DESIGNING WITH RECLAIMED TIMBER

reusable building elements
for topping-up and social cohesion

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Architectural Wood Graduation Studio
Gilbert Koskamp and Stijn Brancart

This graduation project is the final stage of my Master Architecture at TU Delft. I would like to thank my tutors, Gilbert Koskamp and Stijn Brancart, for their enthusiasm, critical attitude and guidance throughout the past three quarters. I would also like to thank the other tutors and students of the Timber for Urban Density studio. I learned a lot during the past year and greatly enjoyed being part of the studio.

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Timber for Urban Density

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Abstract

The Netherlands is facing a severe housing shortage, while the availability of space for new construction is limited. At the same time, the construction industry is responsible for a large share of global CO_2 emissions and material consumption. In addition, neighbourhoods such as Wittenburg in Amsterdam face increasing social vulnerability and reduced social cohesion. Together, these challenges create an urgent need to rethink how cities are densified, how resources are used and how architecture can contribute to social wellbeing.

This graduation project explores topping-up post-war residential buildings as a strategy to simultaneously address these challenges. Thanks to their repetitive concrete structures, flat roofs and overdimensioned load-bearing systems, post-war residential buildings offer opportunities for urban densification through lightweight timber extensions. Within this context, reclaimed timber is explored as a circular material strategy. Reuse is positioned high in the cascading process because it preserves material quality and embodied carbon. However, despite the high availability of timber waste in the Netherlands, direct reuse in new construction remains limited. Reclaimed timber is variable, uncertain and irregular. This challenges conventional architectural processes based on standardisation.

The research explores the following question: How can reclaimed timber be translated into reusable building elements for application in the contemporary building industry? Through literature research, case study analysis and material investigation, a realistic reclaimed timber stock is defined and translated into a representative database. Based on this database, multiple reusable building elements are developed, including structural systems, timber frame elements and finishing applications. The elements respond to the variability of reclaimed timber while anticipating future reuse through modularity, demountability and adaptability.

The developed framework is tested through a design case in Wittenburg, Amsterdam. The project explores the following design question: How can reclaimed timber elements be applied in a topping-up strategy to improve social cohesion, safety and spatial quality in Wittenburg, Amsterdam? Through communal living principles and a contemporary interpretation of eyes on the street, the design introduces shared spaces across multiple scales, from the dwelling to the neighbourhood.

The findings show that reclaimed timber can be translated into reusable building elements when a realistic stock is defined, uncertainty is translated into a representative database and reusable systems are developed that work with material variability rather than against it. The Wittenburg case demonstrates that reclaimed timber can realistically be integrated into a topping-up strategy while contributing to housing densification, reducing environmental impact and strengthening the spatial conditions for social cohesion. In doing so, reclaimed timber becomes not only a sustainable material strategy, but also an architectural design principle for contemporary construction.

Keywords: reclaimed timber – topping-up - reusable building elements - social cohiesion - circular construction

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INTRODUCTION

Problem statement

The Netherlands has a severe housing shortage of approximately 396.000 dwellings (Het Statistisch Woningtekort Uitgelegd | Home | Volkshuisvesting Nederland, 2025). Meanwhile, the availability of space for new constructions is limited. This requires alternative strategies for urban densification. Topping-up existing buildings is a spatially efficient response to this challenge.

At the same time, the construction industry is one of the largest consumers of raw materials and contributors to global CO2 emissions. There is an increasing urgency for more sustainable construction and demolition strategies. The circular economy proposes a model that maximizes the life cycle of products, components or materials. Through reuse, repair and recycling, waste is minimized before final recycling is needed. Reuse is preferred as it is positioned at the top of the cascade utilization. Direct reuse preserves material quality, avoids downcycling and minimizes the demand for virgin resources (Kroll et al., 2025; Vandamme & Rinke, 2025). Reusing a component as it is, maximizes the preserved carbon (Vandamme & Rinke, 2025).

Timber has a crucial role in this transition. It is a renewable material with a high cascading potential. However, in current practice the timber waste mainly gets downcycled or is used for energy production. Although reclaimed timber is physically available, the direct reuse in new constructions remains limited.

This reveals a gap between circular ambitions and architectural practice. Reuse is often seen as a technical or logistical challenge, while the implications for architectural design are less explored. Designing with reclaimed timber introduces variability, uncertainty and irregularity in dimensions, strength and appearance (Huuhka, S., 2018). These characteristics conflict with the current building industry, which relies heavily on standardisation and predictability.

Across the Netherlands there is a large number of post-war midrise residential buildings. These are characterised by repetitive concrete structures, grids and flat roofs, once designed for efficiency and standardisation. They represent about 10% of the total Dutch housing stock (TU Delft, n.d.) and thanks to their characteristics offer a great potential to topping-up, as a means of urban densification.

At the same time, many post-war residential neighbourhoods in the Netherlands are confronted with social and spatial challenges. Vulnerability in these neighbourhoods is often related to loneliness, social isolation, ageing populations and reduced social cohesion. While topping-up is increasingly discussed as a strategy for urban densification, the question remains whether these interventions can also contribute to improving neighbourhood liveability.

One possible direction is the integration of shared living principles, such as cohousing, where collective spaces and informal social interaction can strengthen social cohesion and mutual support. However, there is still limited understanding of how architectural interventions, such as topping-up, can spatially contribute to improving vulnerable neighbourhoods while responding to contemporary housing demands.

To enable the broader application of reclaimed timber, this irregular material needs to be translated into systems that can be integrated into contemporary design and construction process. One way to achieve this is by developing building elements that balance standardisation with variability. Meanwhile allowing for as much direct reuse and future reuse as possible.

Therefore, this research focuses on how reclaimed timber can be translated into reusable building elements that are applicable in the contemporary building industry. It explores reclaimed timber both as a material as well as a driver for architectural design.

Relevance

This research addresses environmental, architectural and societal challenges within the contemporary building industry.

First, from an environmental perspective, the building industry has to reduce the amount it relies on virgin materials and lower the carbon emissions. The direct reuse of reclaimed timber preserves embodied carbon, reduces material waste and minimizes the demand for new raw materials. Although reclaimed timber is physically available, the current construction industry still largely depends on downcycling and energy production. Prioritising direct reuse contributes to a more circular and resource-efficient building industry.

The second perspective is from an architectural view. Reclaimed timber is increasingly understood from a technical point of view, however the implications for architectural design are less explored. The variability and uncertainty of reclaimed timber challenge conventional building methods and require alternative ways of designing. This research contributes to this architectural debate by investigating how reclaimed timber can be integrated into contemporary architecture and topping-up strategies.

The third perspective is socially relevant. Many neighbourhoods in the Netherlands are confronted with challenges related to social isolation, ageing populations and reduced social cohesion. At the same time, these neighbourhoods provide opportunities for densification through topping-up. By combining urban densification with architectural strategies that support social interaction and informal safety, a topping-up can potentially contribute to improving neighbourhood liveability.

Finally, from a knowledge perspective, the research explores how reclaimed timber can move beyond experimental one-off projects and become more applicable in contemporary architectural practice.

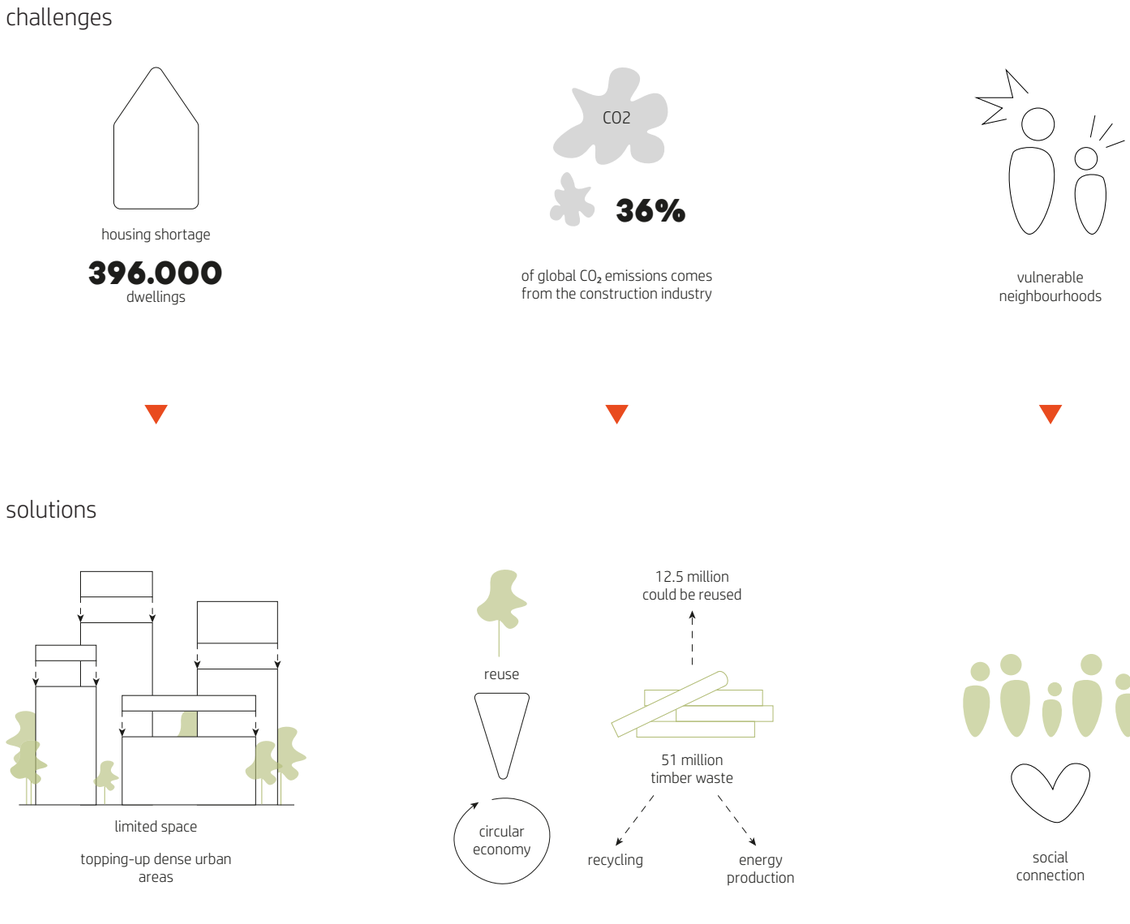


Illustration 1: problem statement, own illustration.

Objective and motivation

The objective of this research is to explore how reclaimed timber can be translated into reusable building elements for application in contemporary topping-up strategies of post-war residential buildings.

The architectural ambition of the project is to investigate reclaimed timber not only as a material, but also as an architectural design principle. The research explores how reclaimed timber can be integrated into contemporary architecture while responding to challenges related to urban densification in vulnerable neighbourhoods.

The technical ambition is to develop reusable building elements that maximise direct reuse, minimise processing and anticipate future reuse through strategies like disassembly and adaptability.

The research is tested through a design case in Wittenburg, Amsterdam, where topping-up is explored as a strategy to increase the housing amount, while improving social cohesion, safety and spatial quality. The motivation for this research originates from an interest in circular construction and architectural design.

Reclaimed timber is often approached as a technical challenge, while its architectural opportunities remain underexplored. This research investigates how reuse can become part of the architectural design process instead of only being a material decision.

Scope

This research focuses on reclaimed timber originating from construction and demolition waste streams in the Netherlands. The emphasis lies on solid timber (classification A and solid B wood), due to its greater potential for direct reuse and structural application.

The research focuses on post-war residential buildings built between 1965 and 1980, which are characterised by repetitive structures and flat roofs and are suitable for topping-up strategies.

The research explores how reclaimed timber can be translated into reusable building elements across different building layers, like structural systems, facade elements and finishing applications. The emphasis lies on minimising processing, maximising direct reuse and anticipating future reuse.

Although the developed framework aims to be broadly applicable to post-war residential buildings in the Netherlands, the research is tested through a design case in Wittenburg, Amsterdam. Wittenburg is selected due to its large stock of post-war residential buildings and its vulnerable neighbourhood status, making it a representative context to test both the spatial and social potential of topping-up

RQ: How can reclaimed timber be translated into reusable building elements for application in the contemporary building industry?

Sub questions

What is the current reclaimed timber stock in the Netherlands?
What reclaimed timber elements can be created from the stock?
How can reclaimed timber elements be applied in a topping-up?

DQ: How can reclaimed timber element be applied in a topping-up strategy to improve social cohesion, safety and spatial quality in Wittenburg, Amsterdam?

Sub questions

How can the vulnerable state of Wittenburg be improved?
How can reclaimed timber be used as an architectural driver in a topping-up?

Program

The design for the topping-up uses reclaimed timber as the primary building system. The topping-up increases the existing building volume by approximately 25%.

The programme consists of a mix of dwelling typologies, including housing for starters, elderly residents and single households. These target groups is chosen as a response to the housing shortage and the needs of Wittenburg.

In addition to housing, the project creates shared spaces based on the principles of cohousing to strengthen the social cohesion and mutual support. These collective spaces are organised across four levels: the individual, the building, the space between buildings and the neighbourhood. Together, they create a continuous social structure that encourages everyday encounters and strengthens connections between residents. Concepts such as eyes on the street by Jane Jacobs are interpreted in a contemporary way to support informal surveillance, social interaction and perceived safety.

Methodology

To answer the research and design question, this research follows a research by design approach.

The first phase of the research consist of a literature review and case study analysis. It focusses on the current timber waste stock in the Netherlands, circular construction and existing reuse practices. After which an understanding of the availability, material properties and challenges of reclaimed timber is achieved.

In parallel, the reclaimed timber stock is analysed and translated into a database of typical elements, based on dimensions, material characteristics and reuse potential. This database is the basis for the development of new building elements.

The second phase of the research focuses on the design of these elements form the database. Different strategies are explored to translate the irregular reclaimed timber into building components. Each element is based on material use, structural logic, adaptability and potential for future reuse.

The last phase of the research is testing the findings in an architectural design. The design case of Wittenburg is used to explore how the elements can be combined and applied in a topping-up. The design process is iterative. Which means that the insights from the design inform the research and the other way around.

It is a non-linear process, which allows for continuous evaluation and more refinement. This ensures that the elements are working in theory as well as in practice.

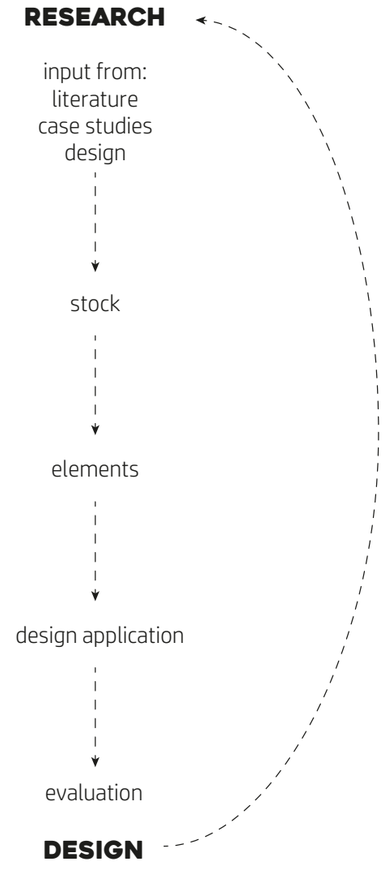


Illustration 2: methodology scheme, own illustration.

RECLAIMED TIMBER

INTRODUCTION RESEARCH

As described in the introduction, there is an increasing urgency to transition from a linear to a circular building industry. Within this transition, reuse plays an important role as it preserves material quality, embodied carbon and reduces the demand for virgin resources. Although sustainable forestry contributes to a more responsible use of timber, it is equally important to reconsider the large amount of timber already available within the demolition and construction waste stream. Currently, most timber waste is downcycled or used for energy production and the direct reuse in new construction is limited.

At the same time, reclaimed timber challenges conventional architectural practice. Unlike virgin timber, reclaimed timber is variable, uncertain and irregular in dimensions, condition and material quality. This makes reuse not only a technical and logistical challenge, but also an architectural one. Especially in the context of topping-up post-war residential buildings, where construction systems are often based on repetition and standardisation.

Therefore, this research explores the following research question:

How can reclaimed timber be translated into reusable building elements for application in the contemporary building industry?

To answer this question, the research is structured in three consecutive steps. First, the current reclaimed timber stock in the Netherlands is explored to understand what materials are realistically available, how they are collected and what challenges influence their reuse. Secondly, this stock is translated into a representative database to define realistic dimensions, material properties and possibilities for architectural application. Finally, a series of reusable reclaimed timber elements is developed. These elements explore how irregular reclaimed timber can be translated into structural and non-structural building components while anticipating future reuse.

Together, these steps move from understanding the available material stock towards developing an architectural framework for applying reclaimed timber within contemporary construction practice.

1. THE STOCK OF RECLAIMED TIMBER

Working with reclaimed timber, means starting with understanding the availability of the timber waste stock. As mentioned in the introduction working with reclaimed timber is often seen as a technical or logistical challenge. However the use of reclaimed timber effects architectural decision such as, grid size, spans, detailing, expression and the relationship between old and new layers. Reclaimed timber is variable in dimensions, condition, finishes etc., therefore architects cannot rely on the same level of standardisation as with virgin timber. For that reason, this chapter maps what a realistic timber waste stock consists of, how it is collected and sorted, what the main properties are and what challenges are relevant for designing with reclaimed timber.

1.1 The timber stockpile

The Netherlands produces annually 1.8 Mton of timber waste (Mantje, 2023). This waste is mainly used for energy production, while only a small part remains in the material loop. According to multiple sources incineration dominates the waste timber industry. What is left is being recycled, but often down-cycled, and direct reuse of timber remains a small share. (Mantje, 2023; Propos, 2022; Minkeles, 2023; Weerdesteijn, 2024, Bruggen & Zwaag, 2017)

In other words, the availability of timber waste is not a problem, but the current process does not enable easy reuse in new constructions.

Figure 3 till 5, are based on the research of TAUW in 2017 (Bruggen & Zwaag, 2017). Most of the timber waste stock is produced in the Netherlands. A small portion is imported from countries such as Norway, Belgium and the United Kingdom, as the taxes for processing waste can be higher in facilities in other countries.

imported	0.131 Mton
produced in the NL	1.610 Mton
total timber waste	**1.741 Mton**

Illustration 3: timber waste in the Netherlands in 2017 (Bruggen & Zwaag, 2017)

processed in the NL	1.120 Mton
processed outside the NL	0.621 Mton
total timber waste	**1.741 Mton**

Illustration 4: timber waste processed in and outside the Netherlands in 2017 (Bruggen & Zwaag, 2017)

downcycled	0.260 Mton
incinerated	0.860 Mton
total processed in the NL	**1.120 Mton**

Illustration 5: timber waste processed in the Netherlands in 2017 (Bruggen & Zwaag, 2017)

1.2 Demolition and construction waste

Timber waste can be divided into four categories according to Sanne Pelt (n.d.): wood from construction and demolition (24%), municipal yards (31%), company waste (25%) and other sources (20%) (Mantje).
This research focuses mainly on construction and demolition waste. Because this waste already consists out of timber that is used in the built environment. Therefore, it already has characteristics that are needed for building materials, elements and products. Furthermore this stream is often standardized. In 2020, the Dutch construction and building industry produced 0.15 Mton of timber waste (RWS, 2020).

The demolition and construction timber waste can be further divided in waste from total demolition, renovation demolition, construction companies, small renovations and unknown demolition.

Mantje (2023) made an estimation of the consistency of wood in the first two categories which makes up around half of the construction and demolition waste:

* Beams (19%)
* Planks (12%)
* Boards material (8%)
* Window frames (13%)
* Doors (2%)
* Door frames (4%)
* Walls and other framework (22%)
* Other (20%)

These numbers give clarity for timber waste per product and building element, but it doesn’ t explain the dimensions, wood species, quality, mechanical properties and possible adhesives or modifications. To further understand the stock, the timber is categorized in the next chapter ‘Collecting the Timber’ .

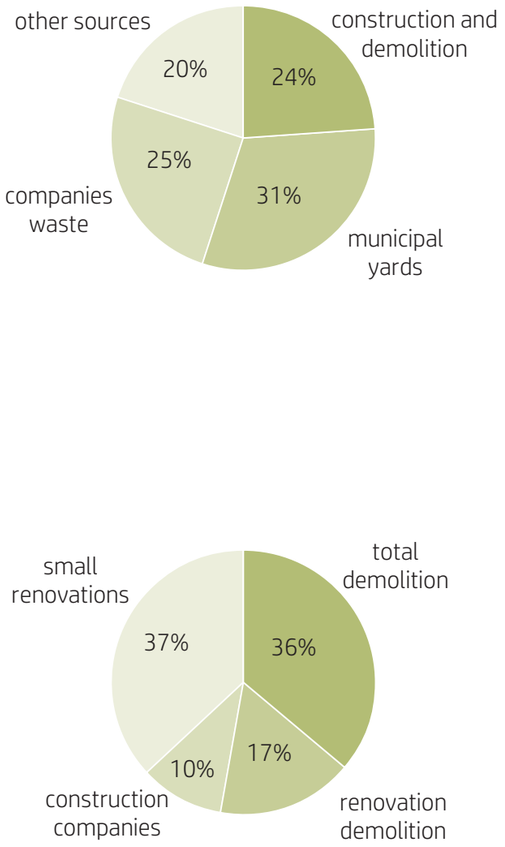


Illustration 6: (top to bottom) division timber waste source, division construction and demolition waste, division total demolition + renovation demolition R-strategies (Mantje, 2023)

1.3 Collecting the timber

In the Netherlands, the timber waste market is organized in three main stakeholders: the demolisher, collector and processor. In practice, the demolition and collecting are often done by the same company and take place at the end of a building’ s life cycle. After demolition, the collected timber is transported to a processor, where it is sorted into different classes. Depending on the classification of the timber it is either used for energy production or downcycled into timber-based products, such as panels and boards (Weerdesteijn, 2024). As a result, the current system is optimized for fast processing and production rather than for high value reuse.

History

Reuse used to be common practice until the second world war. Old buildings were demolished and demolition companies stored the materials until they were sold again. However, after the second world war materials were scarce and became more expensive. The Netherlands faced a big housing shortage and had to build housing in fast and cheap way. Concrete was a suitable answer to this problem and houses were built quickly. A lot of rowhouses and mid-rise apartments offered new housing to the Dutch population. These houses are nowadays 40 – 80 years old and are facing problems. They are being demolished and renovated to make them suite to contemporary demands. But concrete is hard to reuse and is often down-cycled to road material. The overall reuse of products declined and therefore demolition companies have changed their approach towards reuse (Mantje, 2023).

Why this matters today

As described in the introduction, the linear economy needs to transition to a circular economy and that requires materials and components to remain in use for as long as possible. Within the cascading process, reuse has a higher value than recycling. Because reusing a material preserves material quality and avoids immediate downcycling. However, in practice most attention goes to recycling, while systems for reusing remain underdeveloped. This is visible in the timber waste stream: recycling is common, but it often means down-cycling by chipping the timber. These products cannot be recycled again in the same way (Mantje, 2023). This makes recycling a later step in the cascading process, rather keeping it in a high-value loop.

As a result, reclaimed timber is currently reused mainly in markets where performance requirements and certification are less important. Therefore, in the building industry using reclaimed timber remains a niche, despite the potential (Mantje, 2023). The issue is not the absence of timber waste, but the lack of a sorting and processing system that collects timber in a reusable condition for the building industry.

The reuse chain

For this research, the process of reusing timber is divided into three phases: the demolition phase, sorting phase and element phase. This chapter focuses on the demolition and sorting phase. In Chapter two ‘The elements, the element phase is discussed.

The demolition of a building generally follows one of two approaches: traditional or circular demolition. The client decides in advance what demolition method is applied. They differ in the way the materials are collected. In the traditional way, buildings are torn down quickly. With the help of a bobcat the building is demolished and a mixed pile of materials is left. The waste gets downcycled or incinerated. This way reusing the materials or components is almost impossible. However, the circular demolition strategy treats the building as a temporary material bank. The building is disassembled as much as possible. This enables future reuse, remanufacture, repair and upcycling. But, circular demolition takes more time, which often is in conflict with the clients planning and budget constraints.

A key step for circular demolition is early separation. Separating materials at the start reduces time and costs later in the chain. Ideally, recovered materials should be stored in local hubs, as this can reduce transport distances and enable sorting close to the demolition site. Transport is important in environmental terms, as well as for the overall feasibility and impact of reuse strategies. (Mantje, 2023)

AMS Institute (Tsui et al., 2024) did research on circular material hubs (CMH) in Amsterdam. They provided quantitative insight into how CMH could function spatially. The location of these hubs are now chosen arbitrarily by individual companies. AMS used spatial optimisation methods, to find that an optimal configuration for Amsterdam would consist of twentynine timber hubs. Each of them operating at a local scale with an average distance of 3 km from the site.

The study shows that the use of CMH is limited by transport and storage costs (Tsui et al., 2024). In order to scale up the use of reclaimed timber, the economic and spatial organisation of CMH is required. When materials are transported over long distances, storing

reclaimed materials becomes inefficient and there is a greater risk of the timber being downcycled or incinerated.

This shows that, circular demolition alone is not enough to use reclaimed timber to its full potential. To make the use of reclaimed timber economically viable for the building industry, a functioning network of CMH is needed.

In short, circular demolition offers the best conditions for reusing timber, but it is economically disadvantaged in comparison to traditional demolition. The research of AMS Institute shows that reusing timber becomes viable once the reuse chain is supported by a network of circular material hubs. This forms the foundation upon which reclaimed timber can become a reliable resource.

1.4 Sorting

After demolition, reclaimed timber enters the sorting phase. Sorting the timber determines the materials future use: direct reuse, upcycling, downcycling or energy production. Therefore, sorting is not merely a technical and logistic step, but also a decisive moment in the cascading process.

For this research, the classification of timber is important as it reframes the timber from a waste stream to a design resource. By understanding the differences between the classes, it becomes possible to integrate the timber into different building elements.

Classification

The timber in the Netherlands is generally divided into three classifications A, B and C-wood. These classes are based on treatment, contaminations and recyclability. Which is relevant to the processing routes as well as the architectural expectations such as, appearance, structural reliability and reuse potential.

A-Wood

Timber with A classification is the cleanest timber waste. It is untreated, unpainted and free of adhesives. It can originate from packaging materials, pruning wood or milling residues. Approximately 80% of the A-classified timber comes from packing materials, primarily pallets.

Technically, A-wood is the easiest to reuse. Its properties are comparable to virgin timber. Which means there is a high predictability in structural behaviour. However, in practice A-wood is often down-cycled or used for energy production. Because sorting is labour-intensive, A-wood is often mixed with B-wood. This reduces the classification of the timber and limits its reuse potential. (Weerdesteijn, 2024).

From an architectural perspective, A-wood is highly reliable. However it represents only a small part of the total timber waste stream.

B-wood

B-classified timber consists of non-preserved wood that has been glued, painted or does not meet the criteria for A- and C-classified timber. B-wood can be divided into solid and non-solid timber.

Solid timber
Solid timber in this category could be a painted beam, cladding or structural member with a surface treatment. Solid B-wood often has comparable properties to A-wood and virgin timber. The surface treatments may influence the aesthetics, but do not necessarily influence the structural capacity.

The surface treatments can either be accepted as part of the materials expression and make direct reuse able. However, if it is not aesthetically desired the treatment can be removed through sanding. The timber could also be concealed in structural layers. This reduces the need for modification and enables more direct reuse. (Mantje (2023); Van Bruggen and Van Der Zwaag (2017); Weerdesteijn (2024))

Non-solid timber
Non-solid B wood are engineered timber products which hold adhesives, such as CLT, plywood and fibreboard. The presence of adhesives makes it more complicate to reuse. The technical properties are more difficult to assess and the bonding quality is uncertain. Therefore it is harder to predict the structural quality and reuse it is a structural element.(Mantje (2023); Van Bruggen and Van Der Zwaag (2017); Weerdesteijn (2024))

Engineered timber holds a big share in the contemporary timber construction. However, the current reuse systems are not used to its full potential for solid timber, let alone adapted to engineered timber. This research therefore only looks at solid-timber, while recognising the need for further research that is required to develop reuse strategies for engineered timber products.



Illustration 7: A-wood (recycling.nl)



Illustration 8: B-wood (https://shop.veolia.be/nl/content/afvalstromen/niet-gevaarlijk-afval/container-hout/container-b-hout.html)

C-wood

The tird catecory is C-Wood, which consists of preserved or chemically treated timber. This is often done to protect against fire, insects and fungi. The treatment enhances the durability, however it also reduces the recyclability. Classified C timber cannot be easily processed. The Netherlands does not have the right facilities and therefore the timber gets exported for special treatment. This result in additional transport and associated emissions.

This type of timber is the least sustainable of the three classes, in terms of cascading. However the durability characteristics of the timber might offer reuse applications in specific building layers.



Illustration 9: C-wood (www. decovik.nl)

Distribution of the stock

To sum up, timber waste in the Netherlands originates from construction and demolition, municipal yards, company waste and other sources. This waste stream can be further categorised into the three classifications: A-, B- and C-wood. Combined with the information discussed in the previous sections, illustration 10, based on the work of Eijk (2021), provides an overview of the timber waste cycle in the Netherlands.

B-wood represents the largest share of the timber waste stock in the Netherlands. This category can be divided into solid and non-solid timber. Solid B-wood has a high reuse potential, as its technical properties are often comparable to A-wood and virgin timber. Surface treatments can either be accepted as part of the material expression or removed through sanding. Non-solid B-wood, however, poses greater technical uncertainty because of adhesives and composite structures. As a result, its structural performance and future reuse potential are more difficult to assess.

The most challenging timber waste stream is C-wood. Due to chemical treatments and the limited availability of processing facilities, reuse possibilities are constrained by technical, environmental and regulatory limitations. This highlights the need for further innovation in circular timber systems and processing methods.

For this research, sorting forms the first step in defining a reclaimed timber stock to design with. Based on the previous analysis, the selected stock mainly consists of solid A- and B-wood. These categories are considered most suitable for both structural and non-structural applications, as their properties are more predictable and reliable for reuse. By narrowing down the waste stream, an architecturally and technically viable stock is defined. In this way, timber waste is reframed from an undefined material flow into a resource for architectural design.

However, C-wood is not completely excluded. Instead, this research explores how it could still be integrated within specific building layers, where its properties and limitations are more suitable.

1.5 Properties

The properties of reclaimed timber are diverse and difficult to standardize. Even similar building elements originating from the same building can differ because of adjustments during construction, repairs over time, service life damage or decay (Huuhka, 2018). As a result, reclaimed timber cannot be approached with the same level of predictability and standardisation as virgin timber.

For starters, the properties of salvaged timber depend on the timber species. For solid reclaimed timber, the material properties remain comparable to virgin timber of the same species. Timber does not notably decay because of age in terms of load-bearing capacity, compression, tensile strength and bending strength. Only impact bending strength decreases over time (Mantje, 2023). However, biological and physical damage can influence the performance of the timber (Huuhka, 2018).

Damage influencing the structural properties of reclaimed timber can originate from previous use, service life or deconstruction. Examples include nail holes, bolt holes, notches, drying defects, decay and rot. Among these, nail holes and damage to timber joist edges are the most common forms of damage found in reclaimed timber.

Research by Hradil (2014) and Smith (2013) suggests that damage caused by nails can be compared to knots in virgin timber, as both have a similar influence on tensile strength. Nakajima and Murakami (2008) found that the reduction in strength caused by nail holes is only around 10%, even at the maximum allowable quantity of nail holes. According to Falk et al. (2003), machined holes, drilled holes and screw holes can also be approached as knots passing through the cross section (Michael, 2013). These findings suggest that certain forms of damage do not automatically make reclaimed timber unsuitable for structural reuse, but instead require careful assessment and regrading.

In short, the way timber elements are connected influences their future performance and reuse potential. In the contemporary building industry, there is increasing attention for demountable construction strategies, in which entire buildings, modules, elements or components can be dismantled and directly reused. This also highlights the importance of detailing at a smaller scale. Connection methods influence the structural performance of reclaimed timber in future reuse cycles, making it important to consider demountable and low-impact connections already in the design process. This research therefore takes the impact of connection methods into account in the development of reclaimed timber elements.

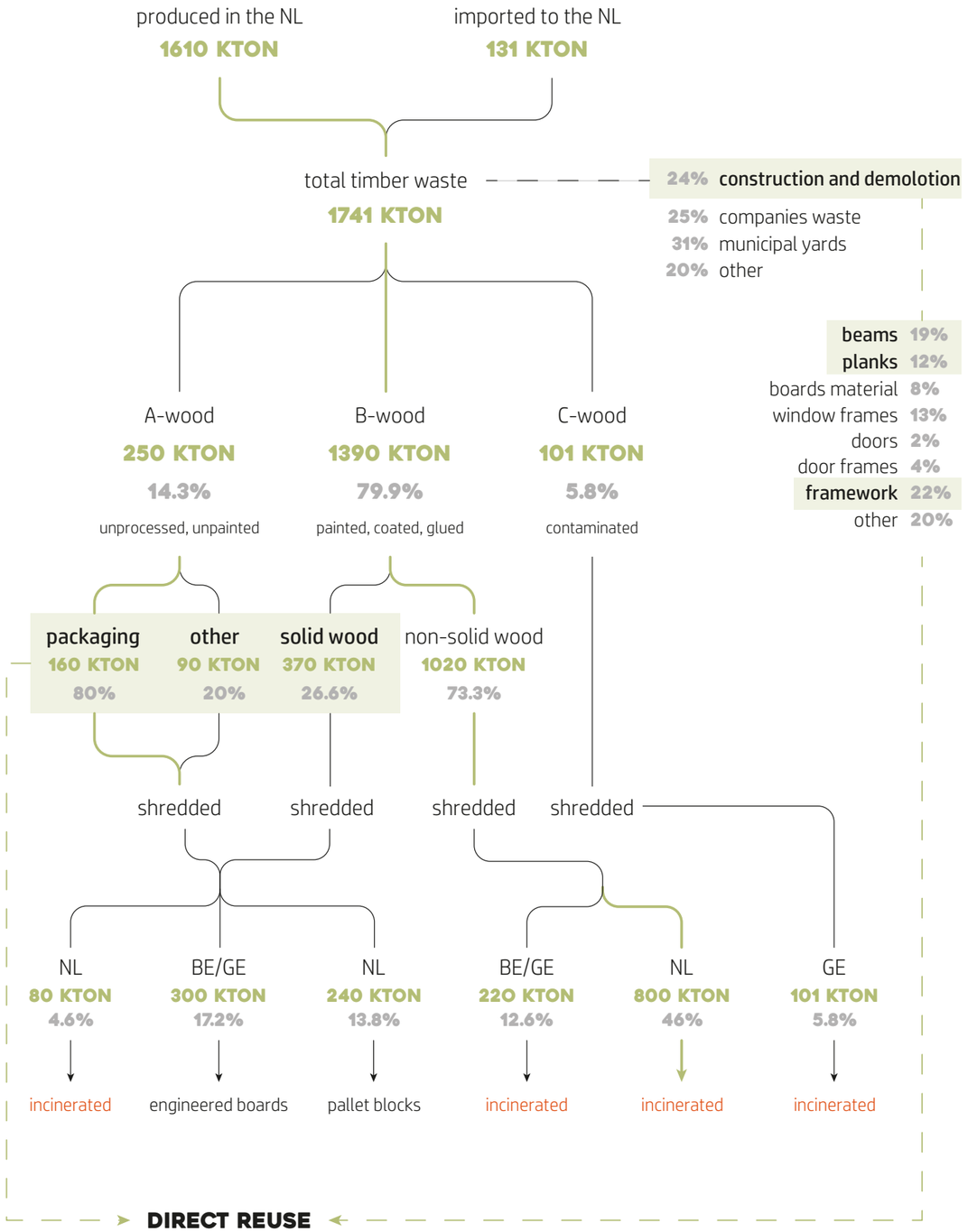


Illustration 10: overview of the timber waste cycle in the Netherlands, own illustration.

Testing

The separation of the timber waste into different classifications A, B and C says something about the general properties of the timber. However, to know in what application the reclaimed timber could be used more properties are necessary to know, for this visual and mechanical grading is needed.

Visual grading can already start at the demolition phase, which saves time and money later in the process. Visual grading includes aspects that are clearly visible at the surface such as decay, permanent warping, holes, cracks etc. For the less visible degradations there are no official grading rules. According to multiple sources developing rules on reusing timber could have a positive impact on the use or reclaimed timber (Mantje, 2023; Huuhka, 2018; Sloopcheck ?? & Van de Minkelis 2022). These less visible properties of the timber, such as the mechanical properties need to be tested with a machine. Which is a time-consuming process, as pieces of wood need to individually assessed. Therefore, reclaimed timber is often used where the mechanical properties are less important (Mantje, 2023).

1.6 Challenges

As described in the previous sections, reclaimed timber has an underutilised potential and availability. However, designing and building with reclaimed timber is still not common practice. Several challenges have already been touched upon throughout this chapter. The following section brings these challenges together and provides an overview based on the literature research.

Many of these challenges are related to the broader building industry and reuse chain, including collecting, sorting, grading, logistics and market conditions. At the same time, several challenges directly influence architectural design, such as uncertainty in dimensions, material variation and structural performance. Rather than discussing these separately, the challenges are discussed together to provide an overview of the main barriers currently limiting the wider implementation of reclaimed timber in the building industry and architectural practice.

Capacity
For starters, the Netherlands has a recycling capacity of 260kton for A wood and solid B wood. This is fully used for Dutch timber waste, which means a large part is being exported or used for energy production, even though this could potentially be reused. The timber that is being recycled is often shredded and used to make pressed plates or pallet blocks. This makes further reuse harder because of the adhesives that are being used. Increasing the recycling capacity in the Netherlands would help reduce the amount of timber that is incinerated. And with new recycling strategies and sorting techniques the timber could be better recycled or even better be reused as it is. Therefore, better sorting techniques are needed. (Van Bruggen & Van Der Zwaag, 2017; Weerdesteijn, 2024)

Sorting facilities
The lack of sorting facilities in the Netherlands is the second challenge. Sorting timber into different classifications and categories is labour intensive and costs a lot. To make it worthwhile for companies to upgrade their facilities to better sorting techniques the demand must be bigger. It is more cost efficient to use incineration as final processing step then further reuse. This challenge leads to 10 to 20% less recycling of A and B solid classified wood. If there are better sorting facilities, further processing is easier. Facilities could be specialized in reusing and recycling only a certain classification of wood. (Van Bruggen & Van Der Zwaag, 2017; Weerdesteijn, 2024)

Database
Better sorting can also help the next challenge, which is the lack of a database. By sorting it is easier to get a grip of the current available timber stock. A data base of reclaimed timber helps engineers, architects etc. to include this type of timber in their design at the beginning of the process. (Van Bruggen & Van Der Zwaag, 2017; Weerdesteijn, 2024)

Uncertain and irregular supply streams
The amount of reclaimed timber depends on the demolition activities. These happen at irregular moments and often have large quantities at once. This makes it hard to make new construction plans based on the reclaimed timber stock. Which means that there is no guarantee of material availability, this makes it difficult to rely on the reclaimed timber stock in conventional supply chains (Huuhka (2018); Mantje (2023) and Michael 2013))

Variation
The collected reclaimed timber has large variations in dimensions, species, strength, treatment, colour and more. Even timber components that were originally identical may have different properties. These changes can occur during construction, service life or demolition. (Huuhka, 2018)

Damage
The collected timber from a demolition or construction site is often damaged, for example with nails, notches and cracks. Which as explained before influences the quality of the timber and its future application possibilities. Therefore the timber needs careful regrading and inspection. (Michael, 2013)

Testing
However, re-grading the strength of the timber takes time and is expensive. And the existing grading standard does not fully include the service damage. Visual grading is good enough for judging the quality of the timber on the surface, but it does not tell its material properties. (alle bronnen van testing)

The reuse timber chain
The current chain for reusing timber requires several manual processes: collecting, sorting, grading and processing. This takes time and costs money. When the process costs more than the resale delivers, it becomes unattractive to sell. (Mantje, 2023) To really make the reuse chain work, every step of the process must be economically viable.

Lack of regulations
Besides, there is a lack of regulations and standardized testing methods for reclaimed timber. Which creates an uncertainty about safety in structural applications. It makes users redundant of using reclaimed timber. (Michael, 2013)

Logistics
A major challenge is the lack of a well-organized system between the different actors in the reuse chain. Research by AMS Institute (Tsui et al., 2024) shows that the current fragmented logistics network a primary barrier is to scaling up reclaimed timber use. In comparison, variations in material properties as dimensions and strength are a design challenge, which this research focuses on.

However, one of the biggest limitations is the logistics. Demolition sites, materials hubs and construction locations are often disconnected, which leads to increased transport, higher costs and more environmental impact. (slotzin nog, misschien iets over de 5km radius)

Awareness
A lot of people still have miss perceptions about timber, for instance about fire safety. Let alone the negative perception reclaimed timber has when it also has cracks and splits making the timber look weak, when it is not. But also a lack of knowledge on how to implement reclaimed timber in the conventional building industry. (Huuhka, 2018 & Michael, 2013).

Economic competitiveness
These challenges combined make reclaimed timber more expensive than it should be. Which is why virgin timber is often cheaper and also a reliable source. Therefore, the use of virgin timber in the building industry is preferred. (Michael, 2013)

In short, the challenges are not related to the physical availability of the material, but to the organisation of the reuse chain and the uncertainty surrounding its application. The current system is optimised for downcycling and energy production, while direct reuse remains limited by factors such as logistics, grading, regulations and market conditions. At the same time, the variability, damage and uncertain properties of reclaimed timber challenge conventional design and construction processes.

However, these challenges should not be seen as limitations, but as opportunities for architectural innovation. In order to design with reclaimed timber, it is first necessary to gain insight into what a realistic and reusable timber stock could consist of. Therefore, the next section translates the findings of this chapter into a representative reclaimed timber database for this research.

1.7 Database

As described in the previous sections, there is currently no national database in the Netherlands that keeps track of the available reclaimed timber stock. As a result, architects and engineers have limited insight into the types, dimensions and properties of timber that is available through demolition and the construction industry. However, by combining the information presented in this chapter with existing material platforms such as Opalis, it is possible to define a representative reclaimed timber stock for the purpose of this research.

Oplais is an international platform that documents reusable materials and tries to connect supply and demand in the reuse market. They document common dimensions, species and reuse practices of the reclaimed timber. Although Opalis does not have a complete national inventory, it does offer useful insight in the typical reclaimed timber elements and its characteristics.

For this research, the focus is on using timber originating from construction and demolition waste. This category represents approximately a quarter of the total timber waste stream in the Netherlands. Within this stream the most common elements are beams, planks and timber for frameworks. Based on the sorting analysis earlier, the defined stock for the database focuses on A-wood and solid B-wood. These categories have similar properties to virgin timber and are therefore more reliable for reuse in a structural way.

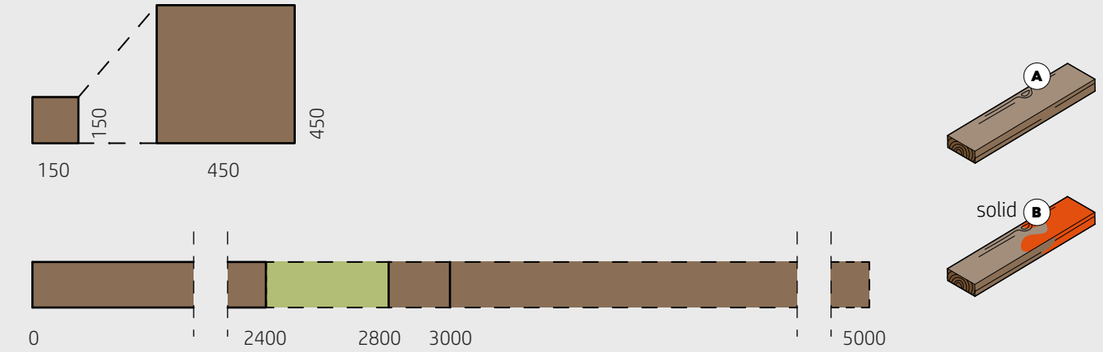
When designing with reclaimed timber, uncertainty regarding material condition is taken into account. The recovered timber can contain nail holes, notches or other damage that influences the structural performance. These can be compared to the same defects knots has in virgin timber and therefore reduces the strength capacity. Research (bron) indicates that reclaimed timber often falls within strength classes C14, C18 and C24. To make sure that the developed design strategies remain applicable to a wide range of reclaimed timber elements, this research assumes a structural strength class of C14 for all structural applications.

By translating the information to the existing timber waste stream into a defined materials stock, the reclaimed timber is approached as a resource for architectural design and not as waste. This defined database therefore is the foundation for the following chapter. In this chapter reclaimed timber elements and design strategies are developed.

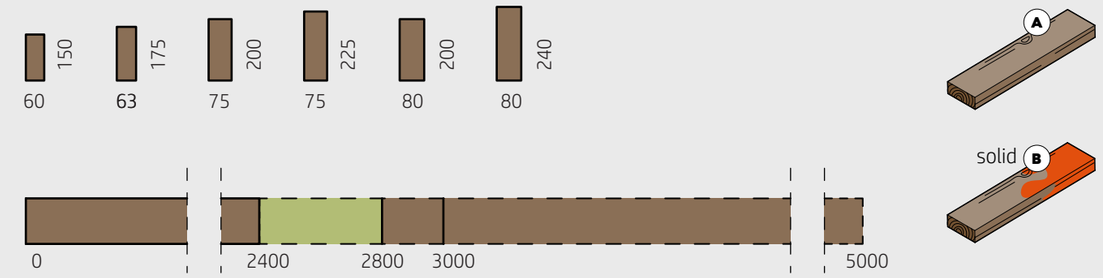
DATABASE OF RECLAIMED TIMBER

Structural timber

Beams
Classification A or solid B timber
Common sections: 150x150 to 450x450 mm
Common lenghts: up to 8 meters, 2.4 to 2.8 meters preferred and up to 5 meters economically beneficial
Common species: oak and also pine, elm and teak
Note: common strength classes are C14 - C18 and C24 and large orders costs lead time

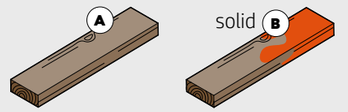


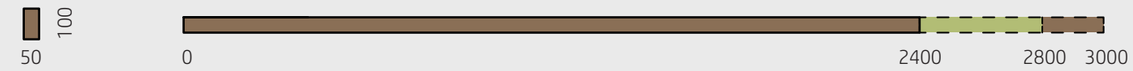
Joists
Classification A or solid B timber
Common sections: most standard sizes 60x150 to 80x240 mm
Common lenghts: up to 8 meters, 2.4 to 2.8 meters preferred and up to 5 meters economically beneficial
Common species: Oak, Pine, Jarrah etc
Note: large inventories which are easily replenished quickly



Secondary structural timber

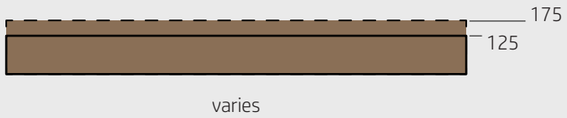
Studwork
Classification A or solid B timber
Common sections: 50x100 mm
Common lengths: 2.4 to 3.0 meters
Common species: softwood, mostly pine
Note: supply has many differences in species, dimensions etc.

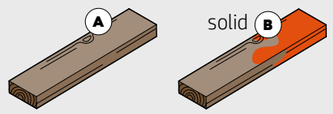




Non-structural timber

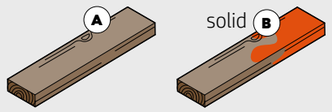
Timber floorboards
Classification A or solid B timber
Common sections: width 125 to 175 mm, heigth varies
Common lengths: varies
Common species: oak and pine, but also jarrah, elm and maple
Note: main construction methods are square edged boards and tongue and groove boards



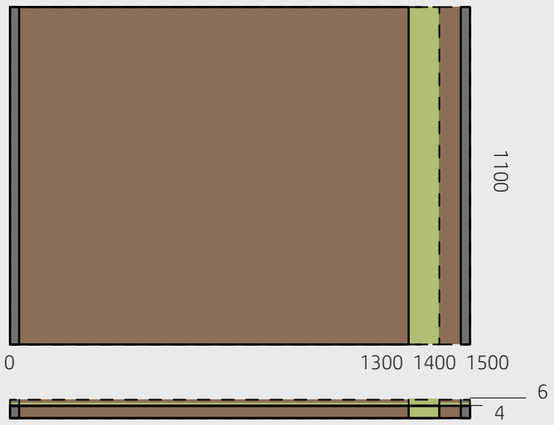


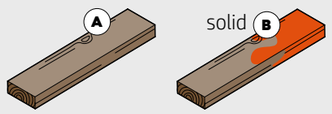
Timber strip flooring
Classification A or solid B timber
Common sections: width 50 to 75 mm, heigth varies
Common lengths: varies
Common species: oak and pine, but also jarrah, elm and maple





Stone slabs
Classification B, less common A
Common sections: width 1000 to 1100 mm, height 40 to 60 mm (1100 x 45 mm most common)
Common lenghts: 1300 to 1500 mm (1400 mm most common)
Common species: azobe, douglas fir and larch
Note: the properties of the stoneslabs differentiate a lot between the three species





Direct reuse of reclaimed timber reduces embodied carbon by replacing new material. According to WRAP (2006), direct substitution saves approximately **0.5 kg CO_2** per kg of timber, equivalent to **225 kg CO_2/m³**. For surface applications, this corresponds to approximately **7.2 kg CO_2/m²** for hardwood and **4.3 kg CO_2/m²** for softwood. Actual savings depend on factors such as transport, processing and timber species·

2. ELEMENTS OF RECLAIMED TIMBER

The last chapter defined a representative reclaimed timber stock and translated this into a database. The next step is exploring how reclaimed timber can be transformed into reusable building elements. This chapter approaches reclaimed timber not as an unpredictable waste stream, but looks at how the characteristics of the stock can become the basis for architectural application.

The variability of reclaimed timber in dimensions, quality and availability challenges conventional building systems that rely on standardisation. Therefore, the aim is not to standardise the material itself, but to develop a reusable logic for working with irregularity. Through a series of structural and non-structural elements, different strategies are explored to translate reclaimed timber into building components that are suitable for contemporary construction.

The chapter includes elements across multiple building layers, including the primary structure, timber frame elements and finishing applications. Each element is analysed through the same framework, focusing on the characteristics of the element, the sourcing of reclaimed timber, assembly strategies, architectural implications and potential for future reuse.

Together, the elements form a reusable system that responds to the realities of the reclaimed timber stock while remaining applicable within contemporary architectural practice.

2.1 Structural element - beams and columns

1 characteristics of the element

Beams and columns are the primary load-bearing structure of a building. The structural elements can be positioned internally or externally, visually seen or hidden. They can span across multiple building layers and require strength and durability over time.

In timber construction the main loadbearing structure is typically composed of 1D elements as beams and columns or 2D-elements as CLT panels or timber frame elements. CLT panels and similar products are engineered elements and include adhesives. This research only focusses on solid timber, which is why engineered timber with adhesives will not be discussed.

The design of the beams and columns depends on the residual strength and dimensions of the reclaimed timber (Parigi, 2021). Reclaimed timber does not significantly lose its structural performance over time, although its performance is influenced by damage, previous use and connection details. This means there is an uncertainty in the material behaviour and requires a more reliable approach (Huuhka, 2018; Mantje, 2023).

2 suitable reclaimed timber stock

The most suitable reclaimed timber for structural applications is A-class and solid B-class timber. These categories have comparable properties to virgin timber, which makes them reliable to use for loadbearing elements.

The available stock includes beams and joists. The beams are typically available in sections from 150x150 up to 450x450 mm. However, this stock is more limited and harder to replenish (Opalis, n.d.). However, joists are more widely available and are therefore used as an alternative source to create larger structural elements.

In terms of length, the reclaimed timber is commonly available between 2.4 and 2.8 meters, while lengths of 3 to 5 meters are considered economically viable. Elements up to 8 meters exist, but are less common, which is why these are not taken into account (Opalis, n.d.).

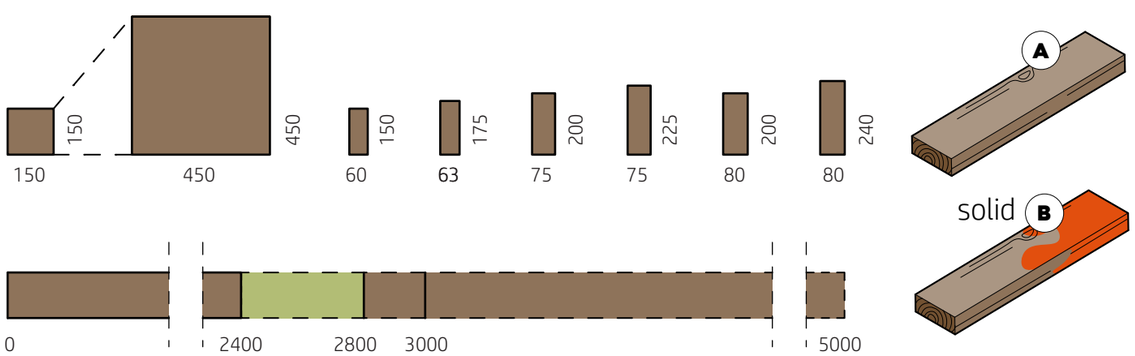
Because of the limited availability of reclaimed beams, both beams and joists are preferred for creating structural elements. As a result, the design needs to allow variation in detailing or accept small losses of material when adapting elements to the required dimensions.

In terms of strength, the mechanical properties of reclaimed timber can be compared to virgin timber. However, the damage of nail holes, notches and previous connections affects the effective strength. These defects can be considered similar to knots and reduce the structural capacity (Smith, 2013; Falk et al., 2003). Which is why this research assumes a conservative strength class of C14 for structural applications, to account for the uncertainty. This ensures that the developed elements are applicable across a wide range of reclaimed timber conditions

3 required transformations

The available reclaimed timber has variations in length as well as cross-sectional. To make it suitable for structural applications a transformation is required.

First, shorter elements need to be lengthened to meet the required span. This can be done by connecting beams from the stock or by combining multiple smaller elements, which are the joists.



scale 1:20
Illustration 11: common dimensions of beams and joists, and waste classification applicable for structural use (own illustration)

Secondly, the elements with a smaller cross-section need to be combined to create larger sections. This will allow the use of more widely available timber while reducing the need for large beam sections.

And last, to maximise the direct reuse, cutting is minimised. Timber elements are preferable only cut at the end of the structure, such as facades or roof edges. This result in a design approach where elements remain as continuous as possible throughout the structure.

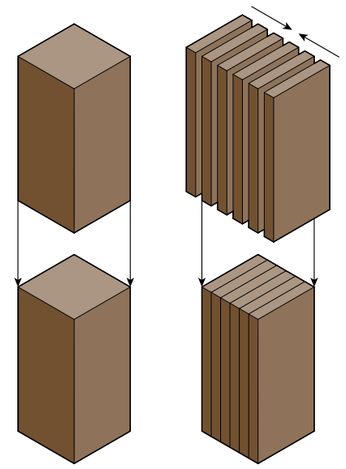


Illustration 12: required transformations: extending beams (left) and stacking smaller elements (right), own illustration.

4 assembly strategies

For the structural connections between the reclaimed timber, timber-to-timber connections are preferred. Het zorgt ervoor dat het hout makkelijker is te scheiden in de juiste hout klasse (A, B of C), waardoor hergebruik daarna weer makkelijker gaat. Furthermore, the use of bolts should be minimizes as much as possible, since drilled holes reduce the residual strength of reclaimed timber. Which therefore negatively influences the future reuse potential. At the same time, the amount of labour and precision that is required for fabrication has to be considered when developing solutions that are applicable to the contemporary building industry.

Extending vertically
When two reclaimed timber beams are combined to create a longer element, the structure requirements differ depending on whether the element is used vertically (column) or horizontally (beam).

A column is primarily in compression and the main challenges are to prevent buckling and maintain a direct load path.

Multiple scarf joints can be used to extend timber columns. A hook scarf joint is preferred as it not only relies on friction between the contact surfaces. Moreover, it also geometrically interlocks, which limits movement between the timber pieces. An example of a structurally effective scarf joined is the stop-splayed undersquinted and cogged scarf joint. The addition of the cog improves the bending strength and the cut on either side of the cog acts as loadbearing points. To strengthen the connection further wooden pegs can be used. (Sobon, 2002 & Timber Frame HQ, n.d.).

Since the available reclaimed timber often has lengths between 2.4 and 2.8 meters, these joints will occur at similar intervals throughout the structural layout.

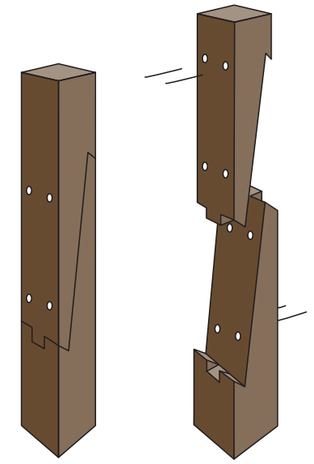


Illustration 13: vertically extending beams with a stop-splayed undersquinted and cogged scarf joint, own illustration.

Extending horizontally
When horizontally extending timber beams, the bending becomes the primary structural challenge. When bending, the upper side of the beam is in compression, while the lower side is in tension. Timber is more vulnerable on the tension side.

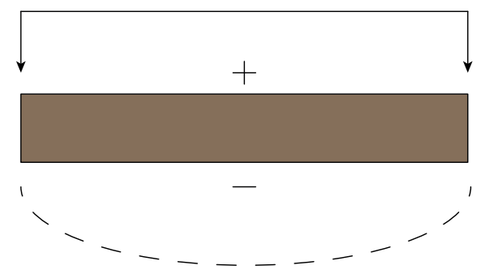


Illustration 14: wooden beam, upper side in compression, lower side in tension, own illustration.

Therefore the splice connection must be able to transfer tensile forces, limit the rotation and prevent slipping of the connected elements. For these reasons, a stop-splayed undersquinted and tabled scarf joint with wedges and pins is a suitable strategy. The addition of the tabling and wedges improves the tensile performance, torsion and bending strength in both directions.

If more tensile capacity is required, multiple tables can be used. However, making the joint more complex increases the fabrication time. Therefore, the more complex scarf joints should preferably only be used when it is structurally necessary.

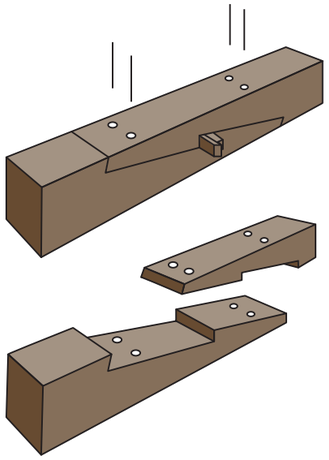


Illustration 15: horizontally extending beams with a stop-splayed undersquinted and tabled scarf joint with wedges and pins, own illustration

Scarf joints reduces the structural performance compared to a continuous member. The combined beam is weakest at the location of the joint. Which is why it is advised if possible to place the joint in areas with lower bending moments. (Sobon, 2002 & Timber Frame HQ, n.d.).

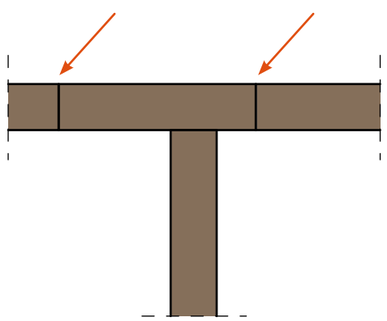


Illustration 16: not common location connection beams on column, own illustration.

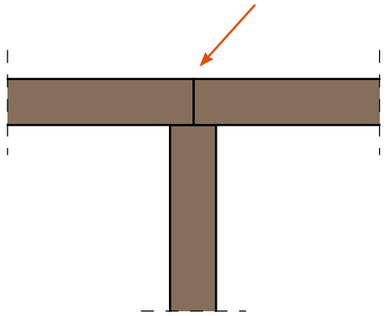


Illustration 17: common location connection beams on column, own illustration.

Keyed beam

The previous two strategies focus on extending timber elements to achieve the required length, which already have the right cross-section. However, they do not address the challenge of combining smaller reclaimed timber section into a structurally larger beam. To achieve this a mechanically laminated beam is proposed, also referred to as a keyed beam.

The keyed beam mechanically combines multiple smaller timber member into one largers structural section. Miller (2009), researched the structural behaviour of keyed beams. The main idea is creating a larger bending section through mechanical interaction between smaller timber elements.

For example, instead of using:

1 x 300 x 300 mm beam

a beam could be made out of:

3 x 100 x 300 mm reclaimed timber joists or

2 x 80 x 240 + 1 x 60 x 240 mm reclaimed timber joists

Although the beams together look like a solid beam, it doesn’ t behave like one. This is where the connection between the layers becomes important. The amount of interaction between the layers influences the efficiency of the beam.

When a force works on the beam, the beam bends. The upper layers are more in compression and the lower layers in tension. If the timber members are only stacked on top of one another, there will be movement between the layers, also known as interlayer slip. As a result, it loses it structural function and stiffness.

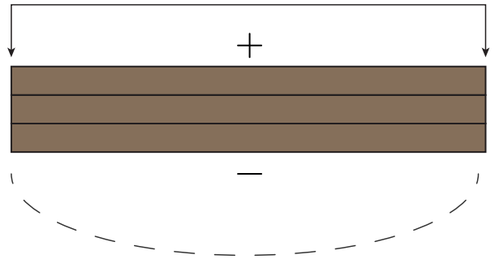


Illustration 18: stacking the joists will cause interlayer slip, own illustration.

To prevent this, shear keys can be used between the layers. These transfer shear forces and limit movement, which enables the different timber members to work together as one structural element. (Miller, 2009)

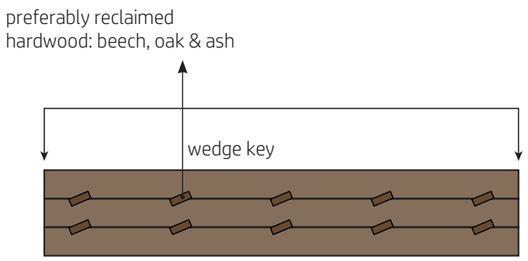


Illustration 19: adding wedge keys to the stacked joists, own illustration.

The keyed beam does not only allow for combining different cross-sections, but also creates opportunities to combine timber pieces of varying lengths. In principle a larger contact surface and mechincal interlocking can improve force transfer between the connected elements. An in practice example of Dondervink, shows the use of a straight lap joint in the keyed beam. Since it has been 6 years (2020) placed it hasn’ t show any deformations.

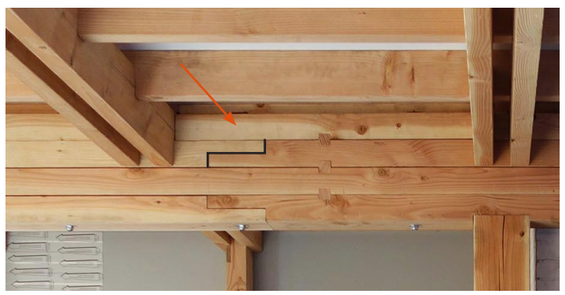


Illustration 20: straigh lap joint in keyed beam at Werkplaats Zaandom, Dondervink (source: dondervink.nl)

However, for a stronger connection a stop splayed scarf joint or other oblique joints could be used. Although, further research is required to know the optimal configuration.

In addition to the shear keys, the beam also requires a clamping mechanism to maintain interaction between the layers. The element has a structural application, which means it has to be as reliable as possible. Therefore steel connections are often preferred. One option could be to used bolts running through all the layers. This creates a strong structural connection while maintaining the possibility for future disassembly. Alternatively, steel straps or other external clamping systems reduces the number of holes in the timber. Though the structural performance requires further investigation. Miller (2009), also discusses spacing requirements for the shear keys and clamping system, which provides an important basis for further structural development.

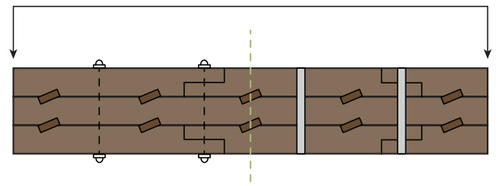


Illustration 21: adding a clamping mechanism to the stacked joists, own illustration.

Although all three connection strategies are labour intensive, thanks to digital fabrication methods such as CNC cutting, the production time may be reduced. However, the economic feasibility likely depends on the scale of the project, where larger project benefit more from standardization and prefabrication than smaller projects.

5 design application

Reclaimed timber as beams and columns influences the architectural design. It effects the structural logic and the spatial organisation, detailing and expression of the building. In conventional timber construction the grid often relies on standardized dimensions. However, reclaimed timber introduces variability in length and cross-sections. As a result, the structural system is based on the architectural intention and characteristics of the available stock.

Smaller structural grid
From the stock analysation in this research, it is known that the stock mainly consists of lengths between 2.4 and 2.8 meters. Therefore a structural grid based on these dimensions, is a logical design response. A 2.4 meter grid would be preferred as it aligns with the most common lengths.

However, when designing with a fixed grid it introduces trade-offs. By standardizing the grid to the shortest common reclaimed timber length, offcuts have to be done on the longer members. These offcut pieces could be reused within the architectural system itself. For example, as intermediary blocking elements or as shear transfer components, comparable to the wedge keys in the keyed beam.

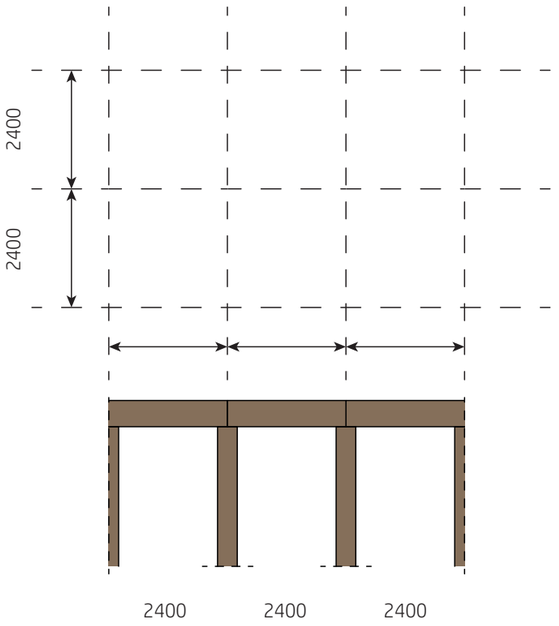


Illustration 22: grid based on 2.4 meters, own illustration.

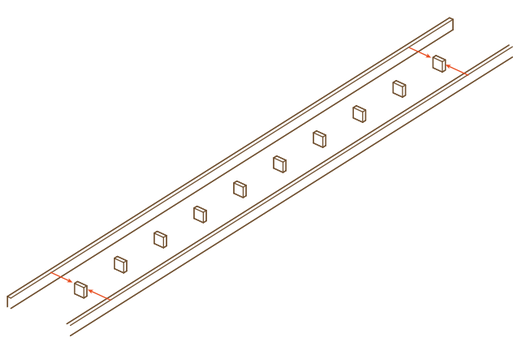


Illustration 23: use of offcut pieces, own illustration.

Continuous structure
To maximize the amount of directly reused timber, the beams can be extended multiple times and only be shortened where strictly necessary, for example near a facade edge. A continuous structural logic is created in which the structural member span through the building rather than stopping at every grid intersection.

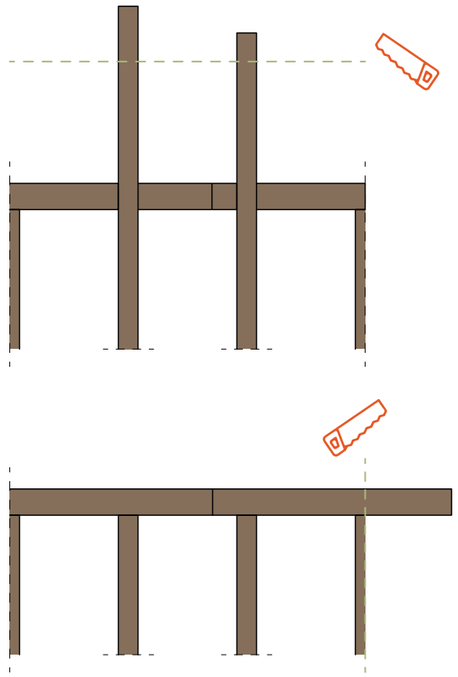


Illustration 24: only cutting of at the ends, own illustration.

However, fully continuous structural members also have practical challenges. Prefabrication and efficient transportation is essential in the contemporary building industry, as it saves on site construction time and disturbances. Extremely long timber elements are difficult to transport and assemble.

For this reason, there needs to be a balance between maximizing direct reuse and maintaining feasible construction logistics. Instead of extending beams to a maximum, the structural members should be standardized to transport efficient lengths. This will then result in a semi-standardized system with extended elements. The member can still vary between predefined lengths instead of fully being continuous.

Variation in detailing
Large reclaimed timber beams are less available, than joists which have a smaller section. As a result in a construction of single reclaimed timber beams, extended scarf elements or mechanically laminated elements as keyed beams. This creates a variation in structural expression and detailing.

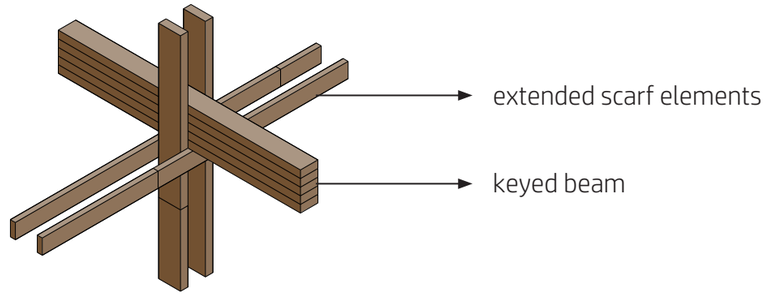


Illustration 25: continuous structure, own illustration.

6 future reuse potential

Using reclaimed timber alone is not sufficient to create a circular system. It is just as important to anticipate on future reuse.

A building has different layers with different life spans. The primary structure is supposed to remain in place for as long as possible. Secondary layers, are like the facades, installations and finishes, these will be replaced earlier. The structural system should therefore not only support the current performance, but also allow for future adaptation, disassembly and reuse.

To enable future reuse as much as possible, first of irreversible damage should be minimized. Which means the elements should be modified as little as possible, like cuts and perforations. Reclaimed timber already has traces of previous use, damaging the structural capacity. Which is why as much residual strength should be preserved. Secondly, connections should be mechanically reversible where possible. This allows elements to be disassembled without destroying the timber. And thirdly, the different building layers should be separated. By separating these layers, replacement of components will not effect the other layers.

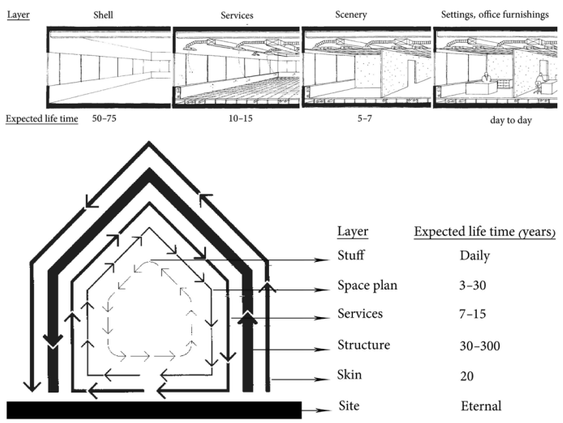


Illustration 26: building layers and expected lifetime according to Duffy 1998 and Brand 1995 respectively (Durmisevic, 2010).

Reusing the proposed structural elements can happen on two levels: reusing the element as a whole and reusing the individual components within the element. First of it is preferred to reuse the element as a whole. This preservers labour and embodied carbon. For example, the extended beams or keyed beams can be dismantled as long as they are reused in a similar structural application without more processing. If that is not possible, the elements can be modified to be reused again in new assemblies.

Lastly, the connection strategies influence the future reuse potential of structural elements. In the proposed system adhesives are avoided. This allows easier disassembly and material separation in future waste stream cycles. Instead, it uses bolts and clamping systems to enable reversibility. However, they still affect the timber, as bolt holes reduce the residual structural capacity and future reuse potential. Ideally, the structural connection would minimize damage to the timber while remaining structurally reliable, but this requires further research.

2.3 Timber frame element

The timber frame element is a multifunctional system that can be applied in different building layers, including internal walls, partition walls, facade elements and floor elements.

Timber framing offers a suitable strategy for working with reclaimed timber, as it allows the integration of elements with varying lengths and dimensions. The system is based on the principle of structural reciprocity. This means that elements support each other along their span rather than at fixed endpoints (Parigi, 2021). Therefore, it allows irregular reclaimed timber pieces to be combined into a coherent structural system with minimal cutting.

A typical timber frame element consists out of an outer frame, secondary structural members, insulation and sheathing layers. Together, these form a stiff 2D element that can function as a structural or non-structural component. While all applications rely on the same system, they differ in detailing depending on functional requirements such as loadbearing capacity, fire resistance or weather protection.

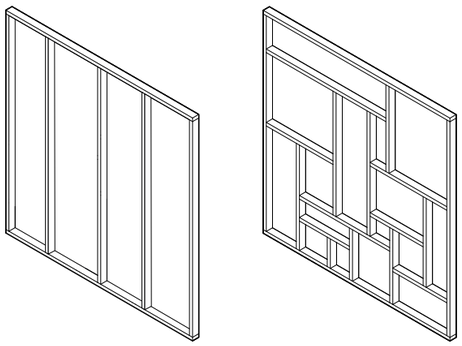


Illustration 27: typical timber frame element (left), reciprocal timber frame element (right), own illustration

In addition, the timber frame system allows for prefabrication. This plays an important role in making reclaimed timber applicable in the contemporary building industry. Construction time and disturbance on site van be minimised, by producing these elements off-site.

At the same time, the system enables a balance between standardisation and variation. The internal structure can adapt to the irregularity of reclaimed timber, meanwhile the outer dimensions of the elements can be standardised. This makes it possible to optimise production, transport and assembly, while still trying to maximise the use of available reclaimed timber.

This combination of adaptability and standardisation makes the timber frame system suitable for larger-scale applications. It bridges the gap between one-off reuse projects and mainstream construction practice.

1 characteristics of the element

The timber frame system functions as a 2D building element and can be applied in multiple layers within the building. It can be structural (shear walls or floors) or non-structural (internal partitions), depending on the application.

The timber frame system primarily needs to respond to horizontal loads in wall applications and vertical loads in floor applications. In comparison to 1D elements such as beams and columns, the timber frame distributes forces across a surface, which allows the smaller timber pieces to work together structurally.

The use of structural reciprocity creates a system without a clear hierarchy. The elements mutually support each other. However, this also creates indirect load paths, which influence efficiency of the structure (Parigi, 2021).

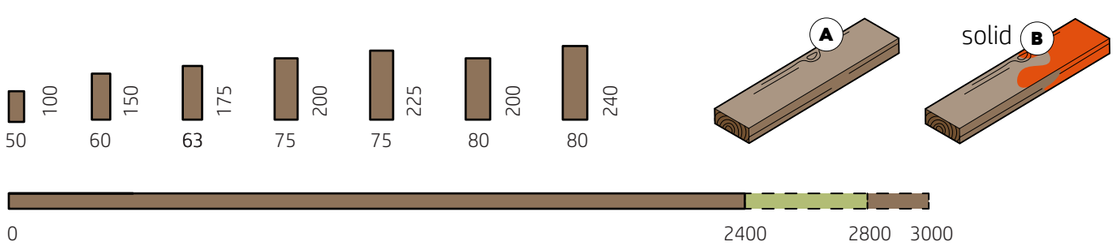


Illustration 28: common dimensions of joists and timber frame elements, and waste classification applicable for structural use (own illustration)

2 suitable reclaimed timber stock

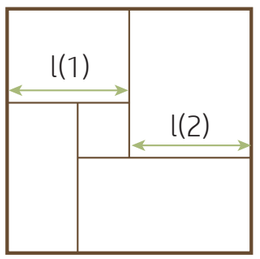
The reciprocal timber frame is very suitable for smaller and more irregular reclaimed timber pieces. Therefore it uses the smaller sections of the stock, such as studwork, planks and shorter joists. While longer elements, 3 to 5 meters, are more economically viable for reuse, the shorter elements (<3 m) are often downcycled or incinerated. This system creates an opportunity to use these otherwise undervalued pieces. By using smaller elements, the timber frame system complements the beam system, which relies on larger sections.

3 required transformations

The advantage of using a reciprocal system is that the reclaimed timber requires minimal transformation. Instead of resizing elements to fit a predefined system, it adapts to the available stock. A combination of timber pieces with varying lengths turns into a structural configuration using the principle of structural reciprocity. Which means there is no strict standardisation of the length of the element, the cutting is minimised and smaller and irregular pieces can be fully utilised.

4 assembly strategies

The reciprocal system works as long as the length of two elements combined, is the length of the entire element: l(1) + l(2) > l(total) (Parigi, 2021).



l(1) + l(2) > l(total)

Illustration 29: schematic representation of reciprocal structure, own illustration.

To connect the timber elements metal dowels are used primarily (Parigi, 2021). These dowel connections allow the different reclaimed timber pieces to be joined without the use of adhesives, making the system reversible. The dowels transfer the shear forces between the elements. They also allow for a relatively simple assembly and disassembly. Compared to bolted connections, dowels require smaller holes. This limits the damage to the timber and improves its potential for future reuse.

In addition, the potential of using wooden dowels is explored. The use of wooden dowels could further reduce the use of non-biobased materials and improve the circularity of the system.

The positioning and number of dowels remain critical for the structural performance of the element and need to be carefully designed.

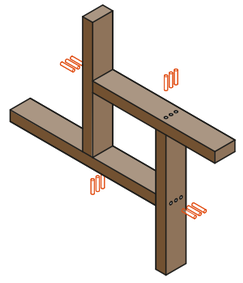


Illustration 30: connection with metal or wooden dowels, own illustration.

Two main structural strategies can be distinguished: a fully reciprocal structure and a hybrid system.

Fully inner reciprocal structure
The fully reciprocal structure has all the secondary elements arranged according to structural reciprocity. It maximises the use of irregular reclaimed timber and minimises cutting and waste. This creates a high degree of direct reuse.

However, it creates indirect load paths. Which creates bending moments and is less efficient for vertical loads.

Hybrid system
To also withstand vertical forces a combination of a reciprocal structure with new full-length vertical elements is recommended. This hybrid system creates a direct load path for vertical forces. This improves the structural performance (Parigi, 2021). To create a balance between reuse and reliability, reclaimed timber is combined with virgin timber. However, it still is preferred to use reclaimed timber for the longer elements, if available.

The timber frame elements need openings for functions such as doors, windows and circulation. There are two strategies within this system or creating openings: predefined openings and opening derived from the reciprocal structure.

Predefined openings
The first strategy has predefined openings, where the position and dimensions are determined in advance. This approach aligns with conventional construction methods and allows for a higher level of standardisation. This makes it suitable for larger-scale projects or projects with limited time. However, it requires timber elements with specific dimensions, which are not always available in the reclaimed stock.

As a result, additional processing is needed. The reclaimed timber needs to be cut to size and the created smaller leftover pieces are more difficult to reuse. Furthermore virgin timber may need to be used to meet required dimension. As a consequence, the overall share of reused timber is reduced within the element.

Openings from reciprocal structure
The second strategy is based on openings derived from the reciprocal structure. In this approach, openings emerge from the geometry of the structural system. The spaces that are created between the reciprocally arranged elements can be used as windows or other openings. This allows the design to adapt to the available reclaimed timber stock, rather than forcing the material into predefined dimensions.

As a result, this strategy allows more reclaimed timber integrated into the element. At the same time, this approach creates a distinct architectural expression. One where the structural logic directly shapes the facade and spatial experience. However, this strategy is less standardised and requires more design time, coordination and flexibility from architects and engineers. Therefore, it is more suitable for smaller-scale projects, where variation and material expression can be prioritised over efficiency and repetition.

maximises use of irregular reclaimed timber	direct load path for vertical forces
minimises cutting and waste	improved structural performance
high degree of direct reuse	balance between reuse and reliability
indirect load paths	requires longer elements
less efficient for vertical loads	

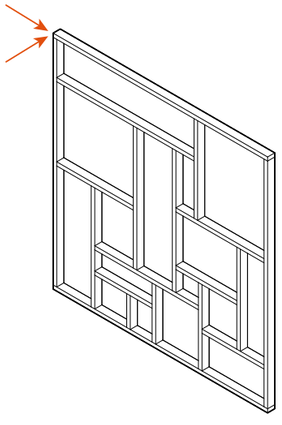


Illustration 31: fully inner reciprocity structure, own illustration.

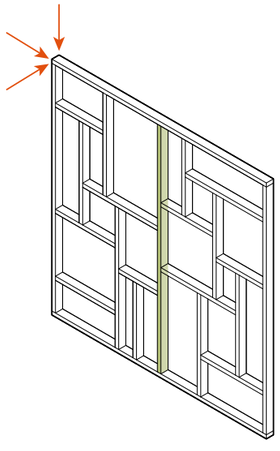


Illustration 32: hybrid frame structure, own illustration.

standardised positions and sizes	maximises use of reclaimed timber
efficient and predicatable	creates architectural expression
requires cutting or new timber	less standardised
reduces reuse potential	more design effort

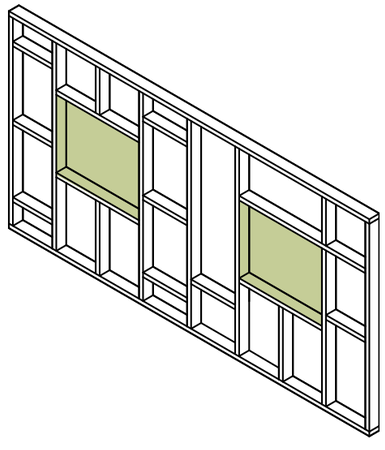


Illustration 33: predefined openings in reciprocal structure, own illustration

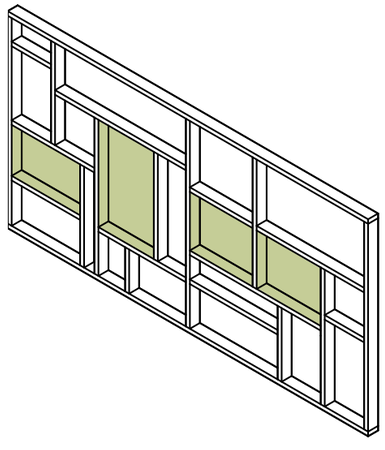


Illustration 34: openings defined by reciprocal structure, own illustration

5 application in design

The timber frame system can be applied in different elements in a design, including internal walls, partition walls, facade elements and floor elements. All elements are based on the same principle, but differ in their detailing depending on the required performance.

This means that one system can be used across multiple building layers, while still responding to different spatial, structural and technical requirements.

Internal wall
The internal wall is the simplest application of the timber frame system. It does not have a structural function and has limited acoustic requirements. This means a single element with a fully reciprocal inner structure is sufficient. The system allows smaller reclaimed timber pieces to be used without additional processing.

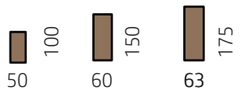


Illustration 35: smaller cross-sections for wall elements, if stock is different other cross-sections work as well, scale 1:20, own illustration.

In addition to the structural layout, the wall includes insulation and finishing layers. A biobased insulation material is preferred, combined with sheathing such as OSB panels.

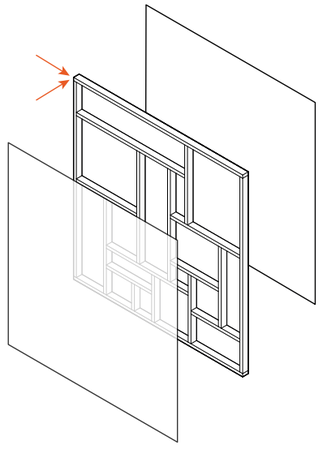


Illustration 36: internal wall, own illustration.

The connection between the internal wall element and the floor or ceiling must be easy to dismantle. This allows for future changes in the spatial layout of the building. Therefore, fixed and irreversible connections must be avoided. A possible strategy is including dry connections such as, screwed of dowelled connections, placing the element within a guiding profile or clamping the element between the floor and ceiling. The solution should allow the wall to be moved without damaging the main structure.

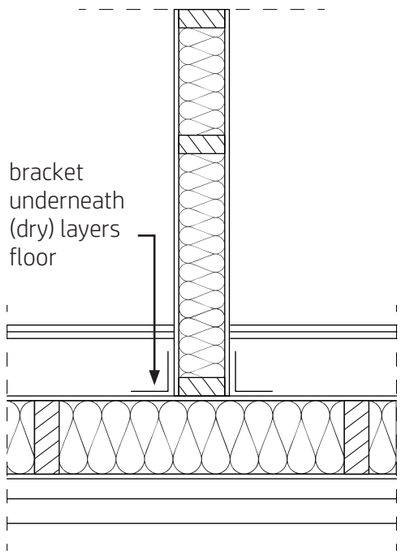


Illustration 37: internal wall detail, scale 1:10 , own illustration.

Partition wall
The partition wall has higher performance requirements, such as fire resistance (60 minutes) and acoustic insulation (52 dB). This means the element needs additional layers compared to the internal wall. In addition, the detailing between the different elements becomes more important, as it directly influences both the acoustic and fire performance.

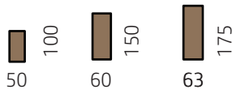


Illustration 38: smaller cross-sections for wall elements, if stock is different other cross-sections work as well, scale 1:20, own illustration.

A typical timber frame partition wall consists of finishing layers, a timber frame element, a cavity with or without additional insulation, and a mirrored build-up on the other side. For the element with a reciprocal structure, the same build-up principle can be applied. However, in this research there is also a focus on future reuse. This means the element should be removable, which is often not the case in conventional timber frame partition walls.

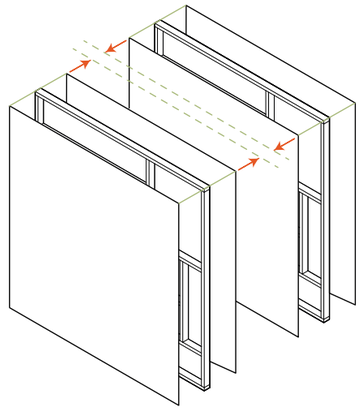


Illustration 39: partition wall, own illustration.

In this case, the element is not part of the main structure. This is a conscious choice, as it increases the potential for future reuse and allows the spatial layout to be adapted over time.

The element could, however, be adapted to have a structural function. This could be achieved by using reclaimed timber with larger cross-sections, increasing the overall thickness of the element or introducing more full-length vertical elements to create a more direct load path. Another option could be to combine two smaller timber frame elements into one structural component. Whether this is feasible depends on further structural exploration.

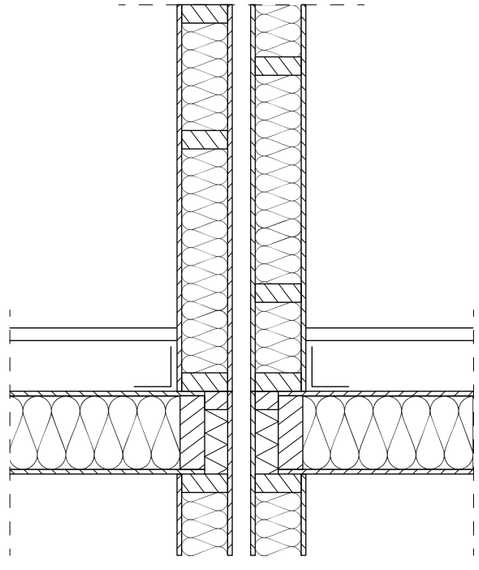


Illustration 40: partition wall detail, scale 1:10 , own illustration.

Facade element
The facade element is similar to the wall elements, but needs different qualities. In this research, a non-loadbearing facade element is proposed, just like the previous timber frame elements. The element is in this case hung from the primary structure. This means the element does not carry vertical loads, but is supported by the main structure and transfers wind loads back to it.

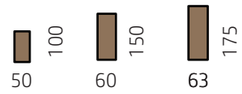


Illustration 41: smaller cross-sections for wall elements, if stock is different other cross-sections work as well, scale 1:20, own illustration.

This allows the element to be dismantled without affecting the primary structure. The facade becomes a separate layer that can be removed, replaced or adapted over time.

The facade is the outer layer of the building, it needs to provide weather protection, airtightness and thermal performance. This means that the different layers should be designed for disassembly and replacement, especially the cladding.

At the same time, the connection between the facade elements is important for the overall performance. The way elements meet each other determines how well the facade performs in terms of water tightness, air tightness and thermal continuity.

This means that the detailing of horizontal and vertical joints needs to prevent water ingress, limit air leakage and reduce the thermal bridging. A few strategies to prevent this are overlapping layers, compressible seals or gasket systems can be used to achieve this, while still allowing the elements to be disassembled. These strategies also influence the architectural expression of the facade. In this research, a solution is explored in which the elements overlap each other, which creates a seamless transition between them.

The challenge of the facade element is to balance performance with reversibility. The connections need to be tight enough to meet building requirements, but also accessible and removable for future reuse or replacement.

In addition, the cladding layer plays an important role in the performance and expression of the facade element. There are different cladding strategies that influence aspects such as weather protection, durability and the

overall appearance of the building. Within this research, the cladding is further explored as a separate element.

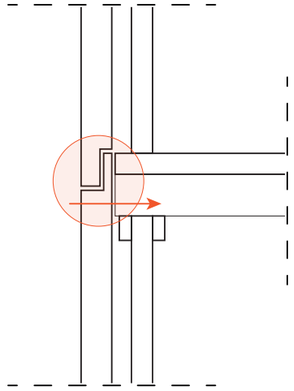


Illustration 42: schematic representation of a detail of overlapping facade elements, own illustration.

Floor element
The floor element differs significantly from the wall elements, as it primarily needs to carry vertical loads. These loads consist of both permanent loads, such as the weight of the structure itself and fixed building components, and variable loads, such as occupants, furniture and temporary use.

This means the structural requirements of the floor element are higher compared to wall elements. Even though the primary loadbearing structure is formed by beams and columns, the floor element still needs to span between these elements and transfer loads safely. For this reason, the timber frame system needs to be adapted when applied as a floor element. Three strategies are explored in this research.

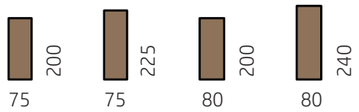


Illustration 43: bigger cross-sections for floor elements, scale 1:20, own illustration.

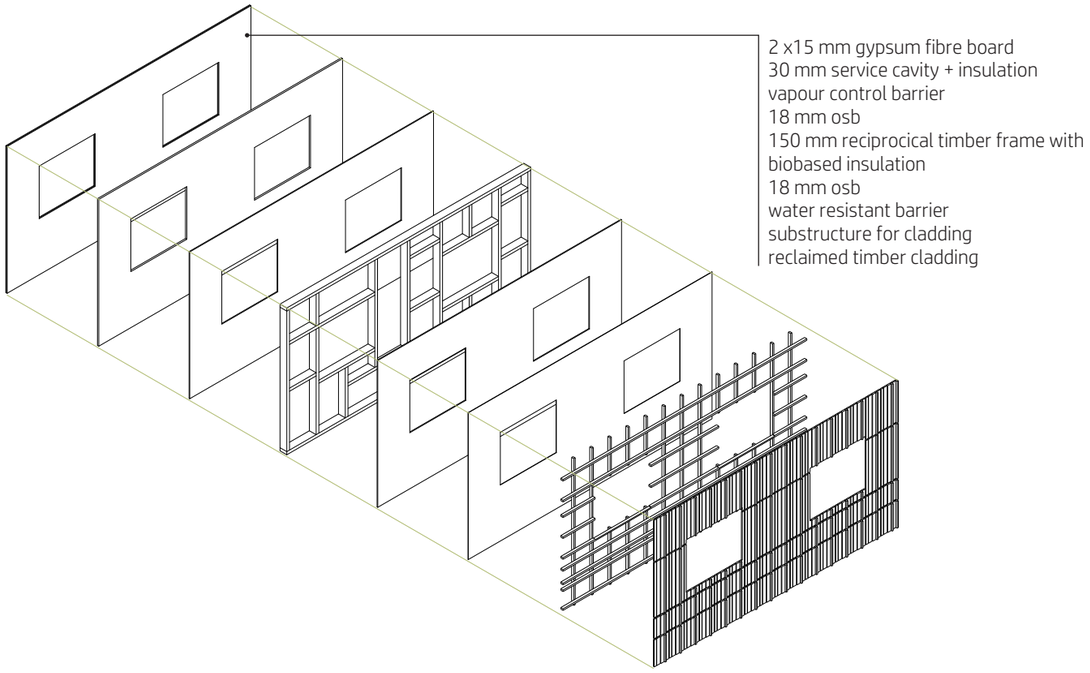


Illustration 44: example of build-up facade element, own illustration.

The first strategy is perfomance dirven and creates one spanning element between beams, where full-length timber elements are placed in the loadbearing direction. These elements form the primary load path, while the smaller reclaimed timber pieces are used to create stiffness in the element. This creates a clear structural logic. However, it depends on the availability of longer reclaimed timber elements. Another option would be a hybrid system, where the longer required pieces are made of virgin timber.

- clear and efficient load path
- lower risk of bending
- less adaptoable to variable stock
- virgin timber for longer pieces

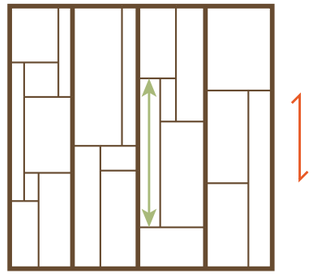


Illustration 45: single-span system, own illustration.

The second strategy is more system driven and combines multiple smaller timber frame elements into one larger floor system. These elements work together to distribute loads in multiple directions. This increases flexibility in the use of reclaimed timber, but may require more coordination and partial standardisation of dimensions. (nog meer uitleggen)

- flexibel system
- wide range of reclaimed timber sizes
- more connections between elements
- structural behaviour less direct

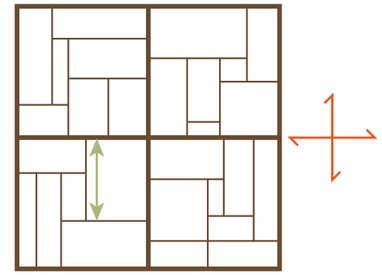


Illustration 46: modular system, own illustration.

The third strategy is material-driven and focuses on creating a direct load path using smaller reclaimed timber elements. The shorter pieces are first sawn to a limited number of standard sizes, for example x, y and z. These pieces are then stacked, with smaller elements placed perpendicular to them.

Together, this forms continuous structural members with a clear load path. This approach allows the use of widely available reclaimed timber stock and more predictable structural behaviour. However, it requires additional processing, results in a higher amount of material loss and reduces the level of direct reuse.

- flexibel system
- wide range of reclaimed timber sizes
- more connections between elements
- structural behaviour less direct

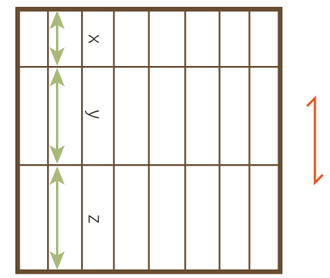


Illustration 47: built-up system, own illustration.

Which strategy is most suitable depends on the available reclaimed timber stock, the required span and the expected loads. The challenge is to balance structural performance and to maximise direct reuse.

6 future reuse potential

In short, the timber frame element is a multifunctional system. While all elements are based on the same principle, small differences occur depending on their application. This also applies to their reuse potential. Due to the layered and modular composition, the system has a high potential for future reuse.

The reuse of the element can be approached on two levels: reuse of the element as a whole, and reuse of the individual timber pieces within the element.

Reuse as a whole
First, it is preferred to reuse the element as it is for as long as possible. This ensures that the stored carbon remains locked in the material and avoids additional emissions, except for relocation or transport. Internal walls are the easiest to reuse, as they are not structurally fixed and can be repositioned when the spatial layout changes. This means the floor plan and the elements can adapt over time.

(evt Plaatje van plattegrond die anders is > anders in design part waar wordt uitgelegd dat het ontwerp inspeelt op de behoeftes van wittenburg nu en in de toekomst anders)

The partition wall can be seen as a combination of two internal walls. This means it can be separated into two elements and reused as internal walls, partition walls or potentially upgraded into facade elements. Internal walls are expected to change most frequently. However the partition walls should remain equally adaptable, as they only differ in their additional layers.

Floor elements are less likely to change position within a building. However, they can still be reused at the scale of the building or in a new project if dimensions and connections allow it.

To make reuse between different projects more feasible, a level of standardisation is beneficial. If elements follow common dimensions, similar to structural grids used in the Netherlands, they become easier to apply in different contexts. For example, wall elements could follow a height of approximately 3 meters. And floor elements could relate either to a 6-meter structural grid (common in timber construction) or a 2.4-meter grid based on reclaimed timber availability.

Disassembly to singular elements
The second level of reuse is the disassembly of the element into individual timber components. Based on the knowledge from the stock chapter, the element can be detailed to support this process. Connections are preferably made using timber dowels, or metal dowels where more strength is required.

These connections create weak points in the timber. When the element is dismantled, the ends of the timber pieces are weakened and might need to be cut off in future applications. This results in a loss of material.

However, the use of dowel connections allows for easier disassembly and better separation of materials, especially when wooden dowels are used. This improves sorting into the correct timber classes (A, B or C), making further cascading more effective. Moreover, the use of wooden dowels improves the circularity of the element. However, their structural reliability and durability require further investigation within this research.

2.4 Finishing layers

There are multiple finishing layers needed, for the floor, walls and ceilings. These need different qualities. A floor needs to be able to be used for a longer period of time, so durability is important. Walls could have this cool look, maybe for the shared spaces, to make people aware of the reused timber. But others have to be ‘housing’ friendly.

1 characteristics of the element

The interior and exterior finishing layers are the last to be discussed reclaimed timber elements. These layers are non-structural, but are an important part of the building as they are visible and directly influence the experience of the space.

Planks account for approximately 12% of the reclaimed timber stock from the demolition and construction sector. There are many ways to use reclaimed timber as a finishing material, this part explores three potential ideas.

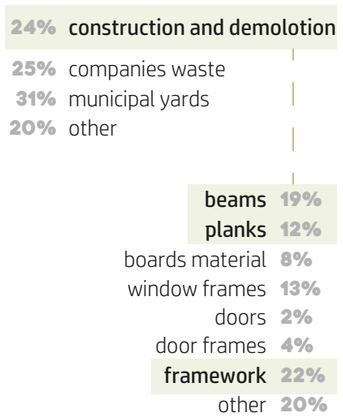
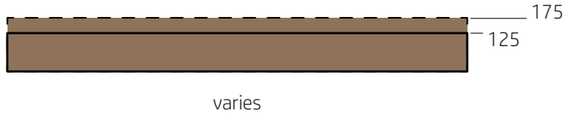


Illustration 48: distribution of construction and demolition waste, own illsutration.

timber floorboards:



timber stripflooring:



Illustration 49: distribution of construction and demolition waste, own illsutration.

Floor, walls, ceilings and exterior cladding need finishing layers. These require different qualities, although the build-up could be similar.

Firstly, for interior finishes safety and usability are important. Reclaimed timber can contain damage, such as nails, splinters and uneven surfaces. Therefore, nails should be removed an timber should be sanded where necessary to create a safe and even surface.

The floor needs the highest performance, as it has to withstand wear over time and provide an even walking surface. Walls and ceilings however, can allow for more architectural expression.

Secondly, for exterior finishes, weathering is the main challenge. The reclaimed timber stock contains many different species and qualities, as a result the timber weather differently. Therefore, the design should first protect the cladding as much as possible. Secondly the individual timber pieces should be easily replaceable, as some pieces will decay faster than others.

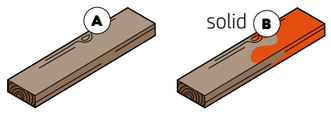
2 suitable timber stock

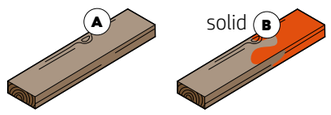
The potential reclaimed timber stock for finishing layers consists out of floorboards, strip flooring and unknown smaller timber pieces. Floorboards and strip flooring are the most directly applicable for finishing layers, as their function stays the same. However, the finishing layers proposes a chance to use smaller pieces, especially in more architecturally expressive strategies.

3 required transformation

For floors, ceilings, walls and cladding similar systems can be applied. However, depending on the element small changes need to be made.

There are three transformation strategies proposed. They range from labour intensive to standardized.





Architectural expression
The first option is to use the smaller reclaimed timber pieces and stack them to create a three dimensional finishing layer. This labour intensive strategy creates a finish with a lot of architectural expression and clearly shows the reclaimed character of the timber.

However, this strategy takes more time and creates an uneven surface. Therefore, it may be more suitable for smaller project or specific spaces within a design. At the same time, this strategy offers a way to reuse smaller timber pieces that otherwise would be used for incineration or downcycled.

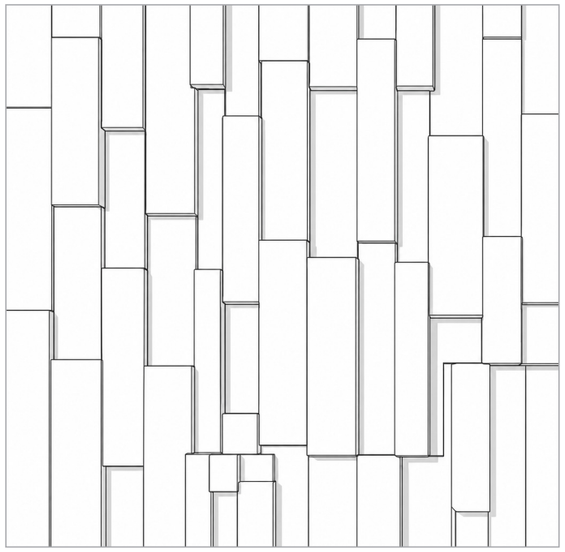


Illustration 50: three dimensional finishing layer, own illustration.

Mode of the stock
The second strategy is to saw the reclaimed timber in to the three most commons sizes within the available stock, based on the mode of the stock. This creates more cut-offs, but reduces the labour time significantly. This strategy may be more suitable for larger project. It also gives the designer more control over the architectural outcome, while the reclaimed character is partly maintained.

Standardized dimensions
The third strategy is to saw all timber to one standardized dimension. This creates an even result and a calmer architectural expression. Because the elements now all have the same size, the assembly process becomes faster and easier to prefabricate. However, this also creates the highest amount of offcuts.

4 assembly strategies

All three strategies can be assembled as prefabricated panels, this minimizes the construction time on site. However, the transportation of these elements has to be carefully considered. Damage can easily occur during transport and assembly.

Similar to the other reclaimed timber elements proposed in this research, using adhesives should be avoided and screws, bolts and other irreversible fixings should be minimized as much as possible.

For floor finishes, a click system or another dry assembly method could be implemented. This would make dismantling and future reuse easier. Although it does require more transformation of the timber time during production.

The potential for prefabrication differs per strategy. The more irregular and expressive systems require more manual labour, meanwhile the standardized strategies are easier to scale up and use in contemporary construction processes.

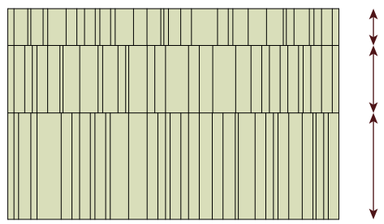


Illustration 51: dimensions based on mode of stock, own illustration.

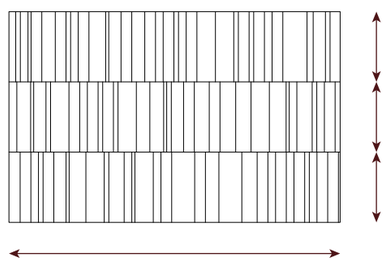


Illustration 52: standardized dimensions, own illustration.

5 design application

The finishing layer on the floor requires the highest level of safety and durability. Therefore, the floor surface should remain even and resistant to wear. For this reason, it is preferred to use floorboards and strip flooring rather than smaller reclaimed timber pieces. Interior walls and ceilings allow for more architectural freedom. Both the architectural expression strategy and the mode-based strategy could work well. The choice depends on the desired outcome.

For exterior cladding, it is advised to place the timber vertically. This way water can drain away more easily and the moisture retention is reduced.

Most of all, the choice between the three strategies is actually a balance between architectural expression, labour time, logistics and economics.

6 future reuse potential

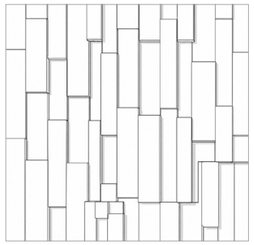
The smaller timber pieces used in a finishing layer, already are in one of the final stages of their direct reuse potential. However, this does not mean the material should not be used for as long as possible. For exterior cladding, protection against weather has an important role in prolonging the lifespan of the timber. Individual cladding pieces will likely only be removed once they no longer fulfil their purpose, thanks to decay or damage. Therefore, direct reuse of these pieces in the same application may become difficult.

For interior finishes, the future reuse potential is higher. Individual timber pieces can be dismantled and reused again in new finishing applications. Therefore, similar to the other reclaimed timber elements the connections should remain reversible.

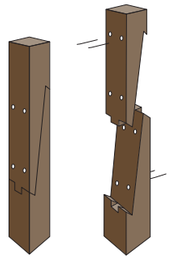
However, it is preferred to first reuse the finishing element as a whole before dismantling it into smaller pieces. For example, an interior finishing element may later be reused as exterior cladding in a future reuse cycle.

Until now, the reclaimed timber elements have been discussed individually. However, not all reclaimed timber applications are equally direct or have the same future reuse potential. Some elements preserve the timber almost as found, while others require greater processing and transformation. Similarly, the possibility of directly reusing the element in future cycles differs. Therefore, the developed elements are positioned along two axes on the next page: direct reuse to engineered and difficult to easier direct future reuse.

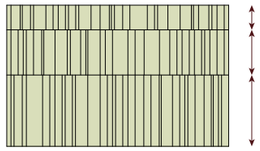
3D cladding/finishing layer



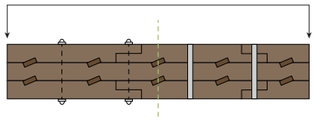
extended column



mode of stock based cladding/finishing layer

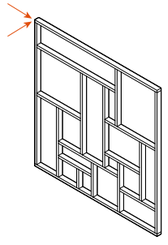


keyed beam

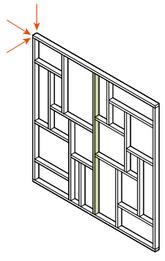


direct reuse

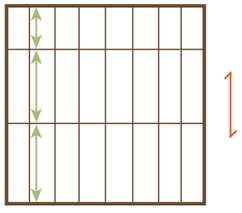
engineered



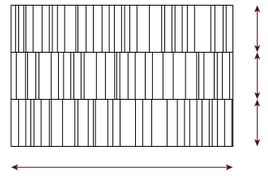
fully reciprocal timber frame



hybrid reciprocal timber frame



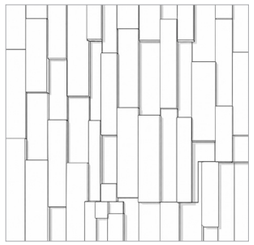
built up timber frame system



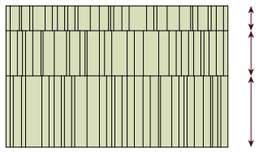
standarized cladding/finishing layer

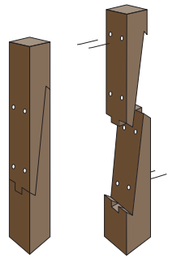
extended column

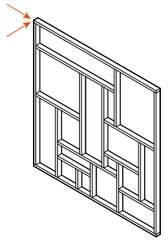
3D cladding/finishing layer



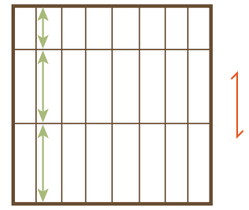
mode of stock based cladding/finishing layer







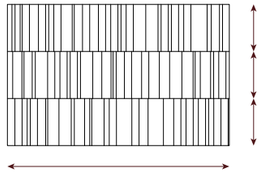
fully reciprocal timber frame



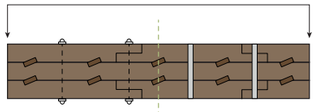
built up timber frame system

harder to future reuse directly

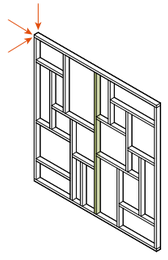
easier to future reuse directly



standarized cladding/finishing layer



keyed beam



hybrid reciprocal timber frame

IN PRACTICE

3. WITTENBURG CASE STUDY

The previous chapter shows how reclaimed timber can be translated into reclaimed timber building elements. Through analysing the stock and properties a series of structural and non-structural elements were developed. However, the application of these elements in architecture remains an important challenge. It is not only a matter of technical performance, but also spatial and architectural.

This chapter tests the developed elements through a case-study located in Wittenburg, Amsterdam. The aim is to explore how reclaimed timber elements can be applied within a topping-up strategy. The case-study is used to examine how the characteristics of reclaimed timber influence architectural decisions, such as the structural system, grid, spatial organisation and relationship between the existing and new building layers.

This chapter first introduces the location and explains why Wittenburg forms a suitable case-study for reclaimed timber topping-up. The focus initially lies on the construction characteristics of the neighbourhood and the post-war residential typology. These determine the opportunities and limitations for the topping-up. Secondly, the selected building and overall topping-up strategy are introduced. Finally, the chapter zooms in on the building method and application of reclaimed timber elements through a representative fragment of the building.

3.1 location

Starting from the Ontwikkelstrategie 2035 Amsterdam, several key principles guide the spatial development of the city. First of all, the city should grow within the existing city boundaries, rather than expanding into the surrounding green landscape. Secondly, new centres should be developed outside of the historical city centre to reduce pressure and establish new local identities. Thirdly, the city requires more green spaces to improve environmental quality and liveability. Furthermore, mobility should support sustainable and healthy movement through prioritising public space, reducing carbon emissions and encouraging walking, cycling and public transport. Finally, urban development should be realised collaboratively with residents, companies and governmental institutions.

These principles form the basis for selecting a suitable location for the case-study. In Amsterdam several neighbourhoods face spatial and social challenges. These are often characterised by small dwellings, low energy performance, maintenance issues and limited access to daily amenities. Research by the municipality of Amsterdam and the University of Amsterdam identifies several vulnerable neighbourhoods in the historical city centre, including the Marine-Establishment, Wittenburg and the Sarphatistrook. There is an opportunity to improve the current situation through an architectural intervention: topping-up of existing buildings. The Marine-Establishment is already undergoing redevelopment, which eliminates this location as a suitable case-study.

Wittenburg offers a unique opportunity for redevelopment. According to the Omgevingsvisie Amsterdam 2050 (Vos, Bogaart, et al., n.d.), Wittenburg can be classified as a luwe stadsbuurt. This means it is a relatively low-density urban neighbourhood with mainly residential functions and opportunities for greenery. This condition is unique considering Wittenburg' s central location and accessibility within Amsterdam. At the same time, the neighbourhood lacks programmatic diversity and spatial quality, creating opportunities for architectural intervention.



Illustration 53: luwe stadsbuurt (Omgevingsvisie 2050, n.d.)

The adjacent neighbourhood Marine-Establishment is currently being transformed into a knowledge district (kenniskwartier). This development will attract new users and activities to the area. As a result, the transformation could positively influence the surrounding Oostelijke Eilanden and increase the attractiveness of Wittenburg.

Wittenburg is part of the three Oostelijke Eilanden and is located between the Marine-Establishment and Oostenburg. These islands used to play an important role as harbour areas for the VOC. However, during the 1960s living conditions had worsened significantly and the municipality decided to demolish large parts of Wittenburg. During the same period Amsterdam faced a severe housing shortage. As a result, there was room for experimentation with new housing typologies, including collective forms of housing.



Illustration 54: Oostelijke eilanden, scale 1:10000, own illustration.

Because of this redevelopment, a large share of the current building stock on Wittenburg was built during the same period. Many of these buildings fall within the category of post-war residential buildings. In this research, Dutch post-war residential buildings are defined as residential buildings constructed between 1965 and 1980. These buildings are generally characterised by repetitive concrete structures, modular grids and flat roofs. Most buildings consist of four to eight storeys and are organised through a repetitive structural system, often based on the width of a single dwelling.

The buildings are mainly constructed in concrete. During this period concrete structures were often over-dimensioned, this results in buildings that are structurally overdimensioned. This creates opportunities for topping-up, as the additional load of the topping up can be accommodated by the existing structure. Furthermore, facades are generally non-load-bearing, allowing interventions to take place without affecting the structural system. The vertical circulation mainly consists of staircases and in some cases lifts. The repetitive character of the construction system is often expressed architecturally through the facade composition. This reinforces the standardised character of post-war housing.

These characteristics offer a great opportunity for topping-up. At the same time, the standardised logic of post-war housing forms an interesting contrast with the variability, uncertainty and irregularity of reclaimed timber. This creates an opportunity to test how reusable reclaimed timber elements can be integrated into a standardised building system.

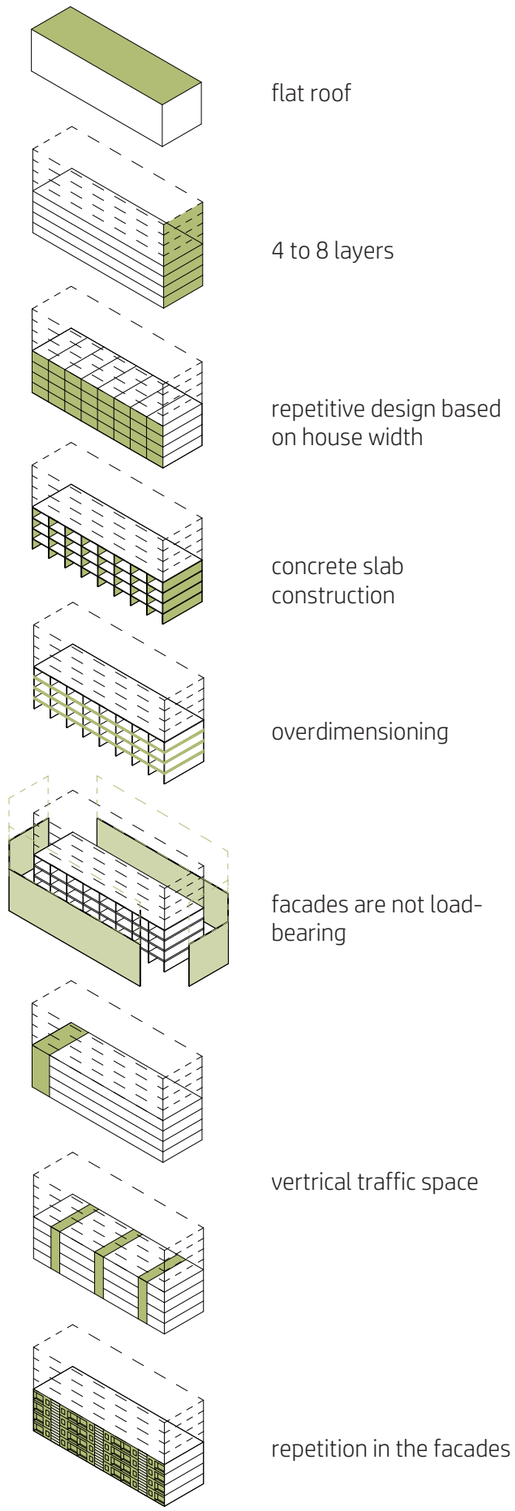


Illustration 55: post-war residential buildings, own illustration.

Figure 56, highlights the buildings on Wittenburg that fall within the category of post-war residential buildings. Buildings marked in the same tint of green represent repeated buildings within the neighbourhood. This highlights the potential impact of topping-up this typology. Rather than functioning as a one-off intervention, the topping-up could be applied at the scale of the entire neighbourhood.

3.2 the building

The selected building for the case-study are two mirrored U-shaped residential buildings. The buildings are identical and positioned towards each other, which together form an inner courtyard. This spatial configuration is one of the reasons for selecting the buildings. The courtyard creates opportunities for shared outdoor spaces and future interaction between residents.

The buildings fits within the category of post-war residential buildings described earlier. Their repetitive structural system, concrete construction and flat roofs make them suitable for a topping-up. Furthermore, because the same building typology occurs multiple times in Wittenburg. Which means the case-study can be seen as representative intervention instead of an one-off intervention.

The topping-up will be consist of two storeys and uses reclaimed timber elements. In the next chapter, the focus lies on the overall building structure and method. The architectural qualities and detailed spatial interventions will be discussed in later chapters.

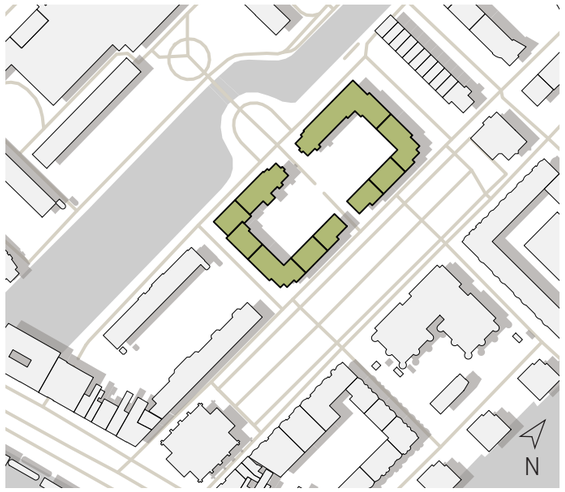


Illustration 57: selected buildings to top-up, scale 1:7500, own illustration.



Illustration 59: Wittenburg, topping-up stempelstructuur, source: google earth.

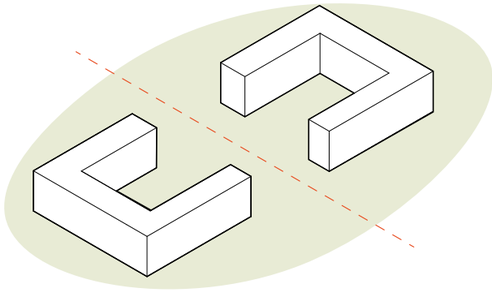


Illustration 58: symmetrical character selected building, own illustration.

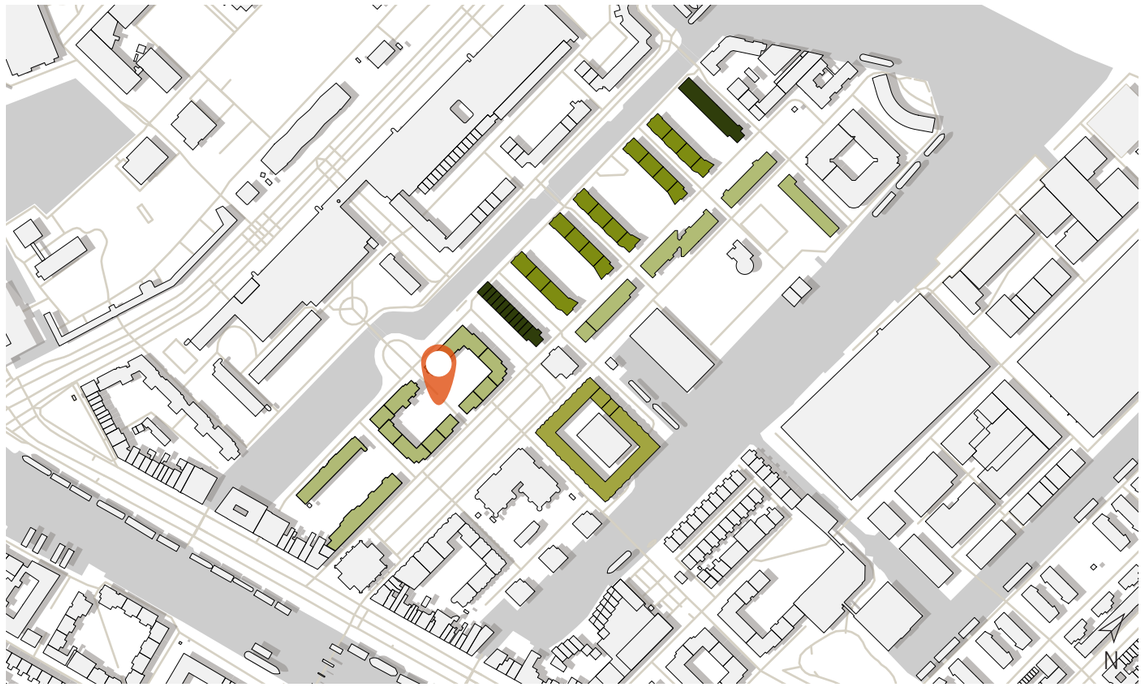


Illustration 56: post-war residential buildings in Wittenburg, Amsterdam, own illustration.



Illustration 60: selected buildings just after the opening, source: Amsterdam Archief



Illustration 61: neighbourhood celebration, source: Amsterdams Archief

4. A RECLAIMED TIMBER CONSTRUCTION

4.1 the structure

The existing buildings will be topped-up with two extra storeys using reclaimed timber as the primary construction material. Wittenburg has good conditions for construction and logistics. Around the buildings there is sufficient space to temporarily store materials and assemble elements on site. The space surrounding the buildings mainly consists of parking spaces and an asphalt playground. This creates the possibility for a temporary construction site directly next to the building.

Due to Wittenburg' s historic harbour and direct water connection, there is also the possibility to transport by ship. This could reduce disturbances caused by transport in the dense city centre of Amsterdam. Nevertheless, road transport remains a suitable option for delivering building materials and reclaimed timber elements to the site.

The topping-up follows the existing structural grid of 2700 and 5400 mm. The main structure of the existing building consists of concrete shear walls. The new primary structure of the topping-up consists of reclaimed timber beams and columns, directly above the existing system. This creates a direct load path from the new structure to the existing building.

Following the existing grid minimises the structural interventions in the current building. Moreover it aligns well with the reclaimed timber stock discussed in the previous chapters. Reclaimed timber is commonly available in shorter lengths and economically beneficial to transport and process in pieces between approximately 3 and 5 metres. Therefore, the existing repetitive structure has suitable conditions for using reclaimed timber into the new structure.

Using beams and columns as a system creates an open floorplan. This increases future adaptability of the building. The internal layers can change over time without affecting the primary load-bearing structure. To further support future flexibility and reuse, the structure is approached as three separate stable systems, as shown in Illustration 63. By separating the structural systems, future transformation, replacement or disassembly can happen independently on the three parts.

Prefabrication plays an important role in the construction strategy. Reclaimed timber elements are assembled as much as possible off-site and transported to the building in manageable sizes. This reduces construction time and disturbance for existing residents during the topping-up process.

In the following section, the construction method is explained step-by-step through a representative part of the building (illustration 62).

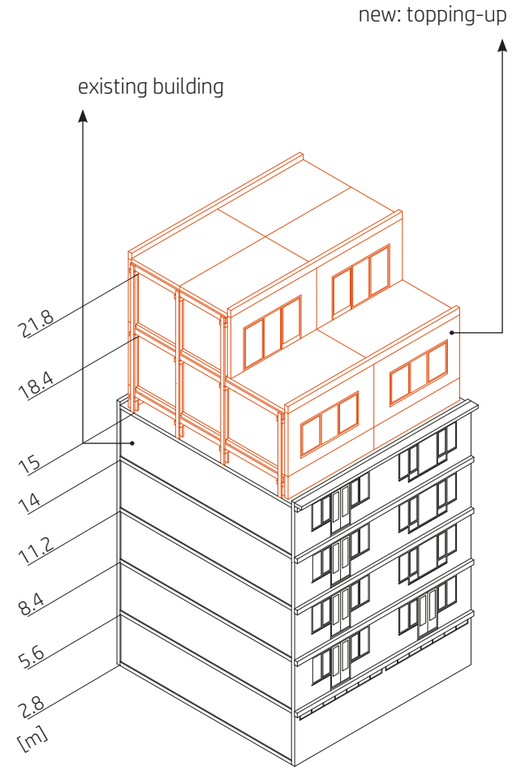


Illustration 62: representative part of the building, own illustration.



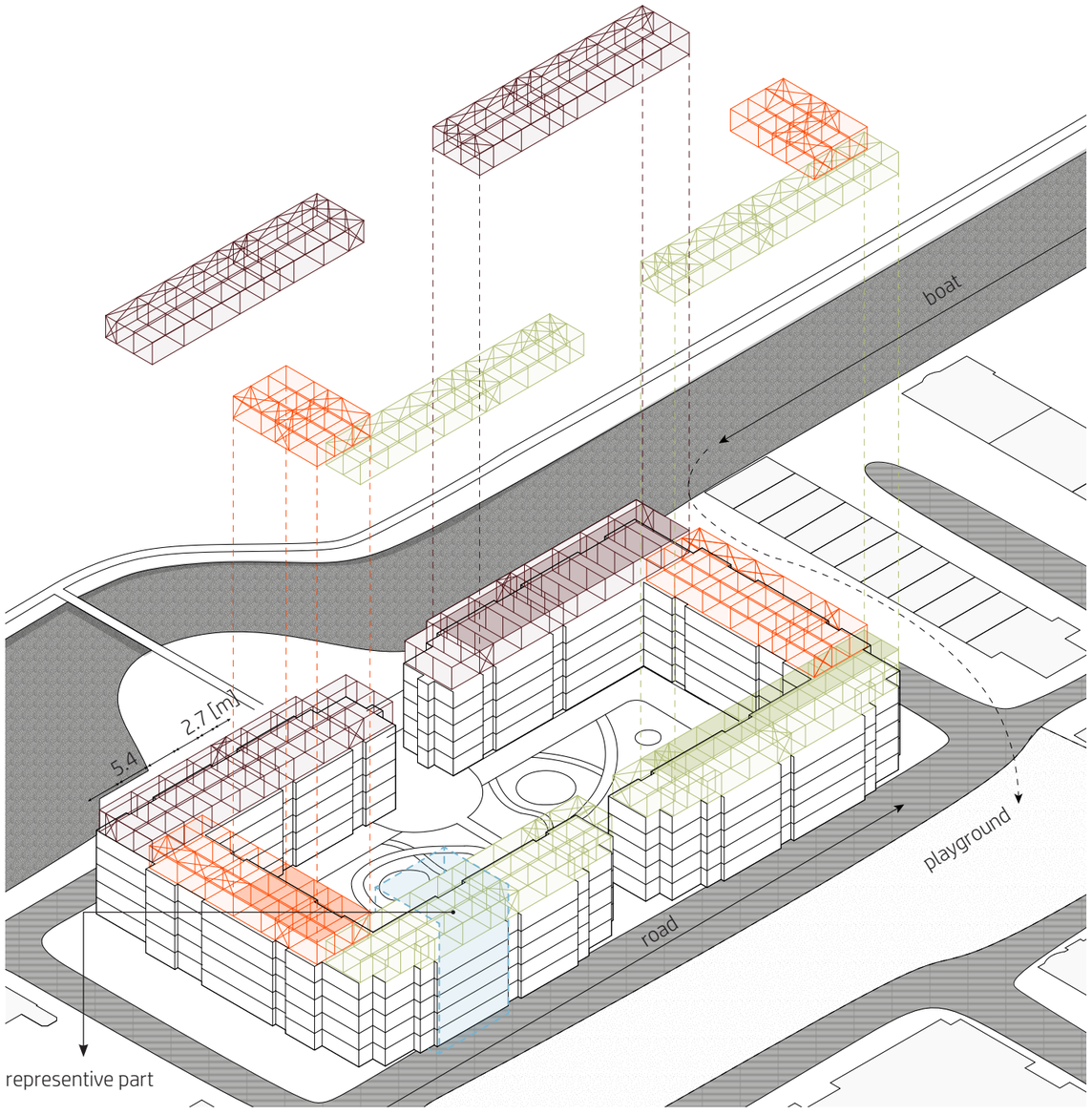


Illustration 63: primary structure and building site, own illustration.

4.2 step 1 primary structure

As mentioned before, the primary structure of the topping-up consists of reclaimed timber beams and columns. These structural elements are based on the extended and keyed beams developed in the Elements chapter. The reclaimed timber members are prefabricated as much as possible and transported to site in lengths that remain feasible for transport and handling.

On site, the beam segments are connected to create a continuous structural system. The structural grid follows the existing layout of the post-war building and positions the loads directly above the existing concrete shear walls. This way there is a direct load path from the topping-up towards the existing structure and reduces additional structural interventions.

The primary structure is fixed directly above the concrete shear walls to the existing roof structure through steel connections, see Illustration 64. To improve the durability of the timber, there is height difference between the concrete roof, steel connection and timber structure. This prevents direct exposure to possible moisture.

The stability is provided through steel rod bracing connected between the beams and columns. Compared to larger bracing systems, steel rods require limited space and can be integrated within the building system. Above all, the connections remain relatively easy to dismantle, which supports future reuse cycles.

The reclaimed timber structure is largely enclosed by secondary building elements, which contributes to the required fire resistance. The structural elements that remain exposed or cannot be sufficiently protected are encapsulated with gypsum boards. This creates a 60-minute fire-resistant layer while minimizing irreversible interventions to the reclaimed timber.

The structural grid depends on two main factors: the grid of the existing structure and the representative reclaimed timber stock. Although shorter reclaimed beams and joists can be extended and combined into larger structural members, it is still preferable to work with the most common timber lengths found in the stock. The research demonstrated that lengths between approximately 2.4 and 5 metres form the boundary between high availability and economic feasibility. Lengths below this range are often less viable to collect, while longer members become increasingly scarce and difficult to transport. Therefore, the spacing between the columns is based on this representative stock, allowing most reclaimed timber elements to be directly integrated with limited processing.

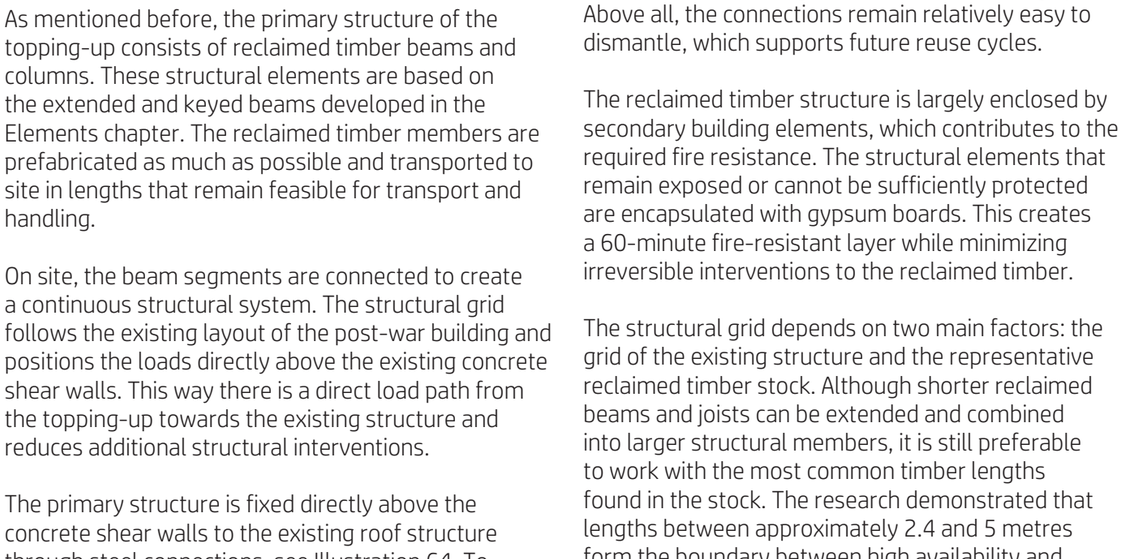


Illustration 64: schematic drawing of primary structure to concrete existing roof structure with steel rods, own illustration.

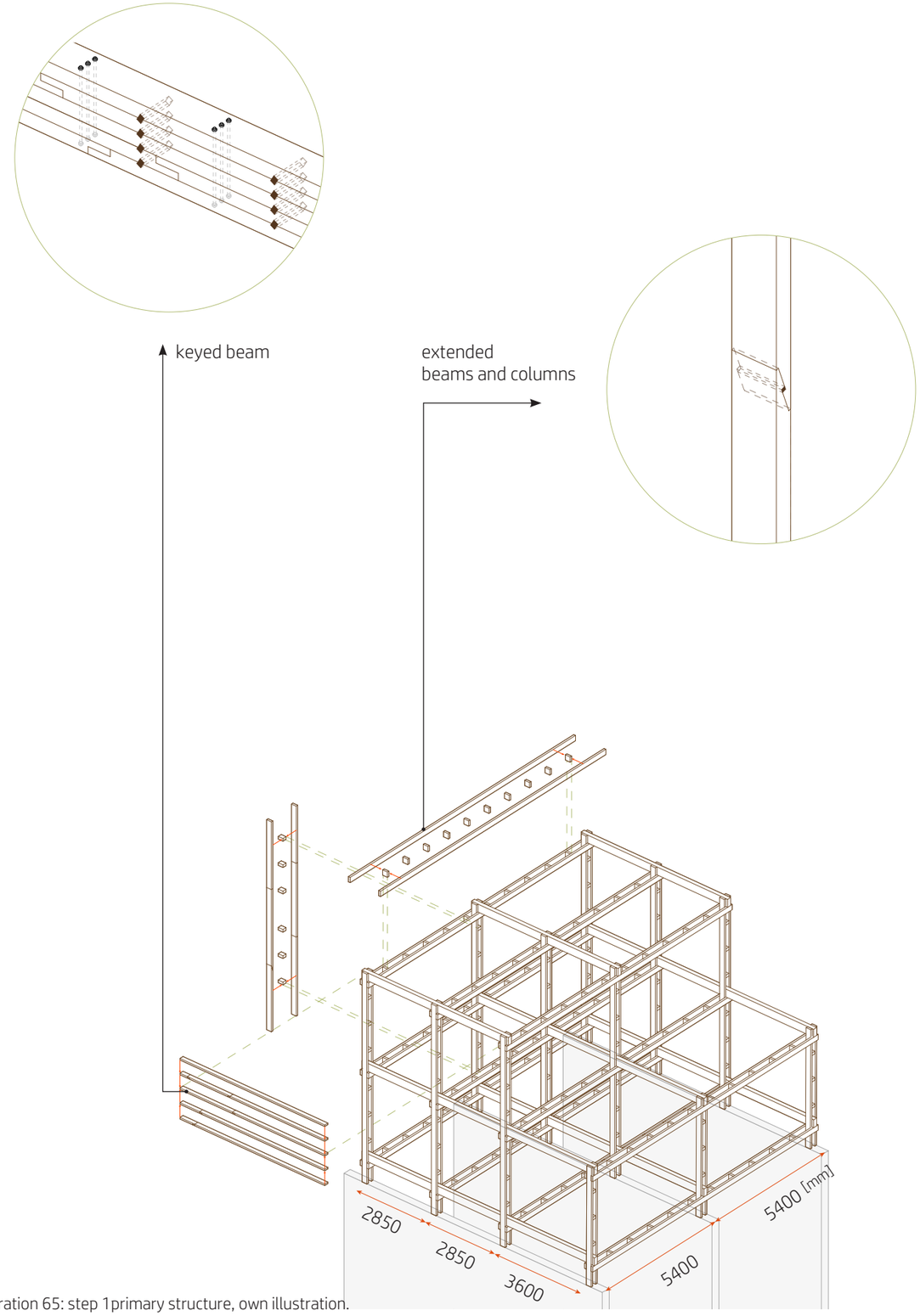


Illustration 65: step 1primary structure, own illustration.

4.3 step 2 floor elements

The next step is adding the floor elements to the structure. The floors are made out of reclaimed timber as well. The choice for the most standardised option, the built-up system discussed in the Elements chapter, is chosen because of the reliability and structural strength capacity. A floor element has larger structural demands compared to wall elements. Because it has to withstand vertical loads from users and interior. Therefore, a more standardised system is preferred. This most standardised option still uses reclaimed timber, however it requires more cutting. It has one direct load path, which works more efficiently compared to a reciprocal structure.

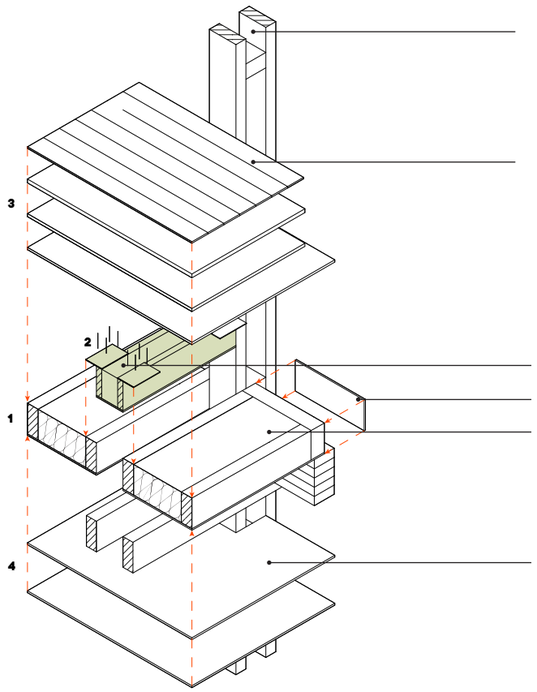
The prefabricated floor element consists of a timber frame, preferably from reclaimed timber if available in the stock. In between the outer frame, smaller reclaimed timber pieces, sawn to the same length, are used to create a stiff and structurally reliable element. The element includes biobased insulation within the timber frame and an OSB panel underneath and an acoustic panel on top of the structural element. These layers together improve the thermal, acoustic and structural performance.

The floor element rests directly on the reclaimed timber beams, see Illustration 67. The elements are placed on site with the help of a crane. As a result of the continuous beam structure, empty spaces between floor elements occur at the beam intersections. These spaces are filled with reclaimed timber and insulation and are hung in between the floor elements, see Illustration 68.

Acoustic performance is an important aspect in a residential buildings. Which is why to reduce the contact sound transmission between dwellings, the build-up includes a floating acoustic layer above the structural floor element. A dry floor heating system is placed above this layer, instead of using a wet construction method. A dry system allows for easier future dismantling. On top, the finishing floor layer can be applied. Depending on the function of the space, reclaimed timber floorboards can be used or more heat conductive materials can be used.

Between the floor elements on either side of the keyed beam, an acoustic material layer, such as wood fibre insulation, is applied. This ensures the floor elements do not directly touch each other and reduces the sound transmission through the structure.

The floor element is designed as a layered system. Different layers have different replacement cycles. For example, the finishing floor and installations can be replaced independently from the structural floor element. This supports the future adaptability and reuse of the building.



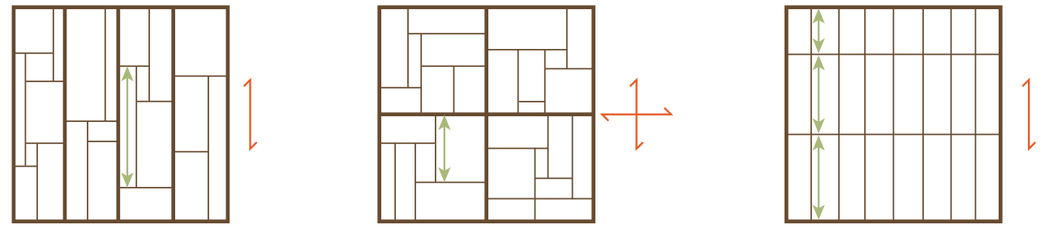
extended reclaimed timber beam with reclaimed timber blocking items in between

wooden floor finish
gypsum fibre dry screed board (25 mm)
aluminium heat distribution plates + underfloor heating (30 mm)
high-density biobased mat (10 mm)

filling piece between two floor elements
acoustic barrier (10 mm)
prefabricated reclaimed timber floor element with biobased insulation (200 mm)
OSB board (15 mm)

acoustic resilient channels (50 mm)
2 × gypsum plasterboard (2 × 12.5 mm)
wooden ceiling finish

Illustration 66: exploded view of floorelement to primary structure, own illustration.



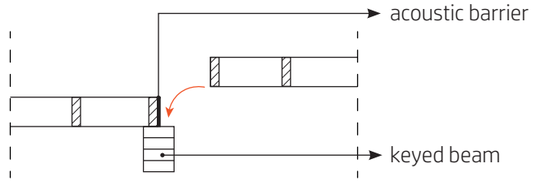


Illustration 67: schematic drawing of floor element on keyed beam, own illustration.

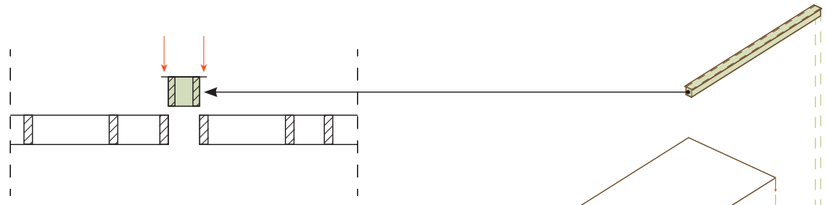


Illustration 68: schematic drawing of filling piece between two floor elements, own illustration

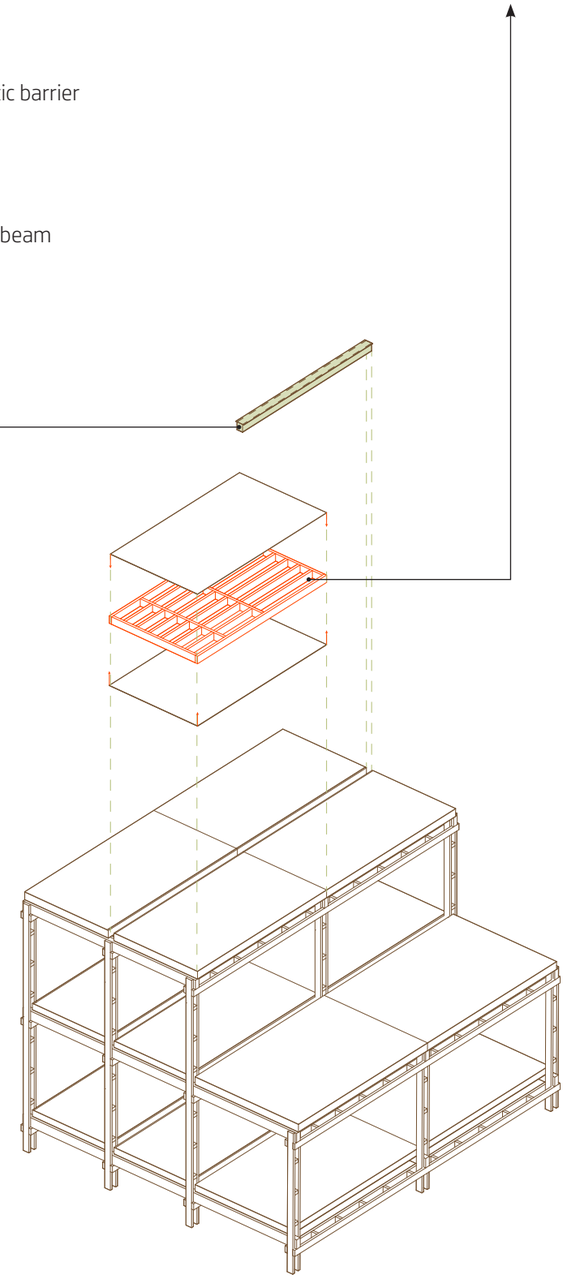


Illustration 69: step 2 floor elements, own illustration.

4.4 step 3 partition wall elements

The third step is adding the separation walls. These are the reciprocal reclaimed timber frame elements developed in the Elements chapter. The partition walls are positioned between the reclaimed timber beams and columns and stand on the floor elements. Because the primary structure remains independent from the separation walls, the layout of the dwellings can be adapted in the future without affecting the structural system.

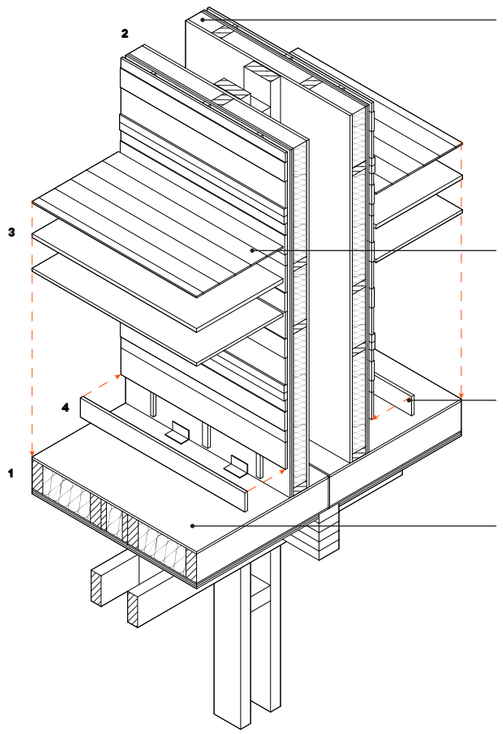
The order of assembly is important, see illustration 70. First, the floor elements are placed and connected to the keyed beams, including the smaller in-between floor pieces to create one continuous floor system. Secondly, the partition walls are positioned on top of the floor elements and connected to the columns of the primary structure. These prefabricated wall elements already include most of the finishing layers.

The partition wall consists of two separate reclaimed timber frame elements with a cavity in between, see illustration 71. This cavity improves the acoustic performance and creates a sound barrier between the dwellings. Together with insulation and finishing layers, the wall is meets the acoustic requirements for residential buildings.

After the partition walls are placed, the finishing layers of the floor can be added over the different floor elements. The final step is attaching the remaining reclaimed timber plank at the bottom of the wall. This plank is left open until the end of construction. This way the connection between the floor finishing and wall can be completed more easily. Meanwhile there remains access for electrical wiring and other installations hidden behind the wall.

Because of the continuous beam structure, the wall elements cannot always continue uninterrupted from floor to ceiling. Therefore, the separation walls are divided into smaller elements positioned around the reclaimed timber structure, see illustration 72. The finishing layers continue over the two elements. At the end there is a visually continuous wall system.

By placing the wall elements around the primary structure, the primary timber structure is protected by gypsum fibre boards. This creates a fire-resistant barrier of 60 minutes. The finishing layers are designed to be easily dismantled, which supports changes in the future and keeps the reclaimed timber elements reusable.



OSB board (18 mm)
prefabricated reclaimed timber wall element with biobased insulation (100 mm)
2 × gypsum plasterboard (2 × 12.5 mm)
reclaimed timber studs
prefabricated reclaimed timber finsihing layer

wooden floor finish
gypsum fibre dry screed board (25 mm)
aluminium heat distribution plates + underfloor heating (30 mm)

reclaimed timber plank

high-density biobased mat (10 mm)
prefabricated reclaimed timber floor element with biobased insulation (200 mm)
OSB board (15 mm)
acoustic resilient channels (50 mm)
2 × gypsum plasterboard (2 × 12.5 mm)
wooden ceiling finish

Illustration 70: exploded view of floorelement to primary structure, own illustration.

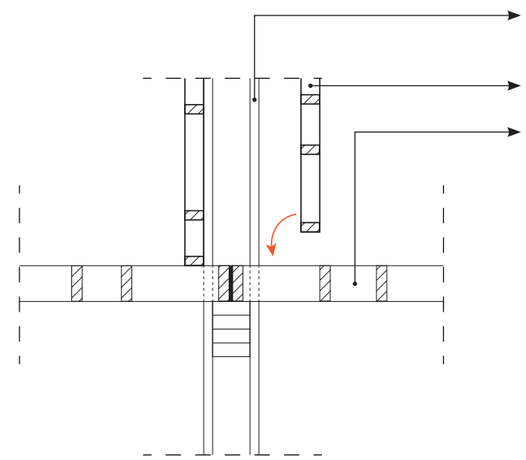


Illustration 71: schematic drawing of two timber frame elements placed against the primary structure and on top of the floor elements, own illustration.

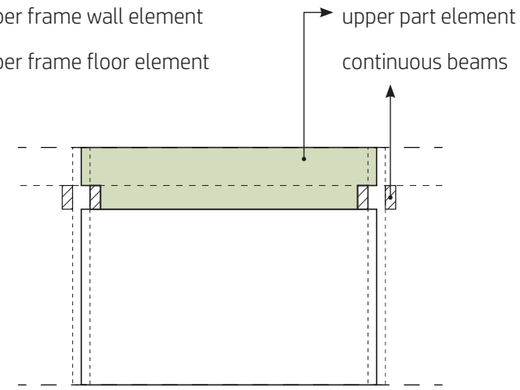


Illustration 72: schematic drawing of two timber frame elements placed on top of each other as a result of the continuous structure, own illustration.

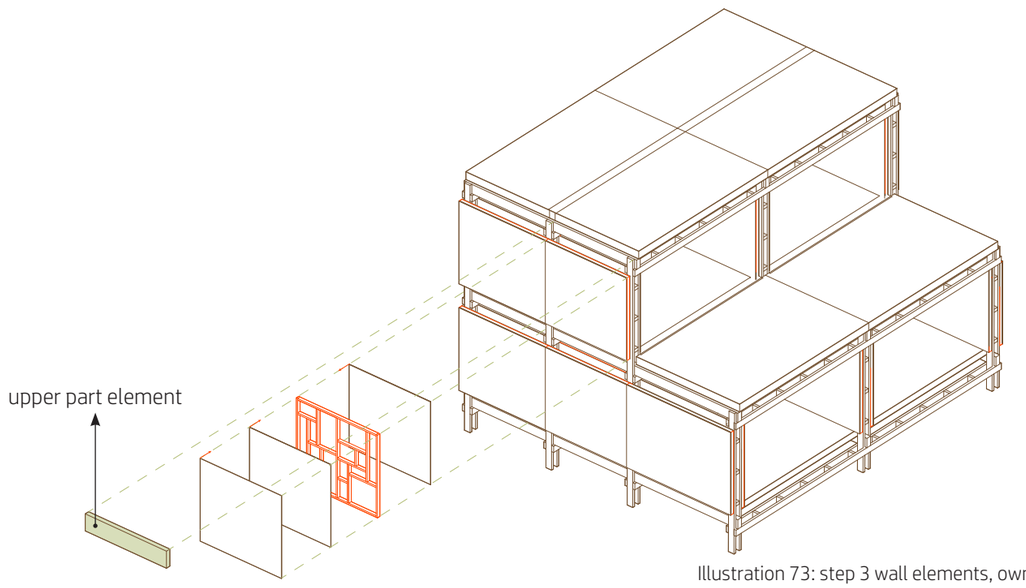


Illustration 73: step 3 wall elements, own illustration.

4.5 step 4 facade elements

The final step is the facade element. The facade closes off the building from external influences such as weather and temperature changes. The built up is similar to the reciprocal wall elements, However, the additional layers and detailing differ because of the climatic demands.

The facade element is designed as a prefabricated and non-load-bearing element connected to both the primary structure and the floor elements. This allows the facade to be assembled efficiently on site and remain independent from the primary load-bearing structure.

The facade build-up consists of multiple layers, each with their own function and replacement cycle. Starting from the outside, the reclaimed timber cladding is applied. Behind the cladding, a ventilated cavity with horizontal and vertical battens ensures that moisture can dry out and reduces the risk of timber decay. This is followed by a weather-resistant layer and a biobased board attached to the reciprocal timber frame. Within the timber frame, biobased insulation is placed to achieve the thermal performance required for contemporary residential buildings.

Towards the inside, another biobased board closes off the timber frame, followed by a vapour control layer. The final interior layer consists of two gypsum boards, which improves the acoustic performance and fire resistance. Together, these layers contribute to an approximately 60-minute fire-resistant facade element.

Because reclaimed timber cladding has a shorter lifespan due to weather exposure, the cladding layer is designed to be easily dismantled and replaced. Since reclaimed timber consists of unique pieces with varying characteristics, it is difficult to predict exactly when individual elements will deteriorate. Therefore, periodic maintenance inspections are required to determine which reclaimed timber pieces need replacement.

After approximately twenty to thirty years, a large share of the facade cladding is expected to have deteriorated. At this stage, the facade can be recladded using the reclaimed timber stock available at that moment. As a result, the appearance of the facade may gradually change over time. This expresses the variability and evolving character of reclaimed timber. Meanwhile, the inner structural layers of the facade can remain in place for a much longer period of time. This supports future reuse and replacement strategies.

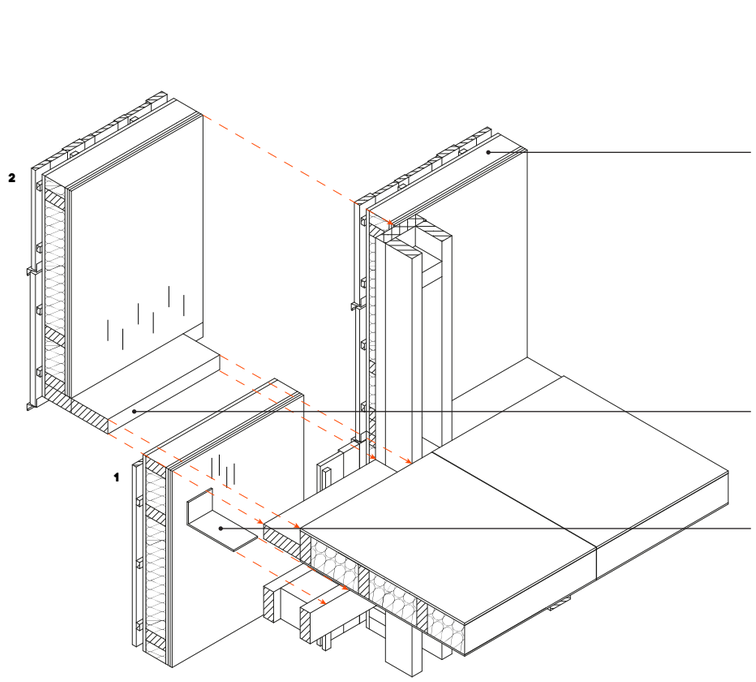


Illustration 74: exploded view of facade element to primary structure and floor element, own illustration.

The facade element is connected to both the floor and primary structure and works as a panelised facade system. Since the facade is directly exposed to wind forces, particular attention is given to the facade connections. Wind loads are transferred back to the primary structure through the panel connections. The facade joints are designed to respond to tolerances, moisture movement and thermal expansion, while maintaining structural stability.

The upper connection to the primary structure is semi-fixed and allows for movement caused by tolerances, moisture and thermal expansion (see Illustration 76). In contrast, the facade to floor connection is fully fixed and provides structural support (see Illustration 76). The connections between facade elements are designed to prevent water penetration and thermal bridging, while maintaining continuity between the prefabricated panels.

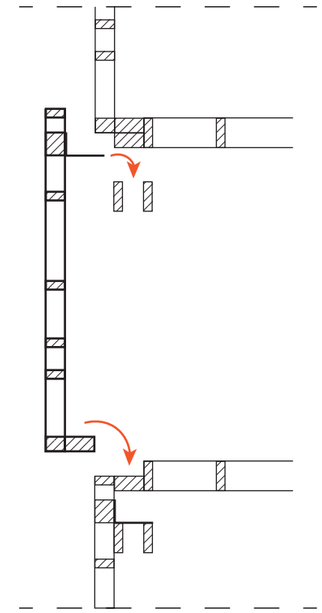


Illustration 76: schematic drawing of panelised facade system, own illustration.

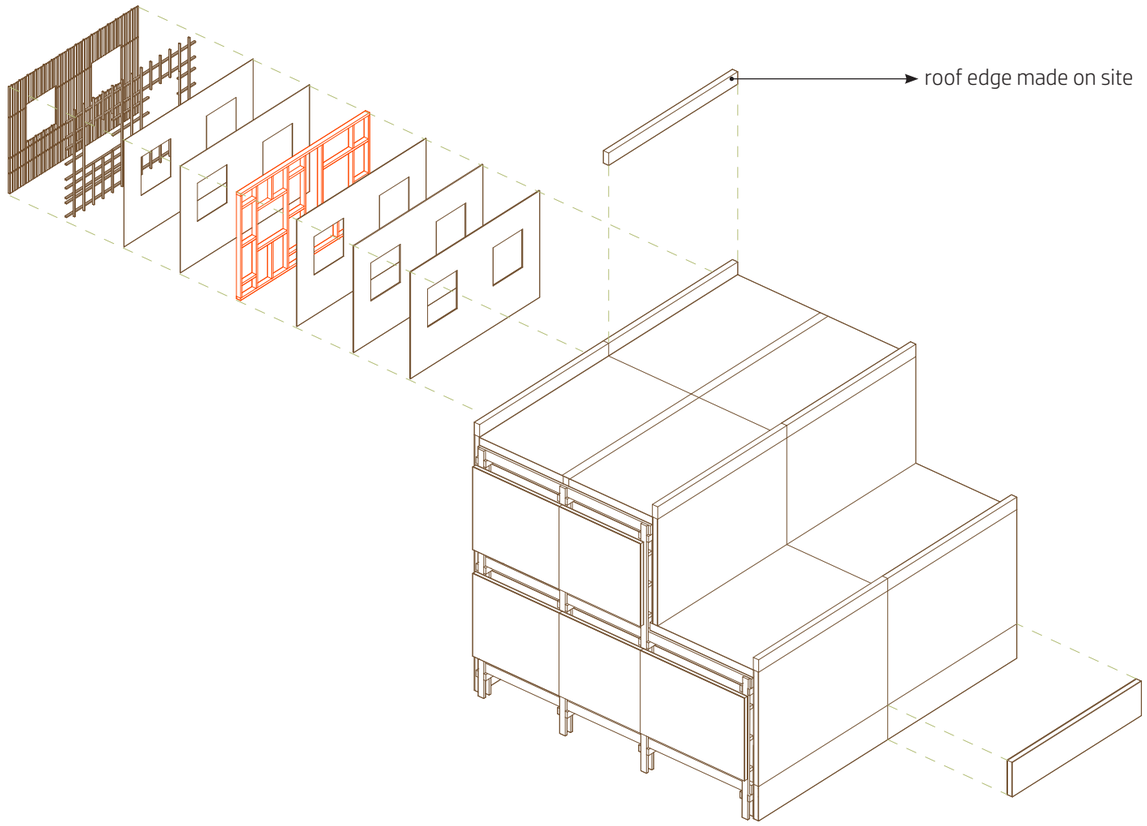


Illustration 75: step 4 facade elements, own illustration.

In short, the construction of the topping-up consists of three independently functioning parts per building and can be divided into four construction steps. First, the primary reclaimed timber structure is assembled, which consists of beams, columns and stability elements. Secondly, the floor elements are positioned between the primary structure. Thirdly, the timber frame elements are connected to the structure, creating the facade and interior walls. Finally, the finishing layers and additional building components are added. Together, these steps create a prefabricated and layered building system, in which the different building layers can be moved, disassembled and replaced over time.

Note: stability of the structure

The overall stability of the topping-up is created with the help of steel rods connected to the primary structure, as explained. However, the timber frame elements also contain biobased panels which could be OSB panels. These panels are able to resist tension and shear forces within the element itself, creating stiffness on a smaller scale. This means that the timber frame elements could also contribute to the overall structural stability of the topping-up.

Nevertheless, the initial idea of this research was to create a structure that stands independently from other building elements. This allows the facade and wall elements to remain non-load-bearing and easier to dismantle or replace in future reuse cycles. In other configurations, the timber frame elements could be designed to function as stability elements as well.

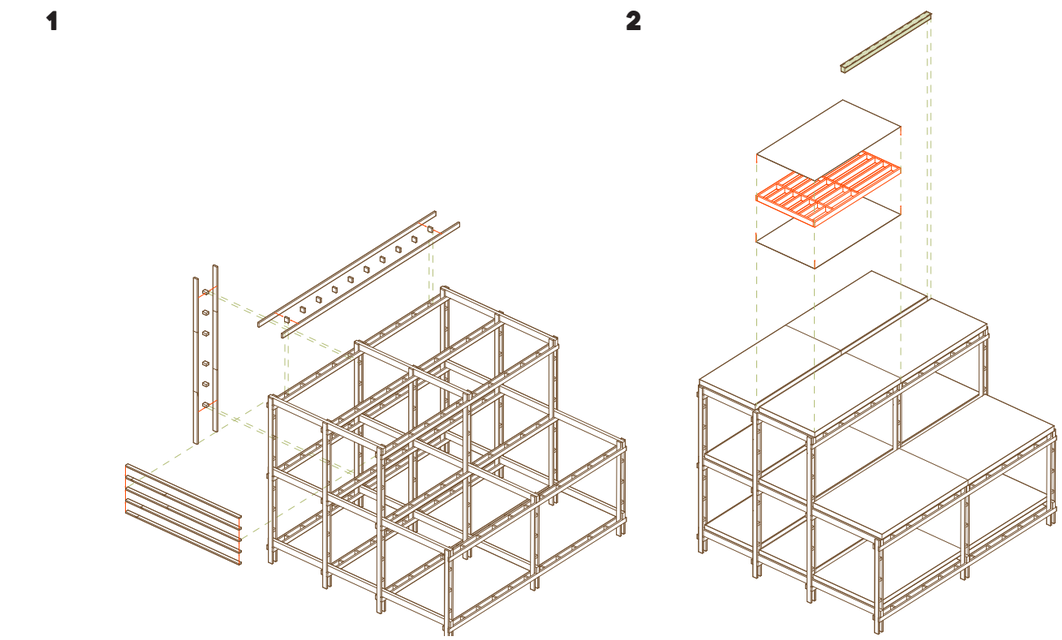


Illustration 77: exploded view of construction sequence, own illustration.

4.6 CO_2 reduction

At the beginning of this research, the problem of the building industry emitting large amounts of carbon was addressed. Designing and building with reclaimed timber is explored in this research as a possible response to this challenge. To understand the environmental impact of designing with reclaimed timber, a CO_2 calculation is made. To estimate the environmental impact of the design, the same representative building fragment used throughout the research is applied to calculate the potential CO_2 reduction. This fragment can subsequently be translated into an estimation for the entire topping-up.

For the calculation, the information gathered in the stock chapter is used. According to WRAP (2006), directly substituting new timber with reclaimed timber saves approximately 0.5 kg CO_2 per kg of material, which equals an average saving of approximately 225 kg CO_2/m^3 timber. For surface applications, this translates to an average saving of approximately 7.2 kg CO_2/m for hardwood and 4.3 kg CO_2/m^2 for softwood. These values are based on direct substitution and represent an average estimation. However, the exact amount of embodied carbon reduction depends on multiple factors, such as transport distances, processing, timber species and other project-specific influences.

There is no clear data available on the ratio between hardwood and softwood within the Dutch reclaimed timber stock. Therefore, an exact calculation of the CO_2 reduction is not possible. The availability of timber species depends on factors such as building typology, construction period, demolition practices and local supply. For this reason, this research applies a scenario-based estimation to indicate the potential environmental impact of reclaimed timber. For each building element, three different scenarios are explored: a predominantly softwood stock (A), a mixed stock (B) and a predominantly hardwood stock (C). This creates a realistic bandwidth for the potential CO_2 reduction instead of a single fixed outcome.

A	80/20	predominantly softwood stock
B	50/50	mixed stock
C	20/80	predominantly hardwood stock

Illustration 78: three stock scenarios

Primary structure

The primary structure consists out of reclaimed beams and joists from the stock, transformed in to extended and keyed elements. According to the stock analysis, the most common species are oak, pine, elm, teak and jarrah (Opalis, n.d.). These species consist mostly hardwood, except for pine which is a softwood. Since each timber species has a different density, a direct calculation based on kg/m^2 is not suitable for structural elements. Instead, the CO_2 reduction of the primary structure is calculated based on the volume of the timber. This will then be combined with an estimated average density and the direct substitution factor of 0.5 kg CO_2 per kg of reclaimed timber (WRAP, 2006). There is no clear data available on the ratio between hardwood and softwood in the Dutch reclaimed timber stock. Therefore three different scenarios are explored. Each scenario represents a different composition of the reclaimed timber stock and therefore a different average density:

A) Predominantly softwood stock (80/20) → 560 kg/m^3
B) Mixed stock (50/50) → 650 kg/m^3
C) Predominantly hardwood stock (20/80) → 740 kg/m^3

The primary structure of the representative building fragment contains approximately 9.39 m^3 of reclaimed timber. This means the estimated CO_2 reduction ranges from 2.63 to 3.47 tonnes CO_2.

Timber frames

Next are the timber frame elements. These elements are used in the floors, internal walls and facade elements. However, the amount of reclaimed timber used differs per application. Floors require more structural capacity than walls and facades, these differences can be seen in the built-up step 2 to 4 in the last paragraphs.

The reciprocal timber frame elements do not have a fixed and repetitive internal layout, this means that the amount of timber per element is difficult to determine. Therefore, the calculation uses a simplified timber intensity per square metre. The calculation separates floors, walls and facade elements.

The timber frame elements are primarily made from reclaimed studwork from the defined timber stock. According to the stock analysis, the studwork mainly consists of softwood species, particularly pine. Therefore, the predominantly softwood scenario can be considered the most realistic estimation for the timber frame elements. Nevertheless, the other two scenarios are also included to create a bandwidth for the potential CO_2 reduction and to take in account the variation of the reclaimed timber stock.

The timber frame elements contain together approximately 22.31 m^2 of reclaimed timber. Depending on the assumed timber stock scenario, the estimated CO_2 reduction ranges from approximately 6.25 to 8.26 tonnes CO_2.

element	area	timber intensity	volume
floors	267,13 m^2	0,045 m^3/m^2	12,02 m^3
walls	202,83 m^2	0,025 m^3/m^2	5,07 m^3
facades	173,88 m^2	0,030 m^3/m^2	5,22 m^3

Cladding

The last layer taken into account in this calculation is the reclaimed timber cladding used for the facades and partition walls. Because the facade and wall elements include openings such as windows and doors, the total cladding surface is reduced by 20% to create a more realistic estimation.

The cladding consists of various reclaimed timber species, often smaller timber sections or timber that is not structurally sufficient for other applications. This means that the ratio between hardwood and softwood can vary significantly depending on the available stock. Therefore, the same three timber stock scenarios are applied.

After correcting for openings, the total reclaimed timber cladding surface equals approximately 81.13m^2 (20% of 101,4172 m2). Depending on the assumed timber stock scenario, this results in an estimated CO_2 reduction ranging from approximately 0.40 to 0.54 tonnes CO_2.

scenario		density	volume	timber weight	CO_2 reduction
A	80/20	560 kg/m^3	9,39 m^3	5256 kg	2628 kg CO_2
B	50/50	650 kg/m^3	9,39 m^3	6101 kg	3051 kg CO_2
C	20/80	740 kg/m^3	9,39 m^3	6946 kg	3473 kg CO_2

Illustration 79: estimated CO_2 reduction of reclaimed timber structure based on three stock scenarios

scenario		effective cladding area	volume	timber weight	CO_2 reduction
A	80/20	560 kg/m^3	22,31 m^3	12.494 kg	6247 kg CO_2
B	50/50	650 kg/m^3	22,31 m^3	14.502 kg	7251 kg CO_2
C	20/80	740 kg/m^3	22,31 m^3	16.510 kg	8255 kg CO_2

Illustration 80: estimated CO_2 reduction of reclaimed timber frames based on three stock scenarios

scenario		effective cladding area	volume	CO_2 factor	CO_2 reduction
A	80/20	81.13 m^2	22,31 m^3	4,88 kg CO_2/m^2	396 kg CO_2
B	50/50	81.13 m^2	22,31 m^3	5,75 kg CO_2/m^2	467 kg CO_2
C	20/80	81.13 m^2	22,31 m^3	6,62 kg CO_2/m^2	537 kg CO_2

Illustration 81: estimated CO_2 reduction of reclaimed timber cladding based on three stock scenarios

Total CO2 reduction

In short, the representative building fragment shows the environmental potential of designing with reclaimed timber across different building layers: the primary structure, timber frame elements and cladding. The results differ depending on the assumed ratio between hardwood and softwood within the reclaimed timber stock. Therefore, three scenarios are explored to create a realistic bandwidth for the potential CO_2 reduction. Although many different combinations are possible, this research applies three representative stock compositions to estimate the environmental impact.

The representative building fragment results in an estimated CO_2 reduction of approximately 9.28 tonnes CO_2 in the predominantly softwood scenario (A), 10.77 tonnes CO_2 in the mixed stock scenario (B) and 12.27 tonnes CO_2 in the predominantly hardwood scenario (C). The representative building fragment can be applied approximately eleven times within the topping-up. This means that the estimated total CO_2 reduction ranges between approximately 102 and 135 tonnes CO_2, with the mixed scenario resulting in approximately 118 tonnes CO_2 reduction.

Because the building is symmetrical, this environmental impact could be doubled. To illustrate the scale of this reduction, the estimated CO_2 saving of the topping-up is comparable to approximately 200 return flights between Amsterdam and Barcelona. The amount depends on the scenario.

In conclusion, the calculation indicates that designing and building with reclaimed timber can contribute positively to reducing the embodied carbon emissions of the building industry. While the calculation gives an indicative estimation it is not an exact outcome. It more so demonstrates the environmental relevance of reclaimed timber as an architectural design principle for topping-up strategies.

scenario	representive building fragment	1 building (11 x fragment)	2 buildings
A	9,28 ton CO_2	102,08 ton CO_2	204,16 ton CO_2
B	10,77 ton CO_2	118,47 ton CO_2	236,94 ton CO_2
C	12,27 ton CO_2	134,97 ton CO_2	269,94 ton CO_2

Illustration 82: total estimated CO_2 reduction on three stock scenarios

4.7 facade fragment 1:20

The 1:20 detail demonstrates how the reclaimed timber elements, existing structure, installations and climatic layers come together to form a functioning building. The previous chapters explain the logic of the reclaimed timber stock, building elements, construction methodology and embodied carbon. This section focuses on how these systems are integrated at the scale of the building detail, see appendix for bigger scale and see next page for full 1 to 20 fragment.

Transition between old and new

The columns of the topping-up rest on the existing load-bearing structure through a steel connection. In this way, the new loads are transferred directly to the existing structure, minimizing interventions to the current building.

Between the existing concrete roof and the new floor of the topping-up, a technical transition zone is introduced. This intermediate layer accommodates the transition between the old and new building systems.

The existing shafts are not always aligned with the spatial organisation of the topping-up apartments. Where alignment is not possible, installations need to be redirected horizontally before entering the new dwellings. This transition space therefore accommodates bends and connections for ventilation, sewage, electricity and other technical systems.

In addition, the transition space accommodates the technical systems required for the topping-up, including mechanical exhaust ventilation for kitchens, bathrooms and toilets. Fresh air is supplied naturally through operable windows, reducing the technical complexity of the topping-up while maintaining indoor comfort. The mechanical exhaust outlets are oriented towards the street facade to prevent unwanted smells towards the gallery and inner courtyard.

The installation space also accommodates the systems needed for heating. The dwellings are heated through a low-temperature floor heating system integrated within the dry floor build-up. This allows compatibility with future sustainable heating systems, such as heat pumps, while maintaining flexibility for future adjustments.

Besides accommodating technical installations, this intermediate layer improves the transition between the existing and new building in terms of acoustics, fire safety and moisture performance. The height of the installation space is based on the requirement that systems remain accessible for maintenance. In the crawlable space future maintenance and technical adjustments can be done, without disturbing the residents below.

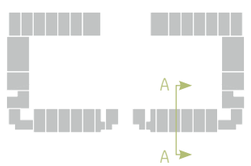
Floor build-up and structural integration

The floor of the topping-up consists of a reclaimed timber floor element spanning between the primary keyed reclaimed timber beams. The structural principle of the floor element and the reclaimed timber strategy have been explained in the previous chapter. At the scale of the 1:20, the focus is how the floor performs as part of the building.

The fire safety of the primary structure of reclaimed timber beams and columns, is achieved through encapsulation. An alternative strategy would be increasing the structural dimensions to achieve the required fire resistance through charring. However, the continuous structure already occupies more space compared to a conventional non-continuous structure. Increasing the dimensions even further would reduce spatial quality and flexibility. The reclaimed timber structure is therefore encapsulated through gypsum fibre boards and the timber frame elements with gypsum fibre boards. As a result a fire resistance of 60 minutes is achieved.

Acoustic performance between dwellings is achieved through the combination of the floor build-up and resilient battens beneath the floor element. Together, these layers create a mass – spring – mass system, which reduces the impact sound and airborne sound, before it reaches the neighbouring apartments.

Within the dwellings, the ceiling remains directly connected to the floor build-up to maintain a domestic spatial quality and avoid a technical appearance similar to office buildings, with lowered ceilings. However, in the shared spaces a lowered and demountable ceiling can be applied where needed, see illustration 85. These spaces require more technical systems, such as mechanical supply and exhaust ventilation. It also functions as an additional buffer improving acoustic comfort in collective areas. The removable ceiling also allows installations to remain accessible for future maintenance and adjustments without destructive interventions to the reclaimed timber structure.



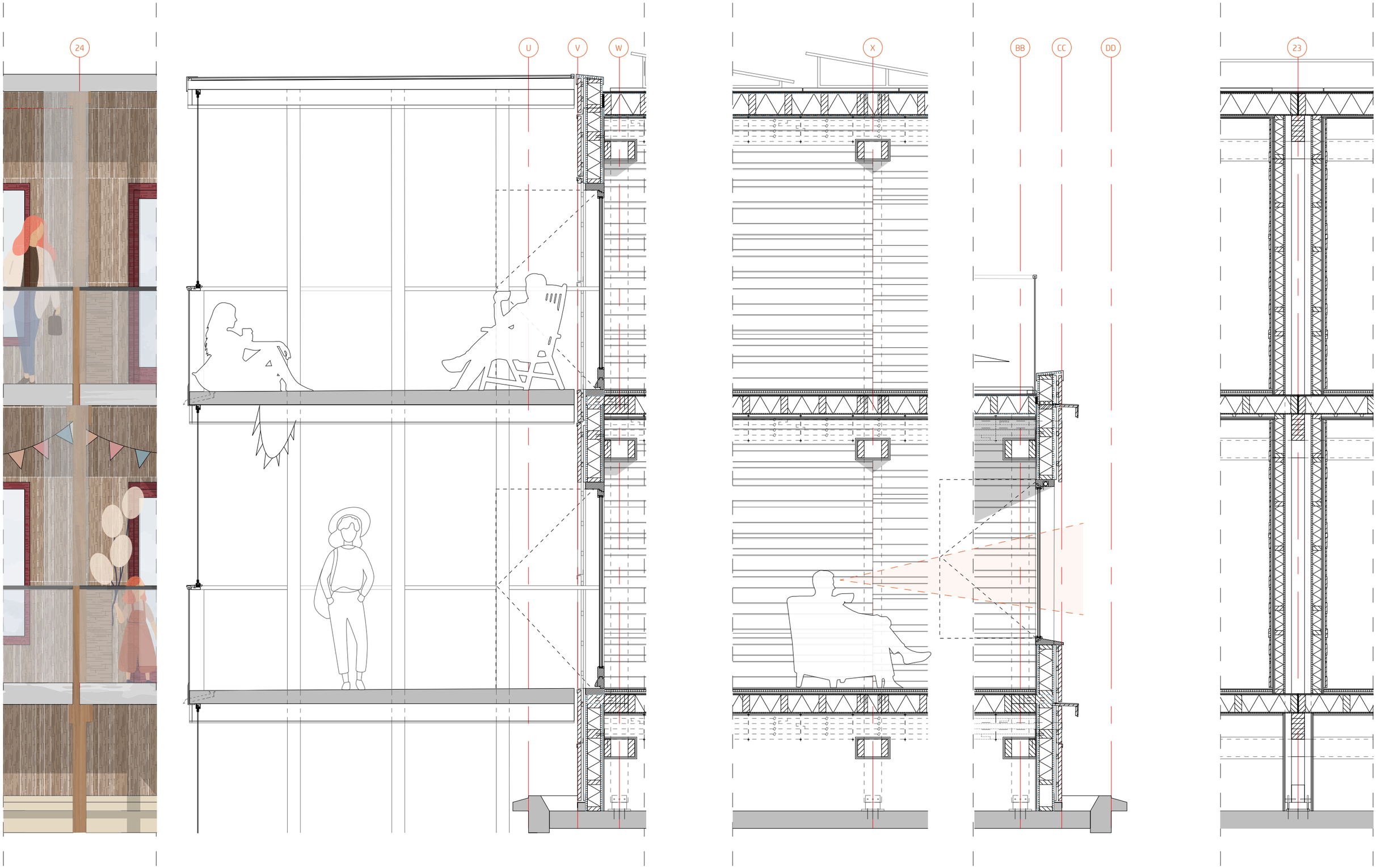


Illustration 83: 1 to 20 scaled to 1 to 40 fragment section A-A, own illustration.

Partition wall and dwelling comfort

The partition wall between dwellings is designed to meet both acoustic and fire requirements, while remaining adaptable for future reuse. The wall consists of a double timber frame system positioned on either side of the primary structure, as explained in the building methodology. Sound transmission is reduced by avoiding direct contact between dwellings. Two layers of gypsum fibre boards are positioned towards both dwellings to achieve a fire resistance of 60 minutes. Together with the insulation and layered build-up, the element provides sufficient mass and separation for acoustic performance.

The wall elements are prefabricated, including the timber frame, insulation, sheathing and finishing layers. The interior finishes are selected according to the character of the dwelling spaces. In the main living spaces, reclaimed timber planks are applied on the longest wall facing the living area. This introduces the architectural expression and tactile quality of reclaimed timber into the dwelling. This way reclaimed timber use is selective and controlled. The reclaimed timber surface becomes a spatial focus. The remaining walls are kept more neutral to create a calmer living environment and provide flexibility for future residents.

In the smaller rooms, neutral finishes are preferred. This creates visual openness and directing attention towards daylight, views on and the relationship between the gallery and street.

The partition walls with reclaimed timber cladding are prefabricated including the cladding. However, the upper and lower timber planks are installed on site. This allows technical installations, electrical outlets and adjustments to be integrated more easily.

Facade element and climatic performance

The facade element is designed as a prefabricated and non-load-bearing timber frame element connected to the primary reclaimed timber structure. Unlike the primary structure, which provides the main stability through beams, columns and bracing, the facade only transfers its self-weight and wind loads back to the structure.

The facade build-up consists of layers with different functions and replacement cycles. Reclaimed timber cladding forms the outer layer of the facade. Behind the cladding, a ventilated cavity improves moisture performance and durability. The weather-resistant and airtight layer protects the inner timber structure

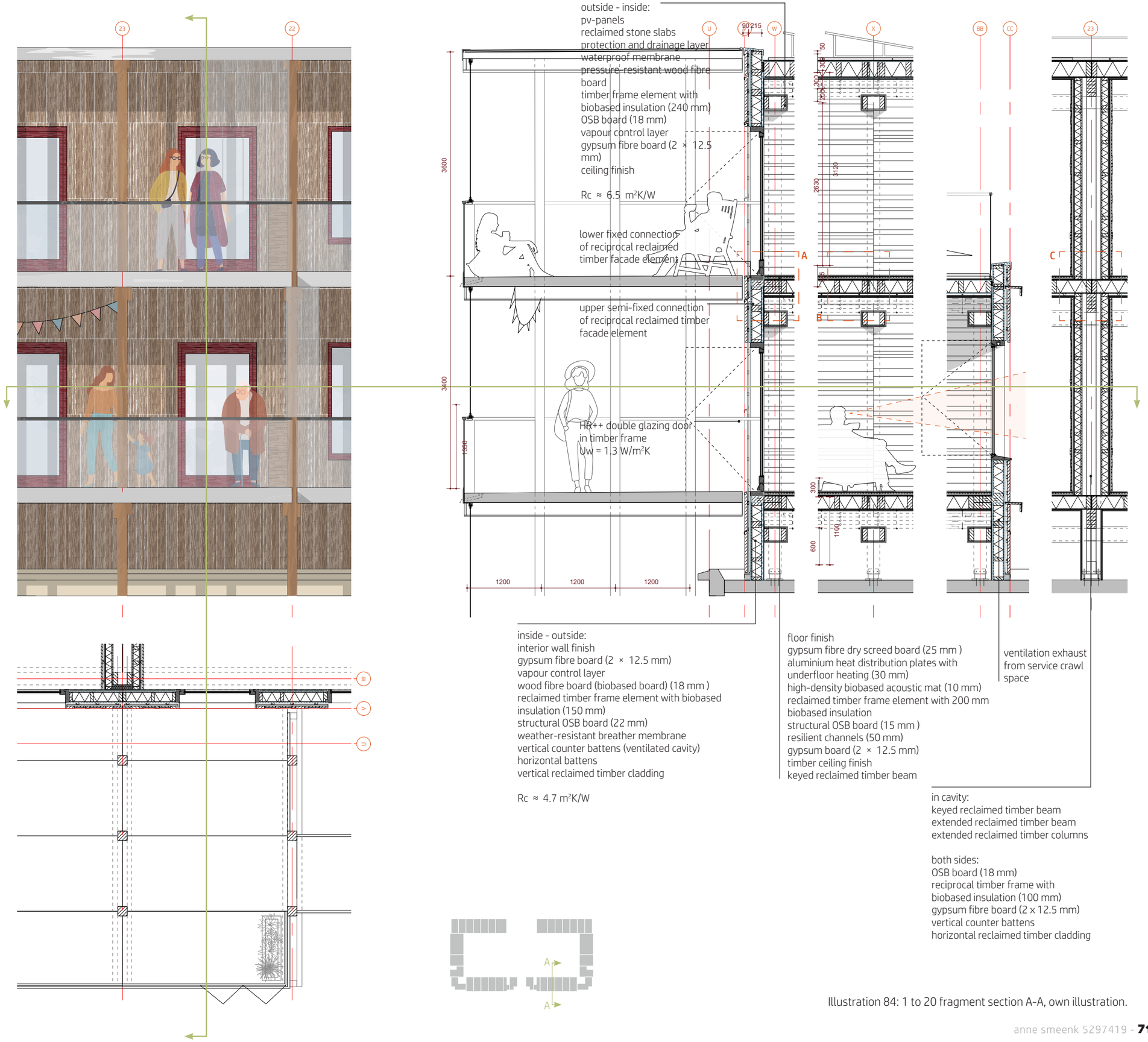


Illustration 84: 1 to 20 fragment section A-A, own illustration.

from wind and moisture penetration, while taped joints between the panels ensure airtightness.

The facade connection is designed differently at the top and bottom of the element. At the bottom, a fixed steel connection transfers the load of the facade element onto the floor structure. At the top, a semi-fixed steel connection stabilises the panel and transfers wind loads, while allowing for tolerances and small movements within the building. This distinction between fixed and semi-fixed connections allows the prefabricated facade element to perform structurally and remain demountable.

The gallery is an additional climatic layer of the building. Besides functioning as circulation and a social interface, it provides shading to the facade and creates a gradual transition between public and private space.

The widened gallery sections are equipped with foldable frameless glass panels above the balustrade. These can be temporarily closed during colder or windier conditions. This improves wind protection and extendd the use of the outdoor space throughout the year. During warmer seasons, the panels can be fully opened to maintain the outdoor character of the gallery.

The layered build-up of the facade and roof assembly contributes to thermal comfort and moisture control. Vapour control layers reduce the risk of condensation in the construction. And the ventilated cavity allows moisture to escape. The timber frame thickness depends partly on the required Rc-value. However, it also depends on the stock. The facade elements within one building part should maintain a consistent depth to simplify detailing, prefabrication and installation.

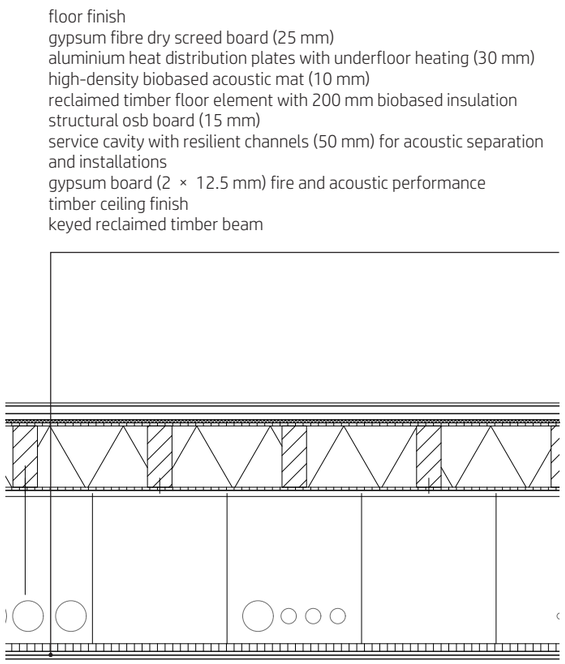


Illustration 85: lowered ceiling 1:5, scaled to 1:10, own illustration.

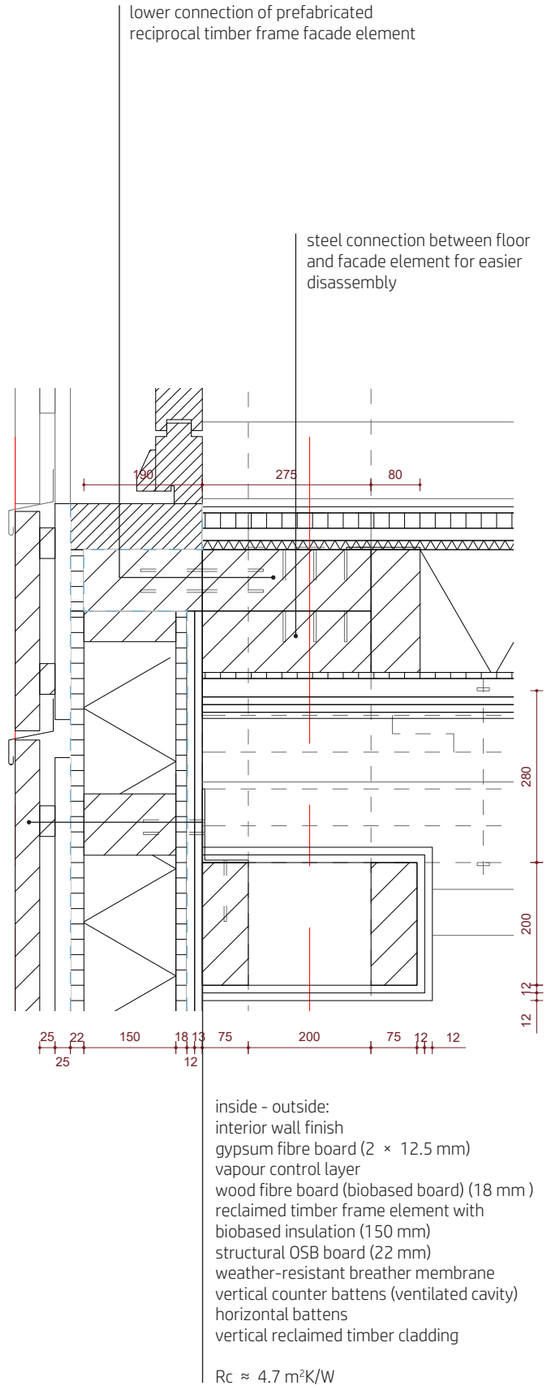


Illustration 86: detail A - vertical 1:5 scaled to 1:10, own illustration.

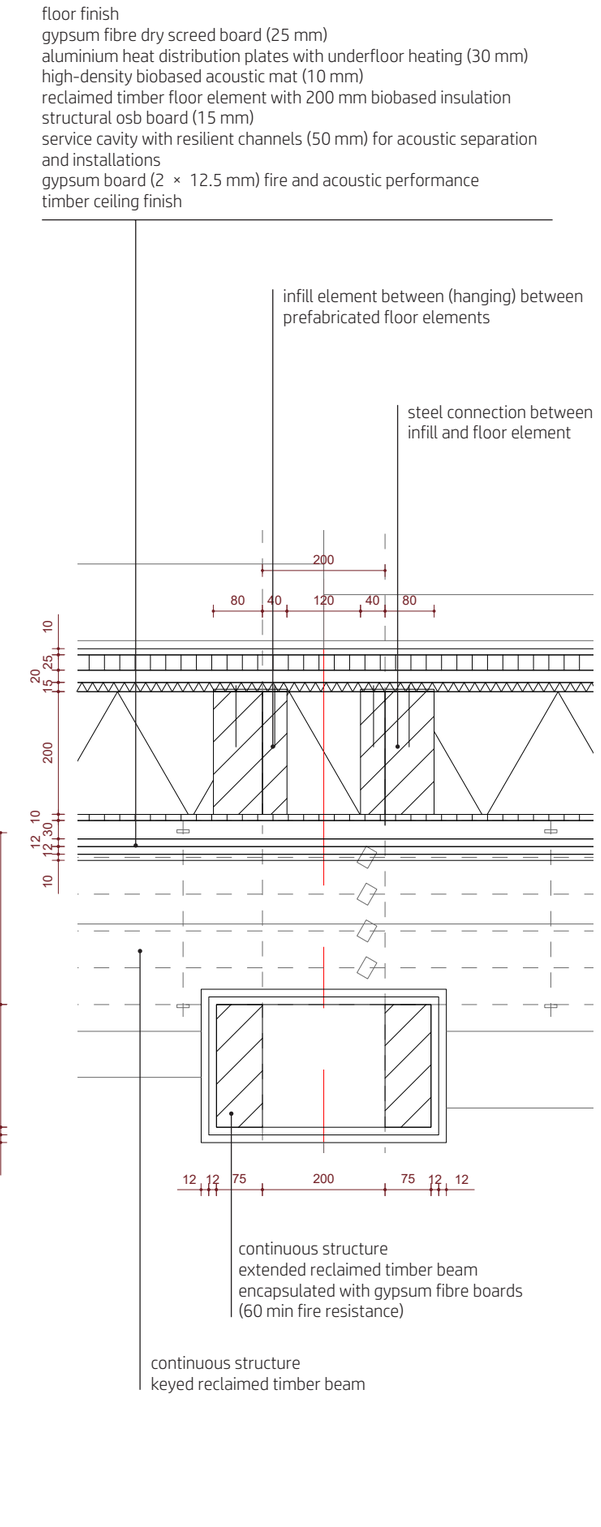


Illustration 87: detail B - vertical 1:5 scaled to 1:10, own illustration.

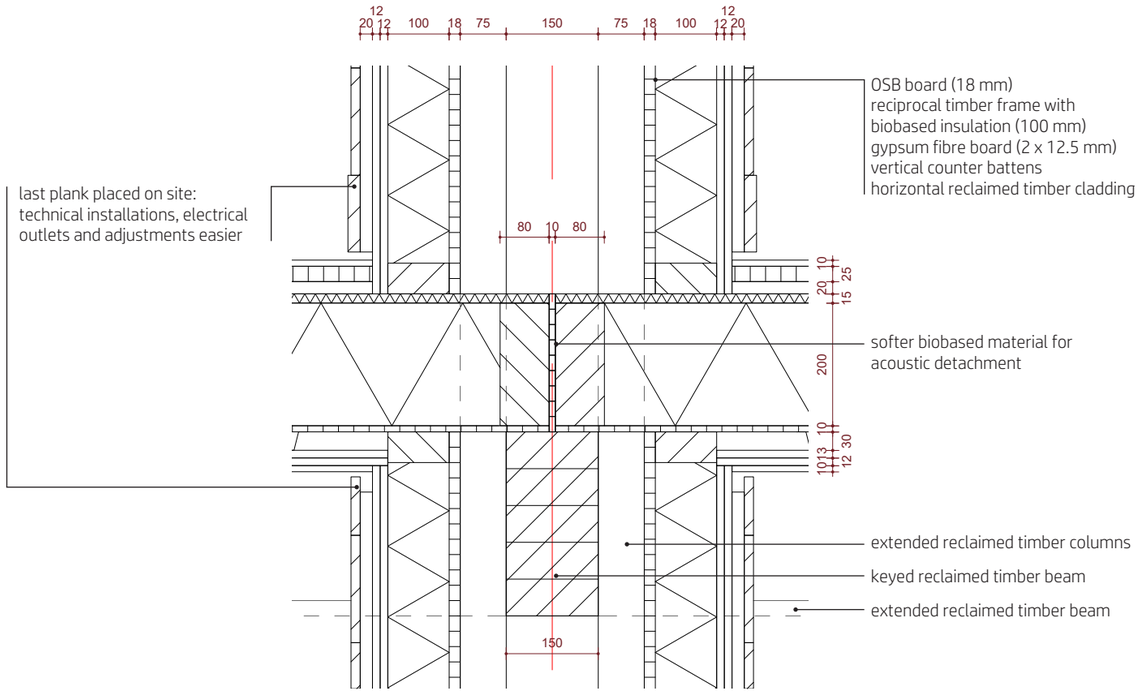


Illustration 88: detail C - vertical 1:5 scaled to 1:10, own illustration.

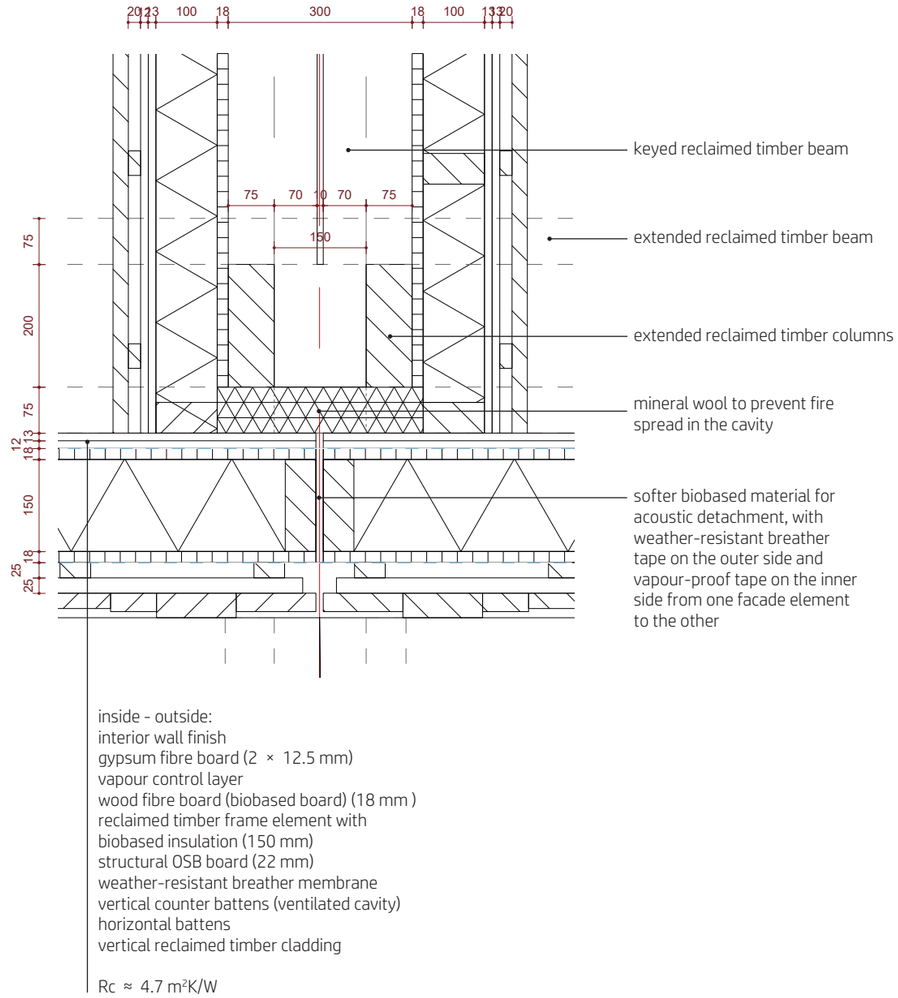
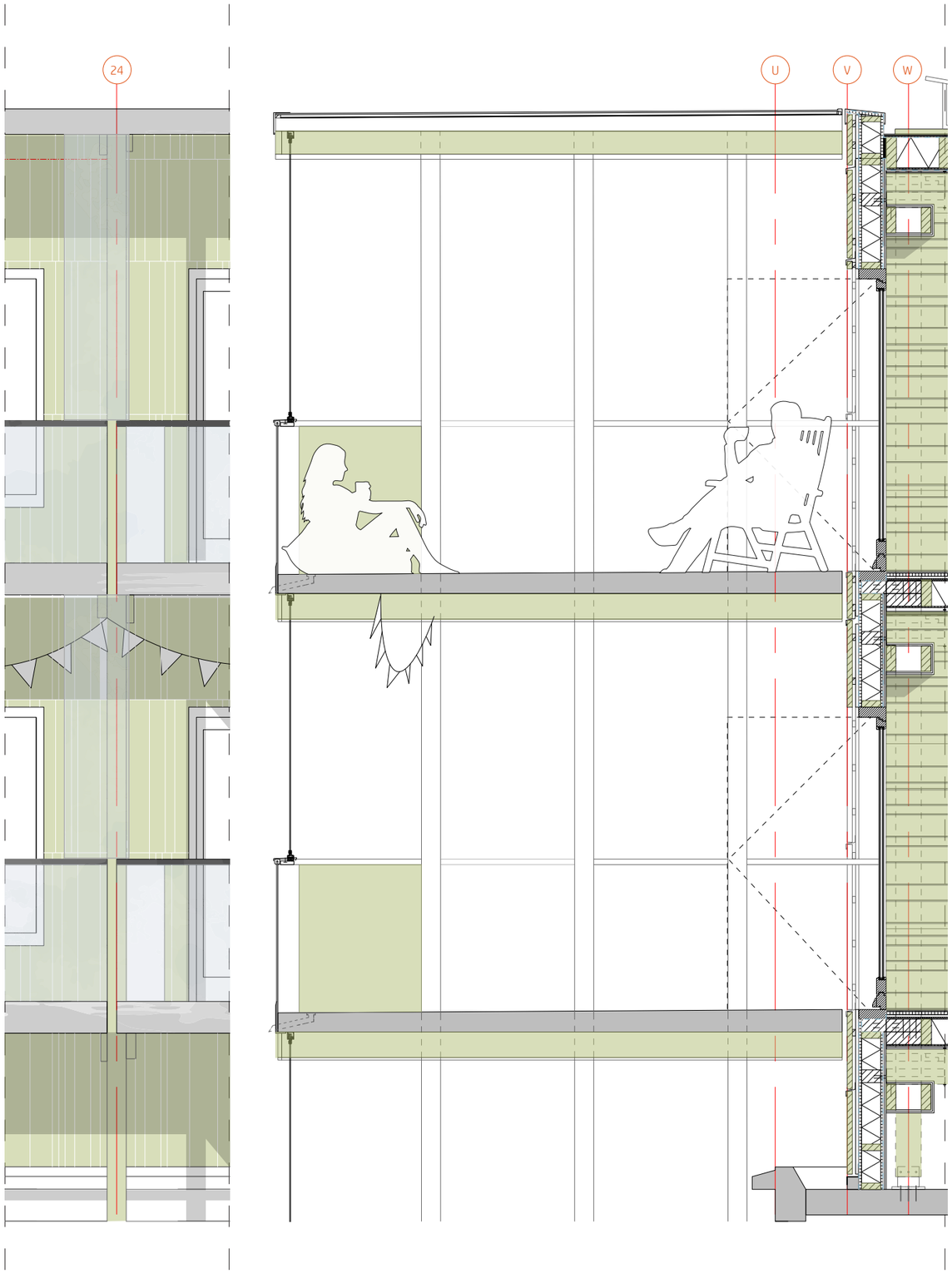
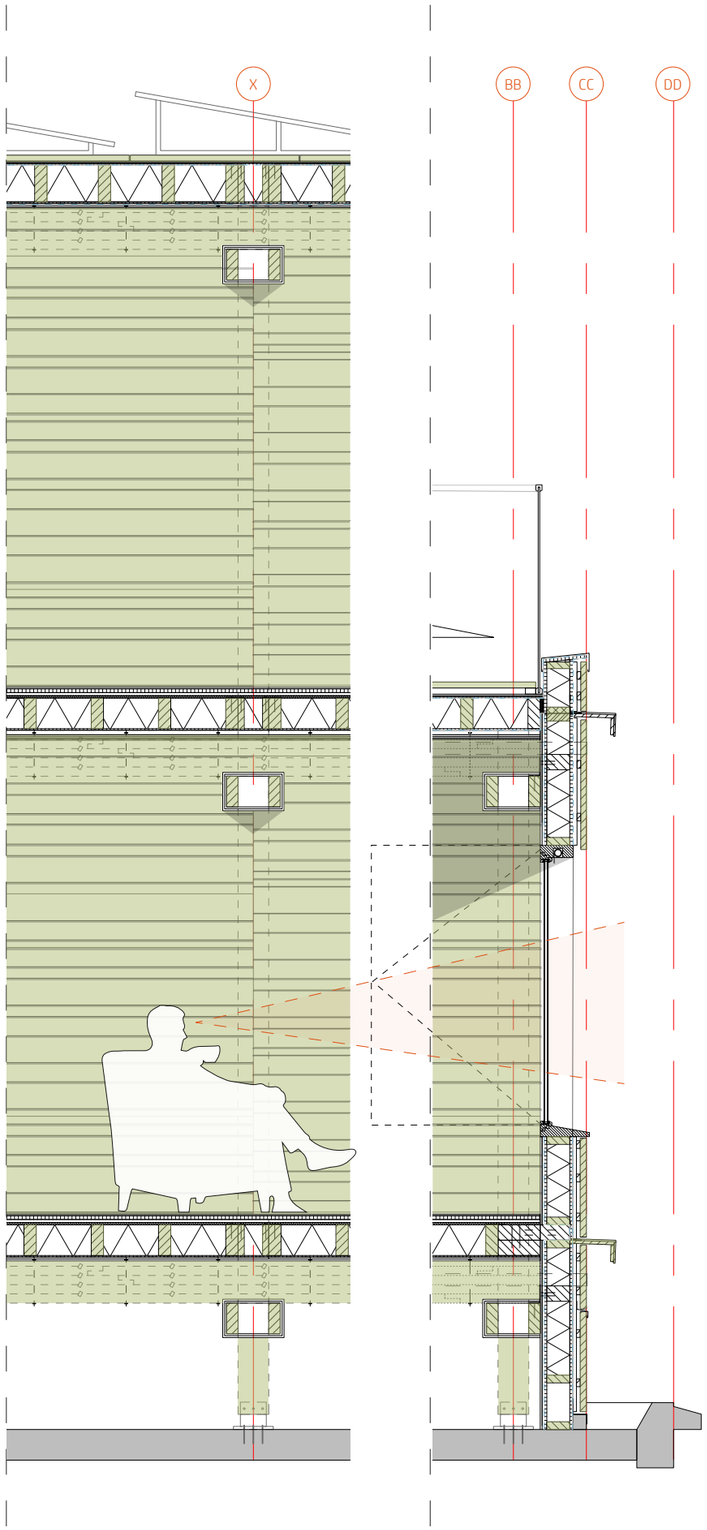


Illustration 89: detail D - vertical 1:5 scaled to 1:10, own illustration.

= reclaimed timber





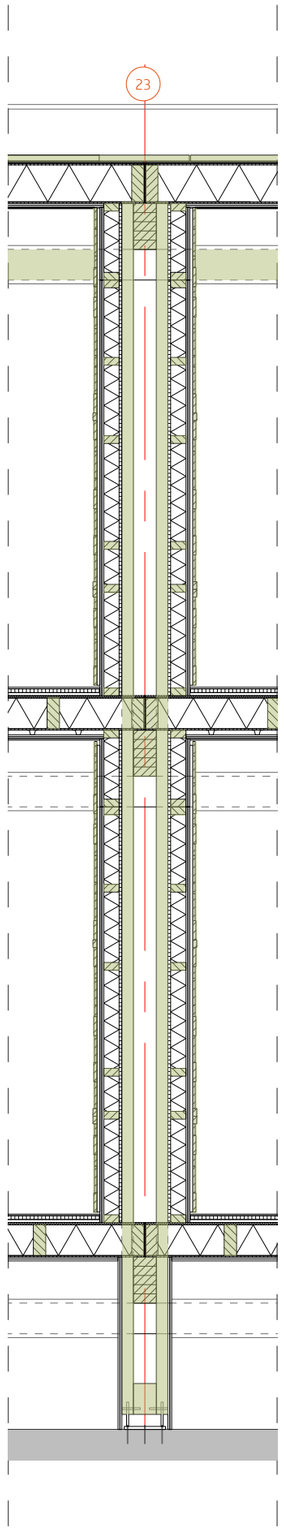


Illustration 90: 1 to 20 fragment with reclaimed timber highlighted section A-A, own illustration.

5. ARCHITECTURAL EXPRESSION BUILDING

The previous chapters focused on the technical development and integration of reclaimed timber elements. This chapter explores how reclaimed timber becomes part of the architectural expression of the building. Instead of only approaching reclaimed timber as a building material or a solution to reduce CO_2 emissions, this project investigates how reclaimed timber can shape the architecture of the building. The variability, irregularity and uncertainty of reclaimed timber influence not only construction, but also the identity, material expression and spatial organisation of the topping-up. Reclaimed timber is approached not only as a technical system, but as an architectural design principle.

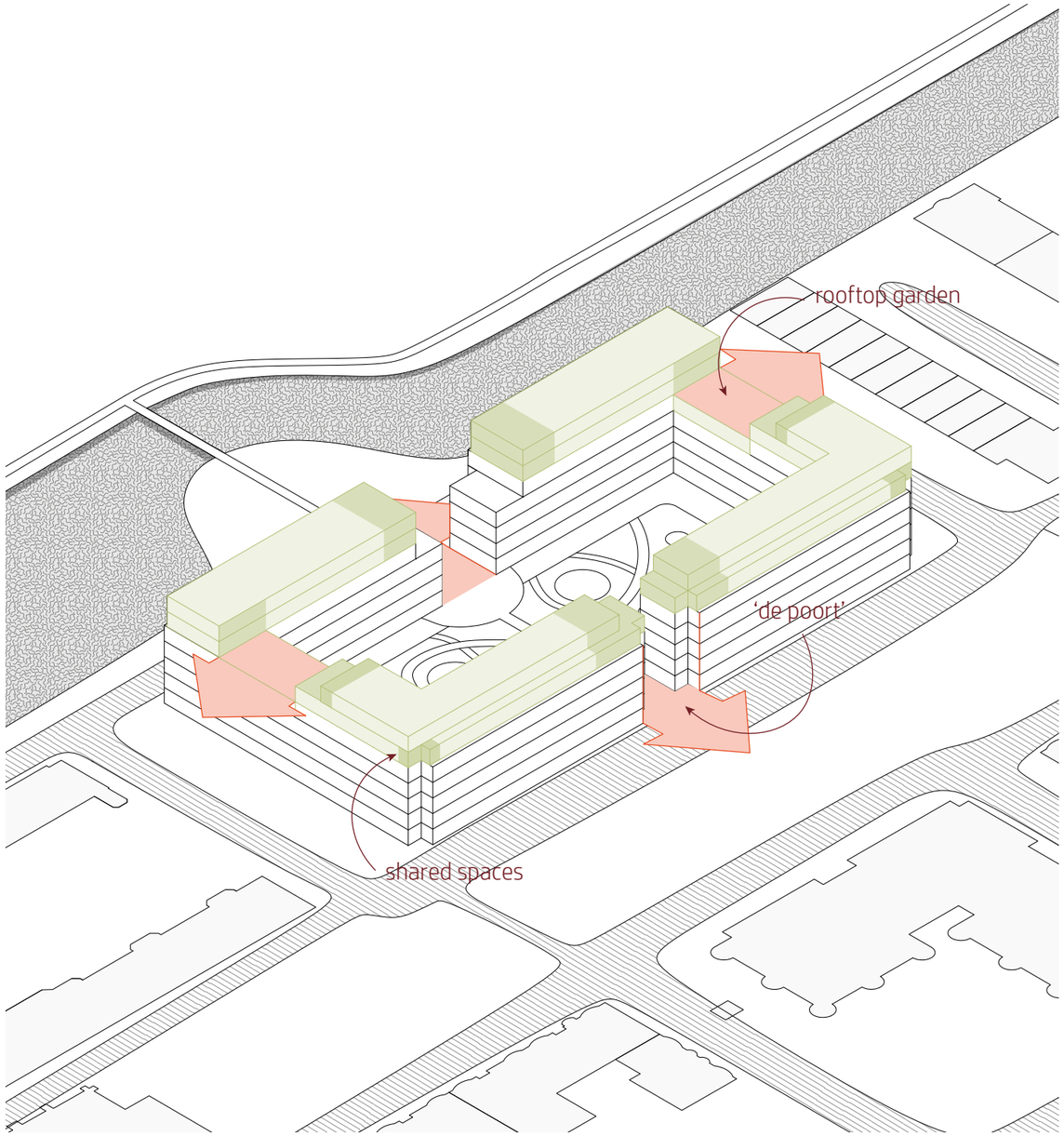


Illustration 91: distribution of facade typologies, own illustration.

5.1 reclaimed identity

At the scale of the building, reclaimed timber becomes visible through the facade. The 1:20 facade detail shows how reclaimed timber can be technically integrated into a facade system. However, at building scale, the reclaimed timber cladding becomes part of the architectural expression.

Because every reclaimed timber piece has its own dimensions, colour, texture and imperfections, reclaimed timber results in a more expressive architecture. However, the variability of reclaimed timber can also complicate large-scale implementation. To make reclaimed timber applicable within contemporary building strategies and larger-scale projects, a degree of standardisation is introduced.

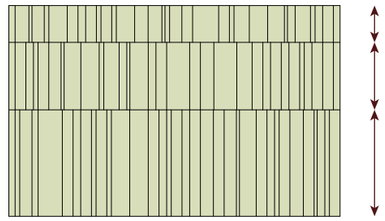
As discussed in the elements chapter, the reclaimed timber cladding panels are based on the mode lengths found within the available reclaimed timber stock. By reducing the amount of different lengths and organizing the timber into a limited number of dimensions, a balance emerges between variation and repetition. This creates a facade that still expresses the irregular character of reclaimed timber, while maintaining a calmer appearance and allowing for faster prefabrication and assembly.

Within the design, different facade expressions are applied according to the spatial importance of the building. Certain areas within the architecture, such as entrances, transitions and collective spaces, receive additional attention through a variation in the reclaimed timber facade panels. While the general apartment facades maintain a calmer and more repetitive expression, shared spaces are highlighted through a different arrangement of reclaimed timber. In this way, the facade communicates differences in use and social character towards the street and inner courtyard.

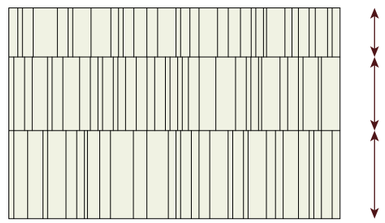
The bird' s-eye facade typology drawing (91) illustrates where different facade expressions are applied within the building. This creates moments of emphasis within the architecture, helping to orient users and reveal the collective functions in the topping-up.

Because reclaimed timber remains a natural and weathering material, maintenance forms part of the architectural strategy. Individual timber pieces may require replacement over time due to local deterioration, which can happen selectively without replacing the entire facade panel. Periodic maintenance checks are therefore required to assess the condition of individual elements, as mentioned in previous chapters.

After approximately 20 to 30 years, facade panels may reach the end of their functional lifespan and require replacement as a whole. Since the cladding system remains prefabricated and mechanically fixed, new panels can be produced using the reclaimed timber stock available at that moment in time. The mode lengths of future reclaimed timber stocks will likely differ from those used present day. Therefore, the renewed facade may slightly change in appearance. In this way, the facade becomes adaptive over time, allowing the building expression to evolve together with the availability and characteristics of reclaimed timber.



Panel A



Panel B

Illustration 92: reclaimed timber facade typologies, own illustration.

5.2 the Poort

When taking a closer look at the facade of the Poort, the subtle variations in the reclaimed timber panels become visible. The overall facade language remains calm and coherent, however the slightly differences highlights collective spaces and entrances. This communicates the way the building is used. The Poort is the entrance towards the neighbourhood, and is therefore a transition between public and private space. At the ground floor, there is a neighbourhood event space. The space is in the building, however it extends beyond the residents of the building and is also for the community of Wittenburg. Activities such as summer barbecues or winter holiday events can take place here. This strengthens social interaction between residents and neighbours. But why is creating space for community so important in Wittenburg?

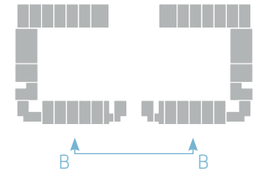




Illustration 93: scale 1:100 scaled to 1:150 elevation B-B, own illustration.

6. THE PROGRAM CO-HOUSING

6.1 Wittenburg a vulnerable neighbourhood

Wittenburg is described as a vulnerable neighbourhood at the beginning of this report. This means that multiple problems occur simultaneously, including health issues, financial difficulties, social challenges and loneliness (Gemeente Amsterdam, n.d.). Besides, the neighbourhood has the highest amount of vulnerable children within the city centre of Amsterdam. And the Oostelijke Eilanden are known as an important recruitment area for criminal activity among teenagers. At the same time, the movement rate of elderly residents is relatively low, while one of the largest age groups consists of residents between 45 – 65 years old (31%) (Kerncijfers Wijken En Buurten 2025, 2025). Combined with the high percentage of single households (59%), this creates a neighbourhood where social isolation and vulnerability can become increasingly present.

However, Wittenburg should not only be approached from its vulnerabilities. Based on the site analysis and reports by the municipality of Amsterdam, resident participation within the neighbourhood is relatively high (Gemeente Amsterdam, 2019). Throughout the neighbourhood, small initiatives demonstrate that there is a sense of care and ownership towards the shared environment. Activities such as neighbourhood events, communal initiatives and local organisations indicate that there is already a basis for social cohesion. This existing involvement creates an opportunity to further strengthen the social structure of the neighbourhood through architecture.

This ties back to the research question:

How can reclaimed timber elements be applied in a topping-up strategy to improve social cohesion, safety and spatial quality in Wittenburg, Amsterdam?

One example is the community centre Witte Boei at Wittenburg. At this location activities are organised from shared meals to language learning in an informal setting. According to De Dames Gaan Vreemd (2014), the challenge of these initiatives is not necessarily participation itself, but rather the lack of interaction between different social and cultural groups within the neighbourhood. Strengthening connections between diverse residents therefore becomes an important spatial challenge.

Co-housing can be a strategy for this challenge. In a chapter of Transformatie naar Woning (pages 121 – 132), Czischke and Van Bortel (2024) describe how co-housing can transform existing residential buildings by combining private dwellings with shared amenities. Within co-housing, households maintain independent apartments, while also sharing facilities and spaces. This encourages interaction, recognition and social cohesion between residents (Czischke & Van Bortel, 2024).

Communes often consist of residents of different ages and backgrounds. They develop their own collective identity through everyday activities such as eating together, celebrating events, supporting one another and informal care (Vereniging Gemeenschappelijk Wonen, n.d.). Through repeated encounters and shared routines, stronger social relationships can emerge.



Illustration 94: problem statement to proposed solution, vulnerable nieghbourhoods, own illustration.

6.2 relevance Wittenburg

This social structure is especially relevant in Wittenburg. Co-housing can support ageing in place, while maintaining a social environment. As one of the largest age groups in Wittenburg grows older, the demand for housing that supports independent living with mutual care is expected to increase (Kerncijfers Wijken En Buurten 2025, 2025). Residents could potentially relocate to another dwelling within the same building as their housing needs change over time.

Research also suggests that collective living can reduce loneliness and improve wellbeing. In an interview by PBS News, Lisa Berkman explains that social isolation accelerates physical and cognitive ageing. Therefore, daily interaction and mutual care within co-housing environments can support long-term wellbeing and independence (Cohousing Communities Help Prevent Social Isolation, 2017).

However, co-housing is not only beneficial for elderly residents. Shared living can also reduce loneliness among younger households, starters and families. Everyday encounters within collective spaces make social relationships easier to establish and maintain, particularly for residents balancing work, care responsibilities or limited social networks (Cohousing Communities Help Prevent Social Isolation, 2017).

Collective living can additionally contribute to informal social safety. Through stronger social connections, residents are more likely to recognise one another, look out for each other and notice unusual situations. This can strengthen the social fabric of the neighbourhood and indirectly contribute to reducing feelings of insecurity.

Wittenburg already contains examples of collective living. The Vierwindenhuis is a social housing experiment dating from the 1980s, developed during a previous housing crisis in Amsterdam. The project challenged conventional housing ideas by creating collective spaces and encouraging interaction between residents (Van Vliet, 2021; Vierwindenhuis - Arcam, 2021). The existence of these examples suggests that collective living already has roots within Wittenburg and provides a relevant foundation for a contemporary reinterpretation.

Additionally, the selected building already contains a shared indoor space, a communal kitchen. This implements that the first foundations for collective living are already present. However, shared facilities alone do not automatically create a strong community. Additional spatial strategies, resident involvement and active use are needed to activate social interaction and collective living over time.

The site visit helped to better understand the existing social dynamics, qualities and challenges of Wittenburg. The observations reveal both existing initiatives that already support social interaction and spatial challenges that limit social cohesion and perceived safety.





Illustration 95: photos from site visit. On top good social initiatives (green), beneath challenges (orange), own photos.

6.3 four levels of collective living

This co-housing strategy is implemented within the redesign of the building. The design introduces collective spaces across four different levels of collectivity: individual scale, within the buildings, spaces between buildings and at the neighbourhood scale. In this way, opportunities for encounter are balanced with privacy and independence. Residents can choose different degrees of participation, they range from private spaces to neighbourhood engagement, see illustration 96.

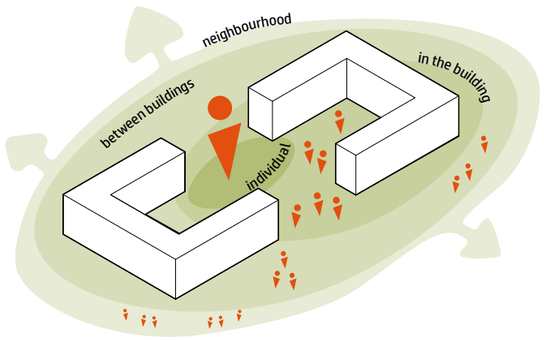


Illustration 96: four levels of collective living, own illustration.

Individual

The first level is the individual scale, which is centred around self-development and wellbeing. Although the apartments remain independent, spaces are introduced that support work, study, reflection and personal growth. Functions such as work and study areas, storage spaces, yoga facilities and indoor greenery spaces encourage residents to develop individual routines. Meanwhile they remain connected to the collective environment. Views towards the gallery, inner courtyard and street create awareness of neighbours and everyday activity, while maintaining privacy within the dwelling.

Within the building

The second level focuses on collectivity within the building, this means supporting everyday interaction between residents of the same building. Examples are shared kitchens, laundry rooms, game rooms, guest rooms, rooftop gardens and herb gardens. These spaces create opportunities for repeated encounters and informal care. Practical functions, such as recycle and share spaces, additionally encourage residents to exchange materials, support one another in daily life and act in a more sustainable way.

Between the buildings

The third level consists of shared spaces between buildings, where exchange and making become central. At this scale, facilities such as a bicycle repair workshop and wood workshop/makerspace strengthen connections between neighbouring residents. By sharing tools, knowledge and activities, these spaces encourage collaboration between residents beyond the scale of a single building.

Neighbourhood scale

Finally, the fourth level extends towards the neighbourhood scale. Spaces such as ateliers and a neighbourhood event space are opened towards Wittenburg. These create opportunities for interaction between residents and the wider community. These spaces support neighbourhood activities that can range from workshops, exhibitions, shared dinners and events. In this way, the design responds to the challenge identified by De Dames Gaan Vreemd (2014), where participation already exists, but interaction between different social and cultural groups remains limited.

This layered approach allows residents to determine their own amount of involvement. However the design increases the opportunities for encounter, informal care and social safety.



Illustration 97: floorplans of collective spaces on individual and building level, own illustration.

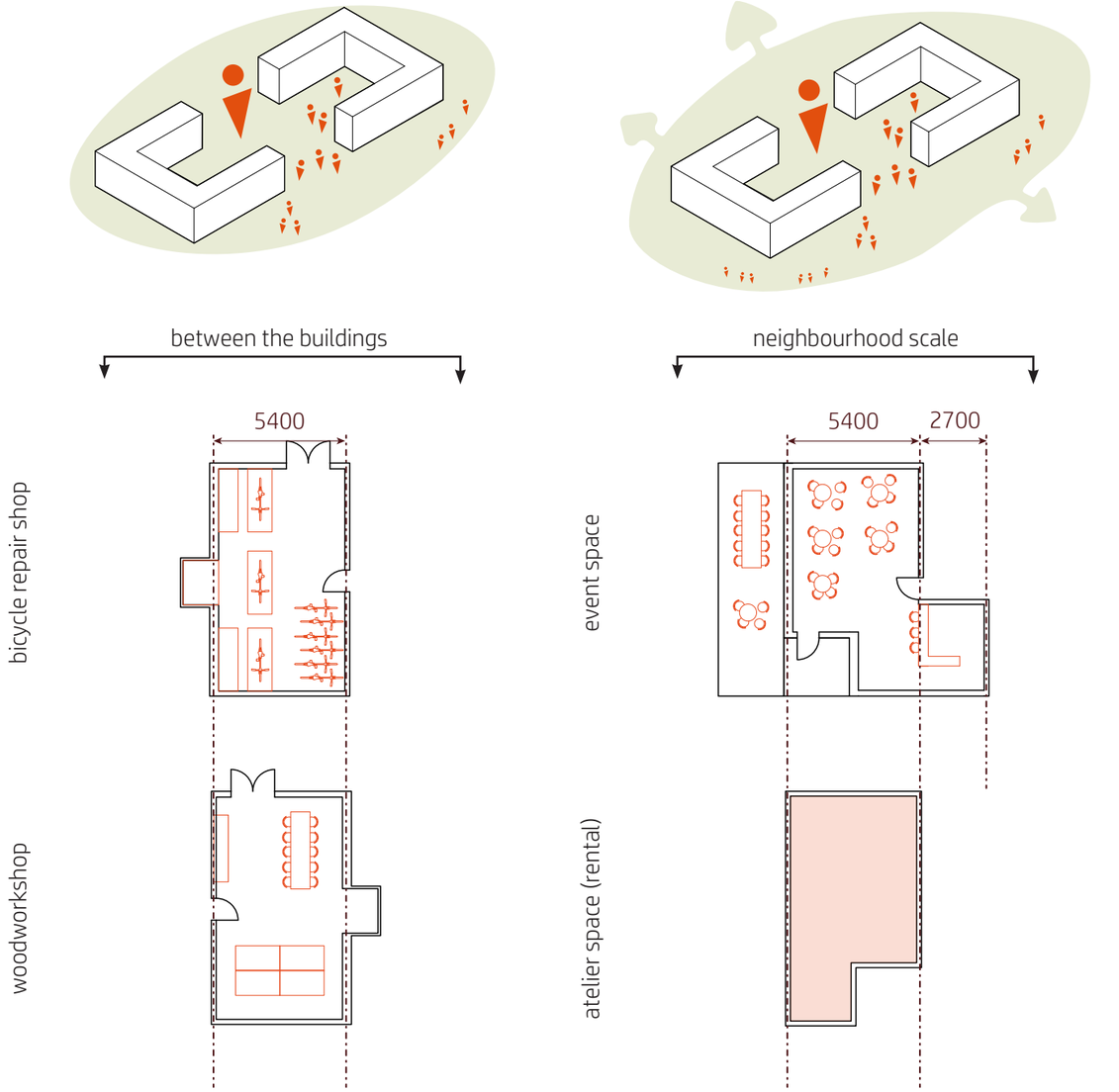


Illustration 98: floorplans of collective spaces between the buildings and on neighbourhood scale, own illustration.

6.4 eyes on the street

These shared spaces are not placed in a random order. To improve the vulnerable condition of Wittenburg, and particularly the relatively high criminality and social vulnerability, this research introduces the concept of eyes on the street by Jane Jacobs.

According to Jacobs (1961) (Ghisleni, 2025), social safety within neighbourhoods is strengthened through the presence of people in public space. Instead of relying on formal surveillance, the safety emerges through everyday activity, visibility and informal social control. The streets become safer when residents naturally observe one another and public life through daily routines, in other words as eyes on the street as Jane Jacobs describes it. Mixing functions and activities throughout the day is essential. This makes sure that different groups of people occupy spaces at different moments in time.

Within this design, the concept of eyes on the street is combined with the co-housing strategy. Co-housing strengthens social cohesion and mutual care between residents and eyes on the street introduces visibility and informal surveillance towards the street, gallery and inner courtyard. The combination of both strategies creates stronger communities and improves perceived and actual safety within the neighbourhood Wittenburg.

In illustration 99, the distribution of shared spaces throughout the building becomes visible. The collective spaces are distributed not only within the topping-up, but throughout the entire building. This means that a small number of residents may need to relocate within the building. However, residents are able to move to another new dwelling in the topping-up if desired. The shared spaces within the existing building are introduced with minimal interventions to the current housing layouts. This strategy is deliberately chosen to minimise disturbance for current residents and reduce construction interventions.

Occupancy during both night and daytime is important when distributing the collective spaces. Different functions attract activity at different moments of the day. Workspaces, ateliers and gardening spaces are primarily occupied during daytime, while communal kitchens, guest rooms, event spaces and shared living functions extend activity into the evening. The shared spaces are therefore strategically distributed across both sides of the building. This ensures activity throughout the day and increases visibility towards the street, gallery and inner courtyard. In other words, the building maintains continuous eyes on the street, and strengthens informal social safety through everyday occupation.

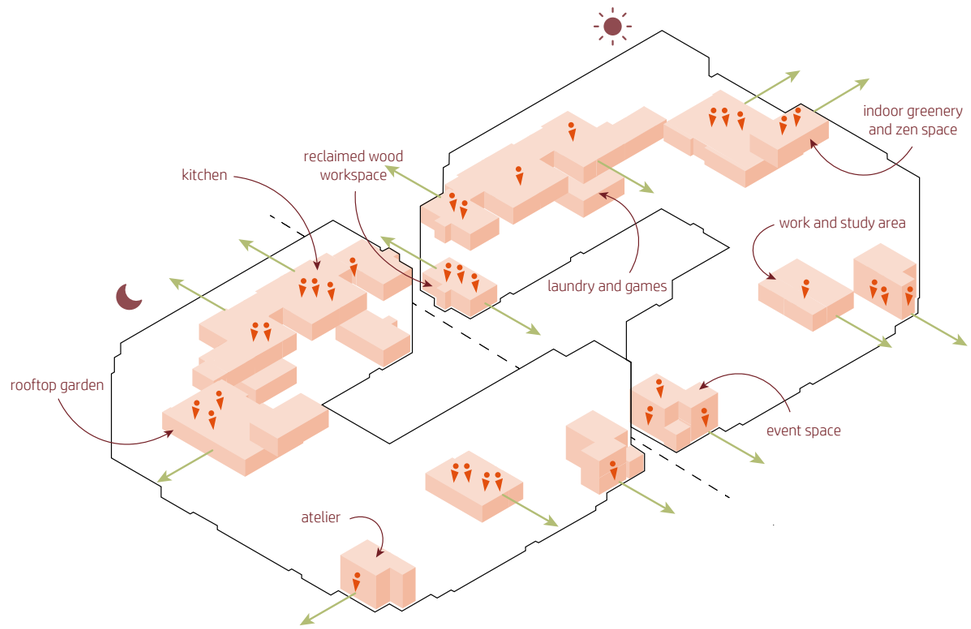


Illustration 99: schematic drawing of distribution of shared spaces day- and nighttime, own illustration.

6.5 housing

The current building already contains a broad mix of dwelling typologies, ranging from one-room to six-room apartments. The most common housing types are two-room apartments (53), three-room apartments (65) and four-room apartments (62). Besides housing, the building already contains ateliers at the corners. These connect the building to the street and introduce a mix of functions at ground-floor level.

However, the topping-up responds to the current housing shortage. The demand for housing increasingly affects starters, elderly residents and single households. The neighbourhood contains a large share of residents between 45 - 65 years old (31%) and single households (59%) (Kerncijfers Wijken En Buurten 2025, 2025). For this reason, the topping-up focuses primarily on one- and two-room apartments. However, a diversity of housing typologies will be maintained.

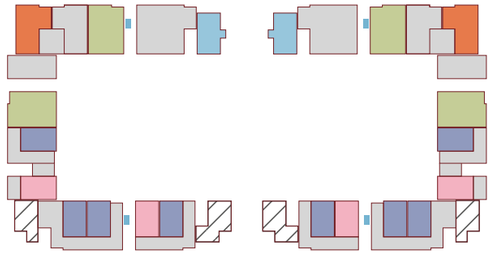
At the same time, the housing strategy aims to strengthen interaction between different resident groups. According to De Dames Gaan Vreemd (2014), the challenge in Wittenburg is the limited interaction between different social and cultural groups within the neighbour-hood. The topping-up therefore introduces a diverse mix of residents through different dwelling sizes and including social housing, rental housing and owner occupied dwellings.

This diversity is strengthened through the co-housing strategy. The collective spaces create opportunities for everyday encounters between residents who might otherwise not interact. As a result, the housing strategy responds to the housing shortage and contributes to social cohesion.

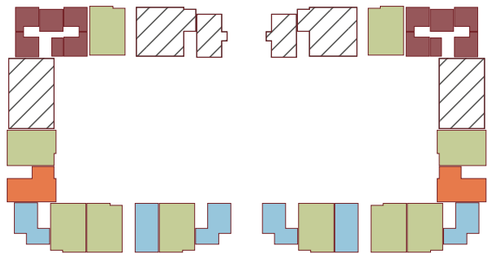
On page 92, the drawings illustrate how the different dwelling types and shared spaces are distributed throughout the building and positioned in relation to one another.



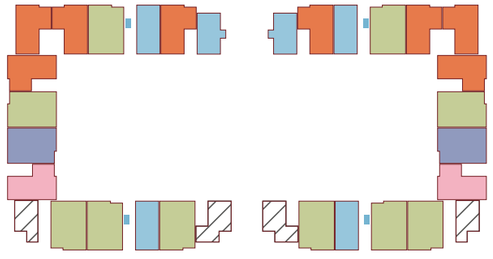
Illustration 100: different dwellings within the existing (black) and topping-up (orange), own illustration.



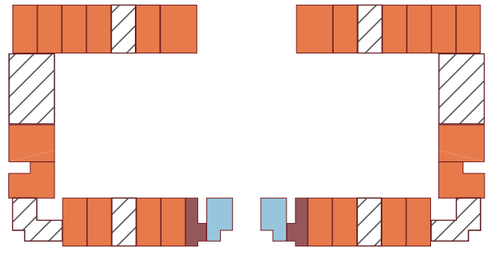
ground floor - existing building



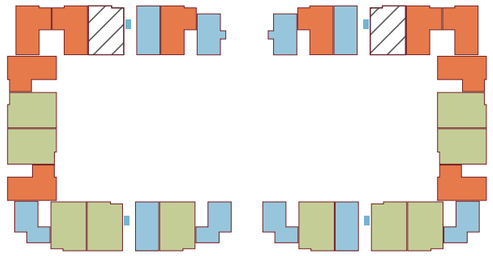
4th floor- existing building



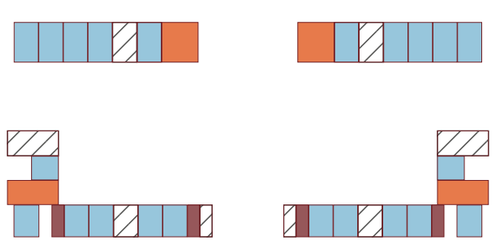
1st level - existing building



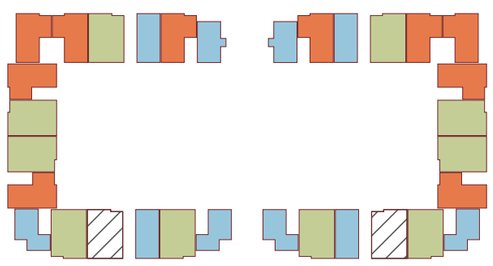
5th level- topping-up



2nd level - existing building



6th level - topping-up



3rd level - existing building

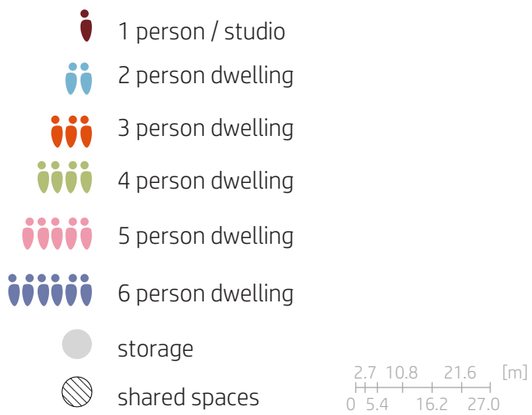


Illustration 101: distribution of dwellings and shared spaces across the different levels of the buiding, own illustration.

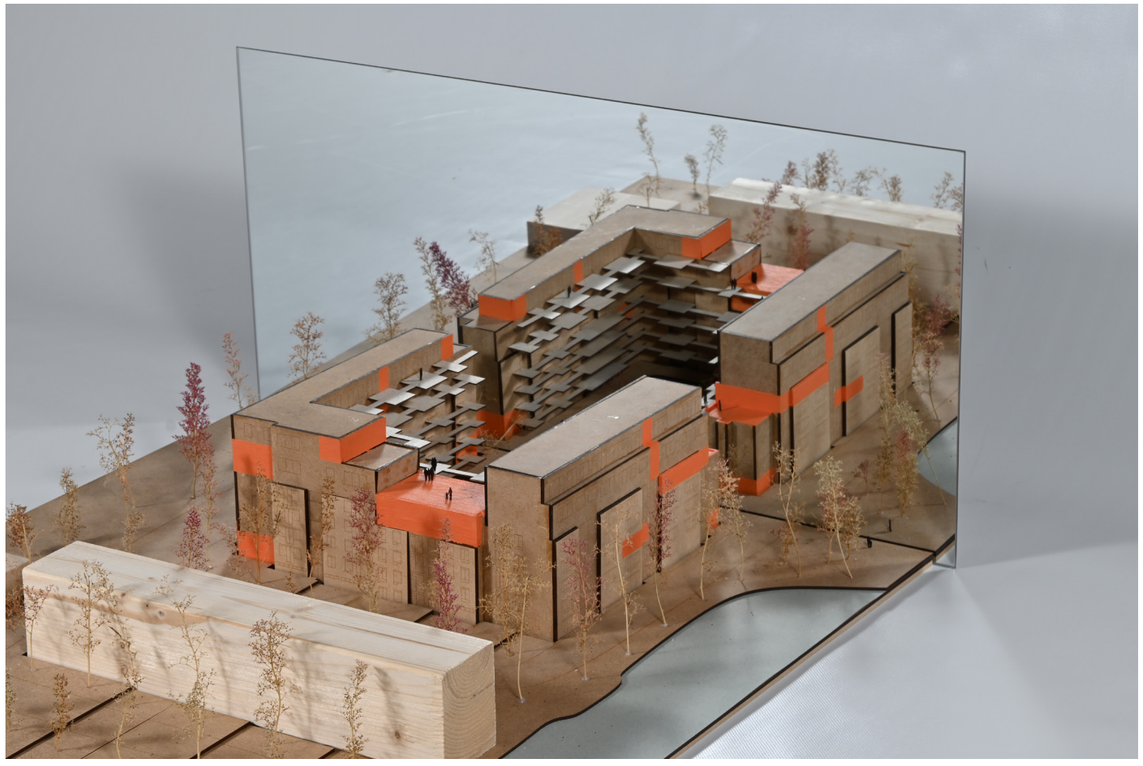


Illustration 102: distribution of shared spaces in orange in the model, own picture.

7. THE GALLERY THE CONNECTOR

7.1 circulation

The introduction of shared spaces throughout the building requires more than only new functions. The different dwellings and collective spaces also need to be physically connected, in such a way that encourages everyday encounters between residents. The circulation of the building therefore becomes an important strategy in strengthening social cohesion within the building.

Existing circulation

In the existing situation the circulation takes place only through vertical staircases. Each building contains eight separate entrances. These connect residents directly to two apartments per floor, with an exception for the studios on the fourth level. As a result, opportunities for spontaneous encounters between neighbours are limited. This reinforces an individual rather than collective way of living. In short, the existing circulation structure offers little support for the co-housing strategy introduced in the redesign.

More encounter

To strengthen interaction between residents, a gallery facing the inner courtyard is added. It functions more than only as circulation, the gallery is a connecting element between dwellings, collective spaces and residents. Through everyday movement, residents naturally encounter one another. This strengthens informal contact and familiarity between neighbours.

However, introducing a gallery alone does not automatically create interaction. Residents need to be encouraged to use the new circulation system. For this reason, two strategies are implemented.

First, the gallery connects the shared spaces throughout the building. Residents are able to move comfortably between their private houses and collective spaces. Meanwhile they are protected from rain and wind. The gallery runs continuously along the building and includes staircases. This creates a clear route between different floors and collective spaces.

Second, two elevators are strategically positioned within each building. The existing circulation system does not include elevators, which limits the accessibility for elderly residents and people with reduced mobility. The elevators are placed at opposite ends of the building. Residents that travel to the upper floors are therefore encouraged to move through the gallery before entering their dwellings. In this way, circulation becomes more than only movement. It creates opportunities for spontaneous encounters between residents.

The dwellings are relatively close to the circulation cores with elevators. There is a maximum walking distance of approximately 30 metres towards the elevators. And staircases are in the existing building every 10 meters. This improves accessibility and supports fire safety. Residents remain within an acceptable distance of escape routes.

Although the Poort and inner courtyard invite interaction with the wider neighbourhood, the gallery itself is exclusively accessible to residents. This creates a degree of ownership and familiarity towards the shared spaces and building community. Residents will gradually recognise one another through repeated encounters, this strengthens social cohesion and contributes to informal social safety.

In this way, the gallery is more than a circulation route. It is a spatial connector between people, functions and the different levels of collectivity within the building.

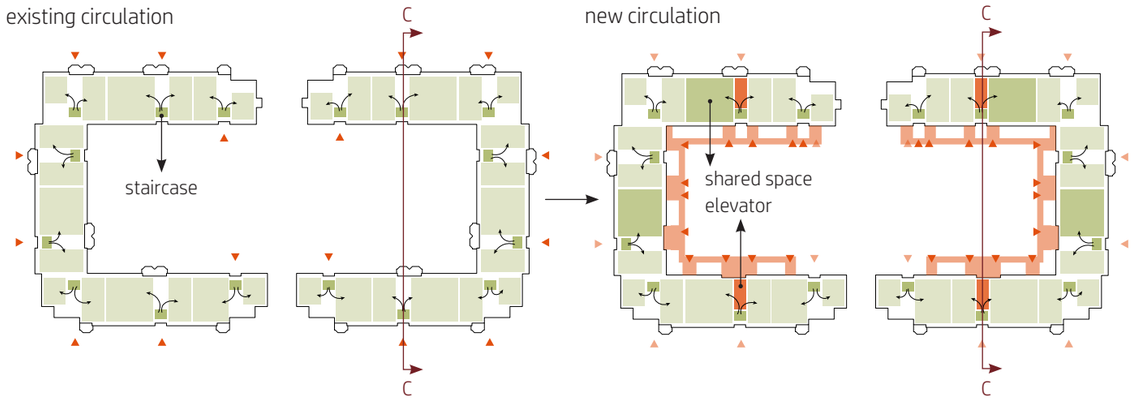


Illustration 103: schematic drawing of existing and new circulation plan, own illustration.

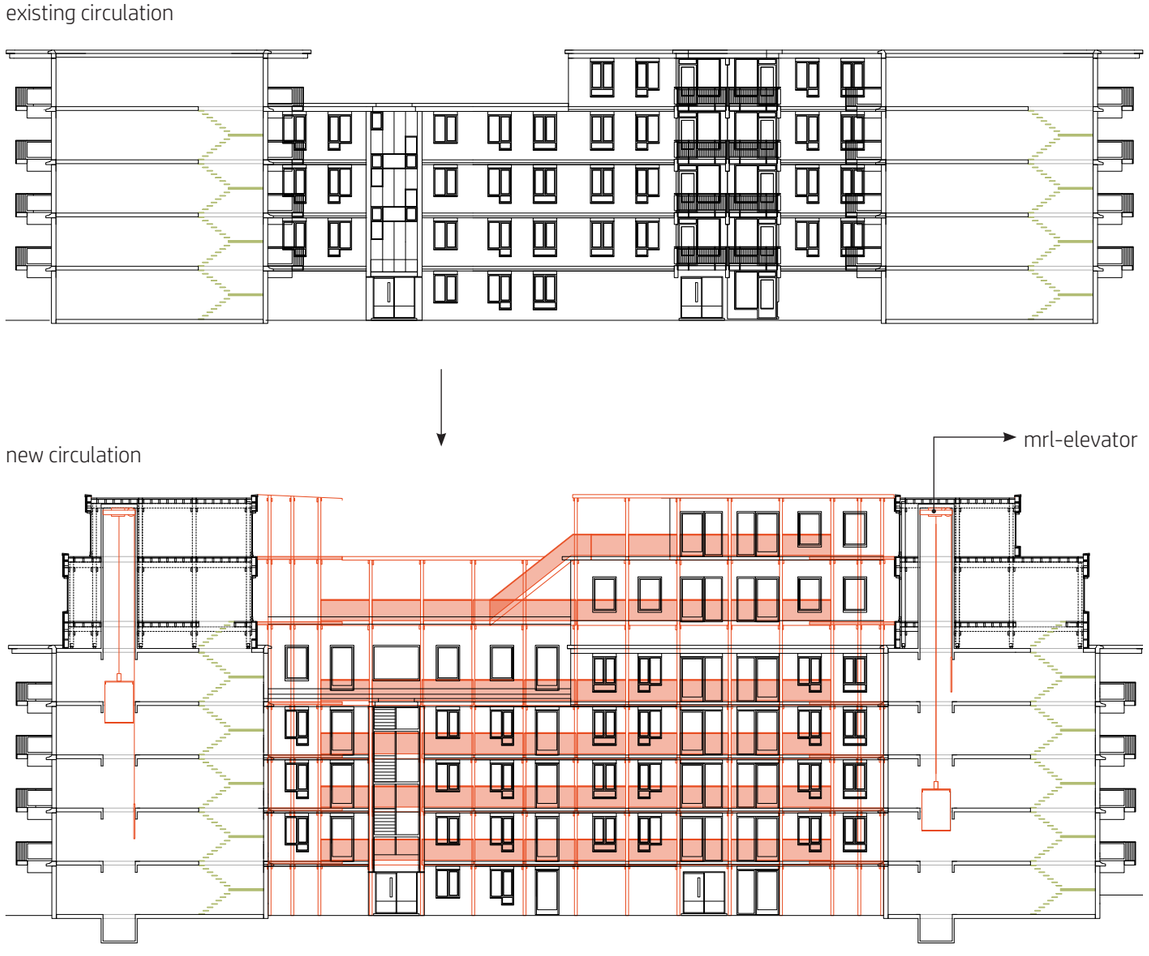


Illustration 104: section C-C scale 1:200 scaled to 1:300, with existing and new circulation, own illustration.

7.2 the gallery, more than circulation

The gallery is more than a connecting element for residents and collective spaces. It acts as a second layer around the building. It functions simultaneously as circulation, climate buffer and extension of domestic living. In this way, the gallery transforms from an circulation element into an important architectural component of the building

Structure and materiality

The gallery is constructed from reclaimed timber beams and columns, and continue the material logic of the topping-up. The structural frame stands independently from the existing building. It means that the gallery does not structurally rely on the building. The stability is provided through slender steel rods. These minimize visual obstruction and maintain views towards the courtyard.

The timber structure is connected to the ground through a timber to steel to recycled concrete connection. By lifting the timber from the ground, direct contact with moisture is avoided, which reduces the risk of fungi and rot. A similar detailing strategy is applied at the transition between the topping-up and the existing roof.

The reclaimed timber beams are additionally protected at their ends through replaceable sacrificial timber elements. These pieces protect the structural timber from weathering and biological degradation. They allow for local replacement without affecting the primary load-bearing structure. At the same time, this strategy keeps the reclaimed timber visually exposed instead of fully wrapping it in protective layer. As a result the material expression stay intact.

The gallery floors consist of recycled concrete slabs. They are chosen for durability and long lifespan. Concrete also offers advantages regarding slip and maintenance.

The balustrade is constructed from triple laminated safety glass. This creates a transparent and calm layer in front of the reclaimed timber facade and maintains views and daylight. The glass balustrade is in contrast with the expressive character of the reclaimed timber behind, keeping the focus on the timber. At the top level, a glass roof protects the gallery from rain while maintaining daylight penetration and openness.

A second skin

The gallery functions as a second skin in two ways: as protection for the building and as protection for the residents.

First, the gallery protects the reclaimed timber facade and structural elements from direct exposure to weather conditions. By limiting the impact of rain and direct sunlight, the lifespan of the timber components is extended and maintenance is reduced.

Second, the gallery acts as a protective layer for residents. During rainy days, residents are able to move comfortably between dwellings and shared spaces while being sheltered. During warmer periods, the gallery creates shade and reduces direct solar exposure on the facade. Through this approach, the gallery contributes to climatic comfort and everyday usability throughout the year.

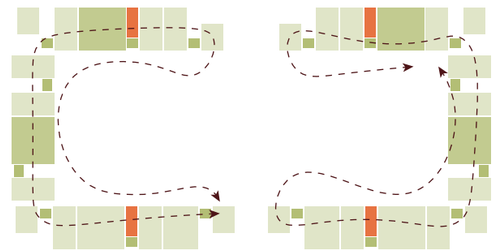
Leefgallerij

Finally, the gallery acts as a leefgallerij. It extends the living space of the existing and new dwellings. The gallery becomes an intermediate zone between public and private life.

At the entrances of dwellings, the gallery widens to create a space for staying and meeting. These extensions create opportunities for placing plants, seating or temporary personal use.

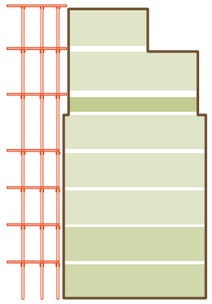
The gallery also responds to the relationship between the topping-up and the existing residents. The introduction of a gallery changes existing views and privacy condition. However, it simultaneously gives something back to the residents through additional outdoor living space, improved circulation and new collective facilities.

As a result, the gallery becomes more than an infrastructural element. It is a second layer of living, connecting residents, protecting the building and supporting the collective ambitions.



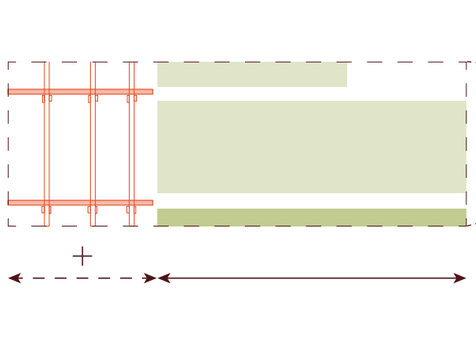
connecting spaces

a second skin protecting:

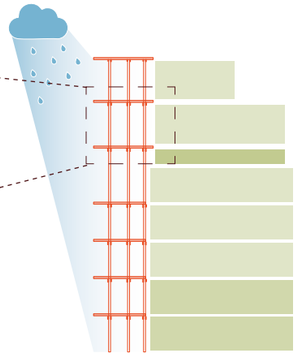


the building

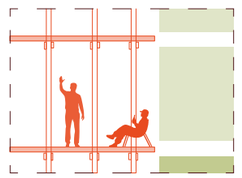
a second skin protecting:



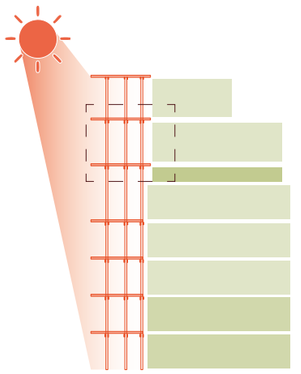
extended living space



the residents against weather



connecting residents



provide shade

Illustration 105: strategies of the gallery, own illustration.

7.3 from building to dwelling

The previous paragraphs explained how collective spaces, circulation and the gallery are introduced at the scale of the building. However, these strategies are not successful on their own and have to be translated to the scale of the dwelling itself. The relationship between private and collective space, eyes on the street, climatic comfort and everyday living continue in the layout of the apartment.

In illustration 105, the floorplan of a dwelling of the existing building and the topping-up are shown. The relationship between gallery and dwelling becomes visible and shows how the building strategy translates into space of a house.

The gallery is directly connected to the dwellings through the living spaces, like the kitchen and living room. These rooms are more public in character and benefit from visual connection and informal interaction. For the existing dwellings, the introduction of the gallery changes the relationship between dwelling and courtyard. While part of the existing view is reduced, residents receive something in return through direct access to the gallery and an extension of their living environment. The gallery is an intermediate space between dwelling and collective life. As a result, the intervention not only changes the relationship between dwelling and courtyard, but also adds spatial quality to the existing apartments.

The current window openings are replaced by doors with the same dimensions. Because this way the interventions to the existing structure are minimized and disturbance for residents is limited. This way residents can access the gallery while there are minimal changes to the facade and existing apartments. The existing dwellings are otherwise left unchanged. The facade frames and glazing were already replaced relatively recently, making further interventions unnecessary and reducing material waste.

At locations where more privacy is required, like bedrooms, a bigger distance is maintained between the gallery and the dwelling. The gallery shifts away from the facade, creating a distance beyond arm’ s reach. This allows visual contact without intrusion, enabling neighbours to recognise one another and creating awareness of everyday activity. Meanwhile a comfortable degree of privacy is maintained. The gallery creates a balance between encounter and privacy.

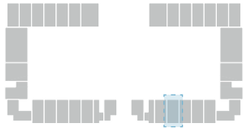
However, one limitation of the current housing layout remains. The apartments are organised towards one side. Which makes it difficult to simultaneously overlook both the street and the gallery. This limits the potential for eyes on the street and reduces visual connection to everyday activity around the building. For this reason, the new dwellings within the topping-up are organised as dual-aspect dwellings, a doorzonwoning. By orienting the apartments towards both the street and gallery side, residents maintain visual connected with activity on both sides of the building. This strengthens informal social control and supports the eyes on the street strategy introduced earlier.

The dual-aspect organisation also improves climatic comfort. Daylight enters from both sides of the dwelling. This improves the quality and distribution of natural light throughout the apartment. In addition, this spatial arrangement supports natural cross ventilation. The dual-aspect layout also reduces dependency on complex technical ventilation systems and therefore technical interventions within the topping-up are minimized.

Fresh air is supplied naturally through operable windows and doors on both facades. Only kitchens and sanitary spaces rely on additional mechanical exhaust ventilation. As explained in the 1:20 detail, extracted air is directed towards the street facade to avoid nuisance towards the gallery and inner courtyard. The wet rooms have a lowered ceiling which conceals technical installations and maintains easy access for future maintenance.

The widened gallery sections additionally function as an extension of the living space, instead of solely acting as access corridors. Within the gallery there are moments for staying, informal encounters and personal appropriation by residents.

In short, the dwelling layout translates the broader ambitions of the building into everyday life in dwellings. The apartments provide private living space, as well as visibility, climatic comfort and informal interaction between residents.



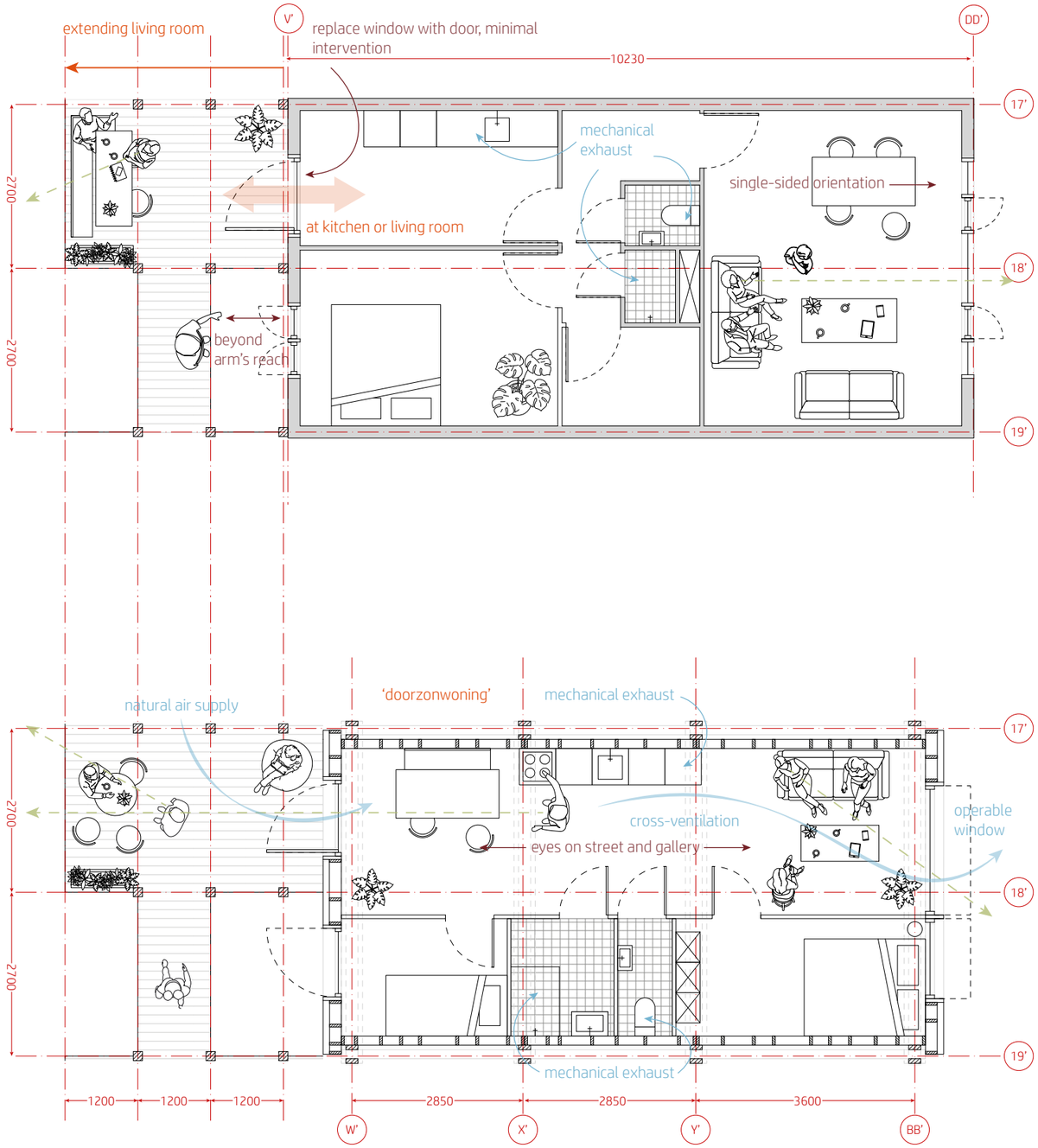


Illustration 106: floorplan of an existing and topping-up dwelling, own illustration.

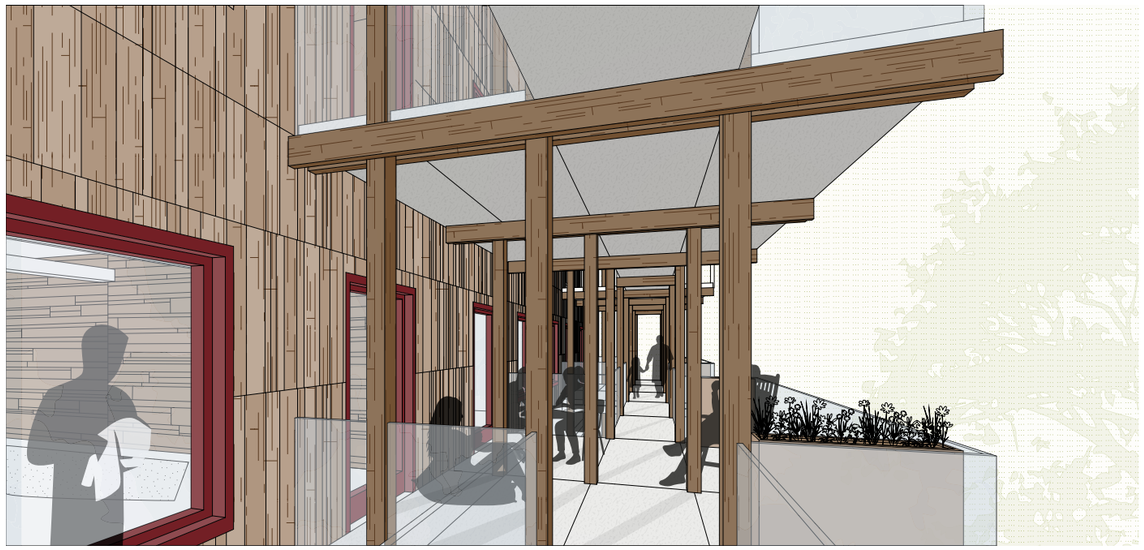


Illustration 107: impression of gallery during spring, own illustration.



Illustration 108: impression of gallery during fall, own illustration.

8. EXPERIENCING THE BUILDINGS

After zooming in from the building to the dwelling, the following drawings shift back to the scale of the building as a whole. Together, they show how climate, movement, privacy and social interaction are organised across the mirrored buildings. The drawings gradually move from the organisation of the sixth floor and rooftop climate strategies, to the collective spaces and circulation of the fifth floor, and finally to the relationship between both buildings through the overall section and facade.

8.1 the 6th floor

The floorplan of the sixth floor shows how the different spaces, climate and privacy levels are organized across both mirrored buildings.

First of, there is a gradient from private, semi-private and public environments in the organisation of outdoor spaces. This way, residents can choose different degrees of interaction.

Than, the plan additionally responds to the dominant south-western wind direction. Outdoor spaces like the rooftop terrace and gallery are protected through glass balustrades and planting which reduce the wind discomfort and improving the use throughout the year.

Also, on the widened gallery sections, foldable glass enclosures can temporarily close the outdoor spaces during colder or windier conditions. This extends the use of balconies and terraces throughout the year while maintaining the possibility to fully open the spaces in warmer seasons.

Next, the building has three microclimates across the building. The inner courtyard remains cooler and more sheltered, the gallery becomes shaded and protected from weather, while the rooftop spaces are warmer, sunnier and more exposed to wind and seasonal changes. This variety allows residents to choose spaces depending on weather conditions, preferred levels of comfort and social activity.

The largest flow of visitors moves through the centre of the inner courtyards, between the mirrored building and through ‘the poort’. To create a sense of privacy for residents of the building, the planting along the gallery is strategically oriented towards this route. From ground level upwards, planting softens views towards the dwellings and improves privacy for residents. At the same time, residents are able to look over the planting from the gallery. This maintains visual overview and contributes to informal social control.

Lastly, there are different atmospheres throughout the building: ‘rust, ruis and reuring’. For example the rooftop terrace is a space of activity and encounter (reuring), the gallery forms the softer background of everyday movement and informal encounters (ruis), and the quieter spaces like the indoor greenery and zen space provide moments of retreat (rust). As a result, the building accommodates collective interaction and individual wellbeing.

8.2 the 5th floor

The next drawing is the fifth floor, it shows the collective organisation of the building and the relationship between the mirrored buildings. While the sixth floor focused mainly on climate, privacy and rooftop spaces, the fifth floor focuses more on everyday movement, shared spaces and social interaction.

The inner courtyard forms the central collective space between the buildings. It functions as the social heart of the project and connects residents through shared routes, seating areas and greenery. Different spatial conditions are introduced to support different forms of use, from informal encounters and everyday movement to quieter moments of retreat.

6TH FLOOR

main circulation route

impact of the south-western wind
is reduced by glass balustrades and
planting.

courtyard → cool & sheltered climate

gallery → shaded buffer zone

roof → warm & exposed climate

shared rooftop
terrace

quiet green retreat

gallery:
everyday meeting space

semi-private terrace

foldable glass enclosure

privacy through planting

N

Illustration 109: 6th floor a 1:200 drawing, scaled to 1:300, own illustration

5TH FLOOR



1. quiet seating area
2. smaller private seating
3. children’ s play area
4. rainwater storage area
5. shared gathering space

Illustration 110: 5th floor a 1:200 drawing, scaled to 1:300, own illustration

5TH FLOOR

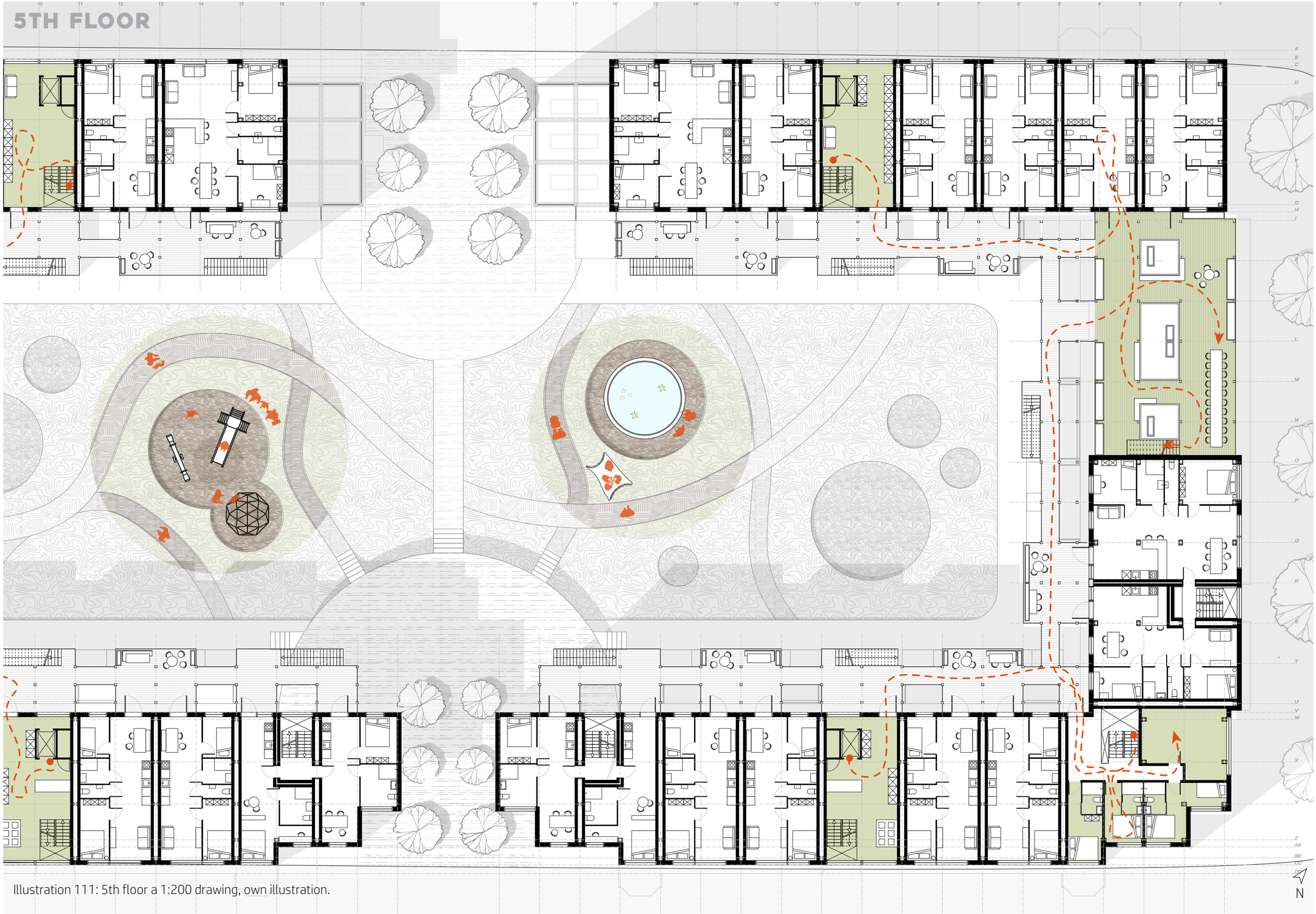
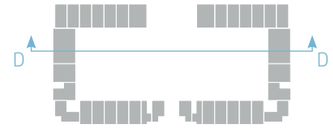


Illustration 111: 5th floor a 1:200 drawing, own illustration.



The architectural design explored how reclaimed timber can shape a topping-up strategy beyond construction alone. Reclaimed timber influenced the project across different scales, from the building expression and spatial organisation to the dwelling and shared spaces. It shaped the architecture, climate strategies and social ambitions of the project.

The design showed how topping-up can respond to multiple challenges at once. It increases housing within the existing city, contributes to reducing environmental impact and supports social cohesion. Through communal living, eyes on the street and layered reclaimed timber systems, different ambitions are combined into one architectural proposal.



Illustration 112: section D-D 1:200 scaled to 1:300, own illustration.

CONCLUSION

At the start of this graduation project three interconnected societal and architectural challenges were identified, together with a possible responses. First, the housing shortage in the Netherlands, for which topping-up existing buildings in dense urban areas was explored as a spatial strategy. Second, the environmental impact of the building industry, for which the direct reuse of timber was investigated as a circular material strategy. Finally, the vulnerability of certain neighbourhoods, for which strengthening social cohesion was explored as a social design strategy.

Based on these challenges and opportunities, the following research and design questions were formulated:

RQ: *How can reclaimed timber be translated into reusable building elements for application in the contemporary building industry?*

DQ: *How can reclaimed timber elements be applied in a topping-up strategy to improve social cohesion, safety and spatial quality in Wittenburg, Amsterdam?*

To answer these questions, the conclusion is structured around four themes: the research into reclaimed timber, the application of reclaimed timber within the architectural design, the social design strategies for Wittenburg, and finally the relationship between reclaimed timber and the social ambitions of the project.

Conclusion of the research

RQ: *How can reclaimed timber be translated into reusable building elements for application in the contemporary building industry?*

The research shows that reclaimed timber can be translated into reusable building elements by first defining a realistic reclaimed timber stock, then translating this uncertainty into a representative database and finally developing reusable building elements that anticipate future reuse. Instead of the challenge being the lack of material availability, the main challenge lies in the organisation of the reuse chain, including sorting, logistics, testing and standardisation.

The research demonstrated that construction and demolition waste, specifically A-wood and solid B-wood, provides the most realistic basis for architectural reuse thanks to its comparable properties to virgin timber. Based on this stock, a representative database was developed to create realistic assumptions regarding dimensions, material properties and availability. This way, reclaimed timber could be approached as a design resource rather instead of an unpredictable waste stream.

Finally, the research showed that reclaimed timber requires a different architectural logic than virgin timber. Instead of forcing irregular materials into a fully standardised system, the developed elements introduce a framework that accommodates uncertainty while remaining applicable within contemporary construction practice. In this way, adaptability, modularity, demountability and future reuse are part of the architectural logic of the system.

Conclusion of the design

Application of the research in the design

DQ: *How can reclaimed timber elements be applied in a topping-up strategy to improve social cohesion, safety and spatial quality in Wittenburg, Amsterdam?*

The reclaimed timber framework was tested through a design case in Wittenburg, Amsterdam. The project demonstrated that reclaimed timber elements can realistically be applied for topping-up post-war residential buildings. The repetitive concrete structures, flat roofs and overdimensioned load-bearing systems of this building typology, proved to be suitable for accommodating a lightweight timber extension.

The design showed that reclaimed timber introduces a different architectural logic than conventional timber construction. The topping-up responded to the variability of the reclaimed timber stock. The structural spans, building elements and construction strategies are developed from the available material dimensions. Despite the uncertainty of the stock and reusable elements were developed that can function within a contemporary and standardised building system. Instead of standardising the material itself, the project standardised the logic of the elements through modularity, prefabrication and demountable connections.

Prefabrication proved to be essential in translating reclaimed timber into a feasible construction methodology. A continuous structure is combined with prefabricated timber frame and finishing elements. This reduces the construction time and disturbance for the current residents. At the same time, the layered and demountable composition anticipates maintenance, transformation and future reuse, which allows the building to adapt over time.

The environmental impact of reclaimed timber was tested through the representative building fragment. The calculations demonstrated a potential embodied carbon reduction between approximately 9.28 and 12.27 tonnes CO_2 per fragment, depending on the timber scenario. The representative fragment fits approximately eleven times within the topping-up. Since the intervention is applied to two symmetrical buildings, the cumulative embodied carbon reduction demonstrates the environmental potential of reclaimed timber at building scale. The transport, processing and other lifecycle impacts were not fully included. However, the calculations indicate that direct timber reuse can contribute to reducing the environmental impact of the building industry. This is done by lowering the demand for virgin materials and preserving embodied carbon.

In conclusion, the case study Wittenburg demonstrated that reclaimed timber can realistically be applied for a topping-up through a combination of prefabrication, modularity and demountable design. The design works with the uncertainty of the material while it remains applicable within contemporary construction practice.

Social design strategies for Wittenburg

DQ: *How can reclaimed timber elements be applied in a topping-up strategy to improve social cohesion, safety and spatial quality in Wittenburg, Amsterdam?*

Besides addressing material and environmental challenges, the project also explored how a topping-up strategy can contribute to improving social cohesion, safety and spatial quality in Wittenburg. Two complementary strategies formed the basis of the design: communal living and eyes on the street. These strategies were translated into architectural interventions across multiple scales, from the dwelling to the neighbourhood.

First, communal living was applied through shared spaces, housing diversity and spatial transitions between private and shared areas. The introduction of communal living rooms, roof terraces, guest rooms and workshops in the project increases opportunities for informal encounters and mutual support between residents. The housing mix for starters, elderly residents and single households further strengthens long-term neighbourhood resilience.

Secondly, the principles of eyes on the street were translated through visibility, occupancy and informal surveillance. The shared functions are distributed throughout the building, dwellings overlook the gallery and surrounding public space, and open sightlines increase the visibility and orientation. As a result, daily activity is more present within and around the topping-up and existing building.

Next, the gallery became the key spatial element connecting both strategies. It functions more than as circulation, it is the social interface between the dwelling and collective life and extends everyday living into the shared domain.

In conclusion, the project shows that architecture alone cannot solve neighbourhood vulnerability, however it can create spatial conditions that support social cohesion, perceived safety and everyday interaction. Through communal living and eyes on the street, vulnerability is translated into concrete architectural interventions for Wittenburg.

Reclaimed timber and the social ambitions of the project

The project showed that reclaimed timber and the social ambitions for Wittenburg are not separate layers, but are closely interconnected. Reclaimed timber was applied from the beginning of the design process. As a result, the logic of reclaimed timber shaped the architecture, spatial organisation and construction methodology of the topping-up.

The variability and dimensions of the reclaimed timber stock influenced structural spans, prefabrication strategies and the organisation of communal spaces. At the same time, reclaimed timber contributed to the architectural identity of the topping-up through the facade, interior finishes and expression of shared spaces. In this way, reclaimed timber became not only a material strategy, but also part of the social and spatial experience of the building.

The layered and demountable design strengthened this relationship. The flexible system that was developed can adapt to changing housing demands and anticipate future transformations. As a result, the topping-up supports long-term adaptability and future reuse. In conclusion, reclaimed timber elements can be applied in a topping-up strategy to improve social cohesion, safety and spatial quality by integrating material reuse with socially driven architectural interventions. The project responds to the three challenges identified at the start of this graduation project. The topping-up increases housing capacity within the existing city, reclaimed timber contributes to reducing the environmental impact of construction through direct reuse and communal living together with eyes on the street strengthens the spatial conditions for social cohesion and perceived safety in Wittenburg.

Ultimately, the research demonstrated that reclaimed timber can be translated into reusable building elements through a realistic material stock, a representative database and reusable building systems. At the same time, the design showed how these elements can be applied in a topping-up strategy that combines material reuse with social ambitions. Reclaimed timber became more than a sustainable material choice, it is an architectural design principle that shaped the construction, spatial organisation and social ambitions of the project.

IMPLICATIONS AND/OR RECOMMENDATIONS

The conclusion demonstrated the potential of reclaimed timber and the proposed architectural design. However, a critical reflection on the research and design process is needed to better understand its limitations, implications and broader relevance for architectural practice.

The temporality of the reclaimed timber stock

The first limitation concerns the reclaimed timber stock used throughout this research. The stock definition was largely based on timber waste data from 2017. While this provided a realistic basis for the representative database, reclaimed timber stocks are likely to change over time. Nevertheless, the developed building elements should be able to adapt to these changes.

Secondly, the construction and demolition waste reflects building practices from previous decades. As a result, the timber stock available today largely originates from older buildings. And future reclaimed timber streams may reflect contemporary construction methods. Timber used today is increasingly designed for disassembly and dry connections, making it more compatible with future construction practices.

This raises an important implication for the architectural profession. Designing with reclaimed timber should not only respond to the current material stock, but also anticipate the future material streams that buildings themselves will eventually become. Buildings designed today can therefore be understood as future material banks. This requires architects to already consider future reuse during the design process.

The gap between architectural ambition and practical reality

This research focused mainly on architectural implications. However, the identified challenges show that reclaimed timber is not only an architectural issue, but also a logistical, organisational and economic one. This partly explains the gap identified in the problem statement between circular ambitions and mainstream architectural practice.

The direct reuse of timber remains difficult because of fragmented supply chains, uncertain availability, sorting, testing and transportation. In many cases, reclaimed timber is financially less attractive than virgin timber. As a result, developers, contractors and architects are less likely to invest in reuse strategies, this causes reclaimed timber to remain underutilised despite its environmental potential.

This also affects the realism of the proposed topping-up. The representative stock provided an indication of what could realistically be available, but it does not guarantee that reclaimed timber is present in the required dimensions, quantities, quality or at the right moment.

Research by AMS on circular material hubs (CMH) showed that reclaimed timber reuse becomes more viable when a hub is located within approximately three kilometres of the construction site. Since this condition was not present within the project, local availability could not be assumed. This shows that successful implementation depends not only on architectural design, but also on regional reuse infrastructures and supply chains.

Before the findings of this research can be applied at larger scales, improvements are needed in the logistical, organisational and economic systems surrounding reclaimed timber. Although technical knowledge on grading and material performance already exists, challenges related to sourcing, transportation and economic feasibility still limit implementation in practice. Therefore, this research recommends further optimisation of reuse infrastructures, supply chains and grading systems. Better coordination between demolition, storage and construction, in combination with circular material hubs and digital material databases, could make reclaimed timber more predictable and economically viable in mainstream construction.

At the same time, wider implementation will likely continue to require coordination, design flexibility and specialist knowledge. In this sense, the architectural profession alone cannot realise large-scale reclaimed timber construction, but depends on broader systemic changes within the reuse chain.

Furthermore, the findings of this research should be interpreted within the context of the Wittenburg case study. Although post-war residential buildings share repetitive characteristics, different building typologies, urban contexts and reclaimed timber stocks may lead to different outcomes. The project should therefore be understood as a framework for architectural decisions instead of a direct applicable solution.

Limitations of the CO_2 calculation

The embodied carbon calculations are an indication and should not be seen as a complete lifecycle assessment (LCA). The used values are based on direct substitution, which means that reclaimed timber directly replaces virgin timber without taking project specific influences in account. Such as transportation,

sorting, storage, processing, testing and material losses were not included. Since reclaimed timber often requires additional logistical and technical operations, the calculated CO_2 reduction represents an optimistic scenario.

This limitation is particularly relevant, because these logistical and organisational challenges are one of the largest barriers to reclaimed timber implementation. Therefore, future research would benefit from a complete LCA including transportation, processing and supply chain organisation.

Nevertheless, the calculations remain valuable in illustrating the environmental potential of reclaimed timber and reconnecting the project to the challenge of reducing the environmental impact of the construction industry.

The representative database and uncertainty

Another limitation concerns the representative database developed in this research. The database translated uncertainty in reclaimed timber into realistic design parameters. However, reclaimed timber remains inherently variable, meaning that selected dimensions, species and material assumptions contain a degree of subjectivity.

The database should therefore be understood as an indication rather than an exact prediction of reclaimed timber availability. Nevertheless, it proved valuable in supporting architectural decision-making and enabled the translation of reclaimed timber into reusable building elements.

The structural feasibility of reclaimed timber also remains partly dependent on assumptions. Conservative material properties and representative dimensions were used to address uncertainty in timber quality and performance. Although this enabled the architectural exploration of reclaimed timber, the developed systems were not fully structurally optimised. Future research could further investigate grading methods, structural performance and material efficiency.

Architectural trade-offs within the design

A critical reflection concerns the continuous structure used in the topping-up. The beams and columns structure created an open floor plan and flexibility for future adaptation. Together with the prefabricated timber frame elements, this allowed replacement, adaptation and future reuse.

At the same time, the strategy introduced disadvantages. The continuous structure required larger structural depths, resulting in spatial loss within the dwellings. Looking back, a different balance between flexibility, structural efficiency and spatial quality may have been preferred.

A possible alternative would have been a greater reliance on prefabricated timber frame elements in combination with new timber for structural optimisation of the timber frame elements. This could reduce structural depth, increase usable floor area and simplify construction while maintaining flexibility and future reuse potential.

However, for the purpose of this research, the chosen strategy remained valuable because it maximised the exploration of reclaimed timber applications and tested how multiple reusable systems could be integrated into one architectural proposal.

Architecture and the limits of social design

Finally, the project demonstrates that architecture alone cannot create a community. The design can stimulate encounters, visibility and informal interaction through communal spaces, galleries and spatial organisation. However, the success of communal living ultimately depends on the willingness of residents to participate and engage in social relationships.

Architecture should therefore be understood as a framework that supports social cohesion and perceived safety, rather than guarantees it. In the case of Wittenburg, the project builds upon an existing culture of resident participation instead of assuming architecture alone can create social cohesion.

REFLECTION

This final section of the graduation report reflects on the graduation process from a personal perspective.

Design process

Looking back at the graduation process, I realise how much the project changed over time. What started as a technical exploration of reclaimed timber and many other topics at the same time, slowly turned into an architectural project about how reclaimed timber can shape construction, space and social ambitions.

At the start of the project, I struggled with narrowing down the topic. Everything felt important. Reclaimed timber, topping-up, social cohesion, climate, detailing, flexibility, I wanted to include it all. Over time, I learned that making strong design choices also means letting things go. Kill your darlings is something I still find difficult, but I definitely became better at it during this process.

Another important lesson was that I waited too long before really starting to design. I felt like I first had to understand everything before putting a pen to paper. Because of this, a lot of time went into research and theory, while form studies and architectural language remained underdeveloped. The design follows the logic of the existing building and reclaimed timber, but I sometimes wonder how different the outcome could have been if I had started designing earlier and allowed research and design to develop more simultaneously.

Although the research methodology described the project as a research by design process, looking back I realise I did not fully work this way from the beginning. Instead of moving back and forth between research and design, I first tried to solve many research questions before designing. Only later in the process did it become more iterative. This taught me that designing itself can also be a way of gaining knowledge. Sometimes, uncertainty only becomes clear once ideas are spatially tested.

Architectural quality and circular ambitions

Another important lesson was the tension between circular ambitions and architectural quality. During the process, I often aimed to maximise the use of reclaimed timber. However, I gradually realised that there needs to be a balance between circularity, construction logic and spatial quality.

The continuous structural strategy is a good example. It created flexibility, an open floor plan and adaptability for the future. At the same time, it also required larger structural depths, resulting in spatial loss within the dwellings. Looking back, I think I would have explored a system with more prefabricated timber frame elements and a limited amount of new timber earlier in the process. This might have resulted in better spatial quality while still maintaining reuse potential.

This made me realise that designing with reclaimed timber is not about maximising reuse at all costs, but about finding a balance between reuse, spatial quality and architectural ambitions.

Understanding of social design

My view on social design also changed during the process. Initially, I strongly believed architecture could actively improve social cohesion and safety. Over time, this became more nuanced.

I still believe architecture can influence behaviour. Shared spaces, galleries, visibility and spatial transitions can stimulate encounters and informal interaction. However, architecture alone cannot create a community. The willingness of residents to participate remains just as important. I now see architecture more as a framework that creates opportunities for social interaction, rather than a guarantee for it.

Designing with uncertainty

And finally, an important lesson of this graduation project was learning to design with uncertainty. Reclaimed timber forced me to think differently. Instead of fixed dimensions, predictable systems and clear answers, the project required constant adaptation. At first, I experienced this uncertainty as a challenge. Later, it became a valuable aspect of the project.

The process taught me to see uncertainty as an opportunity. This way of thinking goes further than reclaimed timber and I will use it in the future to look at architecture more broadly.

Looking back, I think the biggest lesson for me was simply to start designing earlier. I learned that not everything has to be figured out beforehand and that design itself can be a way of thinking, testing and understanding.

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APPENDICES

Renders





APPENDICES

Pictures models



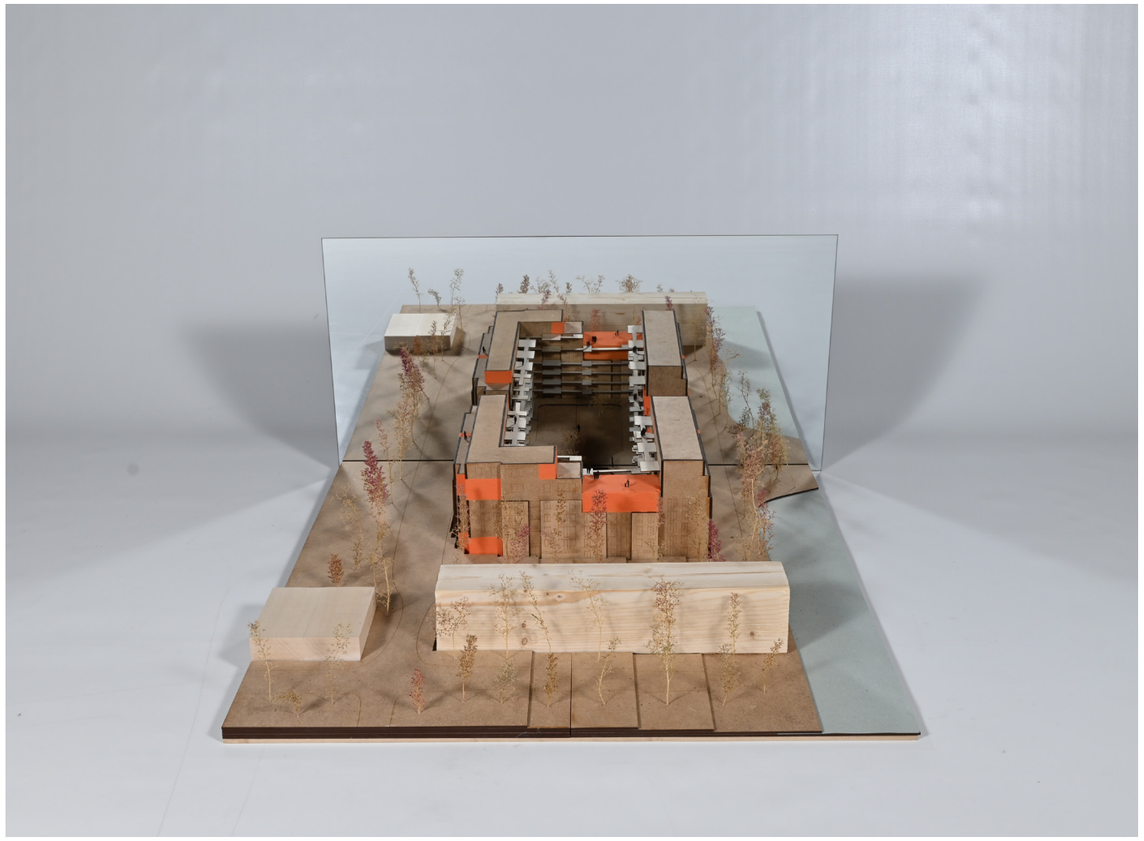


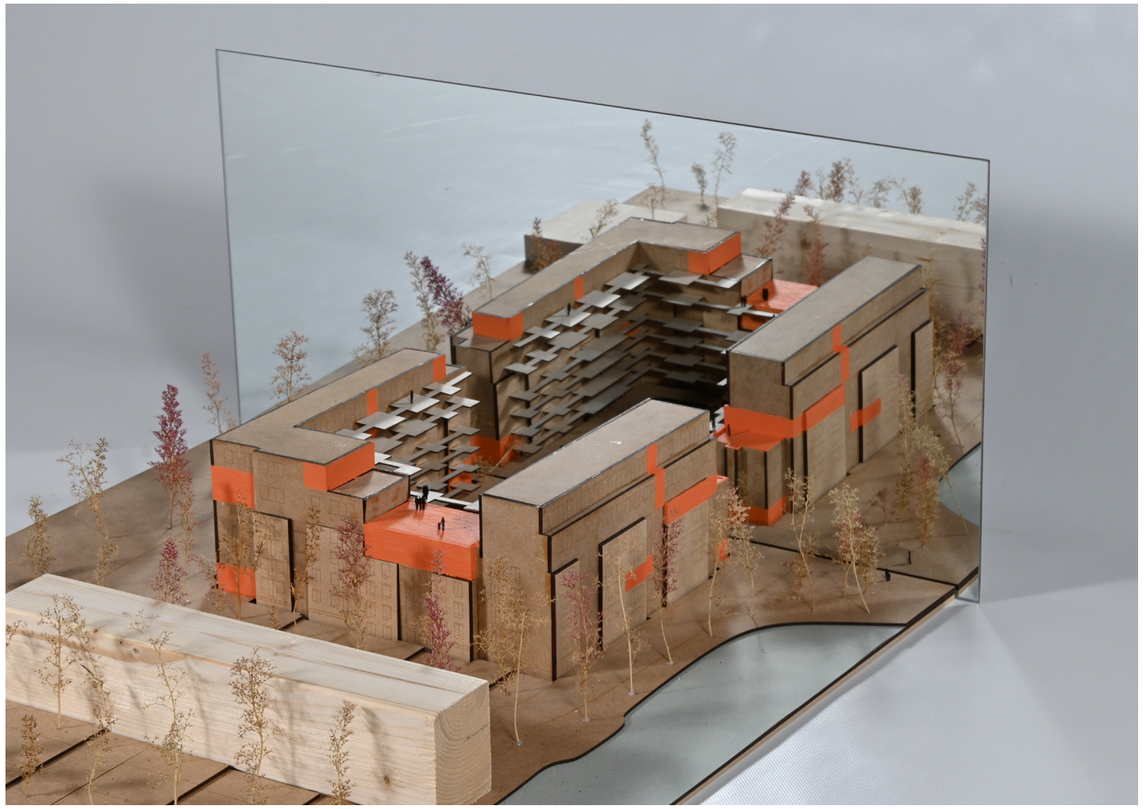




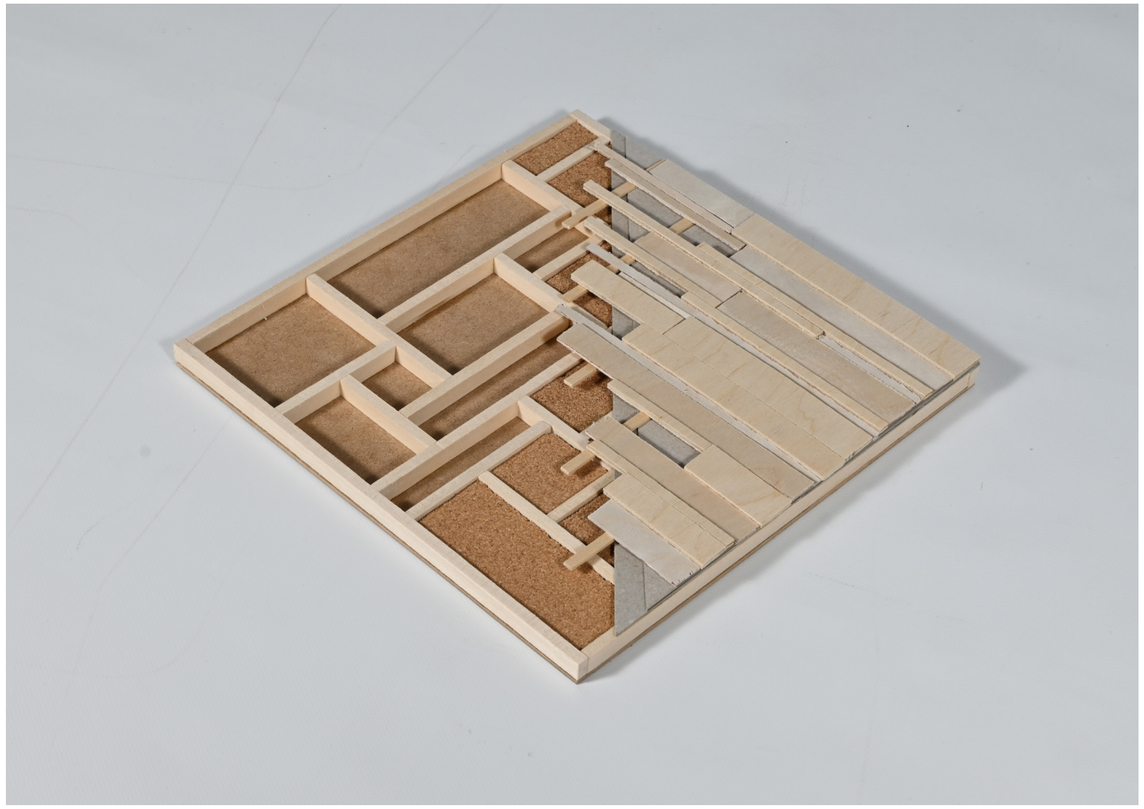












APPENDICES

DATA MANAGEMENT CHECKLIST

Instruction

This checklist is relevant for all graduation projects of the Master AUBS. The form is intended to highlight common aspects of graduation projects that require particular attention with regard to planning the research and data management. Relevant information and supplementary sources regarding each question are provided below each question.

With this checklist, the faculty wants to avoid that students unexpectedly find themselves in complex and stressful situations, in which ethical or privacy matters and/or other laws and regulations become an issue. In projects involving humans, certain types of data processing increase the risks to the human participants: planning such projects requires additional evaluations and advice from university staff before ethical approval can be received and the project can begin. In the case of a graduation project, obtaining additional advice or permits may delay the project with an extra education period or semester. To avoid this, it is recommended that students set up a graduation project with a low level of risk. Therefore, all students have to check their risk, by completing this checklist before their A1.

The first section of the checklist (A) should be completed by all students, together with their supervisor, during the planning of the graduation project, before the A1. It does not need to be submitted to anyone for review or approval. Please consider questions 1 to 3 carefully in relation to the intended graduation project, and answer with ‘yes’ or ‘no’.

The second section of the checklist (B) should only be completed if the graduation project involves working with data from human participants. In that case, the student and their supervisor must apply for and receive ethical approval from the Human Research Ethics Committee (HREC) before the project can begin (see the paragraph ‘Explanation and follow-up’ after the questions). The student can submit the application to the HREC, but the supervisor is responsible for making sure that the project is compliant with relevant privacy regulations and ethical policies.

Section A. General considerations	yes	no
1. Is the graduation project conducted as part of an internship (at a company), or as part of a research project at TU Delft? If a student’s graduation project is conducted at a company or as part of a research project at the university, questions of data ownership and intellectual property rights need to be addressed in a written graduation or internship agreement before the project begins. Students and their supervisor should consult the Intellectual Property Rights of Students webpage. Additional information can also be found in the Extended Personal Research Data Workflow.		✓
2. Does the project involve conducting (part of) the research outside the Netherlands? Students who intend to travel abroad (even to other EU countries) for study, exchange, research, internship, or graduation project purposes need to follow the Travel Safety Protocol. This includes attending a mandatory Travel Safety Training Session: see the Disclaimer.		✓
3. Will the research involve processing data from humans, such as running a survey, conducting interviews or workshops, collecting data through social media or internet forums, or re-using existing datasets about humans provided by a third party? (If ‘yes’, see follow-up questions 4 to 13 in Checklist B.) Students who work with data from human participants must complete the next section and apply for and receive ethical approval from the Human Research Ethics Committee (HREC) before conducting the research.		✓

Section B. Extended risk factors (only if question 3 has been answered with 'yes'.)	yes	no
4. Will the project involve participants who may be considered vulnerable, such as the elderly, refugees or asylum seekers, ethnic minorities, patients, or people with disabilities? Participants who may suffer very adverse consequences (for instance, due to discrimination) if their personal data became publicly available can be considered vulnerable.		✓
5. Will the project involve participants who cannot themselves give informed consent for taking part in the project, but for whom consent must be obtained from a legal guardian? Participants who cannot give informed consent can include, for instance, children or participants with intellectual disabilities, mental disorders, or dementia. Such participants are also considered vulnerable in the context of the General Data Protection Regulation (GDPR).		✓
6. Will the project involve processing any of the special categories of personal data below? - Race - Ethnicity - Criminal offence data - Political opinion - Union membership - Religious or philosophical beliefs - Sex life and/or sexual orientation - Health data (including measurements such as heart rate) - Biometric or genetic data (including fingerprints, iris scanning, facial recognition) The General Data Protection Regulation (GDPR) defines a stricter rules for processing special categories of personal data. If it is necessary to process these data in a project, it is it is important to provide additional safeguards.		✓
7. Will the project involve processing personal data that could be considered sensitive, such as the ones listed below? - Information about a person's income, debts, or other payments - Information about a person's (un-)employment status - Information about a person's performance at school or work - Information about relationship problems or (gambling) addiction - Information about poverty, domestic violence, or youth welfare/social work involvement Some types of personal data are considered sensitive, because they can have a high impact on the privacy of the data subject if other persons gain access to these data. Sensitive personal data should only be processed if necessary: in such cases, additional safeguards need to be put in place.		✓
8. Will the project involve processing video-recordings, or photographs of participants? TU Delft considers photographic and video-materials of research participants to be sensitive personal data. If such data need to be processed, additional safeguards must be put in place.		✓

Section B. Extended risk factors (only if question 3 has been answered with 'yes'.)	yes	no
9. Will the project involve sharing or transferring personal data between multiple partners or collaborating organisations involved, such as between TU Delft and an internship company? According to privacy law, sharing personal data between organisations requires a privacy agreement to be in place: setting this up takes time, and requires support from additional university staff. Furthermore, personal data sharing can potentially expose research participants to different types of risks: these risks must be considered in the ethical application.		✓
10. Will the project involve deception, or covert observation of participants? In some types of research, obtaining informed consent for processing participants' personal data is not an option: for instance, if the research involves deception, or the research is covert (conducted without participants knowing about it). In such situations, the steps to mitigate risks to participants are important, and an alternative legal basis for processing the participant's data needs to be established with the help of additional support staff.		✓
11. Will the project involve working with social media data? Social media data are personal data, but since it is usually not possible to ask for informed consent for processing social media data, another legal basis for processing the participant's data needs to be established. Processing of social media data also involves legal considerations related to terms of use of data from third-party platforms: therefore, research with social media data requires expert support on privacy, ethics, and legal matters.		✓
12. Will the project involve using learning algorithms or other AI to analyse, combine, or otherwise process data from participants? The use of AI in research involves many considerations in terms of data protection, ethics, security, and intellectual property: for more information, see TU Delft's Instructions for use of Generative AI.		✓
13. Will the project involve participants who are based in a country or countries outside of the EU? Students affiliated with TU Delft must comply with Dutch and EU regulations of personal data processing (GDPR). Furthermore, the student and their supervisor must make sure that the research complies with local (privacy) legislations of any foreign destinations. Additional support from an external (local) expert may be required.		✓

Explanation and follow-up

If you have answered 'no' to all questions 4 to 13, your project is likely to be considered low or minimal-risk: see the paragraph 'Projects with minimal or low-risk' on the next page.

If you have answered 'yes' to one or more of the questions 4 to 13, your research likely involves extended or high risks to participants, according to the General Data Protection Regulation (GDPR) and TU Delft's privacy and ethical policies: for information regarding such projects, see the paragraph 'Projects with extended or high-risk' on the next pages.

Projects with minimal or low-risk

If you have answered ‘no’ to questions 4 to 13, your project is likely to be considered low-risk. This does not mean that the project involves no risks at all, but suggests that these risks can likely be addressed by the student and supervisor in the application to the Human Research Ethics Committee (HREC) within the timeline for a graduation project and without need for additional support.

Compiling the HREC application:
An application to the HREC generally involves a Data Management Plan (DMP), a risk-identification and mitigation checklist, and informed consent materials. Master’s students at ABE who intend to compile a HREC application are advised to make use of the following support documents:

- the student guide
- the Example Data Management Plan for MSc projects

The graduation supervisor is responsible for the student’s project and ethical application, and must provide support for compiling the HREC application documents.

Additional support
For low-risk student graduation projects, compiling of the HREC application documents should be done by the student in consultation with the supervisor. The Faculty Data Steward can be contacted for individual questions at datasteward-BK@tudelft.nl: however, the Data Steward does not provide detailed feedback on student DMPs for low-risk HREC applications.

Additional resources
The HREC has guides available for completing the checklist and for compiling informed consent materials. Additionally, the Guide to the Extended Personal Research Data Workflow has been created to help researchers and students who work with human participants comply with both GDPR principles and TU Delft’s policies on Data Management and Human Research Ethics.

Timeline
Minimal or low-risk HREC applications are generally processed faster than extended or high-risk applications (see the paragraph below). Nevertheless, the initial evaluation by the HREC usually takes approximately 2 weeks, and may take longer during busy periods or holiday: see the HREC website for up-to-date information. Additionally, the application may require revisions before final approval is granted. If you do not receive an initial response about your ethical application after 4 weeks from the time of submission, you may follow up with the HREC to enquire about an update.

Projects with extended or high-risk

If you have answered ‘yes’ to one or more of questions 4 to 13, there are potential increased risks related to how data from human participants will be processed in your project. These risks will need to be addressed in consultation with the Data Steward and other relevant support staff before submitting the ethical application to the Human Research Ethics Committee (HREC).

Compiling the HREC application
An application to the HREC generally involves a Data Management Plan (DMP), a risk-identification and mitigation checklist, and informed consent materials. Master’s students at ABE who intend to compile a HREC application are advised to make use of the following support documents:

- the Ethical Approval & Data Management Planning Student Information
- the Example Data Management Plan for MSc projects

The graduation supervisor is responsible for the student’s project and ethical application, and must provide support for compiling the HREC application documents.

Additional support
Once the DMP has been compiled and reviewed by the supervisor, feedback should be requested from the Data Steward via DMPonline. After this, any other necessary support staff will need to be contacted. Crucially, if the project involves one or multiple ways of personal data processing that could result in high-risk to the participants according to the GDPR, the TU Delft Privacy Team must be consulted to establish whether or not a Data Protection Impact Assessment (DPIA) is required.

Additional resources
The HREC has guides available for completing the checklist and for compiling informed consent materials. Additionally, the Guide to the Extended Personal Research Data Workflow has been created to help researchers and students who work with human participants comply with both GDPR principles and TU Delft’s policies on Data Management and Human Research Ethics.

Timeline
It can take a long time to compile a complete research plan and HREC application for projects involving extended risks. DMP feedback from the Data Steward usually takes around 2 weeks, but can take longer during busy periods or holidays. Receiving additional support from other staff, such as the Privacy Team, can take anywhere from a few days to multiple weeks, depending on the project and capacity of university staff. If a DPIA is deemed necessary, it can take anywhere from 4 weeks to several months.

It is important to note that advice from the Privacy Team or other support staff, as well as any additional documents (such as necessary contracts, or a DPIA, if needed) must be in place before the application is submitted to the HREC. The initial evaluation by the HREC can be processed in 2 weeks, but may take longer during busy periods or holidays: see the HREC website for up-to-date information. Additionally, the application may require revisions before final approval is granted. If you do not receive an initial response about your ethical application after 4 weeks from the time of submission, you may follow up with the HREC to enquire about an update.

Considering the limited time available for students conducting their graduation projects, students working with data from human participants are strongly advised to prioritise low-risk research projects. If a student project necessitates processing data in ways that are considered extended or high-risk, both student and supervisor need to be aware of the extended processing times involved in obtaining ethical approval and beginning the graduation project.