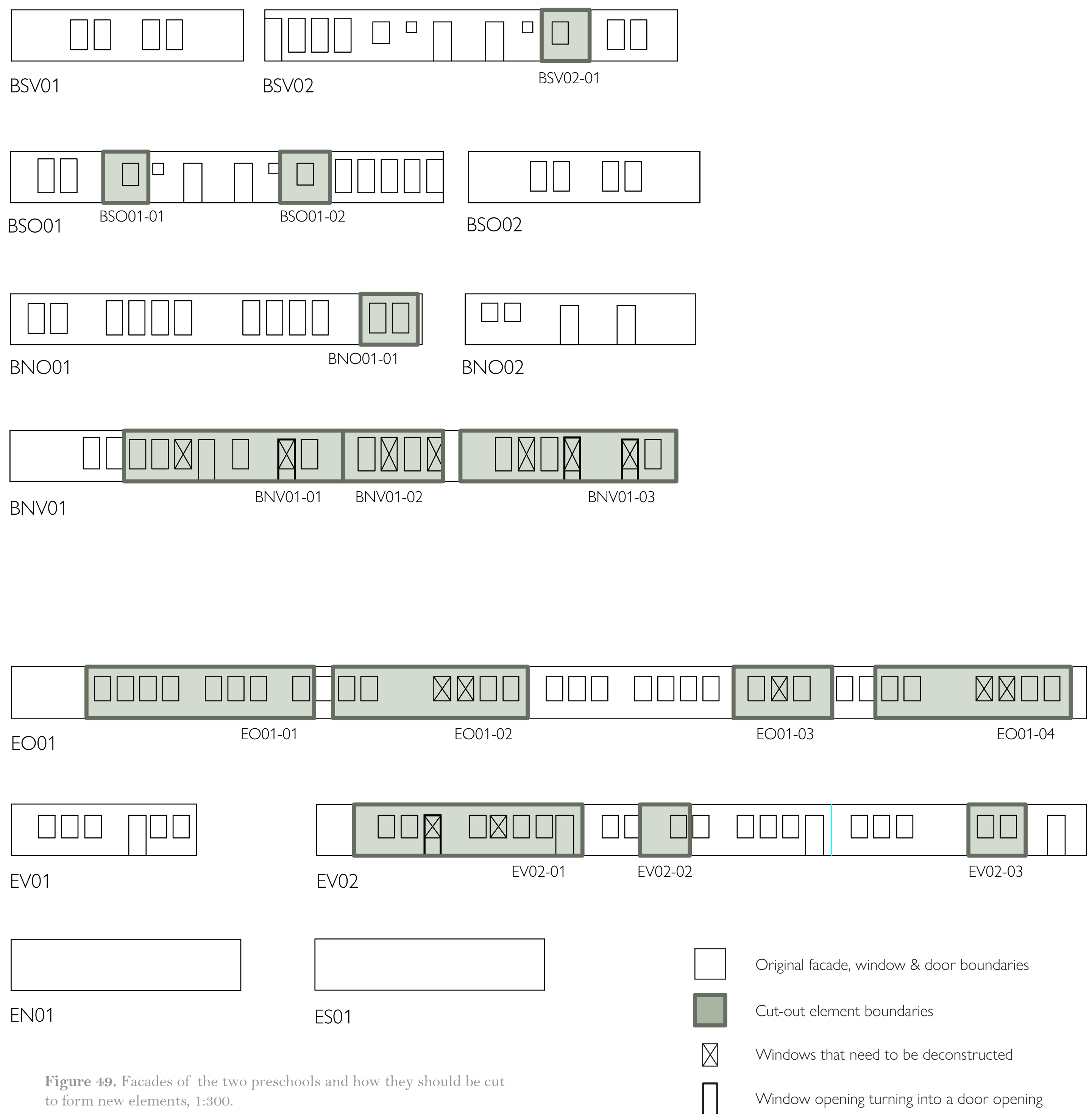


Figure 49. Facades of the two preschools and how they should be cut to form new elements, 1:300.

Visibility in the design process
The final elements including the windows are visible in figure 50 as a facade drawing with wall tags, as well as in table 7. These can work as a base for the deconstruction contractor of the supply project, to know where to cut the elements and what to call them to find their new place in the new construction.

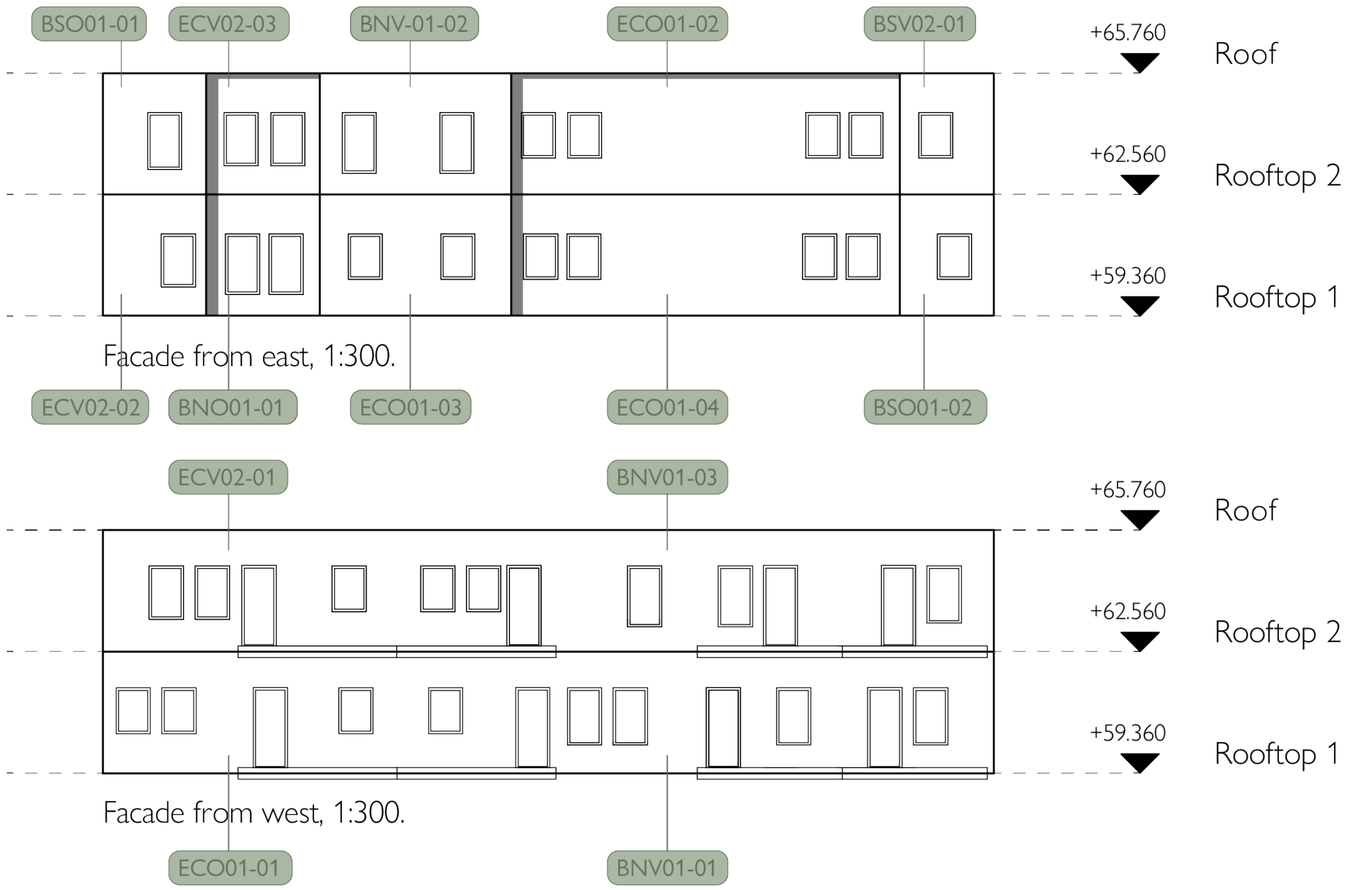


Figure 50. Final facades with reused walls and windows, with wall tags.

Wall schedule

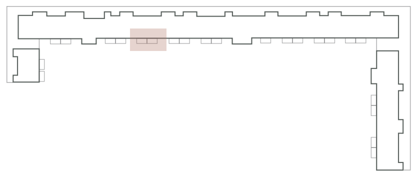
Quantity	Family type	Littera	Length [mm]	Height [mm]	Condition
1	Exterior wall street side	BSV02-01	2400	2700	Reused
1	Exterior wall street side	BSO01-01	2400	2700	Reused
1	Exterior wall street side	BSO01-02	2400	2700	Reused
1	Exterior wall street side	BNO01-01	3600	2700	Reused
1	Exterior wall courtyard side	BNV01-01	11400	2700	Reused
1	Exterior wall street side	BNV01-02	5050	2700	Reused
1	Exterior wall courtyard side	BNV01-03	11400	2700	Reused
1	Exterior wall courtyard side	ECO01-01	11400	2700	Reused
1	Exterior wall street side	ECO01-02	10900	2700	Reused
1	Exterior wall street side	ECO01-03	5050	2700	Reused
1	Exterior wall street side	ECO01-04	10900	2700	Reused
1	Exterior wall courtyard side	ECV02-01	11400	2700	Reused
1	Exterior wall street side	ECV02-02	2400	2700	Reused
1	Exterior wall street side	ECV02-03	3600	2700	Reused

Window schedule

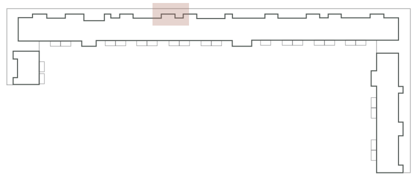
Quantity	Littera	Width [mm]	Height [mm]	Condition
6	BW-0915-X-R	900	1500	Reused
5	BW-0916-X-R	900	1600	Reused
6	ECW-0914-X-R	900	1400	Reused
19	ECW-0912-X-R	900	1200	Reused

Table 7. Updated wall and window schedules with building parts from the reuse database.

Facade towards courtyard, 1:100.



Facade towards street, 1:100.



FINAL PROPOSAL

The final design is done and the reuse choices and implementations can be visualised in the construction principle and through LCA and cost calculations, as well as with visualisations showing the design with reused building parts.

The as-built documents are updated in the BIM model to enable future reuse of the building, see figure 51.

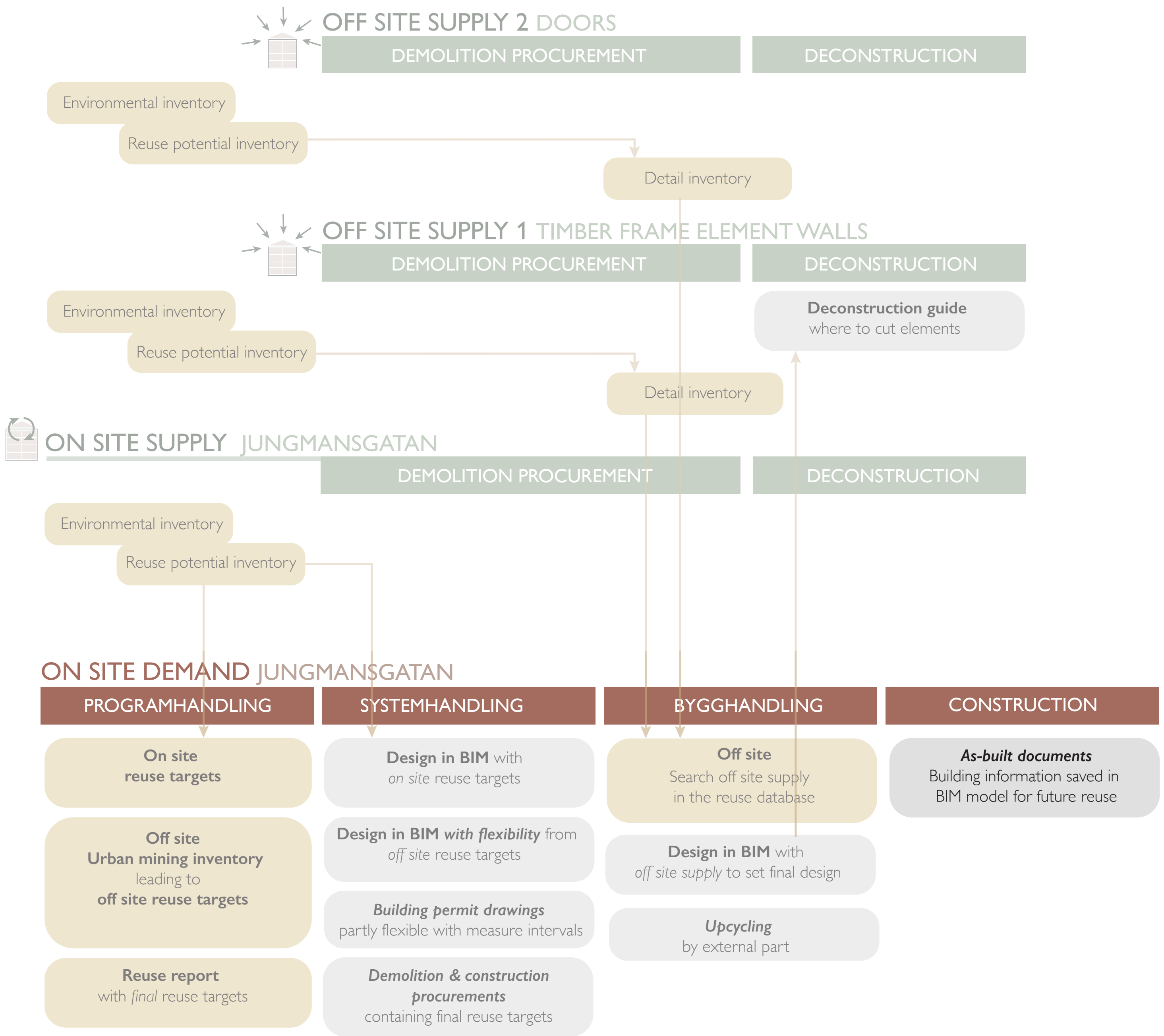


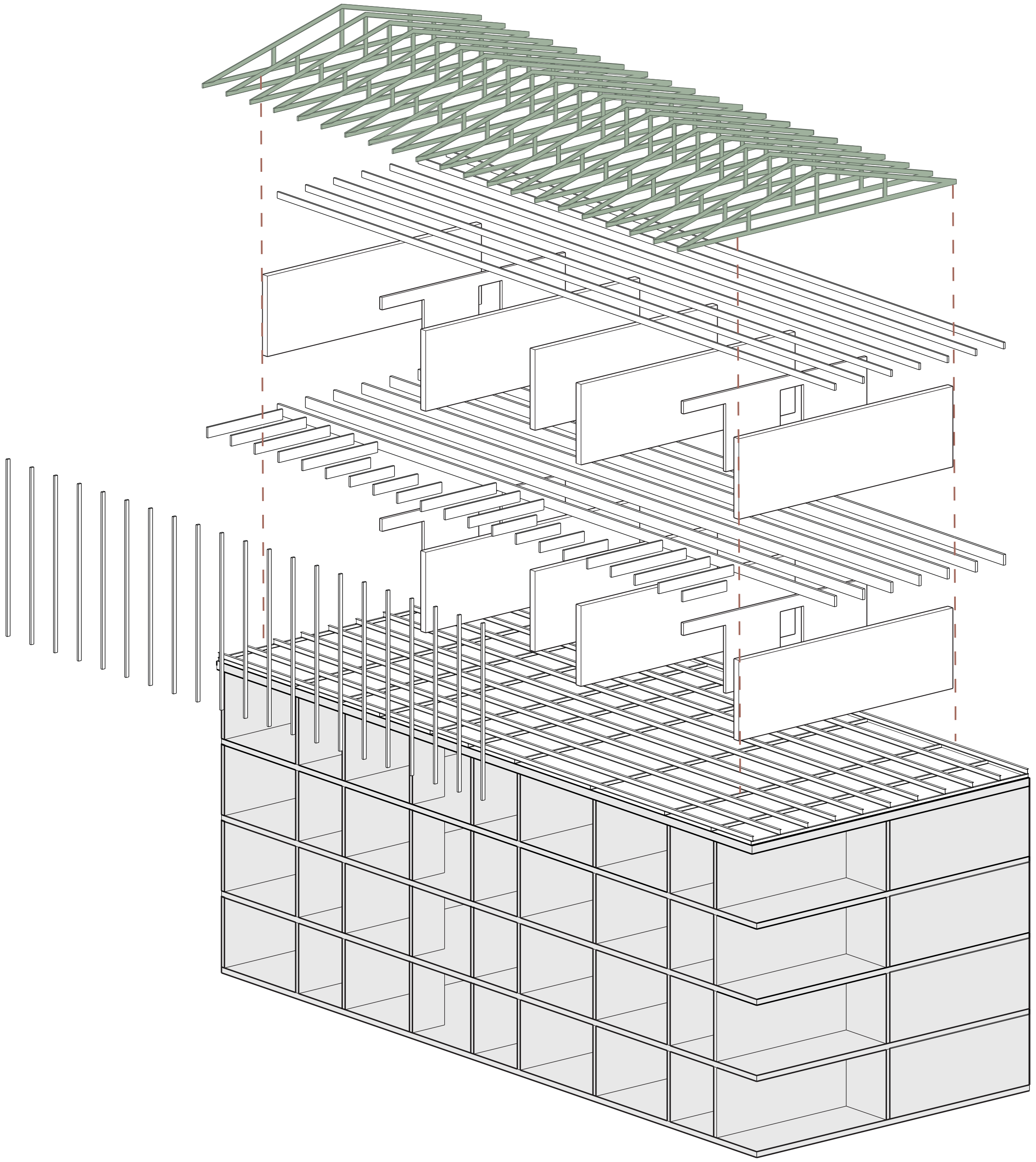
Figure 51. The reuse process performed in the Construction phase.

Life on the rooftop.

CONSTRUCTION PRINCIPLE

A rooftop extension always comes with load bearing challenges. In this case, a former pre study made by a structural engineer has stated the existing construction to be strong enough to carry the loads from a two story rooftop extension constructed in wood or steel, without any reinforcements.

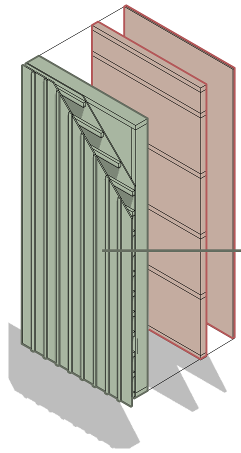
From consultations with structural engineers at Moelven and Rise research project Timber on top, it was decided that the best option is to add a steel frame construction between the existing and new construction to transfer the loads down to the existing walls, as well as to make space for building services.



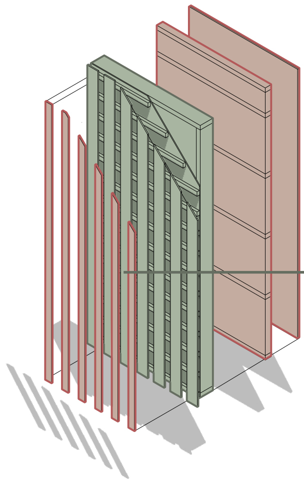
Exploded axonometric illustration showing all structural elements in the construction and how the loads are transferred from the new construction to the existing through a frame of steel.

LEVELS OF UPCYCLING

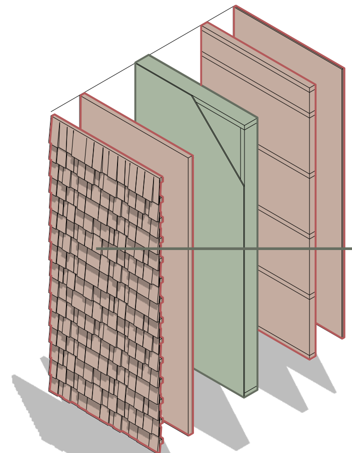
As for the upcycling of the walls, the interior surface layer and vapor layer always need to be deconstructed and replaced (see a more detailed description in appendix B). As for the facade, we had two different concepts - cedar shingles against the yard to harmonise with the existing brick wall, and a grey timber panel against the street (see *Building concepts* on p. 63). This resulted in 3 different levels of upcycling.



The walls that originate from Biskopsgatan can keep its facade and only be repainted.

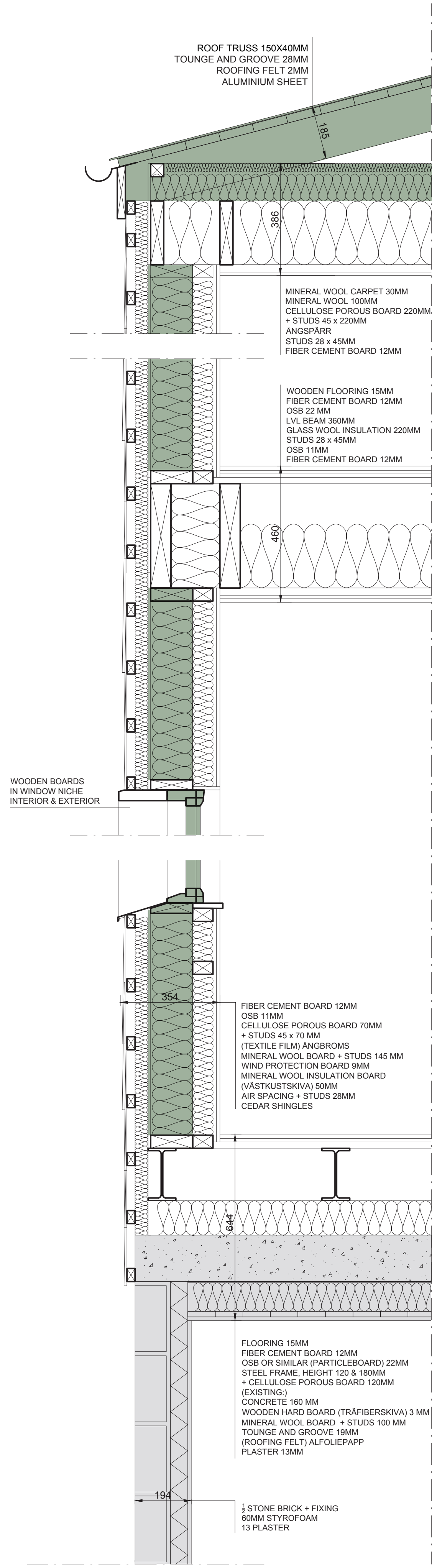


The facade of the walls that originate from Eriksboskolan is partly taken down and substituted with new planks to create a more harmonic expression.



The walls towards the courtyard gets a new facade of cedar wood shingles, as well as an additional insulation board to the exterior.

(Right) Detail section through courtyard side, with reused building parts marked in green, 1:20.

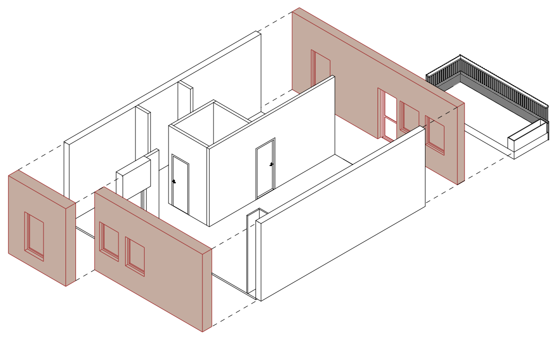


LIFE CYCLE ASSESSMENT & COST CALCULATIONS

REUSE REPORT

To understand the difference between using new building parts, or the reused and upcycled building parts proposed in this thesis, calculations for material and construction cost and emissions for a 1 bedroom apartment were done (see details in appendix C and D). For the upcycled alternative, this only includes the materials themselves and not the cost and emissions for the deconstruction and upcycling.

As anticipated, the emissions as well as the costs are lower for the upcycled alternative. The difference - both in amount of carbon as in money - can be used to form a monetary and carbon budget respectively, giving an understanding on how much playroom there is for the deconstruction and upcycling.



New exterior walls & windows

Global warming potential

14,9 *kg CO_2e/m^2 gross area*

Material & construction costs

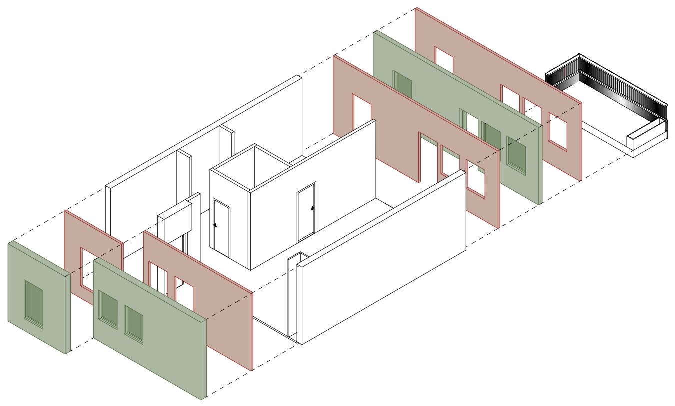
2128 *SEK/m² gross area*

MONETARY BUDGET FOR DECONSTRUCTION & UPCYCLING

1215 *SEK/m² gross area*

CARBON BUDGET FOR DECONSTRUCTION & UPCYCLING

6 *kg CO_2e/m^2 gross area*



Upcycled walls & windows

Global warming potential

0 *kg CO_2e/m^2 gross area*

Material & construction costs

0 *SEK/m² gross area*

Additional layers

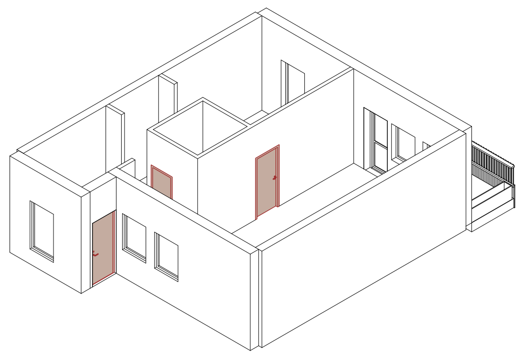
Global warming potential

8,9 *kg CO_2e/m^2 gross area*

Material & construction costs

913 *SEK/m² gross area*

Illustrations of the 1 bedroom apartment with new vs reused building parts marked in red and green respectively.



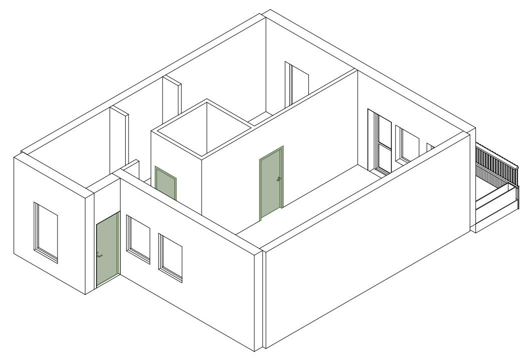
New doors

Global warming potential

0,3 *kg $CO_2e/m2$ gross area*

Material & construction costs

257 *SEK/m² gross area*



Upcycled doors

Global warming potential

0 *kg $CO_2e/m2$ gross area*

Material & construction costs

117 *SEK/m² gross area*

MONETARY BUDGET FOR DECONSTRUCTION & UPCYCLING

140 *SEK/m² gross area*

CARBON BUDGET FOR DECONSTRUCTION & UPCYCLING

0,3 *kg CO_2e/m^2 gross area*

Closeup of the facade at Biskopsgatan's preschool.

CONCLUSION

Our thoughts on the future of industrial reuse, based on the research of chapter 1-4 and our own design process in chapter 5.

CONCLUSION

REUSE ON THE INDUSTRIAL SCALE

How can designing with reused building parts become feasible on an industrial scale?
The factors affecting the design process with reused building parts on an industrial scale can be divided into two parts.

WHAT TO REUSE

Analysis of cost comparisons and disassembly feasibility for both the roof at Jungmansgatan and the walls of the two preschools used in the pilot project of this thesis showed that element reuse is more feasible than material reuse. Element reuse reduces disassembly and reassembly time and therefore costs, making it more relevant to reach reuse on an industrial scale.

HOW TO REUSE

Analysis of previous and ongoing reuse projects indicated a need for better communication between the different inventories as well as the different actors of the project. This would make the reuse process more efficient and as such, more industrial. The communication and efficiency could be improved through development of the inventory processes and the information management, further discussed in the answers to the next two questions.

INVENTORIES

How can material inventories develop to facilitate reuse on an industrial scale?
To make the communication and efficiency of current inventories better, an interconnected inventory process is needed. By letting the different types of inventories build on each other, as concluded in the *inventory funnel* (see figure 53), means that information would not have to be logged twice or inventories be performed in vain, and as such making the inventory process faster.

Furthermore, the results from the analysed inventories along with the findings in the pilot projects indicates the importance of logging reuse potential parameters that are relevant to reach reuse on an industrial scale. These parameters are concluded in figure 52.

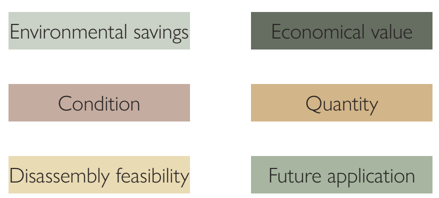


Figure 52. The six most common reuse potential parameters, all highly related to industrial reuse.

INFORMATION MANAGEMENT

How can information management facilitate the implementation of reused building parts in the architect's design process?
Information management can enable a connection between the material inventory and the BIM software used in the design process. This relies on a structured and standardised way of logging the inventories, and of storing all the inventory data in one place. An example of how the inventories could be logged and stored for future compatibility with each other as well as with the design process was developed and can be seen on page 60 and page 77 respectively.

Furthermore, the functions in the BIM software can be used to visualise reuse-related information and decisions throughout the building process. In this thesis, it was done by using *Phasing* and a set of *Reuse* parameters to colour-code and tag BIM objects at different stages in the design process.

The architect's design process with reused building parts would benefit from integrating the inventory data directly into the BIM software. In this thesis, it was done by developing and testing a concept toolchain and workflow for connecting a reuse database to the BIM model to automatically generate BIM objects. These reuse BIM objects could then be designed with directly in the BIM model, to decide which ones to include in the project. This information could then be uploaded back to the reuse database to "reserve" them, see more on page 81.

* * *

Finally, this thesis concludes that reuse of building parts on an industrial scale is not a single person or even single company endeavour. The dialogues and discussions held through all the semi-structured interviews show that by sharing our work - the success as well as the fallbacks - we can learn from each other, and create the progress and courage we need to take on **Reuse Tomorrow**.

Figure 53. The inventory funnel.

REFLECTIONS

THE DESIGN PROCESS

The proposed workflow for a reuse process can be seen in figure 54, and is based on the theoretical research, analysis of reuse projects as well as the pilot project of this thesis.

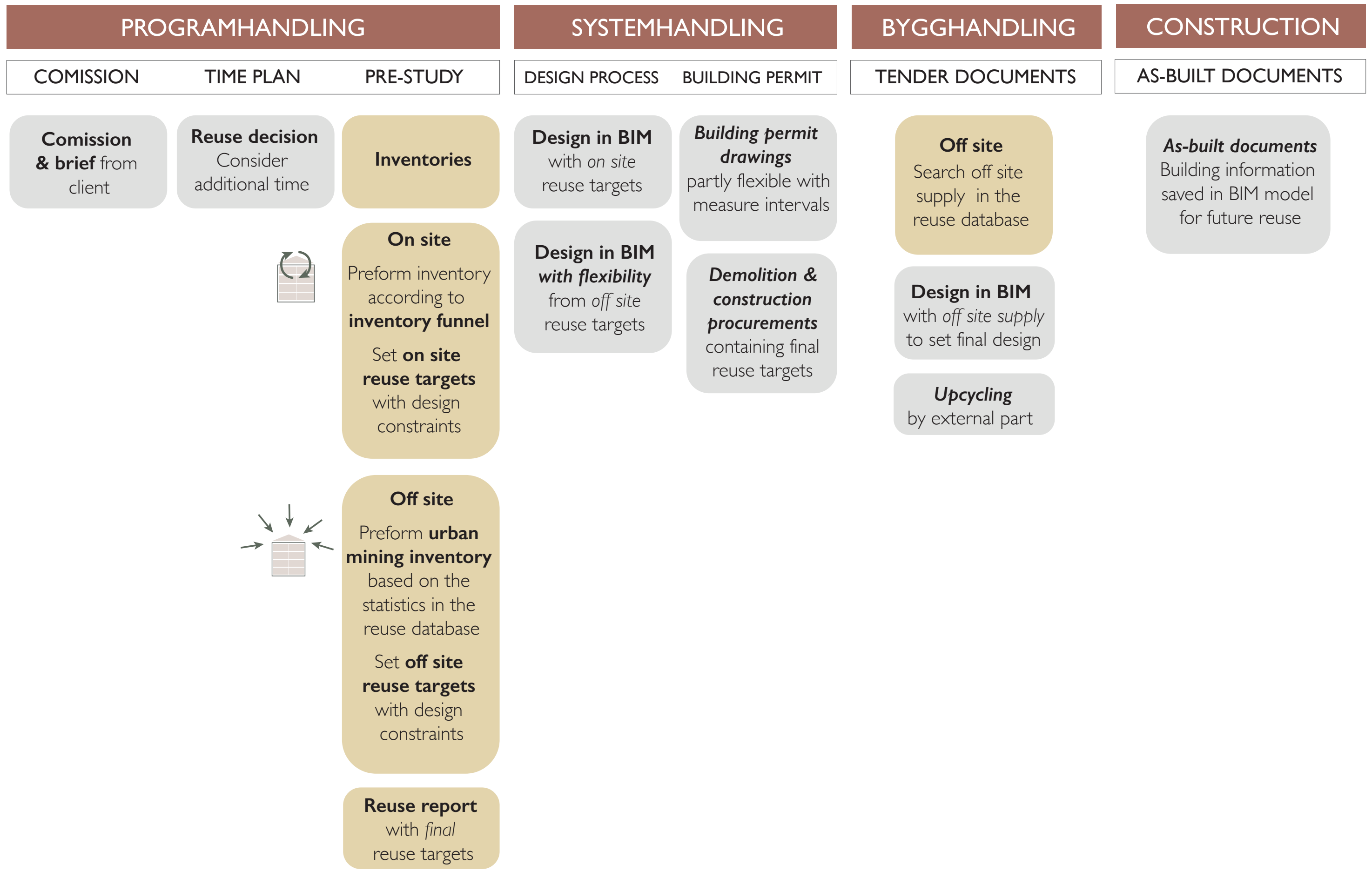


Figure 54. Proposed workflow for a demand project.

In hindsight, it might have been too much to take on both the design with reuse challenge and all its consequences, as well as the design of a rooftop addition which in itself is not a standard typology and as such required a lot of research. In a more "standard" type building it would probably have been easier to incorporate the reused building parts, as a suggestion a preschool as the walls originally came from a preschool.

Does design with reuse result in good architecture? Based on the pilot project of this thesis, it is the reflection of the authors that it is not the reuse itself that sets the constraints for good architecture. It is rather the fact that the reuse process claims a lot of the time of the project, and if more time is not given from the start, it conclusively gives less time for the design part of the project. As such, it might result in - not necessarily less good architecture - but less elaborated and worked through architecture.

ELEMENT REUSE

It would be better to deconstruct the walls by there element joints, but that would make the window matching a lot more difficult and less flexible. It would probably be easier to reuse preschool walls to more generic layouts such as offices or public buildings - housing tend to have less built-in flexibility as well as a need of a more repetitive window placement.

A consequence of reusing the wall elements including their windows is that all apartments get very different window compositions. This results in:

• very different daylight conditions, meaning that it might not be enough to make a daylight analysis of a few type apartments but that one has to be done for each apartment. This would be very time-consuming and require a lot of computer capacity.
• very different plan drawings, meaning that it might be difficult for the property developer to show a type apartment plan drawing for the potential tenant.

Element reuse has proven to be interesting from an economical point of view, but makes the design process a lot more difficult. As such, further research is required on what type of elements from what type of building typologies that matches the needs and functions of what types of new constructions.

Post-fab elements - a new business opportunity?

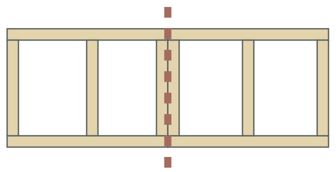
In chapter two, under *Reuse potential inventory*, it is briefly mentioned that element reuse is not a new innovation, although it is far from an established business model. RE-USE Consulting in North America have tried the principle of reusing timber frame elements at a small scale and have been able to share experience on the actual workflow. They call the elements *post-fabs*, since the timber frame elements once were pre-fabs (Bennick, February 11, 2021).

Since this was the only real case example within the field, further research was based on interviews from the deconstruction and construction sector (Fiedler, Bennick, Lindblom, Carlsson, Österberg) with an ability to reflect upon and estimate the feasibility. The conclusion was that there are feasible methods to handle the whole process, but it would have to be tried out further.

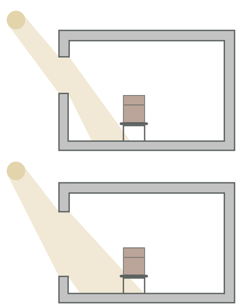
The technical manager at Derome, a company manufacturing prefab element walls, states the reuse of timber frame elements as a potential reuse business. Technically there is nothing strange about it. There needs to be a demand for it, and there needs to be an economical feasible business model. In such a business model, the reused elements would probably be treated in a separate "reconditioning line". The final outcome would be a wall element where some layers might have had to be removed and/or added, and the prefab factory would be responsible for security and guarantees (Carlsson, personal communication February 1, 2021).

The discussion has resulted in a principal solution of how a potential business model could work, from deconstruction (as a supply) into a prefab factory where it is being reconditioned to serve as a new resource in a new construction (demand project). This principal solution can be found in appendix B.

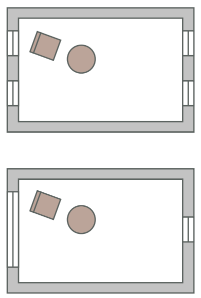
DON'T MIX APPLES & PEARS
To reuse the right type of element for the right type of new construction.



CUT BY JOINTS
Cut by element joints to minimise waste.



DAYLIGHT
A variety of window sizes and positions create very different daylight conditions.



LAYOUTS
A variety of window sizes and positions create very different layouts.

THE INVENTORY PROCESS

Produktbanken by CCbuild is an inventory tool meant to cover a lot of different types of inventories, but in reality it is mostly useful for a detail inventory and makes prepatory logging of data (desktop mapping) a bit difficult. As an example, it is tricky to use Produktbanken for desktop mapping prior to a site survey, as the user has to grade the condition of the building part, which one in reality might not know until after the site survey. To use only one tool through the whole inventory process could save a lot of time which is one of the prerequisites for reuse on an industrial scale. Because *Produktbanken* still provides a great platform with many users, it has a lot of potential for further development as discussed throughout the thesis.

Compatibility

One of the challenges of reuse is to find standardised ways of logging the data. An interesting example was mentioned in chapter 3, where NBS provides a standard way of logging BIM object parameters. Perhaps reuse consultants could use the same system?

Visibility

The visualisation elements in a reuse report are most efficient when the inventory includes more than one building part, so that it is easy to compare which building part has the highest reuse potential and as such might be more important to focus on. In the pilot project of this thesis, the on site inventory only consisted on the roof construction and as such, it was hard to evaluate its reuse potential scores.

THE INFORMATION MANAGEMENT PROCESS

From chapter 5 it can be concluded that a toolchain which allows for integration of inventory data into BIM to facilitate the architect's design process with reused building parts is an idea worth developing. Further research includes both technical and software development aspects as well as user aspects.

Some examples include:
• What happens if there are several supply sources in the reuse database - can you choose which one you want to 'replace'/'load' into the BIM model?
• When several people in different projects are using the reuse database, how does a user "keep ownership" of the elements? Should there be one status called "Reserved" for whenever someone has synced (reserved for 48 hours), and then one status for "New owner confirmed" for when you actually have decided to use it?

These type of questions need to be gathered in relation to user tests as a base for further development.

Compatibility

Just because CCbuild *Produktbanken* is suggested to be used as a reuse database in the *Pilot project* chapter of this thesis, does not mean that is has to be used as an inventory tool. The purpose is to find an agreement on a standardised way of logging the data and what the parameters should be called, so that everyone can upload the information to the database regardless of inventory tool. This is to ensure an open-source and non-monopoly solution where only one product can be used, but encourage several solutions for different needs and types of projects.

A final reflection on BIM and designing with reused building parts is related to circular economy on a larger level. To date, Revit has no built-in way of limiting the amount of instances that can exist of each family type, a function that would be needed to design with a limited amount of available reuse objects on a more industrial and mainstream level. It is a reflection on the linear economy dominating the building industry today - our very own design tools tell us there are unlimited resources.

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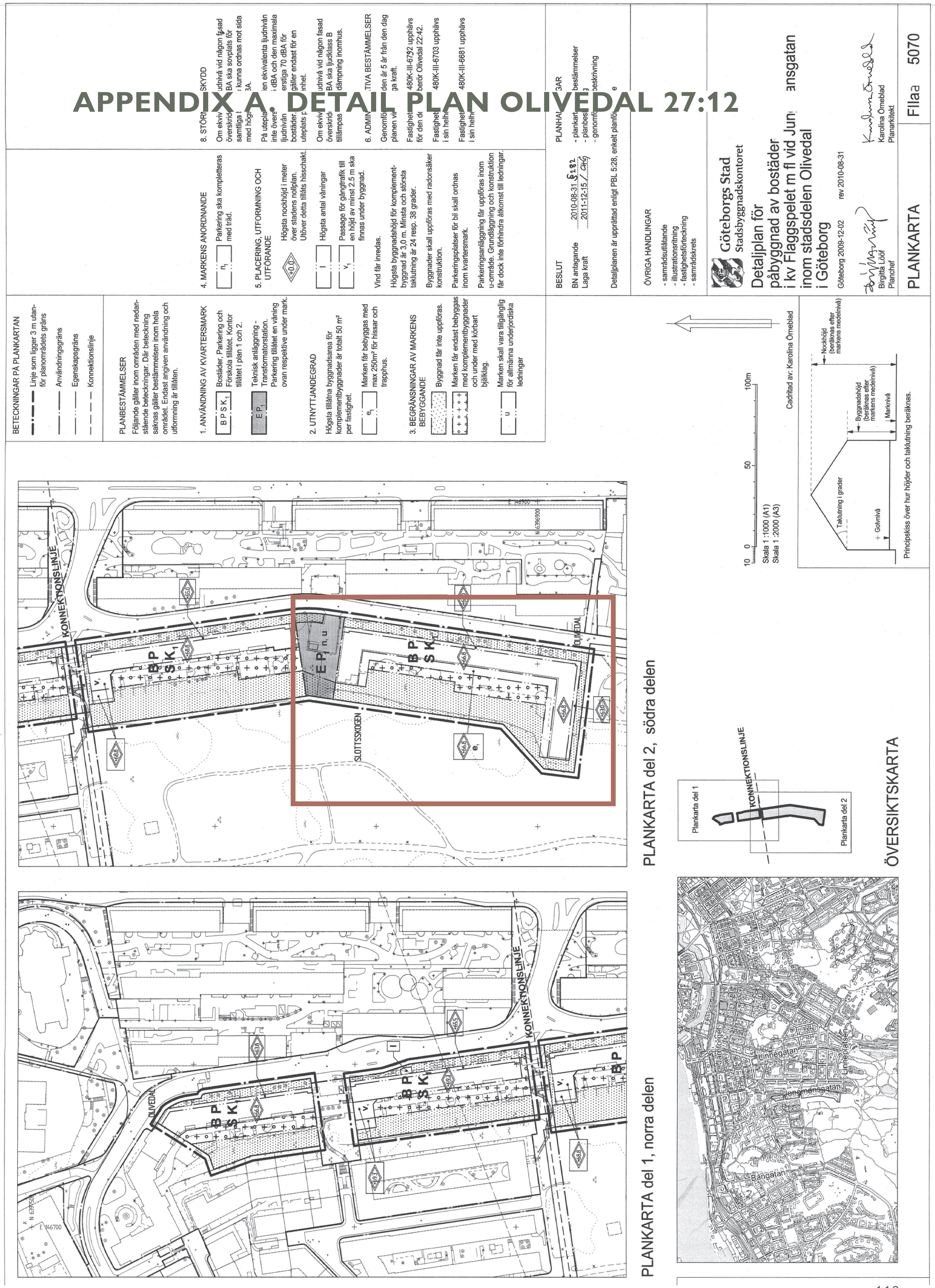
APPENDICES

APPENDIX A. DETAIL PLAN OLIVEDAL 27:12



APPENDIX B. POST-FAB PANELS

TIMBER FRAME ELEMENTS

FROM DEMOLITION SITE TO CONSTRUCTION SITE

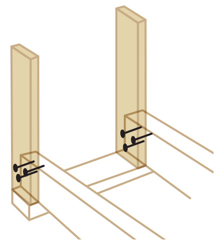
The strategy is to deconstruct the elements as complete as possible with the simplest of deconstruction methods, and with as few additional acts as possible to avoid unnecessary working hours on site, to let the main reconditioning of the elements be done at a factory where it can be done with high efficiency and controlled climate conditions (Fiedler, February 22, 2021). The time on the site is being minimised with as little disturbance to the area as possible.

The first step is the identification on how the horisontal construction has been done. Primarily two different construction principles were used when the buildings were assembled (Fiedler, February 22, 2021). One where the sill is positioned on the concrete base with the floor joists below (type A) and one where the wall joists are fixed together with the floor joists in the same level (type B. The two types has been confirmed when looking at several drawings on principal solutions of the identified building typology.

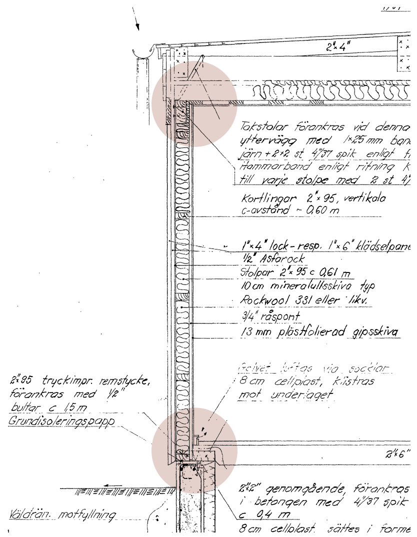
TYPE A

Upper construction:
Usually fixed with a bracket (vinkeljärn).

Bottom construction:
Wall joists are fixed together with the floor joists in the same level



Wall and floor joists attached to each other by nails.



Wall composition (mm):

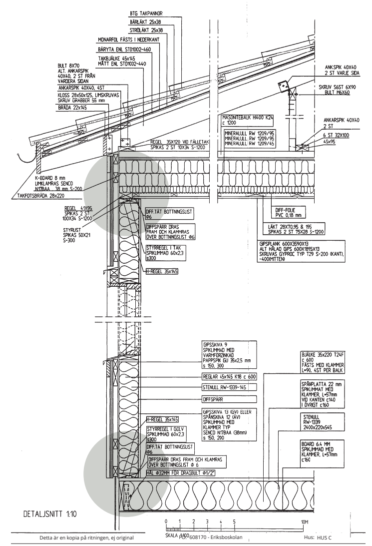
25+25 lockläkt
13 Asfarock
45x95 vertical timber joists cc 610 with100 mineral wool board
17 råspont
13 plastfolierad gypsum board

TYPE B

Upper construction:
Usually fixed with a bracket (vinkeljärn).

Bottom construction:
The sill is positioned on the concrete base with the floor joists below. The sill is fixed tightly with the base with a sill nail (syllspik).

Sill fixed in base with sill nail.

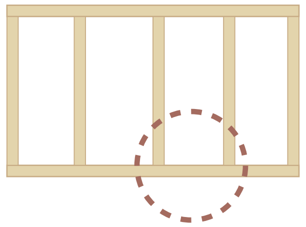


Wall composition (mm):

xx fasadpanel
xx spikläkt
45x145 vertical timber joists cc 600 with 145 Rockwool
vapor layer
13 gypsum board

HORISONTAL DECONSTRUCTION METHOD

Identification of two construction types has led to an investigation of how to best deconstruct these from the roof and base. This has been possible with the aid of previous mentioned actors, Fiedler (Civil engineer), Bennick (RE-USE Consulting), Lindblom (Chalmers workshop) and Carlsson (Derome).



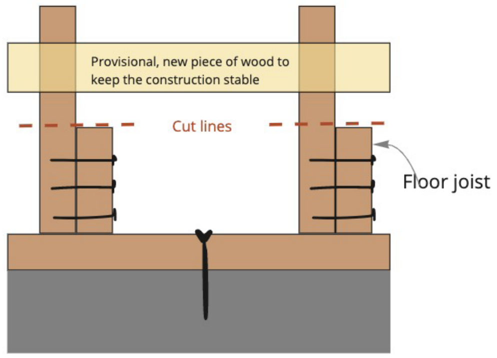
METHOD A

Upper construction:
Identify where the bracket is by sawing a cut along the wall in the inner layer insulation (or heat camera?). Saw loose a fragment of material to reach the bracket unscrew it.

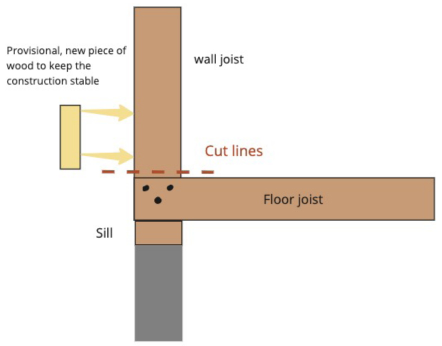
Bottom construction:
The best way to get rid of the sill nail is to:

1. saw the element just above the floor joists by the dotted line

2. screw a provisional pice of wood to make the construction stable until reaching the element factory



Elevation view, deconstruction method type A



Section view, deconstruction method type A

METHOD B

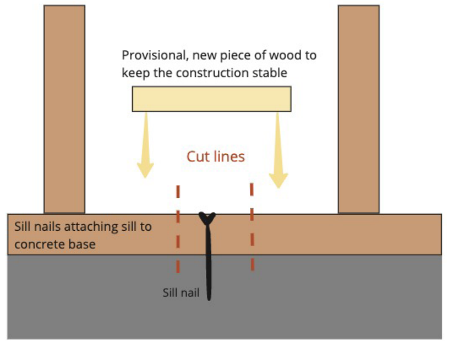
Upper construction:
Same as type A.

Bottom construction:
Identify wether the sill is in good condition, if no, do the same as in type A, otherwise;

1. Identify where the sill nails are by sawing a cut along the wall in the inner layer insulation, in order to find them.

2. Cut out the piece of the sill that is fixed into the base to detach them from each other

3. screw a provisional pice of wood to make the construction stable until reaching the element factory



Elevation view, deconstruction method type B

It might also be possible to cut under the sill, if it is done in the same time as the crane is fixed in the element to be transported away. Then the wall element could be leaned in order to access the fixing between the sill and bolt. Nothing else is being removed from the elements as surface layers and such, the surface layers will have to be replaced later, but can serve as protective layers during transportation.

An element of 3,6 meters weighs approximately 600 kg and would need a truck with crane to be lifted.

The elements are driven to a prefab/reconditioning factory where they are stored until a matching order gets in and the element is ready to be reconditioned for its new purpose.

A crane truck is needed to lift and transport the element.

ACCOMPLISHMENT OF THE NEW ELEMENT

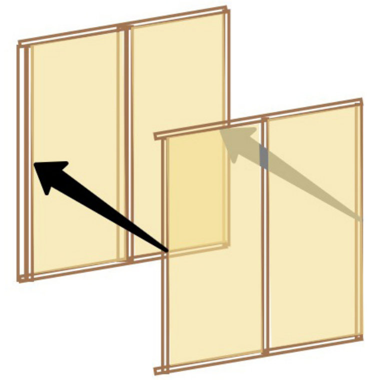
Once the new requirements for the elements are known (an order), the removal of old layers, reconditioning and the adding of new layers starts.

The old facade is replaced only if needed.
The inner layer of insulation and plastic film (if existing) have to be removed for two reasons:
the insulation can cause smell
the vapour layer can cause problem if it gets located in the wrong part of the wall structure (positioned closer to the outdoor than indoor) which might be the case when adding layers on the inside

This means, an additional new layer is added to the interior side of the element to reach todays U-value requirements. To avoid adding a new vapour layer of plastic to the element, the new insulation could be a cellulose based insulation material.

A suggestion along the way has been to ad a massive timber board to the interior of the element, but it would make the solution being indefensibly expensive.

Windows and doors
The first choice is to utilise the same windows and placements of these. New windows and doors can though easily be added by cutting a new hole & setting up new joists (InFutureWood 2020, p. 54). Holes from removed windows can easily be eliminated by filling the gap with a fragment of wind board and insulation.



An additional new layer of studs and insulation is added to the existing element to reach a sufficient U-value

APPENDIX C. LCA

INPUT ASSUMPTIONS

• Facade paints are not considered in the LCA or cost calculations.
• Organic insulation or vapour-open vapour layers does not exist in *Sektionsfakta* nor in *BM 1.0* and has been replaced with mineral wool and vapour layer in both the LCA and cost calculation.
• Cedar shingles are not in *Sektionsfakta*, instead the construction costs are based on a normal wooden cladding.

Density vapor layer: https://oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=99792cbc-c5f4-4d2d-bc9e-3790509891a0&version=20.20.010&stock=OBD_2021_I&lang=en

Virkesåtgång: https://www.svenskttra.se/bygg-med-tra/byggande/virkesatgang/

Density roof tin sheets: https://www.dinbyggare.se/plattak-om-takplat/

Density mineral wool: https://www.rockwool.se/produkter/byggisolering/flexibatts-1/?selectedCat=dokumentation#Tekniskaegenskaper&sortiment

Density roof felt paper: https://oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=64da45fc-f415-4875-8a4e-7c23fe7a7aa9&version=20.20.010&stock=OBD_2021_I&lang=en

Material cost cedar shingles: https://www.byggmax.se/cedersp%C3%A5n-3-10mm-k%C3%A4rnsund-p611052#267=35063

Density Västkustskiva: https://www.beijerbygg.se/privat/sv/produkter/byggmaterial/isolering/stenull/v%C3%A4stkustskiva

Density wood fiber insulation: https://hunton.se/produkter/vagg/hunton-nativo-trafiberisolering-skivor/

Density Cembrit: https://materialmannen.se/hus-bygg/bygg/skivmaterial/cementbaserade-skivor/boacembrit-cemrit-multi-force-byggskiva/boacembrit-cembrit-multi-force-normal-12x1200x2550-mm

Density ceder shingles (area): https://www.byggshop.se/bygg/byggmaterial/tra-och-virke/ytterpanel/cederspan-karnsund-wood-link-3-10mm/p-822988

Density ceder shingles (weight): https://www.byggmax.se/cedersp%C3%A5n-3-10mm-k%C3%A4rnsund-p611052#267=35063

Density OSB: https://materialmannen.se/hus-bygg/bygg/skivmaterial/span-osb-skivor/osb-skivor/ljungberg-fritzoe-osb-klass-3-conti-zero/ljungberg-fritzoe-osb-3-conti-zero-11x2500x1200-3-m2-60

BM 1.0

Klimatredovisning: Bef. tak Jungmansgatan

Baserat på metodik enligt EN 15804 och EN 15978

Resurssammanställning (exklusive transporter inklusive spill), A1-A3 + A5.1

Kalkylresurs eget namn	Kalkylresursens SBE namn	Spill, %	Eget spill, %	Vikt, kg	Energi, MJ	Klimatpåverkan, kg CO2e	Andel av totala klimatpåverkan A1-3 + A5.1 per resurs	Byggdel
Takplåt, förzinkad (IVL LCR)	Takplåt, förzinl	5	5	12420		25983.64	48.08%	43 - Taktäckning
Ljudabsorbent, bullerskiva, akustiktak, -\	Ljudabsorbent	5	5	9933		16663.52	30.84%	43 - Taktäckning
Underlagspapp bitumen (IVL LCR)	Underlagspapp	5	5	13500		8748.62	16.19%	43 - Taktäckning
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	10	35759		2067.07	3.83%	43 - Taktäckning
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	10	9933		574.18	1.06%	41 - Takstomme

Klimatredovisning: Bef. tak Jungmansgatan

Baserat på metodik enligt EN 15804 och EN 15978

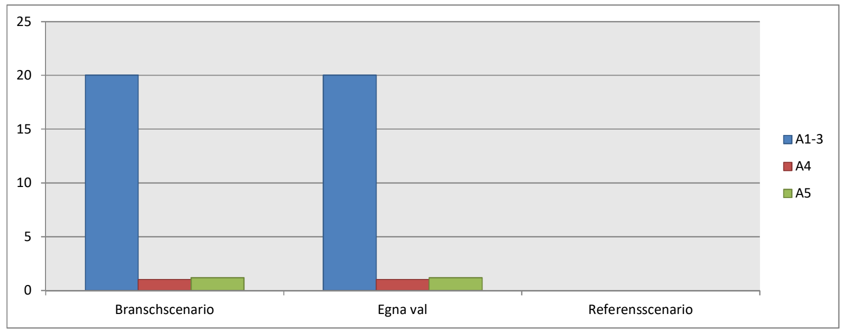
Klimatpåverkan för A1-5 Byggskedet, kg CO_2e per m²

Scenarion

Branschscenariot innehåller branschgemensamma transportavstånd, spill och miljödata för generiska produkter. Under "egna val" har mer specifika data valts. Referensscenariot sätts om det "egna valets" resultatet ska jämföras med ett valbart referensvärde eller kravvärde. Referensscenariot beskrivs av den som gör klimatredovisningen, se textruta till höger.

Nyckeltal

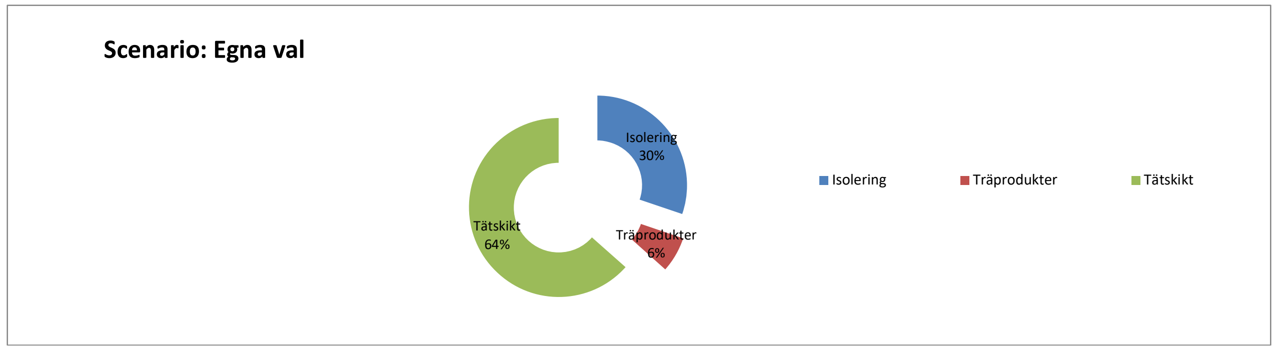
0% Andel EPD:er i förhållande till generiska resurser i scenariot "Egna val"
0% Klimatreduktion "Branschsc." i förhållande till "Egna val"
####### Klimatreduktion "Referenssc." i förhållande till "Egna val"



Klimatpåverkan (GWP GHG), kg CO_2e per m² BTA	Branschscenario	Egna val	Referensscenario
A1-3 Produktskedet	20.02	20.02	
A4 Transport	1.02	1.02	
A5 Bygg- och installationsprocessen	1.19	1.19	
A5.1 Spill, emballage och avfallshantering	*1.19*	*1.19*	
A5.2 Byggarbetsplatsens fordon, maskiner och apparater			
A5.3 Energi till tillfälliga bodar, kontor, förråd och andra byggnad			
A5.4 Byggprocessens övriga energivaror			
A5.5 Övrig miljöpåverkan från byggprocessen			
Summa A1-A5 (kg CO_2e per m²)	22.24	22.24	0
Summa A1-A5 (kg CO_2e)	56634.29	56634.29	0

Beskrivning av referensscenariot

Klimatpåverkan för alla byggresurser, A1-5, kg CO_2e per m²



Part of BM 1.0 results for the existing roof at Jungmansgatan.

Klimatredovisning: Biskopsgatans förskola

Baserat på metodik enligt EN 15804 och EN 15978

Resurssammanställning (exklusive transporter inklusive spill), A1-A3 + A5.1								
Kalkylresurs eget namn	Kalkylresursens SBE namn	Spill, %	Eget spill, %	Vikt, kg	Energi, MJ	Klimatpåverkan, kg CO2e	Andel av totala klimatpåverkan A1-3 + A5.1 per resurs	Byggdel
Stenull (IVL RR)	Stenull (IVL RR	5	5	4016.5		4790.04	48.86%	31 - Väggar
Fönster, tre glas, trä-/aluminium (IVL LC	Fönster, tre gl	0	0	2892.8		3211.01	32.76%	31 - Väggar
Gipsskivor, Brand	Gipsskivor, Bra	12	0	3240.9		1225.06	12.50%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	0	2883		158.57	1.62%	31 - Väggar
Porös board (impregnerad) typ Asfaboa	Porös board (i	10	0	573.39		126.15	1.29%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	0	1902.7		104.65	1.07%	31 - Väggar
Plastfolier (IVL LCR)	Plastfolier (IVL	5	0	55.4		100.24	1.02%	31 - Väggar
Ytterdörrar, trä (IVL LCR), ca 24 kg/m2	Ytterdörrar, trä	0	0	240		55.68	0.57%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	0	571.5		31.43	0.32%	31 - Väggar
						9747.15		

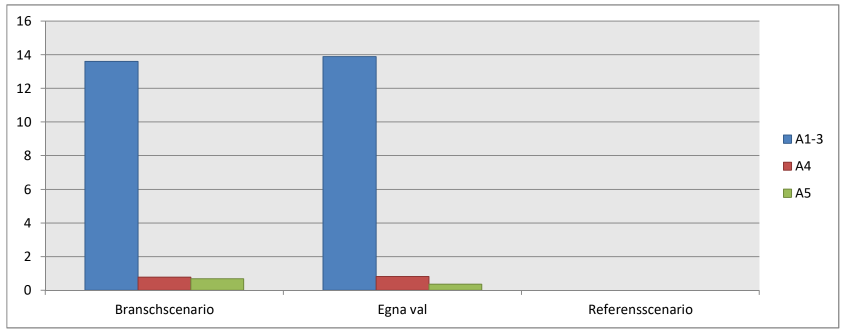
Klimatredovisning: Biskopsgatans förskola

Baserat på metodik enligt EN 15804 och EN 15978

Klimatpåverkan för A1-5 Byggskedet, kg CO_2e per m²

Scenarion

Branschscenariot innehåller branschgemensamma transportavstånd, spill och miljödata för generiska produkter. Under "egna val" har mer specifika data valts. Referensscenariot sätts om det "egna valets" resultatet ska jämföras med ett valbart referensvärde eller kravvärde. Referensscenariot beskrivs av den som gör klimatredovisningen, se textruta till höger.



Nyckeltal

0% Andel EPD:er i förhållande till generiska resurser i scenariot "Egna val"

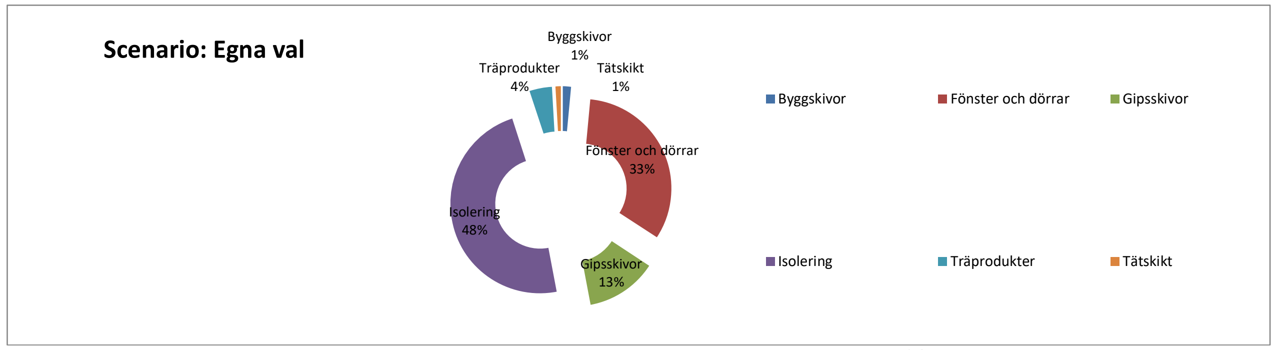
0% Klimatreduktion "Branschsc." i förhållande till "Egna val"

####### Klimatreduktion "Referenssc." i förhållande till "Egna val"

Klimatpåverkan (GWP GHG), kg CO₂e per m² BTA	**Branschscenario**	**Egna val**	**Referensscenario**
A1-3 Produktskedet	13.62	13.91	
A4 Transport	0.79	0.83	
A5 Bygg- och installationsprocessen	0.69	0.36	
A5.1 Spill, emballage och avfallshantering	*0.69*	*0.36*	
A5.2 Byggarbetsplatsens fordon, maskiner och apparater			
A5.3 Energi till tillfälliga bodar, kontor, förråd och andra byggnad			
A5.4 Byggprocessens övriga energivaror			
A5.5 Övrig miljöpåverkan från byggprocessen			
Summa A1-A5 (kg CO₂e per m²)	15.11	15.1	0
Summa A1-A5 (kg CO₂e)	10378.76	10374.55	0

Beskrivning av referensscenariot

Klimatpåverkan för alla byggresurser, A1-5, kg CO_2e per m²



Part of BM 1.0 results for the existing roof at Biskopsgatan's preschool.

Klimatredovisning: Lägenhet Jungmansgatan reuse, new mate

Baserat på metodik enligt EN 15804 och EN 15978

Resurssammanställning (exklusive transporter inklusive spill), A1-A3 + A5.1								
Kalkylresurs eget namn	Kalkylresursens SBE namn	Spill, %	Eget spill, %	Vikt, kg	Energi, MJ	Klimatpåverkan, kg CO2e	Andel av totala klimatpåverkan A1-3 + A5.1 per resurs	Byggdel
Fibercementskivor (IVL LCR)	Fibercementsk	10	10	541		228,41	40,87%	31 - Väggar
Sågad Ceder från Nordamerika, branskyc	Sågad Ceder fr	10	10	88,6		153,72	27,51%	31 - Väggar
Stenull (IVL RR)	Stenull (IVL RR	5	5	68,6		81,81	14,64%	31 - Väggar
OSB-skivor (Flakeboard), 600 kg/m3	OSB-skivor (Fla	10	10	258,7		45,53	8,15%	31 - Väggar
Cellulosaisolering	Cellulosaisoleri	5	5	137,2		26,42	4,73%	31 - Väggar
Plastfolier (IVL LCR)	Plastfolier (IVL	5	5	7,8		14,14	2,53%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	10	104,6		6,05	1,08%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	10	48,2		2,79	0,50%	31 - Väggar

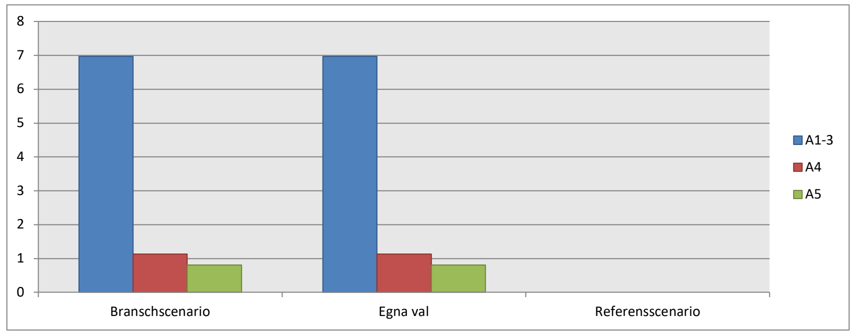
Klimatredovisning: Lägenhet Jungmansgatan reuse, new m

Baserat på metodik enligt EN 15804 och EN 15978

Klimatpåverkan för A1-5 Byggskedet, kg CO_2e per m²

Scenarion

Branschscenariot innehåller branschgemensamma transportavstånd, spill och miljödata för generiska produkter. Under "egna val" har mer specifika data valts. Referensscenariot sätts om det "egna valets" resultatet ska jämföras med ett valbart referensvärde eller kravvärde. Referensscenariot beskrivs av den som gör klimatredovisningen, se textruta till höger.



Nyckeltal

0% Andel EPD:er i förhållande till generiska resurser i scenariot "Egna val"

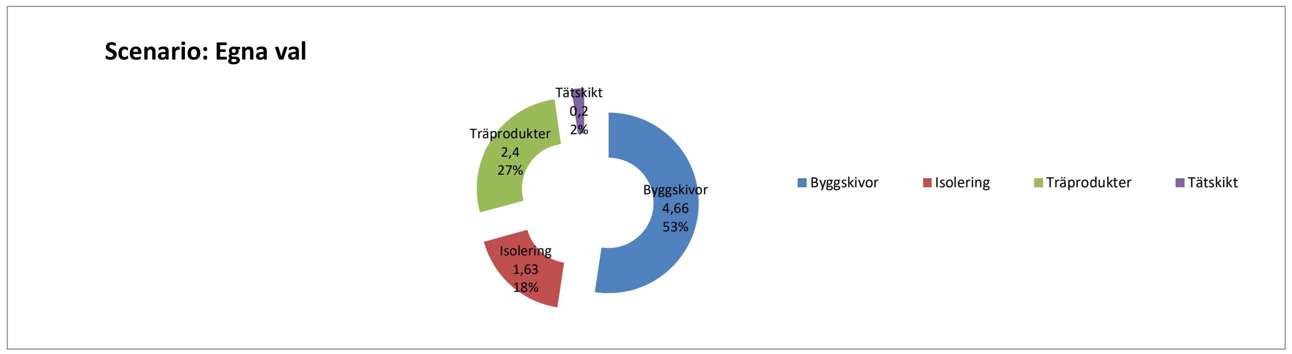
0% Klimatreduktion "Branschsc." i förhållande till "Egna val"

#DIV/0! Klimatreduktion "Referenssc." i förhållande till "Egna val"

Klimatpåverkan (GWP GHG), kg CO₂e per m² BTA	**Branschscenario**	**Egna val**	**Referensscenario**
A1-3 Produktskedet	6,96	6,96	
A4 Transport	1,13	1,13	
A5 Bygg- och installationsprocessen	0,8	0,8	
A5.1 Spill, emballage och avfallshantering	*0,8*	*0,8*	
A5.2 Byggarbetsplatsens fordon, maskiner och apparater			
A5.3 Energi till tillfälliga bodar, kontor, förråd och andra byggnad			
A5.4 Byggprocessens övriga energivaror			
A5.5 Övrig miljöpåverkan från byggprocessen			
Summa A1-A5 (kg CO₂e per m²)	8,89	8,89	0
Summa A1-A5 (kg CO₂e)	640,28	640,28	0

Beskrivning av referensscenariot

Klimatpåverkan för alla byggresurser, A1-5, kg CO_2e per m²



Part of BM 1.0 results for the additional layers in the upcycled alternative of the 1 bedroom apartment at Jungmansgatan.

Klimatredovisning: Lägenhet Jungmansgatan, allt nytt

Baserat på metodik enligt EN 15804 och EN 15978

Resurssammanställning (exklusive transporter inklusive spill), A1-A3 + A5.1								
Kalkylresurs eget namn	Kalkylresursens SBE namn	Spill, %	Eget spill, %	Vikt, kg	Energi, MJ	Klimatpåverkan, kg CO2e	Andel av totala klimatpåverkan A1-3 + A5.1 per resurs	Byggdel
Fönster, tre glas, trä-/aluminium (IVL LC	Fönster, tre gl	0	0	273		303,03	30,97%	31 - Väggar
Gipsskivor, Brand	Gipsskivor, Bra	12	12	458,6		175,42	17,93%	31 - Väggar
Stenull (IVL RR)	Stenull (IVL RR	5	5	137,2		163,62	16,72%	31 - Väggar
Sågad Ceder från Nordamerika, branskyc	Sågad Ceder fr	10	10	88,6		153,72	15,71%	31 - Väggar
Cellulosaisolering	Cellulosaisoleri	5	5	333,2		64,17	6,56%	31 - Väggar
OSB-skivor (Flakeboard), 600 kg/m3	OSB-skivor (Fla	10	10	258,7		45,53	4,65%	31 - Väggar
Cellulosaisolering	Cellulosaisoleri	5	5	88,2		16,99	1,74%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	10	254		14,68	1,50%	31 - Väggar
Plastfolier (IVL LCR)	Plastfolier (IVL	5	5	7,8		14,14	1,44%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	10	204		11,79	1,21%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	10	112,9		6,53	0,67%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	10	86		4,97	0,51%	31 - Väggar
Furu/gran, hyvlad & sågad, 473 kg/m3 u	Furu/gran, hyv	10	10	67,2		3,88	0,40%	31 - Väggar

Klimatredovisning: Lägenhet Jungmansgatan, allt nytt

Baserat på metodik enligt EN 15804 och EN 15978

Klimatpåverkan för A1-5 Byggskedet, kg CO_2e per m^2

Scenarion

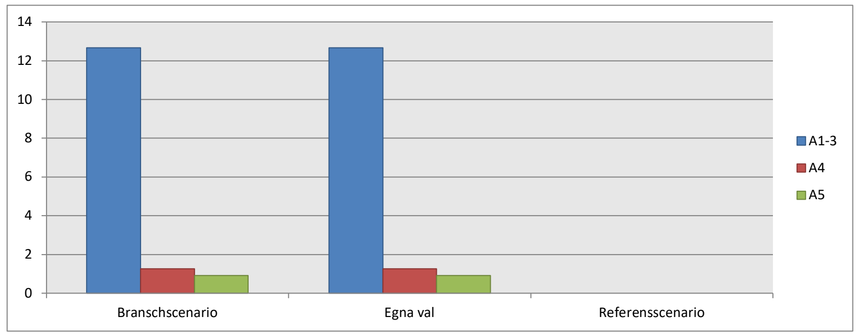
Branschscenariot innehåller branschgemensamma transportavstånd, spill och miljödata för generiska produkter. Under "egna val" har mer specifika data valts. Referensscenariot sätts om det "egna valets" resultatet ska jämföras med ett valbart referensvärde eller kravvärde. Referensscenariot beskrivs av den som gör klimatredovisningen, se textruta till höger.

Nyckeltal

0% Andel EPD:er i förhållande till generiska resurser i scenariot "Egna val"

0% Klimatreduktion "Branschsc." i förhållande till "Egna val"

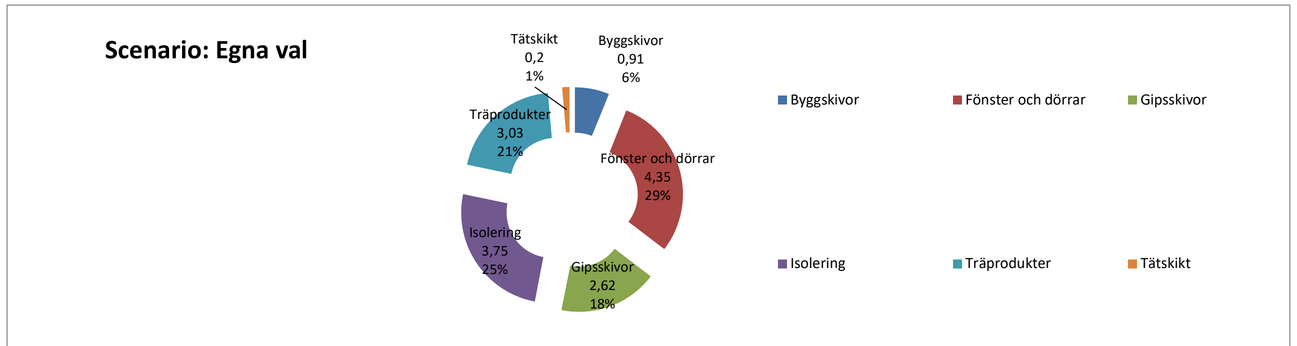
#DIV/0! Klimatreduktion "Referenssc." i förhållande till "Egna val"



Klimatpåverkan (GWP GHG), kg CO_2e per m^2 BTA	Branschscenario	Egna val	Referensscenario
A1-3 Produktskedet	12,67	12,67	
A4 Transport	1,27	1,27	
A5 Bygg- och installationsprocessen	0,92	0,92	
A5.1 Spill, emballage och avfallshantering	*0,92*	*0,92*	
A5.2 Byggarbetsplatsens fordon, maskiner och apparater			
A5.3 Energi till tillfälliga bodar, kontor, förråd och andra byggnad			
A5.4 Byggprocessens övriga energivaror			
A5.5 Övrig miljöpåverkan från byggprocessen			
Summa A1-A5 (kg CO_2e per m^2)	14,86	14,86	0
Summa A1-A5 (kg CO_2e)	1070,19	1070,19	0

Beskrivning av referensscenariot

Klimatpåverkan för alla byggresurser, A1-5, kg CO_2e per m^2



Part of BM 1.0 results for all new materials of the 1 bedroom apartment at Jungmansgatan.

APPENDIX D. CALCULATIONS

	Amount	Unit	Material cost [SEK/unit]	Construction cost [SEK/unit]	Total cost [SEK/unit]	Material cost [SEK]	Construction cost [SEK]	Total cost [SEK]
Windows	57	pcs	6225,9	3185,8	9411,7	354877	181590	536467
Doors	5	pcs	8015,0	4392,9	12407,9	40075	21964	62039
Wooden facade panel "lockläkt"	277	m2	203,1	394,3	597,4	56259	109227	165485
Läkt 28x70 mm cc 600	616,5	m	29,4	71,0	100,4	18125	43758	61883
Asfaboard 9 mm	277	m2	41,6	102,5	144,1	11523	28399	39922
Timber studs 145x45 mm cc 600	616,5	m2	72,45	220,8	293,3	44665	136135	180800
Stone wool insulation 145 mm	277	m2	70,6	63,1	133,7	19556	17476	37032
Vapor layer	277	m2	7,3	63,1	70,4	2022	17476	19498
Gypsum board 13 mm	277	m2	61,2	181,4	242,6	16952	50244	67197
Sill (7.054)	137	m	55,5	118,3	173,8	7604	16207	23811
Total [SEK]								1194135
	Thickness [m]	**Area [m2]**	**Volume [m3]**	**Density [kg/m2]**	**Density [kg/m3]**	**Total weight [kg]**		
Windows		82,65		35		2892,8		
Doors		10		24		240,0		
Wooden facade panel "lockläkt"	0,022	277	6,1		473	2882,5		
Läkt 28x70 mm cc 600			1,20834		473	571,5		
Asfaboard 9 mm	0,009	277	2,493		230	573,4		
Timber studs 145x45 mm cc 600			4,0226625		473	1902,7		
Stone wool insulation 145 mm	0,145	277	40,165	-	100	4016,5		
Vapor layer		277		0,2		55,4		
Gypsum board 13 mm	0,013	277	3,601	11,7		3240,9		

Cost calculations and input for LCA, Biskopsgatan 8.

	Amount	Unit	Material cost [SEK/unit]	Construction cost [SEK/unit]	Total cost [SEK/unit]	Material cost [SEK]	Construction cost [SEK]	Total cost [SEK]
Windows (16.018)	57	pcs	6225,91	3185,79	9411,7	354877	181590	536467
Doors (16.03X)	4	pcs	8014,99	4392,88	12407,87	32060	17572	49631
Sill (7.054)	141	m	55,5	118,3	173,8	7826	16680	24506
Wall (7.004)	309	m2	433,75	1642,49	2076,24	134029	507529	641558
Total						528791	723371	1252162
	Thickness [m]	**Area [m2]**	**Volume [m3]**	**Density [kg/m2]**	**Density [kg/m3]**	**Total weight [kg]**		
Windows		64,4		35,0	-	2254,4		
Doors		8,0		24,0	-	192,0		
Wood facade panel "lockpanel"	0,022	326,3	7,2	-	473,0	3395,5		
Läkt 28x70 mm cc 600			1,2	-	473,0	588,2		
Asfaboard 9 mm	0,009	309,0	2,8		230,0	639,6		
Timber studs 145x45 mm cc 600			4,1	-	473,0	1958,3		
Stone wool insulation 145 mm	0,145	309,0	44,8	-	100,0	4480,5		
Vapor layer		309,0		0,2		61,8		
Gypsum board 13 mm	0,013	309,0	4,0	11,7		3615,3		

Cost calculations and input for LCA, Eriksboskolan building C.

	Amount	Unit	Material cost [SEK/unit]	Construction cost [SEK/unit]	Total cost [SEK/unit]	Material cost [SEK]	Construction cost [SEK]	Total cost [SEK]
Roof incl. rafters (11.003)	2547	m2	272,7	546,2	1644,0	694592	1391286	4187153
Roof tin sheets	2700	m2			825			2227500
Roof felt paper	2700	m2	26,4	55,2	81,6	71280	149053	
Tongue-and-groove panel	2700	m2	89,8	142,0	231,8	242460	383279	
Rafters	210	pcs	85,91	268,1	354,0	18041	56309	
Mineral wool	2547	m2	70,6	80,9	151,5	179818	206173	
	Thickness [m]	**Area [m2]**	**Volume [m3]**	**Density [kg/m2]**	**Density [kg/m3]**	**Total weight [kg]**		
Roof tin sheets		2700		4,6	-	12420		
Roof felt paper	0,002	2700		5		13500		
Tongue-and-groove panel	0,028	2700	75,6		473	35759		
Rafters			21		473	9933		
Mineral wool	0,13	2547	331,11		30	9933		

Cost calculations and input for LCA, existing roof Jungmansgatan.

	Amount	Unit	Material cost [SEK/unit]	Construction cost [SEK/unit]	Total cost [SEK/unit]	Material cost [SEK]	Construction cost [SEK]	Total cost [SEK]	Material cost [SEK/m2 BTA]	Construction cost [SEK/m2 BTA]	Total cost [SEK/m2 BTA]
Existing											
Fönster (16.018)	6	pcs	6226	3186	9412	37355	19115	56470	519	265	784
Vägg (7.004)	39,2	m2	434	1642	2076	17003	64386	81389	236	894	1130
Deconstruction											
Gipsskiva	39,2	m2	0								
Fasadpanel	39,2	m2	0								
Spikläkt	39,2	m2	0								
Additions											
Cedar shingles	19,6	m2	799	552	1351	15660	10820	26481	218	150	368
Sill (7.054)	15,6	m	56	118	174	866	1845	2711	12	26	38
Insulation board 50 mm (IBE.24)	39,2	m2	30	55	85	1172	2164	3336	16	30	46
Studs service layer 70x45 mm (HSD.113)	39,2	m2	50	221	270	1944	8656	10600	27	120	147
Wood fiber insulation service layer 70 mm (IBE.24)	39,2	m2	44	63	107	1725	2473	4198	24	34	58
2 x Cembrit (KBB.21)	39,2	m2	114	355	469	4484	13912	18396	62	193	256
Total						25852	39871	65722	359	554	913
Doors											
Exterior door (16.039+Brattöns återbruk)	1	pcs	400	3431	3831	400	3431	3831	6	48	53
Interior door (16.xxx+Brattöns+Kompanjonen)	2	pcs	1245	1065	2310	2490	2129	4619	35	30	64
Total						2890	5560	8450	40	77	117

Cost calculations, upcycled walls with reused windows and doors.

	Facade length [m]	Facade area [m2]				
Shingles	7,8	19,6				
Panel	7,8	19,6				
Shingles facade						
	Thickness [m]	**Area [m2]**	**Volume [m3]**	**Density [kg/m2]**	**Density [kg/m3]**	**Total weight [kg]**
Ceder shingles		19,6		4,5		88,6
Västkustskiva 50 mm	0,05	19,6	0,98		70	68,6
Vapor layer		19,6		0,2		3,9
Timber studs 70x45 mm cc 600			0,110565		473	52,3
Wood fibre insulation 70 mm	0,07	19,6	1,372		50	68,6
OSB 11 mm	0,011	19,6	0,2156		600	129,4
Cembrit 12 mm	0,012	19,6	0,2352		1150	270,5
Sill			0,050895		473	24,1
Panel facade						
	Thickness [m]	**Area [m2]**	**Volume [m3]**	**Density [kg/m2]**	**Density [kg/m3]**	**Total weight [kg]**
Vapor layer		19,6		0,2		3,9
Timber studs 70x45 mm cc 600			0,110565		473	52,3
Wood fibre insulation 70 mm	0,07	19,6	1,372		50	68,6
OSB 11 mm	0,011	19,6	0,2156		600	129,4
Cembrit 12 mm	0,012	19,6	0,2352		1150	270,5
Sill 145x45 mm			0,050895		473	24,1

Input for LCA, the new materials for the upcycled walls.

	Amount	Unit	Material cost [SEK/unit]	Construction cost [SEK/unit]	Total cost [SEK/unit]	Material cost [SEK]	Construction cost [SEK]	Total cost [SEK]	Material cost [SEK/m2 BTA]	Construction cost [SEK/m2 BTA]	Total cost [SEK/m2 BTA]
Windows (16.018)	6	pcs	6226	3186	9412	37355	19115	56470	519	265	784
Sill (7.054)	15,6	m	56	118	174	866	1845	2711	12	26	38
Exterior wall (7.019)	39,2	m2	631	1769	2399	24723	69332	94055	343	963	1306
Total						62945	90292	153237	874	1254	2128
Doors											
Exterior door (16.039)	1	pcs	8302	3431	11733	8302	3431	11733	115	48	163
Interior door (16.xxx)	2	pcs	1717	1656	3373	3434	3312	6746	48	46	94
Total						11736	6743	18479	163	94	257

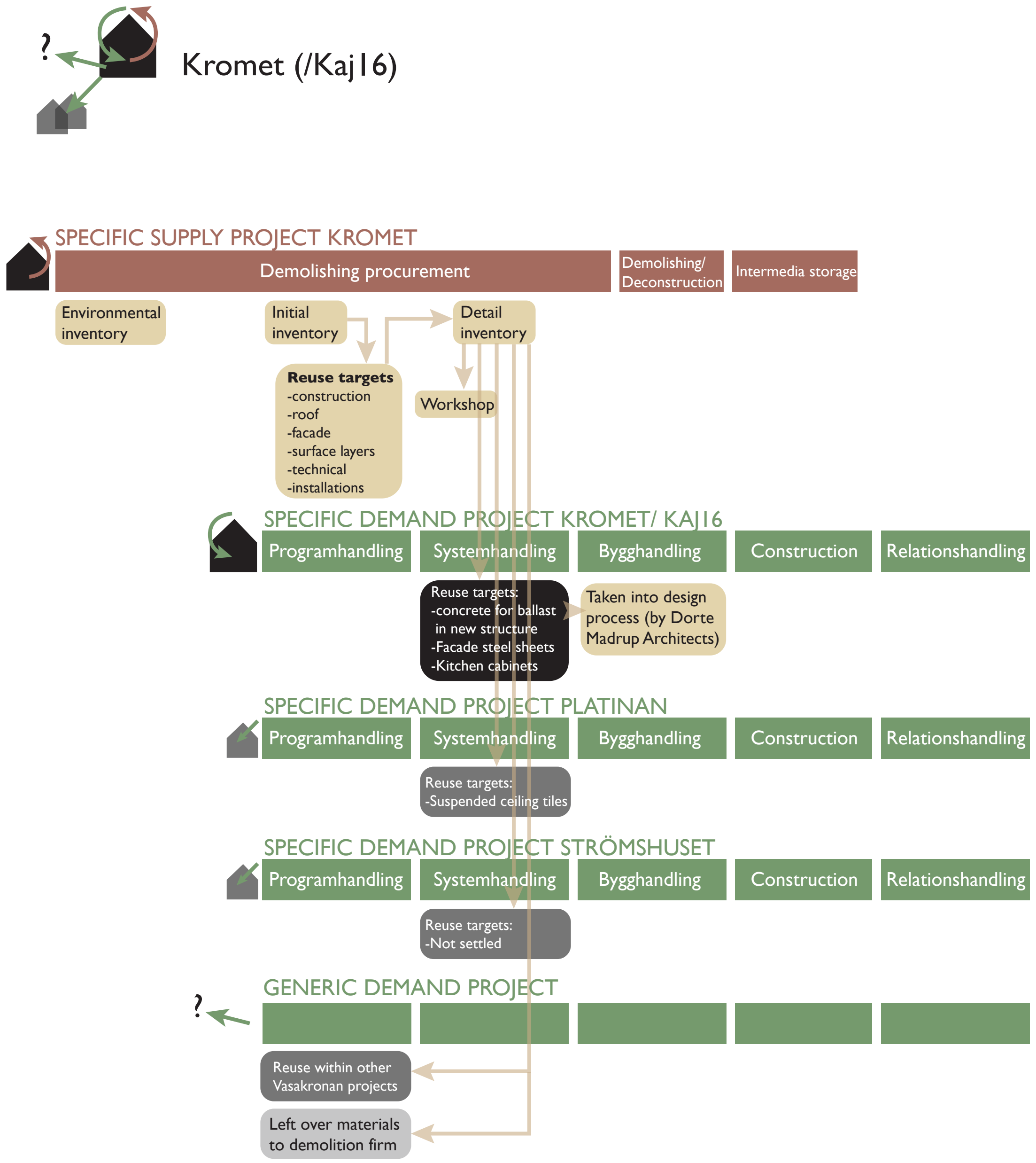
Cost calculations for new walls, windows and doors.

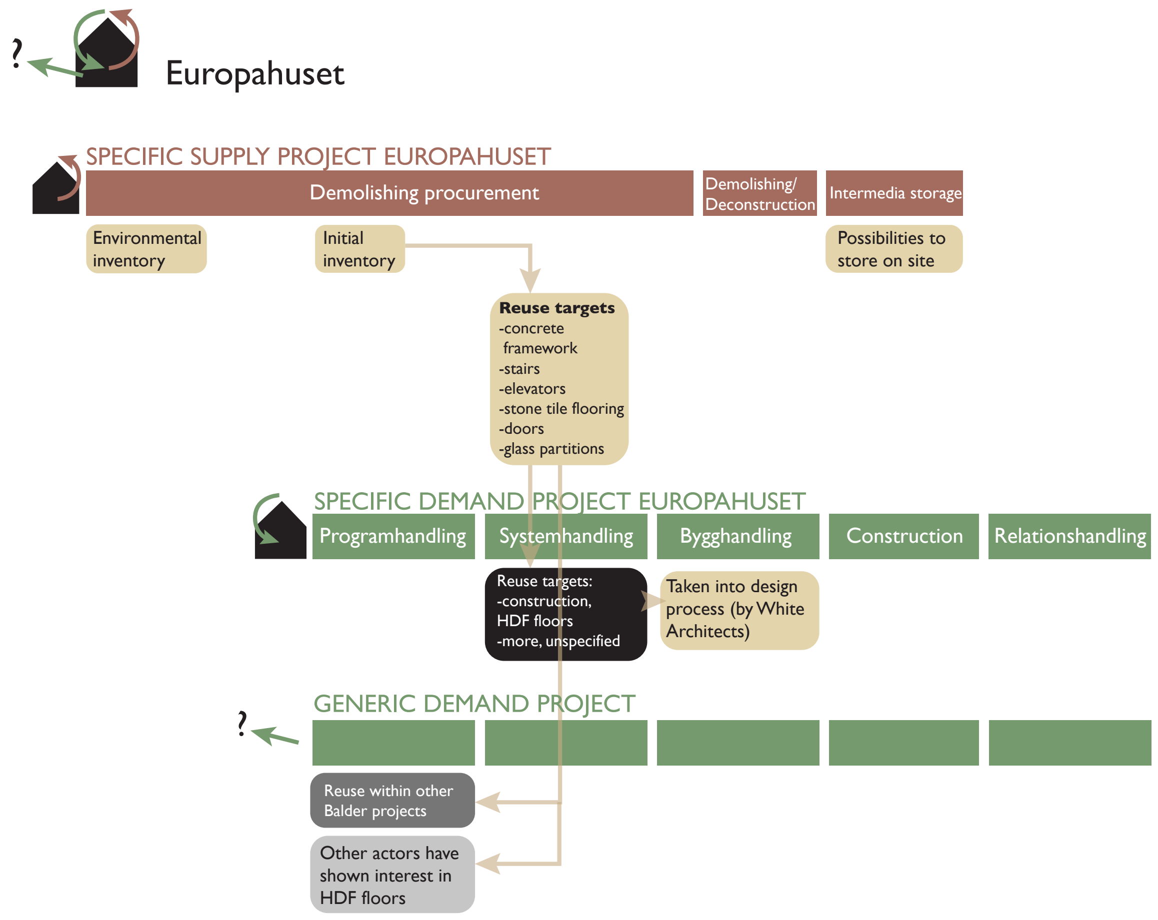
	Thickness	Area [m2]	Volume [m3]	Density [kg/m2]	Density [kg/m3]	Total weight [kg]
Windows		7,8		35	-	273,0
Wood facade panel	0,022	19,6	0,43	-	473	204,0
Shingles facade panel		19,6		4,5		88,6
Läkt 34x70 mm cc 600			0,18	-	473	86,0
Västkustskiva 50 mm	0,05	39,2	1,96		70	137,2
Timber studs 170x45 mm cc 600			0,54	-	473	254,0
Wood fibre insulation 170 mm	0,17	39,2	6,664	-	50	333,2
Vapor layer		39,2		0,2		7,8
Timber studs 45x45 mm cc 600			0,14		473	67,2
Wood fibre insulation 45 mm	0,045	39,2	1,764		50	88,2
OSB 11 mm	0,011	39,2	0,43		600	258,7
Gypsum board 13 mm	0,013	39,2	0,51	11,7		458,6
Sill + wale 170x45 mm			0,23868		473	112,9
Doors						
Exterior door		1,9		24		45,6
Interior doors		3,8		12,6		48

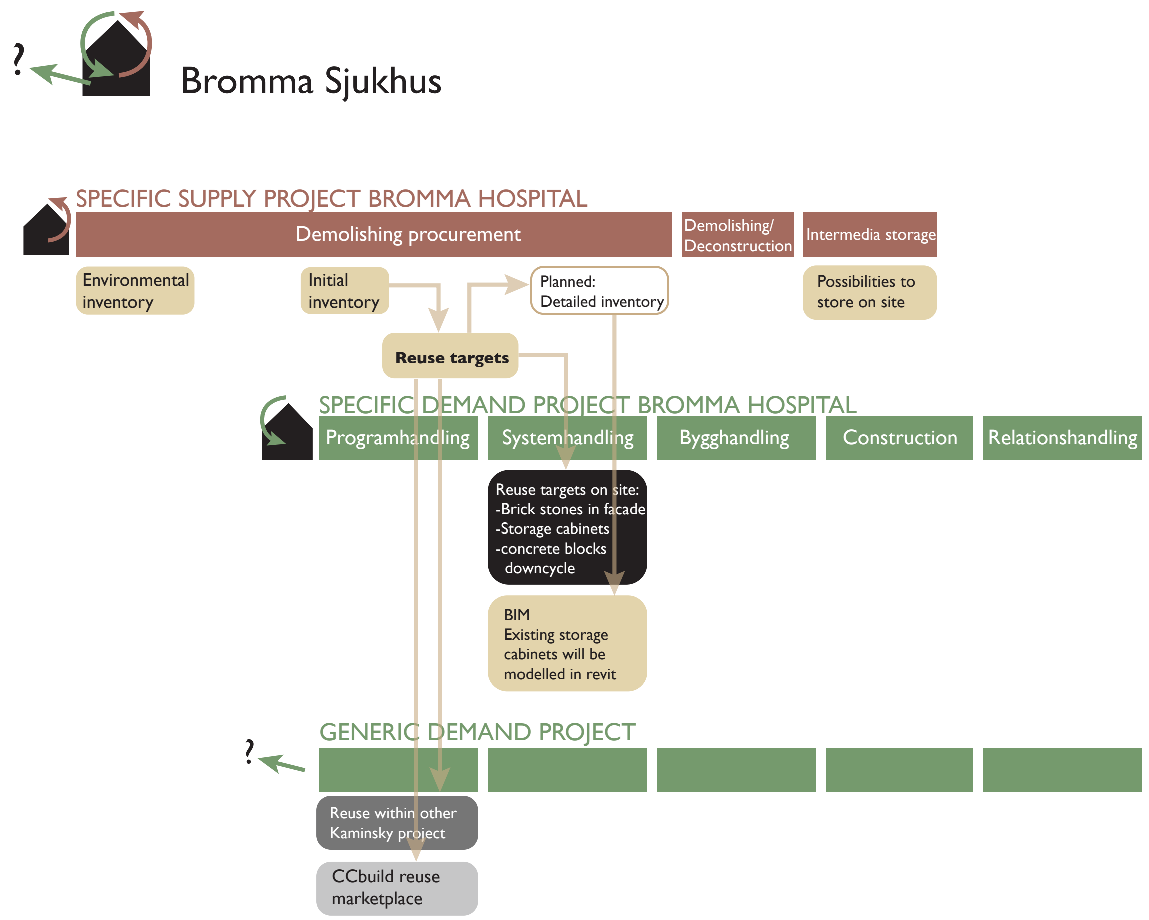
Input for LCA for new walls, windows and doors.

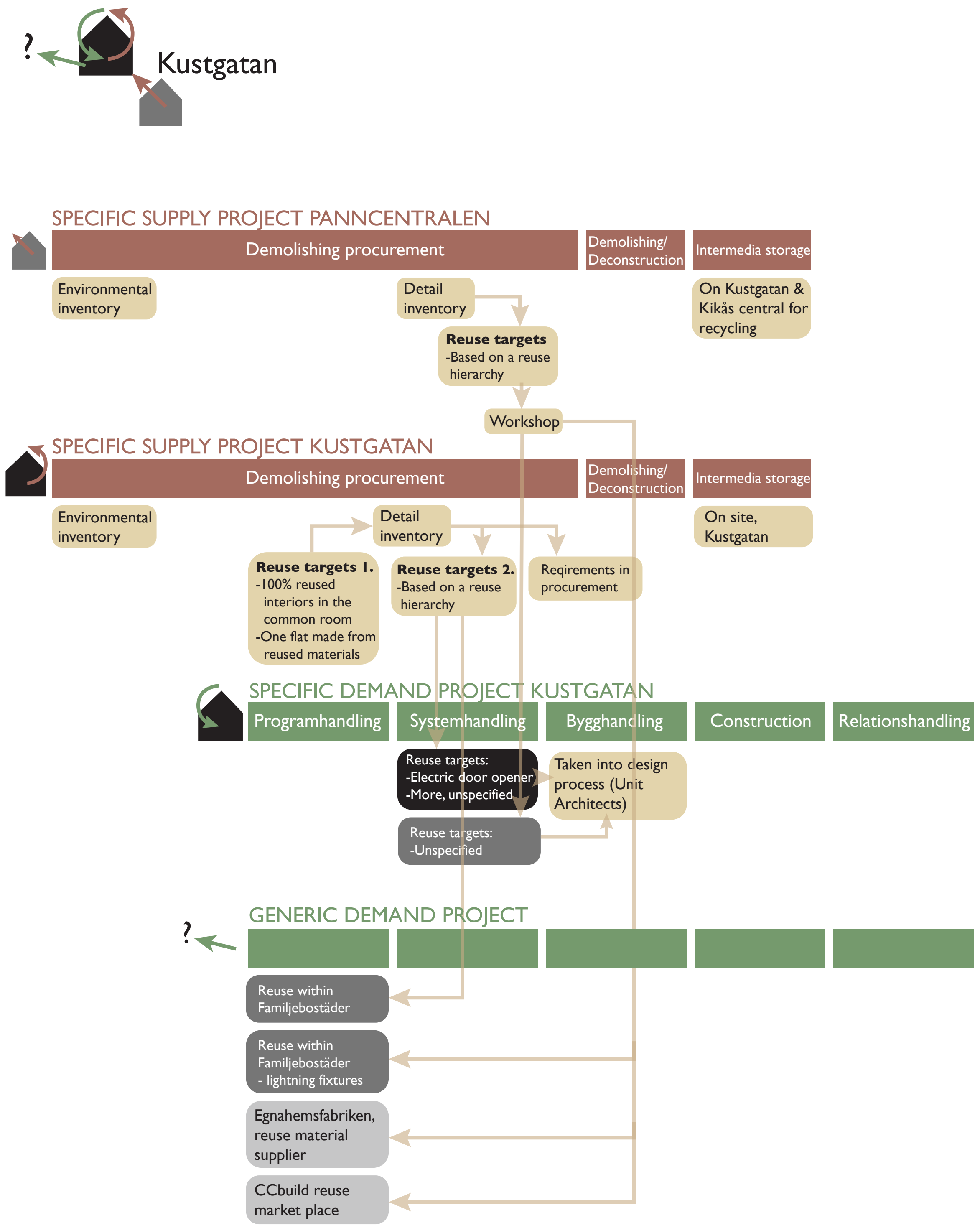
APPENDIX E. REFERENCE PROJECT PROCESS DIAGRAMS

The reuse processes from ongoing projects shred by the actors interviewed were summarised into process diagrams to be compared and analysed. This is what has been the basis of the conclusions made concerning the reuse process and what made it possible to develop the final process diagram that is presented throughout the thesis. The process diagrams presented here are from an early stage but they were not developed further than this as they were sufficient to draw conclusions from.

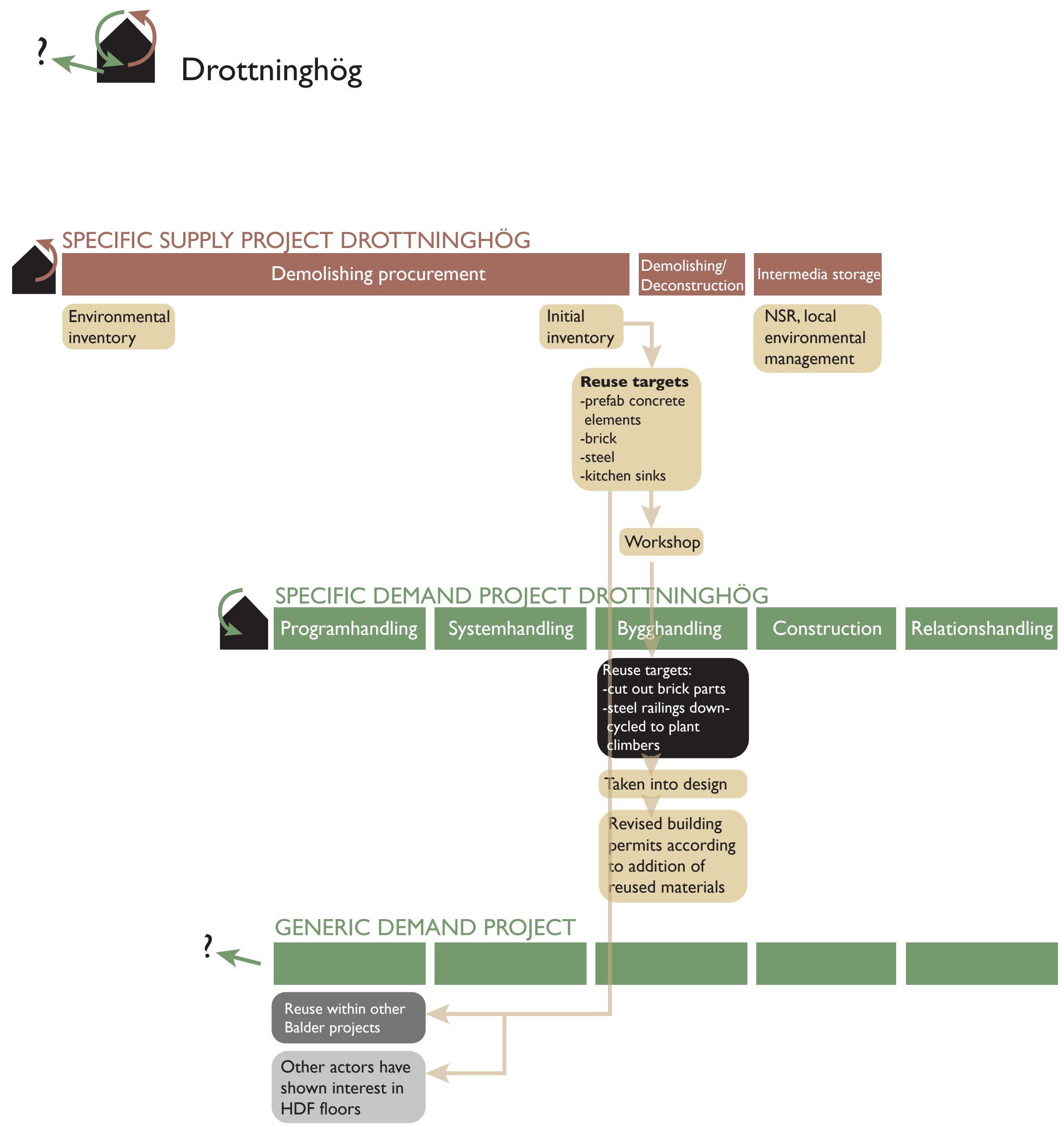






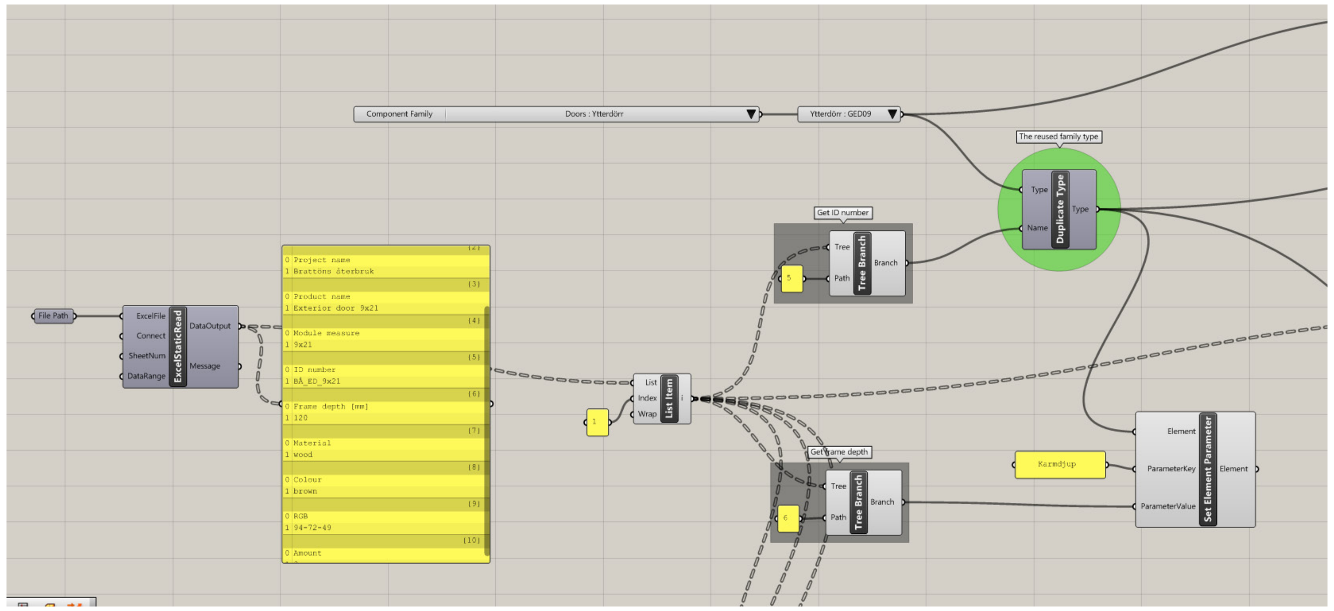


Kustgatan
SPECIFIC SUPPLY PROJECT PANNCENTRALEN
Demolishing procurement
Demolishing/ Deconstruction
Intermedia storage
Environmental inventory
Detail inventory
On Kustgatan & Kikås central for recycling
Reuse targets
-Based on a reuse hierarchy
Workshop
SPECIFIC SUPPLY PROJECT KUSTGATAN
Demolishing procurement
Demolishing/ Deconstruction
Intermedia storage
Environmental inventory
Detail inventory
On site, Kustgatan
Reuse targets 1.
-100% reused interiors in the common room
-One flat made from reused materials
Reuse targets 2.
-Based on a reuse hierarchy
Reqirements in procurement
SPECIFIC DEMAND PROJECT KUSTGATAN
Programhandling
Systemhandling
Bygghandling
Construction
Relationshandling
Reuse targets:
-Electric door opener
-More, unspecified
Taken into design process (Unit Architects)
Reuse targets:
-Unspecified
GENERIC DEMAND PROJECT
Reuse within Familjebostäder
Reuse within Familjebostäder
- lightning fixtures
Egnahemsfabriken, reuse material supplier
CCbuild reuse market place

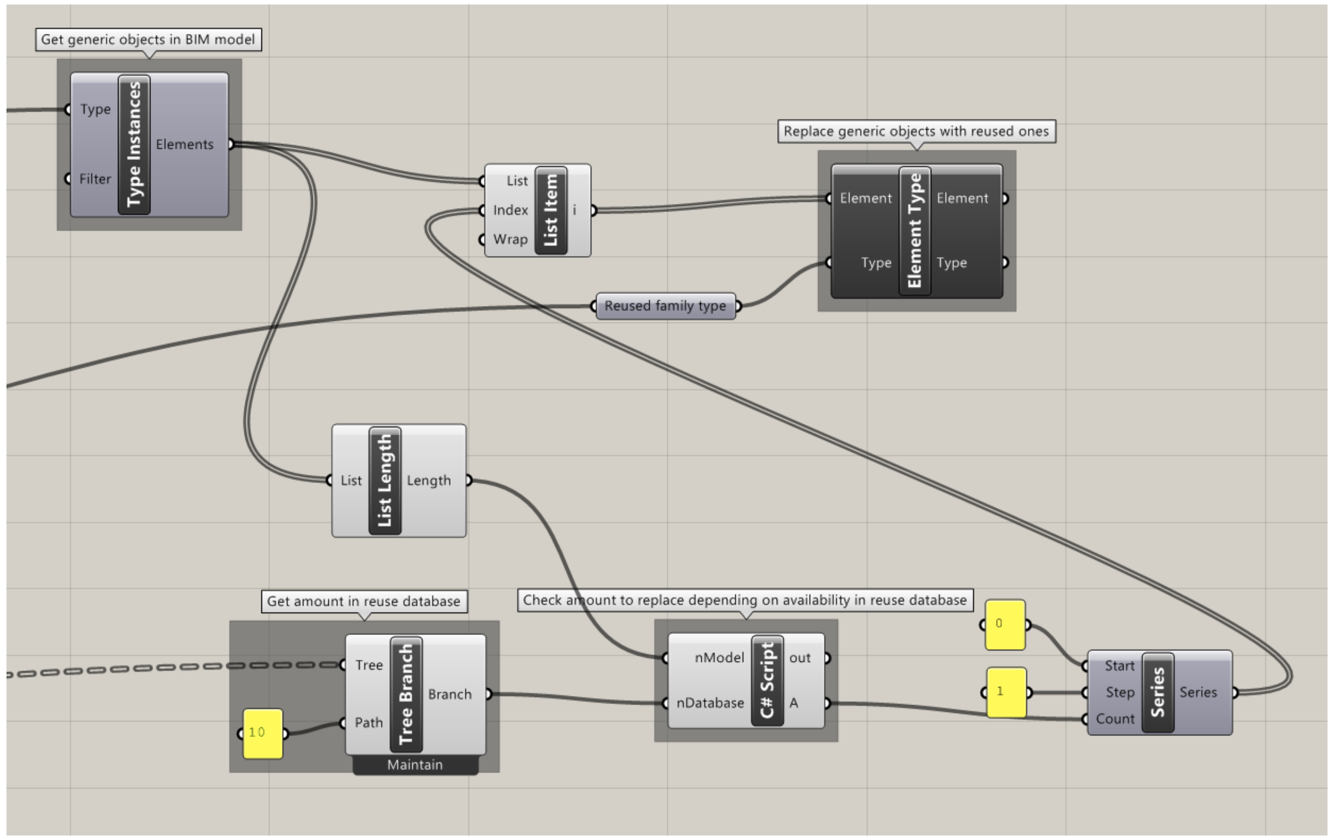


Drottninghög
SPECIFIC SUPPLY PROJECT DROTTNINGHÖG
Demolishing procurement
Demolishing/ Deconstruction
Intermedia storage
Environmental inventory
Initial inventory
NSR, local environmental management
Reuse targets
-prefab concrete elements
-brick
-steel
-kitchen sinks
Workshop
SPECIFIC DEMAND PROJECT DROTTNINGHÖG
Programhandling
Systemhandling
Bygghandling
Construction
Relationshandling
Reuse targets:
-cut out brick parts
-steel railings down-cycled to plant climbers
Taken into design
Revised building permits according to addition of reused materials
GENERIC DEMAND PROJECT
Reuse within other Balder projects
Other actors have shown interest in HDF floors

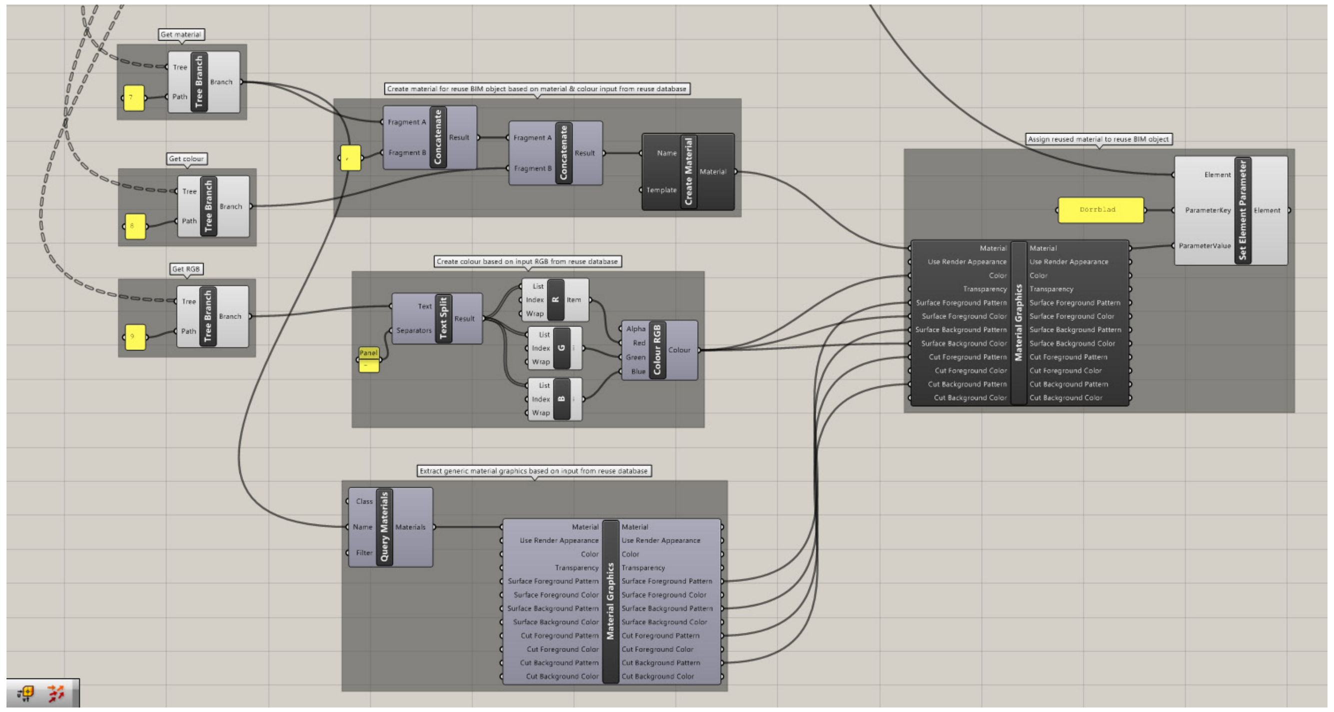
APPENDIX F. TESTING BIM COMPATIBILITY



• Reading in the reuse database (here: an Excel sheet) into Grasshopper.Inside.Revit
• Reading in the generic doors to replace
• Duplicating generic door type to create base for reuse BIM object



• Comparing the amount of generic objects in the BIM model and available objects in the reuse database to replace the right amount of objects.



• Creating a reuse material based on a generic material and input from reuse database.


Welcome to the digital exhibition!