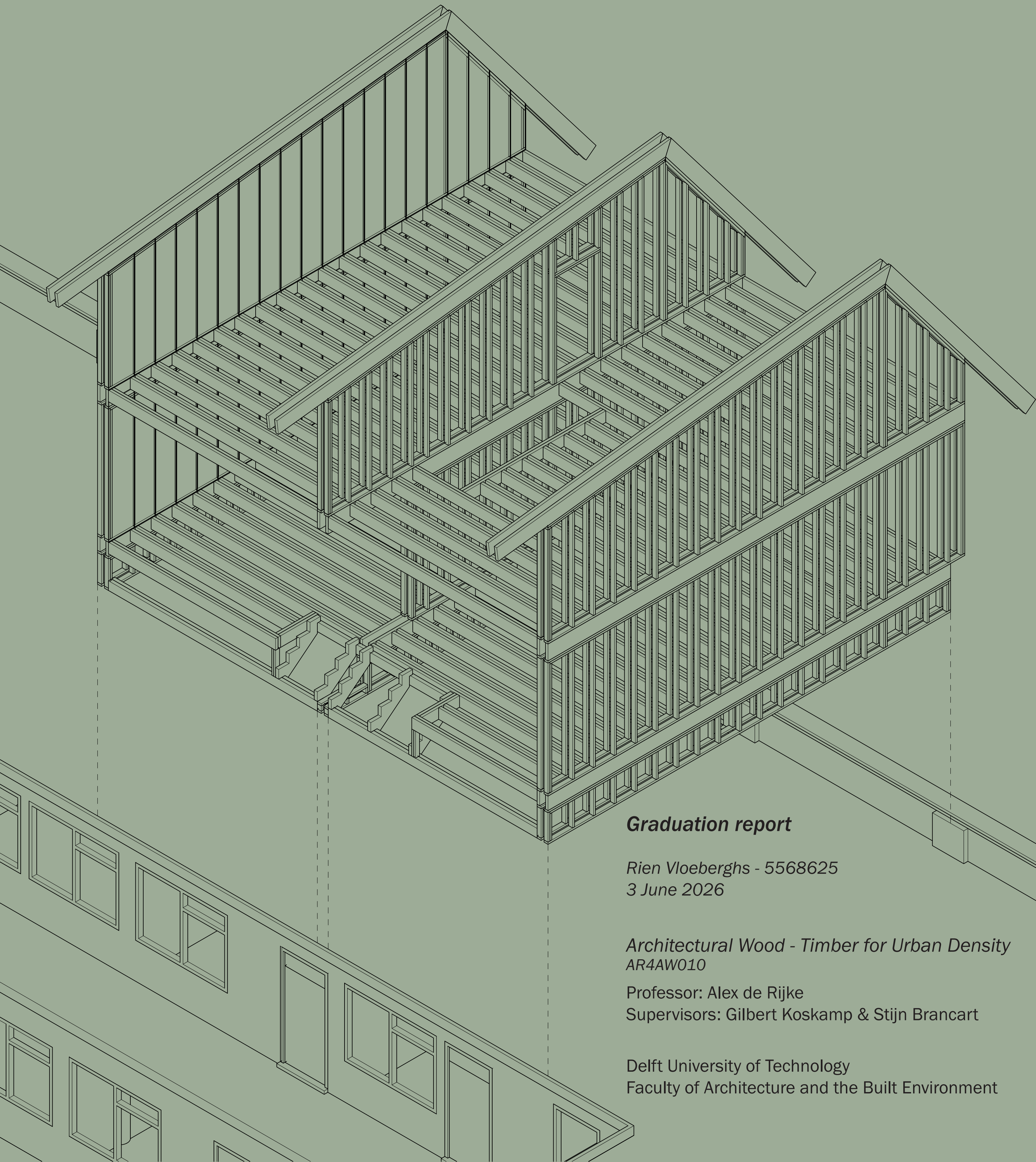
The Poplar Revolution

Exploring poplar in urban densification



Graduation report

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3 June 2026

Architectural Wood - Timber for Urban Density
AR4AW010

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Delft University of Technology
Faculty of Architecture and the Built Environment

Preface

Before you lies the graduation project “The Poplar Revolution”. This project is created within the Architectural Wood graduation studio of the Master Architecture, Urbanism and Building Sciences, track of Architecture, at Delft University of Technology. The research and design for this project took place between November 2025 and June 2026.

During my studies, I developed a certain fascination for building with timber. The material’s many possibilities and applications, as well as its sustainability and workability, are all qualities that have fuelled this fascination. For my graduation project, I therefore wanted to choose a topic that could help increase the share of timber construction in contemporary architecture and the construction sector. The choice of poplar as the subject for this project stems from this. Exploring the potential of this local tree specie for construction offers the opportunity to make better use of this under-utilised timber.

I would like to thank my supervisors, Gilbert Koskamp and Stijn Brancart, for their excellent guidance and support throughout this process. I am convinced that, thanks to your support, I have been able to take this project to a higher level. I would also like to thank those who contributed to this project by engaging in discussions on the subject, in particular Job Wittens and Bart van Dijk.

Finally, I would like to thank my fellow students and friends for their help during this graduation project. I would also like to give a special thanks to my family for their support throughout my studies and for making my study time at the university possible.

Abstract

This project investigates the role that poplar timber can play in the construction sector of the 21st century. The project brings together existing research while investigating how and where poplar timber can be applied in the design of a rooftop extension for the former warehouse d'Peliekaan in Amsterdam. With the main research question "Does poplar timber have potential in the construction sector of the 21st century?", the research focuses on the possibilities and considerations of building and designing with poplar. The design seeks to apply poplar in places where it makes sense, thereby determining the role of poplar timber in the construction sector.

The project demonstrates, through both research and design, the potential for using poplar in structural applications as well as for interior and façade finishes. The research shows that, depending on the sub-variety, poplar can be used as a raw material in almost all mass timber products. Furthermore, poplar timber can be easily modified for use outside the waterproof layer of structures. In the design, poplar timber has been used structurally as laminated studs in a timber frame construction, in a glulam post-and-beam construction, and in a glulam truss bridge and tower. Laminating and finger-jointing poplar ensures that irregularities in the wood structure of the hardwood are removed as much as possible, thereby achieving an expected strength class of C22. For use outside the waterproof barrier, thermal modification appears to be the best option for cladding in the design, while acetylation has been used for the structural application of poplar outside the waterproof barrier.

The design utilises a 2D timber frame structure and a 1D post-and-beam structure. The choice of these systems was based on the use of poplar and the different functions within the design. To introduce vertical adaptability into the 2D timber frame system, principles from balloon framing have been reintroduced by hanging the floor between the walls. The issues the system has with building physics (fire risks and acoustics) have been addressed by creating a modern interpretation of the system using principles from platform framing.

The use of poplar as a building material has influenced the architecture in terms of the choice of structural system and the anatomy of the façade. In this way, the overhang, intended to protect the poplar façade, has become a characteristic feature in the architecture. However, poplar appears to have little influence on the architecture in general and is perfectly suitable as a building material, differing little from other traditionally used timber species such as spruce.

Keywords:
poplar, timber frame construction, rooftop extension

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Part I:
Introduction

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1.1 Problem statement

Over the past decades building with timber has again received an increased interest from the global construction industry. This is mainly due to the new possibilities offered by mass timber products such as CLT, LVL and Glulam that allow timber construction to grow taller (Acker et al., 2020). Alongside these new possibilities, timber construction offers a more environmentally friendly alternative to concrete and steel structures, which currently still dominate the construction industry. However, this growing awareness of climate change and the need to adopt bio-based and circular construction methods also raises the question of which timber to use.

The timber species that are currently most common in European timber construction are softwood species such as spruce, pine, and fir (Tomei et al., 2023). These timber species, while present in European forests, are however also limited in the amount of construction timber that they can supply each year. In the Netherlands for example 93% of the sawn timber and timber plate materials gets imported. This while the harvest of industrial timber from Dutch forests decreases (U. Sass-Klaassen, lecture on Connecting Forest & the Build Environment, Januari 6, 2026). To keep the supply chain short, it is therefore important, also in line with the Copenhagen Lessons, to look for local alternatives in our forests (International Union of Architects, 2023).

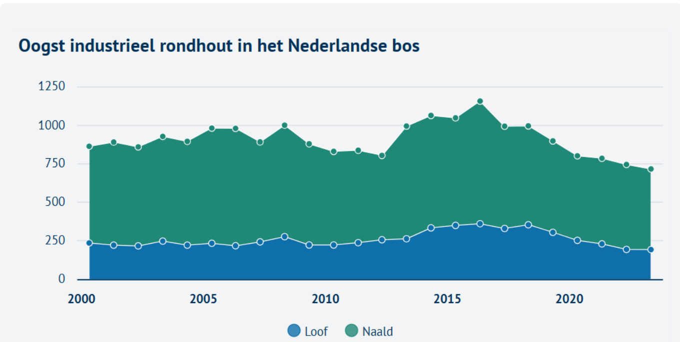


Figure 1: *Harvest industrial roundwood from Dutch forests*

Alongside the rising demand and search for locally available timber, the Netherlands deals with a huge housing shortage which mainly occurs in the urban areas. Looking at Amsterdam for example, we see that housing prices in the city centre have risen enormously as the demand in this area is much greater than the available houses (Dignum, 2022). This trend has consequences for a large group of people. It makes it particularly difficult for young adults who are just entering the housing market, also known as starters, to find a home (De Nederlandsche Bank, n.d.). They often live alone and have limited financial resources. Furthermore, this problem is accompanied by high levels of loneliness among this group (Rijksoverheid, n.d.).

Adding extra storeys to the existing housing stock can offer a realistic opportunity to meet the demand for housing in the city while also giving starters a place on the housing market (Must, 2024). In these topping up projects, where the rooftop extensions are structurally dependent on the existing supporting structure, a lightweight construction is necessary. As a result, there is a need for lightweight and local building materials like timber in order to densify the city.

1.2 Relevance

Poplar is a timber specie with great potential in this regard. As a native, deciduous and fast-growing species, the tree reaches a harvestable size in just 25 years (Westerhof & Kooistra, 2026). In comparison, a coniferous white spruce reaches a harvestable size at an age between 60 and 80 years (Ahmed et al., 2025). Furthermore, on a European level, poplar trees together with other native deciduous species are more resilient to climate change than for example Norway spruce. This, on the condition that they are planted in mixed stands and good forest management practices are in place (Westerhof & Kooistra, 2026).

Poplar timber is known for its light weight, which is a major advantage in lightweight construction and therefore also in topping up projects. However, due to its lower strength compared to spruce, pine and fir, the timber is still rarely used in construction (Westerhof & Kooistra, 2026). Nevertheless, the potential of poplar timber for structural applications is generally recognised in literature. In recent years, there have been many studies into how poplar timber can be used in mass timber products, both in homogenous and hybrid variants. Research has also been conducted into modifying and treating poplar timber to improve its strength and durability. However, the results remain mainly limited to individual studies with a gaining but still very small number of examples from practice. In this context, the hesitation of the market regarding its structural application and durability can be seen as a key reason (Monteiro et al., 2020). At an architectural level, the lack of design focused research into the use of poplar is another important factor.

Personal fascination:

Timber as a biobased and easily workable material that can be used both structurally and in finishes.

↓

Problem:

The demand for timber increases while the production of timber from Dutch forests decreases.

↓

Approach:

Searching for local alternatives in native hardwood species such as poplar.

↓

Challenge:

How do we built with a timber specie that is currently used to make matches and paper?

↓

Research question:

Does poplar timber have potential in the construction sector of the 21st century?

1.3 Objective

The goal of this graduation project is to showcase the potential of poplar timber in modern construction and architecture. While poplar timber's potential as a building material is already acknowledged in literature, it is currently still mainly used in low-value applications such as clogs, matches, paper and OSB panels. Whenever poplar timber does get used in the construction industry, it is generally used as formwork material or as a lightweight finishing board (balatinecz et al., 2001). In this regard, an overview will be made on how poplar can be used as a more valuable material in the construction sector by exploring it's potential in the design of a topping up integrated in the urban fabric of Amsterdam.

1.3.1 Architectural ambitions

- To design a two storeys lightweight topping up in which poplars potential as a building material is explored.
- To investigate the architectural consequences and constraints of using poplar on the architectural expression.
- To demonstrate that qualitative designs can be made using poplar.

1.3.2 Technical ambitions

- To showcase the potential of using poplar as a building material.
- To find the place of poplar in construction, where you should use it, and when are there better alternatives.
- To integrate adaptability in a poplar construction.

1.4 Research and Design questions

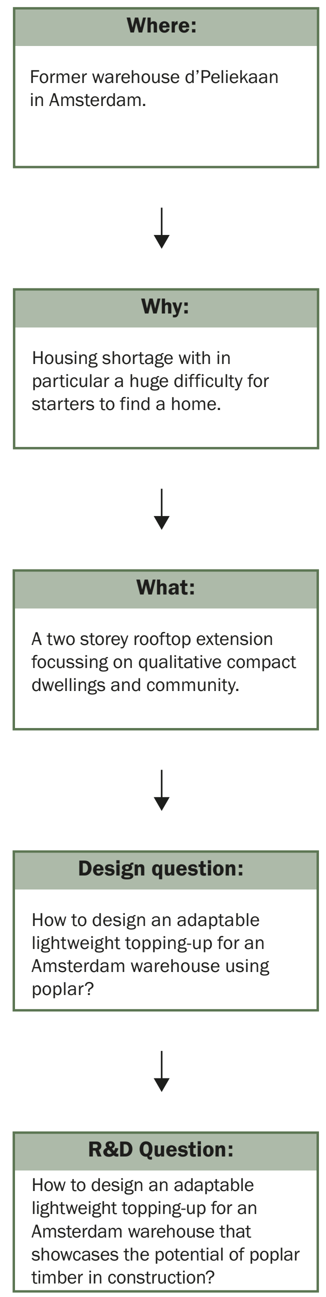
The main research question in this project is: "Does poplar timber have potential in the construction sector of the 21st century?".

Breaking this research question down gives the following sub-questions:

- What are past and current applications of poplar in construction?
- What are the conclusions of existing research into the use of poplar for structural applications?
- How does poplar timber compare to commonly used structural timber species, and which sub-varieties are most suitable for structural use?
- Is poplar's lightweight a potential benefit for structural application?
- How does moisture influence the use of poplar timber outside the waterproof barrier of a building?
- What are the consequences and constraints of working with poplar in architectural design?

At the same time, focusing on urban densification and the opportunities offered by topping-up projects, the project attempts to answer the design question: "How to design an adaptable lightweight topping-up for an Amsterdam warehouse using poplar?". In this question building with poplar is considered a starting point, in which the adaptability of the construction is investigated.

During the process the research and design question will inform each other and can be combined in the question: "How to design an adaptable lightweight topping-up for an Amsterdam warehouse that showcases the potential of poplar timber in construction?"



1.5 Scope

The scope of this project is to use poplar, a timber specie that in the past was regarded as a weed tree (Balatinecz et al., 2001), to densify our cities in a topping up project. In this regard a design will be made for a lightweight two-storey rooftop extension within the city centre of Amsterdam. The rooftop extension itself will be structurally dependent on the existing load-bearing structure. Because of this a building with additional load-bearing capacity had to be selected. Furthermore, the target group for this project are starters, making the proximity of social functions important. Using these parameters, the former d'Peliekaan warehouse, built in 1902 and located in the eastern Kadijken neighbourhood of Amsterdam, was selected as the location for this project.

Figure 2: *d'Peliekaan*

Figure 3: *Opportunity map: Topping up buildings*

1.5.1 d'Peliekaan

The building d'Peliekaan was originally designed by Jan van Looij as a double warehouse of which only the eastern part got built in 1902. The warehouse was used to store colonial goods such as coffee, pulses and seeds, after which it became vacant in the 1970s (Amsterdam Op De Kaart, 2017). In 1987, the warehouse was transformed into an apartment block, during which a large part of the inside of the building was demolished to create a courtyard (see figure 4). However, the original supporting structure of concrete columns and beams has been retained, which is particularly visible in the layout of the ground floor parking garage (see figure 5 & 6).

Figure 4: *Transformation d'Peliekaan 1987*

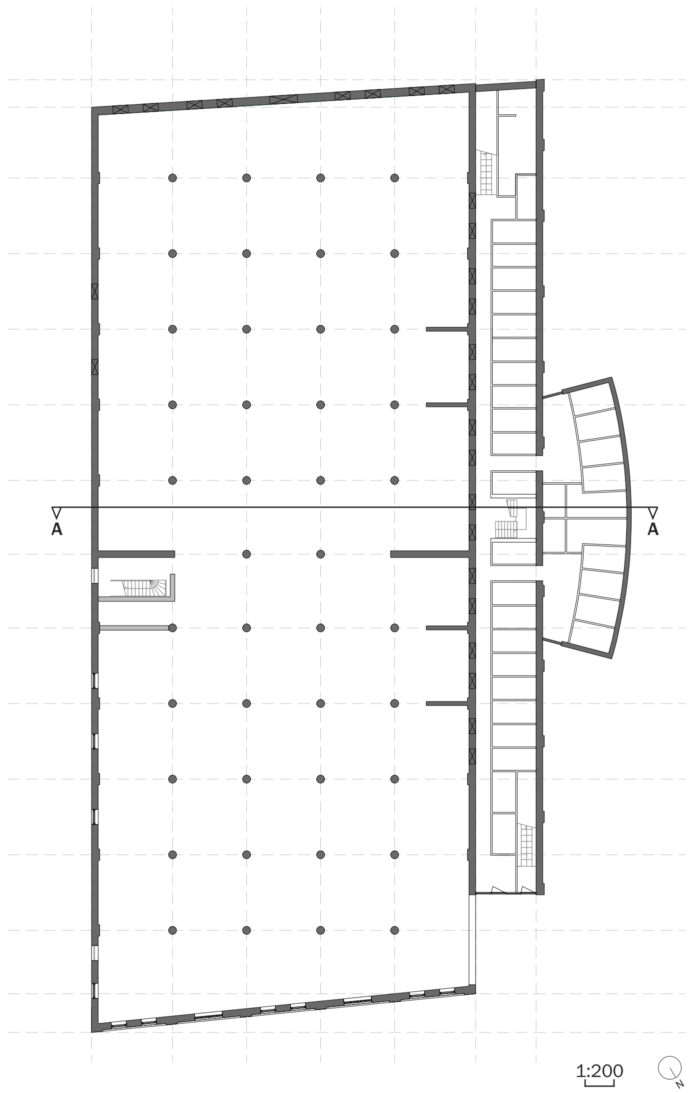


Figure 5: *Original structure in floorplan ground floor*

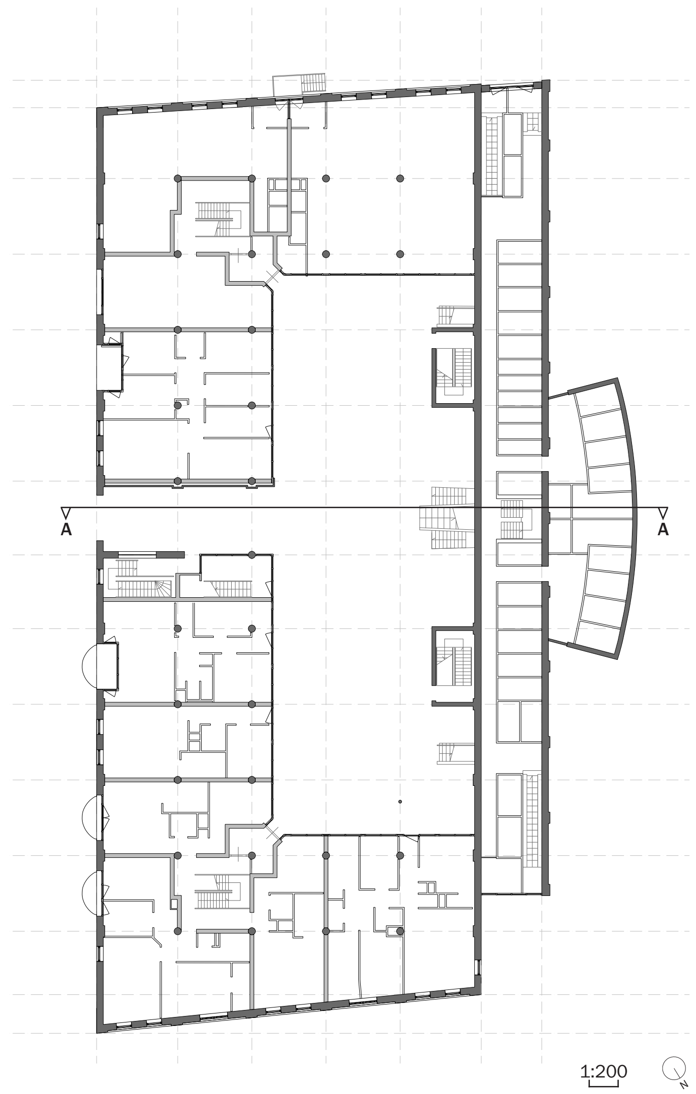


Figure 6: *Courtyard in floorplan 1st floor*

Today, the building still serves as a residential block with a total of 69 dwellings spread across 5 of the 6 floors. The courtyard, created in 1987, is used solely as a circulation space, while the sun terrace (created on top of the storage units in the transition zone with the adjacent courtyard) appears to be abandoned (see figure 9). Nevertheless, the building and the courtyard offer great potential, highlighted by the large amount of greenery on the galleries (see figure 11). This greenery suggests a desire of the current residents to see the grey and paved character of the space transformed. A desire that might also apply to the adjacent Matrozenhof (see figure 8).

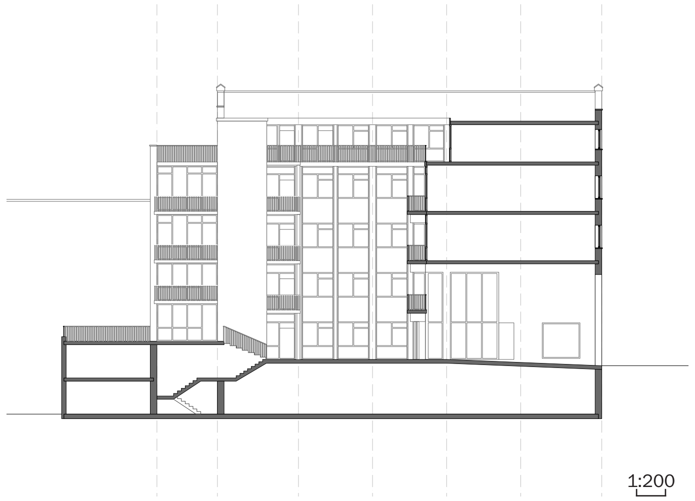


Figure 7: *Section A-A*

Figure 8: *d'Peliekaan and neighbouring Matrozenhof*

Figure 9: *Sun terrace in between adjacent courtyards*

Figure 10: *New façade of inner courtyard from 1987*

Figure 11: *Galleries covered in greenery*

1.5.2 Kadijken and Nieuwe Vaart

The Kadijken is a neighbourhood in the east of Amsterdam, situated by the Nieuwe Vaart, a canal that was very important for the development of both the neighbourhood and Amsterdam in general. As the area was very important for the harbour industry, numerous warehouses were built along the Nieuwe Vaart in the second half of the 19th century. Due to the growth of larger ships however, this industry moved away from the Nieuwe Vaart in the mid-20th century, and in the 1980s and 1990s the entire neighbourhood was converted into residential properties. Most of the warehouses were demolished, while a few, including d'Peliekaan, were transformed. Today, more than 90% of the neighbourhood consists of residential buildings (AlleCijfers.nl, 2025), with residents having to travel towards the inner city centre of Amsterdam for public services and social interactions.

D'Peliekaan, being centrally located in the neighbourhood connecting the Hoogte Kadijk behind it with the bank of the Nieuwe Vaart, has the potential to better connect the neighbourhood and its residents. The qualities of the location are currently largely lost, due to the heavily paved nature of the neighbourhood and the lack of public functions. Topping up d'Peliekaan, incorporating both dwellings and a public function, can contribute to redeveloping the space from a solely functional circulation space into a recreational area, thereby better connecting the people in the neighbourhood.

Figure 12: *d'Peliekaan along the Nieuwe Vaart*

Figure 13: *Quality of waterfront*

1.5.3 Programmatic needs

The topping up will focus on housing for starters, as this target group is experiencing a lot of difficulties in the housing market. The dwellings themselves will concentrate on space-efficient design, delivering maximum quality in a compact and feasible manner. In addition, the project will focus on creating a community, bringing people together and encouraging social encounters. The aim is not only to prevent loneliness among a target group that often lives alone, but also to create a connection with the neighbourhood. Finally, the design is challenged to be adaptable in a way that through minimal interventions the function of the topping-up can change. The earlier transformation of d'Peliekaan, during which half of the building was demolished, only highlights the importance of adaptability in a project and design.

Part II:
Approach

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2.1 Methods

The research in this project uses multiple research methods to answer the sub-questions. In the first phase, a literature review combined with a case study will be used to answer the first two sub-questions. Doing this will provide insights into how poplar has been and is currently used in the construction sector, while also giving an overview of its possible structural applications.

In a second phase a comparative approach will be used when focussing on the structural properties and application of poplar. This will be done by first conducting a literature review and tests into the properties of poplar and comparing them to other commonly used structural timber species. Next, using a case study and research by design the research will investigate how a poplar construction differs from a traditional spruce construction. In this way, design guidelines can be developed for the structural application of poplar which will inform the design process.

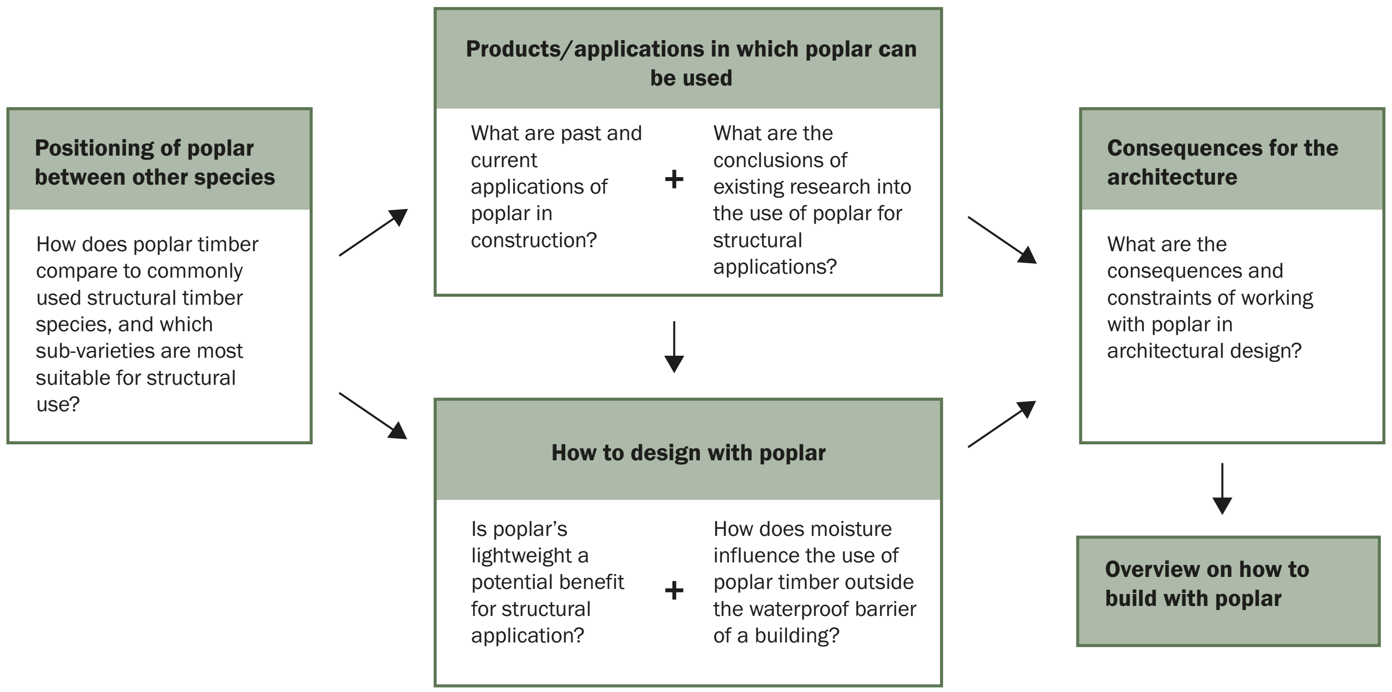
In a third phase, the durability of poplar will be examined by investigating how moisture influences the use of poplar outside the waterproof barrier of a building. This will mainly be investigated through a case study, a literature review and interviews, resulting in the development of architectural design guidelines on the application of poplar outside the waterproof barrier.

In the fourth phase the guidelines and knowledge gained from the research will be used in the design process and using research by design in combination with interviews the consequences and constraints of using poplar on the architectural design will be identified.

The expected outcome of this project is an overview of how poplar can be used in the construction sector. The overview will bring together the possible applications and products using poplar timber as well as provide design guidelines for the structural use of poplar and the use of poplar outside the waterproof barrier of a building. The design of the rooftop extension on d'Peliekaan warehouse will demonstrate how poplar can be used in a more valuable way as a building material while also showcasing its influence and effects on the architecture.

Alongside the research into the potential of poplar other design related challenges considering for example the target group, adaptability and green architecture will be researched. The research into these topics will be conducted for a small part though a literature review but mostly through research by design.

Relation between sub-questions



Research methodology

Research → Design

	Sub-questions	Methodology	Expected outcome	
Context	What are past and current applications of poplar in construction?	Literature review	List of the current applications of poplar.	Phase 1
	+			
Context	What are the conclusions of existing research into the use of poplar for structural applications?	Literature review Case study	Identifying the possible structural applications of poplar in construction.	Phase 1
	+			
Strength	How does poplar timber compare to commonly used structural timber species, and which sub-varieties are most suitable for structural use?	Literature review Testing	Positioning of poplar in between commonly used structural timber species and an identification of its structural properties.	Phase 2
	+			
Strength	Is poplar's lightweight a potential benefit for structural application?	Case study Site visit Interview Research by design	Design guidelines for using poplar in structural applications.	Phase 2
	+			
Durability	How does moisture influence the use of poplar timber outside the waterproof barrier of a building?	Literature review Case study Interview Research by desing	Design guidelines for using poplar outside the waterproof barrier	Phase 3
	+			
Anatomy	What are the consequences and constraints of working with poplar in architectural design?	Research by design Interview	Influence of using poplar on the architectural expression.	Phase 4

↓

An overview of how to design with poplar, integrated into a research informed design.

2.2 Planning

The planning for this project includes the important deadlines and presentation moments. The goal set out in the planning is to have the research into poplar more or less completed by the time of the A2 presentation. Furthermore, at this stage the idea is to have the main outlines of the design ready. The objective here is for the design to address the challenges of building with poplar in an architectural manner, based on the output of the conducted research. After the A2 presentation, there will be time to reflect on the design and work out the technical details.

Planning	w2.09	w2.10		w3.01	w3.02	w3.03	w3.04	w3.05	w3.06	w3.07	w3.08	w3.09	w3.10	w4.01	w4.02	w4.03	w4.04	w4.05	w4.06	w4.07	w4.08	w4.09	w4.10
	A1 21/01		TU Break							Submission graduation report 25/03	**A2** 01/04						**PIN UP** A3 rehearsal		Submission graduation report 27/05	**A3** 03/06		**A4** 17/06	Graduation exhibition
Sketch design phase																							
Wood World excursion																							
Digitalisation building plans																							
Architectural design development																							
Technical design phase																							
Finalising presentation drawings																							
Building presentation models																							
Reflection																							
Literature review																							
Case study																							
Research by design/detailing																							
Gathering materials tests																							
Testing																							
Graduation report																							
Refining presentation																							

2.3 Theoretical background

As mentioned earlier in the introduction, the potential of poplar timber for structural applications is generally recognised in literature. Apart from studies into the use of poplar in mass timber products, or the treatment of poplar timber to improve its durability, there are also a few studies that investigate the use of poplar timber in constructions and designs. The work of Mulders from 2008, for example, is the first study in the Netherlands that, in addition to testing the structural properties of poplar beams, also delivers a design using poplar. In this design for a visitor centre, the entire main load-bearing structure was designed and calculated using poplar timber.

Another study in the Netherlands involving a design made with poplar timber is the work of Obers from 2019. In this study, the structural properties of poplar (Accoya-treated and untreated) were tested, after which the results were used in the design of a pedestrian and cycle bridge. This bridge was designed for two locations, with a short span of 43.15 metres and a long span of 55.11 metres.

Since 2024, researchers in the Netherlands have been conducting the 'Hoogwaardig Houtgebruik' study, which investigates the supply and quality of four fast-growing native hardwood species. Within this study, research is being conducted into how poplar timber grown in the Netherlands can be used in construction. As part of this, in collaboration with Peppelhout (a Dutch company focussing on the use of poplar in construction), the first poplar timber frame construction in the Netherlands is being built during the period of this graduation project (see figure 14 & 15). Test equipment will be integrated in the construction and used to monitor the performance of the timber over time.

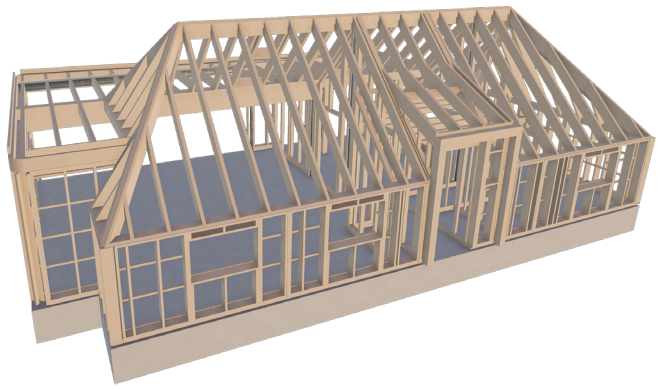


Figure 14: *Poplar timber frame construction Peppelhout*

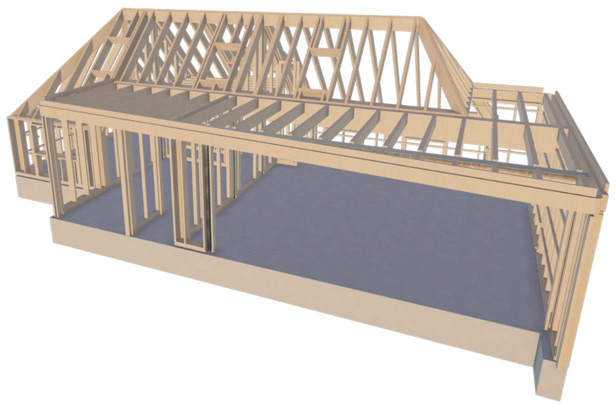


Figure 15: *Poplar timber frame construction Peppelhout*

Part III:
Research for design

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3.1. Past and current use

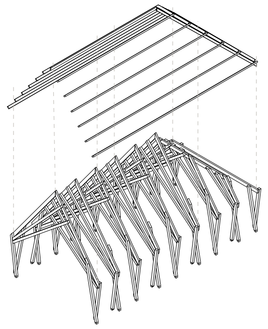
What are the past and current applications of poplar in construction?

Poplar timber has historically been used in several applications related to the construction sector. Schreiner (1959), Fraanje (1998 & 1999) and Herdova et al. (2025) describe the use of poplar timber in the roof structures of farm buildings as purlins, stringers, rafters and even scaffolding, mainly in countries such as France and Slovenia. In France, Fraanje (1998 & 1999) also writes about the use of poplar timber in several pilot projects involving timber frame construction, its use as laminated PLATO poplar in interior and exterior window frames, and the processing of poplar in early glulam beams (see figure 16). In addition, poplar timber or Aspen was also used as lumber in America and Canada, although on a small scale due to the dominance of softwood in this market and the lower strength and durability of poplar timber compared to these softwood species (Balatinecz et al., 2001). However, examples of structural applications of poplar in buildings are difficult to find. The workshop of the carpentry firm Kuperus & Gardenier in Lelystad (see figure 17) and the "Biobasecamp" pavilion by studio Marco Vermeulen, exhibited at Dutch Design Week (DDW) in 2019 (see figure 18), are two of the few examples where poplar timber has been used structurally (architectenweb, n.d. & Studiomarcovermeulen, n.d.). Both examples use the trunk as a structural column, in which case the timber is not sawn or processed into mass timber products.

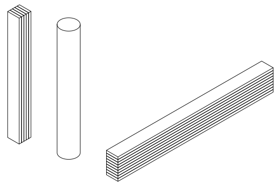
Other relevant uses of poplar in the construction sector include its application in composite boards such as OSB, plywood, LVL, PSL, LSL and I-beams (Balatinecz et al., 2001; Koman et al., 2023; Wikstrom, 2023). Furthermore, poplar was formerly used as flooring in railway wagons and trucks, as described by Fraanje (1999) and Schreiner (1959). The use of poplar for floors, ceilings, walls and façades is also a possibility and is promoted in the Netherlands by the Dutch company Peppelhout (see figure 19 & 20) (Peppelhout, n.d.).

Categories of use in construction:

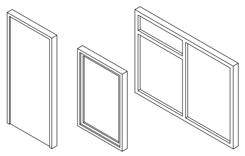
1. Roof structures farmbuildings



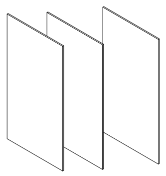
2. Post and beam (Glulam)



3. Door and window frames



4. Composite boards



5. Walls, floors, facades and ceiling finishes

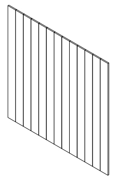


Figure 16: *Construction with laminated poplar beams by Ets-Fournier*

Figure 17: *Construction workspace with poplar trunks as columns*

Figure 18: *Populus Ellert columns in pavilion DDW 2019*

Figure 19: *Poplar facade Karkooi Breda*

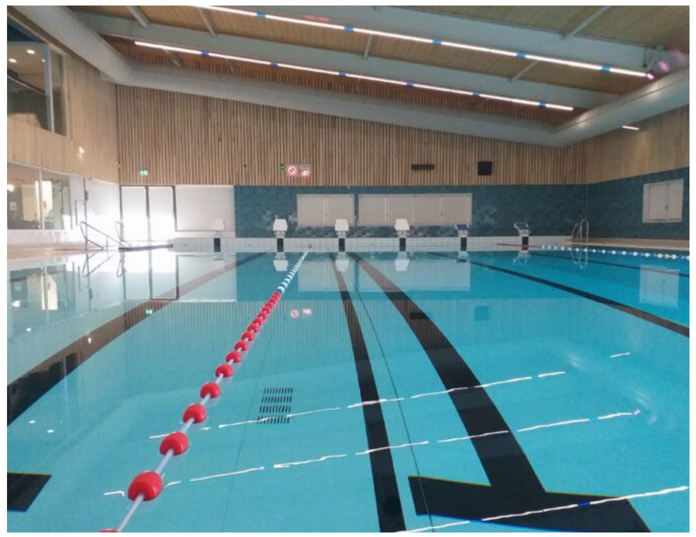


Figure 20: *Poplar interior in the swimming pool of Sint Oedenrode*

3.2. Result of current research

What are the conclusions of existing research into the use of poplar for structural applications?

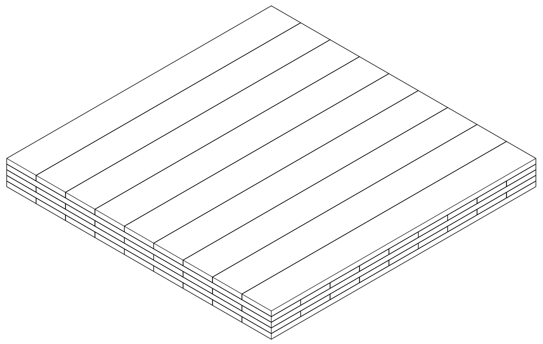
Due to its fast-growing nature, a lot of research is currently being done into structural applications for poplar timber in construction. Most research looks into using poplar in mass timber products both in homogeneous and hybrid products. The main conclusion of all this research is that poplar can be used as replacement for softwoods (spruce), which are currently the main raw material, in mass timber products (Das et al. 2022).

Important to take in consideration with these studies is that they are mainly individual studies which use different sub-varieties of poplar that also originate from different growing areas. It is therefore not possible to simply assume that every sub-variety of poplar can be used in all these building products. Nevertheless, the studies give an overview of the possibilities of poplar timber in mass timber products.

Looking at today's construction industry, we see that the first steps are being taken towards the use of poplar in structural building components. However, the industry is still a long way from being able to use poplar timber on a large scale. Both the need for further research and the financial aspect play a major role in this. At present, poplar timber is not yet financially competitive with spruce timber. Therefore, if we want to use poplar for structural purposes today, we will mainly have to look at timber frame construction in combination with glulam columns/beams.

(Mass) timber products

1. CLT



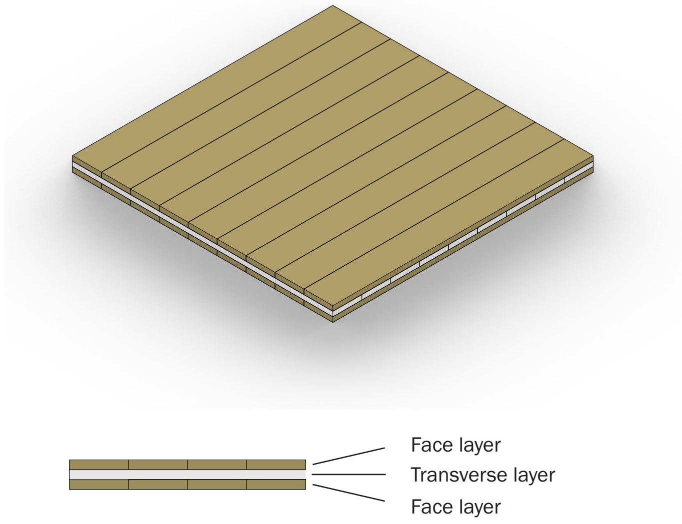
Many studies have looked into using poplar in cross laminated timber (CLT). The main conclusion here is that poplar can be used as a replacement to spruce and other softwood species in the fabrication of CLT. The study of Das et al. (2022) in which they tested CLT made from the Populus Tremula L. (also known as Aspen) showed that poplar CLT meets the minimal requirements specified in the EN 16351 (2015) standard. As a result, poplar timber is a suitable raw material for the production of CLT.

Furthermore, in the research of Das et al. (2022), a table is made comparing the properties of poplar CLT to traditional softwood CLT (see table 1).

CLT Panels	Modulus of Elasticity (E_{mg}) (N/mm^2)	Bending strength (f_m) (N/mm^2)	Rolling shear strength (f_r) (N/mm^2)	Bond shear strength (f_v) (N/mm^2)
Aspen CLT	7907 – 8183	30.35 – 31.29	1.73 – 2.04	2.8 – 3.2
Irish Sitka spruce (Sikora et al. 2016 a,b)	7583	37.67	1.0 – 2.0	2.8 – 6.1
Southern Pine (Cao et al. 2019; Hindman and Bouldin 2015)	12240	33.62	1.77	4.38
Canadian Hemlock (He et al. 2018)	7670	21.63	1.57	

Table 1: *Comparison of properties of aspen CLT with other softwood CLTs with similar density (Das et al., 2022, p.516)*

2. Hybrid CLT

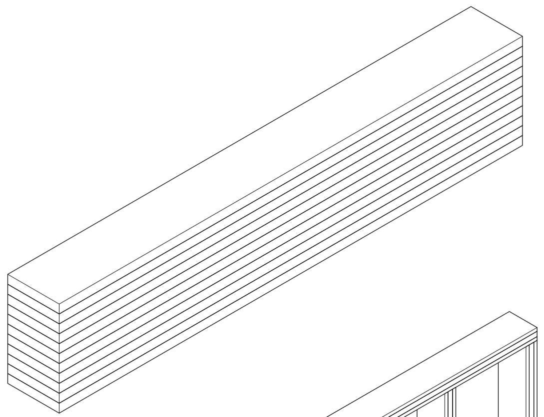


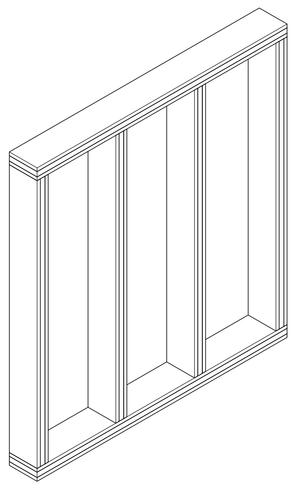
Hybrid CLT is CLT in which the face or outer layers of the CLT are made from a different timber specie than the transverse of inner layer(s) of the CLT.

Hematabadi et al. (2021) tested hybrid CLT made out of two poplar (Populus Alba) face layers and one transverse layer of beech (Fagus Orientalis). The results of their tests showed that hybrid poplar-beech CLT has a greater load-bearing capacity than homogeneous poplar CLT. Furthermore, they concluded that this hybrid poplar-beech CLT has tremendous potential for structural use in the construction sector.

The research of Li & Ren (2022) and Wang et al. (2014) both investigated using poplar in the transverse layers of CLT with larch in the research of Li & Ren (2022), and Douglas fir (Pseudotsuga Menziesii) and pine (Pinus radiata D.) in the research of Wang et al. (2014) as the face layers. Both researches concluded that using poplar is the transverse layer of CLT delivers CLT that can be used for structural applications. In the research of Wang et al. (2014) they even concluded that utilizing poplar (Populus euramericana) as a transverse layer for CLT panels with face layers of Douglas fir (Pseudotsuga menziesii) and pine (Pinus radiata D.) has similar strength to homogeneous Douglas fir CLT.

3. Glulam



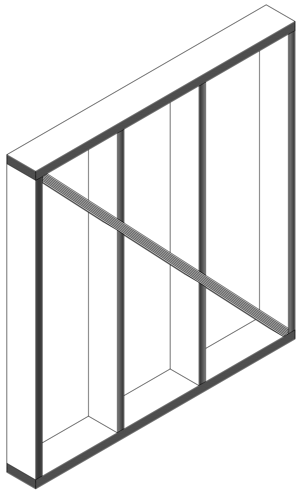


Using poplar in glulam is nothing new. Fraanje (1998) already mentioned glulam poplar beams as a possible use for poplar timber. There are examples from the same period of glulam poplar beams manufactured by a regional company in France. Fraanje (1998) refers to the research of Milosavljevic (1983), who states that glulam beams made from the hybrid variant Populus canadensis can span up to 15 metres and compare favourably with fir (Abies alba) beams.

Monteiro et al. (2020) encourage the use of poplar timber as a raw material for glulam. They say that by processing poplar in glulam, it is possible to take advantage of poplar characteristics which in a solid poplar section would be seen as a disadvantage.

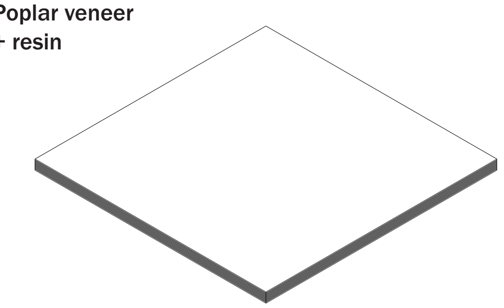
On another scale, Peppelhout, a Dutch company focusing on using poplar in construction is at the time of this research building the first timber frame construction in the Netherlands for which they use laminated poplar (from the Populus canadensis) as studs while also incorporating a glulam beam spanning 8 meters.

4. LVL (timber frame)



Liu et al. (2020) tested the performance of poplar LVL in timber frames and frame-shear hybrid walls. In this research the initial stiffness of the poplar LVL frame-shear wall was 24% and 22% lower than conventional shear walls made with spruce-pine-fir studs and OSB or plywood sheathing. However, the poplar LVL frame-shear wall showed a lower degradation in stiffness than a conventional shear wall. The research concluded (as it is a Chinese research) that hybrid frame-shear wall structures made with poplar LVL and OSB sheathing walls meet the requirements of Chinese standards. For a pure poplar LVL frame to meet this standard, diagonal braces into the frame are required.

5. Modified LVL



The research of Gao et al. (2022) investigated how the strength and stability of poplar timber could be improved, making it structurally more suitable for construction. To do so they used an environmentally friendly acrylic resin to fill the cell cavities in poplar veneer after which the veneer was laminated into LVL. In doing so the poplar LVL gained 81,36% of its weight but also improved in (flexural) strength as it exceeded the highest flexural strength required for structural timber. Overall, the modified LVL demonstrated significant improvements of the mechanical strength and dimensional stability.

6. Densified

New density: 1000+ kg/m^3

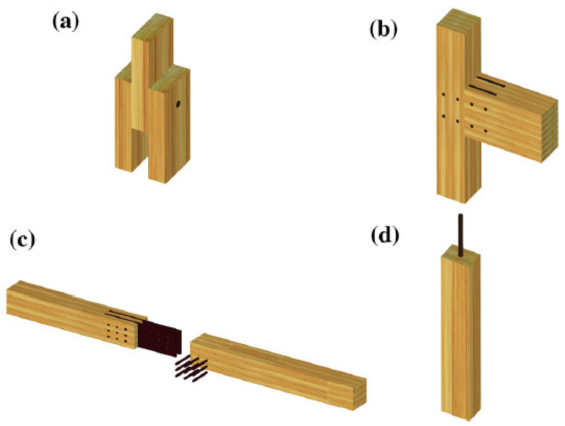
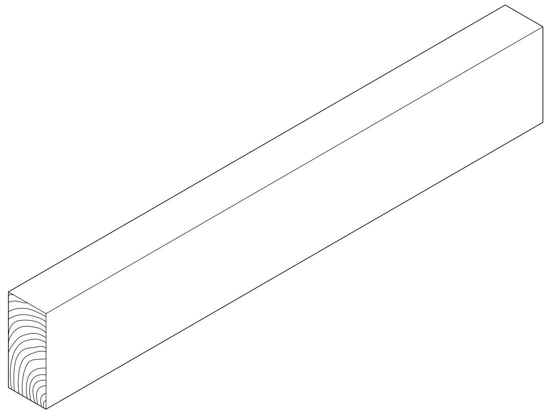


Figure 21: *Examples of applications using the densified wood as connection material: A shear joint; B beam-column connection; C beam-beam connection; bonded-in rod joint (Xu et al., 2021, p.14116)*

The potential for using poplar timber as a bio-based connection material to replace steel connections has been investigated in the work of Xu et al. (2021). In order to obtain the mechanical properties required in such connection elements, the poplar timber was densified in the study. The mechanical properties after the densification process where improved to an extend that they are better than the properties of high-density hardwood species, the density of the poplar itself increased to over 1000 kg/m^3.

The study focused on connections with densified poplar plates and dowels. The densified poplar dowels presented potential as a fastener comparable to a steel dowel. In comparison, a steel dowel of grade 3.6 with a diameter of 8 mm could be replaced by a poplar dowel with a diameter of 12 mm. Furthermore, they concluded that densified poplar could be used as an alternative to hardwood in timber joints with bonded-in hardwood rod and timber joints with slotted-in hardwood plate.

7. Sawn timber

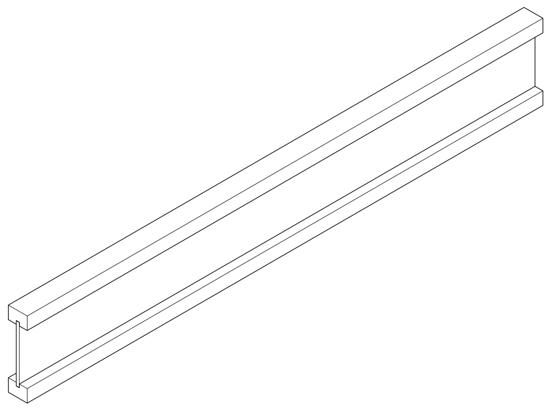


In addition to gluing and using poplar timber in mass timber products, research is also being conducted into the structural application of sawn poplar timber. New Zealand research by Satchell & Moore (2022) using Populus deltoides Marshall x P. yunnanensis Dode shows that sawn poplar timber meets market quality and regulatory requirements for structural use. In this study, the timber was treated (with boron) to comply with New Zealand regulations and be able to keep the beams exposed in the construction. Another interesting conclusion of the study is that the mechanical properties of poplar increase as the tree grows larger, meaning that trees can be selected for felling in order to obtain structural sawn timber.

The study by Pásztory & Rébék-Nagy (2017) investigated the behaviour and performance of sawn poplar timber in a timber frame construction compared to a traditional spruce frame. The main findings here are that poplar performs much better than expected in the timber frame (given the difference in properties between the timber species). It is therefore concluded that poplar timber can be a good substitute for spruce timber as stud material in a timber frame construction, especially as vertical studs.

Research by Mulders (2008) and Obers (2019) also demonstrates the structural potential of sawn poplar timber.

Other research & possibilities

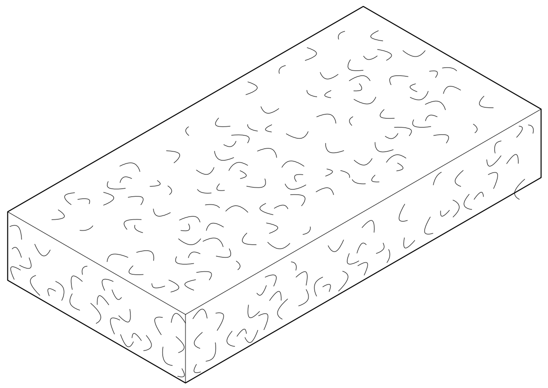


Research into the use of poplar timber as a structural element in the construction sector is ongoing. In addition to the studies and applications discussed in (mass) timber products, there are many other studies investigating this potential. For example, Bath (2021) investigated how poplar CLT columns could be reinforced by simply connecting the lamellas with bolts, with positive results. Propopulus, a European organisation that investigates how we can make better use of poplar timber, has also been conducting research. This resulted in, for example, a house built with poplar plywood, as well as MCLam beams, a hybrid (glulam) beam made of poplar timber and larch.

It is clear that there are many possibilities with poplar timber and that there is still much unexplored potential. For example, an I-beam made of poplar timber, whether hybrid or not, could be an interesting subject for new research.

Insulation

Wood fibre insulation



Besides the research into the application of poplar for structural use, there is also interesting research being done in using poplar for thermal insulation. In their research of 2025, Seminara et al. looked into the potential of poplar timber as wood fibre insulation. Because of its low density, long fibres (ranging from 1 to 1.23 mm) and relatively high fibre content of the timber (approximately 60%), poplar exhibit good thermal insulation properties. These properties give the timber the potential to capture more air in the structure of the timber which contributes to a low thermal conductivity. The conclusion of their research is therefore that poplar is a suitable raw material for wood fibre insulation.

3.3. Properties

How does poplar timber compare to commonly used structural timber species, and which sub-varieties are most suitable for structural use?

The poplar tree is a tree species with a wide variety of sub-varieties and clones. As a result, the mechanical and visual properties of poplar are highly dependent on the different sub-species and the growing environment/conditions (Centrum-hout.nl, 2014; in Obers, 2019). In addition, the structure of poplar timber, as a hardwood species, contains more irregularities than softwood species, which affects the properties and strength of the timber. As a result, it is very difficult to determine characteristic properties for poplar. In literature, we therefore see that the properties of poplar timber often vary from one another.

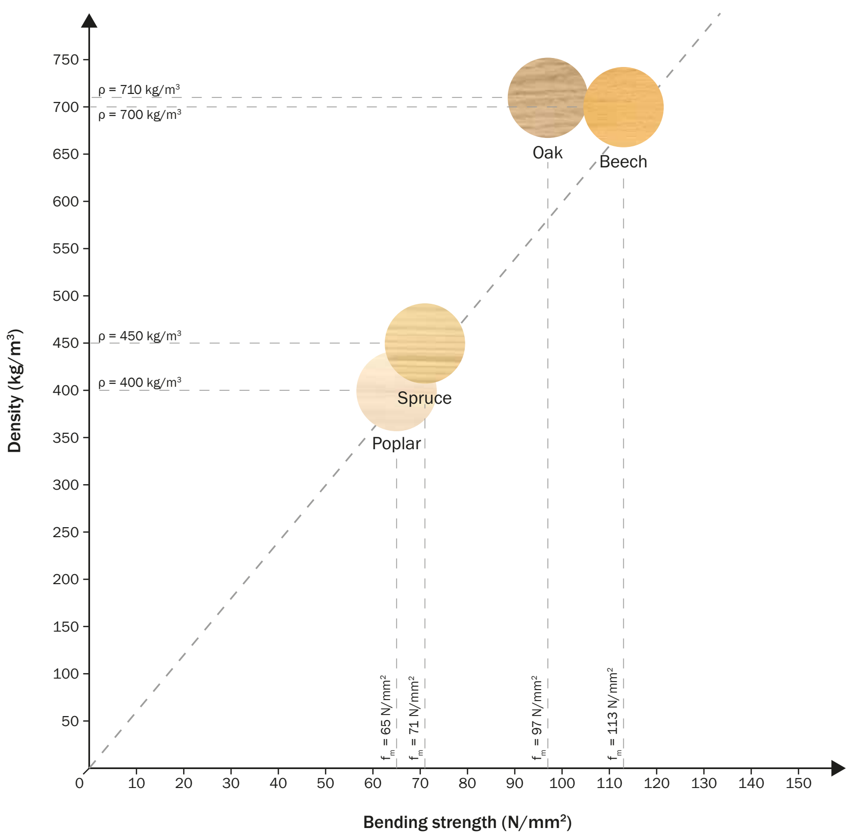
To get an overview of how poplar timber compares to traditionally used structural (soft)wood species in construction (spruce) and other hardwood species (oak and beech), the following table (table 2) and graphs (graphs 1-4) have been created. For this purpose, the properties published by Hout Info Bois (n.d.) have been used. These properties were, however, obtained from test pieces that were too small to be representative in structural dimensions. Nevertheless, the data does allow us to make a comparison between the timber species.

Looking at the strength classes and strength class determination of poplar timber, it is noticeable that although poplar is a deciduous tree, poplar timber is classified in strength class C for softwoods (and not D as is usual for hardwoods). This is because the properties of poplar timber in terms of strength and density lie much closer to those of softwoods (see graphs 1-3). Furthermore, the density and mechanical properties of poplar timber are too low for it to be classified in strength class D.

Average properties of poplar in comparison to spruce, oak and beech

Properties		Poplar	Spruce	Oak	Beech
Wood type		Hardwood	Softwood	Hardwood	Hardwood
Average density at moisture content 12% (kg/m³)	ρ	400 (300-520)	450	710	700
Brinell hardness // grain (N/mm²)		29	31	57	71
Brinell hardness ⊥ grain (N/mm²)		12	13	32	28
Shrinkage a relative humidity of 90 to 60% (%)	*rad.* *tang.*	0,7 1,9	0,9 2,0	1,2 2,1	1,2 2,5
Shrinkage a relative humidity of 60 to 30% (%)	*rad.* *tang.*	0,6 1,4	0,8 1,5	0,8 1,2	0,9 1,5
Dimensional stability		moderately stable	moderately stable	low to moderately stable	low stability
E-modulus (N/mm²)	E_0	9000	11 000	12 500	13 500
Average bending strength (N/mm²)	f_m	65	71	97	113
Average compression strength (N/mm²)	$f_{c,0}$	33	45	50	54
Average tensile strength (N/mm²)	$f_{t,0}$	72	85	100	145
Shear strength (N/mm²)	$f_{v,0}$	6	6,5	10	10
Durability classes		V	IV	II	V

Table 2: *Average properties of poplar in comparison to spruce, oak and beech (made by the author)*



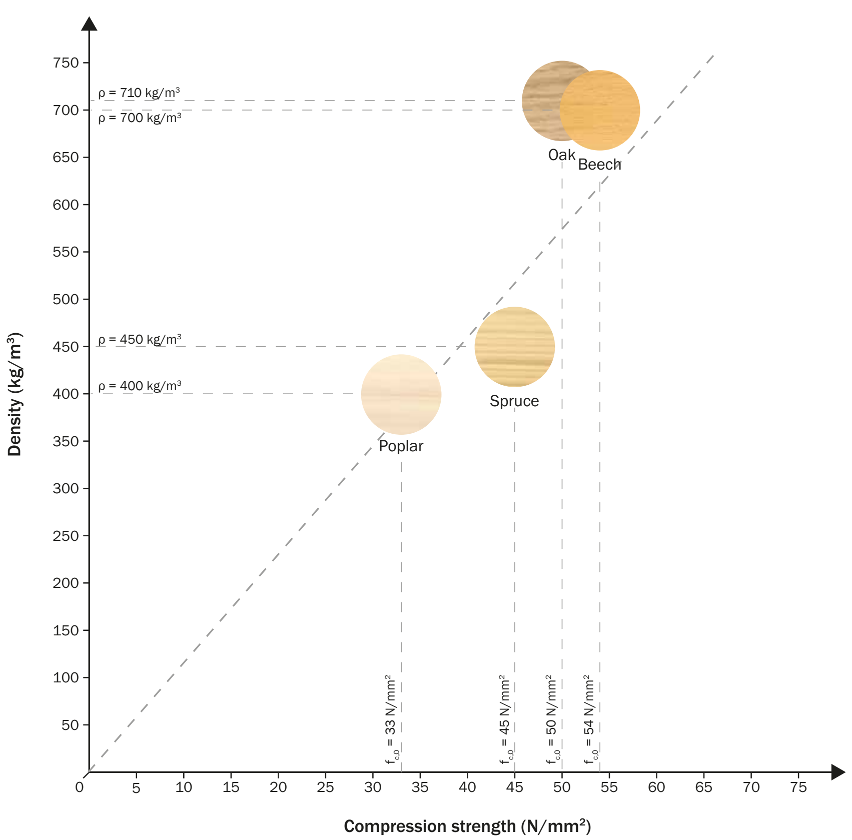
Graph 1: *Bending strength to density ratio (made by the author)*

Strength to density ratio Bending strength

Strength to density = Bending strength/Density

Poplar:	**162 500 Nxm/kg**
Spruce:	157 800 Nxm/kg
Oak:	136 600 Nxm/kg
Beech:	161 400 Nxm/kg

A comparison of the bending strength in relation to the density of the timber species shows that poplar timber offers the best ratio, closely followed by spruce timber.



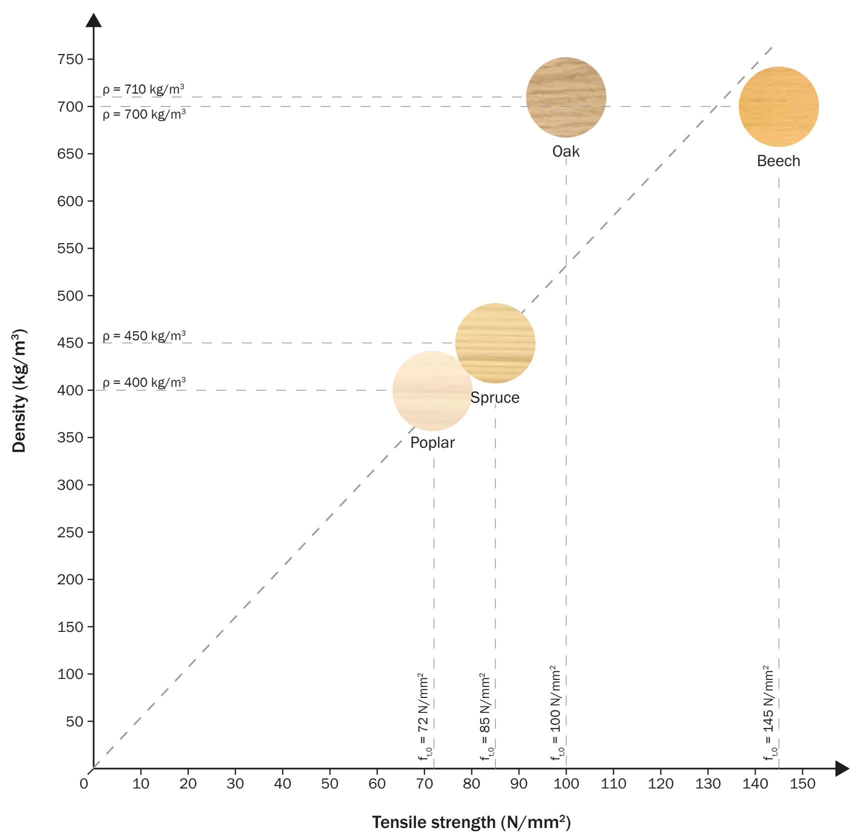
Graph 2: *Compression strength to density ratio (made by the author)*

Strength to density ratio Compression strength

Strength to density = Compression strength/ Density

Poplar:	**82 500 Nxm/kg**
Spruce:	100 000 Nxm/kg
Oak:	70 400 Nxm/kg
Beech:	77 100 Nxm/kg

A comparison of the compression strength in relation to the density of the timber species shows that poplar timber offers the second-best ratio, with a ratio that is 17.5% lower than that of spruce. However, the ratio of poplar timber is still considerably better than that of beech and oak.



Graph 3: *Tensile strength to density ratio (made by the author)*

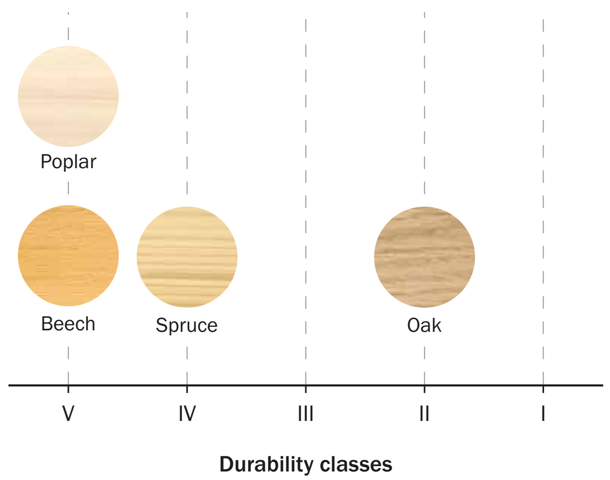
Strength to density ratio Tensile strength

Strength to density = Tensile strength/Density

Poplar:	**175 000 Nxm/kg**
Spruce:	188 900 Nxm/kg
Oak:	140 800 Nxm/kg
Beech:	207 100 Nxm/kg

A comparison of the tensile strength in relation to the density of the timber species shows that poplar timber has a lower ratio than spruce and beech. Beech timber performs above average in this respect, while spruce and poplar timber are average.

Durability class



Graph 4: *Durability classes (made by the author)*

Poplar timber is classified within the lowest durability class, which indicates that poplar timber in contact with the ground will survive for less than five years without being attacked by fungi. This can be partly explained by the low density of poplar timber. There is a correlation between the density of timber and its durability class, although this is not a fixed rule. This is showcased by beech timber which also belongs to durability class V, even though it has a similar density to oak.

Strength classes of poplar sub-varieties (sawn timber)

Populus canadensis Robusta

- Mulders (2008) *NL*
  C20
- Obers (2019) *NL*
  Acetic anhydride modified
  C20
  Unmodified
  C18
- EN 1912 (+2024) *FR*
  C18, C24

Populus canadensis Koster

- Mulders (2008) *NL*
  Rejected
- Obers (2019) *NL*
  Acetic anhydride modified
  C16
  Unmodified
  C14

Populus canadensis Ellert

- Obers (2019) *NL*
  Rejected

Populus tremula L.

- Herdova et al. (2025) *SK*
  C24

Populus nigra

- EN 1912 (+2024) *DE*
  C22

Load-bearing walls:
Populus Robusta, Populus Tremula L., Populus Nigra

Non-load-bearing walls:
Populus Koster

Table 3: *Strength classes of poplar sub-varieties (made by the author)*

The strength class determinations in this table (table 3) for different sub-varieties of poplar are taken from research by Mulders (2008), Obers (2019) and Herdova et al. (2025), and from EN 1912 (+2024). These studies and sub-varieties were selected on the basis of sub-varieties present in European (and Dutch) forests. The strength class determination in the studies was carried out for sawn timber.

Within the different sub-variants, we see that the strength classes vary between the studies. This can be explained by the different growth areas from which the timber originates, as well as the irregular structure of the timber, which results in large differences between individual test elements within the studies.

The Populus Ellert tested in Obers' study (2019) cannot be allocated to a strength class. The structure of the timber is important in this respect. Populus Ellert contains more reaction wood than, for example, Populus Robusta, which belongs to the same hybrid group canadensis but has very little reaction wood (Mulders, 2008).

This table and studies show that Populus Robusta has promising mechanical properties in terms of strength, stiffness and density for structural applications, as Fraanje already stated in 1998. Populus Tremula L. and Populus Nigra also have good mechanical properties for structural applications, while Populus Koster is more suitable for use in light, non-load-bearing interior walls.

Peppelhout poplar timber frame construction:

Peppelhout is building the first poplar timber frame construction in the Netherlands. Poplar timber from the hybrid group canadensis is being used for this, with almost all of the timber coming from the sub-variety Populus Robusta (J. Wittens, personal communication, February 26, 2026). Before being used in the timber frame construction, the poplar timber is finger-jointed and laminated into poplar beams. This removes as many irregularities and weak spots in the wood as possible.

A strength class of C18 has been used for the calculation of the construction during the design phase. The strength class C18 is used as this is the only strength class in which poplar timber is currently available in the Netherlands (B. van Dijk, personal communication, March 3, 2026). However, the beams still need to be tested in order to be definitively classified in a strength class. It is expected that they will be classified in at least strength class C22 (J. Wittens, personal communication, Februari 26, 2026). Plans are being made (during the course of this graduation project) to also test the beams at the Faculty of Civil Engineering at Delft University of Technology and TNO. Here they will compare the results of the poplar beams to spruce beams with a strength class of C18 and C24, while also looking into whether the beams can be made slimmer due to finger-jointing.

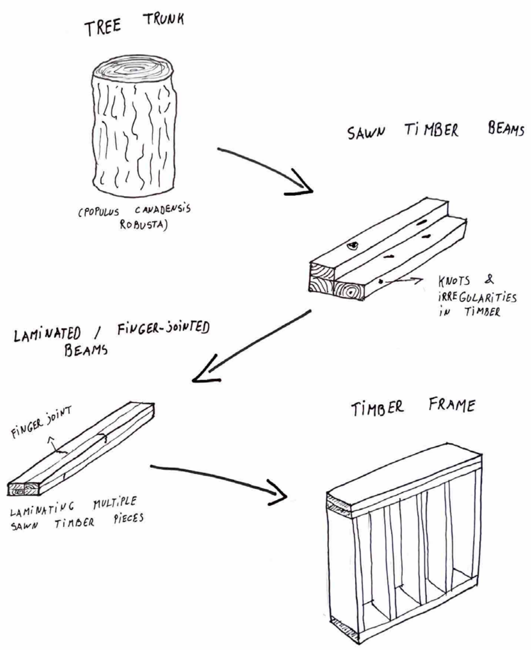


Figure 22: *From trunk to timber frame Peppelhout*

Figure 23: *Felling poplar trees*

Figure 24: *Sawn poplar 'shorts'*

Figure 25: *Fingerjointed and laminated poplar beams*

Figure 26: *Planing fingerjointed and laminated poplar beams*

Testing laminated poplar beams

Pending the results of the tests being carried out at the Faculty of Civil Engineering at Delft University of Technology and TNO, smaller laminated poplar beams measuring 44x82x450mm were tested in this study. The three-point bending tests were carried out on the Tecquipment MF40 MaTe-frame. As this test bench is designed for testing small components, the beams could not be tested in the strong direction (82mm), resulting in the beams being tested in the shorter direction (44mm).

A first test was carried out with a distance of 200mm between the support points. In this test, however, the testing bench proved not to be strong enough to cause failure of the beam. As a result, the test was terminated at a load of 32 kN, by which point the deflection had already exceeded the bench’s measurable range (see figure 27).

The following three tests were carried out with a distance of 398mm between the support points, the maximum span for the testing bench (see graph 5). In these tests, a relatively large difference was observed between test piece 1 and test piece 2. Test piece 1 reached a maximum load of 24.3 kN, whereas test piece 2 failed at a load of just 12.5 kN. However, test piece 3, which failed at a load of 19.3 kN, demonstrates that the effective force will probably lie somewhere in between. To draw any definitive conclusions, however, further research is required, such as the tests that will be carried out at Delft University of Technology and TNO. The results of the tests in this study are not representative but serve as an indication of how laminated poplar performs. The detailed data obtained from the tests are included in the appendix.

Figure 27: *First terminated test in which the test bench reached its maximum load without causing failure*

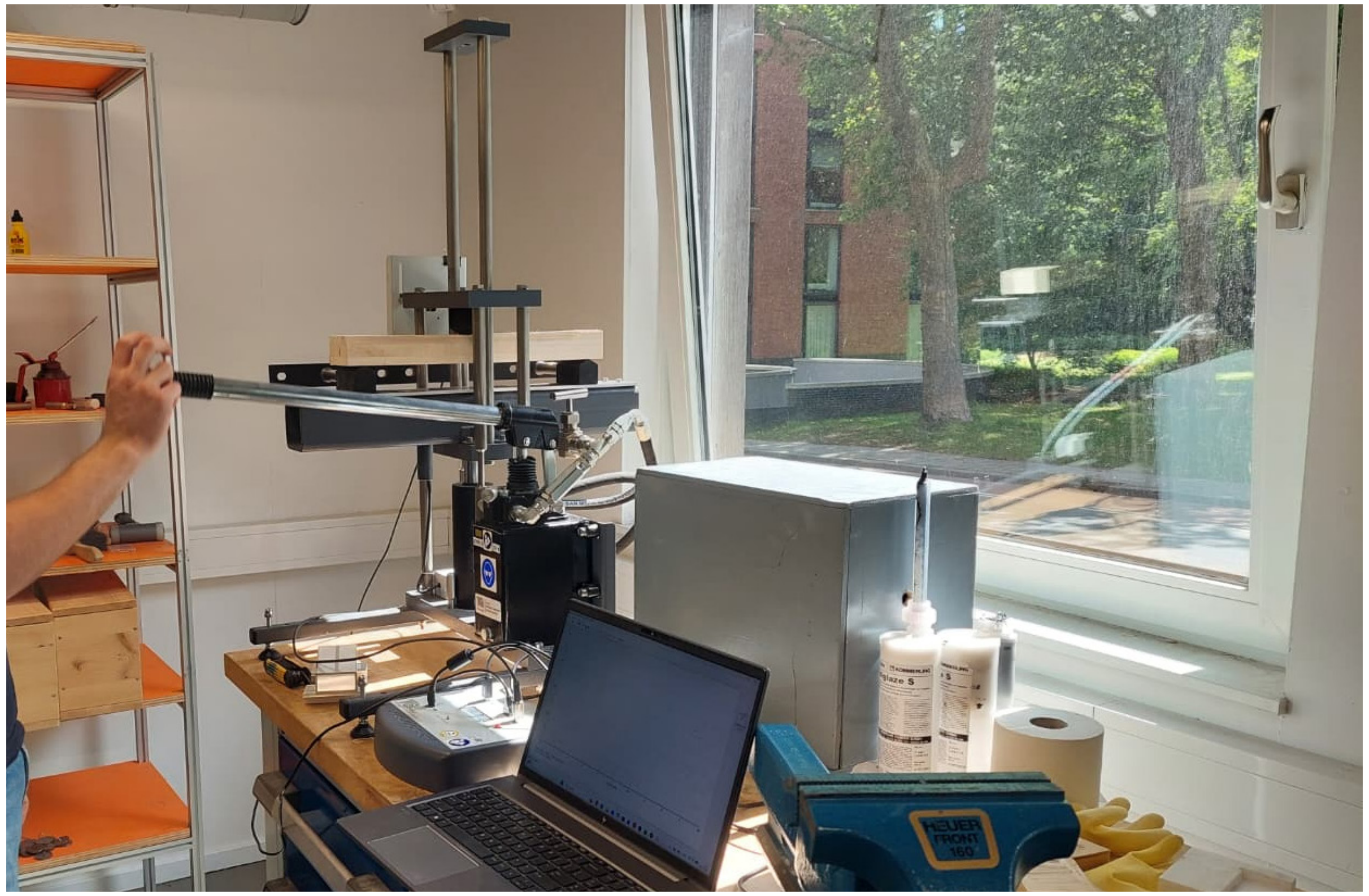
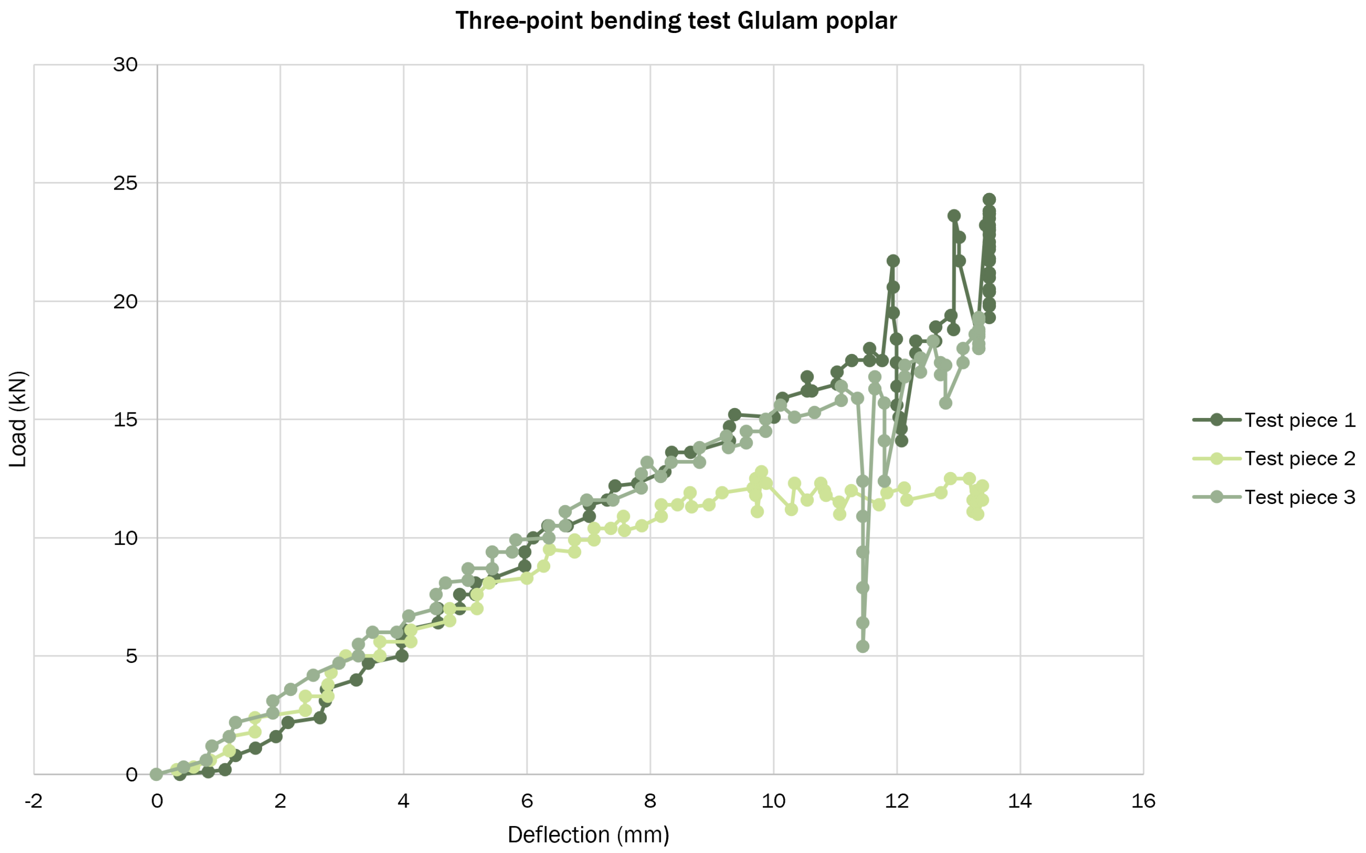


Figure 28: *Testing set-up*

Figure 29: *Failure of test piece 1 (L=398mm)*



Graph 5: *Comparison results test pieces (L=398mm) (made by the author)*

During the tests on test piece 3, a failure was observed at a finger joint (see figure 30). During the test, a significant tensile force was applied to this finger joint connection as it was positioned at the bottom of the setup. However, this should be no reason for the finger joint to fail. It is reasonable to expect that the strength of the adhesive in the finger joint connection should not be weaker than the strength of the timber. As the finger joint has separated cleanly and has not failed across its entire width, it is therefore likely that the failure was caused by an adhesive fault in the connection.

Figure 30: *Failure of test piece 3 (L=398mm) at finger joint*

Karakteristieke eigenschappen en sterkteklassen van gezaagd naaldhout													
	C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	
$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50	N/mm^2
$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16	kN/mm^2
ρ_{mean}	350	370	380	390	410	420	450	460	480	500	520	550	kg/m^3
ρ_k	290	310	320	330	340	350	370	380	400	420	440	460	kg/m^3
$f_{t;0;k}$	8	10	11	12	13	14	16	18	21	24	27	30	N/mm^2
$f_{t;90;k}$	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	N/mm^2
$f_{c;0;k}$	16	17	18	19	20	21	22	23	25	26	27	29	N/mm^2
$f_{c;90;k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2	N/mm^2
$f_{v;k}$	3,0	3,2	3,4	3,6	3,8	4,0	4,0	4,0	4,0	4,0	4,0	4,0	N/mm^2
$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7	kN/mm^2
$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53	kN/mm^2
G_{mean}	0,44	0,50	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00	kN/mm^2
$G_{0,05}$	0,29	0,34	0,38	0,40	0,42	0,46	0,48	0,50	0,54	0,59	0,63	0,67	kN/mm^2
Tabel 1. Karakteristieke eigenschappen en sterkteklassen van gezaagd naaldhout													

Table 4: *Characteristic properties and strength classes of sawn softwood (Centrum Hout, 2014, p.2)*

Conclusion

It can be concluded that poplar sub-varieties such as Populus Robusta, Populus Tremula L. and Populus Nigra are suitable for structural applications. However, the strength class is highly dependent on the growing environment and also varies within the same sub-variety. Laminating and finger jointing are good methods for removing irregularities from the timber and thereby improving its quality. Doing so also makes the timber stronger and potentially classifies it in strength class C22 or higher. However, further testing is needed to confirm this. In comparison, spruce, which is traditionally widely used in construction, is available in strength classes C18 and C24.

3.4. Lightweight structural application

Is poplar's lightweight a potential benefit for structural application?

To determine whether poplar results in a lighter structure compared to a traditional spruce structure, a case study is being conducted on the first poplar timber-frame structure that is being built in the Netherlands. For this structure, laminated poplar studs were used, for which a strength class of C18 was used for the calculations. However, it is likely that the laminated poplar studs have a strength class of C22, as already discussed in paragraph 3.3. Pending an exact determination of the strength class for the laminated studs, this paragraph examines the difference between a C18 and C22 poplar structure with a traditional C24 spruce structure.

Case study: Peppelhout poplar timber frame construction

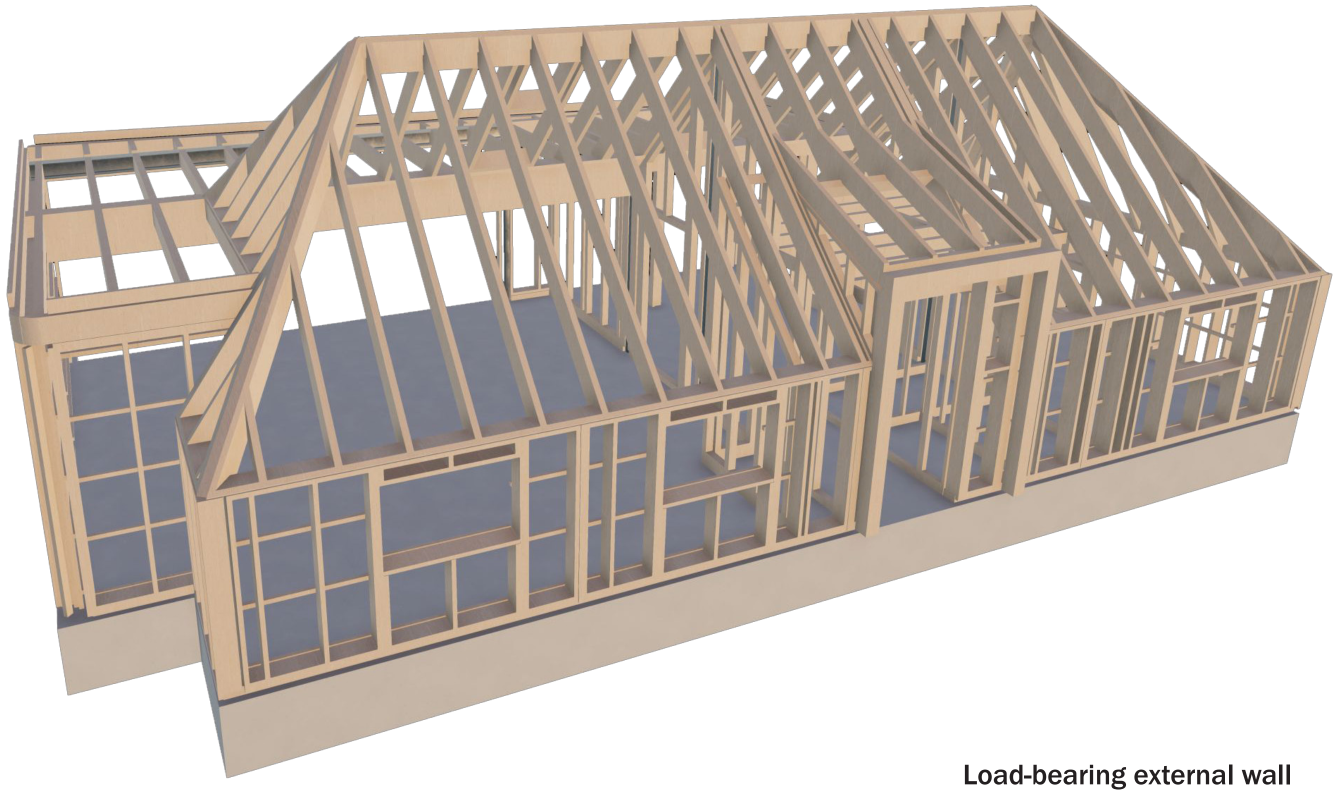


Figure 31: *Poplar timber frame construction Peppelhout*

Composition of timber-frame construction

An analysis of the timber frame structure was carried out using the 3D model of the building (which was shared with the author by Job Wittens, co-owner of Peppelhout and the contractor/client in the construction project). The analysis reveals that, at the frame level, the structure is constructed in a very standard manner, comprising vertical studs, a single bottom plate and a double top plate. The heart-to-heart distance between the vertical studs of 500mm in the walls and 600mm in the roofs are also typical dimensions in timber frame construction. The heart-to-heart distance was therefore not influenced by the use of poplar in the structure but stems from the structural engineer's calculations based on the strength class. The recommended heart-to-heart distance is subsequently adjusted to the (standard) dimensions of the selected sheet materials that enclose the frame and ensure stability, in this case ESB sheets (B. van Dijk, personal communication, 3 March 2026).

Load-bearing external wall
Vertical studs: 42 x 194mm
Heart to heart distance: 500mm

Load-bearing internal wall
Vertical studs: 82 x 95mm
Heart to heart distance: 500mm

Flat roof
Beams: 82 x 244mm
Heart to heart distance: 600mm
Span: 3500mm

Angled roof
Rafters: 62 x 244mm
Heart to heart distance: 600mm
Span: 3000mm

Floor (sawn timber)
Beams: 82 x 140mm
Heart to heart distance: 405mm
Span: 3500mm

At component level, we see that the dimensions differ from the standard sizes used in timber frame construction. This is due to the lamination of the poplar beams, during which no account was taken of achieving standard sizes. As a result, for example, the components from the load-bearing external walls have a cross-section of 42x194mm instead of 38x184mm, which is a commonly used size for load-bearing external walls in timber frame constructions. Consequently, the entire structure has become custom-made, with, among other things, standard insulation packages of 200mm thick that had to be made 6 mm thinner to fit in the construction (B. van Dijk, personal communication, 3 March 2026).

The entire timber frame construction industry is designed to fit the standard dimensions of low-cost Scandinavian spruce or SLS. The customized nature of Peppelhout's poplar timber frame construction therefore means that, as a product in timber frame construction, poplar is not commercially viable on the market. Before poplar can play a significant role as a structural building material in timber frame constructions, it will therefore first have to comply with these standard dimensions (B. van Dijk, personal communication, 3 March 2026).

Figure 32: *Assembly on site timber frame construction*

Figure 33: *Prefabricated poplar timber frame elements*

Standard sizes

To determine how poplar timber fits within the standard dimensions and what this means for the structure, a calculation was carried out based on the maximum load of a C24 spruce vertical stud (38x184mm) and the cross-sectional area required to withstand this load in C18 and C22 poplar timber. Using this required cross-section, the table of standard sizes for timber frame construction was then consulted to determine the eventual cross-section.

When we compare the results of the calculations with the standard dimensions for timber frame construction, it appears that the same cross-sections are obtained for both C18 and C22 poplar. The standard dimensions resulting from this are either 38x235mm or 50x184mm, keeping first the thickness of the beam and then the height of the beam equal to the C24 spruce beam of 38x184mm. Working with standard dimensions in poplar therefore results in the structure being over-dimensioned (see tables 5 & 7).

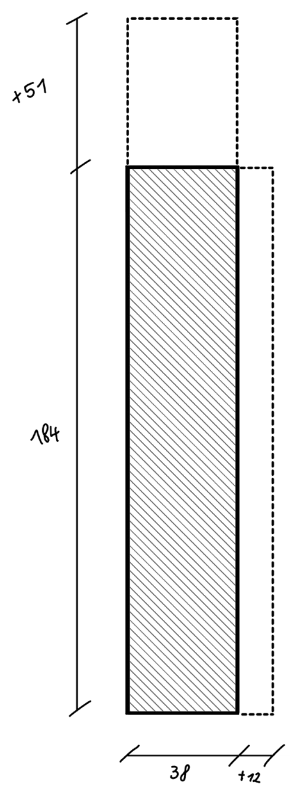


Figure 34: *Fitting studs to standard sizes*

Properties spruce C24

type	C24	
f ck 0	21	[N/mm^2]
f cd 0	10,08	[N/mm^2]
density	450	kg/m3
depth	38	[mm]
height	184	[mm]
A	6992	[mm^2]
W_y =	214421,3333	[mm^3]
I_y =	19726762,67	[mm^4]
E =	11000	[N/mm^2]

Total load F_G: 70,48 kN

Properties poplar C18

type	C18	
f ck 0	18	[N/mm^2]
f cd 0	8,64	[N/mm^2]
density	400	kg/m3
depth		[mm]
height		[mm]
A	0	[mm^2]
W_y =	0	[mm^3]
I_y =	0	[mm^4]
E =	9000	[N/mm^2]

Total load F_G:	70,48 kN
Reduced compressive strength:	8,64 N/mm
Required cross-sectional area A =	8157,33 mm^2
With equal thickness spruce	214,67 mm
With equal height spruce	44,333333 mm

Properties poplar C22

type	C22	
f ck 0	20	[N/mm^2]
f cd 0	9,6	[N/mm^2]
density	400	kg/m3
depth		[mm]
height		[mm]
A	0	[mm^2]
W_y =	0	[mm^3]
I_y =	0	[mm^4]
E =	10000	[N/mm^2]

Total load F_G:	70,48 kN
Reduced compressive strength:	9,6 N/mm
Required cross-sectional area A =	7341,60 mm^2
With equal thickness spruce	193,20 mm
With equal height spruce	39,9 mm

Table 5: *Calculations of vertical stud in timber frame construction for spruce C24, poplar C18 and poplar C22 (made by the author)*

The use of poplar in the construction also affects the Rc value of the insulation packages. For example, with a 38x235mm vertical stud, the insulation package will be more than 50mm thicker, which improves the Rc value of the wall. On the other hand, when a 50x184mm vertical stud is used, more timber will protrude through the package, resulting in a lower Rc value (see figure 34).

Although poplar timber has a lower density than spruce timber (see table 6), a poplar timber frame construction is not necessarily lighter than a spruce construction (see figure 35 & 36). When working with standard dimensions, the supporting structure made of poplar timber is in fact over-dimensioned, resulting in more timber being used than is necessary (see table 6). This extra volume, however, does allow more CO_2 to be stored within the structure.

Mass required cross-sectional area		
Spruce C24	3,1464 kg/m	
Poplar C18	3,2629 kg/m	
Poplar C22	2,9366 kg/m	→ Mass: -6,6% Volume: +13,5%
Mass standard sizes		
Spruce C24		
38x184mm	3,1464 kg/m	
Poplar C18		
38x235mm	3,5720 kg/m	
50x184mm	3,68 kg/m	
Poplar C22		→ Mass: +13,5% Volume: +28%
38x235mm	3,5720 kg/m	
50x184mm	3,68 kg/m	

Table 6: *Calculations of mass per metre in standard sizes for spruce C24, poplar C18 and poplar C22 (made by the author)*

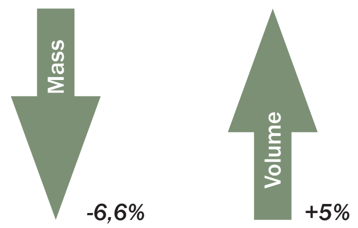


Figure 35: *Poplar (C22) vs spruce when building with required cross-sectional area*

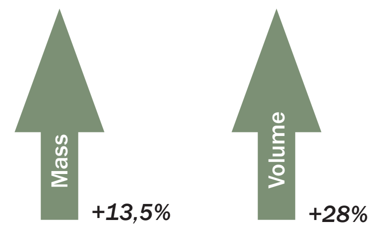


Figure 36: *Poplar (C22) vs spruce when building with standard sizes in timber frame construction*

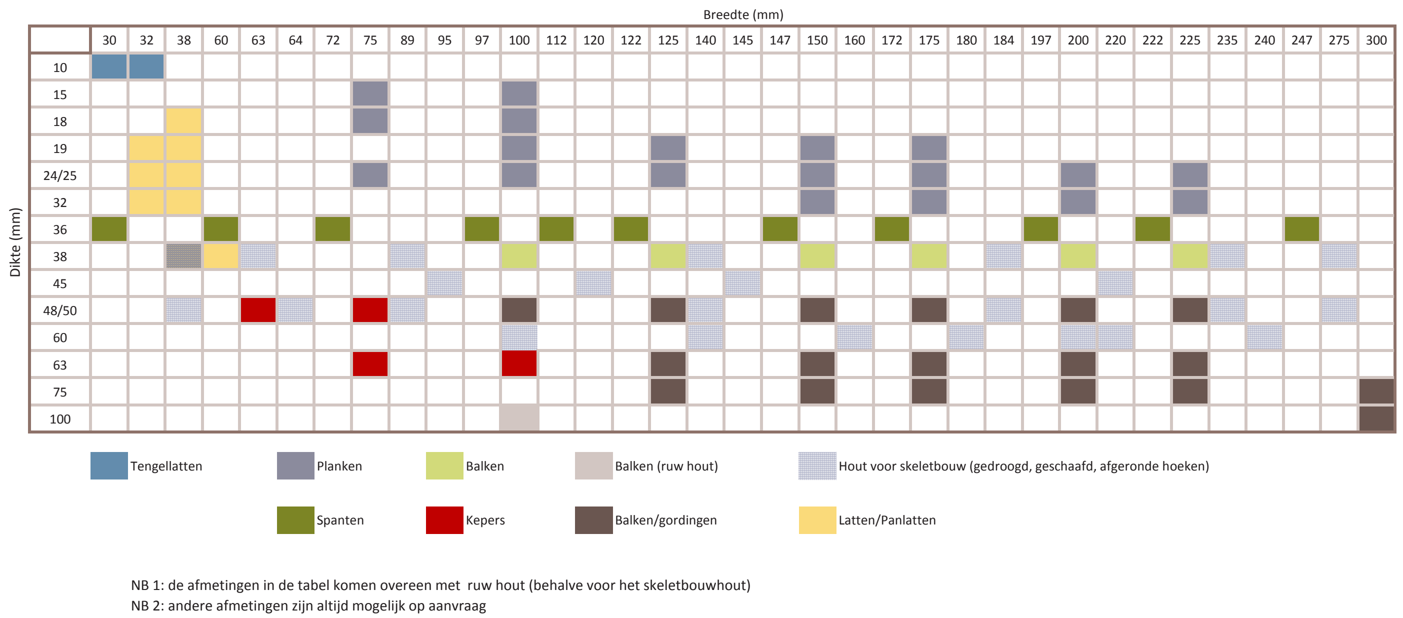


Table 7: *Standard sizes of timber (Hout Info Bois, n.d.)*

3.5. Durability

How does moisture influence the use of poplar timber outside the waterproof barrier of a building?

Case study: Peppelhout poplar timber frame construction

In the timber frame construction of Peppelhout, poplar is not only used as a structural element but also in the façade cladding. Due to its low durability, the timber (like most timber species) was first treated before being used outside the water-retaining layer. When modified, however, poplar timber performs similarly to other timber species, requiring a smart design of the façade structure and water drainage to ensure a long service life (B. van Dijk, personal communication, 3 March 2026). For use within the waterproof barrier of the construction, however, it is advised to use untreated poplar timber, as this remains the most durable method with the highest cascading potential (Fraanje, 1998).

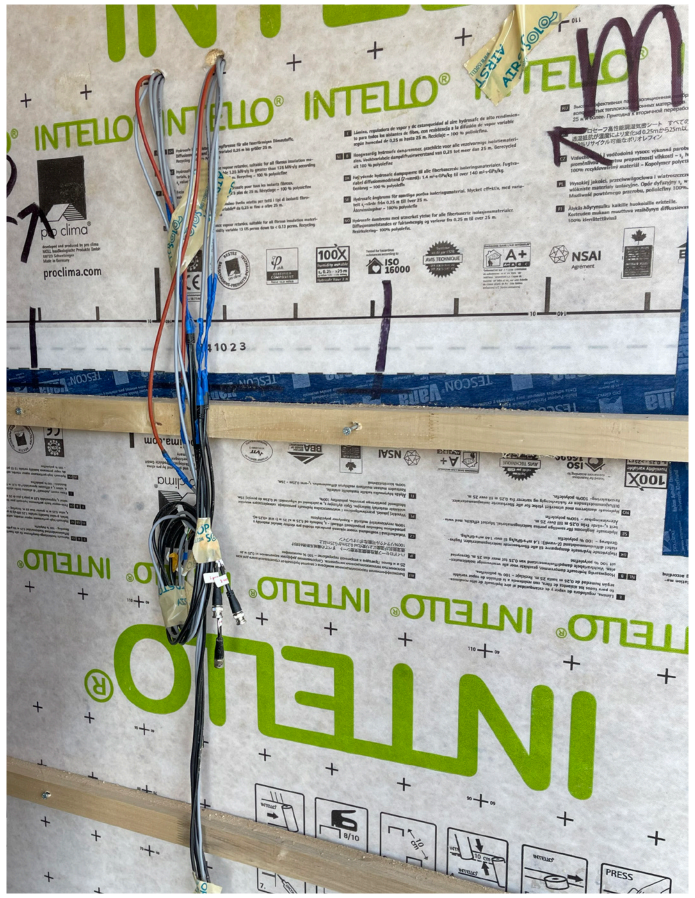


Figure 38: *Monitoring equipment integrated in frames*

In the façade package of the Peppelhout case study, you can therefore see that the timber within the waterproof barrier is untreated, while the timber of both the spruce framework and the poplar cladding is treated (see figure 37). To further demonstrate and investigate how untreated poplar timber performs within the structure, monitoring equipment has been installed at multiple locations within the façade package of the Peppelhout building as part of the 'Hoogwaardig Houtgebruik' research (see figure 38).

Façade package (from outside to inside):

- **20mm - Poplar façade cladding (thermally modified)**
- 28mm - Hor. framework (42x28mm) modified spruce
- 22mm - Vert. framework (42x22mm) modified spruce
- Fonta WH waterproof barrier
- 16mm - Ageplan board
- **194mm - Poplar timber frame (42x194mm)** + wood fibre insulation
- 15mm - ESB board
- Intello vapour-permeable membrane
- 44mm - Hor. framework (44x44mm) spruce, technical cavity
- 12,5mm - Fermacell
- 3mm - Clay plaster

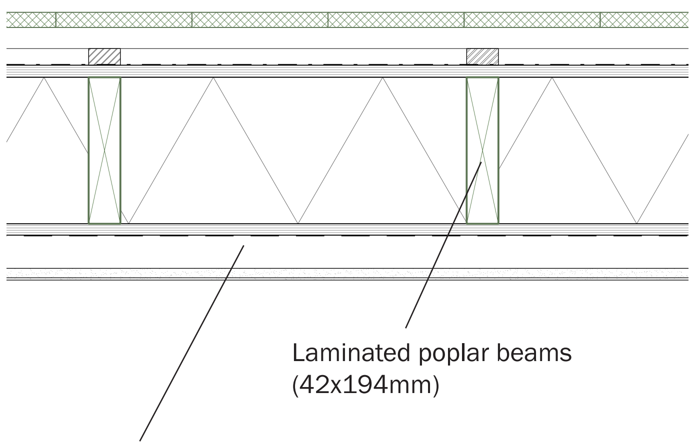


Figure 37: *Façade package outer wall*

A poplar support beam treated with red lead has been used at the connection with the ground level and the concrete foundation slab. This coating prevents water from being drawn into the timber, thereby preventing the beam from rotting (see figure 39).

The timber frame structure is assembled on site out of prefabricated elements. Although this significantly reduces construction time on site, the prefabricated parts are still exposed to the weather and rain during construction. Consequently, a large tarp was placed over the structure during construction pending the waterproofing of the roof (see figure 40).

Figure 39: *Connection poplar frames to concrete foundation*


Figure 40: *Covered construction site*

Because the efficiency of the various timber modification processes depends to a certain extent on the species, due to differences in the anatomical structure of different timber species, it is important to identify the possible modification techniques for poplar timber. Species with a higher density are generally more difficult to modify than hardwood species such as poplar. The porous structure of poplar timber is an advantageous characteristic for many modification techniques (Jiang et al., 2022).

Thermal modification

Thermal modification of poplar timber is considered an environmentally friendly modification technique (Jiang et al., 2022). Thermal modification involves heating the timber to above 180 degrees Celsius. This alters the chemical composition of the lignin, cellulose and hemicellulose in the timber. In addition to darkening the colour of the wood, this also increases its durability and dimensional stability (Obers, 2019). This makes the wood decay-resistant and inedible to most micro-organisms and fungi, making it ideal for outdoor applications (Acker et al., 2020 & Jiang et al., 2022).

When thermally modifying timber, there are many different variables that can be adjusted, leading to different processes and techniques within thermal modification (Obers, 2019). In general, higher temperatures in the modification process make the timber more durable but also reduces its mechanical properties. It is therefore very important to find a good balance between durability, dimensional stability and strength in the process. A good example of this is the PLATO process (Providing Lasting Advanced Timber Option) (Jiang et al., 2022). This PLATO process also makes it possible to compress and bend timber in the shape which is desired (Fraanje, 1998).

Thermal modification of timber typically results in a reduction of its mechanical properties. However, this is not always the case, as certain processes can also have a positive effect on some mechanical properties (Acker et al., 2020). Nevertheless, thermal modification is known to make timber more brittle and cause it to lose some of its mass, leading to its use primarily in façade cladding (Obers, 2019). Depending on the process, poplar timber can achieve a durability class of 1 or 2. The use of thermally modified poplar timber in CLT is another application that shows great potential according to the research by Acker et al. (2020) & Jiang et al. (2024).

The Dutch company Peppelhout, in collaboration with Prowood, offers thermally modified poplar timber for façade cladding that complies with fire class B. To achieve this, the thermally modified poplar timber is treated with Flamefix, a biodegradable binding agent (Prowood, n.d.).

Finally, as a sustainable modification technique, thermally modified timber has good cascading potential (Fraanje, 1998).

- **Water repellent and decay resistant**
- **Reduced vulnerablility to fungi**
- **Fire class B when treated with Flamefix**
- **Good cascading potential**

Chemical modification

Chemical modification of timber, like thermal modification, protects the timber against decay by making it inedible to most micro-organisms and fungi. It also reduces the timber's tendency to swell and shrink, making it less prone to cracking (Acker et al., 2020). Unlike thermal modification, chemical modification processes use chemical products in addition to heat. However, this does not mean that chemical modification of timber is automatically an unsustainable method (Obers, 2019).

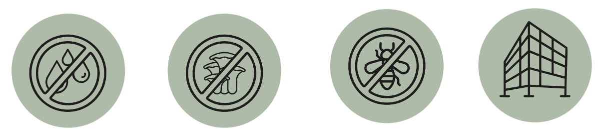
1. Acetylation

During the acetylation process, timber is treated under high pressure in a vacuum with acetic anhydride, which causes an endothermic reaction in the timber (Mulders, 2008). The aim of the treatment is to reduce the OH groups in the timber that can cause moisture binding. The timber produced using this technique is also known as Accoya and, after treatment, still contains only timber-specific substances, making it an environmentally friendly process (Mulders, 2008 & Obers, 2019).

Research shows that poplar timber, due to its highly porous structure, is comparatively easier to impregnate than some refractory species such as spruce (Jiang et al., 2022). Acetylating the timber ensures that it absorbs hardly any water and is resistant to fungi and insect attacks. The timber is therefore given a durability class of 1 (Obers, 2019).

In addition to improving durability, acetylating timber also has a positive effect on its mechanical properties. In the study by Bongers & Beckers (2003), the properties of acetylated poplar timber were compared with those of untreated poplar timber. This showed that only the equilibrium moisture content decreased and all other properties increased or remained the same. This result was also confirmed in the study by Obers (2019), in which acetylated poplar timber was classified in a higher strength class than untreated poplar timber.

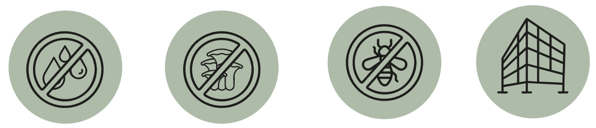
Although the chemical modification of timber can make it less suitable for cascading and some timber recycling streams, acetylated timber has potential for reuse.



- **Water repellent and decay resistant**
- **Reduced vulnerablility to fungi**
- **Higher resistance to insect attacks**
- **Increased mechanical strength**
- **Good cascading potential**

2. Furfurylation

In the furfurylation of timber, timber is impregnated with furfuryl alcohol under high pressure. This alcohol is plant-based and derived from biomass, which means that the modified timber is environmentally friendly (Mulders, 2008). The open pits and looser structure of poplar timber make furfurylation more suitable for this type of timber than for other types (Jiang et al., 2022). The result after modification is timber with a durabilty class 1, improved dimensional stability and resistance to fungal and insect attacks. The extra furfuryl group in the timber prevents fungi and insects from recognising the timber (Obers, 2019). Finally, the mechanical properties of furfuryl-treated timber can also be positively influenced depending on the level of furfurylation. However, the biggest problem with furfurylation of poplar timber is embrittlement (Jiang et al., 2022).



- **Water repellent and decay resistant**
- **Reduced vulnerablility to fungi**
- **Higher resistance to insect attacks**
- **Increased mechanical strength**
- **Good cascading potential**

Wood preservation

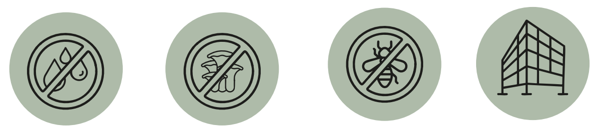
In addition to timber modification, there is also wood preservation, which often involves adding toxic substances to the timber. An example of this is CCA (copper chromium arsenic) treatment, in which metal salts are soaked or impregnated under pressure into the timber. This application is also possible with poplar timber and can protect the timber against moisture. From an environmental perspective, however, it is a problematic method. If this timber ends up in nature, it is considered toxic waste in the Netherlands. The cascading potential of this method is therefore low (Fraanje 1998).

Another wood preservation treatment is boron treatment, in which boron salts are introduced into the timber using a diffusion method. This method is less harmful to nature but also has no lasting effect. This is because the boron salts are water-soluble, which means they can be washed out by rain. This makes that the method is not suitable for outdoor applications (Satchel & Moore, 2022).

Less environmentally friendly method!

Resin treatement

Modifying poplar timber with resin is a possible strategy for making the timber more durable. Filling the pores with resin reduces the amount of moisture that can penetrate the timber and makes it more difficult for micro-organisms to reach nutrients in the timber. Research by Gao et al. (2022) further shows that the mechanical strength of poplar timber can also increase significantly when treated with resin. However, depending on the resin used (synthetic or natural), it may be a less environmentally friendly method than thermal and chemical modification.



- **Water repellent and decay resistant**
- **Reduced vulnerablility to micro-organisms**
- **Increased mechanical strength**

Natural treatement using Fungi

A relatively new method of modifying timber involves the use of fungi as part of a passive and natural technique. This technique involves placing a dominant mold on the timber and covering it with linseed oil, which serves as food for the mold. This creates a biofilm on the linseed oil from the dominant fungus, which protects the timber from attacks by other fungi. Furthermore, this fungal layer will repair itself when damaged, as long as the fungus has sufficient food. It is however not clear whether this method also protects the timber against water absorption, and whether linseed oil needs to be reapplied repeatedly throughout the lifetime of the timber. The main focus of the method is therefore to protect the timber against fungal attacks (Obers, 2019).

- **Reduced vulnerablility to fungi**

Advantages and disadvantages modification techniques for poplar

Modification technique	Advantages	Disadvantages	Applications
Thermal modification	• Water repellent • Reduced vulnerability to fungi	• Embrittlement • No specific influence on insect attacks • Loss of mechanical strength	Façade /outdoor cladding
Acetylation	• Water repellent • Reduced vulnerability to fungi and insect attacks • Increased mechanical strength	• -	Exposed structural elements Façade /outdoor cladding
Furfurylation	• Water repellent • Reduced vulnerability to fungi and insect attacks • Increased mechanical strength	• Embrittlement	Exposed structural elements Façade /outdoor cladding
Wood preservation	• Water repellent	• No lasting effect depending on technique • Depending on technique it can be considered toxic waste	Exposed structural elements Façade /outdoor cladding
Resin treatement	• Water repellent • Reduced vulnerability to fungi and insect attacks • Increased mechanical strength	• Less environmentally friendly depending on the used resin	Exposed structural elements Façade /outdoor cladding
Natural treatement using Fungi	• Reduced vulnerability to fungi	• Lot of uncertainty regarding water protection and whether linseed oil needs to be reapplied over time	Façade /outdoor cladding

Table 4: *Advantages and disadvantages modification techniques for poplar (made by the author)*

Part IV:
Research by design

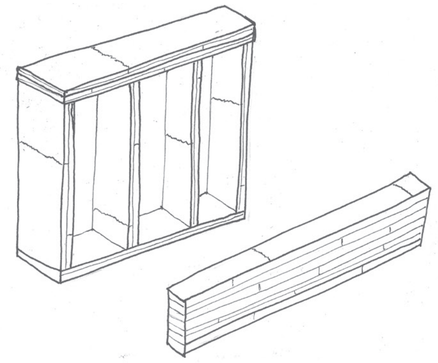
4.1 Principles and program 52
4.2 Design process and explorations 56
4.3 Design results 76
4.4 Architectural consequences 96

4.1. Principles and program

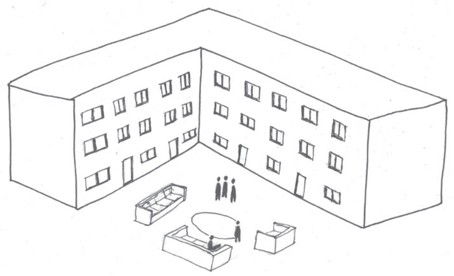
Design principles

Based on an analysis of the site, the existing building and the target group (as discussed in paragraph 1.5) specific design principles have been formulated. Furthermore, the design serves as a test case for researching the potential of poplar timber in the construction sector of the 21st century, which is the main focus of this project. The design principles formulated are:

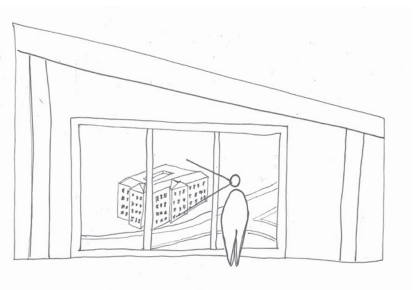
- Poplar as a building material
- Community based design
- Sightlines
- Green architecture
- Adaptability



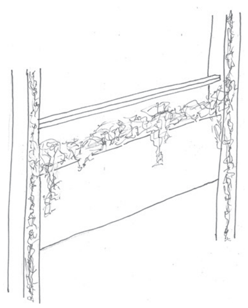
Poplar as a building material



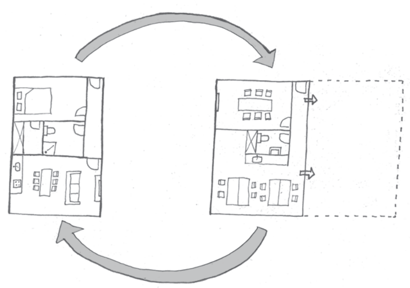
Community based design



Sightlines



Green architecture



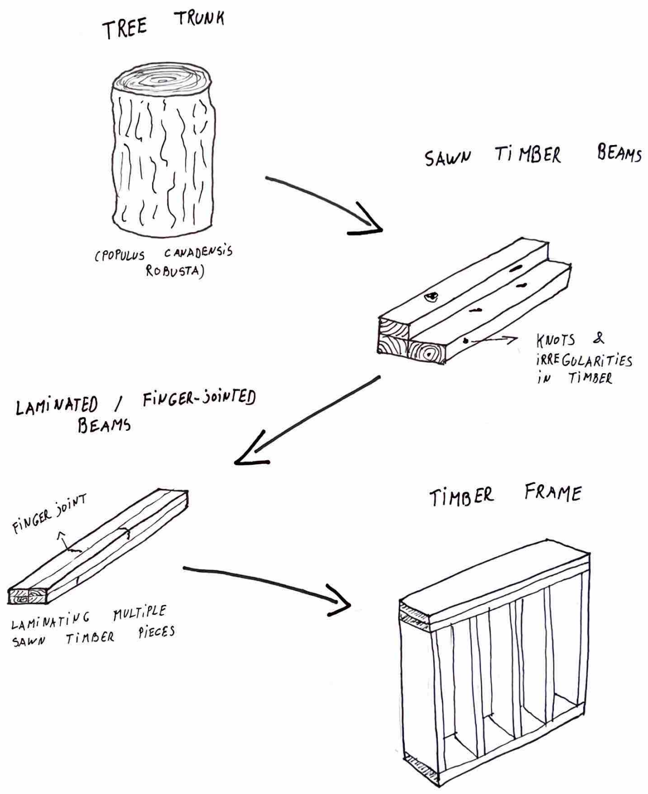
Adaptability

Poplar as a building material

The design phase for the top-up on d'Peliekaan started alongside the research into the potential of poplar as a building material, as reported in part three. For this reason, initial conclusions were drawn up from the research at the start of the design process considering the choice for a structural system and the use of poplar in the façade.

The decision was therefore made to use a structural system combining primarily a 2D timber frame construction with a 1D post-and-beam construction. This decision was based on the Peppelhout case study (see paragraph 3.4), which demonstrates that this type of construction is possible with poplar and fits well with the programme. A timber frame construction is, in fact, well suited for smaller dwellings and is much lighter than solid CLT slabs, which is important when adding storeys to an existing load-bearing structure. As it was already clear at this stage of the project that a public function would also be incorporated into the design, a more open 1D post-and-beam construction was chosen here. For both structural systems, the poplar timber would be laminated to remove irregularities in the timber, with the laminated poplar timber assumed to have a strength class of C22.

In order to be able to use poplar as a façade cladding and to extend the lifespan of the timber in the facade, the decision was made relatively early in the process to include an overhang in the design. This overhang will simultaneously contribute to the architectural expression of the design.

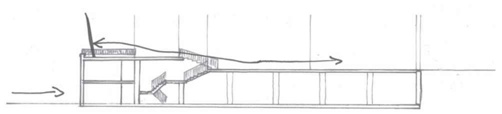


Removing irregularities in the timber by laminating it for structural use

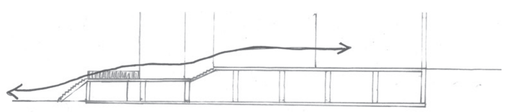
Community based program

The programme for the rooftop extension includes dwellings for starters as well as a public function. For the public function, the choice was made to add a coffee house to the design that can be used for multiple purposes. During the day, the space will serve as a public coffee house for the neighbourhood, and in the evening (after 5pm) it will function as a communal living area with a kitchen and seating area for the residents of d'Peliekaan. This part of the building will also be equipped with (home) workspaces that can be used during the day by the residents of d'Peliekaan and local residents, but which can also be used in a multifunctional way, for example for events.

In the design, this multifunctional public space is situated on the north side, overlooking the Nieuwe Vaart and the Maritime museum. To ensure easy access from the street, a lift and staircase will be added to the neighbouring Matrozenhof to provide a direct connection to the neighbourhood.



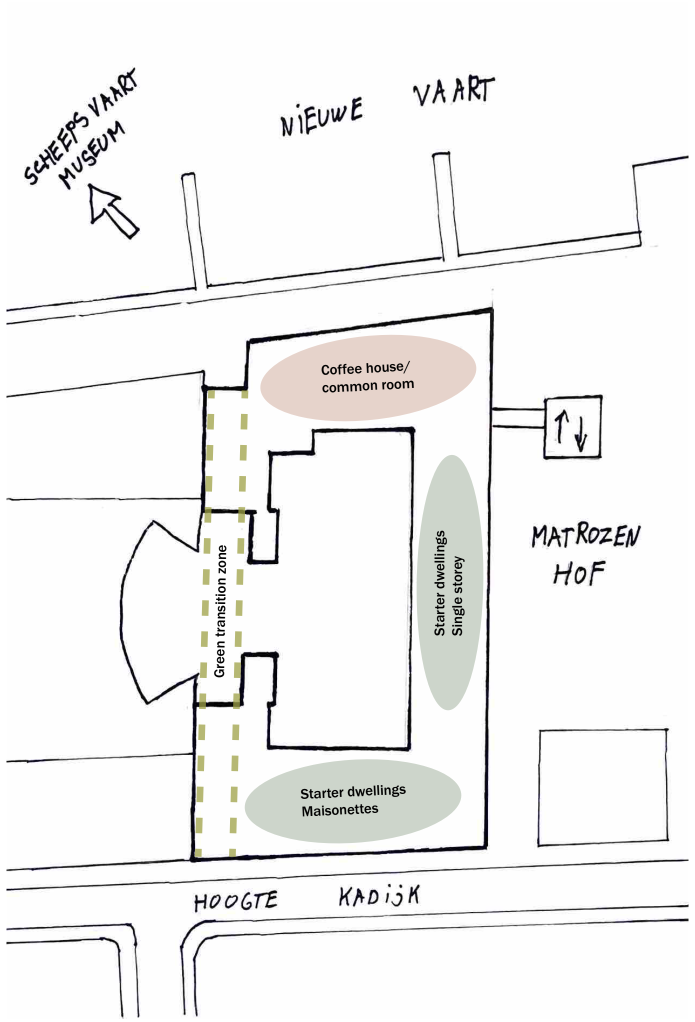
Current situation with storage units blocking the connection



New gradual connection

The compact starter dwellings are positioned on the east and south sides of the rooftop extension, with a division between single-storey dwellings and two-storey dwellings, or maisonettes.

On an urban level, d'Peliekaan will again be enclosed as a building block restoring its original form of 1902. This will be achieved by creating a green web of plants that reunites the building in a natural and transparent way. This greenery, however, will not form a rigid boundary but will function as a communal transition zone between the courtyard of d'Peliekaan and that of the adjacent building. To facilitate this, one storey of the existing storage units will be removed and converted into a communal terrace with an urban garden as a connecting element between the two courtyards. This green transition zone will also function as a collective space at the level of the top-up.



Program

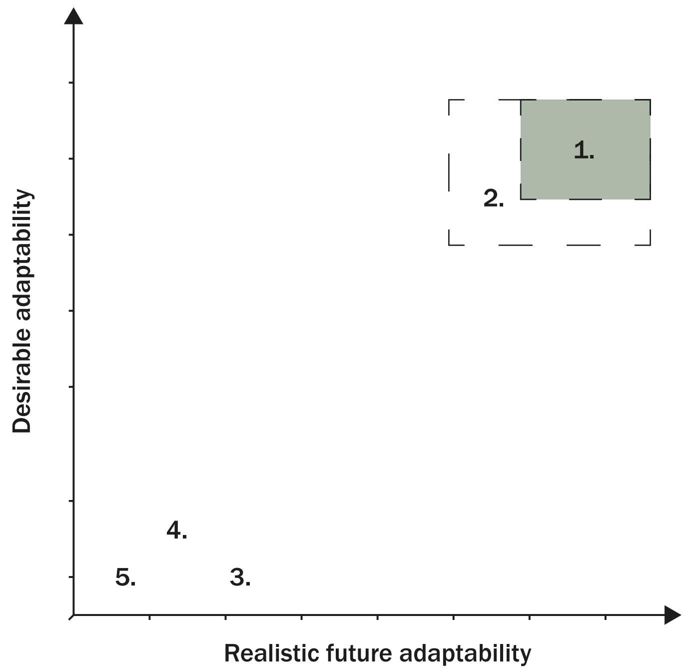
Adaptability

To determine the necessary adaptability for the design, an overview of potential future functions was created. These potential future functions were then placed in a graph comparing the probability and desirability of the new function. This shows that, in particular, small-scale adaptability and changes of function are both realistic and desirable.

Possible reuses of the design include expanding the starter dwellings into family houses or small office spaces for start-ups. However, as changing the function to small office spaces imposes different structural requirements under the Building Regulations, this future function is less realistic.

Incorporating adaptability into the design of timber buildings primarily involves technical aspects relating to the load-bearing structure and connections (Vandamme & Rinke, 2023). The use of a poplar timber frame construction as a structural system offers the possibility of creating future openings in load-bearing walls, thereby introducing horizontal adaptability into the design. To simplify vertical adaptability, the design opts to use the balloon method in timber frame construction for connecting the floors.

Possible future functions

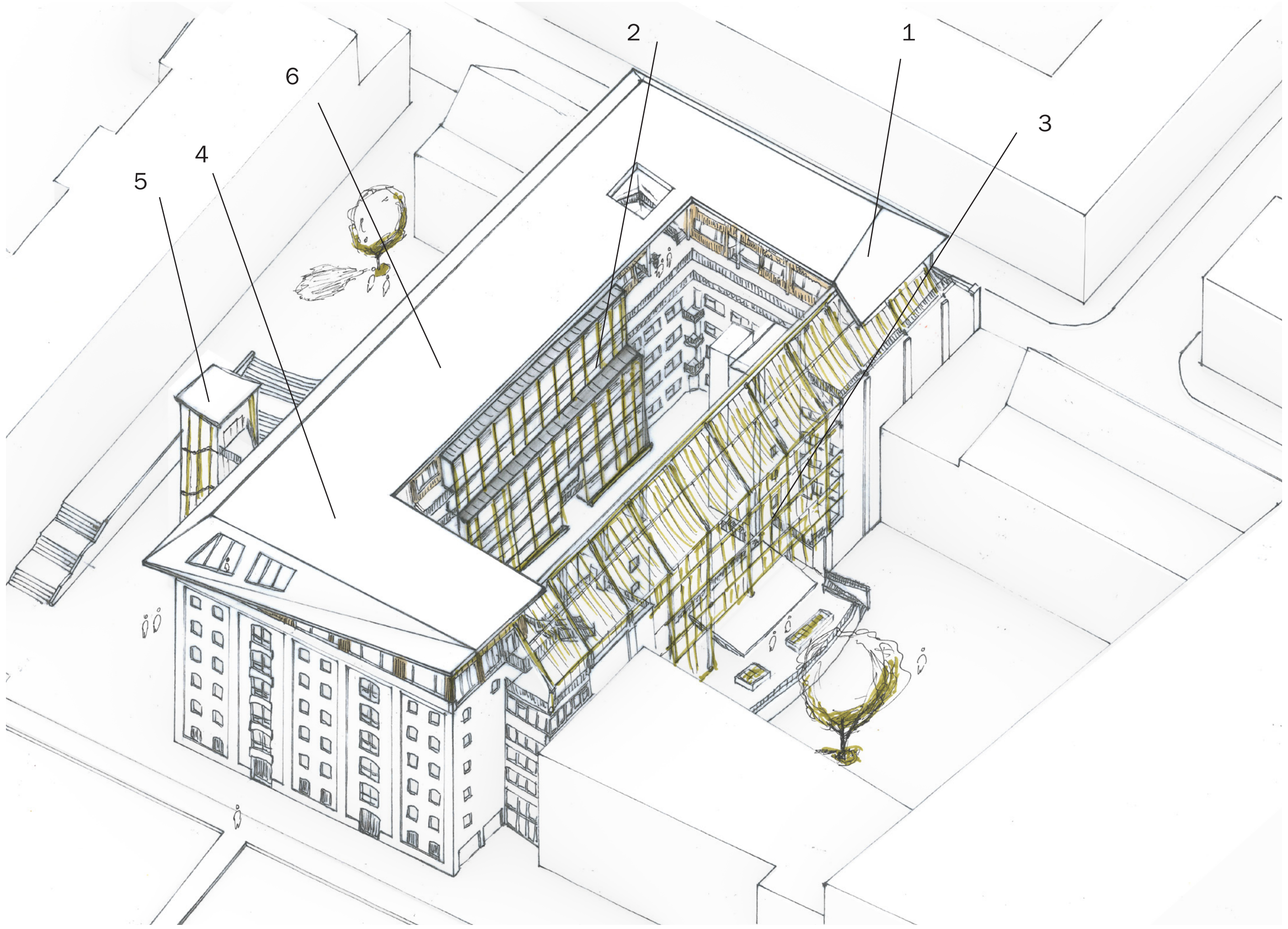


From starter dwellings to:
1. Family houses *($45m^2 \rightarrow 90\ m^2$)*
2. Offices (start-ups) *($45m^2 \rightarrow 180m^2$)*
3. One big office *($45m^2 \rightarrow$ entire top-up)*
4. Shops *($45m^2 \rightarrow$ entire top-up)*
5. Industrial function *($45m^2 \rightarrow$ entire top-up)*

Possible and desirable adaptability

4.2. Design process and explorations

Given the scale of the project and the various aspects on which it focuses, this paragraph divides the project into different interventions, as shown in the axonometric drawing, which was produced for the A2 presentation. First, the roof and circulation of the project are discussed (1). This is followed by a more detailed overview of the design process for the gallery, where inspiration is taken and how the existing building has been integrated (2). Next, the green transition zone is discussed (3), followed by a closer look at the public function at the front of the top-up (4) and the access from the adjacent Matrozenhof (5). Finally, the design process for the starter dwellings and the integrated adaptability are discussed (6).



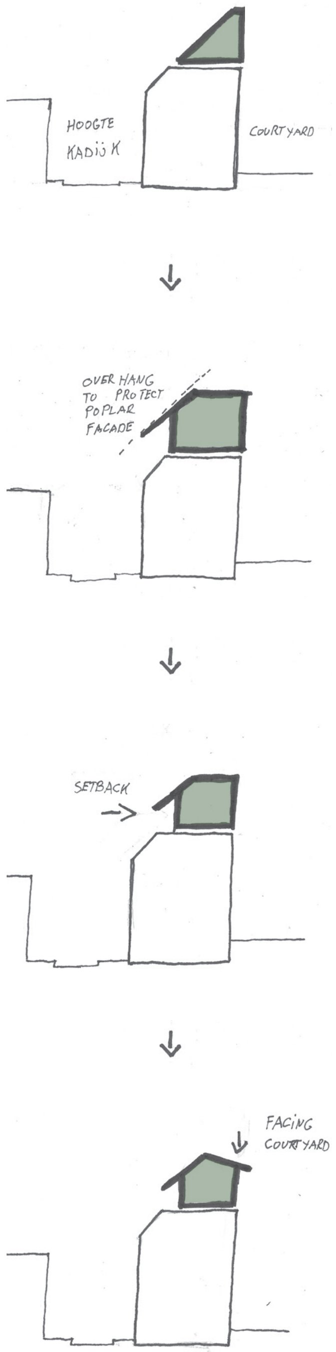
Axonometric drawing design at A2

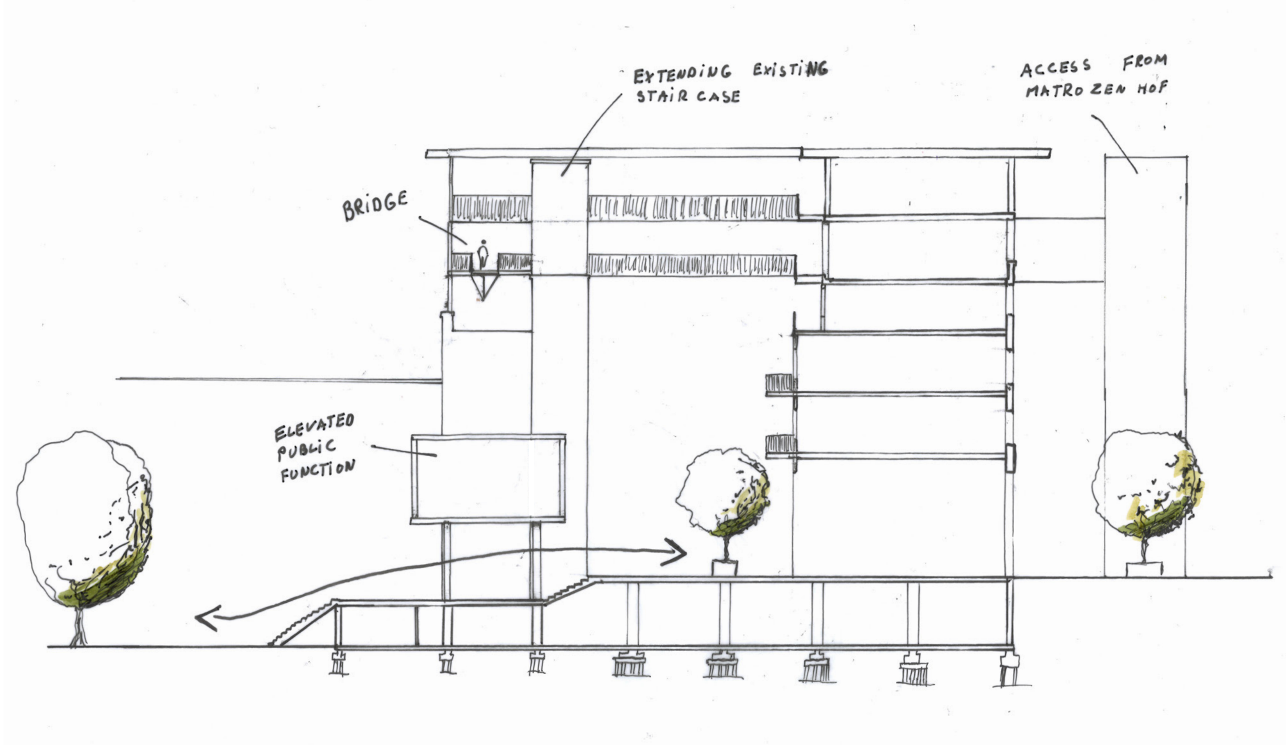
1. Roof and circulation

As **poplar** is being used as a façade cladding material in the project, the decision had already been made to incorporate a roof overhang into the design. In the initial design, this overhang was simply seen as a horizontal extension of a flat roof. However, it quickly became clear that this overhang would not provide sufficient protection for the **poplar** cladding, so a sloping angle was added to the roof and the overhang to better protect the poplar façade. The angle chosen for the outer and most exposed façade is inspired by the existing roof of the building along the Hoogte Kadijk. On the courtyard façade, the angle of the overhang is significantly less steep. This was done to preserve the quality of the dwellings and to gently guide the view from inside the dwellings towards the courtyard.

The access to the dwellings was designed in parallel with the design of the roof. Initially, a separate gallery was provided for both storeys of the extension. However, this would have separated the residents' circulation routes too much, making the space feel much more anonymous. In a later version, a single gallery was therefore chosen, with a typical Dutch porch (see figure 41) providing access to the dwellings on the top floor of the extension. In this way, the gallery becomes more of a meeting place where neighbours can interact.

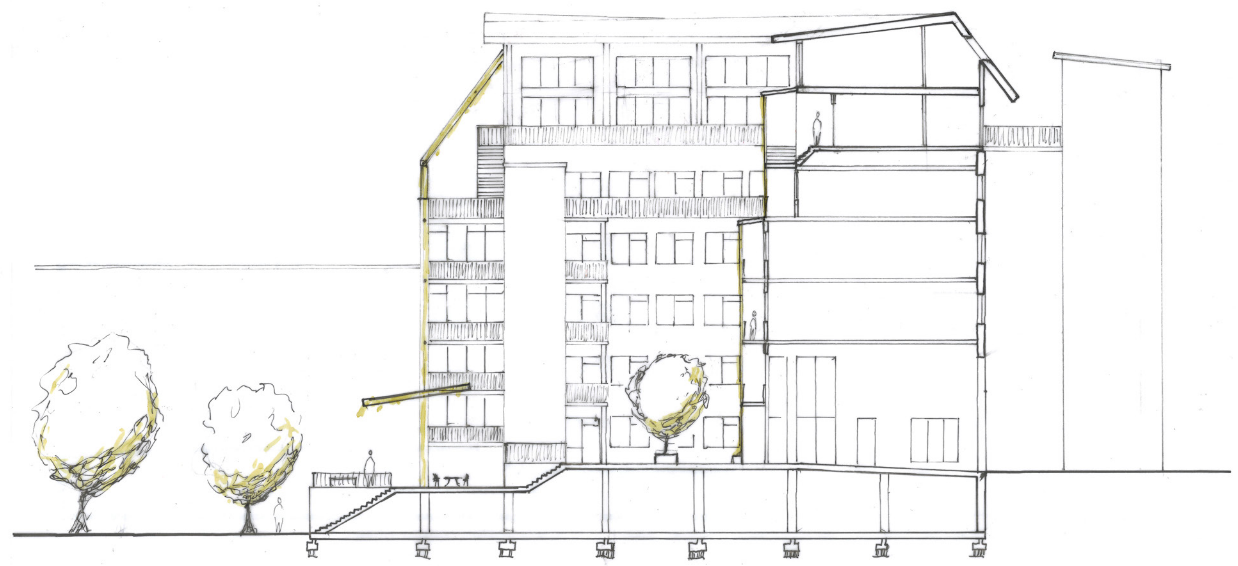
Figure 41: *Porch houses in The Hague*





First design section with flat roof and double gallery

1:200



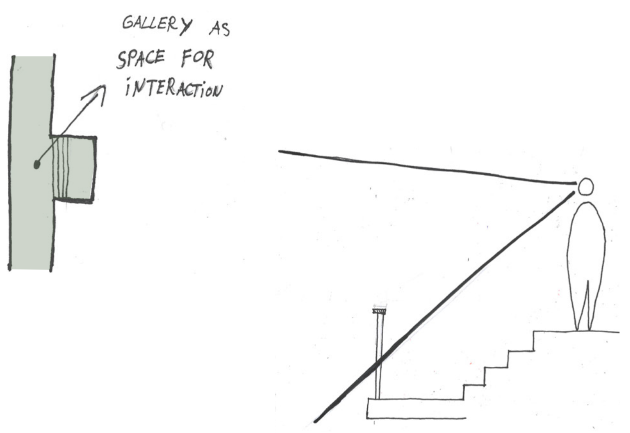
Elaborated section of design with new roof shape and single gallery

1:200

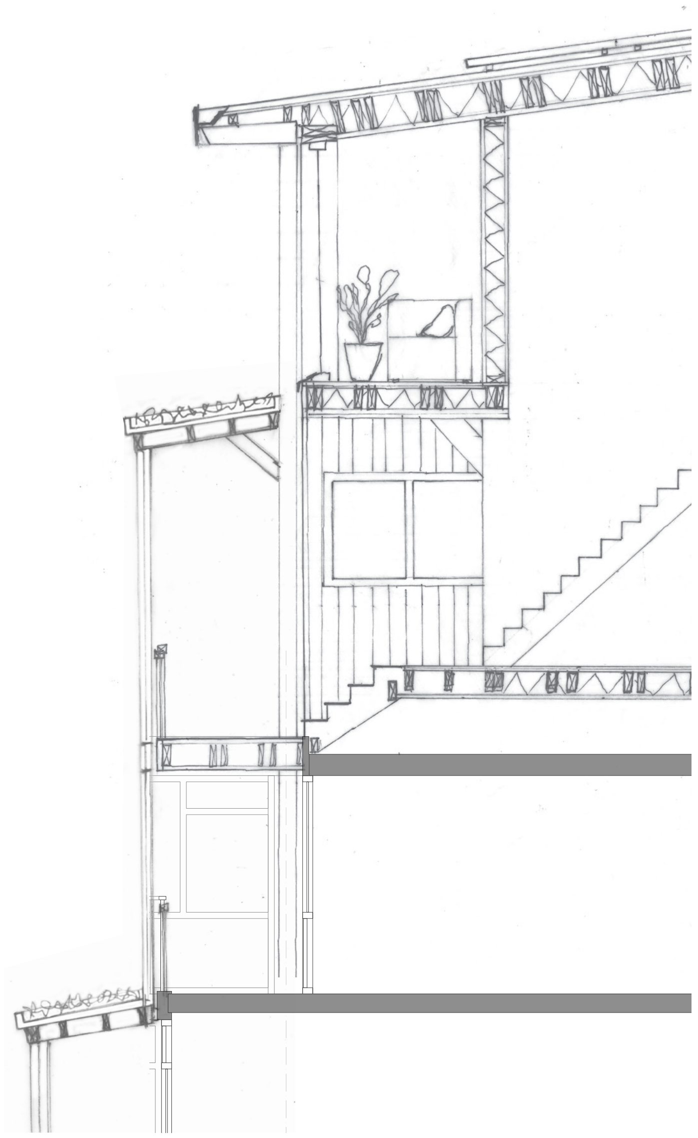
2. Gallery and ‘second skin’

The design of the gallery is entirely based on the target group and the principles of community-based design and green architecture. The gallery, as a result, serves as the connecting element between neighbours and the various functions within the top-up. Early on in the design process, it was therefore decided to widen the gallery at the level of the front doors of the dwellings and to raise the dwellings slightly. This creates a transition between the gallery and the dwellings, functioning as an outdoor space and an extension of the dwellings. Raising the dwellings, in turn, creates a visual connection between the residents of the top-up and the courtyard. Another advantage of elevating the dwellings is that the space created between the existing roof and the floor of the top-up provides room for pipes and installations.

A ‘second skin’ structure made of acetylated **poplar** timber is placed over the top-up gallery and the existing gallery. This structure rises in a stepped pattern, ensuring that the gallery becomes an extension of the living space rather than being strictly a circulation space. Initially, a green roof was planned for the roofs of this ‘second skin’ structure, as well as for the top-up. However, due to the height of the top-up and the strong winds at this height, the green roof was quickly removed from the design. The idea of adding climbing plants to the structure to give the gallery a natural feel stayed in the plan. Figures 42 & 43 served as inspiration for the design of the ‘second skin’ structure.



Widening and extending the gallery to encourage social interaction and create visual connections



‘Second skin’ structure gallery and elevated dwellings 1:50

First option with a gallery on each level

Second option with a porch principle and one gallery

Figure 42: *Herzog de Meuron Rue des Suisses Apartment Buildings*

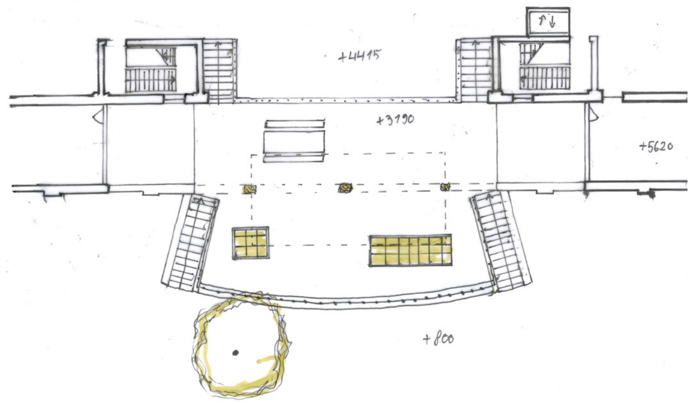
Figure 43: *Louisen Center, Bad Homburg, Germany*

3. Green transition zone

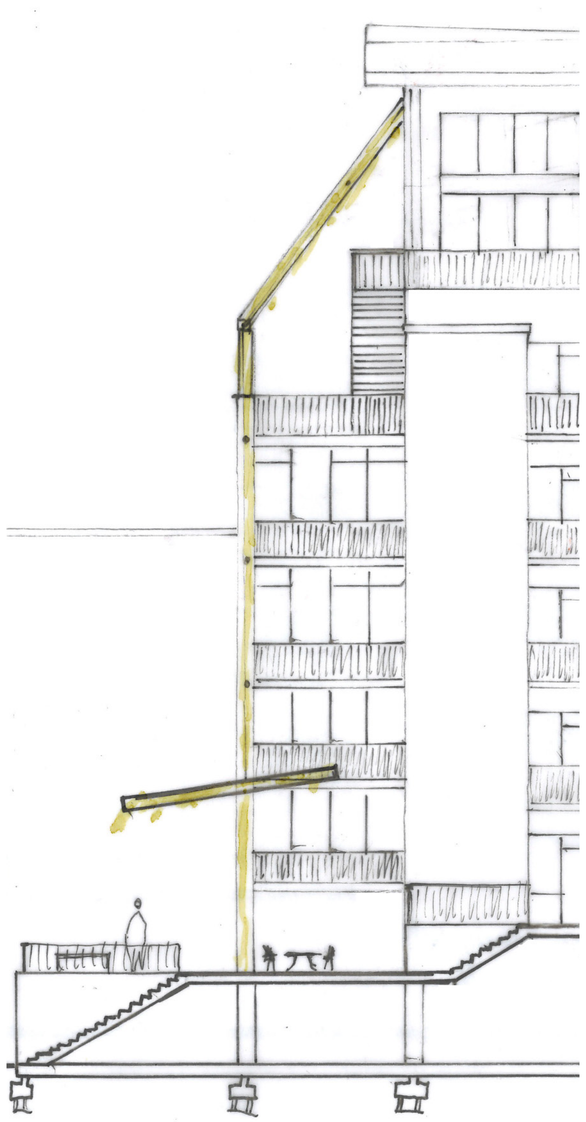
The inspiration for the green web to restore the original form of d'Peliekaan from 1902 was taken from the MFO park in Zürich. The web will in a natural and transparent way serve as a dividing line in the urban block while in fact it serves as a communal space with a shared terrace and urban garden for the residents of the adjacent buildings. In terms of climate, the green canopy will provide shade in summer, helping to keep the courtyard cooler. The presence of greenery in an urban environment can help lower the outside temperature in summer by about 1 to 3 degrees (Zhang & Dai, 2022).

Figure 44: *MFO Park Zürich*

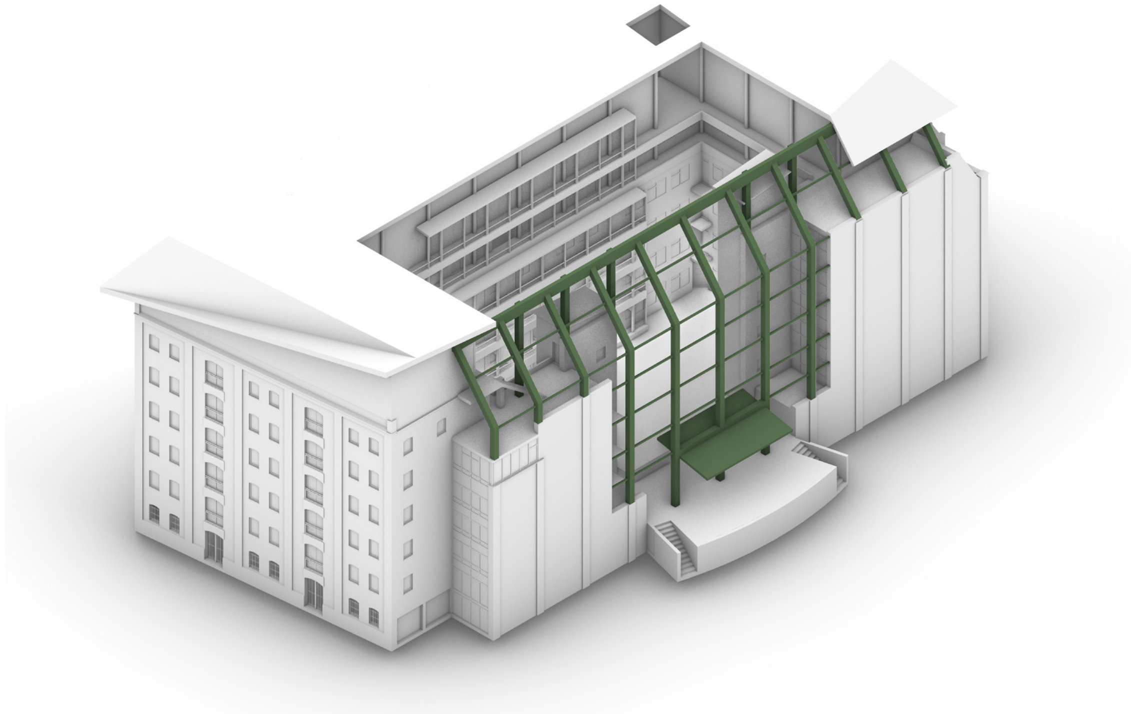
Initially, the web was designed as a large steel structure that would run from the courtyard all the way up to the roof of the top-up. However, this would have resulted in a large and heavy structure requiring a great deal of steel. The architectural decision to incorporate a bridge into this web at the level of the top-up, however, opened up the possibility of constructing it using **poplar** timber in combination with steel cables. Obers' 2019 research demonstrates how acetylated **poplar** timber can be used in pedestrian and cycle bridges. Based on the results of this research, a truss bridge has been positioned at the top of the green web, which closes the U-shape of the building at the level of the top-up. In the design, this bridge serves both as a circulation route and as a roof terrace.



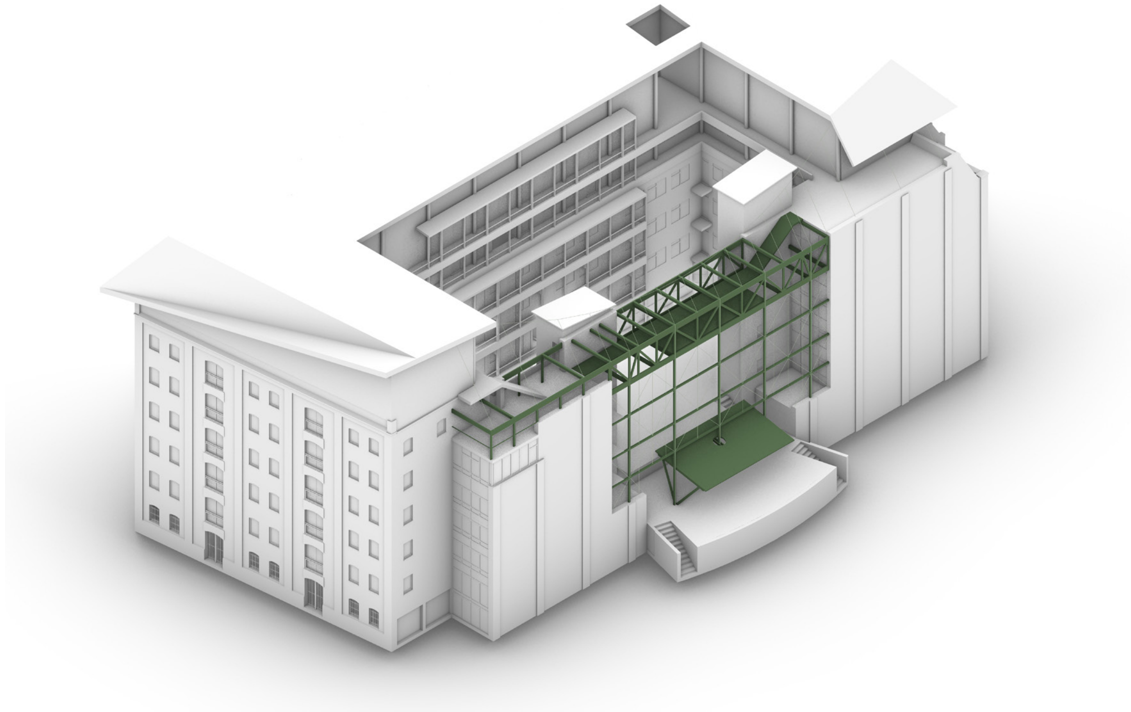
Floorplan communal/shared terrace 1:200



Section green web with initial steel design 1:200



Initial steel design for green web



Elaborated design green web with poplar truss bridge and poplar frame

Plants

The climbing plants used in the green web, as well as on the 'second skin' structure above the gallery and on the elevator tower on the Matrozenhof, require the right conditions in order to grow properly. This relates to the soil type and the nutrients required in this soil (whether or not in a planter), the orientation in relation to sunlight, water supply and the type of support needed. The different types of climbing plants, categorised by the climbing technique they use, are: clinging rootlets, creepers, twining plants, tendrils and scrambling climbers (see figure 45). The design utilises steel cables as climbing aids and a **poplar** timber frame as the supporting structure. Consequently, support climbers of the twiner and tendril types will be primarily used in the design, as these can grow effectively along the steel cables. However, some clinging rootlets and creepers can also be used (Petschek & Gass, 2011).

A selection has been made of potential plants that could be used in the design (see figures 46-49). This selection takes into account plants that can grow tall enough (20 metres) with the chosen support system and that can thrive in the site's conditions (sunlight, etc.). The book 'Constructing Shadows: Pergolas, Pavilions, Tents, Cables and Plants' by Petschek & Gass (2011) was the primary source used to make this selection.

Additionally, the design incorporates space for rainwater storage that can be used to irrigate the plants, while planters are positioned at various points within the structure to allow different species of climbing plants to grow from multiple locations.

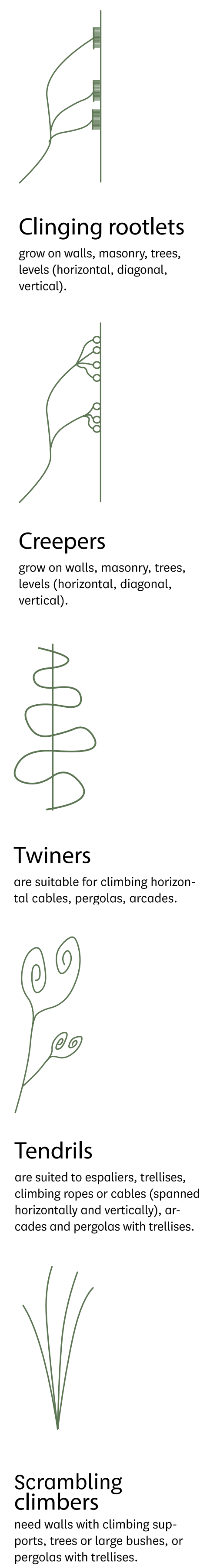


Figure 45: *Climbing forms (adapted by the author)*

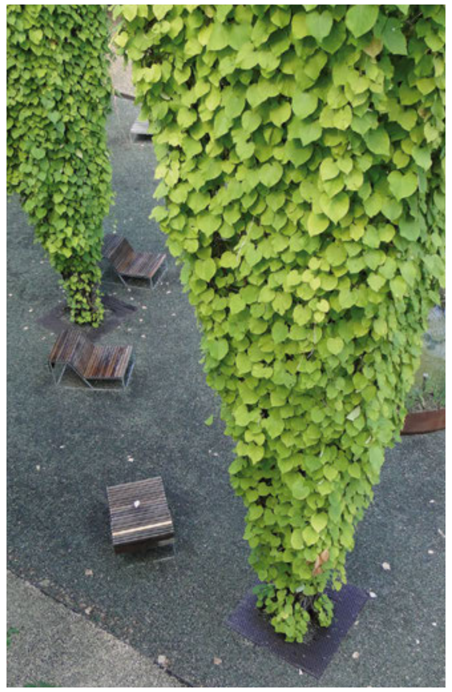


Figure 46: *Aristolochia manshuriensis*

Climbing form:
Twiners

Growth rate/height:
Grows up to 2m/y
8-10m tall
4-6m wide

Location:
Shaded/sunny places

Hardiness:
to -20° C

Special note:
Pipe-shaped yellowish-green flowers

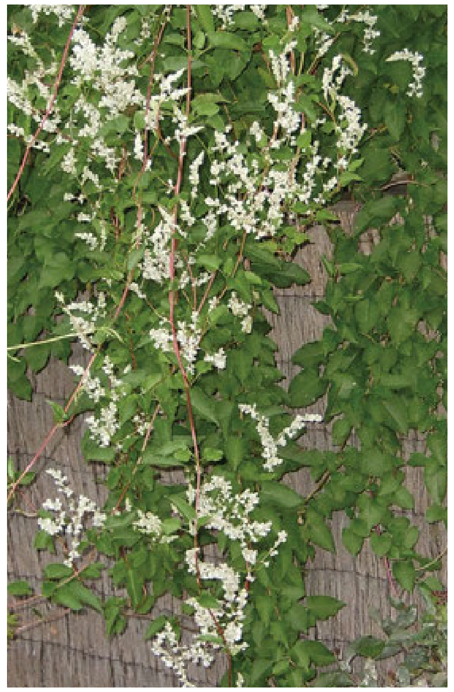


Figure 47: *Fallopia baldschuanica*

Climbing form:
Twiners

Growth rate/height:
Grows up to 8m/y
8-15m tall
4-8m wide

Location:
Semi-shaded/sunny places

Hardiness:
to -20° C

Special note:
White flowers

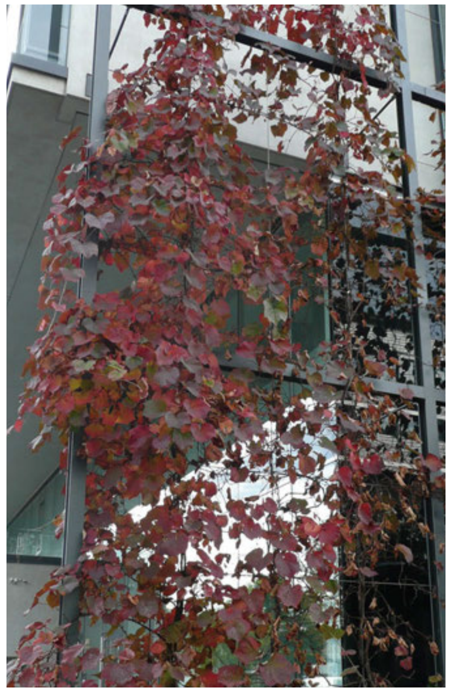


Figure 48: *Vitis aestivalis*

Climbing form:
Tendrils

Growth rate/height:
Grows up to 2m/y
15-20m tall
8-10m wide

Location:
Semi-shaded/sunny places

Hardiness:
to -30° C

Special note:
Green in spring/ summer, vibrant red in autumn

Figure 49: *Parthenocissus (quinquefolia, tricuspidata)*

Climbing form:
Creepers

Growth rate/height:
Grows up to 2m/y
10-25m tall
6-15m wide

Location:
Semi-shaded/sunny places

Hardiness:
to -25° C

Special note:
Does not need pruning

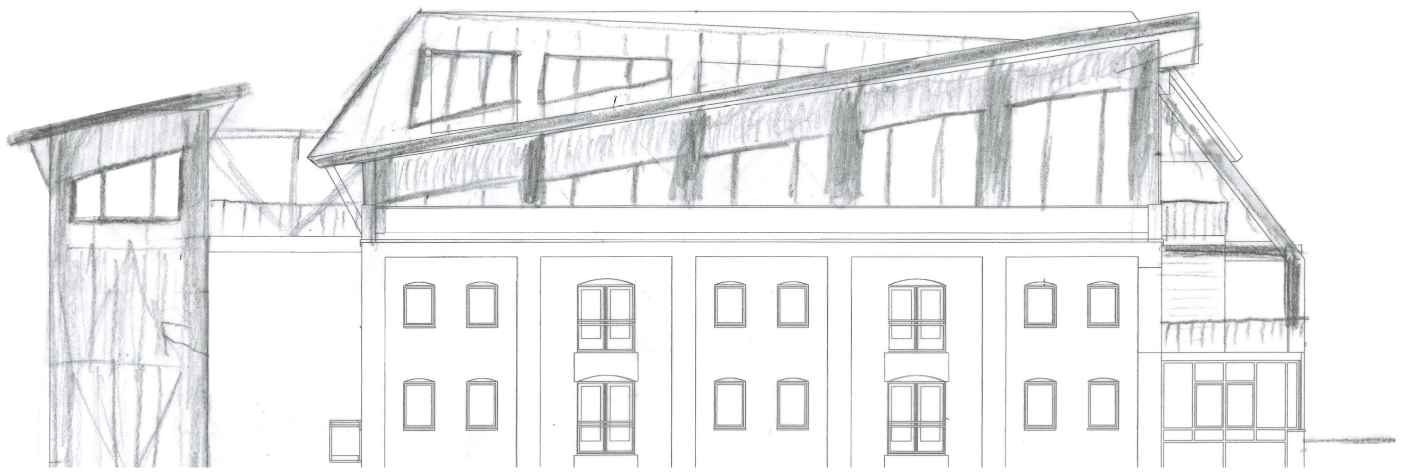
4. Coffee house/common room

The coffee house and common room have an open-plan layout, for which a **poplar** post-and-beam construction was chosen. This allows the floorplan to be divided flexibly. The main space is visually connected to the courtyard within the building, as well as providing a view across the Nieuwe Vaart. Separated by the bar/kitchen, a separate corner has been designed as a 'living room' for the residents of d'Peliekaan. A spiral staircase integrated into the bar connects to the multifunctional (work)spaces above.

The overhang of the roof has been flipped in this section of the top-up. This enhances and accentuates the views from the coffee house across the Nieuwe Vaart and the Maritime Museum as part of the architectural design. The façade design follows the structure of the existing building and is finished with thermally modified **poplar** timber. The interior of the space is finished with untreated **poplar** timber.

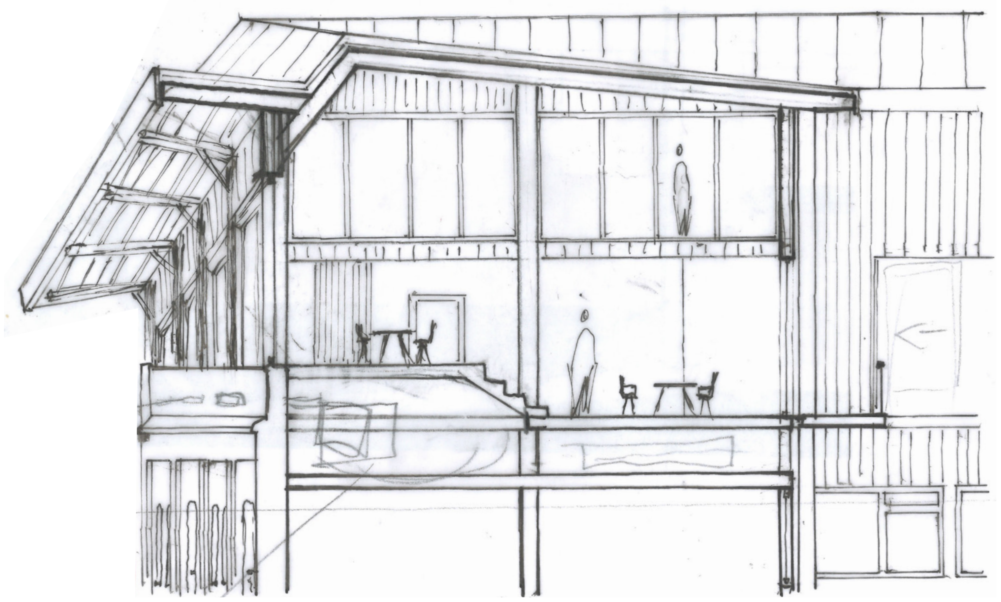
Figure 50: *Staircase Vakwerkhuis Delft*

Thermally modified poplar and unmodified poplar for interior and exterior finish



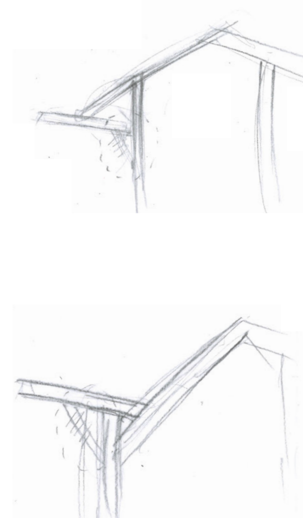
Design explorations Nieuwe Vaart elevation

1:200

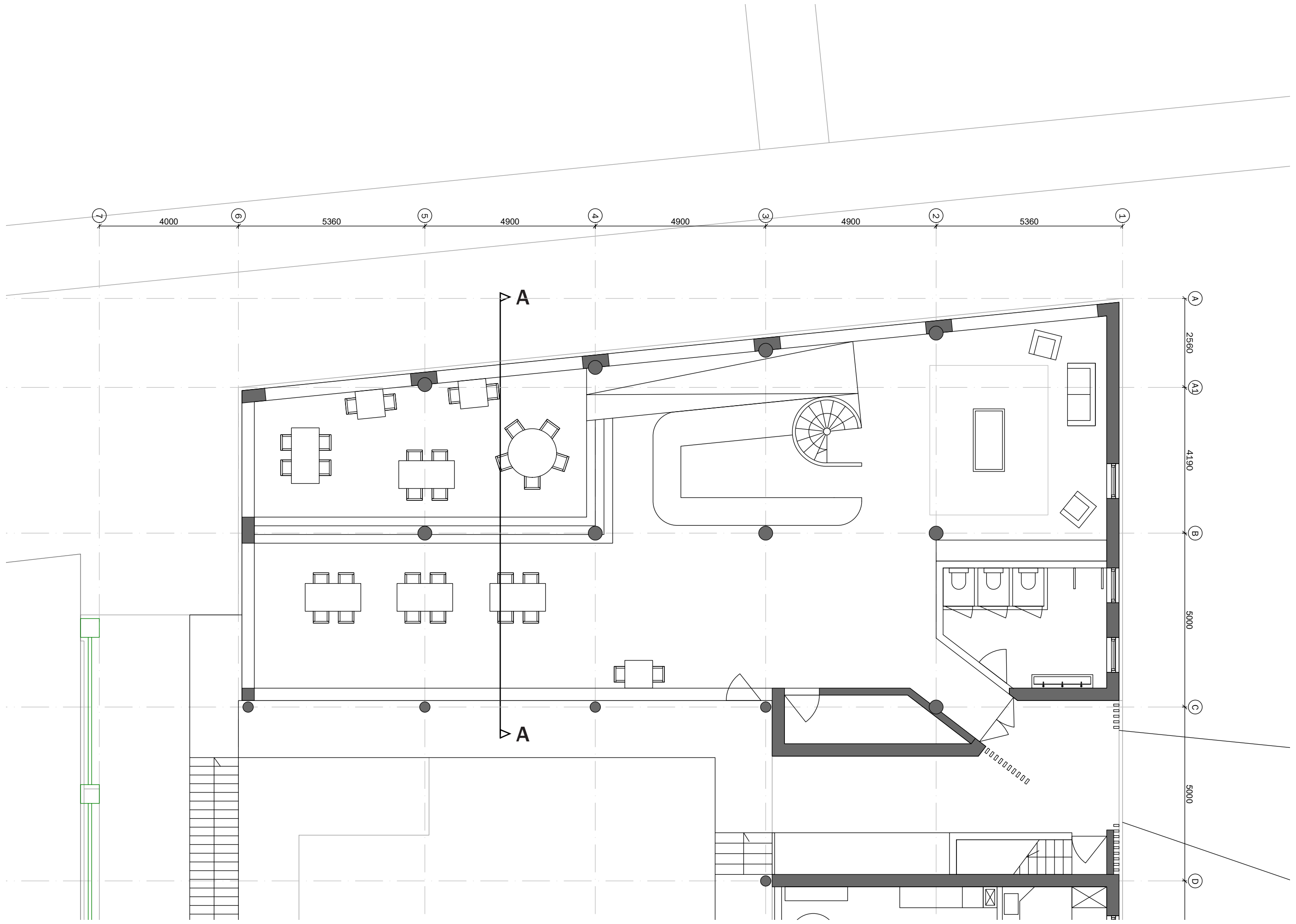


Section fragment through public space A-A

1:200



Principles of connection glulam poplar columns and angled roof beams



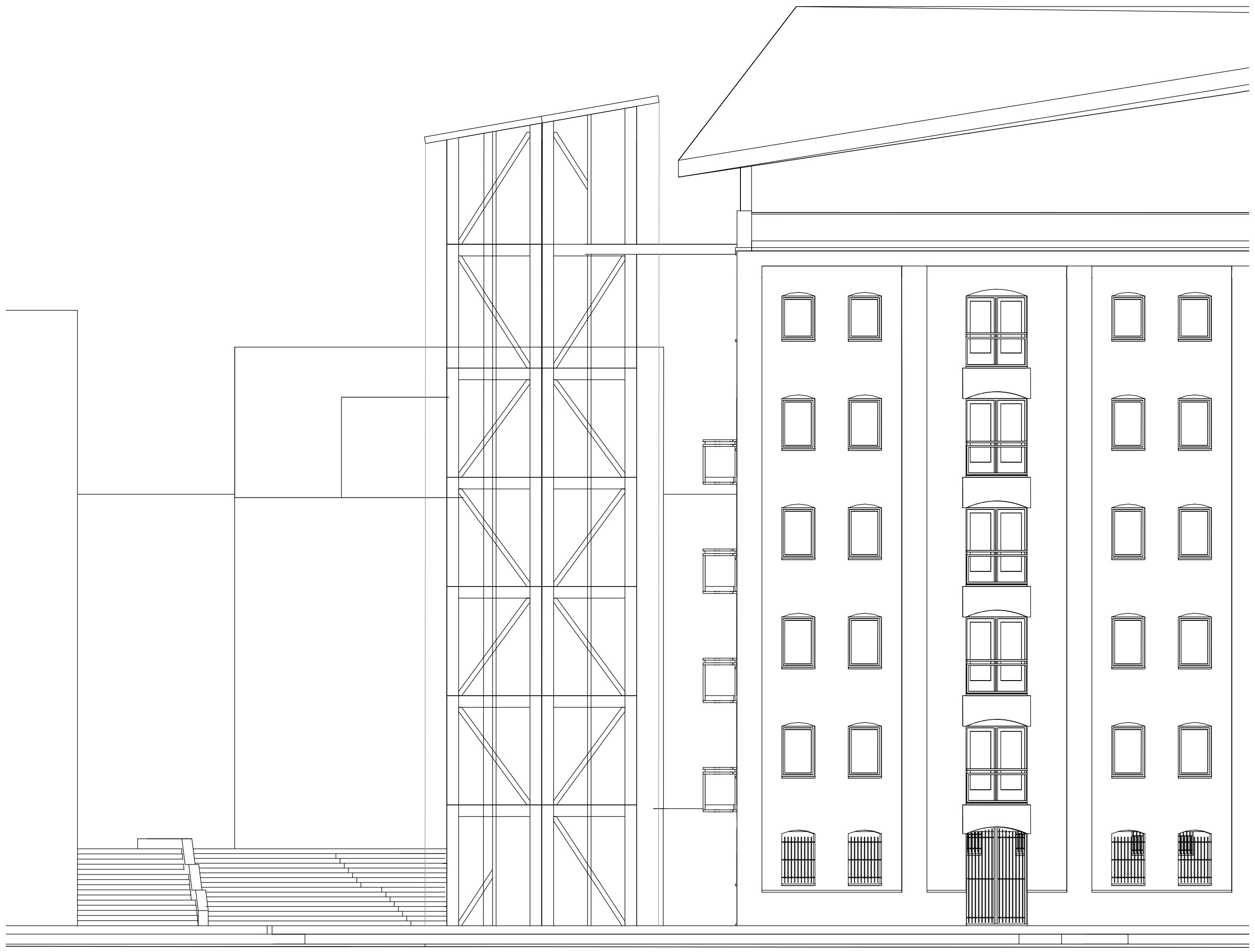
Floorplan coffee house/common room

1:200

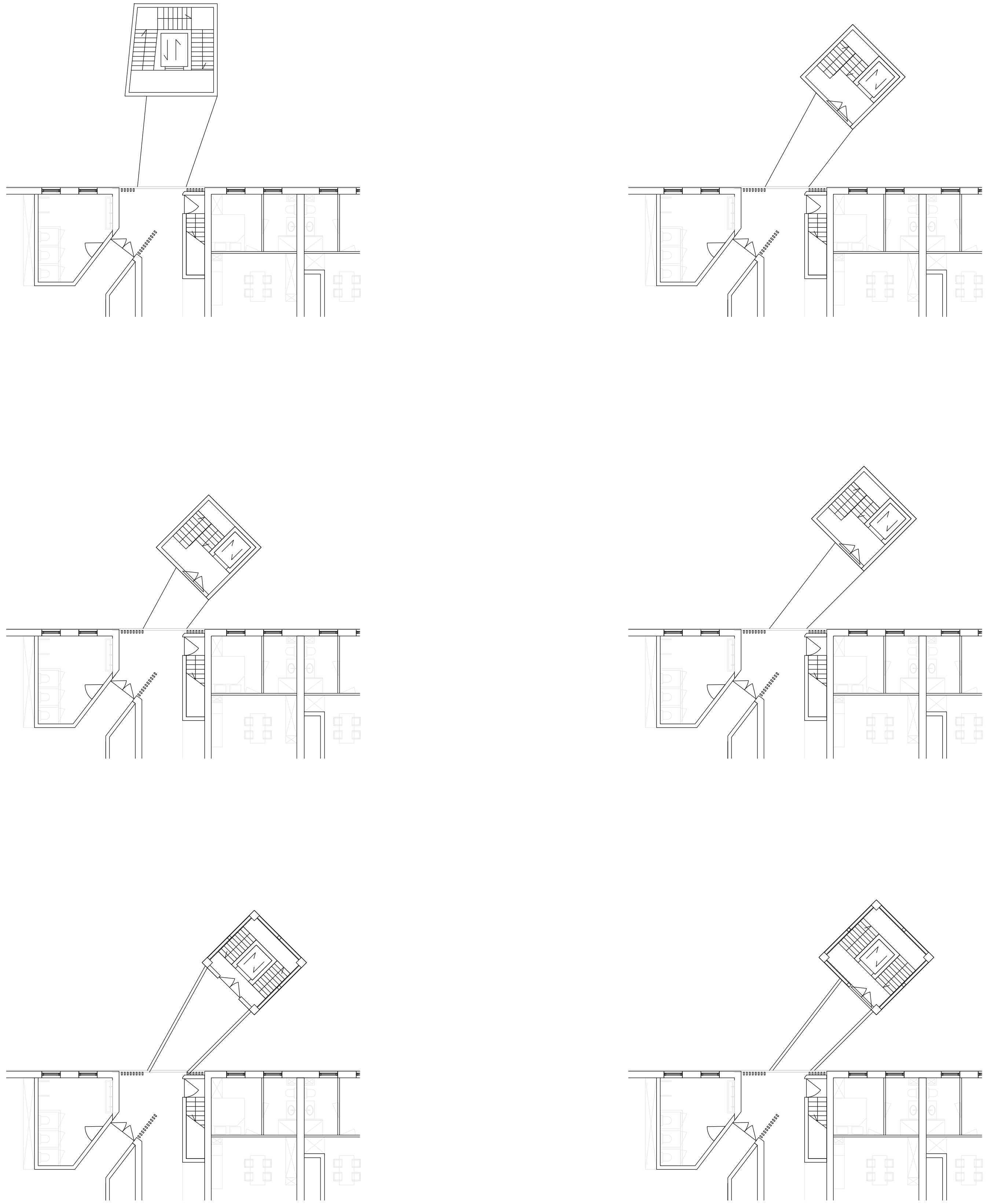
5. External staicase and elevator

When designing the external staircase and elevator connecting to the Matrozenhof, there are many factors to take into account. Factors such as the tower's positioning on the existing ground level, the connection at the top with the top-up, and the apartments in the existing building all influence the design. For this reason, the decision was made early on in the process to rotate the tower by 45 degrees relative to the existing building. As a result, the tower forms a less dividing element on the square, the existing homes maintain their sightlines, and the visitor flow towards the coffee house is enhanced at the top of the tower.

To enable the use of **poplar** in the tower of the external stairwell, the tower has been designed as a vertical truss structure. The **poplar** timber used here is glued and acetylated.



Nieuwe vaart elevation designproces external staircase 1:200

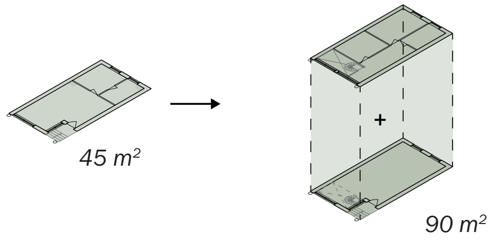


Floorplan testing oriëntation and layout external staircase with connection to top-up 1:300

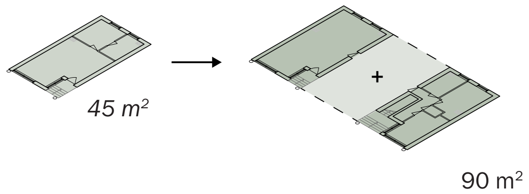
6. Starter dwellings and adaptability

The starter dwellings are arranged in such a way that the living areas face the gallery. This is intended to enhance connection and interaction with neighbours passing by, but also to foster a sense of community based on the principle of courtyard living.

As already indicated in paragraph 4.1, the design incorporates small-scale adaptability of the starter dwellings to family dwellings. The strategies applied for this are both horizontal adaptability, by merging two dwellings horizontally, and vertical adaptability, where two dwellings situated one above the other are merged. To test whether this also results in usable spaces and dwellings, floorplans were used to investigate what these family homes might look like according to both strategies.

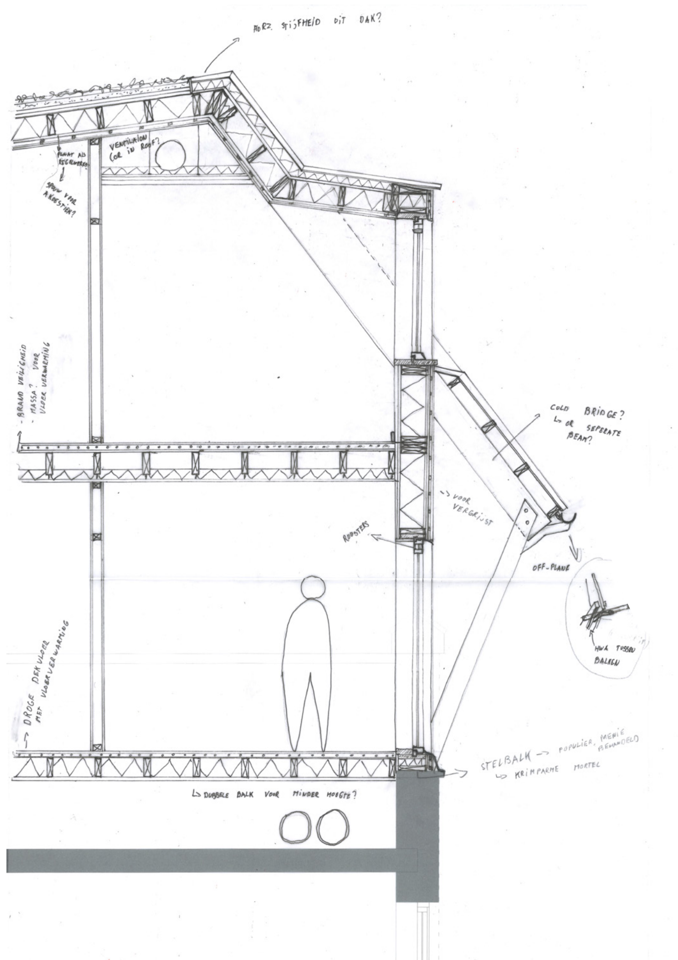


Vertical adaptability dwellings



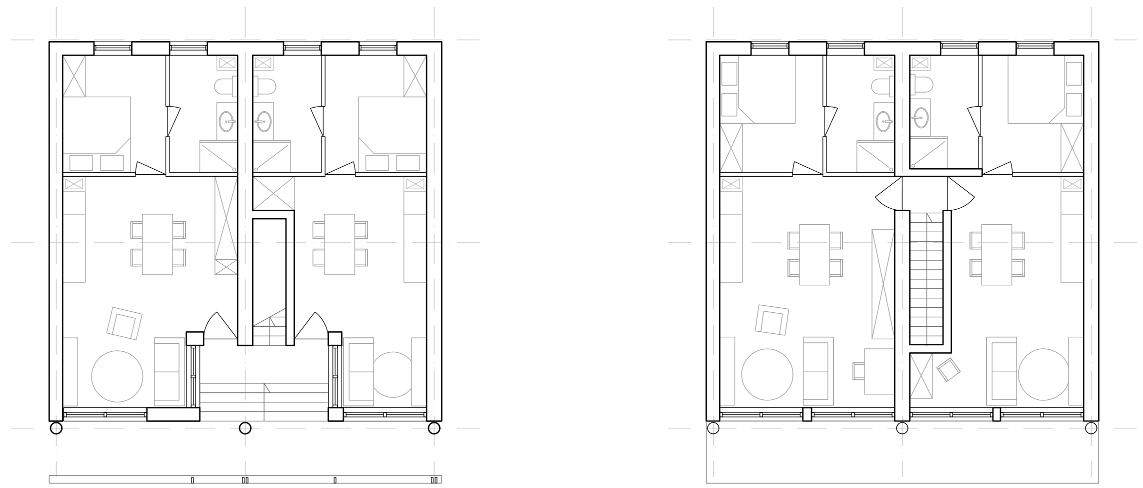
Horizontal adaptability dwellings

1:50 work model dwellings with porch and 'second skin'



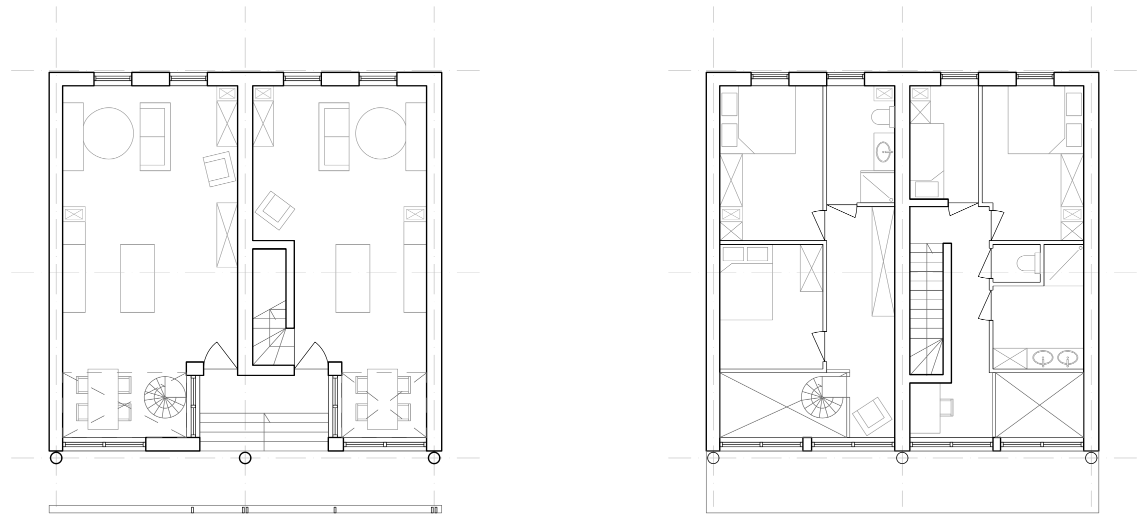
1:20 design drawing with first principles

1:20



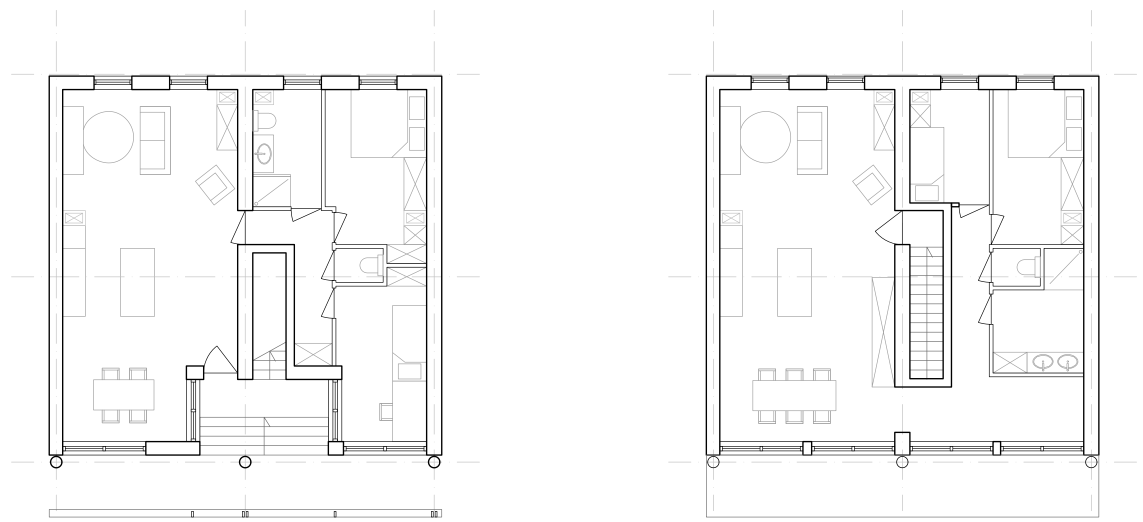
Floorplans starter dwellings (left: 6th floor, right 7th floor)

1:200



Floorplans family dwelling vertical adaptability (left: 6th floor, right 7th floor)

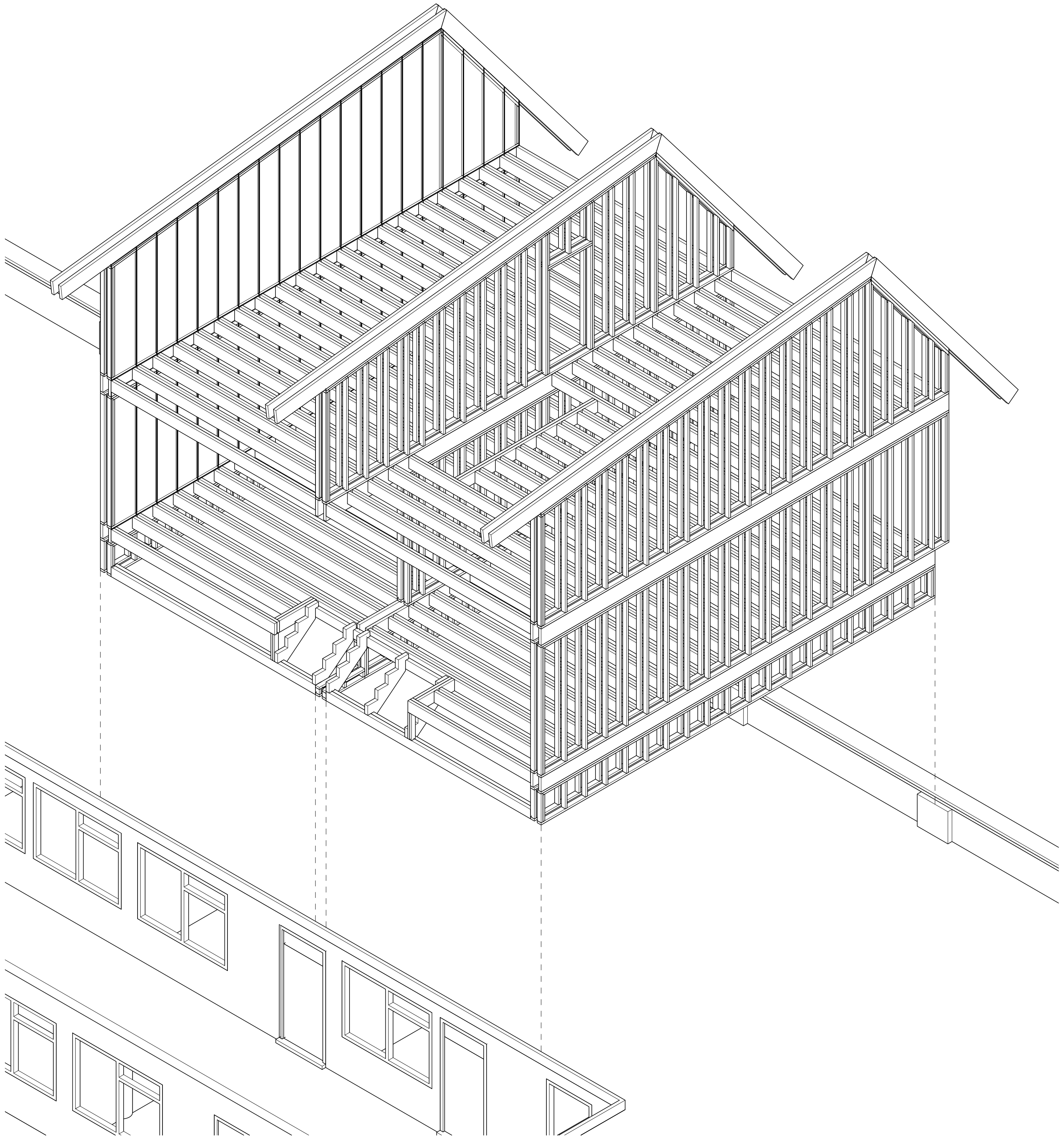
1:200



Floorplans family dwelling horizontal adaptability (left: 6th floor, right 7th floor)

1:200

In order to make future adaptations as easy as possible, particular attention was paid to the structure and connections of the **poplar** timber frame. The double **poplar** floor beams (as visible in the axonometric drawing below) originally designed to lower the height of the **poplar** beams were replaced with single **poplar** floor beams, thereby reducing the heart-to-heart distance of the beams to 400 mm.



Poplar timber frame top-up with doubled floor beams

Poplar balloon framing

From an acoustic point of view, a decoupled **poplar** wall construction has been chosen for the load bearing separating wall. To determine the thickness of the wall, the required cross-section of the vertical studs was taken into account, as calculated in paragraph 3.4. The required area was then divided between the two decoupled frames, after which a standard size of 45x95mm was chosen for the vertical **poplar** studs.

The floor is hung between the walls using principles from the balloon framing method in timber frame construction. This type of construction isn't really common in Europe as it has problems in terms of building physics (fire safety and acoustics). Furthermore, traditional balloon framing requires long timber elements as the wall elements run from the foundation to the roof in one continuous section (Isaacs & Victoria University, 2013). Partly for these reasons, platform framing is the most common timber frame construction system in Europe, however this system places the floor beams in between the wall element making it harder to make changes in the future.

In the design, a modern interpretation of the balloon frame has therefore been adopted, incorporating elements of platform framing. In terms of building physics, the decision was made to split the wall frames at the floor level, where a rim beam is integrated into the wall. The floor beams are attached to this rim beam using the Sherpa aluminium dovetail connection system (see figure 52). This connection ensures that the beams can be easily removed in the future, which simplifies future changes.

Figure 52: *Sherpa connection*

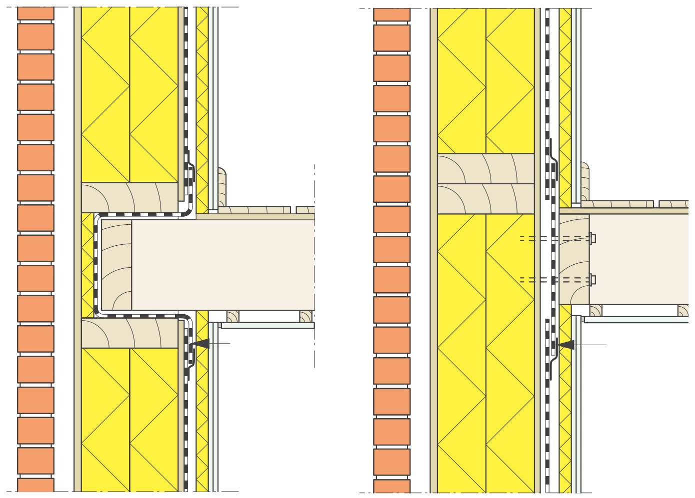
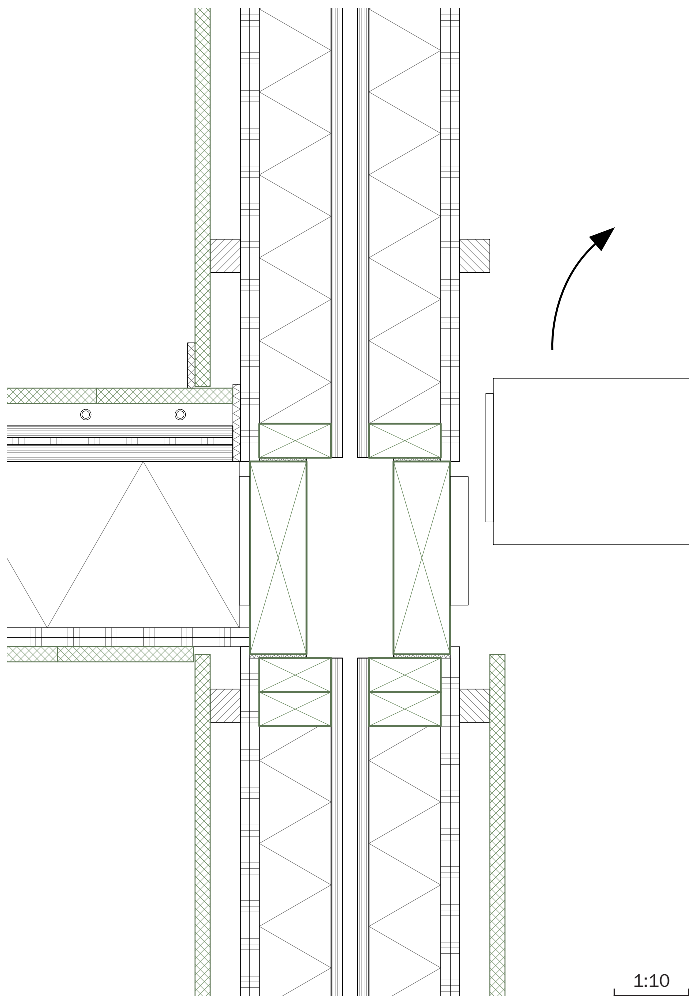


Figure 51: *Platform framing (L) and Balloon framing (R)*



Adaptable dwelling separating floor construction

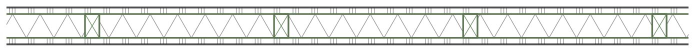
1. Remove poplar wall finish
2. Remove floor and ceiling package
3. Take out the floor beams

Poplar in timber frame construction packages

Inner wall (non load-bearing):

- 2,5mm - Plaster finish
- 16mm - Clay plasterboard
- **63mm - Poplar timber frame (38x63mm, h.t.h. 500mm)** + wood fibre insulation (acoustics)
- 16mm - Clay plasterboard
- 2,5mm - Plaster finish

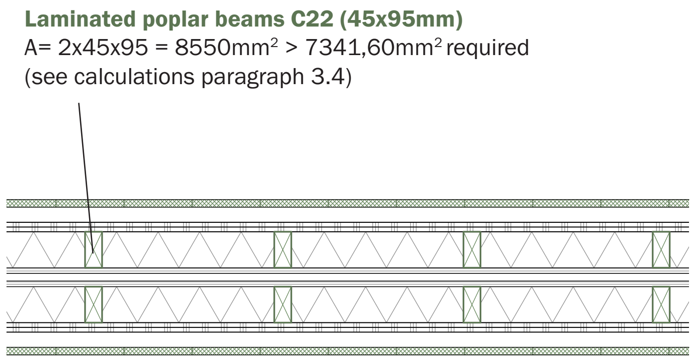
Total thickness package = 100mm



Load bearing dwelling separating wall:

- **20mm - Poplar interior wall finish**
- 40mm - Hor. framework (40x44mm), technical cavity (adaptability)
- 2x12,5mm - Plasterboard (fire safety)
- **95mm - Poplar timber frame (45x95mm, h.t.h. 500mm)** + wood fibre insulation (acoustics)
- 15mm - ESB board (stability)
- 20mm - Cavity (acoustic decoupling)
- 15mm - ESB board (stability)
- **95mm - Poplar timber frame (45x95mm, h.t.h. 500mm)** + wood fibre insulation (acoustics)
- 2x12,5mm - Plasterboard (fire safety)
- 40mm - Hor. framework (40x44mm), technical cavity (adaptability)
- **20mm - Poplar interior wall finish**

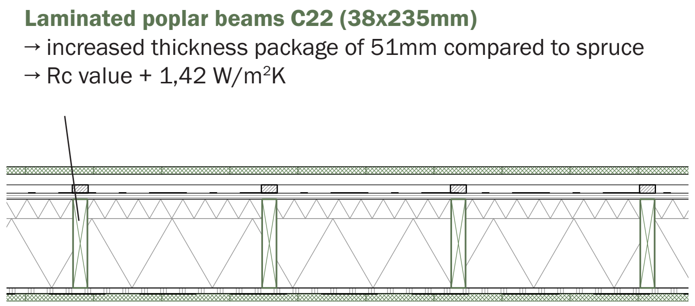
Total thickness package = 410mm



Façade package (from outside to inside):

- **20mm - Poplar facade cladding (thermally modified)**
- 28mm - Hor. framework (28x42mm), modified spruce
- 22mm - Vert. framework (22x42mm), modified spruce
- 16mm - Agepan board (stability)
- Waterproof, vapour-permeable membrane
- **235mm - Poplar timber frame (38x235mm, h.t.h. 500mm)** + wood fibre insulation (thermal insulation)
- 15mm - Gypsum fibreboard (fire safety)
- Vapour-permeable membrane
- **20mm - Poplar interior wall finish**

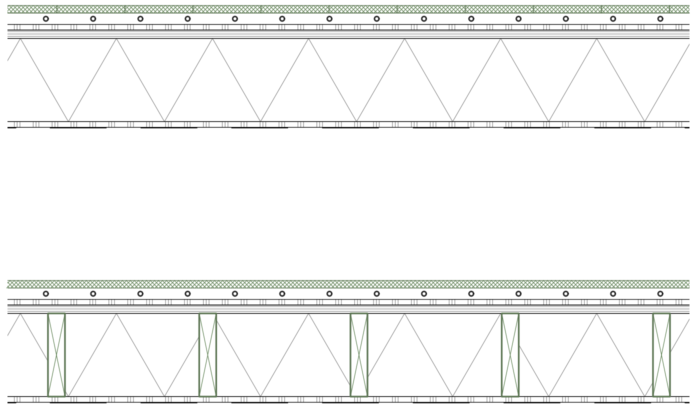
Total thickness package = 362mm



Ground floor top-up (from inside to outside):

- **20mm - Poplar floor**
- 30mm - Dry wood fibre floor-heating system
- 15mm - Plasterboard (fire safety)
- 22mm - ESB plate (structural)
- **220mm - Poplar floor beams (45x220mm, h.t.h. 400mm)** + wood fibre insulation (thermal insulation)
- 15mm - Plasterboard (fire safety)
- Vapour-permeable membrane

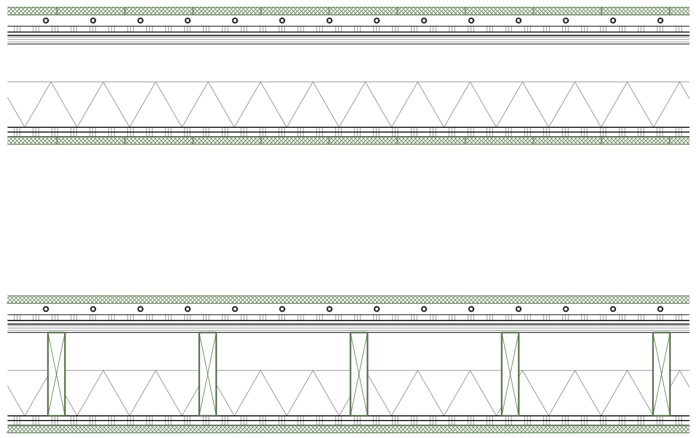
Total thickness package = 322mm



Dwelling separating floor

- **20mm - Poplar floor**
- 30mm - Dry wood fibre floor-heating system
- 15mm - Plasterboard (fire safety & acoustics)
- 10mm - Wood fibre board (suspended floor, acoustic decoupling)
- 22mm - ESB plate (structural)
- **220mm - Poplar floor beams (45x220mm, h.t.h. 400mm)** + 120mm wood fibre insulation (acoustics)
- 2x12,5mm - Plasterboard (fire safety)
- **20mm - Poplar ceiling finish**

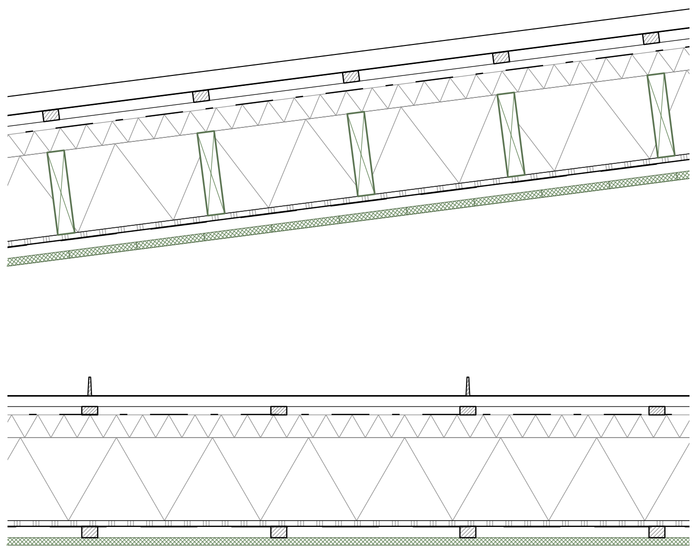
Total thickness package = 362mm



Roof package (from outside to inside):

- 1mm - Galvanized, brushed stainless steel plate
- 50mm - Framework 2 directions (28x42mm & 22x42mm)
- Waterproof, vapour-permeable membrane
- 60mm - Compression-resistant wood fibre insulation (thermal insulation & acoustics)
- **220mm - Poplar floor beams (45x220mm, h.t.h. 400mm)** + wood fibre insulation (thermal insulation & acoustics)
- 15mm - Plasterboard (structural & fire safety)
- Vapour-permeable membrane
- 30mm - Framework (30x44mm), technical cavity (adaptability)
- **20mm - Poplar ceiling finish**

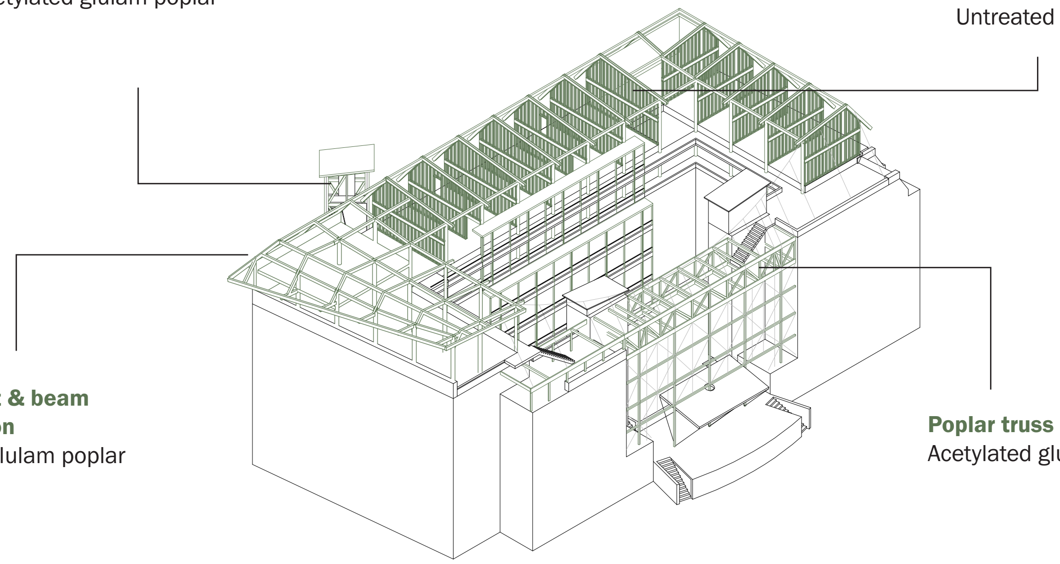
Total thickness package = 396mm



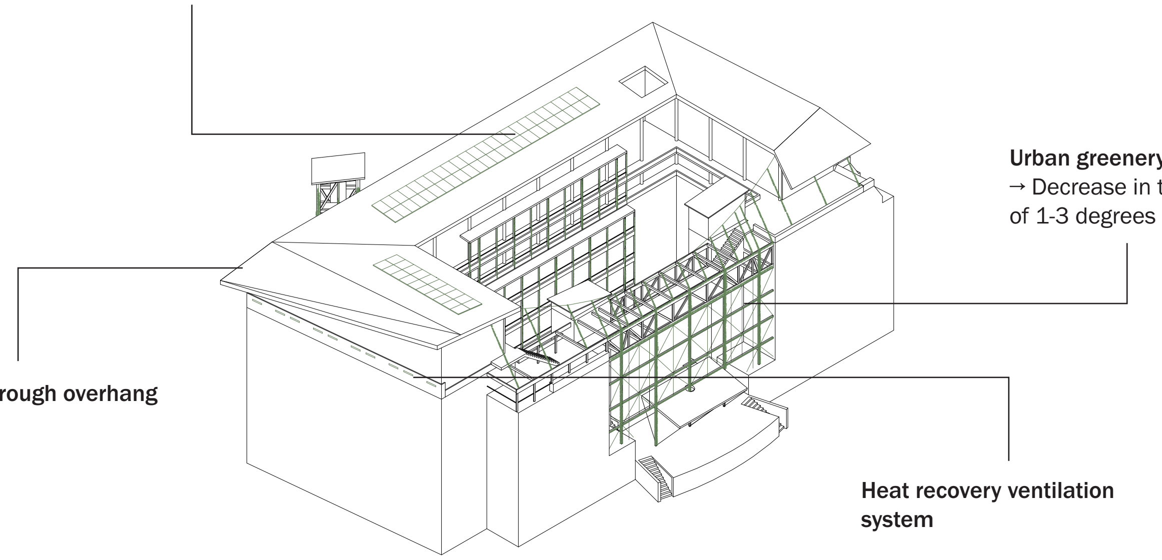
1:20

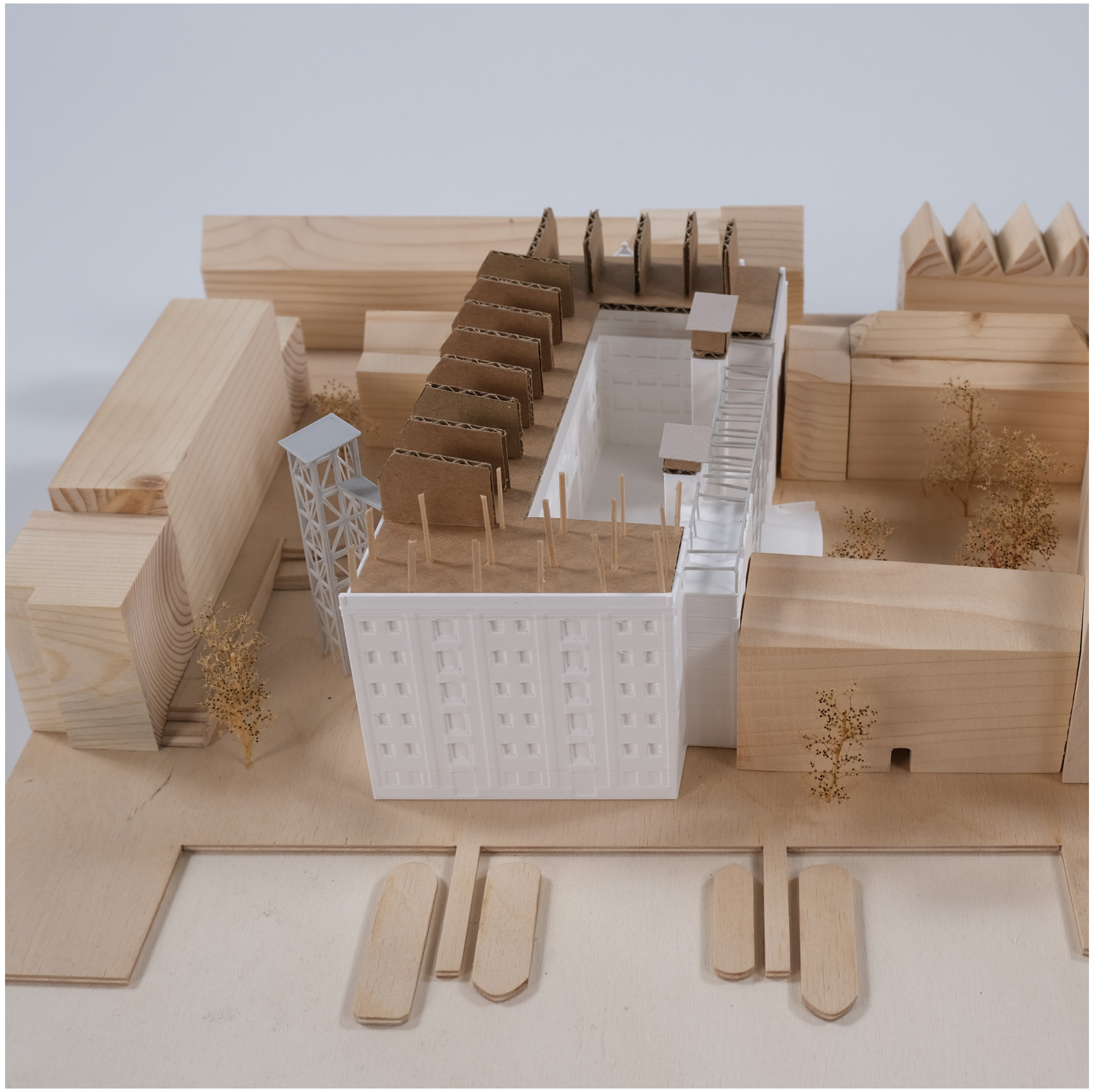
4.3. Design results

Structural systems

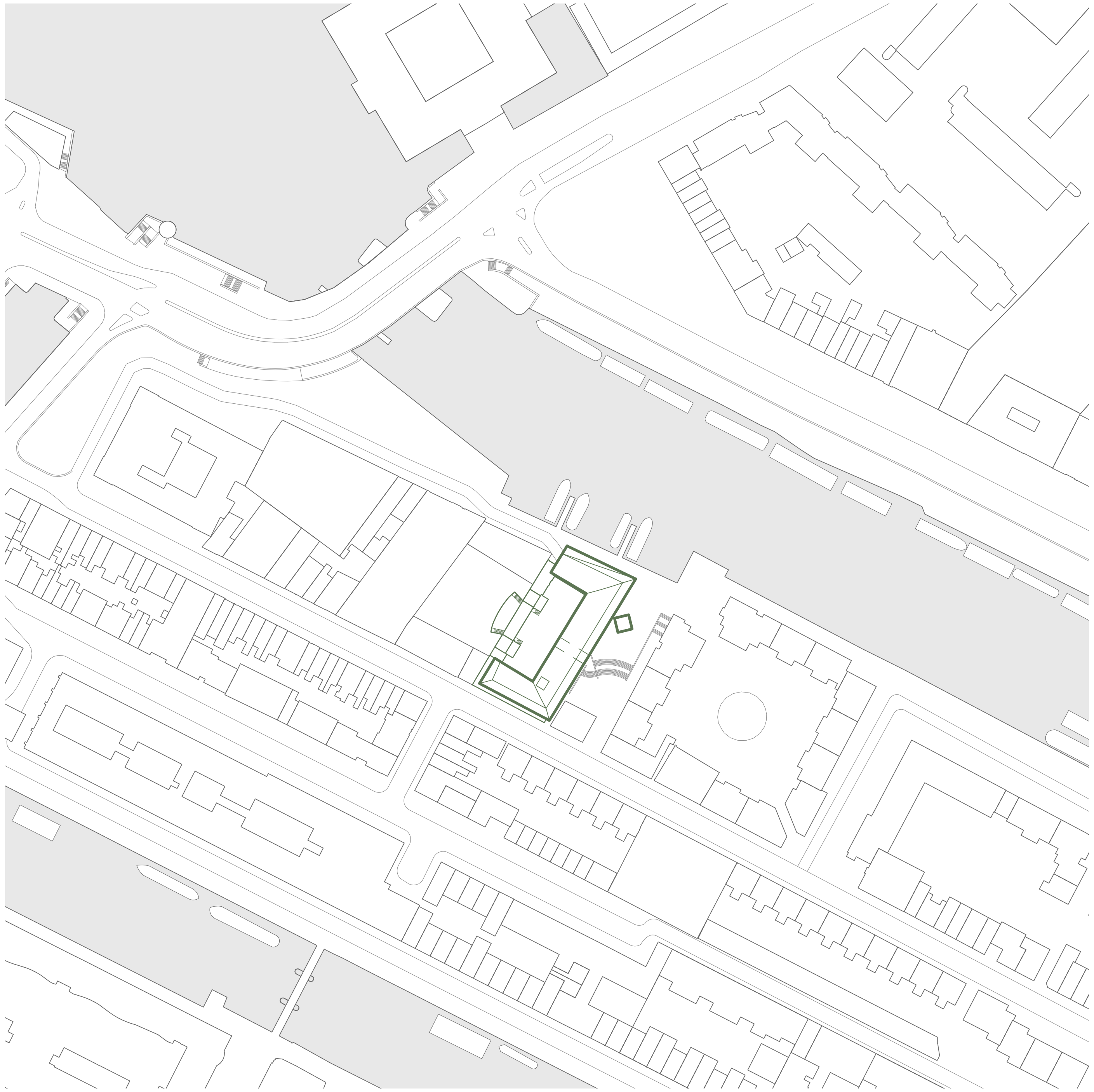


Climate principles building level





Structural poplar principles in 1:300 model

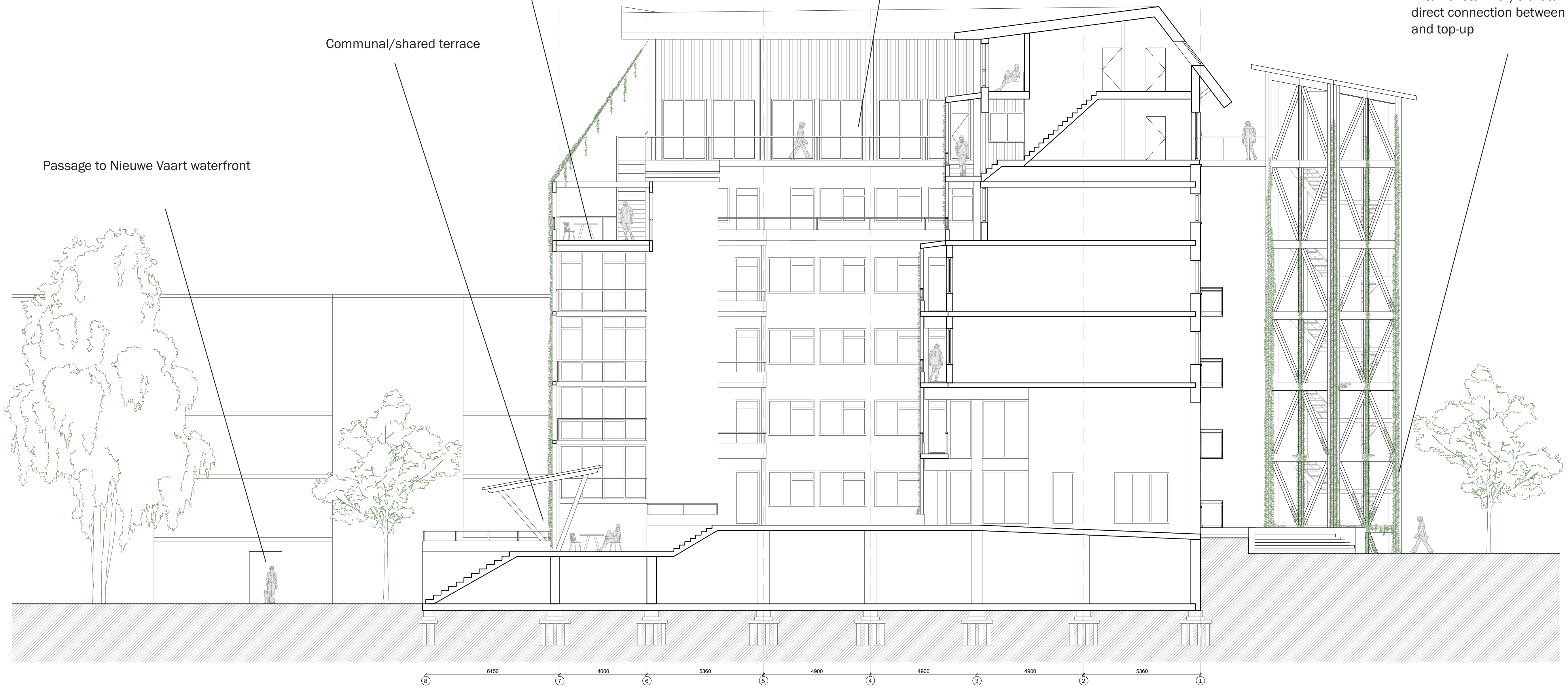


Site plan d'Peliekaan

d'Peliekaan in surroundings with an activated and green waterfront

With the design situated along the Nieuwe Vaart, a vision has been put together to turn the now completely paved waterfront into a green space. Car traffic here will be restricted to local residents only, and the waterfront will be designed to serve as a recreational area for local residents.

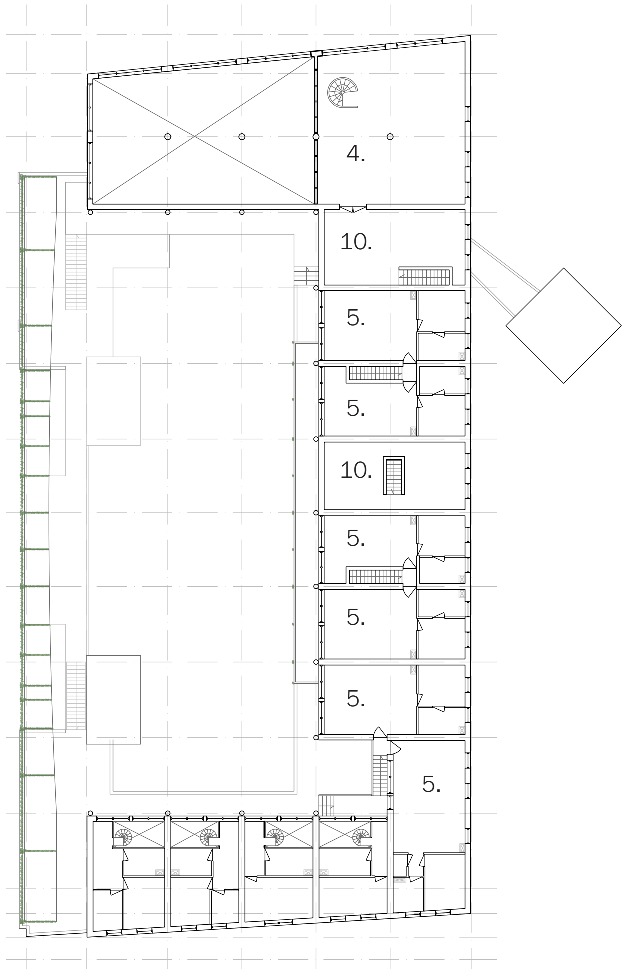
The design includes many spaces for neighbours to meet and get together. This has been done to encourage social interaction and community initiatives. A distinction has been made between public, communal and collective spaces. The shared terrace at the base of the green web is intended for all residents of the neighbouring courtyards. The passage through the adjacent building to the Nieuwe Vaart also ensures that passing pedestrians can make use of the green courtyard. Higher up in the top-up, more collective spaces have been created for the residents of d'Peliekaan. The coffee house, which is directly accessible from the adjacent Matrozenhof, is public during the day and collective at all other times.



Section A-A

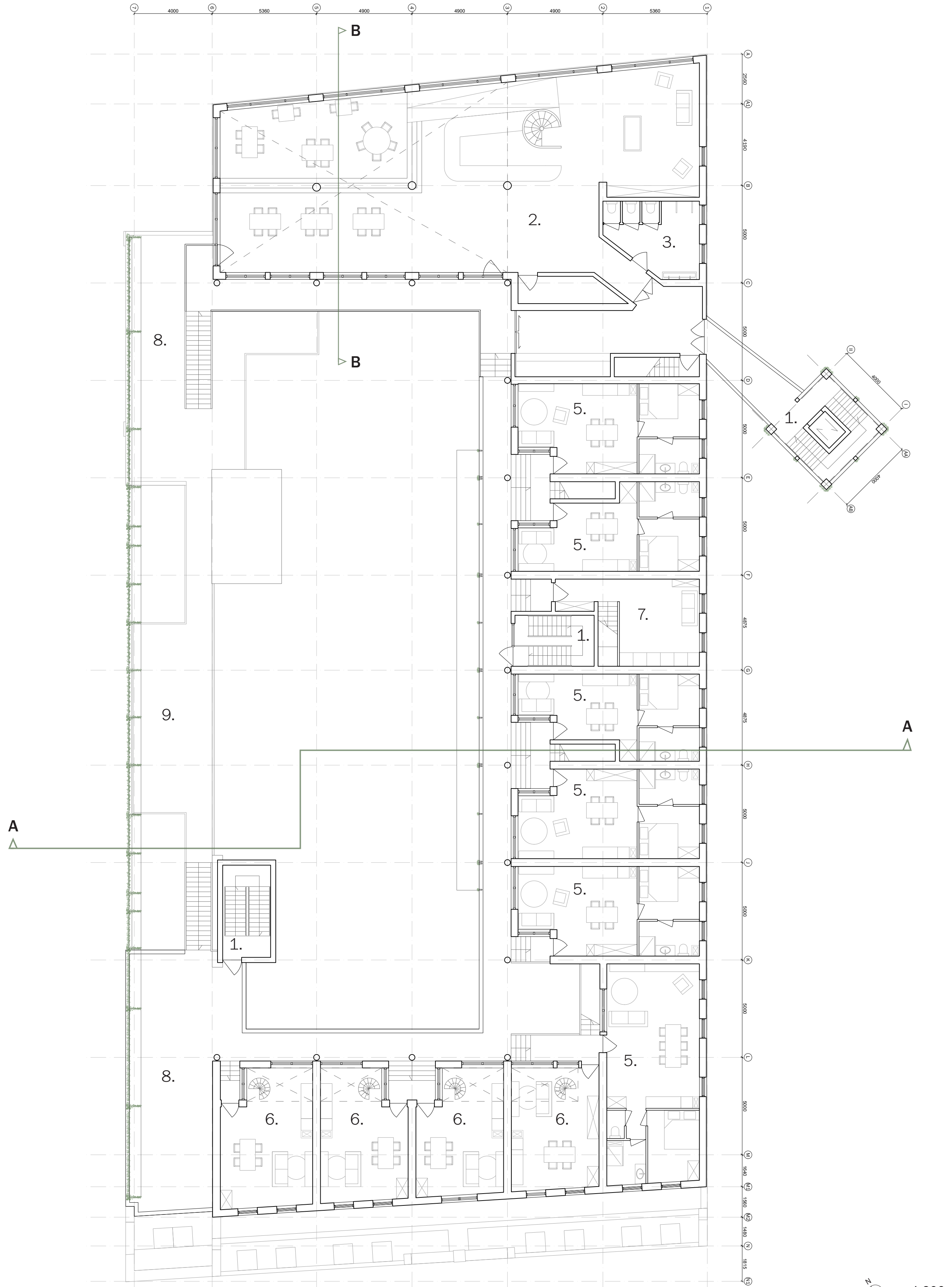
1:200

The coffee house/common room in the top-up is situated at the north façade of the building, offering views over the Nieuwe Vaart and the Maritime Museum. This public space is accessed from ground level through a tower that is rotated 45 degrees relative to d'Peliekaan. In this way, visitors are guided into the public space in a straight line from the top of the tower. The dwellings are connected to one another by a single gallery. Along this gallery, a shared laundry room has been provided and existing stairwells have been extended to ensure accessibility.



Floorplan top-up (7th floor) 1:500

1. Elevator and staircase
2. Coffee house (9-17h)/common room
3. Toilets
4. Multifunctional co-working space
5. Single storey starter dwellings (± 45m²)
6. Duplex starter dwellings (± 60m²)
7. Communal laundry room
8. Roof terraces
9. Bridge
10. Technical space/storage



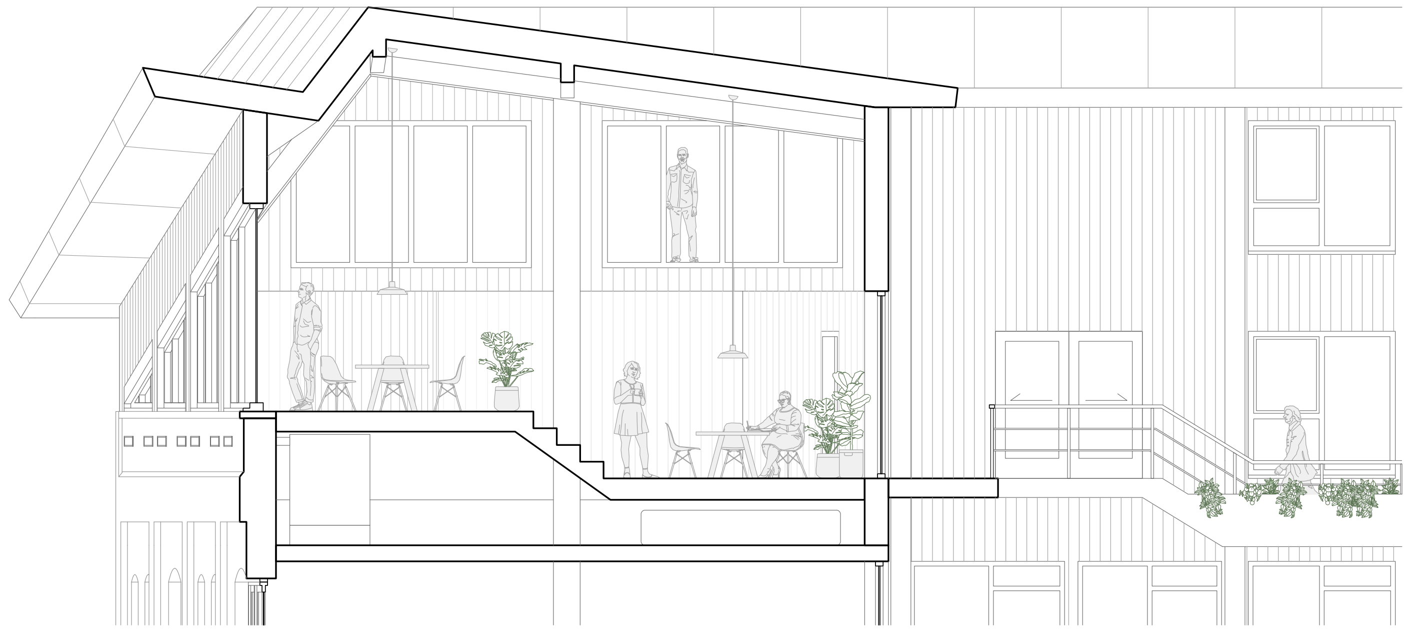
Floorplan top-up (6th floor) 1:200

Elevation Matrozenhof (E) 1:200

Elevation Hoogte Kadijk (S) 1:500

Elevation Nieuwe Vaart (N) 1:500

The façade design is based on the existing rhythm, with the window openings of the top-up aligned with the existing window openings of d'Peliekaan. Slots have been cut into the existing roof edge as part of the ventilation system. These slots are also aligned with the window openings and form the transition between the existing and new sections. The north façade is characterised by the roof edge and the large windows.



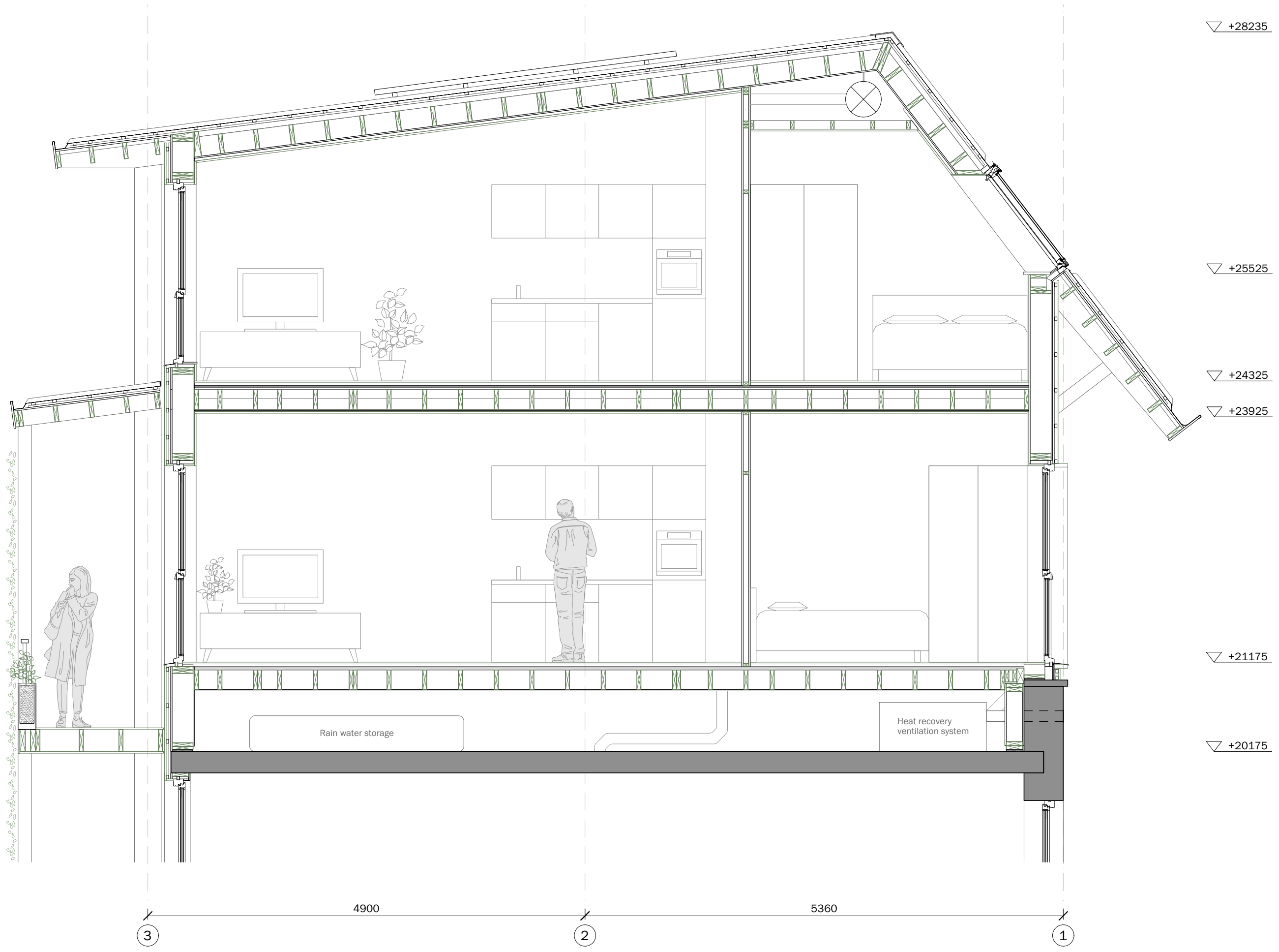
Section fragment coffee house/common room B-B 1:100

The coffee house has been designed to offer views both of the Nieuwe Vaart and of the courtyard. In this way, the coffee house serves as a transitional zone between the busy city and the tranquillity of the courtyard. To ensure that the public space and its visitors remain clearly separated from the residential units, the gallery leading to the dwellings has been lowered to create a distinct transition zone.

Impression view across Nieuwe Vaart on Maritime museum

Final 1:50 model of dwellings and gallery

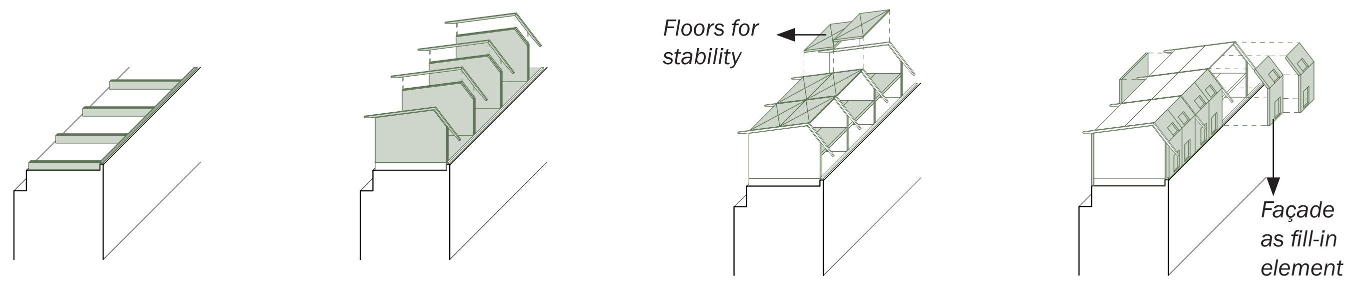
Impression of dwellings and gallery on top of the existing building, complete with a renovation of the courtyard façade



Section dwellings C-C

1:50

Prefabricated assembly



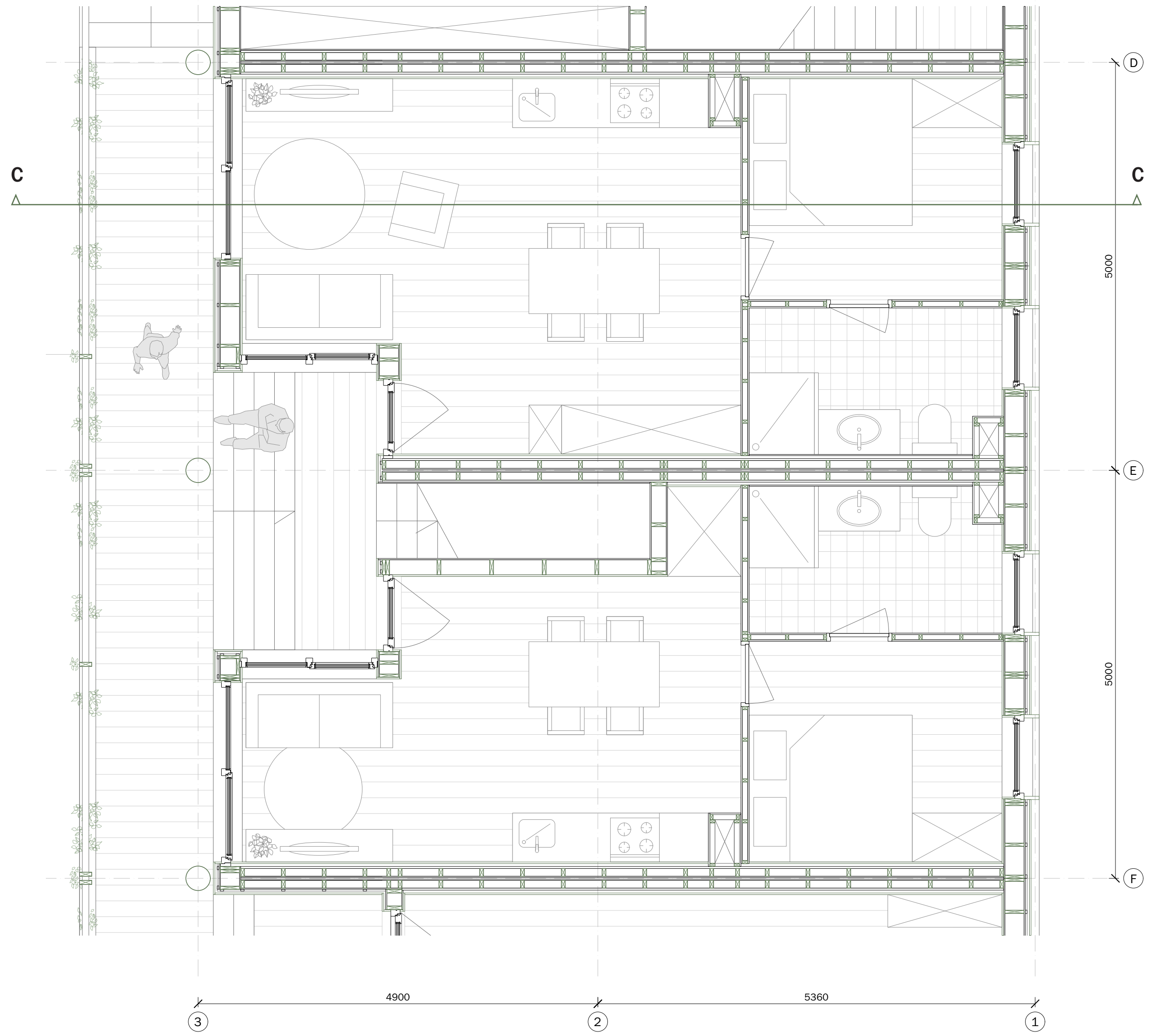
Step 1:
Install the **poplar** “foundation” frame on the existing roof

Step 2:
Mount the **poplar** dwelling separating walls and floors onto the foundation frame

Step 3:
Add the prefab **poplar** roof elements

Step 4:
Add the **poplar** façade elements

** Steps 2-4 are carried out simultaneously for each dwelling to ensure stability*



Floorplan dwellings

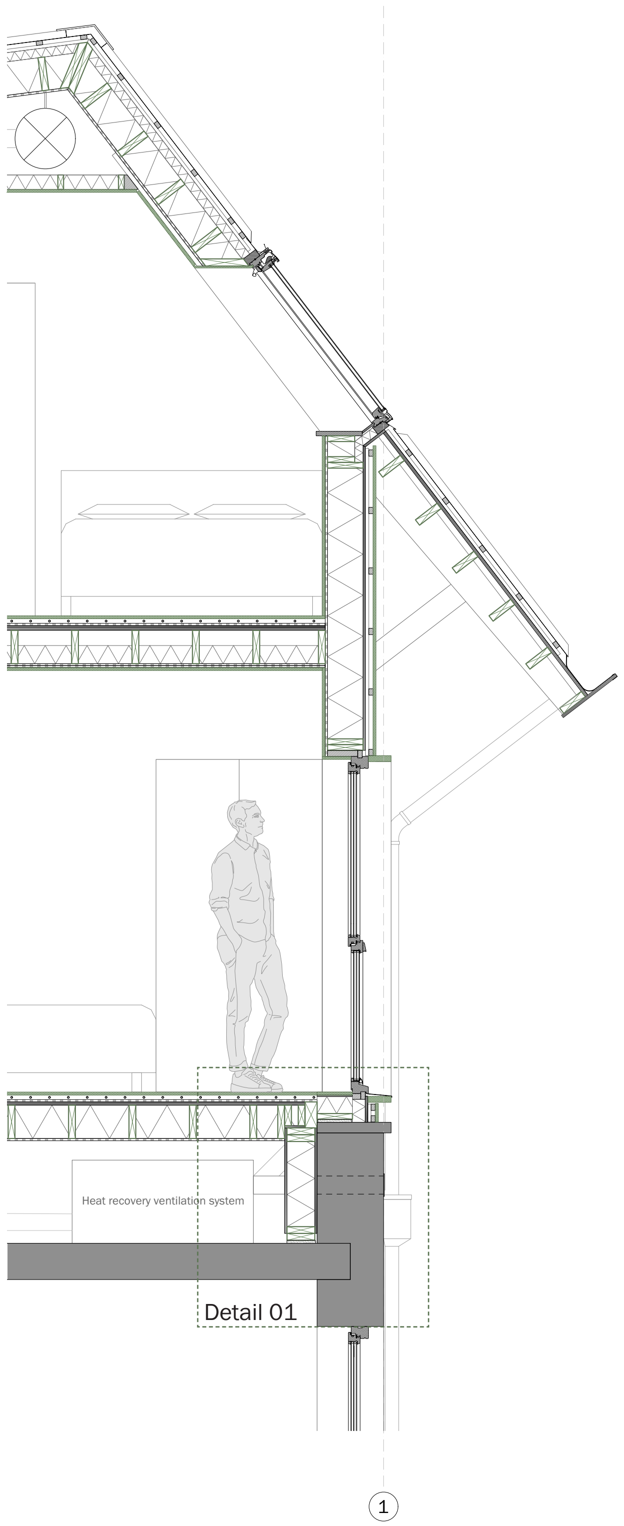
1:50

The starter dwellings have a compact layout, with the living area oriented towards the gallery and courtyard. To ensure vertical adaptability of the dwellings, a poplar balloon frame has been used, as discussed in paragraph 4.2. To enable horizontal adaptability, additional vertical studs have been added to the dwelling separating walls, allowing for future openings to be created.

In terms of assembly, the entire top-up is constructed from prefabricated elements that can be transported to the site via the Nieuwe Vaart. From there, the prefabricated elements can be lifted onto d’Peliekaan using a crane.

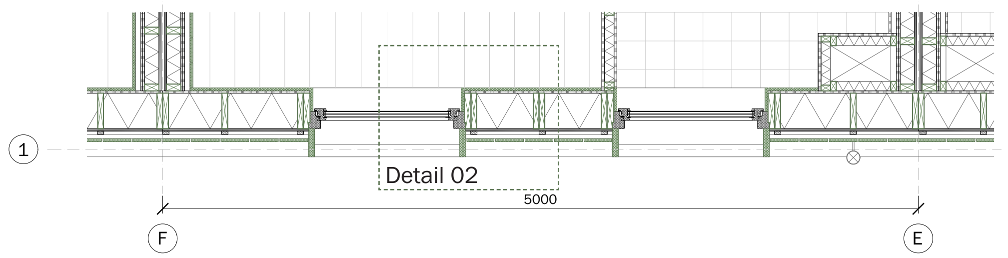
Thermally modified poplar

Thermally modified poplar timber after lying outside for three weeks

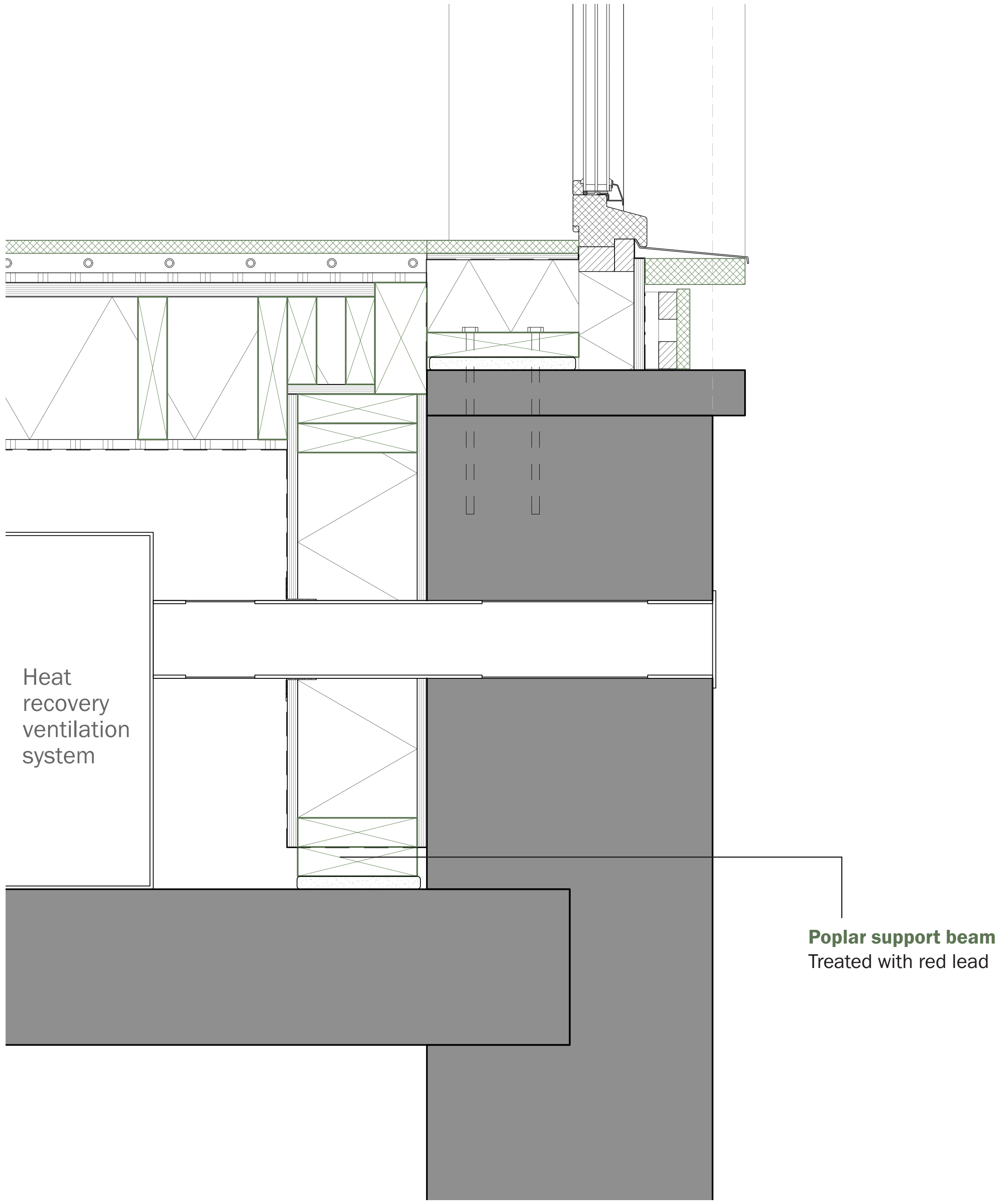


Façade fragment Matrozenhof elevation

1:20

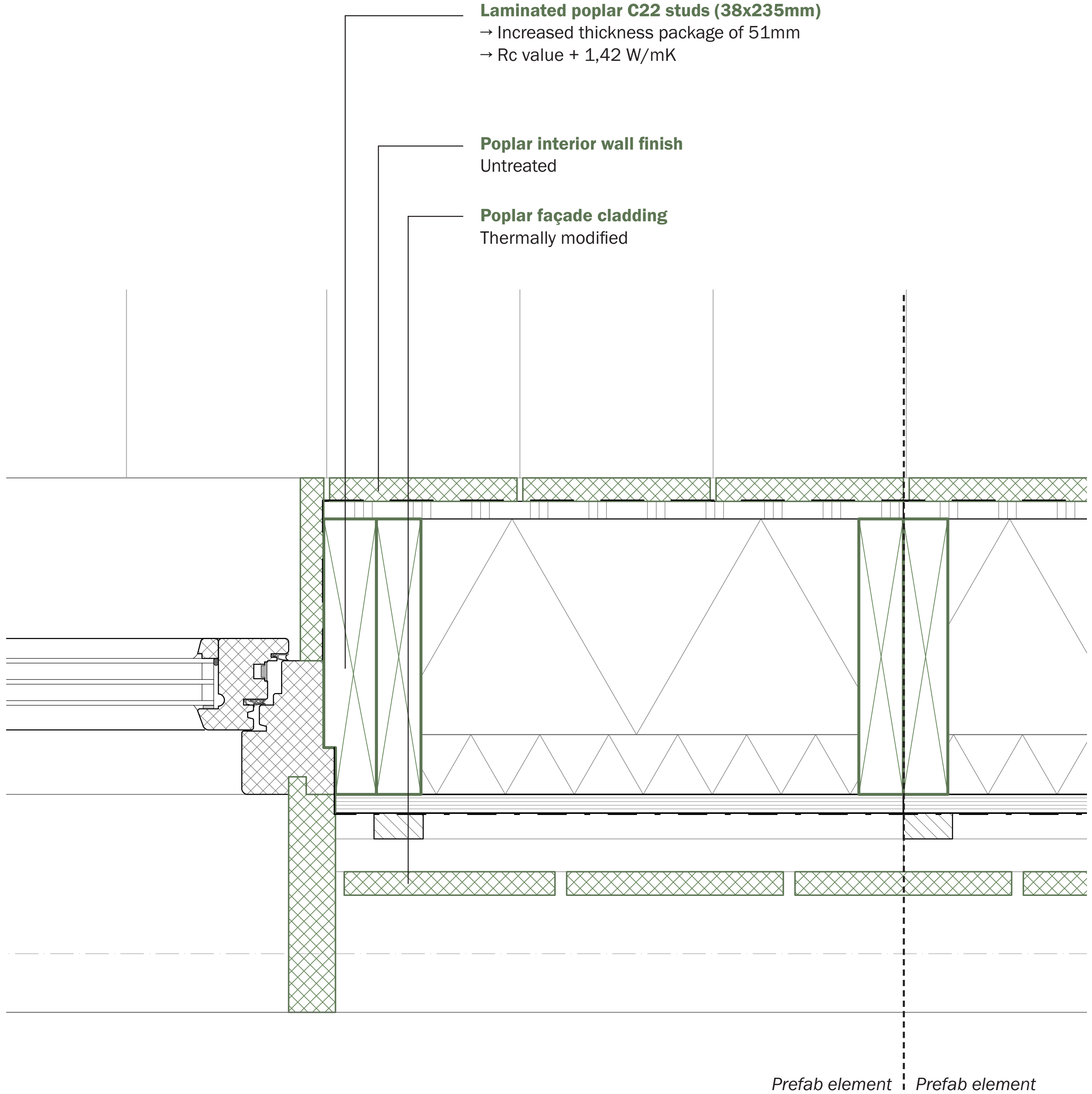


A characteristic element of the design, and of the façade, is the roof and the overhang it creates. This overhang will provide better protection for the thermally modified poplar timber in the façade, thereby extending its lifespan. The poplar timber itself will also weather differently due to this overhang, eventually taking on a silver-grey colour.



Detail 01: connection top-up to existing structure 1:5

Where the structure connects to the existing roof, a reinforcement element is installed alongside the existing roof edge. This element provides additional structural support for the roof extension and assists in the installation of the prefabricated components. Before these elements can be installed, however, an edge beam made of red lead-treated poplar timber is first aligned on the roof using shrinkage mortar. This shrinkage mortar absorbs any irregularities in the roof, after which a perfectly straight beam forms the basis for the structure.



Detail 02: horizontal connection windowframe 1:5

The use of poplar in the façade package increases the thickness of the entire package and thereby improves the façade's Rc value. It also eliminates the need for an additional layer of rigid insulation outside the studs of the timber frame structure. The window openings in the façade are further accentuated by a frame. This frame projects out to the same level as the roof edge of the existing warehouse. In this way, depth is added to the façade and a connection is created in the transition between the existing structure and the top-up.

Impression design top-up with activated and green waterfront

4.4. Architectural consequences

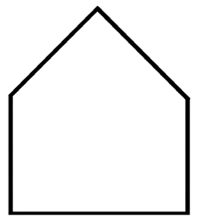
What are the consequences and constraints of working with poplar in architectural design?

The research conducted in part three shows that poplar can definitely be used in both the construction and the building envelope of a building. The effects of using poplar on the architecture were investigated in the design of the rooftop extension on d'Peliekaan, as discussed in the previous paragraphs (4.1–4.3). The design demonstrates how the roof design has become a defining feature in the architecture. The overhang created to protect the poplar cladding has a strong articulation which has ultimately also been used to strengthen the sightlines from the rooftop extension within the architecture.

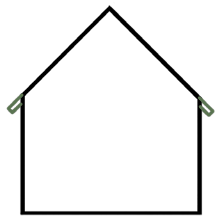
Some examples from practice where poplar was used as a cladding material (see figure 19, paragraph 3.1) however do not show any overhang. The difference between these examples from practice and the design of the top up on d'Peliekaan is that the cladding on d'Peliekaan is much more difficult to replace. Consequently, proper protection of the poplar cladding is essential to extend its lifespan. The importance of proper protection and drainage of the poplar cladding is also highlighted by Job Wittens, co-owner of Peppelhout and supplier of poplar timber in the Netherlands. Besides an overhang, a vertical application of the timber in the façade is recommended, for a horizontal application a clapboard finish is the only option (J. Wittens, personal communication, 26 February 2026).

The use of poplar therefore means that the anatomy of the façade, together with water drainage strategies, influences the overall architecture. Although this is important for all timber species, it is perhaps slightly more so for poplar. Other influences on the architecture are however very limited. Bart van Dijk, architect of the Peppelhout case study building, notes little difference compared to buildings or structures made of spruce or oak. Both in terms of architecture and detailing, he sees hardly any difference. For him, the difference lies in the package composition, which, due to the deviation from standard SLS dimensions, resulted in a lot of custom work (B. van Dijk, personal communication, 3 March 2026). In the design of the top-up, these issues were resolved by using standard dimensions in the package composition.

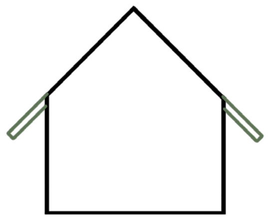
Finally, Job Wittens believes that poplar's main strength lies in the aesthetic. Poplar timber has a fresh appearance in interiors and, unlike spruce for example, it has the advantage of not yellowing. When used as cladding, poplar timber weathers nicely into an elegant silver-grey façade (J. Wittens, personal communication, 26 February 2026).



Standard typology roof brick façade



Standard typology roof timber façade



Standard typology roof poplar timber façade

1:100 model final design

1:100 model final design

Part V:
Conclusion & discussion

5.1 Conclusion 100
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5.1 Conclusion

One of the main conclusions of this project is that poplar, depending on the sub-variety, can indeed be used as a building material in constructions. The hybrid group of Populus canadensis, which are well represented in the Dutch poplar stock, for example, is perfectly suitable for structural use. However, as the timber structure of poplar is very irregular, gluing the timber is recommended to achieve a higher strength class. Although this has not yet been confirmed, it is expected that a strength class of C22 will be achieved for glulam poplar, which has also been adopted in the design of the rooftop extension on d'Peliekaan.

As the strength class of poplar differs from that of traditional C24 spruce constructions, it must be taken into account that the dimensions of structural elements will be larger when using poplar. However, if one considers only the strength required, the weight of a poplar timber frame construction remains 6.6% lighter than a spruce construction, whilst the volume of timber increases by 5%. Nevertheless, for poplar to be commercially viable in timber frame constructions, the dimensions must be aligned with standard SLS sizes. When this is done, the poplar construction becomes over-dimensioned and is 13.5% heavier than a spruce construction, whilst the volume of timber increases by 28%. Using poplar as a structural element (in timber frame construction) therefore does not directly result in a lighter structure, though more CO_2 is stored within the structure.

In addition to its structural use within constructions and the waterproof barrier, poplar can also be easily modified for use outside the waterproof barrier. For example, acetylating poplar timber improves not only its durability but also its mechanical strength. Thermal modification is sufficient for the use of poplar timber in façade cladding. However, to extend the lifespan of poplar outside the waterproof barrier, it is recommended, even more so than with other timber species, to create a good façade design that protects the timber. Therefore, a roof overhang is strongly recommended for a poplar façade, which has certain consequences for the architectural expression. As a result, the articulation of the roof design and the overhang became the characteristic element in the design of the top-up on d'Peliekaan.

To answer the main question of this project, 'Does poplar timber have potential in the construction sector of the 21^{st} century?', it can be said that poplar certainly has potential as a building material in the construction sector of the 21^{st} century. There are, of course, still obstacles to be overcome. For instance, there is the cost of poplar compared to the cheaper Scandinavian spruce. But there is also the challenge of transforming the results of current research about using poplar in mass timber into poplar-based products available on the market. Nevertheless, the design demonstrates how a high-quality design can be created using poplar, without having to compromise on user comfort. Furthermore, the poplar balloon frame in the design ensures that the dwellings are easy to adapt. A feature that is often set as a goal for the 21^{st} century construction sector but is not always that easy to put into practice.

Ultimately, the design demonstrates the potential for using poplar in timber-frame construction, post-and-beam construction, and for both external cladding and interior finishes for floors, walls and ceilings. The use of poplar in, for example, framework is theoretically possible but perhaps not desirable. While poplar is indeed a fast-growing tree, monoculture poplar forests are not the answer to the rising demand for timber. Furthermore, the stock of poplars in Dutch forests has declined significantly in recent years because of its label as a weed tree. The transition to using poplar timber in the construction sector is therefore a long-term process in which poplar could take an increasingly larger share and thus claim its own place in the construction sector.

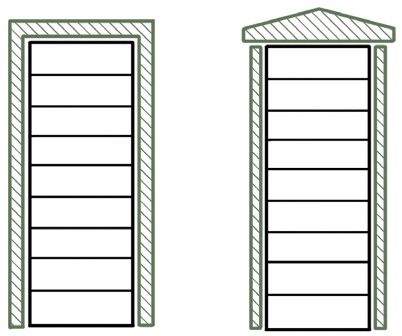
5.2 Discussion

The rooftop extension on d'Peliekaan demonstrates the potential that lies in densifying the city by adding storeys to the existing housing stock. Even in a historic context, next to the UNESCO-protected city centre of Amsterdam and on a former warehouse from 1902, an extension can bring added value. While in practice the strategy of recessing the extension onto the roof is often used, making it invisible from ground level, the design demonstrates how, by showing the extension, both the existing building and the extension as a whole are strengthened. The rooftop extension, together with the existing building, thereby bring their own architectural language to the city.

While timber, due to its light weight, is the logical choice for building a rooftop extension, the decision to use local poplar timber is less obvious. Nevertheless, this project demonstrates that there is no reason not to use poplar in construction. When used outside the waterproof barrier, it is important to treat and protect the poplar timber. It is therefore recommended to take this into account from the very start of the design process. In this way, the strategies intended to protect the timber can become an integral part of the architecture.

Research by Obers (2019) shows that acetylated poplar timber is perfectly suitable as a structural material for a pedestrian and cycle bridge. This research was therefore used as the basis for the design of the bridge in the design of the top-up on d'Peliekaan. In the design, however, the bridge is positioned between the building and no account has been taken of the additional forces that this imposes on the bridge. Furthermore, the bridge is suspended above a semi-public space, which places additional demands on the safety of the structure. To further prevent decay of the timber, it is therefore advisable to place a sacrificial layer over the structural acetylated truss beams. This layer will protect the timber without the need to install an entire roof over the structure. However, the choice of poplar for this location and purpose may be open to debate. In practice, tropical azobé hardwood is likely to be considered the safer option.

It is clear that poplar timber can be used in higher-quality applications within the construction industry. However, using a timber specie such as poplar in construction does require more attention, as there are still very few completed reference projects. Further research and projects such as Peppelhout's poplar timber frame construction are therefore needed to convince the construction sector of its potential.



Sacrificial layer to protect structural glulam beams

5.3 Reflection

The process of this graduation project started with a thorough and extensive research into the possibilities of using poplar timber in the construction sector. Using the knowledge and initial conclusions from this research, the design process started. This method allowed important decisions to be made early on in the process, including choices about the construction systems used and the importance of an overhang. As a result, the design started with a slight head start, which had a positive impact on the rest of the design process. The method used, involving thorough preliminary research, was therefore well suited to this project and is recommended for similar projects.

During the design of the rooftop extension, the main design tools were the section drawings (1:200, 1:100, 1:50, 1:20) and the 1:50 scale model. This model, used as a working model, provided a lot of information about the relationship between the existing and the new structures, while also being useful for testing the spatial layout of the dwellings. In addition, it served as the primary design tool for designing the overhang and the relationship this creates between the top-up and the street. Visualising ideas in the 1:50 scale model generated many design iterations, which influenced and strengthened final design choices.

Given the scale of the project and the various factors influencing it, ranging from the scale of the individual user to that of the city, certain focus points were established in the design. This focus was primarily on the starter dwellings, the development of the poplar timber frame construction, and the adaptability of the poplar balloon frame. These aspects were, in fact, the most important for the research. Consequently, other interventions were developed to a different scale and level of detail. Nevertheless, the overall design delivered is clear in the choices made and has taken into account the various scales and stakeholders it affects. Adding two storeys, or approximately 25%, proved to be a suitable strategy for the building, the context, and poplar as a structural building material.

Finally, as part of the preliminary research and the project, the intention was to test 1800mm long laminated poplar beams in order to obtain an initial indication of the strength class that can be assigned to laminated poplar. Although the beams were available on time, it proved difficult from an organisational point of view to test the 1800mm long beams. Consequently, shorter elements were tested at the very end of the project, of which the results have been included in part three of the project. During the design process, it was therefore not possible to make use of the results of these tests, leading to a (realistic) assumption being made regarding the strength class. Although the tests were not representative and the results arrived too late to be incorporated into the design, they still add value to the project showcasing the structural potential of poplar.

'Second skin' structure gallery

Relation top-up to existing and street

Design variants 1:50 model

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Figures

All drawings or photographs without a cited source (in parts IV and V) are the original work of the author.

Figure 1:
U. Sass-Klaassen, lecture on Connecting Forest & the Build Environment, Januari 6, 2026

Figure 2:
Own image

Figure 3:
Must. (2024). *Kansenkaart Optoppen Bebouwing Totaal* [Map]. https://www.must.nl/projecten/op-zoek-naar-ruimte-quickscan-optoppen-amsterdamse-binnenstad/

Figure 4:
Stadsarchief Amsterdam / Ino Roël

Figure 5-13:
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Figure 14-15:
Personal communication with Job Wittens

Figure 16:
Fraanje, P. (1999). Constructie van gelamineerd populierenhout. From *Natuurlijk bouwen met hout* (1st ed., p. 330), Uitgeverij Jan van Arkel.

Figure 17:
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Figure 18:
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Figure 19:
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Figure 20:
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Figure 21:
Xu, B., Wang, B., Yu, K., & Bouchaïr, A. (2021). *Journal of Material Science* 56(25). p.14116

Figure 22:
Own work

Figure 23-26:
Personal communication with Job Witttens

Figure 27-30:
Own images

Figure 31:
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Figure 34-40:
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Figure 41:
Haagse Portiekwoning. (n.d.). *Laakkwartier* [Photograph]. https://ikgidsudoordenhaag.nl/nl/haagse-portiekwoning/

Figure 42:
Herzog de Meuron. (n.d.). *149 Rue des Suisses Apartment Buildings* [Photograph]. https://www.herzogdemeuron.com/projects/149-rue-des-suisses-apartment-building/

Figure 43:
Carl Stahl Architektur. (n.d.). *Louisen Center, Bad Homburg, Germany* [Photograph]. https://csarc.com.tr/tr/referanslar/louisen-center-bad-hamburg

Figure 44:
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Figure 45:
Petschek, P., & Gass, S. (2011). *Constructing shadows : pergolas, pavilions, tents, cables, and plants* (p.75). Birkhäuser.

Figure 46:
Petschek, P., & Gass, S. (2011). *Constructing shadows : pergolas, pavilions, tents, cables, and plants* (p.80). Birkhäuser.

Figure 47:
Petschek, P., & Gass, S. (2011). *Constructing shadows : pergolas, pavilions, tents, cables, and plants* (p.92). Birkhäuser.

Figure 48:
Petschek, P., & Gass, S. (2011). *Constructing shadows : pergolas, pavilions, tents, cables, and plants* (p.112). Birkhäuser.

Figure 49:
Petschek, P., & Gass, S. (2011). *Constructing shadows : pergolas, pavilions, tents, cables, and plants* (p.102). Birkhäuser.

Figure 50:
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Figure 51:
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Figure 52:
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Appendix

Data management checklist

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.		✓

Test results of glulam poplar beams *(paragraph 3.3)*

Test piece 1 (L=200mm)

Deflection (mm)	Load (kN)
0,362	0,1
0,71	0,2
0,772	0,8
1,019	1,4
1,104	2
1,261	2,5
1,504	3,3
1,512	2,8
1,926	3,6
2,204	4
2,204	4,7
2,419	5,4
2,813	5,9
2,99	6,5
3,59	6,8
3,59	7,6
3,723	8,4
4,063	8,4
4,063	9,1
4,168	8,6
4,368	9,4
4,543	10,2
4,977	10,2
4,977	11,1
5,102	11,8
5,357	12,2
5,365	11,6
5,471	12,5
5,933	12,5
5,933	13,4
6,184	13,4
6,184	14,2
6,335	14,8
6,531	14,3
6,533	13,8
6,844	14
6,844	14,8
6,975	15,8
7,344	15,8
7,344	16,8
7,431	17,4
7,655	16,7
7,658	16,2
7,879	17,1
8,153	17,5
8,153	18,4
8,23	19,2
8,514	19,6
8,689	19
8,694	18,5
8,823	19,1
9,034	20,1
9,264	21,1
9,426	21,9
9,729	22,2
9,74	21,7
9,743	21,2
9,745	20,7
9,881	21,4
10,096	22,3
10,173	22,8
10,173	23,3
10,406	23,8
10,492	24,4
10,779	24,7
10,785	24,2
10,791	22,6
10,795	23,6
10,798	23,1
10,862	23,3
11,112	23,8
11,112	24,3
11,205	24,8
11,205	25,3
11,424	25,8
11,608	26,4
11,804	26,9
11,868	26,3
11,874	25,7
11,888	25,2
11,89	24,7
12,138	25,6
12,298	26,5
12,298	27,1
12,475	27,7
12,659	28,6
12,807	29,2
12,947	28,5
12,959	27,9
12,966	27,3
13,262	27,5
13,262	28,4
13,326	28,9
13,326	29,5
13,469	30
13,469	30,5
13,6	31,3
13,674	31,8
13,674	31,2
13,674	30,7
13,674	30,2
13,674	29,7
13,674	30,4
13,674	30,9
13,674	31,4
13,674	32
13,674	31,5
13,674	32

Test piece 1 (L=398mm)

Deflection (mm)	Kracht (kN)
0,368	0
0,823	0,1
1,095	0,2
1,267	0,8
1,589	1,1
1,929	1,6
2,122	2,2
2,638	2,4
2,728	3,1
2,745	3,6
3,229	4
3,427	4,7
3,966	5
3,966	5,6
4,008	6,1
4,559	6,4
4,559	7
4,909	7
4,909	7,6
5,159	7,6
5,159	8,1
5,462	8,3
5,958	8,8
5,958	9,4
6,097	10
6,339	10,5
6,654	10,5
7,012	10,9
7,012	11,4
7,303	11,6
7,425	12,2
7,789	12,3
8,236	12,8
8,348	13,6
8,652	13,6
9,285	14,1
9,285	14,7
9,371	15,2
10,005	15,1
10,141	15,9
10,542	16,2
10,542	16,8
10,617	16,2
11,033	16,5
11,033	17
11,264	17,5
11,553	17,5
11,553	18
11,762	17,5
11,938	21,7
11,938	20,6
11,938	19,5
11,993	18,4
11,993	17,4
11,997	16,4
11,997	15,6
12,035	15,1
12,069	14,6
12,079	14,1
12,302	17,8
12,302	18,3
12,63	18,3
12,63	18,9
12,879	19,4
12,92	18,8
12,928	23,6
13,01	22,7
13,01	21,7
13,308	18,6
13,442	23,2
13,498	21,7
13,499	19,8
13,499	20,5
13,499	21,2
13,499	21,8
13,5	19,3
13,5	19,9
13,5	20,4
13,5	20,4
13,5	21
13,5	21,2
13,5	21,8
13,5	22,3
13,5	22,3
13,5	22,8
13,5	22,2
13,5	23
13,5	23,5
13,5	23
13,5	22,5
13,5	23,1
13,5	23,8
13,5	24,3
13,5	23,7
13,5	23,2
13,5	23,8
13,5	24,3
13,5	23,7

Test piece 2 (L=398mm)

Deflection (mm)	Load (kN)
0,319	0,2
0,591	0,3
0,861	0,6
1,166	1
1,171	1,6
1,583	1,8
1,584	2,4
2,4	2,7
2,4	3,3
2,772	3,3
2,772	3,8
2,817	4,3
3,061	5
3,609	5
3,609	5,6
4,117	5,6
4,117	6,1
4,748	6,5
4,748	7
5,187	7
5,187	7,6
5,383	8,1
5,996	8,3
6,267	8,8
6,36	9,5
6,769	9,4
6,769	9,9
7,082	9,9
7,082	10,4
7,362	10,4
7,559	10,9
7,581	10,3
7,86	10,5
8,175	10,9
8,175	11,4
8,444	11,4
8,644	11,9
8,666	11,3
8,949	11,4
9,164	11,9
9,669	12,1
9,712	12,5
9,712	11,8
9,737	11,1
9,806	12,8
9,879	12,3
10,29	11,2
10,338	12,3
10,544	11,6
10,761	12,3
10,825	12
10,852	11,8
11,06	11,5
11,072	11
11,262	12
11,712	11,4
11,837	11,9
12,116	12,1
12,159	11,6
12,715	11,9
12,871	12,5
13,174	12,5
13,237	11,6
13,237	11,1
13,286	12
13,298	11,5
13,307	11
13,386	11,6
13,386	12,2

Test piece 3 (L=398mm)

Deflection (mm)	Load (kN)
-0,018	0
0,43	0,3
0,796	0,6
0,884	1,2
1,167	1,6
1,269	2,2
1,875	2,6
1,875	3,1
2,164	3,6
2,526	4,2
2,949	4,7
3,26	5
3,26	5,5
3,49	6
3,888	6
4,081	6,7
4,525	7
4,525	7,6
4,674	8,1
5,038	8,2
5,038	8,7
5,434	8,7
5,434	9,4
5,761	9,4
5,813	9,9
6,354	10
6,354	10,5
6,621	10,5
6,621	11,1
6,965	11,6
7,389	11,6
7,855	12,1
7,855	12,7
7,95	13,2
8,165	12,6
8,342	13,2
8,796	13,2
8,796	13,8
9,229	14,3
9,268	13,8
9,559	14
9,559	14,5
9,868	14,5
9,868	15
10,113	15,6
10,338	15,1
10,662	15,3
11,101	15,8
11,101	16,4
11,36	15,9
11,447	12,4
11,447	10,9
11,447	9,4
11,447	7,9
11,447	6,4
11,449	5,4
11,64	16,3
11,64	16,8
11,796	15,7
11,796	14,1
11,796	12,4
12,129	16,8
12,129	17,3
12,381	17,6
12,383	17
12,588	18,3
12,706	16,9
12,706	17,4
12,79	17,3
12,79	15,7
13,071	17,4
13,071	18
13,27	18,6
13,324	18
13,324	18,5
13,324	18
13,324	18,6
13,324	19,2
13,324	18,7
13,324	18,2
13,324	18,8
13,324	19,3