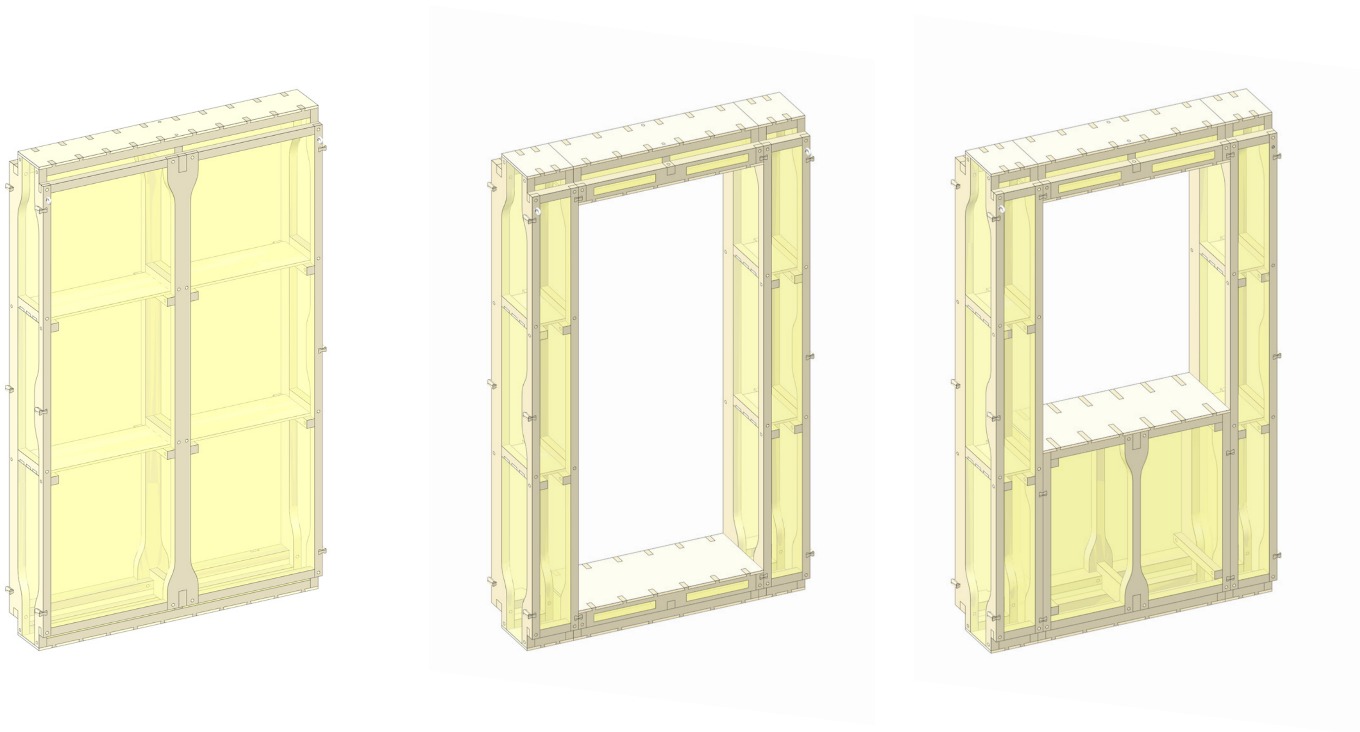

Reconsidering Façade Culture
Graduation Project

A study into a modular facade system for ecological architectural tectonics

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2024-2025

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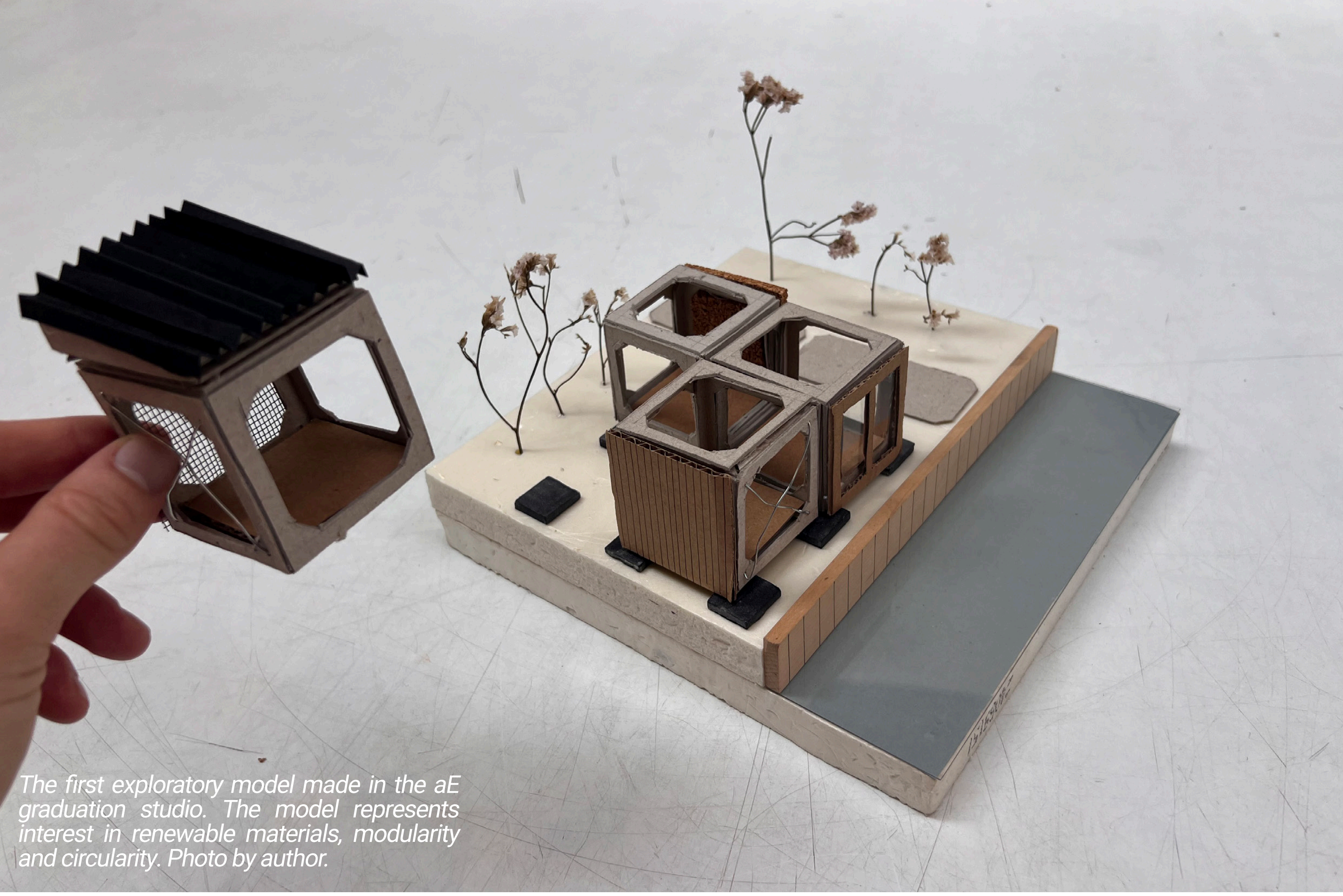

The first exploratory model made in the aE graduation studio. The model represents interest in renewable materials, modularity and circularity. Photo by author.

Preface: argumentations for choice of studio

Working on the interface of technology and aesthetics, of form versus function, that is what inspires me. To use technology as a tool for current societal problems. The Architectural Engineering Graduation Studio provides the space to explore subjects linked to these themes. Additionally, the studio offers the freedom to explore one's own role in the architectural field, giving opportunity to the potential of personal interests and knowledge.

During the Bachelor I completed an internship as a Minor at the architectural office of cepezed, where I developed a fascination and gained experience in circular and sustainable building solutions. In Msc 2 I followed the 'Circular Product Design' (AR0145) and 'Eco-friendly Material Choices' (AR0203) electives, which has built upon this fascination and methods like experimentation and prototyping. This research plan is therefore the result of a combination of my personal interests: circular economy principles and biobased building technology as a solution for sustainable building design. This year I have further deepend my skills on these topics, to serve as specific knowledge for the subsequent design.

Glossary of key words

Vapor open construction (vapor regulating, vapor diffusion):

A way of building where the building's skin is open for water vapor to move through freely. It is a more self regulating method for the indoor climate, which often is experienced as more healthy and comfortable. Additionally, it is a more passive method of climate control and is therefore more sustainable. Biological materials often have this property as default, like wood or biological insulation materials. The facade is still water and wind sealed. *Joostdevree.nl. (n.d.). Dampopen bouwen. Retrieved October 23, 2024, from https://www.joostdevree.nl/shtmls/dampopen_bouwen.shtml*

Bio-based design:

A movement in design where biological materials (infinite) are used as much as possible, instead of technical materials (finite). Goal is to design more sustainable by reducing the environmental impact in material consumption. Moreover, is biological material storing CO_2 during growth. *Wikipedia contributors. (2024, September 17). Bio-based material. Wikipedia. https://en.wikipedia.org/wiki/Bio-based_material*

Ecological Architectural Tectonics (EAT):

A form of design by using direct and indirect forms of nature, as well as space and place conditions, to connect people with it's natural environment. Stephen Kellert launched a framework with principles that belong to biophilic design. (Bio-philic, bio = the living, philic = to love) *Wikipedia contributors. (2024a, September 10). Biophilic design. Wikipedia. https://en.wikipedia.org/wiki/Biophilic_design*

Plug and Play (PnP):

Originated from computer science, it concerns a certain component that is compatible with a larger system to such a degree that it only needs a (quick) installment. The term is accompanied by other principles in the field of engineering like prefabrication, and modular design. *Wikipedia-bijdragers. (2022, June 14). Plug-and-play. Wikipedia. https://nl.wikipedia.org/wiki/Plug-and-play*

Product-as-a-Service (PaaS):

An economical construct where the producer/supplier of a product is and remains responsible for the whole product's lifecycle. The producer sells a result, but not it's material form. It allows material products to behave more as temporary 'services' to decrease it's environmental impact. This includes repairs and substitution during operation and recylcing and recoverig at the end-of-life. Usually it involves rental based compensations. This model is the opposite of the more common Service-as-a-Product (SaaP). *Product-as-a-Service (PAAS). (n.d.). https://www.abnamro.nl/nl/zakelijk/duurzaam-ondernemen/product-as-a-service.html*

Open Building:

Coined by John Habraken in 1961, is an approach to building design where (social or technical) change of use is anticipated. by designing a building that is flexible to change, it can still comply with future demands, thus preventing demolition. It outlines a more definitive *support structure* (or base building), with more temporary *infill components* (or fitout). It is a theory that relates to principles like the modular design and design for disassembly (DfD). Moreover, it is a relevant model for participation in building projects by the end users and other parties with interest. *Wikipedia contributors. (2021, May 1). Open building. Wikipedia. https://en.wikipedia.org/wiki/Open_building*

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02| The research: towards sustainable facade culture

1.1 | Problem statement

Humans are increasingly living out of balance with its environment. The relationship humans have with the natural world is unsustainable, nevertheless we are dependent on it for restoring this relationship. The notion of the nature – culture divide poses therefore a relevant theory in providing a possible explanation for this imbalance, where culture can be described as everything that humans have created and juxtaposing that with everything that is natural (i.e. not by humans created).

Projecting this onto the built environment, the construction industry is one of the most polluting and material intensive sectors of all. Not only is it damaging essential ecological systems, it is also depleting the world of finite resources like iron ores and limestone. In the Netherlands, the built environment is a large emitter of CO_2 standing at 38% of the total emissions (DGBC, 2021). Simultaneously, the share (by weight) of biobased materials in the built environment is still very low, standing at 2% for wood and 0,1% for other biobased materials (NIBE Research, 2019). Yet, sustainable solutions to these pressing problems is sometimes lacking and innovation relative to other sectors lags behind (Boton et al., 2020). In addition to the earth, are current practices also damaging the wellbeing of people living within these buildings, where 75% of environment related symptoms reported to the GGD in 2019 and 2022 concern the indoor climate (CLO, 2022). Especially with renovated buildings, energy consumption and related emissions by services takes up a large part of the total as shown by the diagram on below. Often, they consume even more than designed for (Ministerie van economische zaken, landbouw en innovatie, 2011).

More specifically, one of the areas where this becomes physically most manifest is with façade construction. Using linear economy principles, air- and water tight construction methods, and creating uniform indoor climates with huge energy demands, the current façade culture might be conceiling us from this natural world. Moreover, a research on housing in the Netherlands showed that the façade (as defined by Brand, 1997) is the second largest CO_2 emitter within a whole building, measured with the MPG (DGBC, 2021). The MPG (Milieu Prestatie Gebouw) is a nationally recognized method of measuring a building's environmental impact (RVO, 2017). Additionally, façade products are (on average) within the top five largest contributors to environmental impact of a whole building.

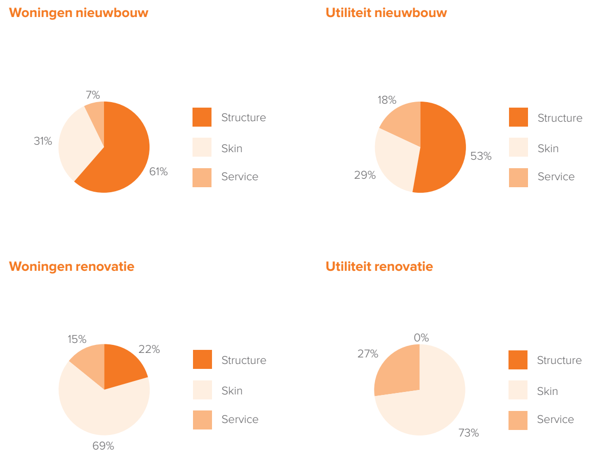


Fig. 1.1: Impact of material related emissions per building layer, divided in housing-utility and new construction-renovation (DGBC, 2021).

This raises the question how the façade can be employed as a means to reconnect. Ecological design principles have to become a more integral part of facade design. By restoring the relationship to a more symbiotic modus operandi, façade construction can become more beneficial for both culture *and* nature.

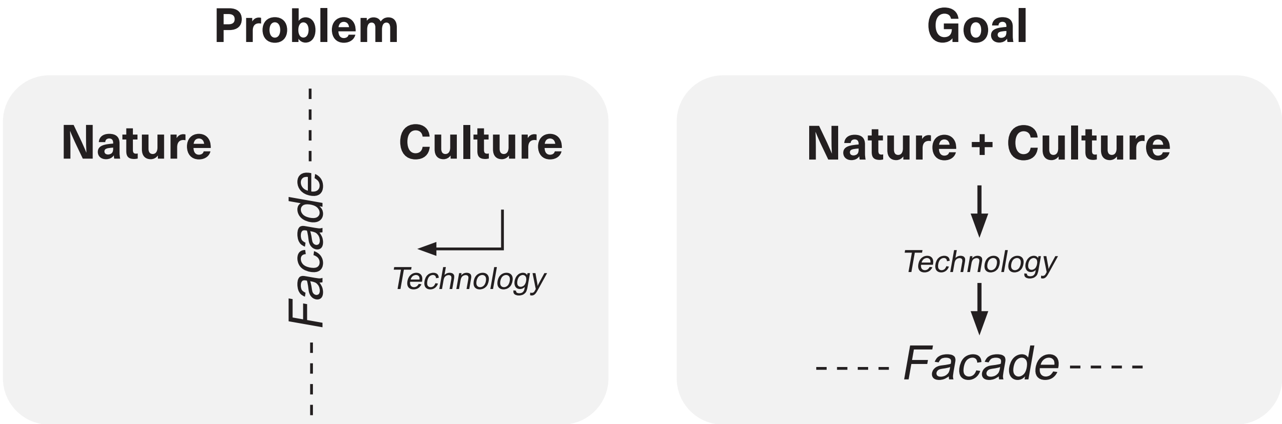


Fig. 1.2: the nature-culture divide. Diagram by author.

1.2 | Main objective

In the introduction above, three main problems can be distilled. Firstly, the construction industry being material intensive. Secondly, it is emitting damaging and toxic chemicals in the construction process. Thirdly, lack of proper design qualities for long life spans can result in premature demolition. To adress these problems, three corresponding paradigms are presented as goals to achieve a more balanced nature-culture design approach. The circular economy principles concerns the deployment of R-strategies such as reduce, reuse and recycle. The biobased materials are not only renewable, they also store carbon during their growth and are biodegradable. Lastly, climate design for wellbeing can guarantee buildings that are more resilient to societal changes, allow for more personal preferences and most importantly optimizes the climate for health and comfort. This way, it can align the economical lifespan more with the technical lifespans and prevent sudden obsolescence.

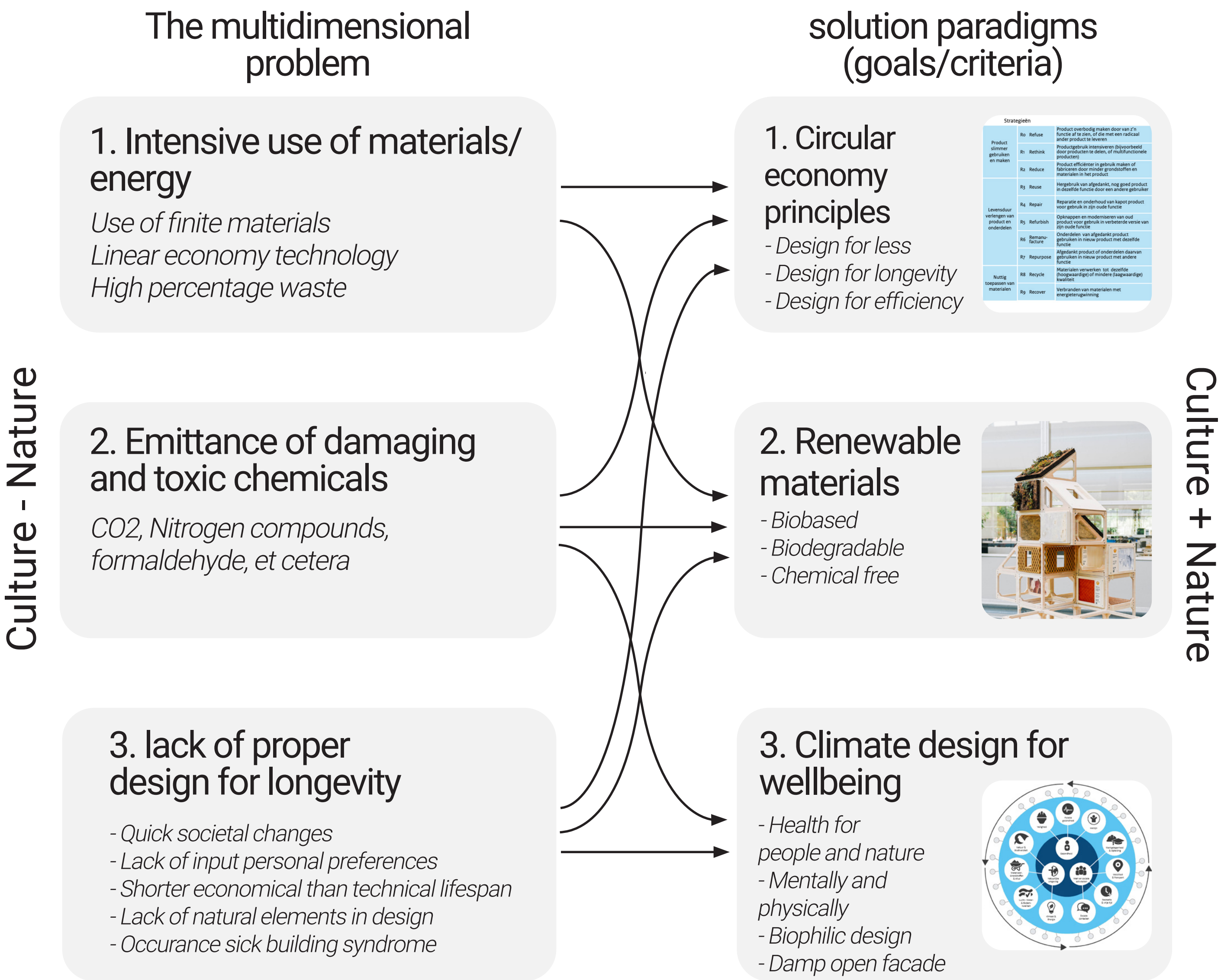


Fig. 1.3: linking the multidimensional problem statement to possible respective solution paradigms. Diagram by author.

1.3 | Overall design objective

The goal of the graduation project is to develop a facade system that reconsiders our relationship to the natural world and the subsequent ecological processes. Employing technology as a tool is a key factor where both culture and nature are the premise. How can we design this facade system, how does the building affect the facade and vice versa?
The interrelationship of the facade with the building as a whole is complex. The shearing layers by Stewart Brand (1997) offer a relevant paradigm. It structures the different building components in accordance to their function and average lifespan, and can offer methods for sustainable building design. Therefore, it will be used to structure the research objective and the following design objective. In the wider context, are the division of these layers part of the broader concept of open building. Here, a more permanent structure offers space for more specific (more temporary) infill components. The to be developed facade system will be part of the infill of a building.
An important factor in facade design is the program the facade serves. A dwelling simply has different use cases than offices. Moreover, do these programs require different design specifications by regulation of the Dutch building decree (Bouwbesluit). In this graduation project are therefore programs chosen that are the most common. In doing so, the overall applicability of the research results and design will be the highest. This will concern dwellings as a main focus with offices as a second to prove versatility. Ideally, the design will consist of a building 4/5 stories with residential and office program. A relevant site for the overall design will be chosen after or during the execution of the research, but will be somewhere in the Netherlands. Although this objective has a large technical challenge, the flexibility modular systems offer ultimately will be translated into architectural diversity.

Design question: How can we design buildings that maximize the potential of modular façade systems?

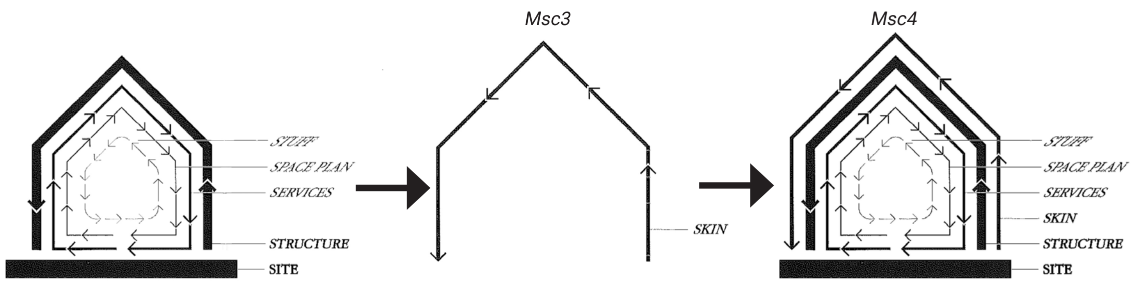
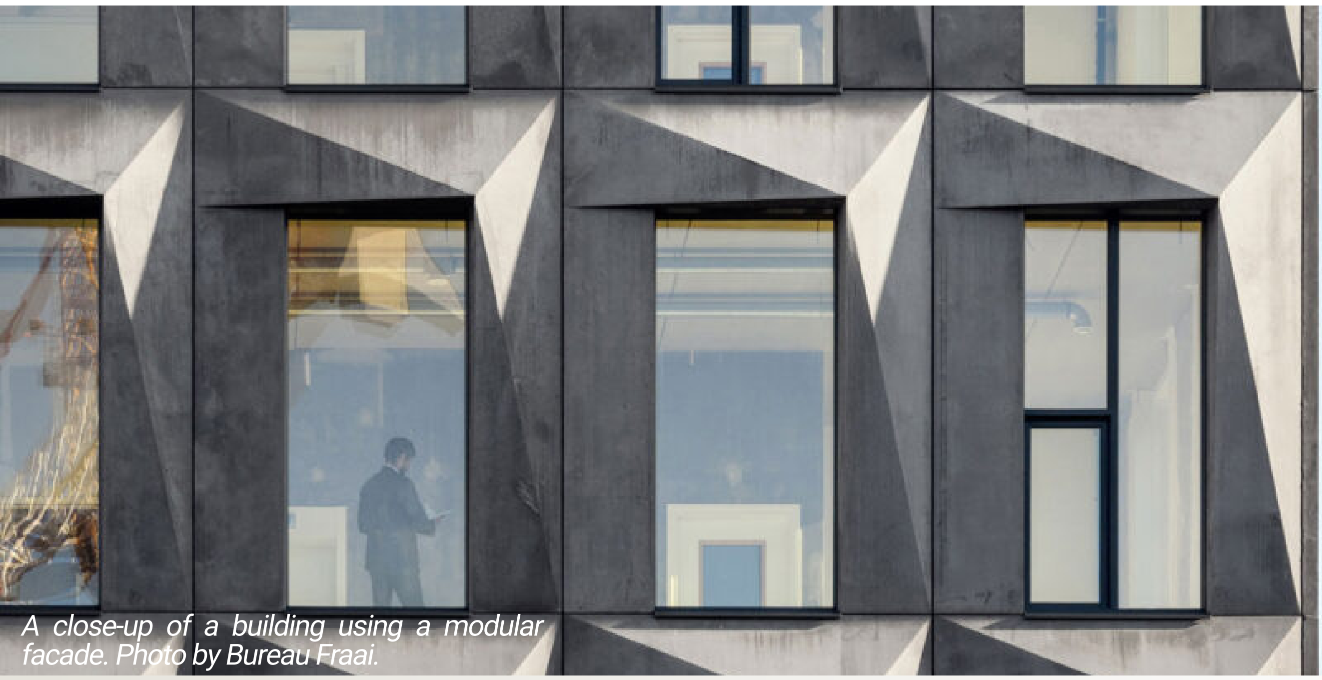


Fig. 1.4:The interrelated nature of building layers, defined by Stewart Brand (1997), altered for reinterpretation.



A close-up of a building using a modular facade. Photo by Bureau Fraai.

Installation of the modular and biobased Natural Pavilion. Photo by DP6.

1.4 | Theoretical framework

Ecological Architectural Tectonics (EAT)

Given the complex and multi-dimensional nature of the problem statement, structuring the research is essential. Architectural tectonics dives into this thematic and can offer guidance. It describes tectonics as architectural design where structure, materials and the spatial experience are integrated to form a coherent and clear entirety (Mahmood & Al-Alwan 2023). These tectonics, however, still mainly focus on the cultural aspect of the built environment. For the thematic research these three pillars are relevant since they align with the sustainability goals mentioned in the main objective. 'Experience' here is interpreted as the conditions of the space during use. Since these conditions - especially with facade design - are often closely related to the climate, the third pillar will be defined as the (indoor) climate. By applying these goals onto the three pillars, a more integral approach of facade design can be achieved: Ecological Architectural Tectonics (EAT). The diagram on the next page elaborates this visually.

Modularity

To fuse these three pillars of tectonics into an integrated facade system and product, modularity offers relevant models. Modularity in this context, deals with a system consisting of individual modules that are interconnected with universal joints. Each module can have different, unique properties, within a wider standardized framework. It is the embodiment of the paradox of standardization vs customization.
The research results might also hold potential relevance for the development of a facade by *Product as a Service (PaaS),* since it lends itself well for mass production (standardization) and product diversity (customization). However, given the research focus, no economical research will be executed.

Three pillars of Architectural Tectonics

Structure

The structure has a couple of functions. Firstly, it has structural properties, to resist natural forces like gravity, wind, earthquakes and more. It guarantees stability for self support. Another function is to order a facade in a certain way. The structure determines spatial layouts, open and closed space and certain shapes. The goal is to make a standardized spatial framework for the facade.

Materials

Materials are the embodiment of the structure. They can have properties beneficial for the structure (e.g. strength) or the climate (e.g. thermal conductivity). In addition, they have a certain texture or tactility that can be viewed as an aesthetic. It has weight, erodes or doesn't, et cetera. The goal is to make a list of suitable materials with their properties, and to see how they can serve for the structure, climate control or aesthetics.

Climate

This concerns the indoor climate. The facade has some 'basic' functions like protecting from rain, wind, warmth or cold, UV radiation, the amount of daylight, noise, etc. In addition it needs to support the users in more complex processes by offering enough ventilation, shade, desired humidity and connection to outdoor climate. The goal is to collect the material providing the basic functions and create tailored solutions for the more complex ones, to guarantee wellbeing.

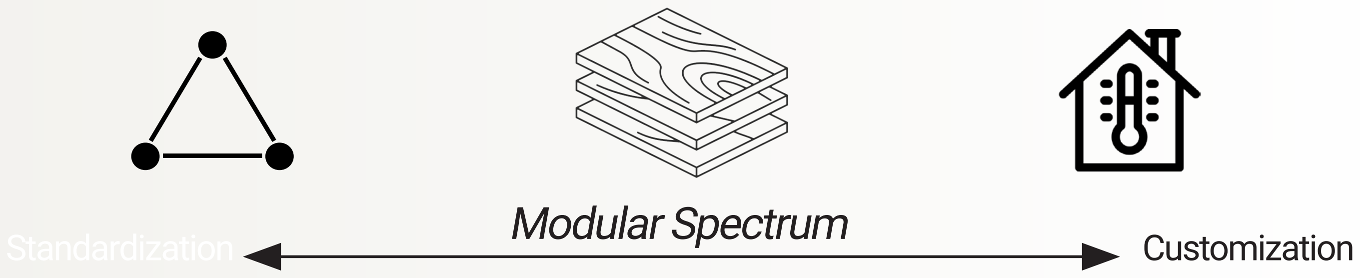


Fig. 1.5: the three pillars of architectural tectonics, linked by the concept of modularity. Diagram by author.

1.5 | Thematic research objective

The research objective is to develop a façade system, that comply with the principles of architectural tectonics as much as possible. In this case the chosen research objective is closely related to the overall design objective. In essence the goal is to integrate the threepiece sustainability goal with architectural tectonics. The research consist out of two parts: A (investigation) and B (experimentation). In part A, by starting with the criteria definition on the building scale, it can lead to input for the facade on the facade component scale (which in turn functions as input for the criteria on the building scale again in Msc 4). Then, information will be gathered on each of the three tectonic pillars: structure, material, climate (in chronological order) and how to relate them to their correspinding sustainability goal. The deployed methods will be literature studies and cases studies, as well as the use of databases like Ansys Edupack. The integration of these three pillars will happen in part B. The best suited properties will be chosen to create a facade system. Here, chronological order is less the focus, as it will happen iteratively. The research allows flexibility for the uncertainty related to iteration and experimentation. Part B will be executed by research by design (i.e. sketching, CAD) and prototyping. Eventually, output of this research in Msc 3 can serve as direct input for the design in Msc 4, and will function as the proof of concept of the research results. The site selection and analysis will take place in approach to the Msc 4. The Research belongs to the theme of **MAKE** as stated by the research plan instruction document.

How can a modular facade be developed with Ecological Architectural Tectonics (EAT) theory?

Part A:
What are the requirements for:
1. the facade's *structure* and how can it be standardized for the circular economy?
2. the facade's *materials* and how can it consist of as much renewable materials as possible?
3. the facade's *building physics* and how can it be customized for wellbeing?

Part B:
How can the insights of 1-3 be combined for an intergal facade system?

Installation of prefab 'modular' strawbale panels as facade. Photo by Ecococon.

1.6 | Graduation project diagram

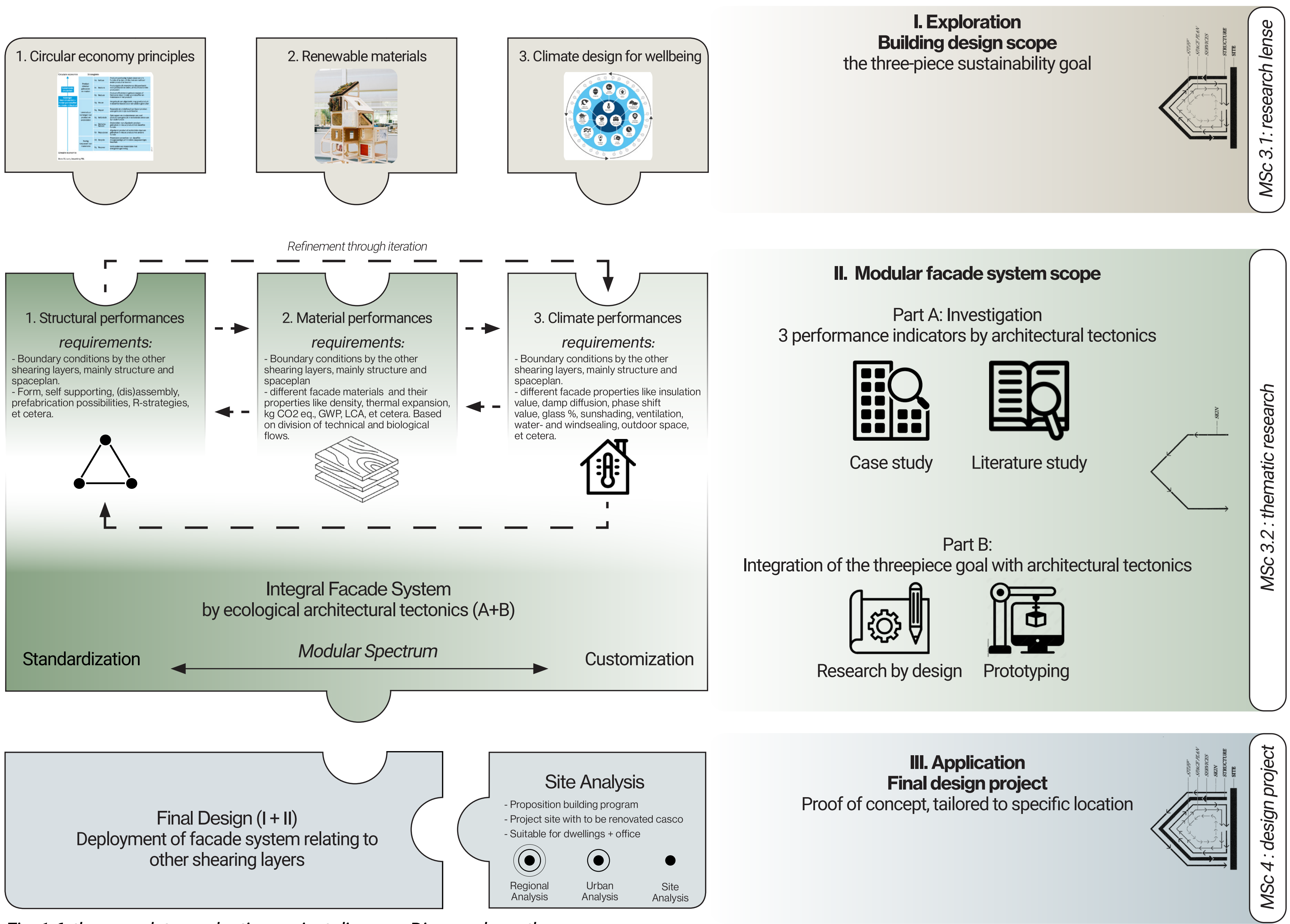


Fig. 1.6: the complete graduation project diagram. Diagram by author.

1.7 | Project timeline

Semester 1

Site analysi	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	2,1	2.2	2.3	2.4	2.5	2.6			2.7	2.8	2.9	2.10
Month		**September**					**October**					**November**				**December**				**January**		
Date	2/9 - 6/9	9/9 - 13/9	16/9 - 20/9	23/9 - 27/9	30/9 - 4/10	7/10 - 11/10	14/10 - 18/10	21/10 - 25/10	28/10 - 1/11	4/11 - 8/11	11/11 - 15/11	18/11 - 22/11	25/11 - 29/11	2/12 - 5/12	9/12 - 13/12	16/12 - 20/12	23/12 - 27/12	30/12 - 3/1	6/1 - 10/1	13/1 - 17/1	20/1 - 24/1	27/1 - 31/1
Delivery	Design tutoring every Tuesday Research tutoring every Wednesday									**P1**	Design tutoring every Tuesday Research tutoring every Wednesday						Christmas Holidays		Design tutoring Research tutoring		**P2**	
										01 | Introduction												
	Composing research plan																					
										02 | The research: towards sustainable facade culture												
Part A							Collecting relevant case studies				Analyze facade climate											
												Analyze biobased materials										
													Analyze structures									
Part B															Experimentation & facade design				Experimentation & facade design			
										03 | The design: transforming the Beatrix gebouw Utrecht												
Site analysis															Site selection				Site selection			

Semester 2

Week	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10
Month		**February**				**March**				**April**					**May**				**June**	
Date	10/2 - 14/2	17/2 - 21/2	24/2 - 28/2	3/3 - 7/3	10/3 - 14/3	17/3 - 21/3	24/3 - 28/3	31/3 - 4/4	7/4 - 11/4	14/4 - 17/4	22/4 - 25/4	28/2-2/5	6/5 - 9/5	12/5 - 16/5	19/5 - 23/5	26/5 - 28/5	2/6 - /6/6	10/6 - 13//6	16/6 - 20/6	23/6 - 27/6
Delivery	Design tutoring and building technology tutoring every Tuesday							**P3**	Design tutoring and building technology tutoring every Tuesday						**P4**	Design tutoring and building technology tutoring every Tuesday				**P5**
								03 | The design: transforming the Beatrix gebouw Utrecht												
	Archival documentation		Initial design ideas & sketches				adaptations structure		Adaptations structure	Architectural drawings				Technical & detail drawings		Technical & detail drawings		Model making & documentat-ion	Impressio-ns & booklet	
										04 | Reflection										
														Reflection					Reflection	

Fig. 1.7: The complete graduation timeline. This a general indication, rather than an exact representation. In reality, work overlaps and is more fragmented across the year.Table by author, based on the aE graduation calendar.

Demolition of building in the linear economy.
Photo by A. Jansen B.V.

1.8 | Relevance

The graduation project has multifaceted relevance, ranging from the wider to more specific use cases.

In the wider scope of the design objective, the graduation project aims to offer solutions for both dwellings and offices. A modular facade system can for example unlock new opportunities to transform/renovate old building stock into new dwellings, to address the current housing crisis. This also complies with the transformation of offices due to the decrease in office demand by the covid pandemic. Additionally, modular facade can integrate program- or site specific properties to account for a certain (visual) identity or vernacularity.

The research treats multiple topics. The Dutch government aims to run on a full circular economy by 2050 (50% at 2030). The circular principles are there, but practical applications often lack feasibility. The elaboration of circular technologies is essential. (Automized) Prefabrication allows for faster, more precise assemblies with less waist. DfD prolongs lifespans of materials and components immensely, reducing the increasing costs of materials and labor.
By using more renewable materials, we not only comply with the circular economy goals but also store CO2 in the process. Furthermore, it reconsiders the human position within the wider ecological systems, which is crucial to reduce our environmental impact.
Lastly, the covid pandemic showed us the importance of proper indoor climate control for health benefits. Still, even after the pandemic it is important to address these topics, as symptoms like the sick building syndrome are more than ever relevant. The use of proper climate design and materials boost health physically and mentally, a topic that has gained more recognition the last decades.

Modularity is the factor that combines the three topics above, and can offer flexibility to otherwise quite static' components in the building industry. This flexibility can account for personal preferences, and therefore allow more user participation. It gives answers to ever - and faster - changing living patterns, and thereby making it significantly more lucrative.
Another advantage of modular flexibility is that it can be tailored to fit both office and dwelling criteria. This way, the facade components do not even have to be swapped when changing program.

The topics listed above are not completely new to facade design, but it is the combination of them in this research that can result in new findings. Moreover, a lot of the topics are little applied in practice, like modularity. By linking them to similar potential topics, novel opportunities can arise.

2.1| Facade structure

For the structure, the criteria (see below) subsequent of the circular economy are relevant because they determine for a large part the spatial design. For example, standardized façade elements with universal connections that functions nearly independent from the buildings support structure, will (intuitively) have different spatial consequences on the design. In this part, these premises will be elaborated to then stipulate the spatial preconditions of the façade system.

Structure
- Reduce, reuse, repair, remanufacture, refurbish, recycle.
- Components approach
- Open building/ shearing layers stewart brand
- Demountable, universal connections
- As independent as possible: when cassette a is removed, b can stay
- Casette system
- Hoisting equipment
- Low tech
- Prefabrication
- Standardization

Facade as a 2D plane

The notion of the façade as a 2D plane is a relevant one for it's spatial determination. Of course, a façade also has a third dimension; the thickness (x), but its implications are less than its width (y) and height (z) (figure 2.2). To guarantee the most flexibility (i.e. customization), the façade needs to answer the most individual demands. This means that a façade needs to be able to change for one household or tenant, whilst remaining the rest for a building. This, of course, does not exclude the option of refitting a façade for a whole building all at once. Therefore, the program of the building largely determines the spatial dimensions of the façade elements for width and height. In addition, it determines to what point the panels will be prefabricated: plug and play panels that cover a full apartment, office space or shop (figure 2.2). Exceptions here concern practicalities, for example: when a program is too large for it's façade to be lifted by crane, it can still be divided into smaller panels to be mounted. Protocol will then be to divide the panel into the grid size of the structure; from column to column. Figure 2.4 gives insight into the different building elements though the different scales. These elements are given a name to organize the system respective to the interscale approach. From

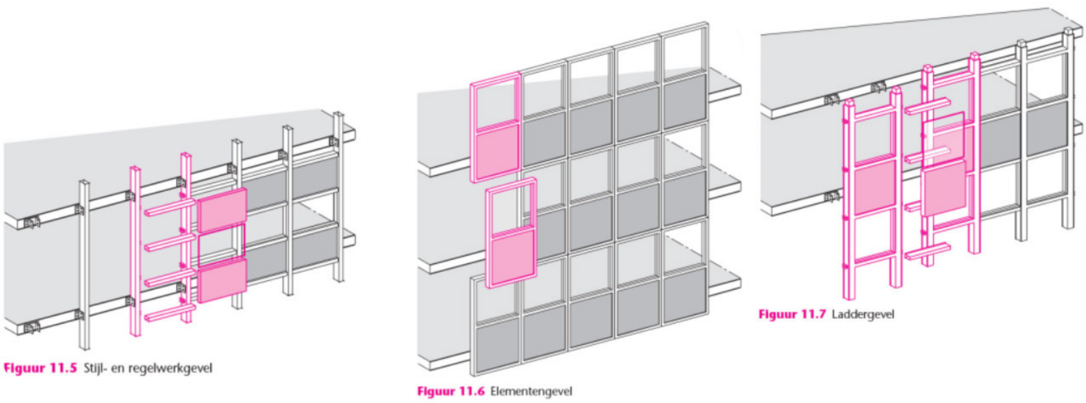


Fig. 2.1: Types of curtain walls: element facades have the highest rate of prefabrication.

panels (program scale), to cassettes (individual scale), down to components (sub-individual) and single parts. If all elements on all scales allow some form of differentiation, the most versatile system is established. It can then respond to irregularities on the level of a building, a single program or even on the level of a single person.. A façade construction type called element façade uses much of these properties already and is mainly applied to glass and steel/aluminum curtain walls (figure 2.1). Therefore it is not only a proven concept (structurally, economically), it provides insights into the spatial design of such system. They usually follow a grid plan (y)

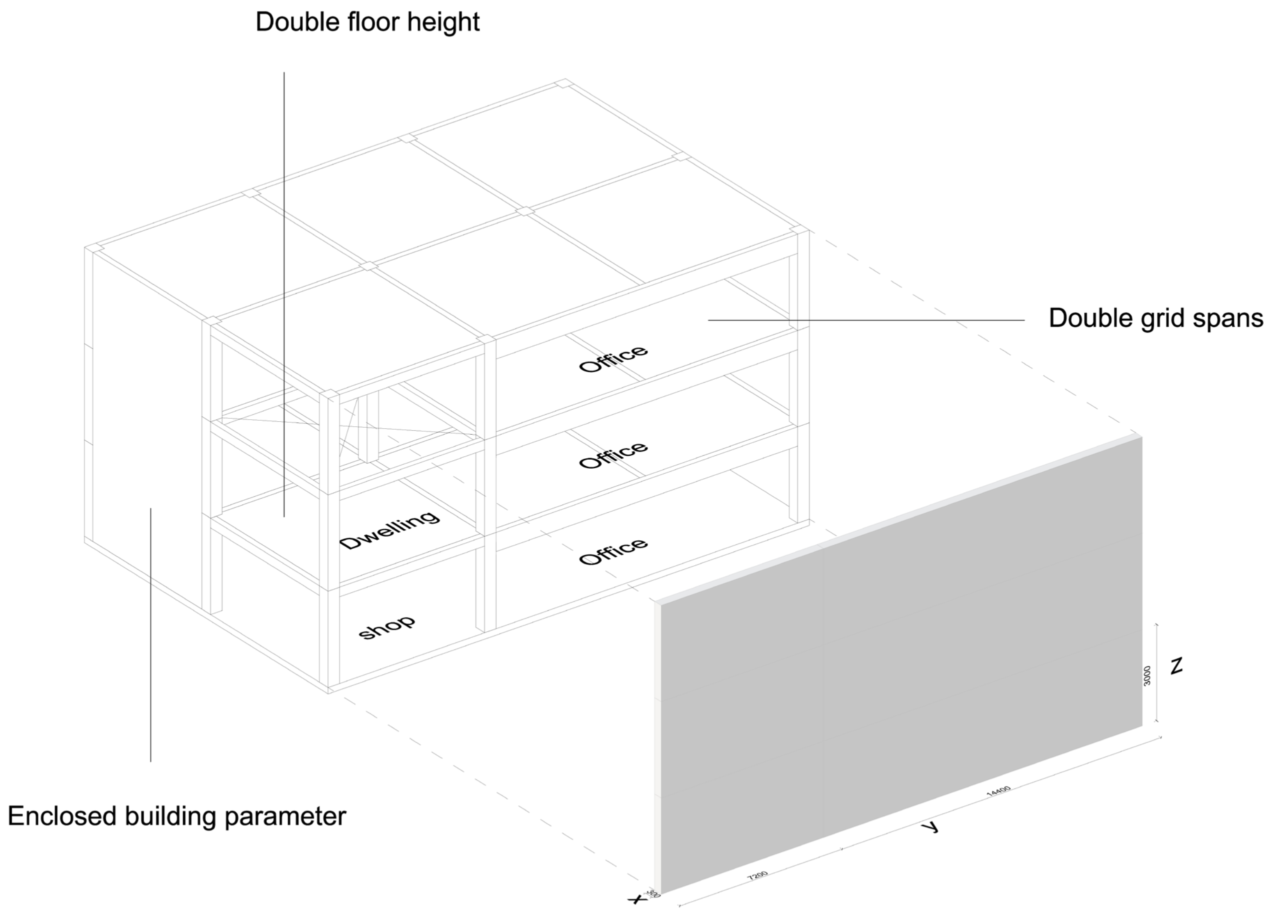


Fig. 2.2: Types of curtain walls: element facades have the highest rate of prefabrication.

dimension of 7,2 meters. It is a multiple of 1,8 meters and is one of the standard dimensions used in grids for larger, multi-tenant office buildings. Simultaneously is the 1,8 meter 'module' sized according to individual human dimensions, fitting the spatial experience in the direct human reach (figure 2.3). This grid also complies with criteria from dwellings and shops. It can be the rough size of a small apartment unit of ±40m², or two can make a larger apartment unit for a family of 4 with ±80m². A brief study in figure 2.4 shows the possibilities and consequences of designing with this grid size. The height (z) will be according to the floor heights. The versatility of the façade system also concerns the application on the scale of a complete building. It is the visual factor of a building to the public and urban domain, and for a large part determines its aesthetics. Different building shapes and orientations require different façade solutions. A massing study in figure 2.6

shows a couple of different general shape strategies for buildings. These possibilities are rough guidelines for the system to take into account when designing in chapter III. Premise is to allow the floorplan to have this flexibility, by favoring an open support structure as much as possible in line with open building practice (i.e. columns and beams). With existing buildings these dimensions are readily determined and a façade system should then be tailored to this.

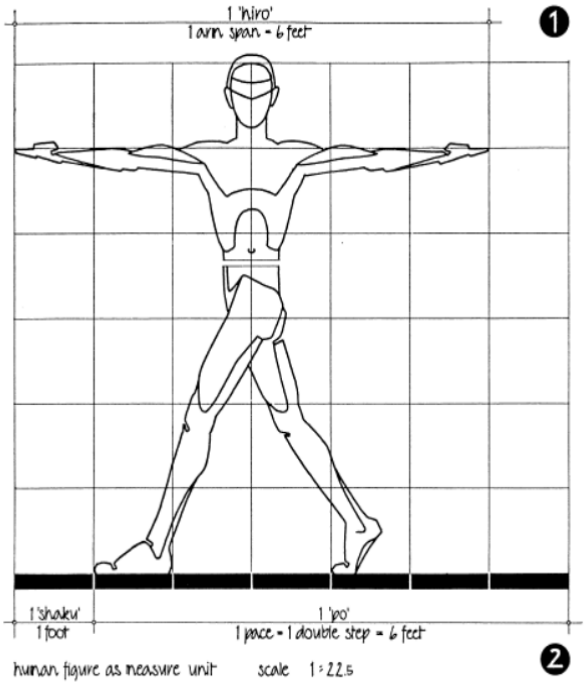


Fig. 2.3: Traditional Japanese architecture has been designed according to the human scale for centuries. 1 'po'is 6 feet ≈ 1,80m.

Fig. 2.4: Floor plan study of programs for grid dimensioning.

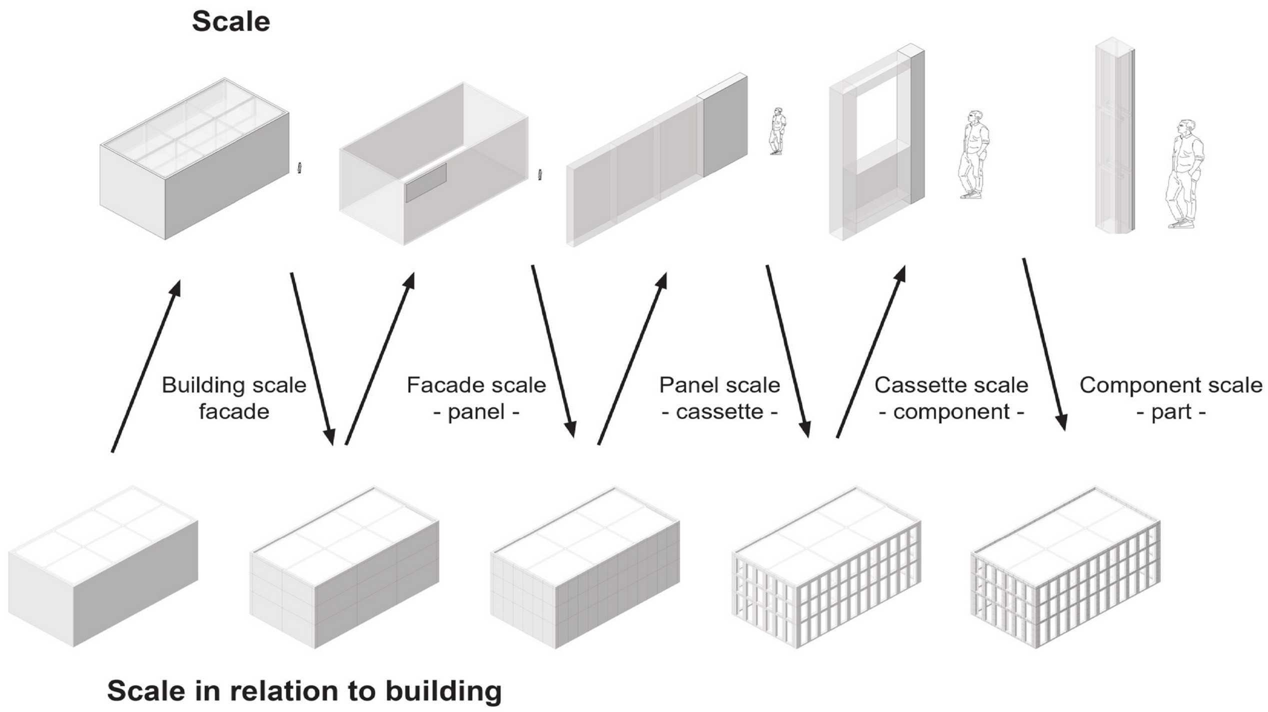


Fig. 2.5: The interscale approach visualized. Ranging from interventions on the scale of a complete building, all the way down to single parts. Central in the approach is the cassette, which operates the closest to the scale of the human reach. When differentiation is created on each scale, but within this standardized system, the best modular result can be accomplished.

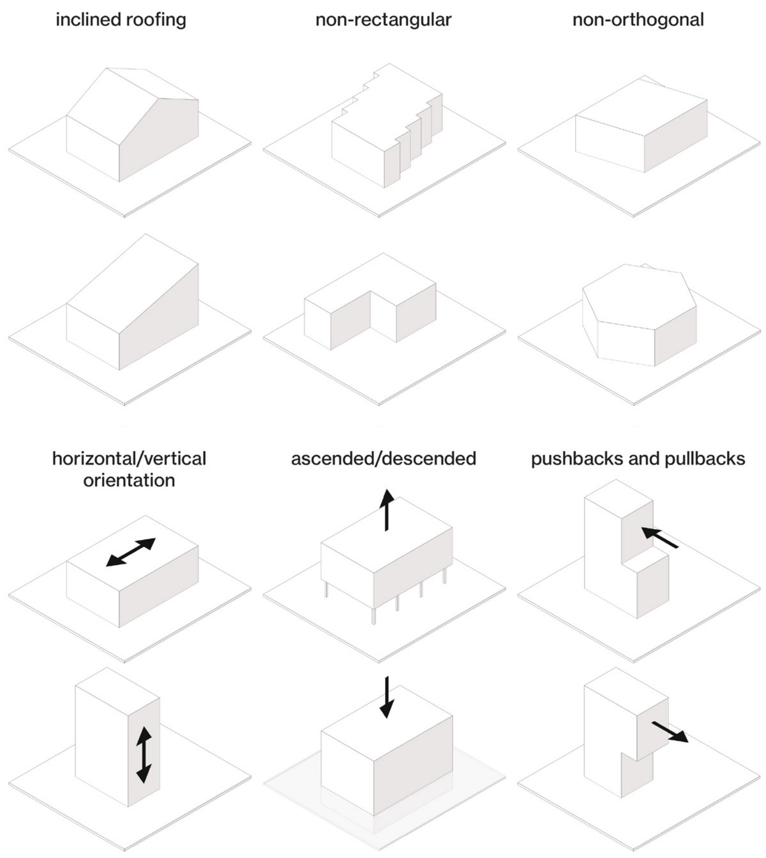


Fig. 2.6: Scale 1 (building typology). Above is a massing study to determine the application field of the system. Limited in shape for organic and inclined facades, it still allows for a variety of design options. The options vary from inclined roofs, non-orthogonal shapes to façade with set-backs or overhangs.

Preconditions of standardized connections

Interlayer connections

A building is essentially a highly complex composition of interrelated layers with each their own functions and lifespans. This is the perspective on the built environment proposed by the notion of open building. If sustainability is the goal, it would be logical to make these elements relate to each other as independent as possible. This way each layer can live the most of its corresponding lifespan, which is one of the circular economy goals. A layer's own functions should not be limited by the properties of the other layers. The layers most adjacent are most critical, for the façade this is the buildings support structure and the space plan (partition walls, connection to outside space, et cetera).

If the shearing layers as proposed by Brand are solely viewed upon their lifespan, a hierarchical set can be extrapolated (figure 2.7). In case of the façade, in general only the buildings support structure has a longer lifespan (site excluded, since it has (almost) no spatial consequences in connections to the façade). It creates therefore a kind of spatial template upon which the other layers can be 'filled in'.

A place where the façade and structure always meet and connect (both new construction and renovation), is at the edge of a (structural) floor or on the sides of beams. Here the main mounting will take place. The advantage of this approach is that the façade can take exceptional conditions in the support structure into account: double height floors, double grid spans, enclosures of building perimeter, et cetera (figure 2.2). Since all forces exercised on the façade are transferred into the structure, the connections require significant strength. All connection types are also visually listed in figure 2.8.

Intralayer connections

To accomplish the flexibility in the façade system, all connections need to be identified and designed as demountable. All connection types correspond to the interscale approach described in the previous paragraph: panel connections, cassette connections, component connections, and individual part connections. Since wood is the only structural material used in the façade system (see chapter 2.4) and it is easily processed, all intraconnections are 100% wood based. Each connection type is elaborated on the next page from large to small scale.

Brands shearing layers in hierarchy

1. Site	(infinite) ↓
2. Structure	(200-300 years) ↓
3. Skin	(50-100 years) ↓
4. Services	(15-30 years) ↓
5. Space plan	(5- x years) ↓
6. Stuff	(1 day - x years) ↓

Fig. 2.7: A buildings shearing layers according to Brand, a hierarchic set extrapolated.

- Panel connections (figure): since all cassettes are connected individually to the support structure, only a thermal, water/air proof connection is needed between the panels. This happens horizontally by half overlapping with a wood frame ‘ribbon’, filled with cellulose insulating mats, along the floor edge. This ribbon is attached to the floor, and subsequently is the cassette attached to the ribbon.
- Cassette connections: these connections require more structural properties to make multiple cassettes act as one panel, especially when hoisted. In addition, it is important that the between-cassette seams are air and watertight. Therefore is chosen to apply the X-fix connector: a plywood friction it connector for structural use (Salzberger, 2024). It can be demounted by drilling it out, leaving little waste.
- Component connections: the connections here are the same as the panel cassette connections, again for structural capabilities and water proofing.
- Individual part connections: these connections depend highly upon their individual characteristics, functions and loadbearing types involved. Inspiration was taken from traditional Japanese construction methods with wood, described in Measures and Construction of the Japanese House (1985). 4 main types are formulated for 4 different functions:
- overlapping dowel connection: between frame members for flush cassette perimeter.
- adjacent dowel connection: between frame members directed inwards of cassette.
- tangent dovetail connection: connection of anti-buckling plates to cross beam.
- perpendicular dovetail connection: connection of panel caps to panel frame.
These connections are mostly friction fit, but are also locked in by cancelling each others only remaining DoF (degree of freedom).

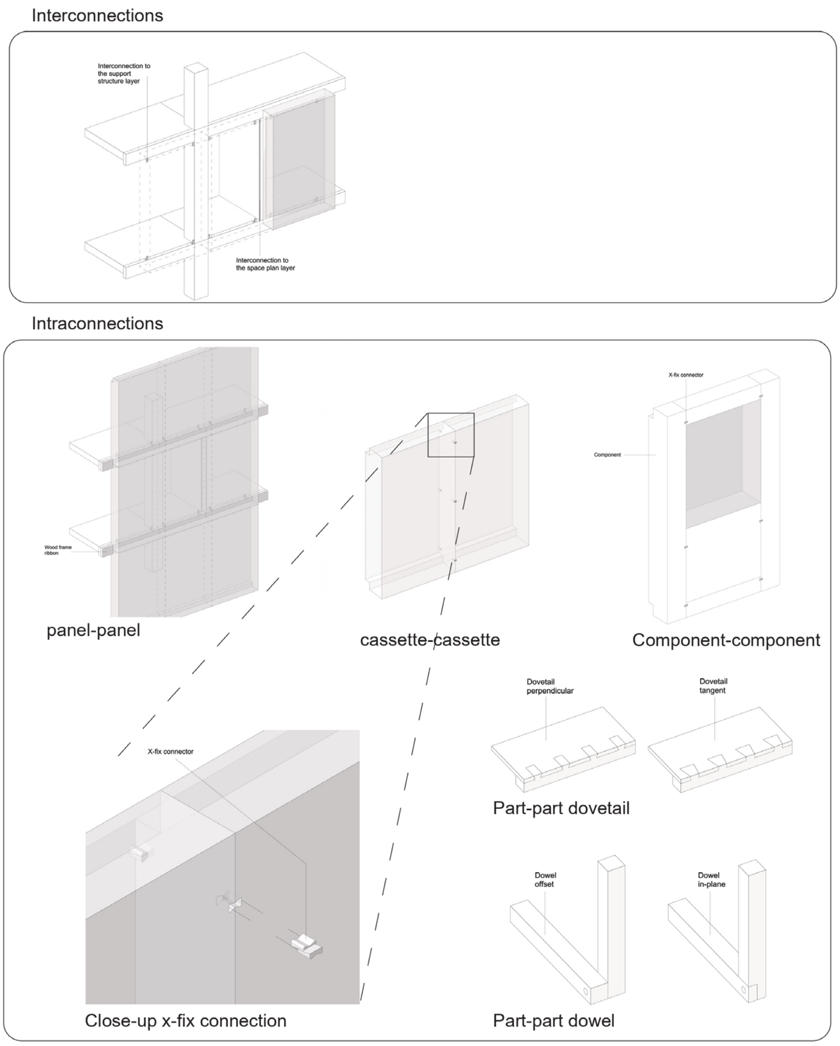


Fig. 2.8: The interlayer and intralayer connection types. All connections are demountable and made with renewable materials as much as possible. All connections shown are for structural purposes. However, the connections between cassettes and components are also for thermal, water and wind sealing. The origins of applied connection types used ranges from more advanced carpentry technology , to ancient Japanese timber building practices.

2.2 | Facade materials

In this chapter the material possibilities of the façade system will be explored. The criteria for materiality are listed below. The spatial preconditions determined in previous chapter, in combination with the climate criteria in 3.3, offer a template where materials can be chosen for. This template (figure 2.9) provides the minimum for a typical façade formation, with materials complying with the criteria. In some cases, more options are suited for a certain part. For example, multiple façade finishes create more visual and aesthetic diversity.

Materials
- Physical properties - Mechanical properties - Fire proof - Rule: use biobased materials, only a finite (but 100% recyclable) material substitute if necessary - Manufacturing properties (embodied carbon) - Local availability materials - LCA - No or limited amount of toxics chemicals or VOCs

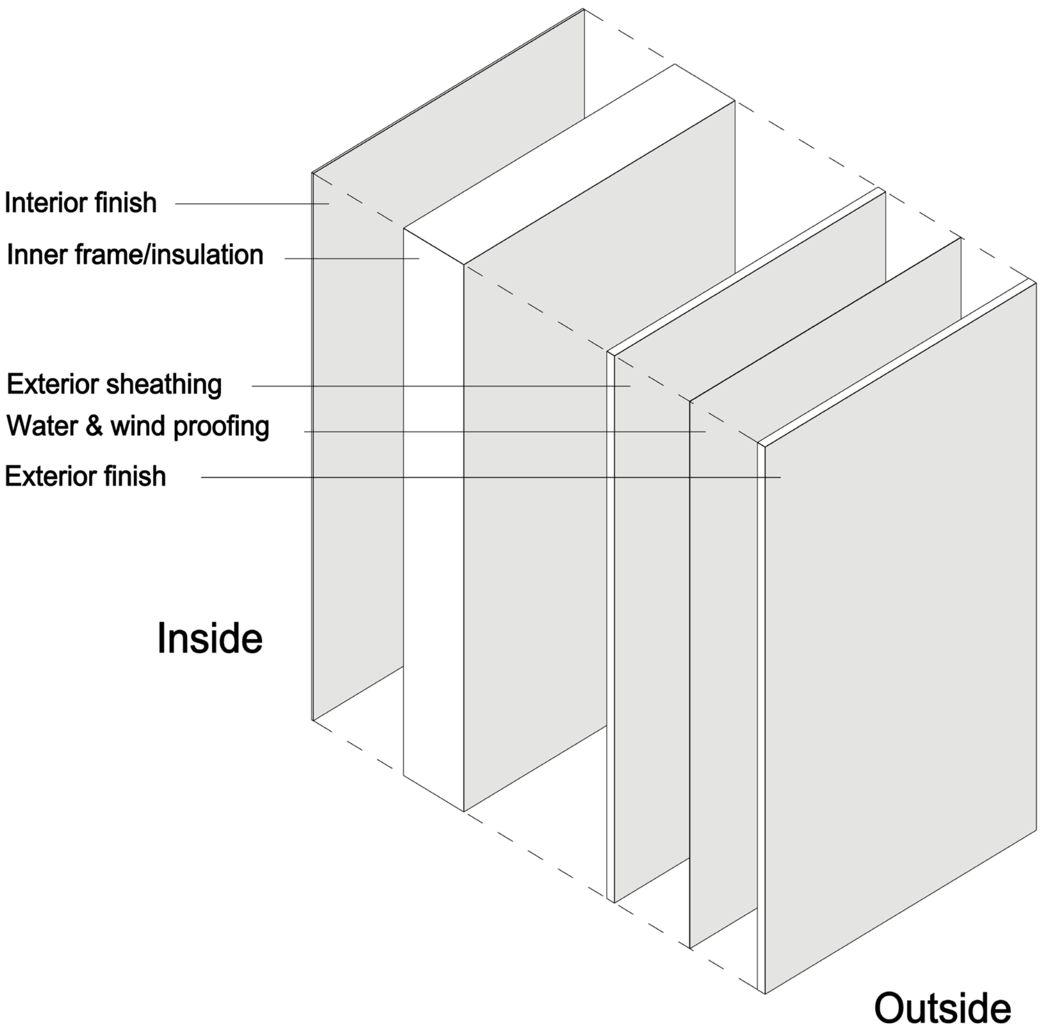


Fig. 2.9: The material template with all minimum requirements for the façade.

Most materials were found on online databases and websites, and their validity was checked by additional FSC, PEFC, EPD or other sustainability certifications. Another important factor was the vicinity of the product production (within Europe), to prevent high transport emissions. The final selected materials are listed in figure 2.10 and comply almost completely with all criteria. They are discussed for their choice below, per material (or layer). This chapter does not cover façade accessories (balconies, galleries). Figure 2.11 has visualized the final selection in a matrix.

Inside finish

The inside finish has to comply with multiple functions, and is therefor difficult to comply completely. Firstly, high fire resistance is required to a; prevent potential inside fires to spread outside and b; protect the steel connectors. Another aspect is a low vapor diffusion coefficient, allowing inside vapor to travel outside and vice versa. In contrast to normal gypsum boards, do clay boards have a very low coefficient because of the metycellulose and wood fiber content. Lastly, the boards are very strong, and dimensionally stable. This allows clean inside finishes, that can be further finished (e.g. clay stucco with pigment).

The frame & insulation

The frame concerns the façade's structure, while also holding space for insulation. One product came forward with potential relatively quickly: pressed straw panels made of wood, biobased plywood and straw. These panels can have high R-values (with 30-40cm thickness), are almost completely biobased and are constructed of relatively abundant and nearby materials: (spruce) wood and straw. Moreover, they are vapor open and are fire resistant above minimum regulations. They are relatively lightweight and are suited for prefabrication. The plywood is needed for capping the bottom and top of the frame. Currently, the plywood is only produced in either China or South America, resulting in higher transport emissions. The frame only needs to account for bearing it's own weight and small wind loads. Other insulation options include the cellulose mats or wool mats, and are applied on more exceptional locations in the façade.

Sheathing

This layer is needed for the outside of the façade to have a smooth and uniform surface, allowing outside finishes to attach more freely. It also serves as a seal between panels (in addition to improved insulative, sound and air tightness properties). Wood fiber board is readily used with straw panels, and is the main choice here. It is fairly vapor open, fire retardant in the straw panel construction and fully biobased consisting of wood fiber and lignin. This sheathing is not structural, but is dimensionally stable. It is attached to the straw panel by screws.

Water & wind proofing

This product is anthracite in color, leaving the aesthetic image fully to the facade finishes. The foil does contain polypropylene and TEEE that releases volatile organic compounds, but because of the outside placement, in combination with a vapor open façade, results in a lesser risk. The foil is waterproof but vapor open. Another point is that the material is not biobased and made from fossil raffinates, but fully recyclable. The foil is UV-resistant, protecting the materials it covers.

Outside finishes

For a diverse aesthetic appeal, multiple façade finishes were chosen. Marc Koehler differentiates three main visual façade types: monolithic, rhythmic and patched/collage. These three types were adopted, and linked to similar biobased materials. For the monolithic appeal, the Nabasco tiles and chestnut shingles were chosen that - on the building scale - appeals more as one object. Wooden cladding is suited for rhythmic patterns and can play in depth. This can concern treated wood or charred for a darker tone. Lastly, a combination of these can make a more playful, contrasting image. They could vary per panel or even cassette. The finishes are nailed/screwed onto horizontal and vertical battens, which are in turn screwed to the wood fiber boards. Other optional finishes include a planted façade and PV-integrated finishes, but are not elaborated in this research.

Connectors
Connectors are divided into two types: for the strawpanel frame and for the further in- and exterior finishes. The strawpanel connectors are largely biobased and consist of dowels, together with the X-fix connectors. The X-fix connectors will probably – like other plywood products – contain about 2% of urea formaldehyde glue. Other connectors are regular screws, nails and nuts and bolts of stainlesss steel.

Fig. 2.10: Materials table visualized.

MATERIAL	COMPOUNDS	AVAILABILITY/SCALABILITY	CO2 Footprint (kg/kg) Calculated with edupack	FIRE PROOF	THERMAL EXPANSION (μstrain)	VAPOR DIFFUSION coefficient (wet cup, 50% RH, 23 C) with correct thickness	Thermal conductivity coefficient (W/m K)	Av. Density (kg/m³)	Sounds insulation value (dB)	Regenerative rate (years) for at least 1m³
INSIDE FINISH										
Lemix clay boards	Clay, wood fiber, jute fiber, metycellulose	Available in the Netherlands, produced in Germany.	0,064	Class A1-S1-d0	0,01mm/m/K	Av. 7,5	0,353	1450	52 dB	Compostable, recyclable
STRUCTURAL										
Spruce wood	100% natural wood	Available in the Netherlands, Austria, Switzerland, Scandinavia and Baltic area.	0,352	120 min (with ecococon), class B-s1, d0	2-11 *10^-6	100	0,24	510	54 in ecococon	20-40
Multiplex (stabiofloor)	90% birch/poplar wood, 10 % bone glue	Currently south America/China	0,6	Class D- s2, d0	6-8 *10^-6	70	0,13	550	n.a.	Abbatoir pigs: 0,5 (approx. 28 pigs for 1m³ of multiplex). Birch regrows in 20-30 years and poplar in 15-20 years.
INSULATION										
Straw insulation	100% straw	Available in all of Netherlands, assembly in Slovakia	0,8	120 min Class B-s1, d0	n.a. (2mm tolerances)	1,4	0,0645	110	54 in ecococon	1
Cellulose mat insulation	Shredded Cellulose, fire resistant natural salts	Thermal: Sweden icell Acoustic: Nederland cyclin	1,22	B-s1, d0	n.a.	1,1	0,036	85 (acoustic mat) 32 (thermal mat)	45 with 50mm acoustic mat	0
Isolena Wool insulation	100 % wool	Available in Netherlands, German company	1,35	Class C or D, but retardant in wood stud construction	n.a.	1	0,037	23	50-60	50
SHEATHING										
Wood fiber board (WFB) (pavatherm)	Wood fiber , lignin	Available in Switzerland	Positive, not specific.	Class E, but retardant in wall construction	10-15	3	0,038	110	21	20-40
WATER AND WIND PROOFING										
Polytex Pro	Polypropylene microfiber, high density polyethylene (hdpe)	Available in the Netherlands, made in Luxemburg	2,178+4,71	E	Unknown, but resistant from -40 to +100 C and flexible	44,44	0,47	145 g/m²	n.a.	Not regenerative, but recyclable
OUTSIDE FINISH										
Nabasco façade tiles (10010)	Natural fibers, natural resin (85%biobased with 8010)	Produced and developed in the Netherlands	0,6	B-S1, d0	10-15	N.a.	N.a.	1700	n.a.	1 year
Chestnut shingles	100% wood	Available in the Netherlands, wood grown in France	0,3623	F-s1-, d0	2-11	n.a.	n.a.	480	n.a.	20-40
Charred wooden planks (accoya)	100% wood (Pinus radiata)	Available in the Netherlands, wood grown in New Zealand.	CO2 negative for whole life	Class D or E, depending on thickness	0,8% from 20 °C (65% RV) dry to wet	n.a. (ventilated)	n.a.	512	n.a. (ventilated)	25-30 years (50 years service life)

Fig. 2.11: Materials table, continues on next page.

OPTIONAL OUTSIDE FINISHES										
PV integrated panels	Black/dark blue	Dimensions: 1800x600cm (5 per cassette)	Supplier: Gevel zonnepanelen voor prachtige gebouwen | Solarix							
Planted facade	green	Dimensions: 555x635mm (modular)	Supplier: SemperGreenwall Outdoor – De groene oplossing voor uw gevelproject							

CONNECTORS										
Stainless Steel screws/nails	±15% chrome, ±0,25% carbon, ±15% nickel, iron, for example	Available in the Netherlands, made in Germany	s± 5-7, with roll forming, foil rolling, wire drawing,	n.a.	9-11	n.a.	25-30	7720-7880	n.a.	Not regenerative, but recyclable
	martensitic AISI 416 annealed		coarse and fine machining							
Steel connector		Available in the Netherlands, from Tata steel Ijmuiden. many suppliers				n.a.			n.a.	Not regenerative, but recyclable
Wooden dowel	Beech	Available in Netherlands, from Switzerland	0,4285	Class B-s1,d0 (in ecococon)	33-44 *10^-6	n.a.	0,15-0,17	755	n.a.	30-60
X-fix wood connector	98% Birch, 2% urea formaldehyde	From Austria, available in the Netherlands	0,582	Class B-s1,d0 (in ecococon)	6-8	n.a.	0,3-0,36	750	n.a.	20-40

Fig. 2.11: Materials table, starts on previous page.

2.3 | Facade climate

The façade plays an important role in the building's climate regulations. It protects us against heat, cold, wind, rain and everything other outside phenomena. It is the reason facades are tailored to their respective climate. The Netherlands has a moderate maritime climate (type Cfb), met relatively mild winters and mild summers. It rains year round with 800-900mm per year and wind comes primarily from the SouthEast direction. Another important aspect is the local ecology types that occur. All these factors together form the boundary conditions in which the facade has to be developed. Figure 2.12 shows the relation between the façade and the climate.

Climate and experience
- Thermal insulation - Sound insulation - Water and wind tight - (direct or indirect) Daylight entry/ % glass and shading - Rainwater drainage - Heating/cooling - Vapor regulation (vapor open) - Integration of vegetation - integration of animal habitats (insects, nesting boxes) - Water buffering - Outside space (French balcony, balcony, loggia, entrance gallery) - Thermal accumulative capacity/phase shifting - Ventilation/openable facade elements

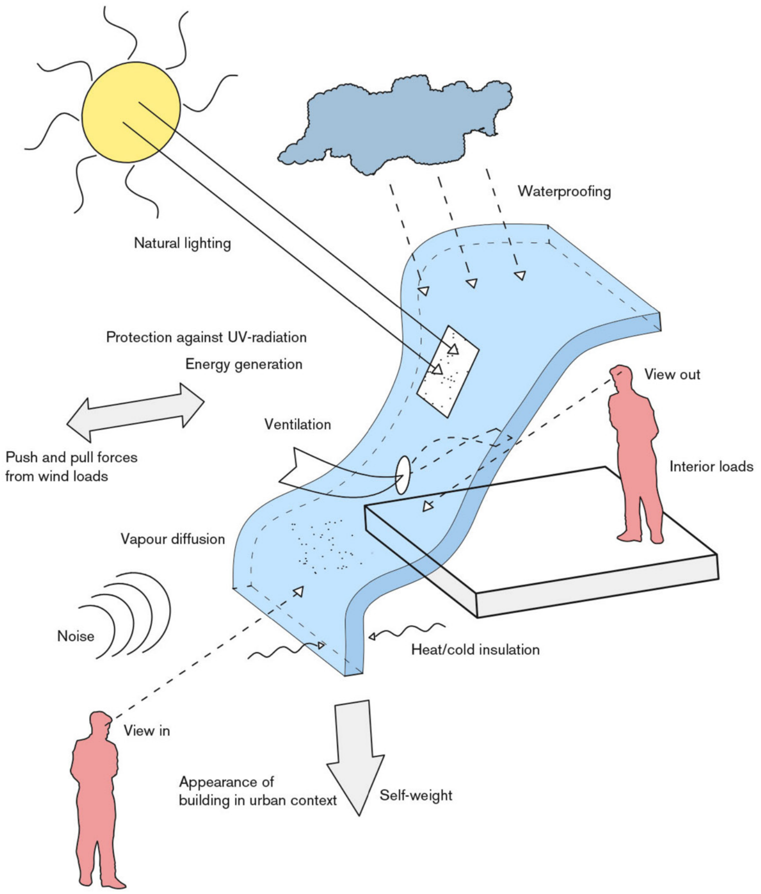


Fig. 2.12: All functions of a facade in the climate perspective.

How the façade system performs in terms of climate regulation, is greatly dependent on it's structural and material properties. Many aspects have already been partially covered in this research, for example the water and wind proofing in paragraph 2.2, and affect the climate performance. First, some properties of two standard cassette types will be discussed. Type one is a closed cassette, type two is a cassette with floor-ceiling height opening. They are the most extreme in their performances. Type three is a cassette with façade opening, plus a parapet, with performances in between the other two types. Finally, some exceptions in the standard cassette types will explored to accommodate to all the possible needs in the façade.

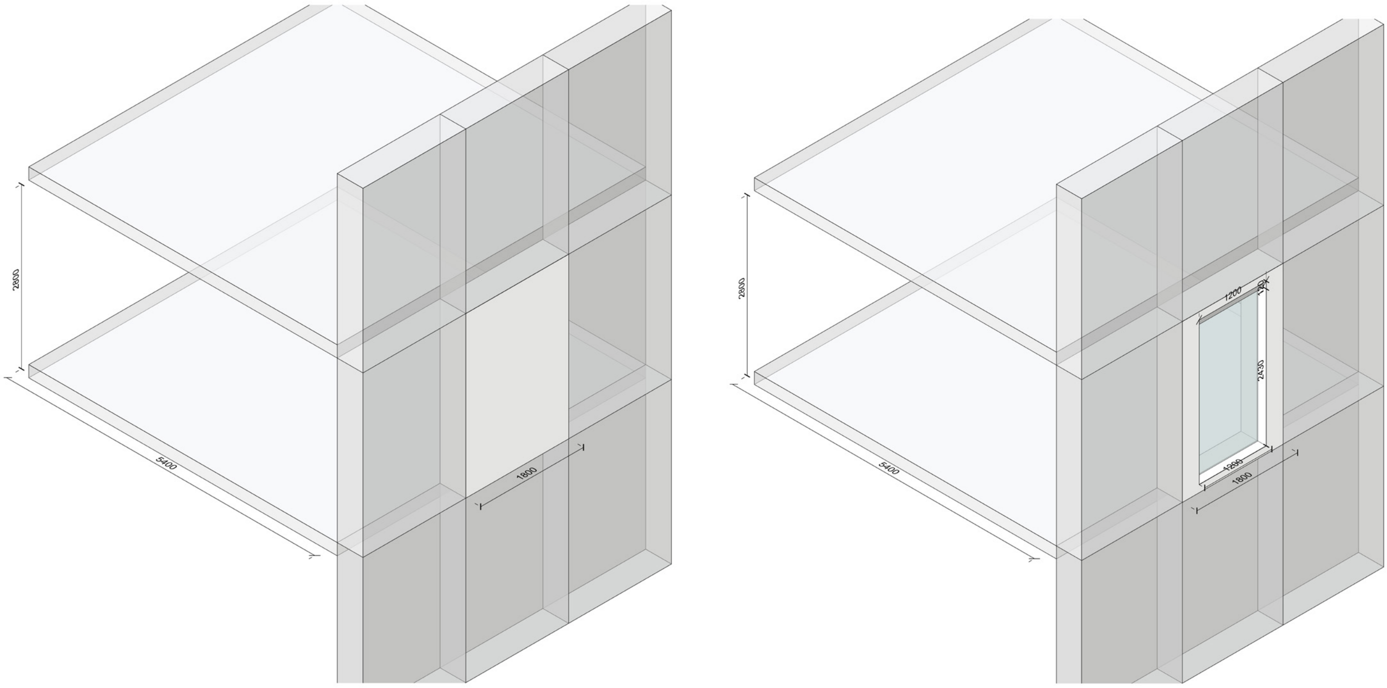


Fig. 2.13: Two standard cassette types, but in their properties the most extreme for climatological consequences. Type 1: enclosed (left), type 2: full opening (right).

Water and wind proofing, waterdrainage
The modularity of the system requires an unconventional high flexibility between building elements. Here arises a problem, because with high flexibility of many elements come more gaps and seals that can create potential water and air leaking. These so called tolerances are also higher with bio-based materials. In this regard, two main sealing areas and solutions will be discussed.
The first concerns the horizontal sealing between two stacked cassettes (figure 2.14 left). This area makes use of the pulling force of the steel L-profile, pulling the cassettes onto the support structure. Both cassettes half-overlap with the ribbon. Between the ribbon and the cassette is a wool felt strip to neutralize tolerances. Additionally, are wood fiber boards placed as an extra outer ribbon along the same area on the outside. They are friction fit by custom 3D printed PLA plugs, which can be demounted by pulling out and are fully reusable.
Vertically, the sealant again makes use of the pulling forces of the connections (figure 2.14 right). Now, the X-fix connector between two cassettes pulls them together, with a wool felt strip in between.

Rainwater drainage is facilitated by drainage pipes. Their diameter and placement is dependent on the roof type and total roof surface. An important note is that, if possible, to allow the façade system its flexibility, the drainage pipes do rather not run along the façade but through the core of the building. Likewise, this allows for potential reuse of rainwater.

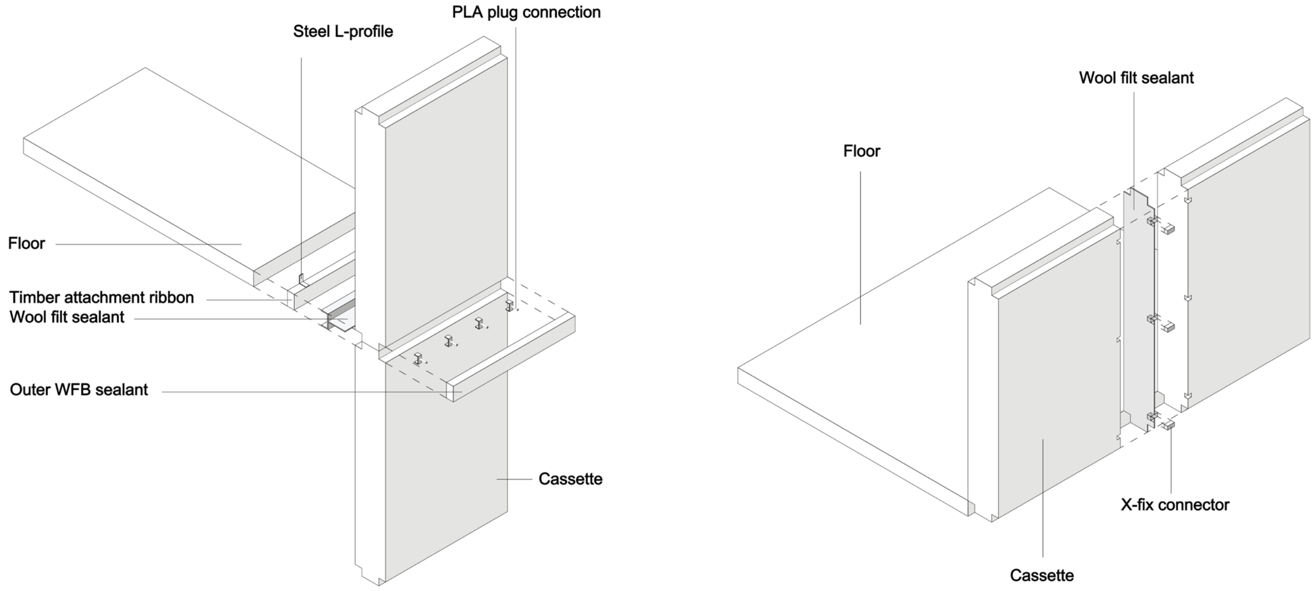


Fig. 2.14: The vertical (right) and horizontal (left) sealing between the cassette modules.

Vapor diffusion en condensation

These physical phenomena can cause the development of mold, freezing of construction materials, unhealthy indoor environments and blocking of sight through windows. Therefore, it is important to see how these materials would react under the circumstances of the Dutch climate. For condensation, both cassette types are examined, since they are both affected. However, for the vapor diffusion only the closed casette is examined, since it concerns only the façade structure. For exact calculations, see the research paper.

Vapor diffusion is the horizontal transportation of water vapor through a construction, caused by a difference in vapor pressure on either side of the construction. Conclusion:

- Beacuase of the high thermal resistance of the structure, surface condensation will not occur, even in the critical winter period.
- Internal condensation does occur at the critical winter period, but is not critical as such to cause any harm to the façade construction or its users.

Thermal conductivity

The main insulating materials are the straw and wood fiber boards. Thermal resistance of a façade $R_c = \text{thickness}/\lambda$ is measured in m²K/W. This depends on the material thickness (in meters) and thermal conductivity coefficient (λ in W/mK): straw: 0,045 and wood fiber board (WFB): 0,038 (see figure 2.11). In this case, we take HR+++ glass with a U value of 0,7 W/m²K. Additionally, there has to be accounted for transitional resistance on the inner ($R_{si}=0,13$) and outer ($R_{se}=0,04$ façade surface. Thermal bridges due to the wood frame are here marginalized, but in the design should be optimized for thermal and sound insulation by seperation of the frame members.

Type one: $R_{total}=R_{si}+R_{straw}+R_{WFB}+R_{se} = 0,13 + 0,4/0,045 + 0,05/0,038 + 0,04 = 7,68$ m²K/W.

Type two:

This type consists of multiple façade elements in parallel, so an average insulation value can be determined. The U value of all elements need to be determined first: $U=1/R_{total}$. For the element with straw and WFB: 1/7,51=0,13 W/m²K. $\bar{U} =(U_{window}\, A_{(window}+U_{(straw+WFB)}\,)\, A_{(straw+WFB))}/A_{total}$

$\bar{U} =(0,7 \cdot 2,92+0,13 \cdot 2,48)/5,4 = 0,44$ W/m²K. So the average insulation value is:

$R_{total}=0,13+1/0,44+0,04 = 2,45$ m²K/W.

Type two is obviously a weak spot in the thermal resistance. The ratio of open/closed façade

surface should be kept in mind when designing a building.
The façade system does not contain heating or cooling installations.

Ventilation
Ventilation is facilitated in type two only, since the grilles are placed along with façade openings. This is a common building practice, because both daylight and ventilation requirements usually concern the same spaces, like living rooms, bedrooms, offices, et cetera. Additionally, all windows and doors applied can be opened for an increased ventilation capacity. The grille used is the following: https://www.duco.eu/nl/producten/raamventilatie/ventilatie-en-zonwering/ducotwin-120-zr-ak.
The ventilation capacity is 14,5 $dm^3/s/m$ grille.The ventilation capacity per person is about 7 dm^3/s. The ventilation grill is as wide as the façade opening: 1,2 meters. This means the ventilation capacity per cassette is $1{,}2 \cdot 14{,}5 = 17{,}4\ dm^3/s$. This is sufficient for ±2,4 persons, without creating an overpressure on the grille. Determining if this is suffcient for a building, strongly depends on other aspects - like program, space plan, ventilation type (A,B,C,D) - and their design. The grille is placed above the sunscreen, preventing ventilation obstruction.

Sound
For sound insulation properties, many factors play a role and can influence the perfomance drastically. This was tested exclusively for airborne sound in the research paper, since that is what the façade system primarily experiences. The required calculations displayed are proof of the performances. All information about the sound requirements and performances were used from the Bouwfysica book, chapter 11. The calculation was executed for two main situations, to demonstrate the versatility:
- type one: standard closed cassette
- type two: cassette with floor-ceiling window

In short, only type one meets the minimum requirements needed for dwellings (≥ 35dB) and offices (≥ 40dB). A building with only cassettes type two will not be sufficient, and need to be alternated with type one to some degree. Situations with smaller windows will (intuituvely) have a higher insulation performance and meet the criteria as well.

Climate façade finishes
These outside finishes include two options: a green façade (including nesting boxen for birds, bats or insects), and PV panels.
The green façade finish can have multiple advantages: increased biodiversity, filtering air pollutants, buffering rainwater, decreasing temperature of microclimate and increased thermal/acoustic insulating performance. There is also the possibility to add nesting boxes between the vegetation panels. The waterbuffering is 20L/m² façade surface at a maximum. Like in practice, they can be placed on the most top row of the green layer so that it is out of human reach. Another important factor in determining the application, is where the cassette is placed in the façade. If it is placed under a balcony, gallery, or on a north orientation, sunlight will be significantly reduced and the placement might have to be adjusted. This is less of an issue with railings, since they are executed in thin steel wiring.
For the PV-panels, a similar approach to the placement of nestingboxes was used. Due to the risk of damaging the PV-panels by human activity, they have to placed somewhat out of human reach.

Daylight entry and sunshading
For daylight entry, two main window types are implemented in the façade system: the floor-ceiling window (figure 2.13) and the window with parapet. The floor-ceiling window is also suitable for doors. Of course, depending on which window type is used, different sunlight entrance values are established. The glass used in the façade is HR+++, which reflects a high amount of the suns heat

(g=0,6).
For sunshading, a drop-arm sunscreen is chosen for multiple reasons (see ventilation paragraph for exact product). The function of the sunscreen is to obstruct any heat from entering the building and to prevent blinding the inside users. First of all, this is a system that is placed outside, making the reflected and absorbed heat to be released to outside air instead of inside. Secondly, does this system allow for (partial) views outside. Thirdly, is there a possibility to automatically fold or unfold, making it suitable for dwelling, office and commercial spaces. The share of the total amount of energy from sunlight that eventually reaches inside, is called sunlight factor g. For HR glass in combination with the drop-arm screen an average g-factor of 0,15 can be reached. Since the final performance of the façade openings and sunshading is highly dependent on other design aspects as well (e.g. façade orientation, building shape and dimensions , et cetera), no specific calculations are made here. A study on sunslight entrance in combination with the sunscreen, however, does reveal the performances during all seasons of the year in the Netherlands (figure 2.15). It reveals that in summer almost all heat is blocked from entering, preventing high energy consumption for cooling. In winter it can block sunlight to prevent blinding, but simultaneously enter the opening and reduce energy consumption as a result of heating.
Some verification calculations were executed concerning the phase shifting values and the thermal accumulation of the façade system. These can be viewed in the research paper. In short it shows that, although the phase shifting is more than enough (6,5 days), thermal accumulation is relatively weak with approximately 1,5 hours. This could create problems, and should be accounted for when designing a building with this system (i.e. with cooling methods).

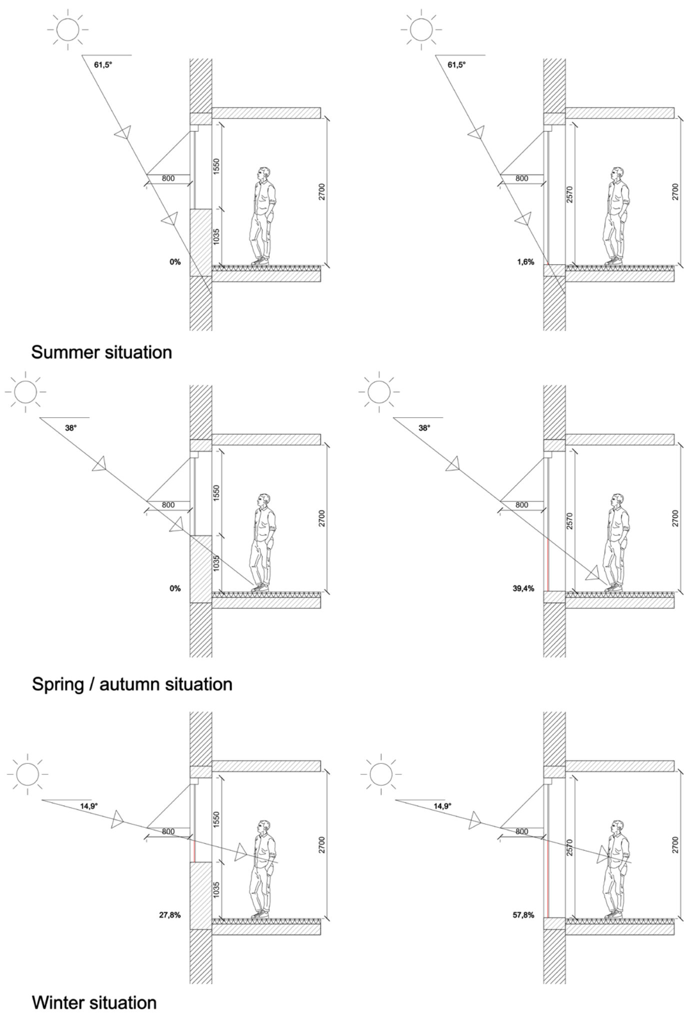


Fig. 2.15: Determination of sunlight entrance in the seasons for the Dutch climate, calculated for cassette type 2: full floor-ceiling opening and type 3: window with parapet.

Climate type matrix
The façade system has to offer a wide range of custom options in relation to the climate. This is realised through the variety at the component scale. Fundamentally, are the three types of cassettes accompanied by additional options in relation to the climate. In figure 2.16 all options are listed in a matrix.

Research conclusion
In this chapter, an extensive research was conducted by investigating the development of a façade system using the framework of architectural tectonics. This method allowed the study to focus on three major pillars in the façade design, being the façade structure, the materials used and the study of climate phenomena projected on the façade. These three topics were linked to their respective sustainable construction paradigms, to aim for an integration of more sustainable construction practices. In conclusion, could be stated that all topics within the sustainability paradigms were touched upon in this research. The theoretical basis (chapter II) produced the general design preconditions, to elaborate a façade system in the design (chapter III). An important note is that there is not one correct way of designing a façade system with these parameters. Design is always intuitiveand subjective to some extent.
A relatively high degree of modularity was achieved, by a) safeguarding standardized connections types, b) examining different customizations in the climate design, c) taking inventory on a variety of renewable construction materials and d) a consistent operation on different scales. This resulted in a coherent overall façade system.
The research covered all three required EAT pillars quite extensively, yet the final options might still be considered limited. Relevant follow-up research would be to explore more complex façade shapes, to expand the system's application field. This could include more inclined, organic or even parametric design solutions. The use of more and different biobased materials is also a field for investigation. The research result is therefor a more general design template, rather than the outcome for one specific design solution.
There is also room for optimization in the façade's accessories, like the balcony and outside gallery, which include mostly circular principles but is not optimized more for biobased potential.

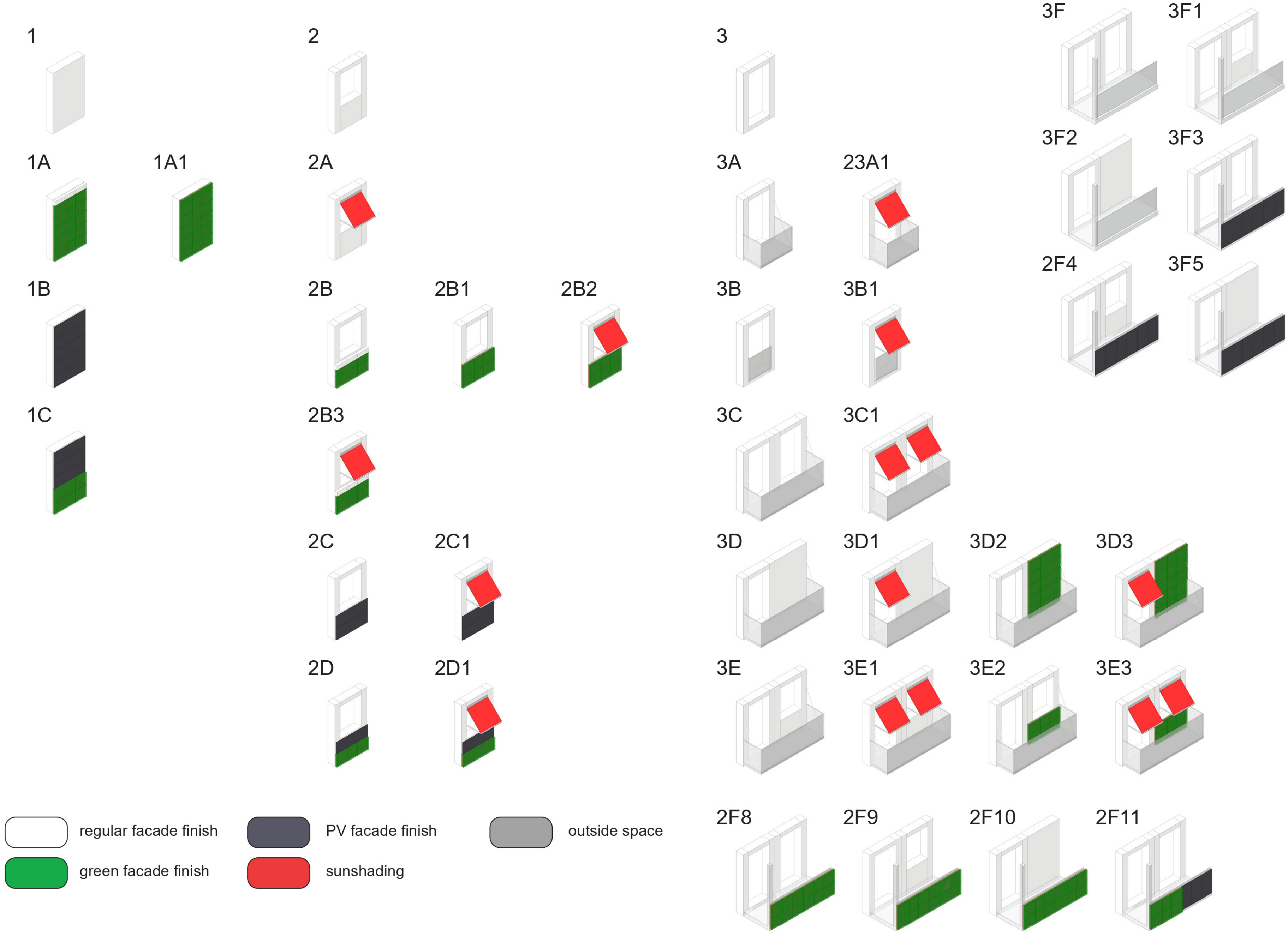


Fig. 2.16: Climate variables in facade matrix. A matrix showing all climate design options for the façade. The more options, the more the façade system can be tailored to the user's specific demands. Nevertheless, it is all based on the same façade system. The different regular façade finishes are excluded here.

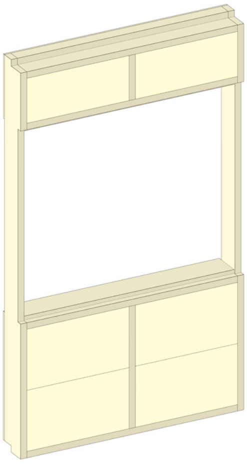
2.4 | The facade system design

After gathering information on all three EAT pillars, the next phase began of drafting the facade system design. With each pillar contributing the respective knowledge, most preconditions were for the most part readily determined. It is important to note, however, that the research and design goes hand in hand. When thinking about the requirements and their spatial consequences, automatically the design process starts simultaneously. It is only in this part, though, that full attention was focused on the elaboration and documentation of this system with the three EAT pillars integrated, linked by modularity.

Cassette design iterations

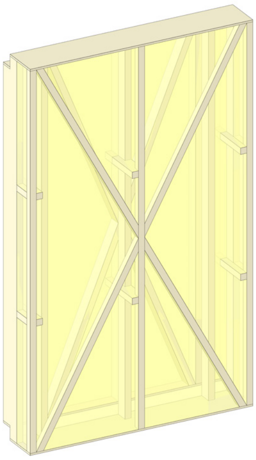
The design of the facade system can be divided into two domains: the core system on the one hand and additional facade layers on the other. With a central and essential role in the facade system, the core system was designed first. Relatively quickly in the EAT research the various advantages of a timber-straw combination became clear, providing guidance to the development of the design. In line with the findings for the facade structure, are the outer dimensions sized according to the 1,8m grid. There is however flexibility in width (min. 0,9m) and height (max. 4,5m).

Fig. 2.17: Collage of the sketches made during the design of the facade system.



V1

V1 was the first draft of the cassette design. Here, a boxed shape was created of timber with plywood for stability, including an opening for a window. notches were designed around edges for proper sealing.

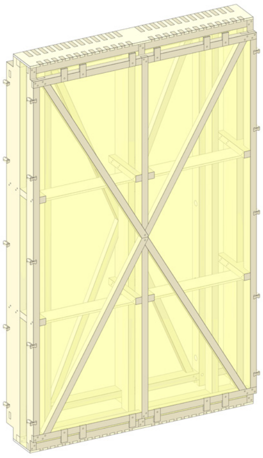


V2

V2 was the first design of the cassette based on a timber-straw combination, after the gained knowledge from the materials study. It contains beams, columns and cross bracing elements. Notches were now on the interior side for individual installment.

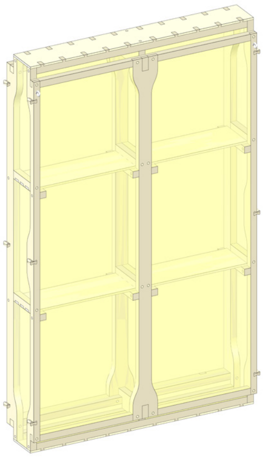
V3

V3 was a relatively small iteration on V2, adding additional notches on the exterior side for proper wind and water sealing. recesses in the sides were also addes to allow room for connecting cassettes side by side.



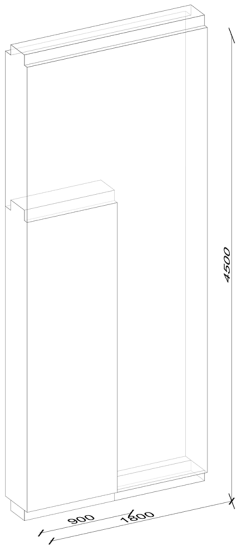
V4

V4 made much improvement on the use of solely renewable materials, replacing steel screws with wooden dowel and dovetail connections. cassette-cassette connection is established by the x-fix connector.



V5

V5 continued the principles of V4, but by radically simplifying the design it reduces part count and used material, cost and production time.



The width of a cassette can vary from 0,9-1,8m and the height can be any floor height up to 4,5m.

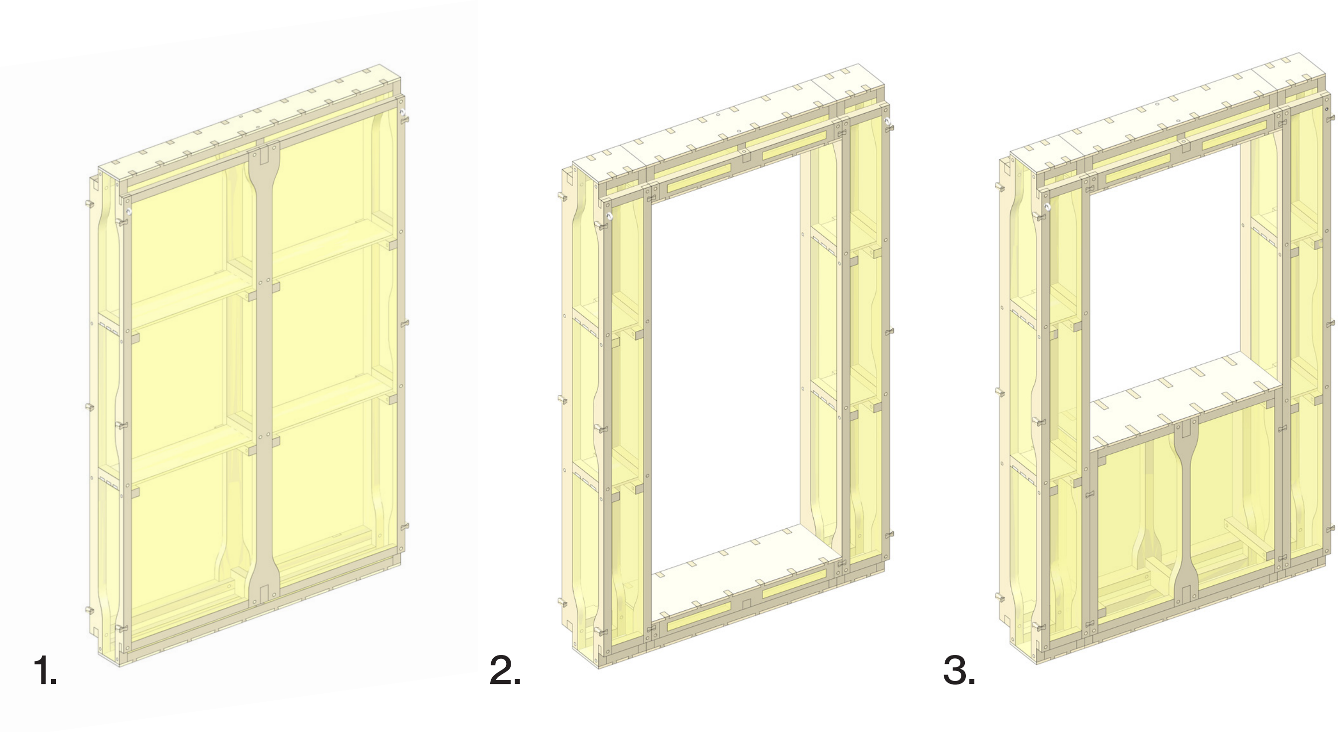


Fig. 2.18: The final timber-straw cassette design, with three standard types; 1. enclosed, 2. floor-ceiling opening, 3. regular window opening with parapet.

Aligning with the results from the study into the EAT pillars, are three different cassette types developed in the final version of the cassette design. They embody the standard building blocks of the core system. Additionally, they are based on the general requirements of the building programs they are designed for: dwellings, offices and retail. Cassette type two and three on their turn contain multiple standardized components, like the vertical side mullions, upper/lower lintel and the parapet. Because of the standardized components being fully demountable, they can be taken apart and for example switch the lower lintel for a parapet. Each type has stainless steel hoisting loops in the upper corners for hoisting on the building site.

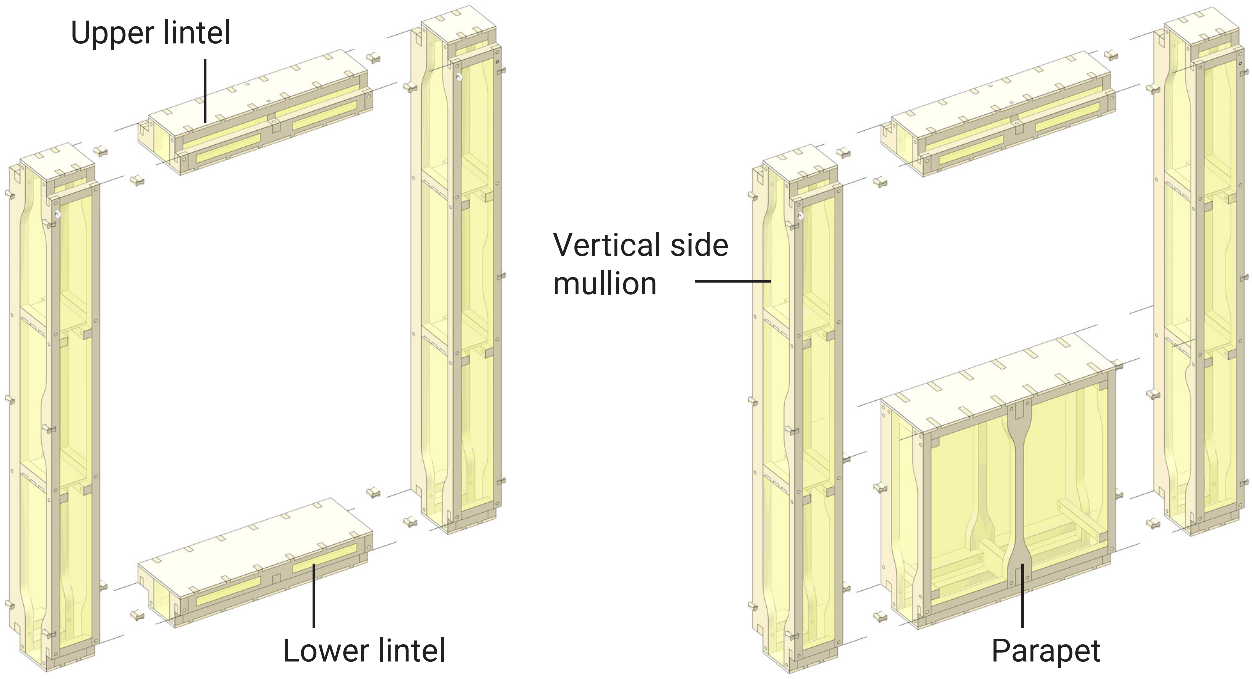


Fig. 2.19: Exploded axonometries of cassette types two and three, showing the following components: vertical side mullions, upper and lower lintel and a parapet.

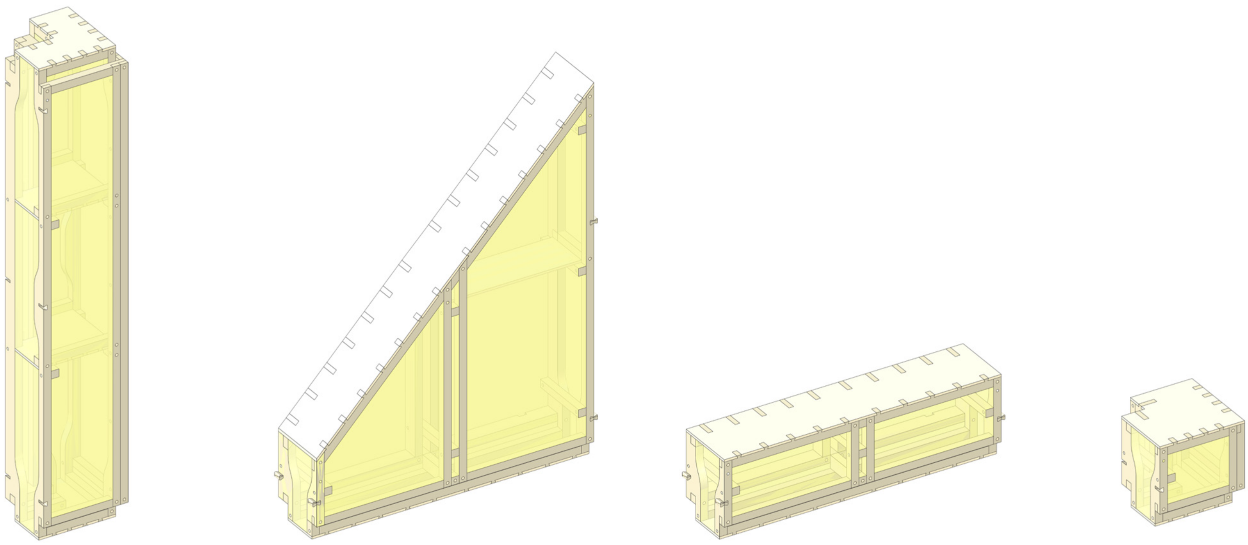


Fig. 2.20: The exceptional cassettes, to account for facade corners and roof edges. From left to right: facade corner cassette (inward and outward), pitched roof edge, flat roof edge, facade corner roof edge.

Of course, with just the three standard cassette types it is not possible to cover a complete building structure. There exceptions that need to be accoutned for. These exceptions mainly include facade corners (inward and outward), roof edges (pitched or flat), or a combination of the two. By making a general template for them, together with the three standard cassette types create a complete facade kit of parts, where all cassettes act like puzzle pieces to comprise the whole facade system. The statement of them being templates is important, because they are principles that can be custom taylored to the specific building design situation. For example: the pitched roof edge is not necessarily 45º, butcan vary for anything between 0º and 90º. The same applies to the degree of the facade corners.

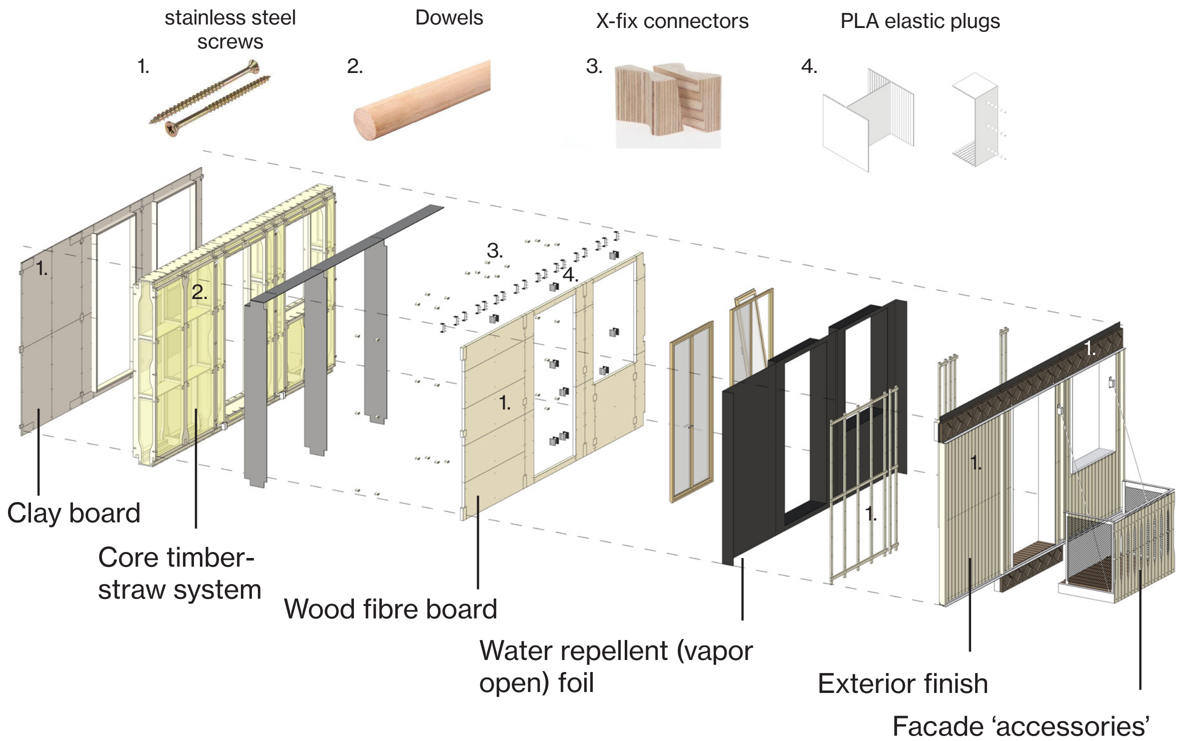


Fig. 2.21:

In figure 2.21, the complete facade system is visualized. Here, the relation of the core timber-straw system with the other interior and exterior layers are shown. Important to show here is also the used connections and their materiality. The core system consists of mostly wood-based connections, but most other connections are screws. Another important connection type is the PLA 3d-printed plugs/clamps. PLA (poly lactic acid) is made of renewable materials (residual agricultural waste) and designing it as plug and/or clamp allows it to be demountable. This connection type is mainly used in the sealing connections for quick and easy installment on the construction site. Whilst PLA is theoretically biodegradable, in practice is not hardly ever done. Additionally PLA is quite flammable, though it is not used for structural connections. Therefore, untill infrastructure for PLA end-of-life treatment is established, the stainless steel screws are used for these connections. All connections are demountable.

Fig. 2.22: The full prefabricated panel, in this example consisting of the three standard 3 cassette types. The balcony railing is also detailed according to the shapes of the timber used inside the core system.

Cassette type two can also be accomodated by complementary facade 'accessories', these accessories concern elements that facilitate outdoor spatial experiences, like (French) balconies or a gallery for accessability (see figure 2.23). This is designed in such a manner so the cassettes only have one universal structural attachment point dedicated for all accessories. Additionally, by viewed these elements as facade accessories, safeguards the continuity of the thermal barrier between inside and out. In figure 2.24 the attachment of the gallery structure to the facade system is

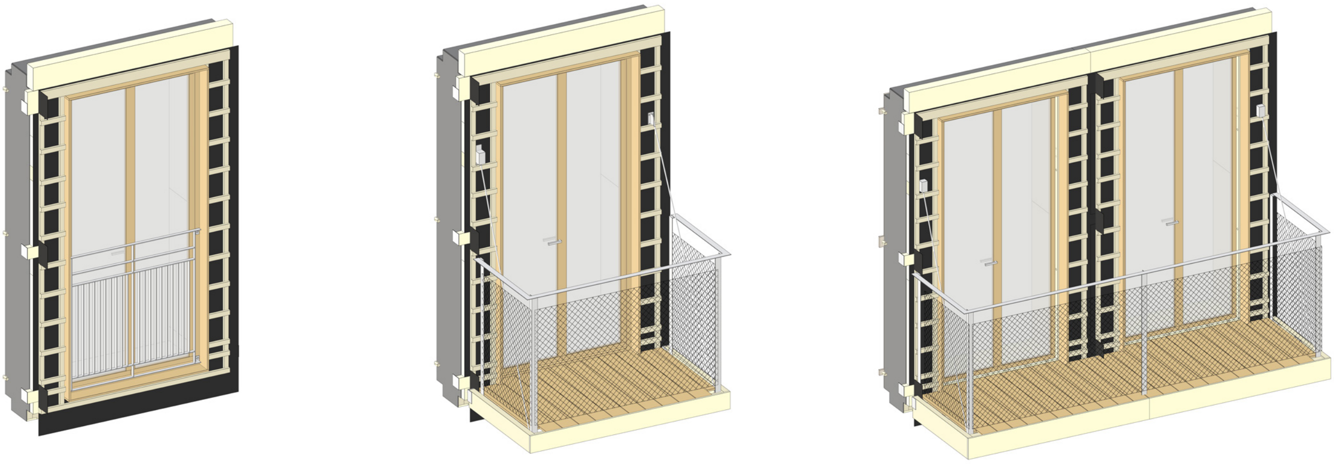


Fig. 2.23: The design of several facade 'accessories', applying to cassette type three. Left: cassette with French balcony, middle: cassette with small balcony, right: double cassette with large balcony.

illustrated. The close up on one of the cassettes shows the attachment point: a steel pin with screw thread and a U-profile welded to the end. The steel screw thread is screwed into a Rampa insert nut, which is screwed in the timber frame of the cassette. A rubber sealant is fastened with a nut on the exterior side.

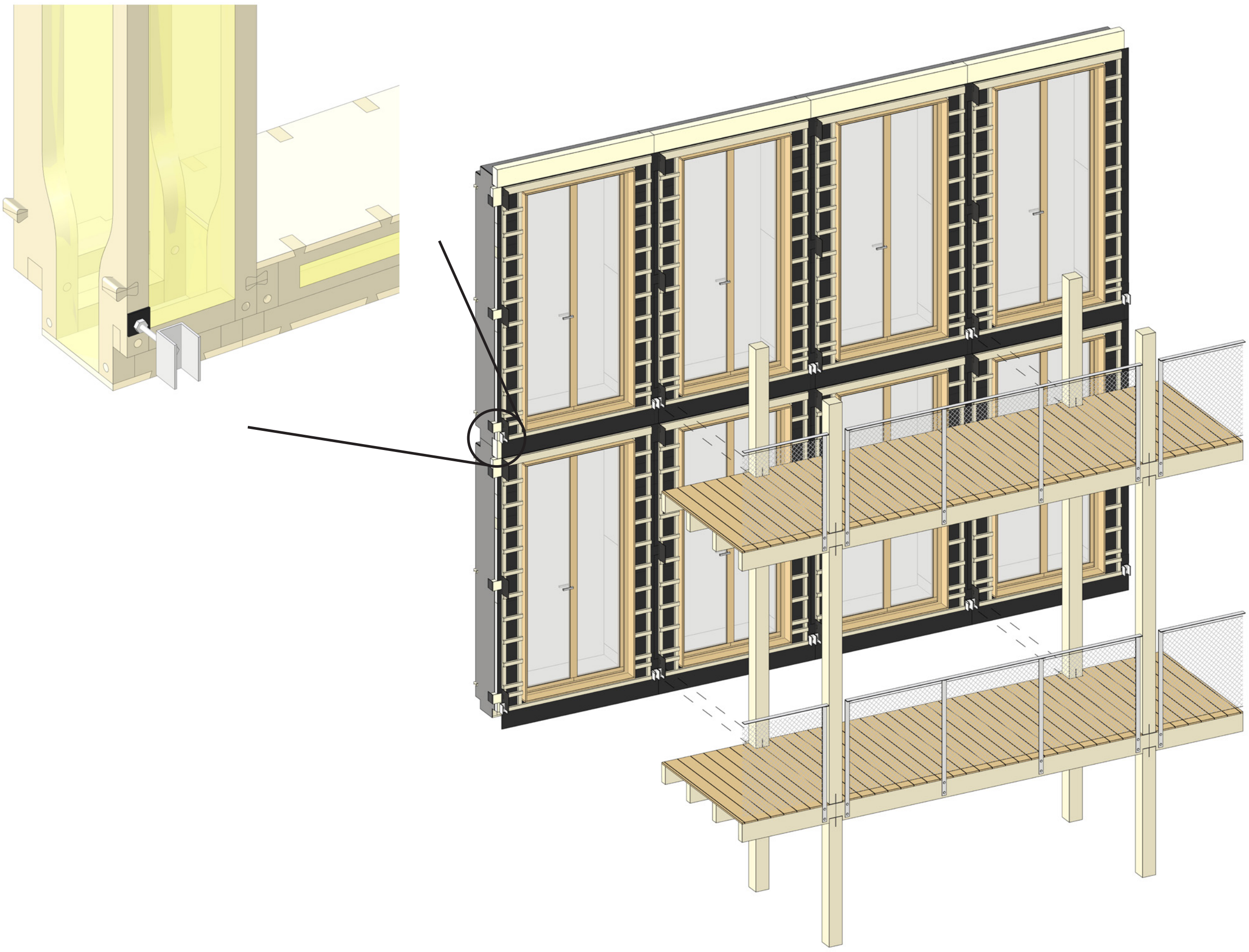


Fig. 2.24: A facade of 8 cassettes with a gallery 'accessory. The close up shows design of the attachment point for the facade accessories.

2.5 | The facade core system assembly

The materials needed and used in the production and operation phase of the cassettes are designed as a kit of parts. This kit is made up of 99,99% biobased materials, and during production only 0,1m³ of waste is created. This, however is mostly straw which can simply be reused in the cassette production. Other waste consists of wooden snippets, shavings and wood dust, which is suited for energy recovery or repurposing.

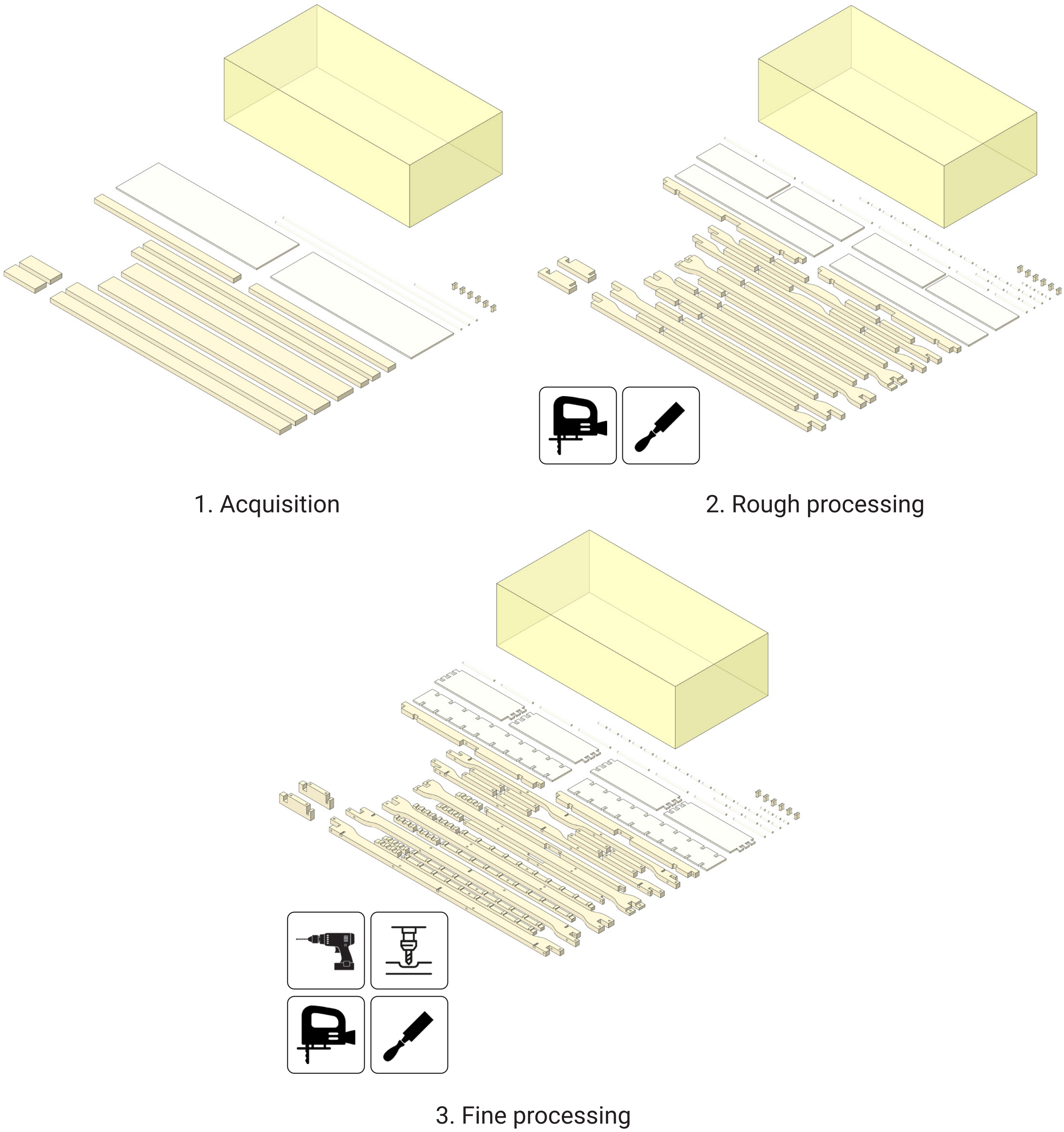
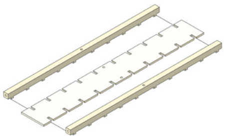


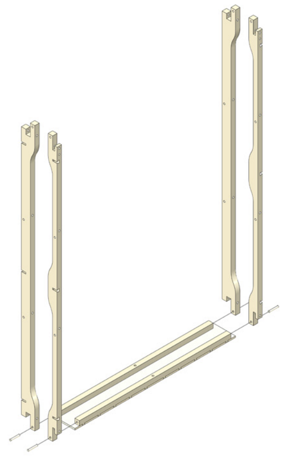
Fig. 2.24: The three main steps to create the kit of parts.

The assembly process in the factory

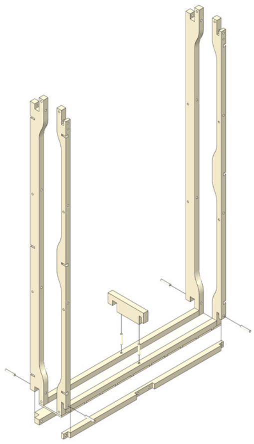
The assembly process of a cassette is relatively easy and quick: with a hammer and an industrial press the cassette is assmebled in only twelve steps.These steps are listed below:



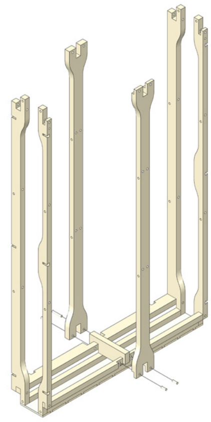
1. Attach bottom beams on bottom plate.



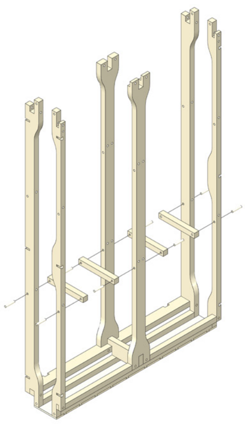
2. Attach corner columns to bottom beams.



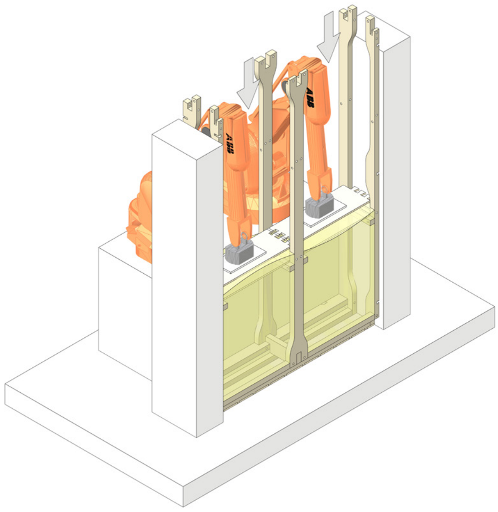
3. Attach lower cross brace and lower beams.



4. Attach middle columns.

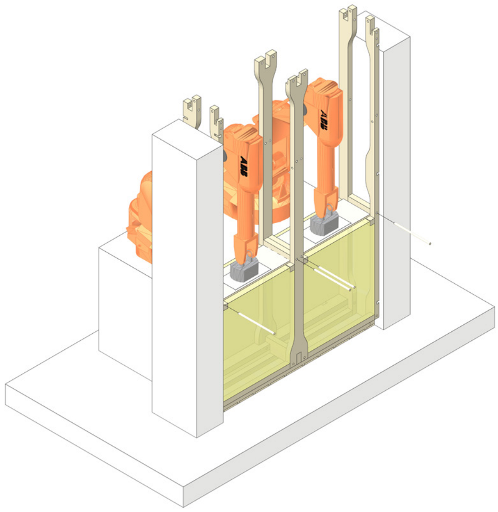


5. Attach anti-buckling braces.

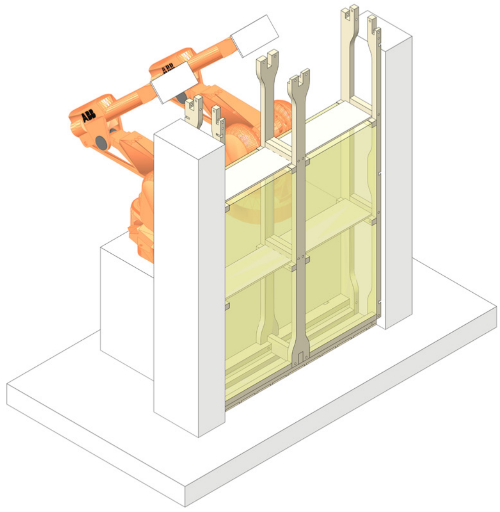


6. Place straw in first compartment and press down with anti-buckling plates.

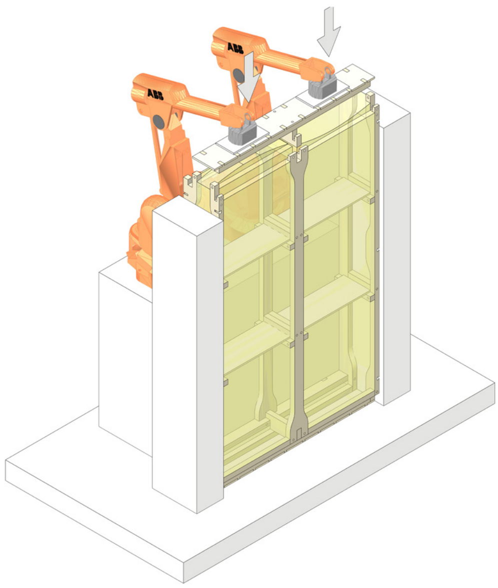
Fig. 2.25: The twelve steps of the cassette assembly process. *Continues on next page.*



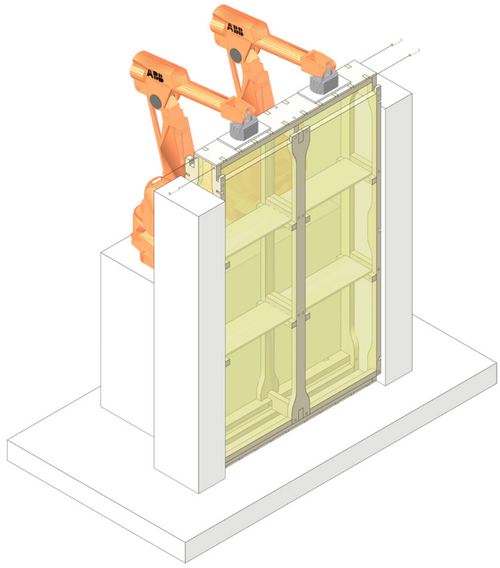
7. Attach plate braces.



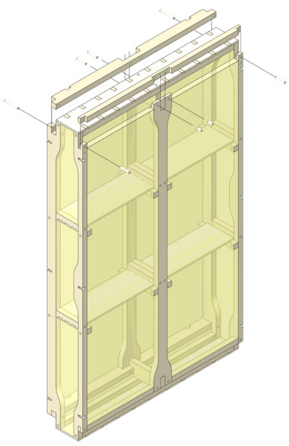
8. Repeat process for second straw compartment.



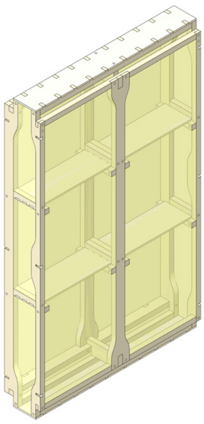
9. Repeat process for third straw compartment with top plate.



10. Attach top plate.



11. Attach upper beams.



12. Complete timber-straw cassette.

Fig. 2.25: The twelve steps of the cassette assembly process. Starts on previous page.

The assembly process on site

The assembly on the construction site is because of the high level of prefabrication aso relatively easy and quick. First, the prefabricated ribbons are installed on the floor or beam edges (figure 2.27). These ribbons consist of a timber frame with wooden dowel half-lap joints, filled with insulating cellulose fiber mats (figure 2.26). Cellulose is chosen here because the ribbons elements are too small for pressed straw. Two attachment points on either side are made to house large steel L-profiles. These profiles are connected to the floor/beam edges by drilling bolts through them into the floor/beam. This makes the facade system fit for both renovation and new construction. On top and below of these L-profiles are smaller steel L-profiles (for structural load transfer from facade directly to buildings support structure) for the attachment of the cassettes. A bolt is drilled, through the smaller steel L-profile, into a Rampa nut in the timber frame of the cassette (right image in figure 2.28). Each attachment point has some degree of freedom in two directions (y and z) to safeguard attachment despite small deviations in the dimensions. The L-profiles are offset from either side, because in case the ribbon/cassette needs to be attached near a column, it is still in reach for the facade installer. The width of the ribbon corresponds to the 1,8m grid size of the cassette. The depth is 10cm and the height corresponds to the height of the floor/beam edge.

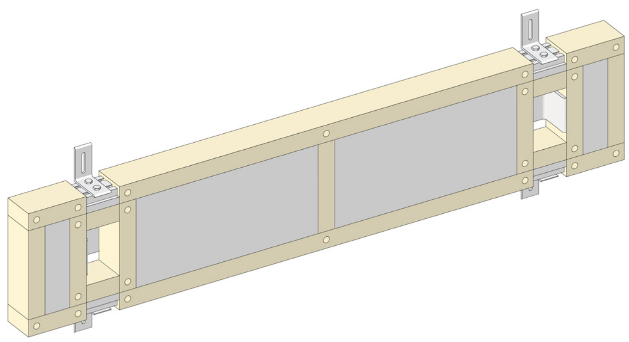


Fig 2.26: The prefrabricated ribbon element.

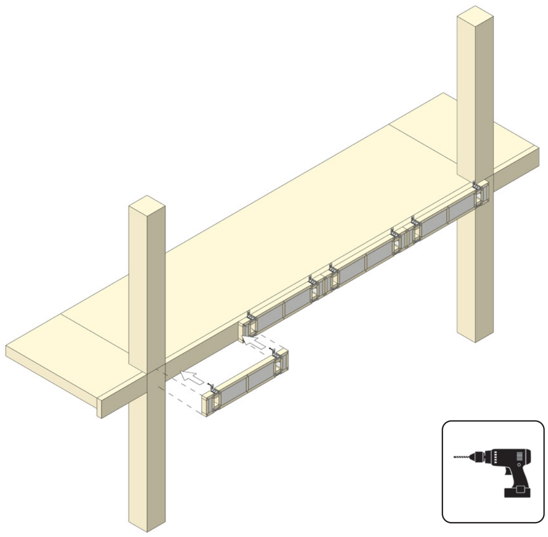


Fig 2.27: The first step for assembling the core system on-site. The ribbons are drilled into the floor/beam edge.

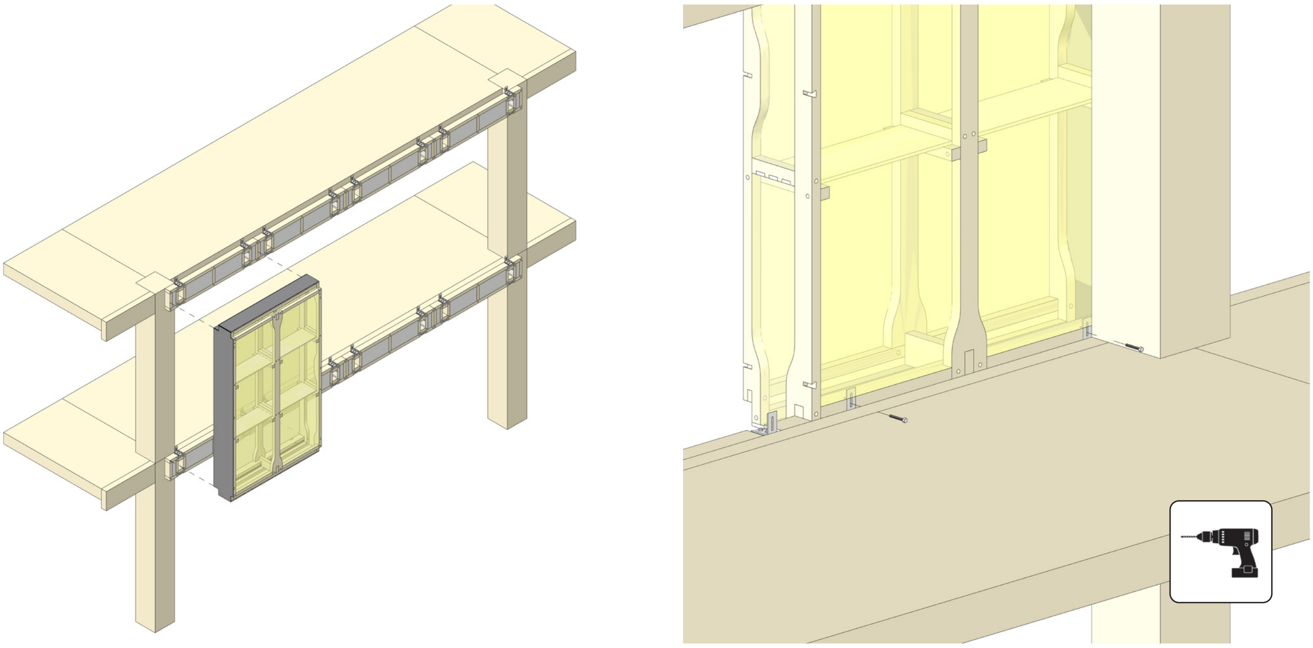


Fig 2.28: The second step for assembling the core system on-site. To show the principle, only one cassette is assembled onto the building in the figure. In reality full prefab panels, consisting of 3-4 cassettes, are installed at once on 3-4 ribbons. In the image on the bolts are shown that are driven through the slits in the steel L-profiles into rampa nuts of the timber frame.

The on-site assembly of the cassette to the support structure is spatially complex. To explore and comprehend how this could be executed, a small 1 : 25 scale model was made to test the (theoretical) feasibility. This was a crucial last step in the facade system design, which marked the beginning for the 1 : 1 scale standard cassette prototype.

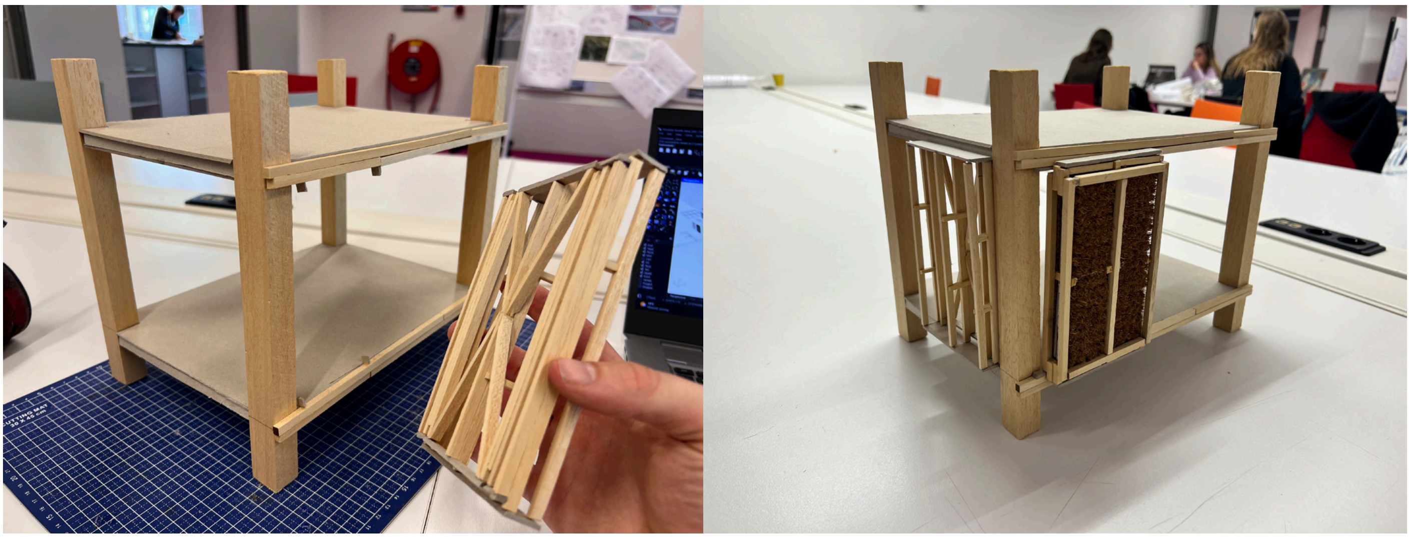


Fig 2.29: Sketch model in scale 1 : 25 of cassette principle design and attachment to buildings support structure. Left: cassette V2, right: cassette V5.

The prototype

A prototype was developed to test the feasibility of the designed core system. It comprises a sized down version of the type 1 cassette of 1x1 meter. However, the connections remain 1 : 1. The only difference in principle is that no anti-buckling plate and braces are needed within the prototype.

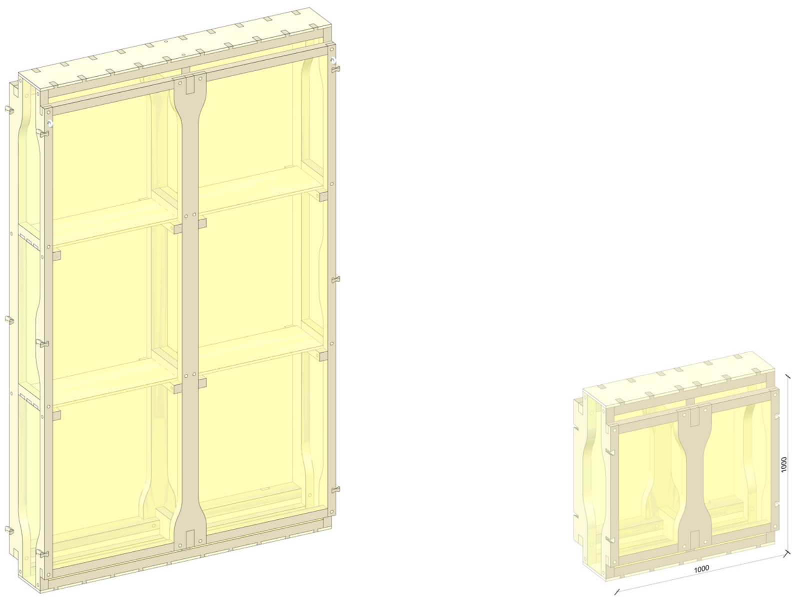


Fig 2.30: Left: the standard casste type 1, right: the prototype of 1x1m. About 1/6 of the size of the actual cassette.

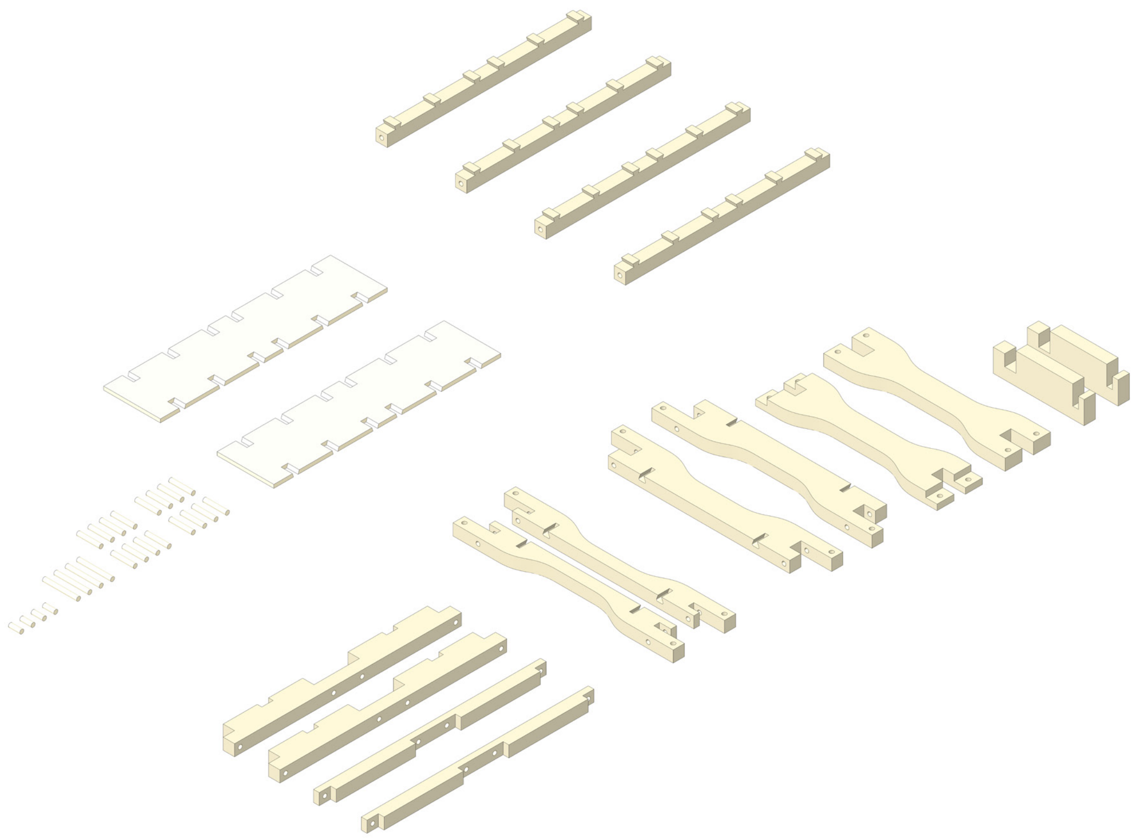


Fig 2.31: The prototype kit of parts.

The first step in the production of the prototype was underestimated. All parts had to be somewhat adjusted in their design to fit the prototype preconditions and the standard available wooden products. Subsequently, all these materials were bought an transported in to the faculty. As a single student with only a bike, this was challenging. Eventually all parts were there and the processing could start.

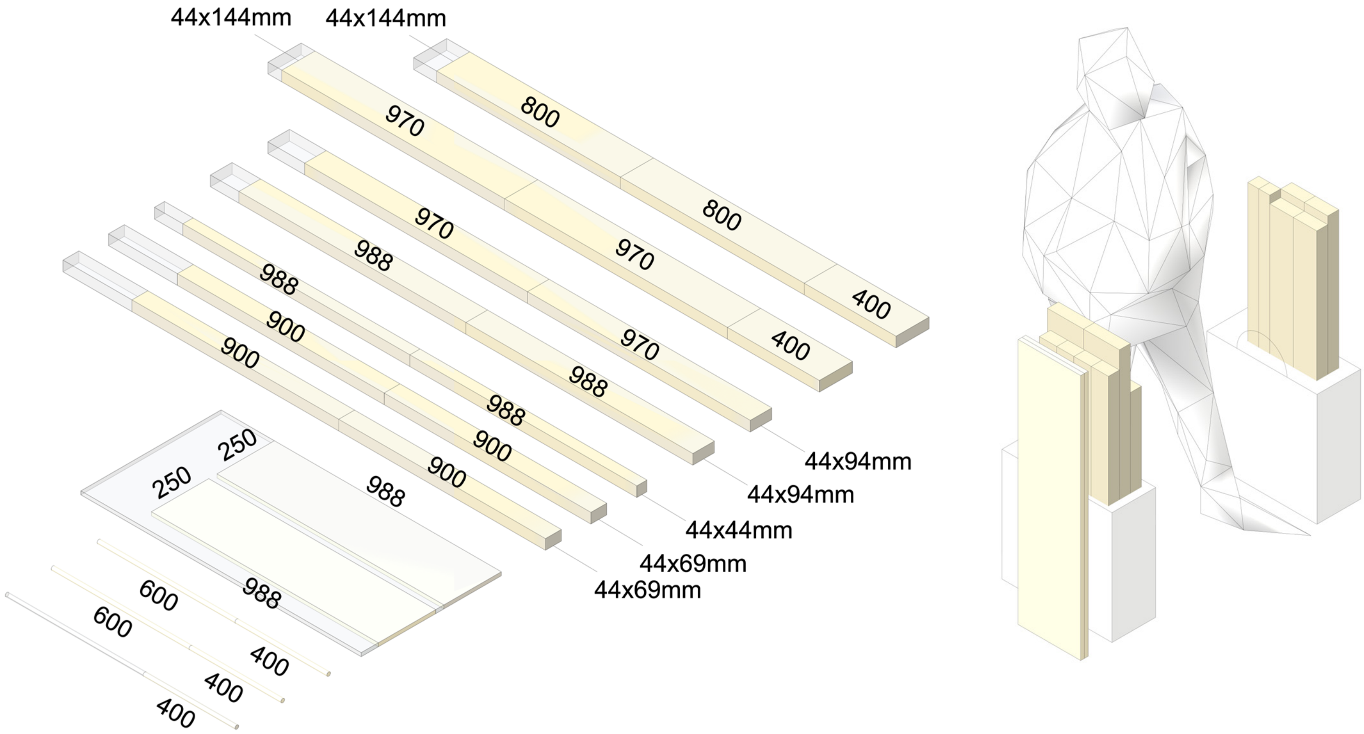
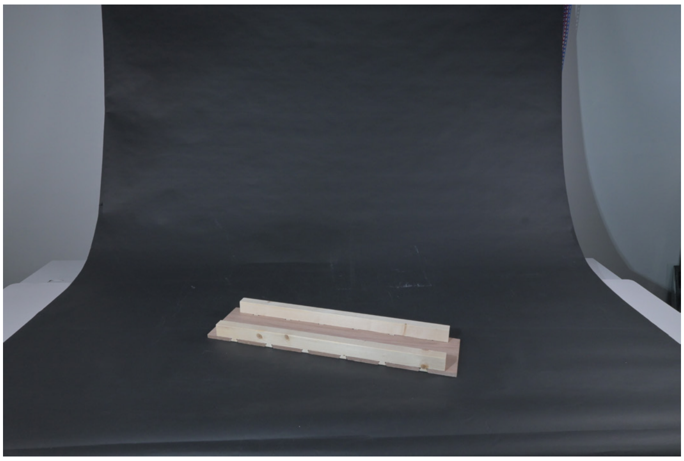


Fig 2.32: The logistics: retrieving all parts from standard wooden products sold in hardware stores and transporting them in two large shopping bags to the faculty.

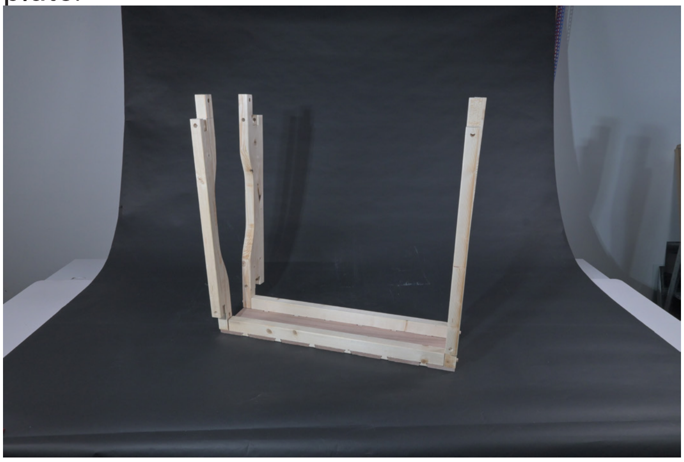
The processing of the wood took about a 100 hours in total. One part had to be remade, as a mistake was made. New wood had to be bought from the hardware store. The old wrongly processed part was reused in the urban model shown in chapter three. Eventually, when all parts were processed (figure 2.31), the assembly could commence.

Fig. 2.33: The real prototype kit of parts.



1. Attach bottom beams on bottom plate.

2. Attach front corner columns.



3. Attach rear corner columns.

4. Attach lower front beams.

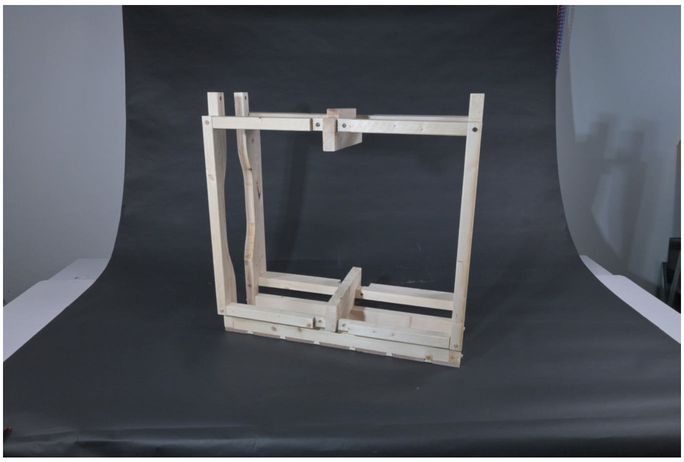
Fig. 2.32: The sixteen steps of the cassette prototype assembly process. Continues on next page.

5. Attach lower rear beam.

6. Attach lower cross bracing.

7. Attach upper front beam.

8. Attach upper rear beam.



9. Attach upper cross bracing.

10. Attach front middle column.

Fig. 2.32: The sixteen steps of the cassette prototype assembly process. Continues on next page.


11. Turn the frame.


12. Reach rear side of the frame.


13. Attach rear middle column.


14. Apply the plywood mold.


15. Press the straw.

Fig. 2.32: The sixteen steps of the cassette prototype assembly process. Continues on next page.

Fig. 2.34: The sixteenth step: complete timber-straw cassette prototype with the top plate. Starts on page 59.

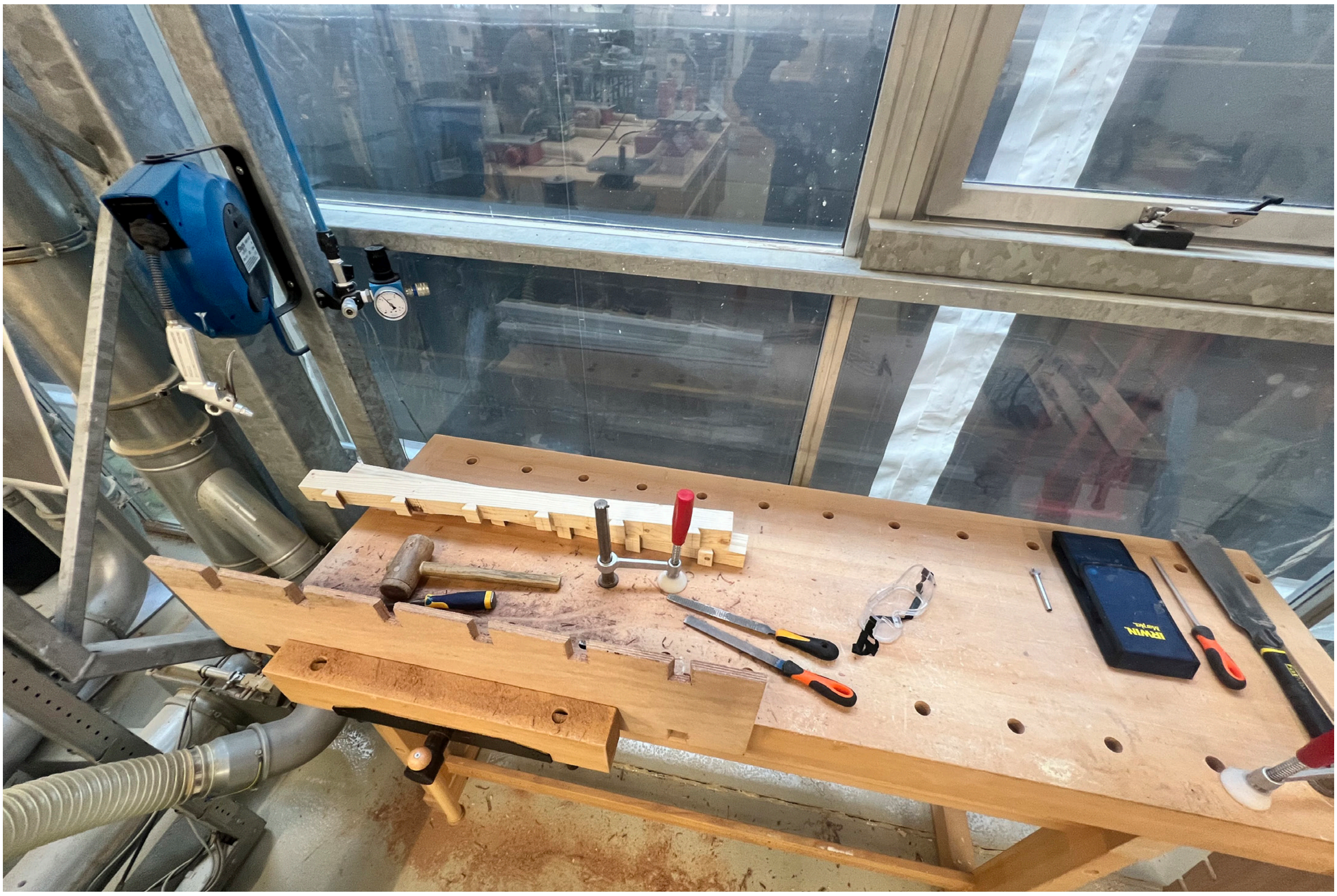


Fig. 2.35: Processing the timber parts for the dovetail connection using files, a hammer, a handsaw and chisels.

Fig. 2.36: Assembly of the timber frame with dowels and a hammer.

Fig. 2.37: Installing the plywood mold to press the straw in the timber frame.


Fig. 2.38: The finished timber-straw cassette.

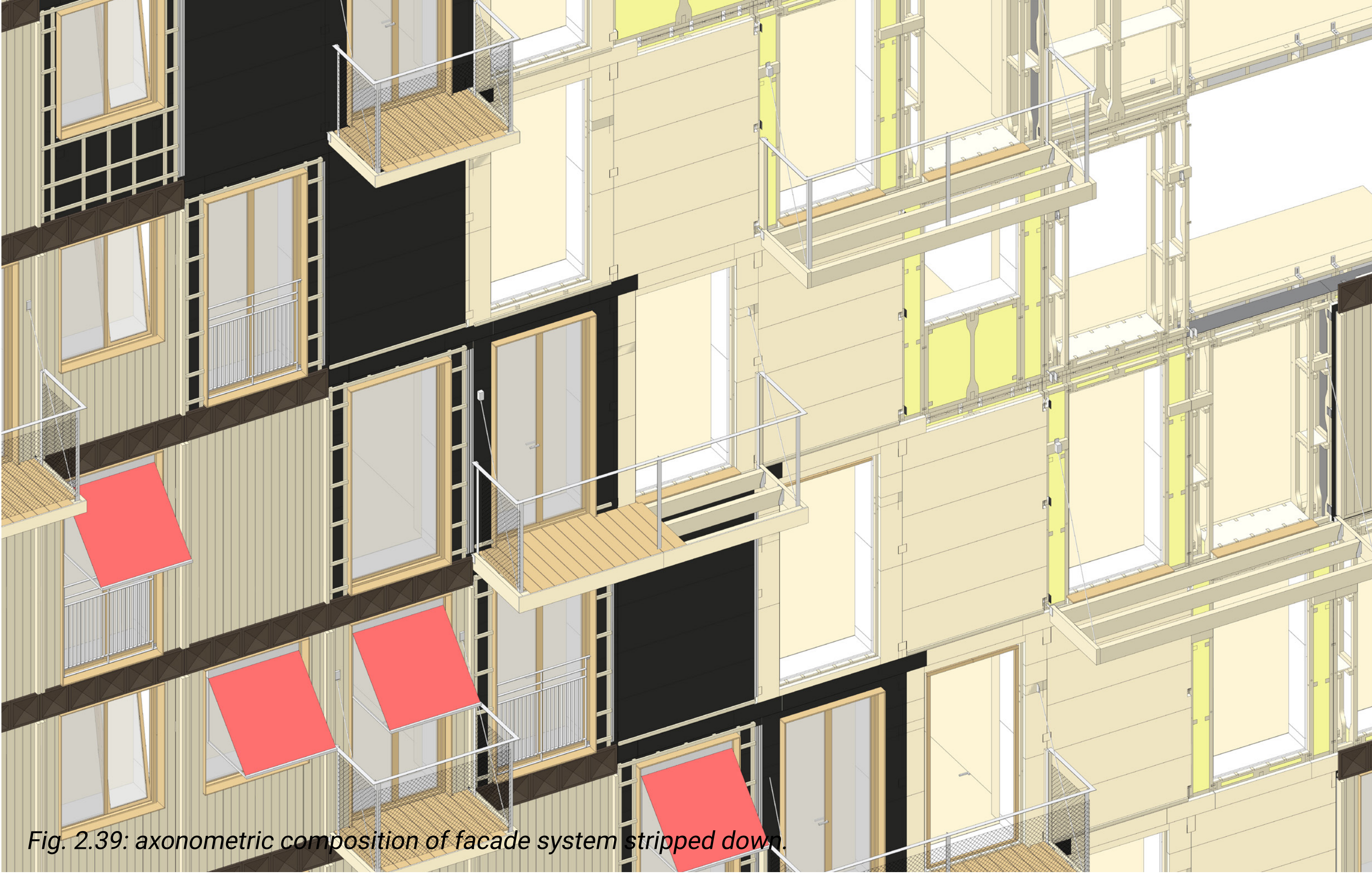


Fig. 2.39: axonometric composition of facade system stripped down.

Research conclusion

In this chapter, an extensive research was conducted by investigating the development of a façade system using the framework of architectural tectonics. This method allowed the study to focus on three major pillars in the façade design, being the façade structure, the materials used and the study of climate phenomena projected on the façade. These three topics were linked to their respective sustainable construction paradigms, to aim for an integration of more sustainable construction practices. In conclusion, could be stated that all topics within the sustainability paradigms were touched upon in this research. The theoretical basis (chapter II) produced the general design preconditions, to elaborate a façade system in the design (chapter III). An important note is that there is not one correct way of designing a façade system with these parameters. Design is always intuitiveand subjective to some extent.

A relatively high degree of modularity was achieved, by a) safeguarding standardized connections types, b) examining different customizations in the climate design, c) taking inventory on a variety of renewable construction materials and d) a consistent operation on different scales. This resulted in a coherent overall façade system.

The research covered all three required EAT pillars quite extensively, yet the final options might still be considered limited. Relevant follow-up research would be to explore more complex façade shapes, to expand the system's application field. This could include more inclined, organic or even parametric design solutions. The use of more and different biobased materials is also a field for investigation. The research result is therefor a more general design template, rather than the outcome for one specific design solution.

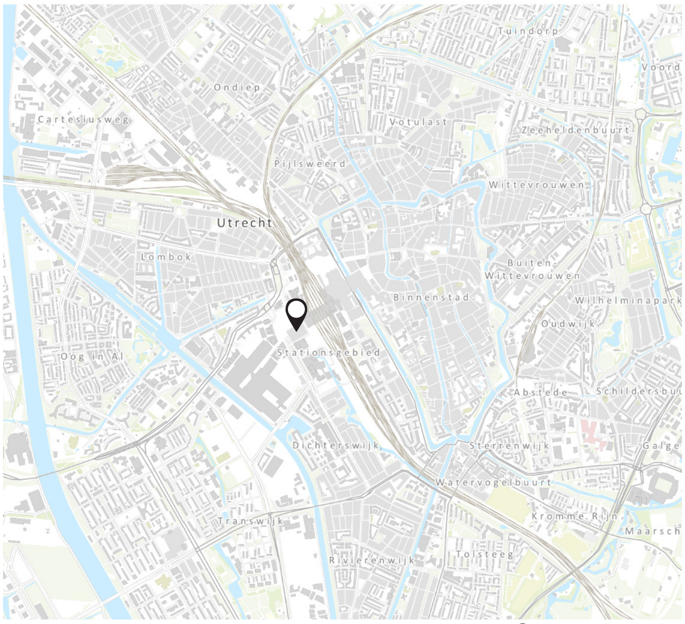
There is also room for optimization in the façade's accessories, like the balcony and outside gallery, which include mostly circular principles but is not optimized more for biobased potential.

3.1 | Site requirements and selection

In this chapter, the insights gained in chapter two are applied to a concrete design assignment. This assignment is free to choose, but is for a large part readily determined by the research. First, a site is to be chosen. The following criteria are essential in the site selection:

The site has to:
- concern new construction and renovation
- be somewhere in the Netherlands (because of the specific Dutch climate)
- have the renovation building to be suitable for the developed facade system
- be suitable for and gain quality by adding dwellings, offices and retail

Many sites were explored, like the wisselspoor area in Utrecht Northwest, or the area around Fonteinland in Leeuwarden. Main search criteria was the presence of an existing building with a clear, simple structure to renovate. Eventually, the Beatrixgebouw next to Jaarbeursplein was found and complied with all requirements. Additionally, did the direct urban environment allow for much potential to improve the spatial experience, by contributing to the station area redevelopment. The currently very closed building can be opened up and connected to the neighbouring central station, which is the largest and in the middle of the country. It would thereby not just be a renovation, but rather a transformation



Scale 1 : 30.000

Scale 1 : 10.000

Fig. 3.1: Location of the Jaarbeursplein, just west of the central train station and the city center of Utrecht. Map by Gemeente Utrecht, z.d..

Another advantage in the case of the Beatrixgebouw, is that the current owner is considering to sell the building after 2028 as demand for exposition spaces have declined (figure 3.2).
For the new construction site, the bus stop area north of Jaarbeursplein was designated for development. This is in line with the current real plans of oopen, a project by Studio Heatherwick and Nudus within the larger scope of the station area redevelopment (figure 3.3).


DUIC Nieuws Dossiers Krant Zoeken

Jaarbeurs overweegt verkoop Beatrixgebouw na 2028

ALGEMEEN 6/4/2020 - 12:28 – *Redactie*

Fig. 3.2: Article of local newspaper stating that the owner considers selling the Beatrixgebouw after 2028. By duic redactie, 2020.

Fig. 3.3: Birds eye rendering of the new development of oopen in Utrecht. By Nudus, 2020.

As stated in the research plan, was the intention to apply the facade system to new construction and renovation to prove versatility. Eventually is opted to only use the system in the transformation of the Beatrixgebouw, because of two reasons. The first being the time constrains of the graduation project. Secondly, if the facade system works for renovation projects, it will also work for new construction projects. This is because new construction allows greater flexibility in the design around the system. Renovation (and transformation) is different in this case, so succesfully applying the facade system to a transformation project can be interpreted as a succesfull application to new construction indirectly. This means that only the Beatrixgebouw will be redeveloped.

Fig. 3.4: The Beatrixgebouw after completion in 1970, viewed from the Croeselaan. Photo by Eric Koch.

3.2 | Archival Documents

As the focus is now completely on the transformation of the Beatrixgebouw, an important first step is to collect as many architectural documents from the archive as possible. It took some time and investigation, but eventually these documents were found and retrieved from het Utrechts Archief and comprise floor plans, sections and one elevation of the southwest facade.

The building was desgined by famous Dutch architect Rein Fledderus and the construction completed in 1970. Fledderus designed the Beatrixgebouw, named after princess and former Dutch queen Beatrix van Oranje-Nassau, as one project in a larger series of buildings commisioned by the Jaarbeurs, as demand for exposition space grew in the last half of the previous century (Van Loon, 2011). After analyzing the documents, multiple charactersistics were noticed and starting points were developed. The first being that the building has a clear and plain structure of columns and cassette floor slabs with grid dimensions of 9x9 meters, being approximately 130 meters long, 90 meters wide and 40 meters high. This coincides perfectly with the 1,8m grid size of the facade system (1,8x5=9). Secondly, was noted that the floors have a height of 4,8 meter from center to center. Such floor height is a challenge, since it is too (uncomfortably) high for a single storey dwelling, but too low to fit in a double storey dwelling according to building regulations.
Lastly, for stability does the building rely on multiple technical cores scattered across. The cores house vertical transport and conduit shafts. They can be considered challenges in the transformation on the one hand, because they cannot (all) be removed. On the other, do they offer potential as existing infrastructure to order the new design around.

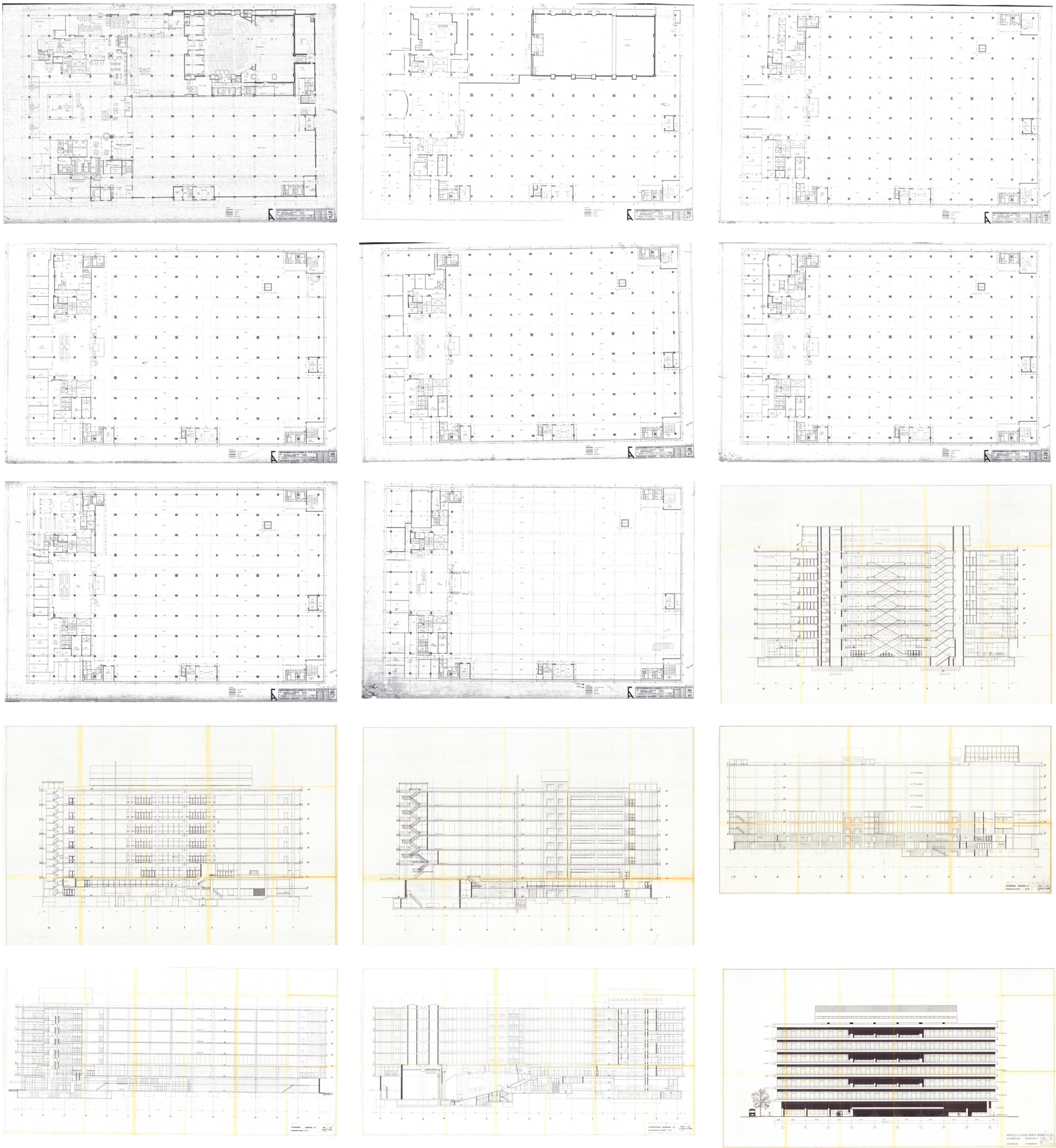


Fig. 3.5: Matrix of collected archival drawings of the Beatrixgebouw, comprising all floor plans, sections and one facade elevation. By het Utrechts Archief, 2025.

3.3 | Initial design ideas and sketches

Already towards the end of the research, some first design ideas were generated. These ideas are captured in the CAD drawings below. Still with the new construction assignment in mind, was a combination of the different characteristics from the facade system designed onto a support structure. It features a combination of open and enclosed facade surfaces in different shapes and different materials, as well as multiple facade 'accessories like the awnings, PV-panels, greenery and balconies. Even though these ideas were not developed further directly, they still served as a indirect input for the transformation of the Beatrixgebouw.

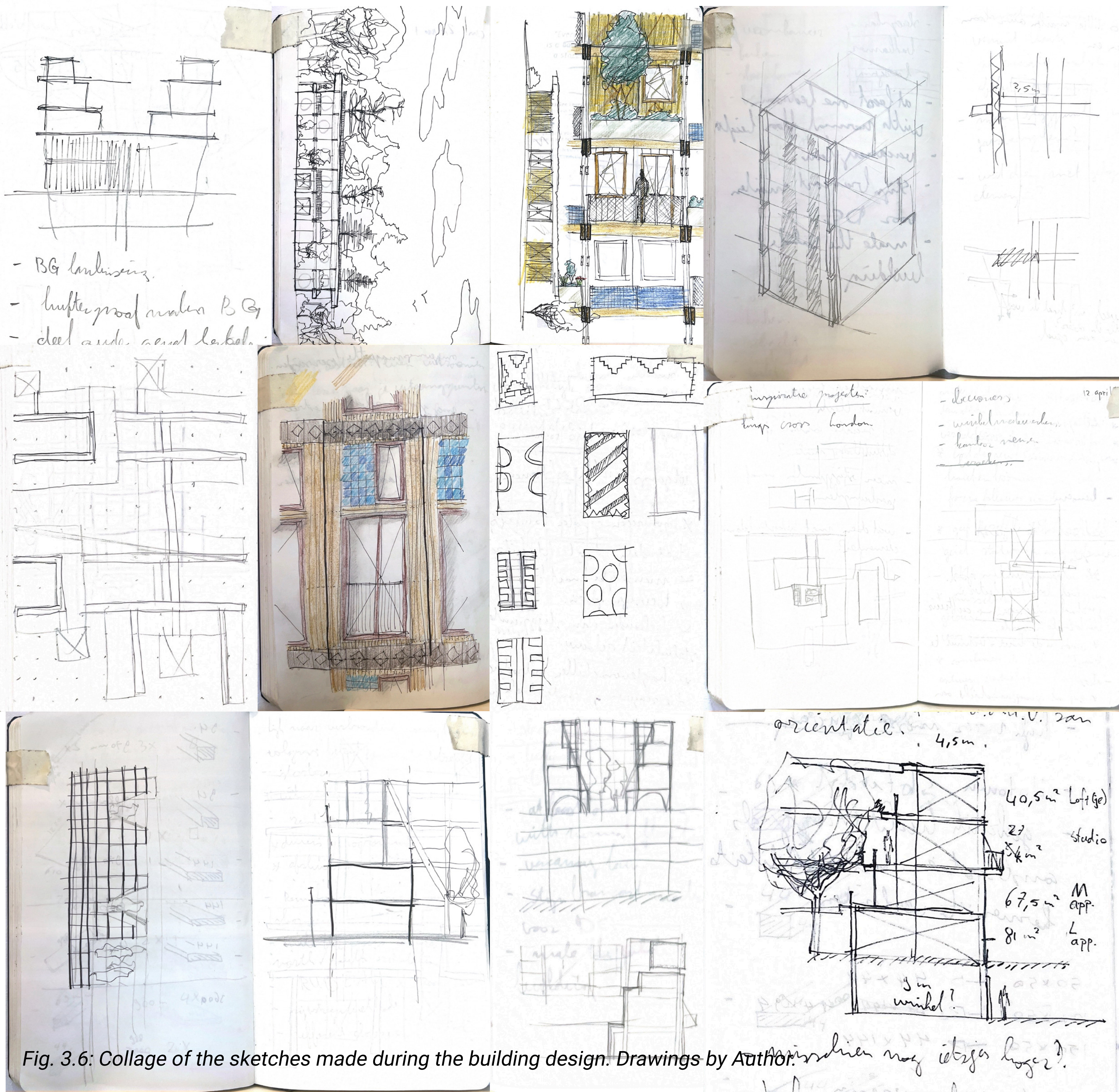


Fig. 3.6: Collage of the sketches made during the building design. Drawings by Author.

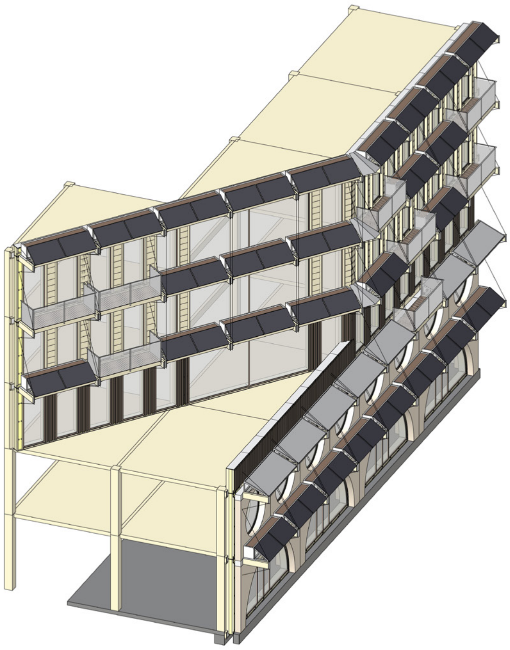


Fig. 3.7: Axonometric CAD drawing of the first facade idea for a new construction scenario, complete with multiple shapes, corners, a roof terrace and various accessories. Drawing by Author.

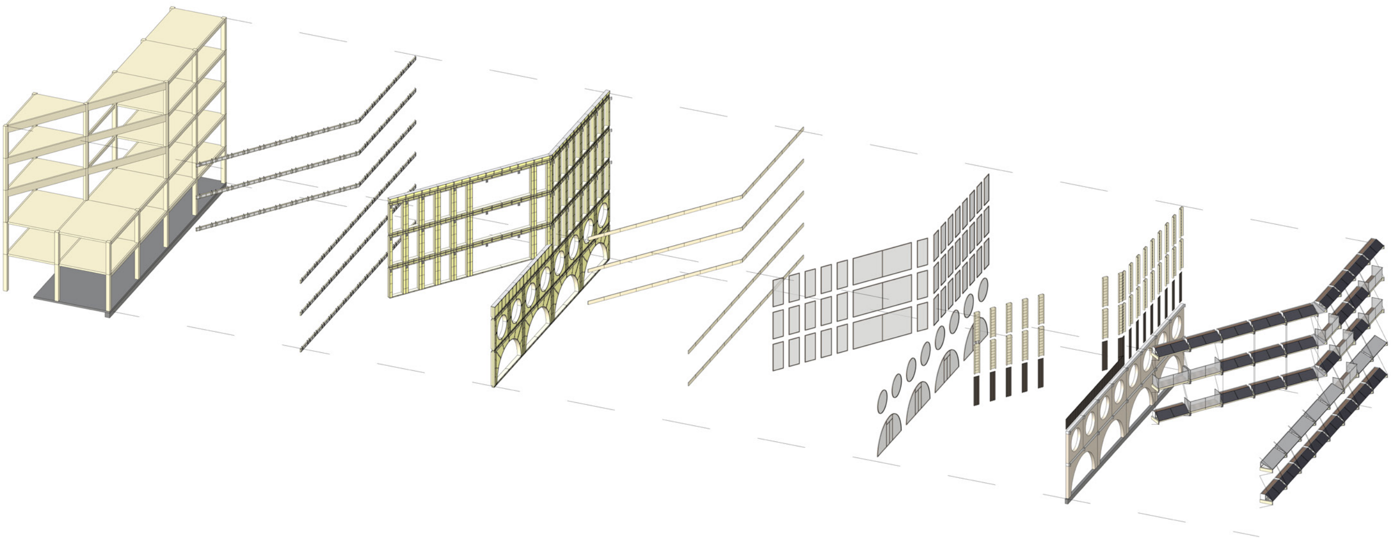


Fig. 3.8: Exploded axonometric CAD drawing of the first design idea with the layers from left to right: mass timber support sructure, timber frame interior ribbons, timber-straw panels, wood fibre exterior ribbons, window frames, facade finishes and facade 'accessories'. Drawing by Author.

This indirect input was translated and projected onto the original elevation drawing to explore the possibilities (figure 3.12). Again, the ratio of open and closed areas in the facade is created, as well as the integration of geenery, different shapes and accessories. From the beginning it felt important to preserve the strong design language of the horizontal floor edges to make the building not only still somewhat recognizable after transfromation, but also to honor the building and it's historical value. Although this was already a relatively satisfactory beginning, it became clear that the current volume was not suited for the envisioned programming of dwellings, offices and retail. Especially the first two have strict daylight requirements, which is challenging in the current enormous and enclosed volume.

Testing different facade integration designs

Considered as a side track in the design ideas, iss explored how the facade system could be integrated into the design. One idea iss to display the facade system and its Ecological Architectural Tectonics (EAT) to the public by applying a translucent facade finish, like repurposed polycarbonate sheets. These ideas are tested in quick renderings of fictional buildings as seen in the images of figure 3.9 - 3.11. Although showing promise by the striking contrast of the cooler industrial materiality of the exterior polycarbonate and the warmer ecological interior timber-straw cassette, it would result in substantially more usage of finite materials (polycarbonate sheets) and would eliminate the vapor open properties. It is therefore decided to not continue with this idea.

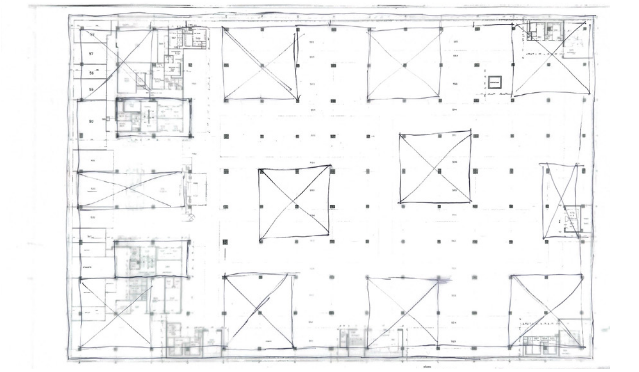
Fig. 3.9: Night render of an appartment building to test the facade integration with polycarbonate sheets and lighting. Render by Author.


Fig. 3.10: Second render at day to test the idea on a fictional pavilion with other facade openings and accessories like PV panels and greenery. Render by Author.

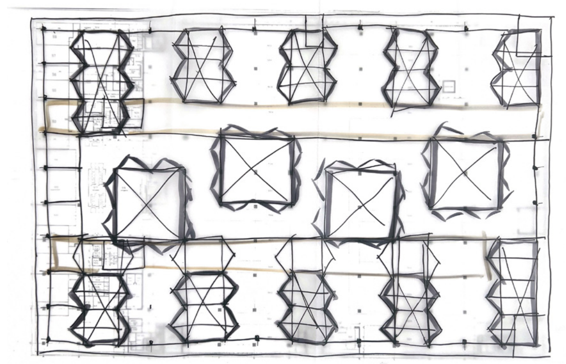

Fig. 3.11: Third render of the same pavilion at night to test difference in appearance. Render by Author.

Fig. 3.12: First sketch of the Beatrixgebouw transformation, drawn over the original elevation drawing. Drawing by Author.

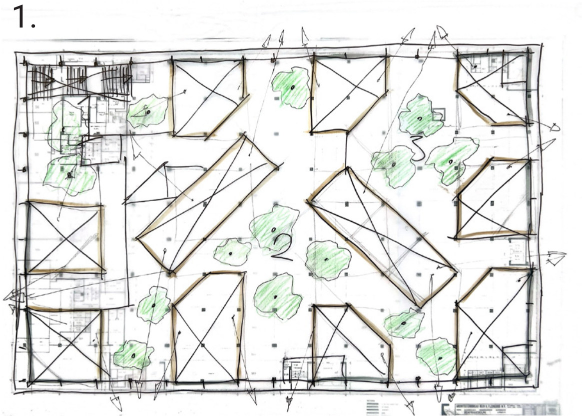
To make the envisioned programs suitable for the tranformation, the building has to be 'opened up', or rather be carved out to increase it's surface (read facade) area. The next step is to draw some ideas and variants over the floorplan, to order the programs over the exisiting spatial layout. The first set of sketches are shown in figure 3.13. Here, some volumes on the size of a couple of dwellings were draw over the strict grid of columns. It was only then that was realized how large of a building it actually is. It occured that, to transform this building it required an urbanistic approach first before work on architecural issues could begin. After all: small neighbourhood would be added to Utrecht. It is important to note that the drawn blocks were not planned on top of the existing structure, because an increased height would alienate the human scale of the building even more. As within the research, is the human scale also during the design an important guideline to create pleasant and human/nature centered spaces. In figure 3.13, image 3 it is thus visible how these blocks are accompanied by greenery and plenty of streets, squares and collective/public space. This small green neighbourhood would be around 3-5 storeys and would rest upon a 'pedestal' of 2-3 storeys that contours the existing building perimeter(figure 3.14, image 3). The floor edges would be preserved where possible to make this group of blocks a unified whole. New problems arose. The first being that not all blocks would be structurally stable, as they lacked connection to existing stability cores or any other lateral stabilization. The second one concerned the size of the blocks to fit the dwellings only back to back, allowing one one direction for daylight entry. Finding this insufficient, was decided to further develop the concept for dwellings with daylight from two opposite directions as a minimal dwelling quality. The solutions found are displayed in figure 3.14. Multiple ideas, one more radical (image 1) than the other, show the attempt of different strategies. Eventually the idea of the neighbourhood on a pedestal, elevated out of the city's hustle and bustle, remained the favourite and got adjusted for more views and daylight. The dwelling ans shop would now be organized conform the Barcelona model, having larger urban blocks with inner courtyards. Between these blocks would be a public pedestrian space with shops, while the more timid courtyards are a collective outside garden for the residents of the respective blocks. This would allow for a good ratio of public, semi private and private spaces (figure 3.14, image 4). Moreover are the blocks placed in such a manner that one side is outside the existing building perimeter, as it were eliminating this side and creating a group of outward facing U-shaped blocks as a remainder. This benefits the sunlight entrance and the outward views to the city center.



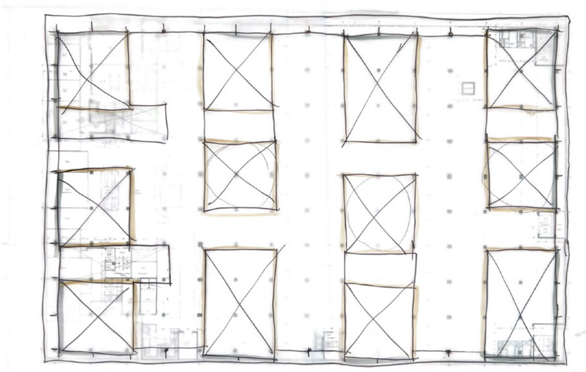
1.



2.

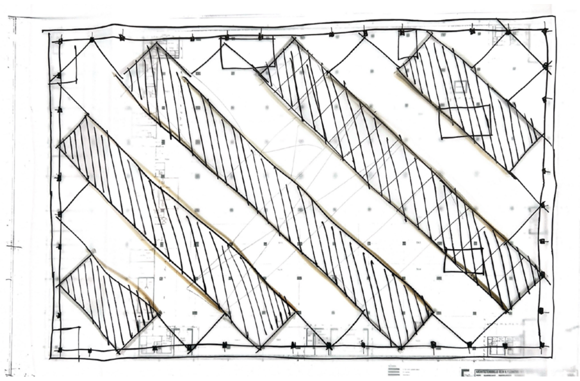


3.



4.

Fig. 3.13: Multiple sketches of floor plan design variants for opening up the Beatrixgebouw, using an urbanistic approach. Drawings by Author.



1.

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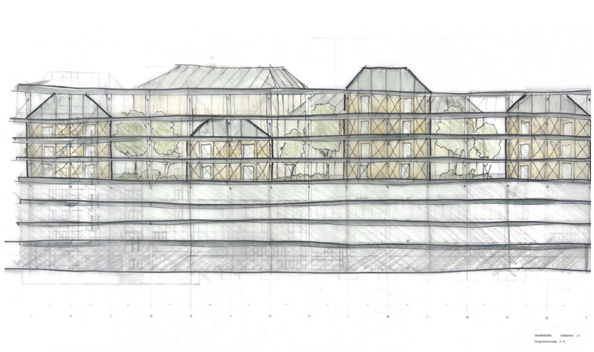

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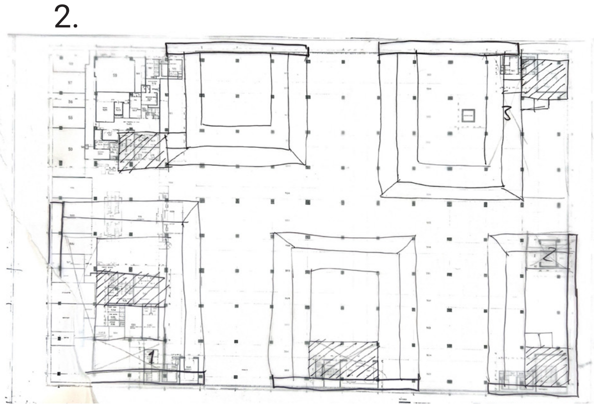
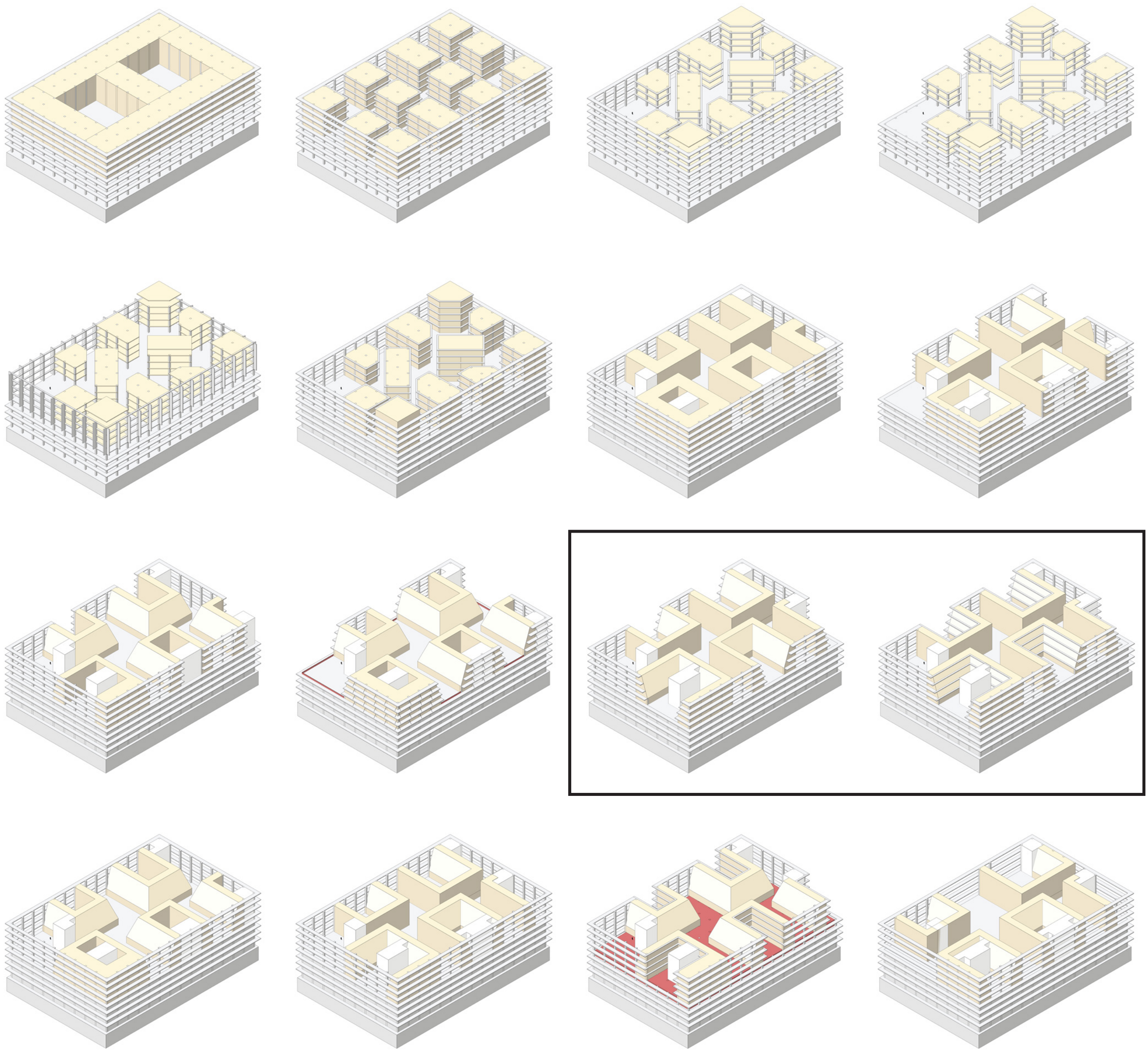


4.

Fig. 3.14: Second round of design sketches of floorplans, sections and elevations to create dwellings with high daylight quality and views. Drawings by Author.

Testing the ideas in 3D CAD models

The ideas are simultaneously and subsequently translated and tested in 3D volumetric models. This creates a deeper understanding of all spatial consequences and allows for more precise finetuning. The amount and size of blocks, their orientation, preservation of the floor edges and chamfering the edges for improved sunlight entrance were characteristics that got played with. Finally the two versions outlined in figure 3.15 were chosen upon their characteristics to continue with, because they match all desired criteria mentioned earlier this paragraph most.



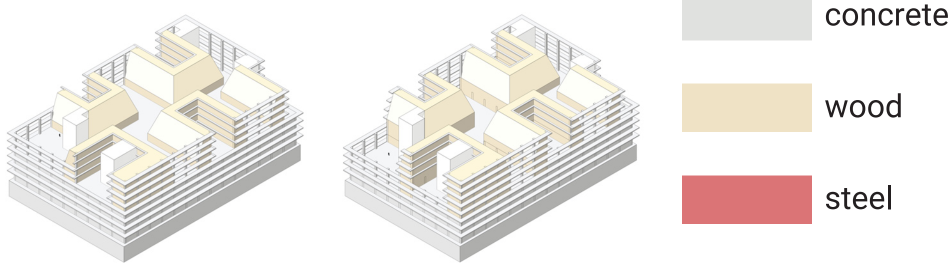


Fig. 3.15: Testing different versions of 3D volumetric CAD models as a tool to decide the final volume. Drawings by Author.

The final volume

The final volume, shown in figure 3.16, shows how the combination of programs would fit in the shaped volume, as a final result from the initial design ideas and sketches. The focus was to have a good ratio between dwellings, offices and retail, as well as keeping the theater as it is. When puzzling with the programs it was the goal to prevent the programs from conflicting with each other. For example, parking space is hard to realize anywhere except for the ground floor whilst for dwellings it is not favorable to place them directly on the street as the neighboring programs do not match. This way the residents are raised above the city ground level, having a calmer living pace with great view all over town.

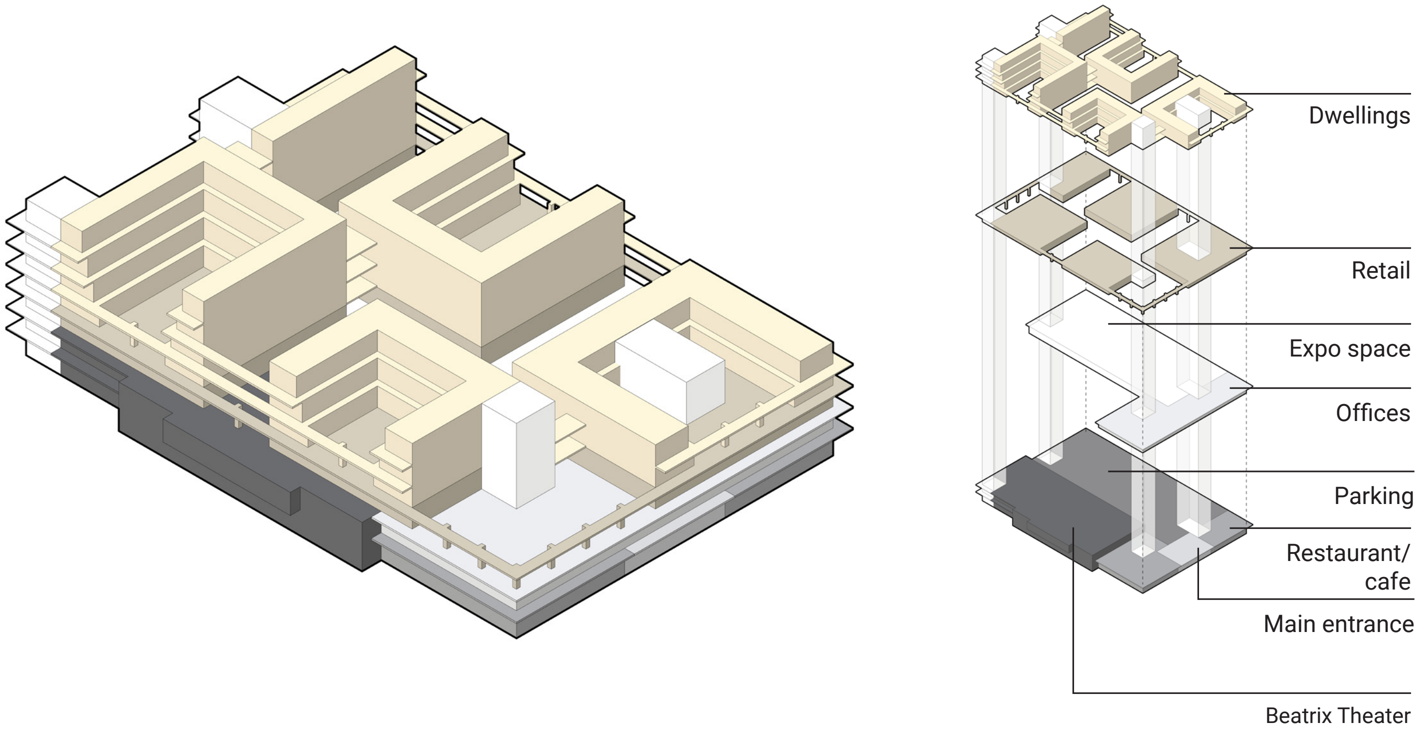


Fig. 3.16: Axonometric CAD drawing of the final building volume (left), divided in colors for different programs (right). Drawing by Author.

3.4 | Adaptations to existing structure

In order for the new design of the tranformation to work, the existing structure needs to change. The building has been through some transformations already, like the top-up of an extra floor made with steel columns instead of concrete and the expansion of the theater foyer. To work out how the next change would occur, a detailed spatial comprehension of the building is to be acquired first. Hence, a 3D CAD model of the complete building structure was made, based on the information of the archival documents (figure 3.17). Then, step by step, the adaptations were designed and documented. They are displayed in firgure 3.18. Strategy is to remove the floor areas level by level, 'carving' out the building to the final volume. Critical is the insertion of vertical concrete slabs from bottom to top around the u-shaped blocks. This is for extra stability, which will be discussed further later in the paragraph. After the demolition is finished, some ares that need new construction are filled in with mass timber, like some new floor slabs and the addition of walking bridges between u-shaped blocks. At the Southwest corner of the building (the bottom corner at step 8 in figure 3.18), some floor area is taken out to make room for a new large stairway with escalator and an elevator. Lastly, floor areas are removed and replaced with steel containers to contain the soil for the green areas. They are supported by the existing columns underneath. The theater remains identical as before.

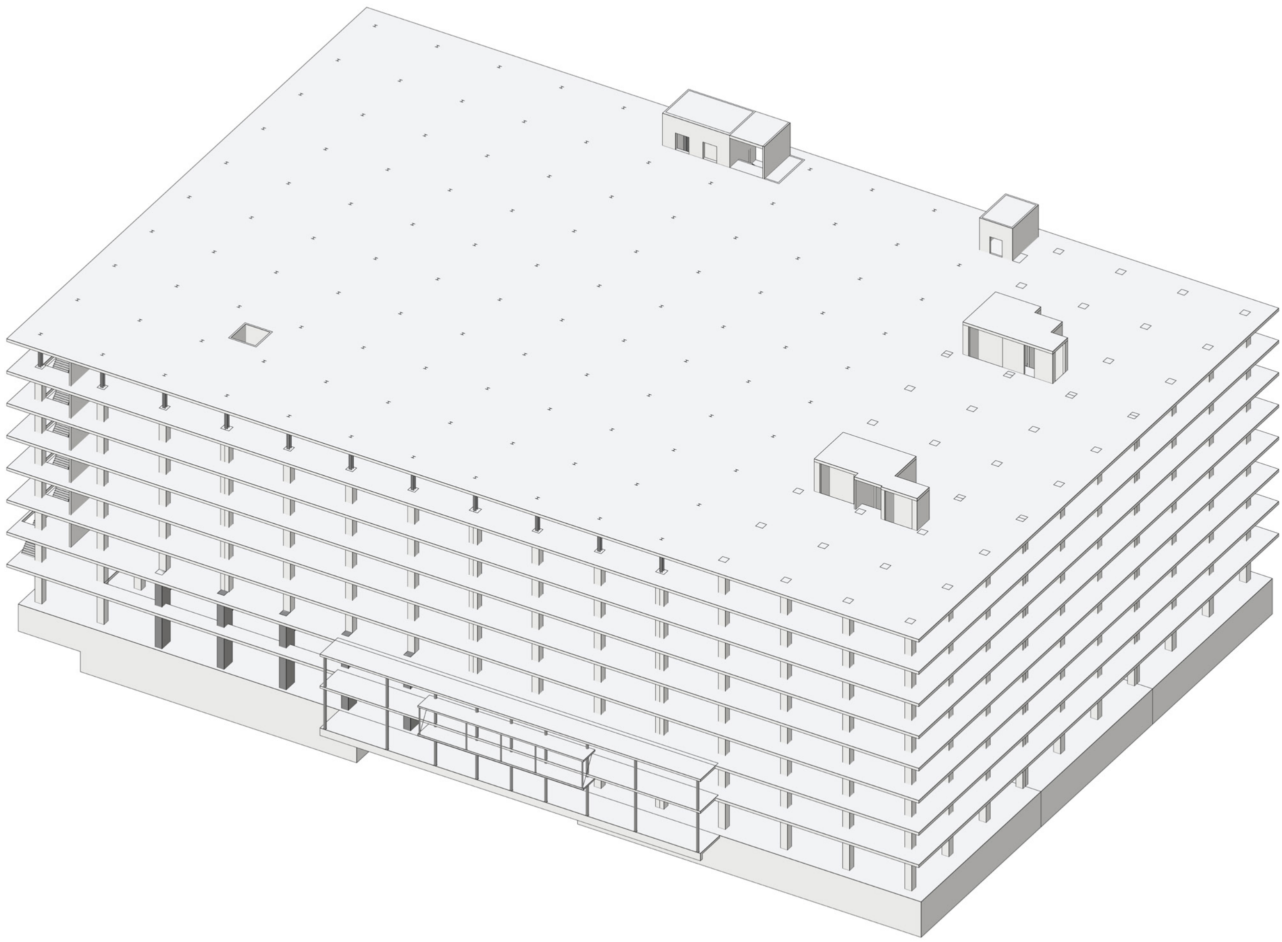


Fig. 3.17: Axonometric CAD drawing of the complete existing building structure. Drawing by Author.

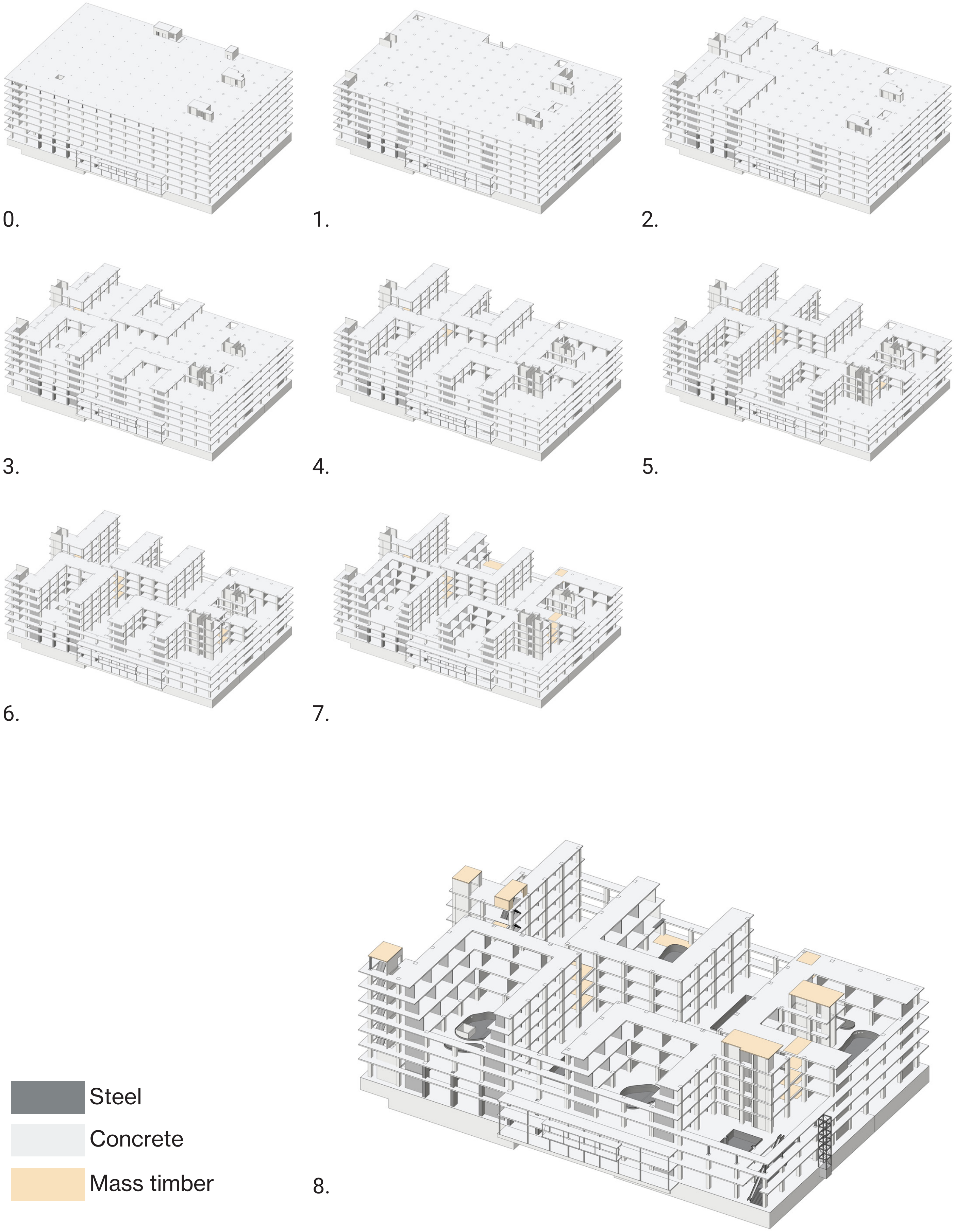
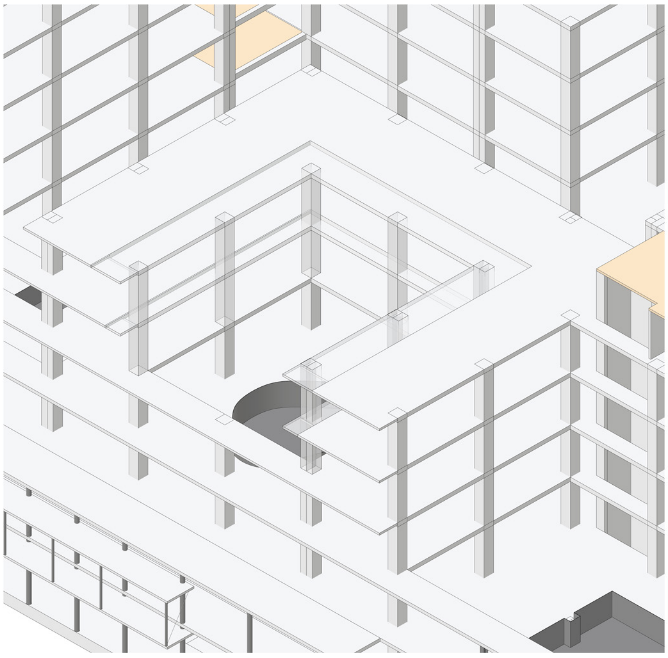


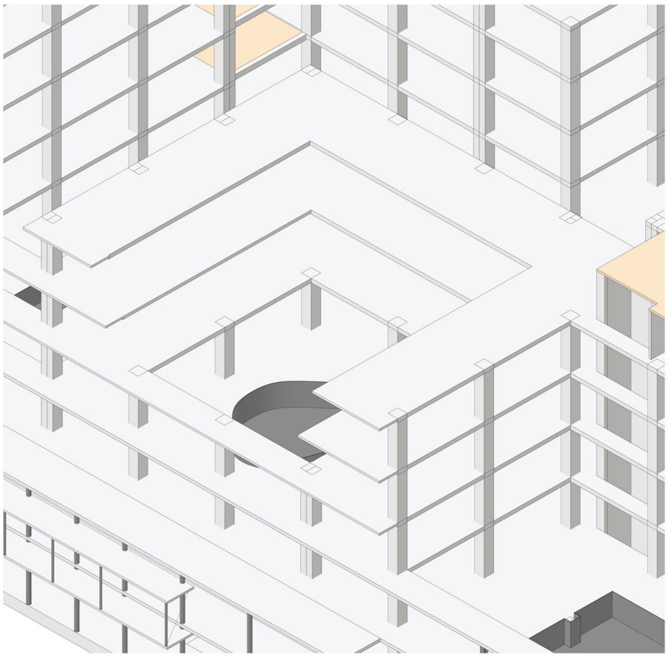
Fig. 3.18: Matrix of axonometric CAD drawings showing the changes to the building structure step by step. Drawing by Author.

Structural interventions

As mentioned earlier this paragraph: the addition of vertical concrete slabs is essential. This is because of the stability requirements of the new u-shaped blocks. They are no longer sufficiently supported by the existing stability cores. To explain the old and new situation with all acting forces, block B is displayed in figure 3.19 in a series of images. First, the old situation is shown in the first image. All translucent objects will be removed to achieve the new setbacks in the facade. This, however, means that the columns will be removed ass well which is shown in the second image. Of course this is not stable, so all acting forces are analyzed to present a solution to fit all. The acting forces are: normal forces from gravity (image 3), shearing forces from wind load (image 4) and torsion forces around the U-shape corners from wind load (image 5).
The initial idea was to apply slanted columns in line with were the old columns were (image 6). They were designed from mass timber to apply more sustainable construction materials. This would not work, because the slanted columns only account for the normal force, not shearing and torsion as the momentum would be too large (image 7). After a construction consultation it became clear that only concrete is strong enough to withstand the pressure occuring as a conssequence from these forces. It is also crucial that the slabs are placed all along the u shape, since every wing has to be stable on its own (image 8).

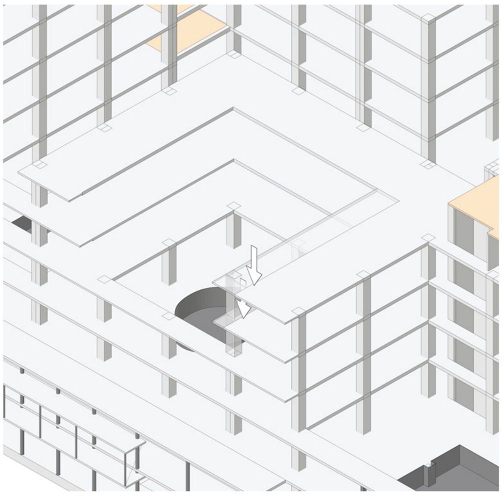


1. Old situation with the to be removed objects shown translucent.

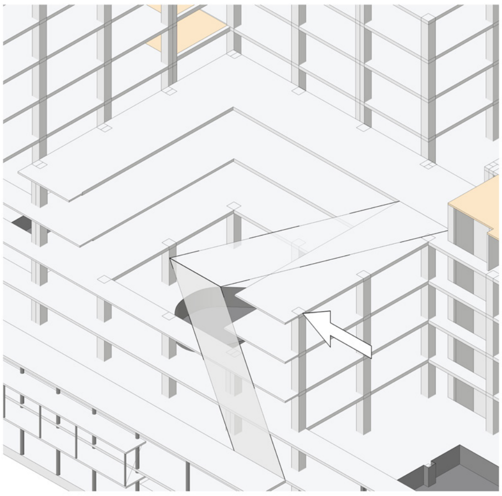


2. The new situation without interventions.

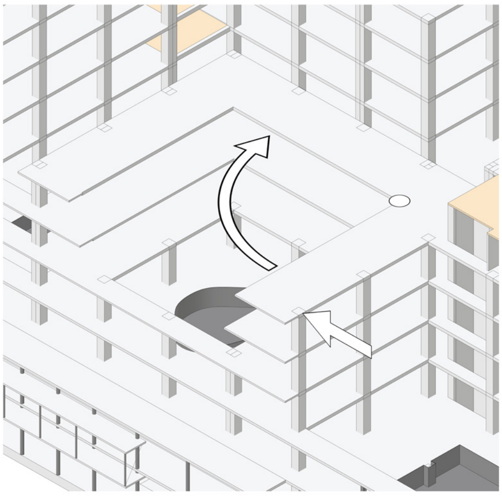
Fig. 3.19: Axonometric CAD drawing of the structural interventions in the existing building structure. Continues on next page. Drawing by Author.



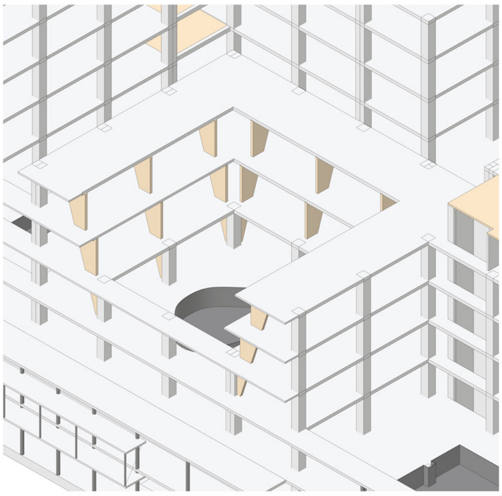
3. Normal force.



4. Shearing force.

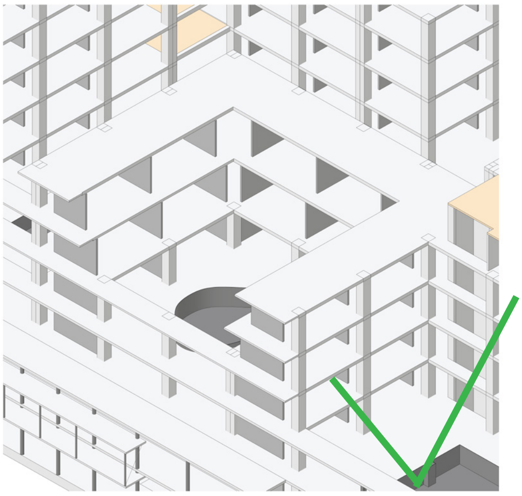


5. Torsion force.



6. Slanted mass timber columns.

7. Slanted columns are not sufficient.



8. Only sufficient material: concrete slabs.

3.5 | Architectural drawings

Starting again at the urban scale, is the integration of the building in its direct urban context drawn. The axonometry shows how the placement of the u-shaped blocks react to the space around the building, acting as viewpoints towards famous Utrecht place like the Croeselaan, Jaarbeursplein en the central station (figure 3.20). As was envisioned from the start and stated in paragraph 3.1; does the location of the building hold great potential as it is directly next to the station and inside the station area redevelopment. Connection to both is essential. That is why the 'pedestal' the u-shaped blocks are placed on is only 2 storeys high: to link the urban platform of the train station as good as possible to the newly created street of the Beatrixgebouw. However, the storeys of the Beatrixgebouw do not line up with the train station platform, resulting in a 2 meter height difference. This height difference is solved by adding hill- like structure to the train station platform for pedestrians to gradually walk up the streets within the Beatrixgebouw. Along this walk are multiple pedestrian facilities of aid, like a step-less escalator, an elevator, ramp an even a wheelchair friendly ramp. Visitors can also exit or enter the new raised urban level on the pedestal from the west corner of the Beatrixgebouw, located at the Jaarbeursplein.

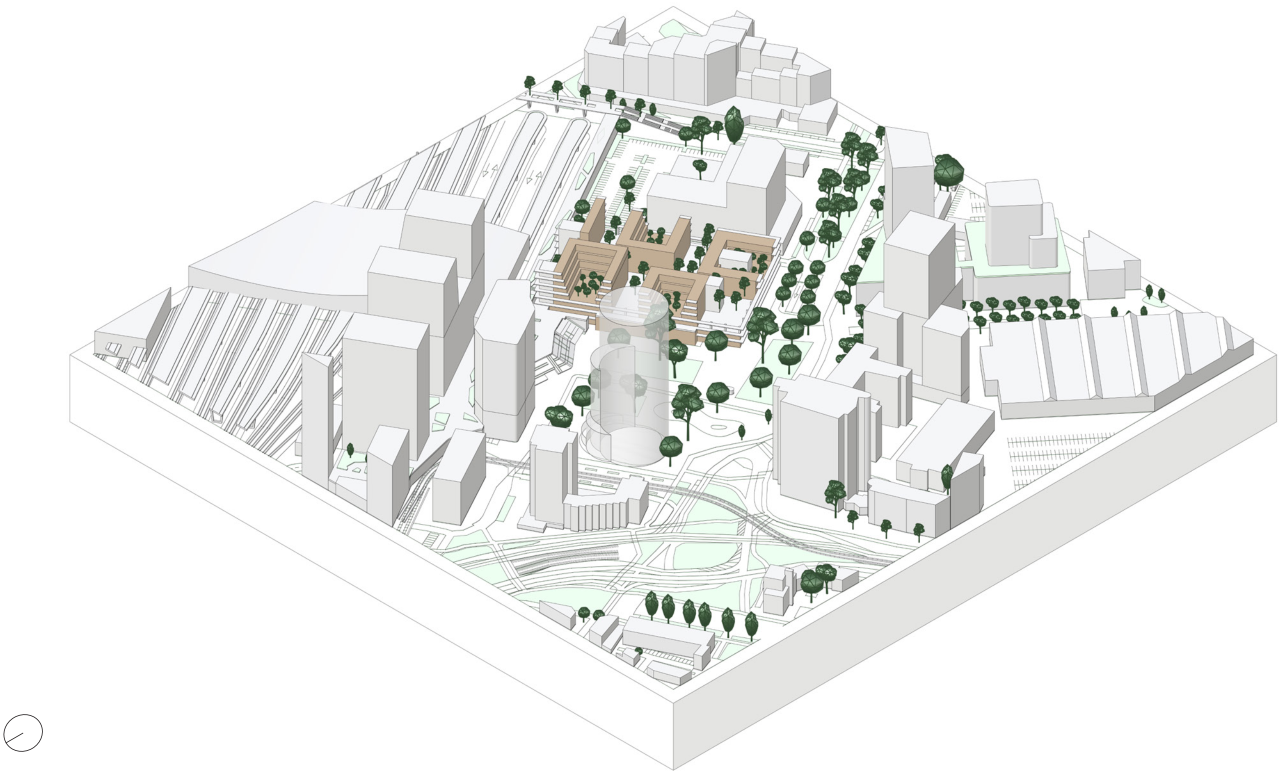


Fig. 3.20: Axonometric CAD drawing of the direct urban environment, viewed from north. The building remains relatively low compared to other development nearby. The building design is highlighted in a wood-like color. Drawing by Author.

Scale 1 : 1000 (scaled to fit)

Fig. 3.21: Top view CAD drawing of the building design in relation to its direct urban environment. Notable is the redesign of JAarbeursplein with densified greenery, shaped in the similar design language as the riased urban platfrom by group A. Drawing by Author.

The Mineurslaan street (directly south of the Beatrixgebouw) will remain to possess it's function as a logistical vein for the building, but gains a new function as main entry and exit for users and residents of the building traveling by car, or other forms of transportation.

Ground floor plan and the building settlement

In figure 3.23 manifests how the building settles in the urban context, and especially what kind of consequences that has for the passer-by, users and visitors on eye-height level. Though having large programs which require enclosure (theatre, parking), the building tries not only to open up more on the Croeselaan side with a big restaurant and cafe but also invite them in. In between is the main entrance of the building located with access to the restaurant and café, vertical transportation facilities, mailboxes and even some rentable office space. This main entrance, together with the large stairs on the west corner of the building are counterpart entrances of the one on the station side. Circulation on the raised urban level (on the pedestal) can subsequently occur properly in both directions, which is crucial for a lively, highly urban environment. Another reason this is important has to do with the preconditions for retail spaces. The transformation has to provide the environment where enough people can walk by the stores and consume their goods. Point is not to enable a hyper capitalistic space, but rather to safeguard feasibility of the retail programs. This point is extensively discussed in the book 'The Harvard design school guide to shopping', where in figure 3.22 an illustration from Otis (elevator and escalator company) is displayed from presenting the key principle humorously plain (Chung et al., 2000b). To elaborate, are shops and services envisioned for the transformation that support the local community with daily, primary needs. Types of retail suitable include for example a supermarket, hair salon, café, small clothing store or pharmacy or drugstore.

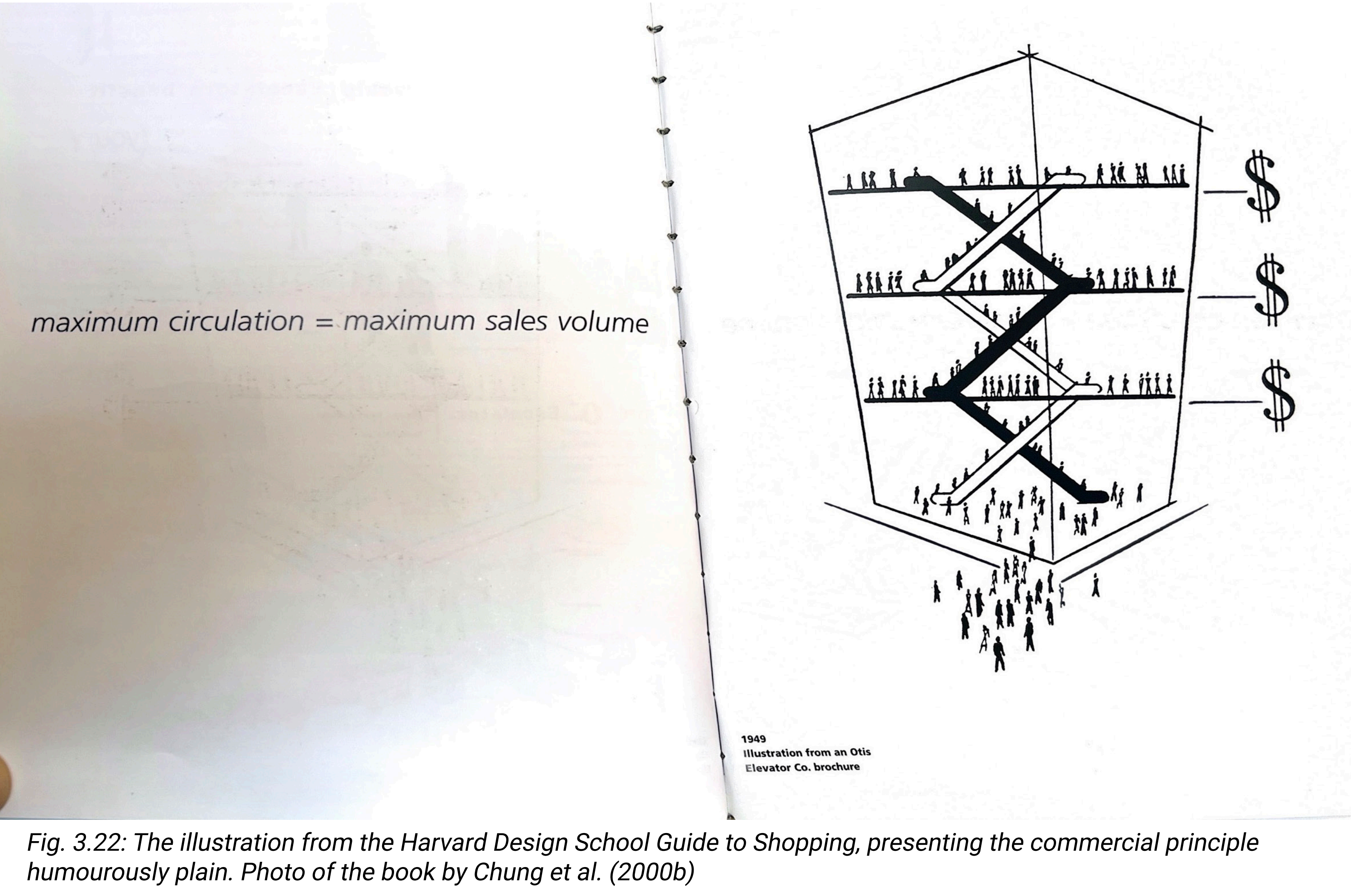
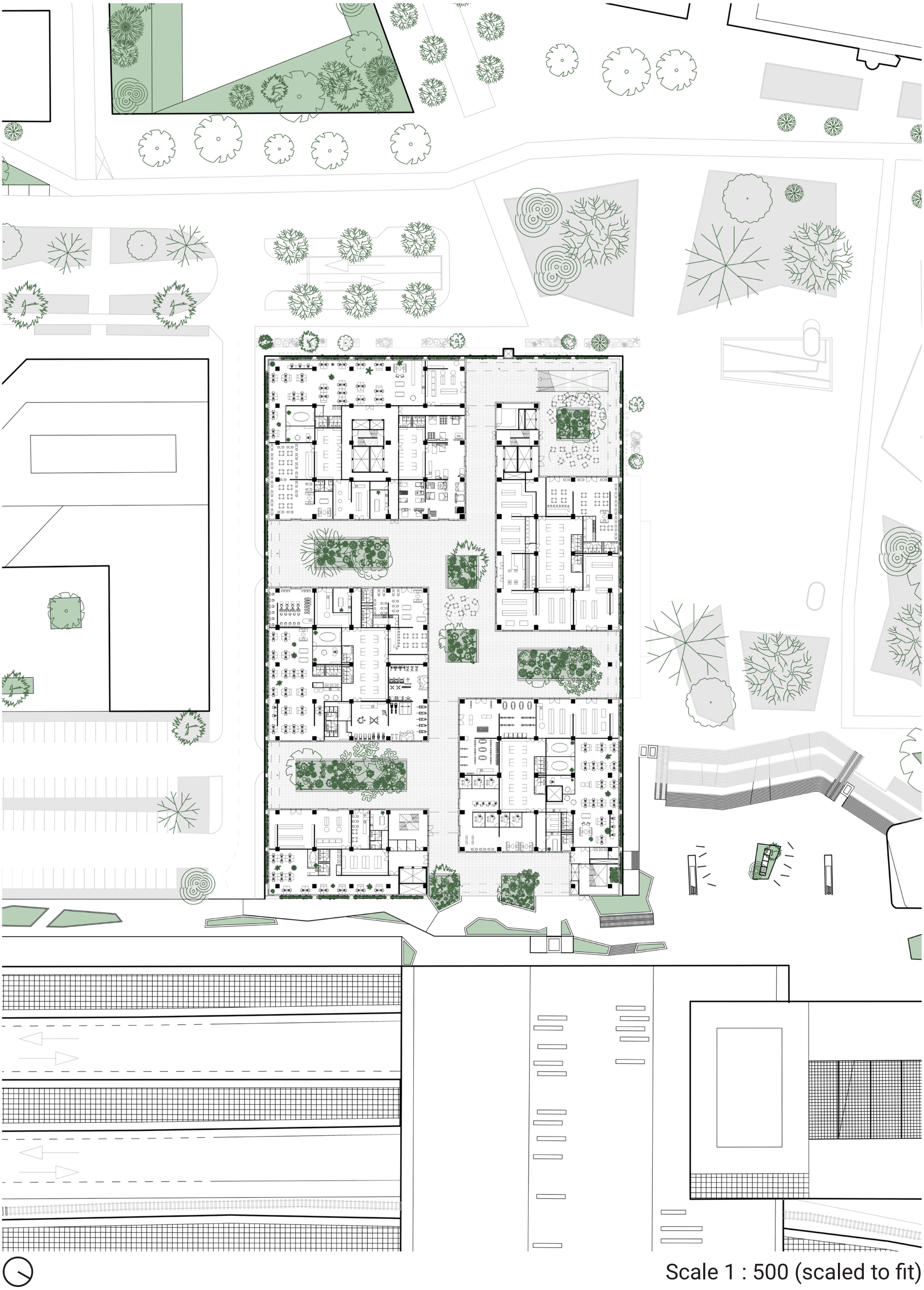


Fig. 3.22: The illustration from the Harvard Design School Guide to Shopping, presenting the commercial principle humourously plain. Photo of the book by Chung et al. (2000b)

Fig. 3.23: CAD drawing of the ground floor plan and its connection to the neighbouring spaces like the bus stops, the Jaarbeusplein and parking spaces. Drawing by Author.



Scale 1 : 500 (scaled to fit)

Fig. 3.24: CAD drawing of the floor plan on the raised urban level showing the first level of the u-shaped blocks with retail and offices spaces, together with the connection to the central station and the stairs to Jaarbeursplein. Drawing by Author.

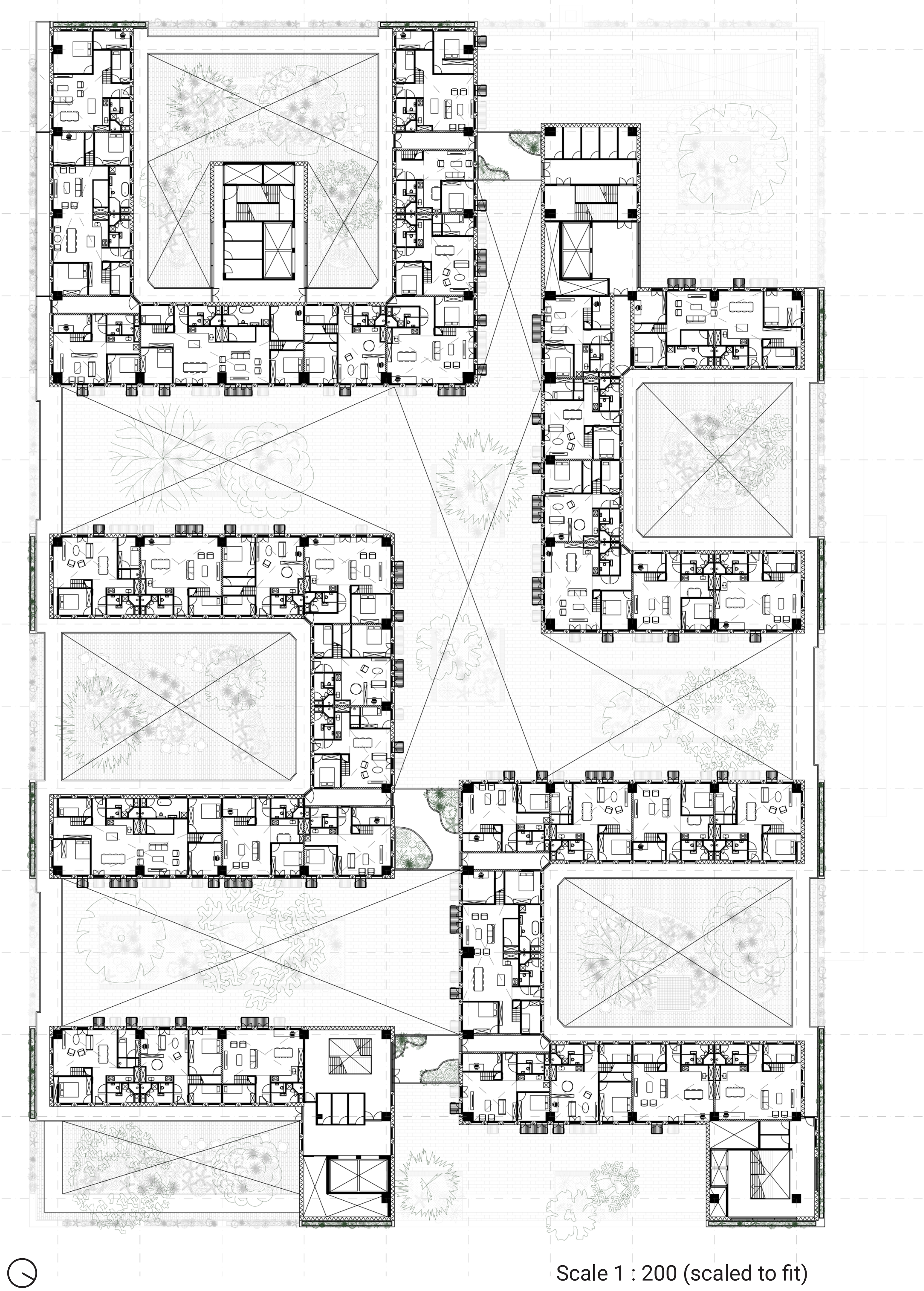


Fig. 3.25: CAD drawing of the floor plan on the fifth storey showing a typical dwelling fitout. Drawing by Author.

With making the floorplan of a typical dwelling fitout as in figure 3.25, the most challenging aspect concerned the proper flight routes. When in case of flight at least two directions have to be provided, where a stairwell is within 35 meters reach. After a long period of puzzling, this was achieved with thanks in part to walk bridges crossing between Block A-B and C-D-E. Other measures include the use of the preserved perimeter floor edges as galleries between blocks. In total four vertical transport cores with 8 large elevators and four stairwells guarantee a quick and safe flight in case of emergency. Lastly, it is notable that some space around these cores is also used as rentable residential storage spaces. Instead of residents having to travel all the way to the ground floor, they can access the storage on the same floor as their dwelling.

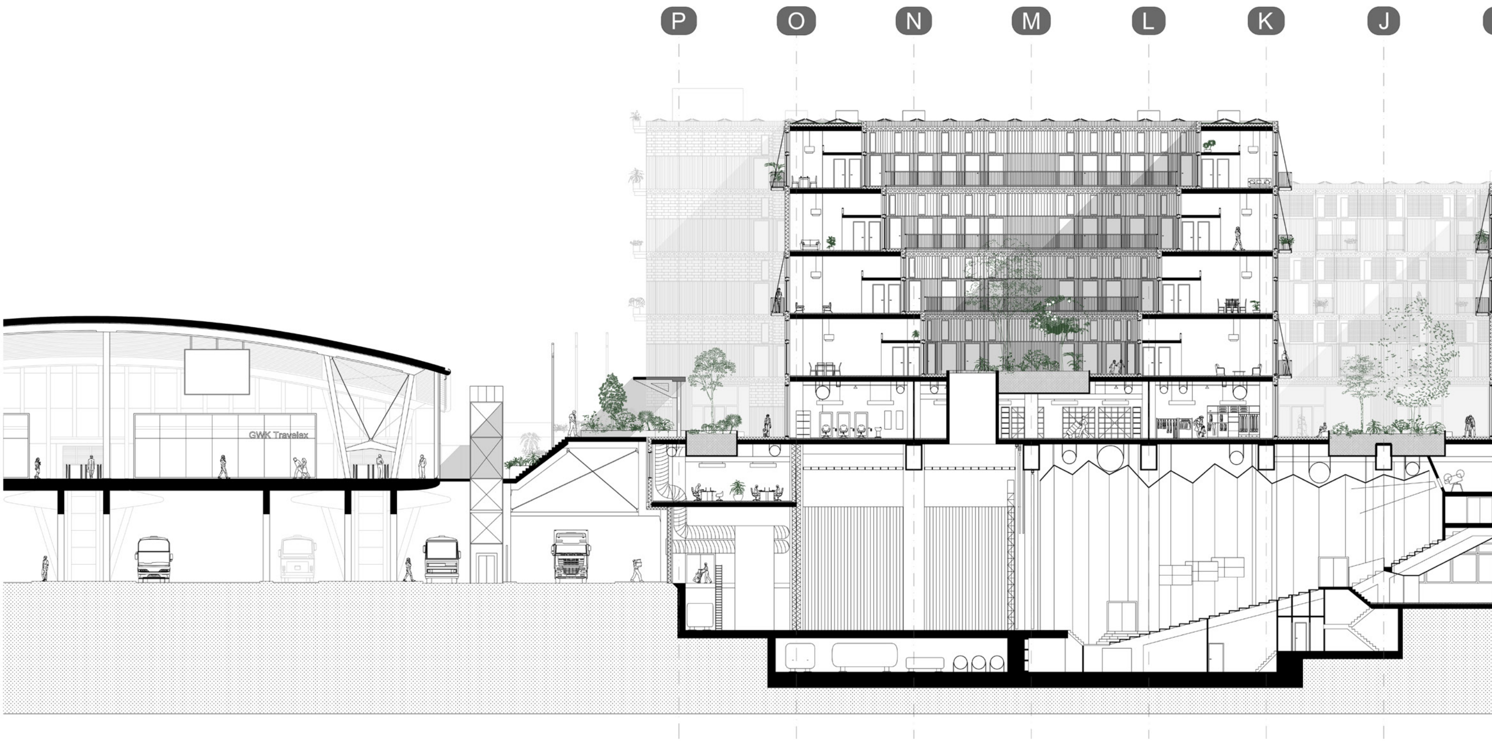


Fig. 3.26: CAD drawing of longitudinal section Drawing by Author.

Longitudinal section

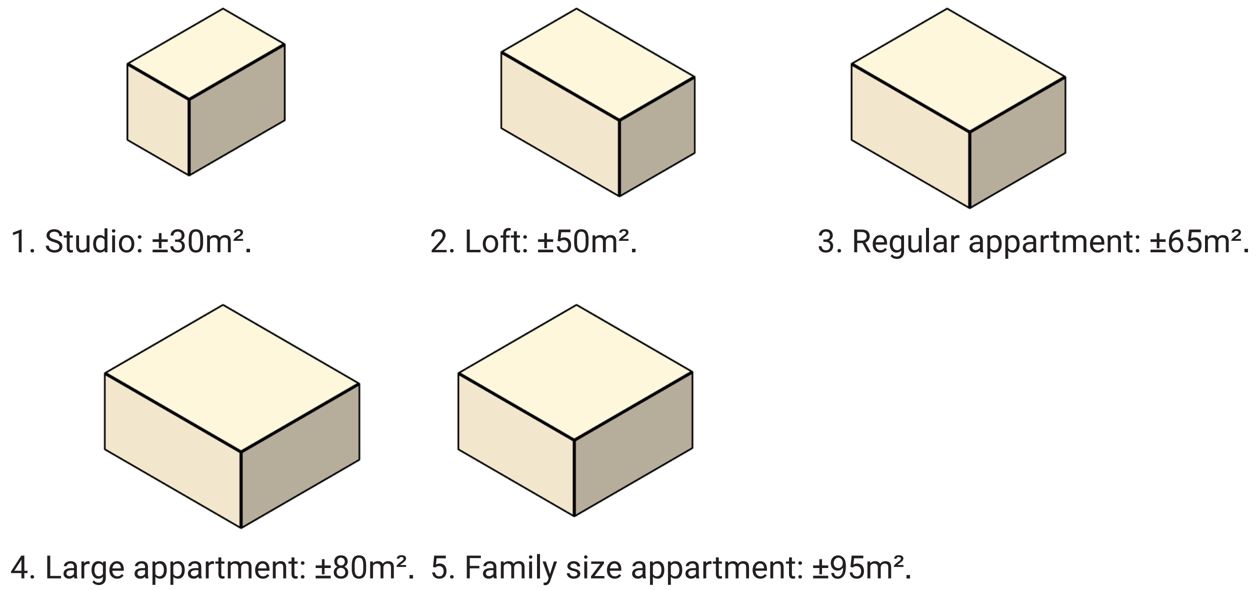
This longitudinal section of the design (figure 3.26) aims to once more show how the building is connected to its environment and how walking through it as a pedestrian would look like. The raised urban platform of the station blends over in the new raised urban level of the Beatrixgebouw where the local community and travelers can shop for their primary needs. Simultaneously is the ratio of public/semi private and private space visible. In between the blocks are the (public) streets with retail, while inside the blocks are the (collective) courtyards placed. In between the streets and courtyards are of course the (private) dwellings. In the pedestal is visible how the theater neatly fits in, with the foyer and the restaurant and retail are housed next to it. Also, can the logistical heart of each block be seen (also visible in figure 3.24), right underneath the courtyards of the dwellings above. This 'back of house' makes sure all retail and office spaces have sufficient and efficient supply, along with additional services for the retail space like canteens, toiletry and storage. These 'hearts' are in each block connected to a vertical transport core, except for the one in Block C. This block receives supply from the other vertical transport cores. Figure 3.24 also points out that these blocks do not only have retail space, but is alternated with office space as well around the building perimeter.

Scale 1 : 500 (scaled to fit)

Dwelling typology and distribution

In paragraph 3.3 was mentioned that the dwellings placed above (or rather on top of) all other programs, but what types of dwellings and for whom was not discussed. In general, there are five types of dwellings intended in the building: a studio (±30m²), a loft (±50m²), a medium (regular) sized appartment (±65m²), a large appartment (±80m²) and a family sized appartment (±95m²). By have a range of different appartment in different sizes, they can respond to the various demand in the housing crisis (figure 3.27). Although the dwellings being versatile, they try to address certain groups in society: students, elderly, starters and (young or starting) families as they - in general - experience the most challenges in their search.
The different sizes of the dwellings are no strict boundaries, as an open building approach allows grid units to be linked for double dwellings sizes (figure 3.27), or be halved for smallers dwellings. The range and flexibility in dwelling sizes does not only ease the process of establishing the right ratio of social (40%), middle (30%) and high segment (30%) rent, but also creates different households in one building. This last part especially is a large factor in preventing gentrification. A studio for example houses a single person like a student, the loft could be assigned to starters, the medium sized appartment is suited for eldery and the family sized appartment is for a family of 4-5.

Four more generic dwelling floor plans were developed and shown in figure 3.28. This was done to show the versatility in floor plan layouts for different residents. As discoverd when analyzing the archival drawings, are all storeys at least 4,8 meters high (center to center). This means all dwellings have a ceiling height 4,8 meters. This is uncomfortably high for a single storey dwelling, but too low to fit two storeys in. That is why is opted to envision and design a prefab timber volume for each dwelling. This volume serves as a mezzanine, creating more floor area then is regulatory possible, since the minimum required floor height for dwellings in transformation is 2,3 meters. Although the mezzanine is then officially not rentable, does it make the dwelling more lucrative and can influence profitablitity indirectly. This prefab volume also houses all technical installations required for the bathroom, toiletry and kitchen and even has a room built in for residents to choose how to furnish. The volume is consistent in size and borders the kitchen and stairs on one side and the facade facing the courtyard on the other. The residual floor area is different in size per dwelling type and free for the residents to furnish how they like. For example. they can choose to leave it completely open as shown in floor plan type 3, but can also add additional rooms like bedrooms or a home office as in floor plan type 5 (figure 3.28).As two dwellings share a conduit shaft located at the wall in between them, the technical infrastracture is then mirrored forcing the whole floor plan to mirror. This means that all shown dwelling floor plans in figure 3.28. can be mirrored, having effectively 10 floor plan types. A more detailed dwelling render in 3D is also shown in paragraph 3.5. (figure 3.33).



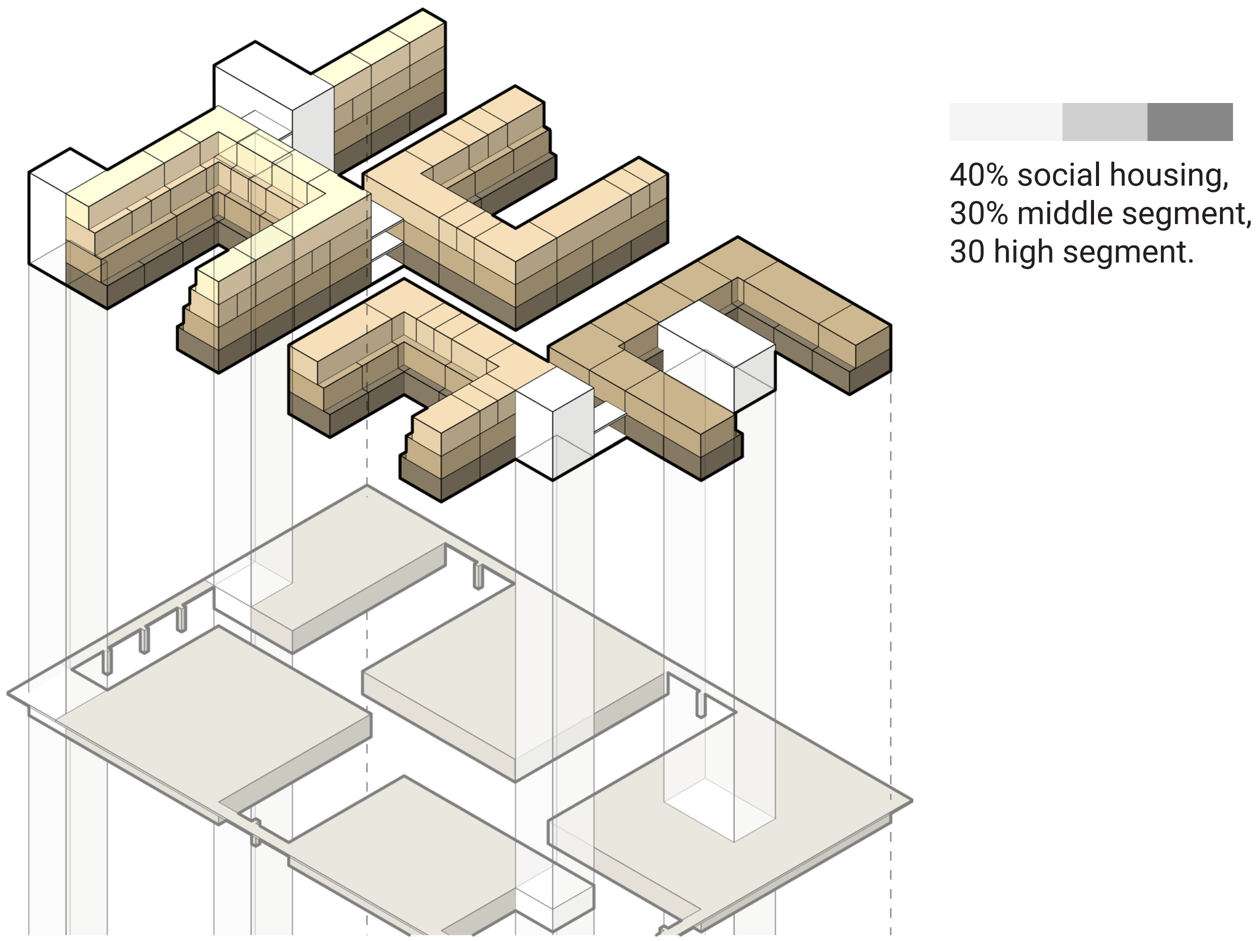
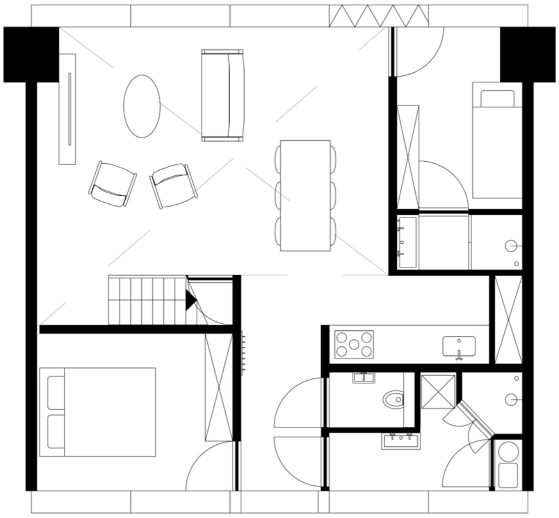


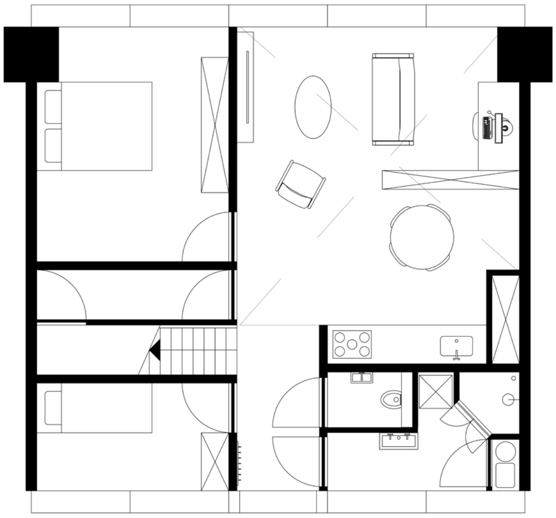
Fig. 3.27: Axonometric CAD drawig of a possible dwelling fitout, to achieve a balanced ratio between dwelling sizes and types. Drawing by Author.

Floor plan type 1



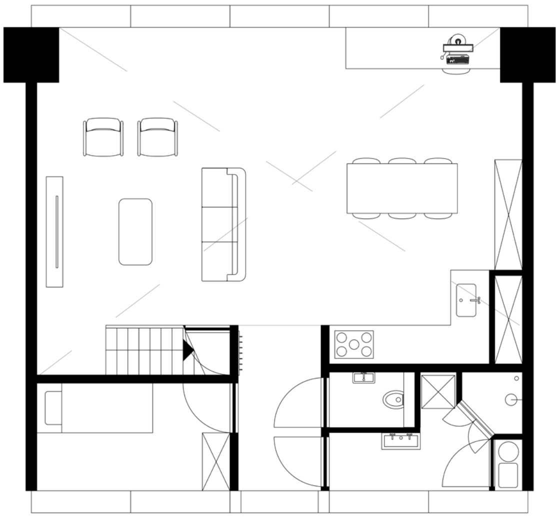
Scale 1 : 50 (scaled to fit)

Floor plan type 2



Scale 1 : 50 (scaled to fit)

Floor plan 3



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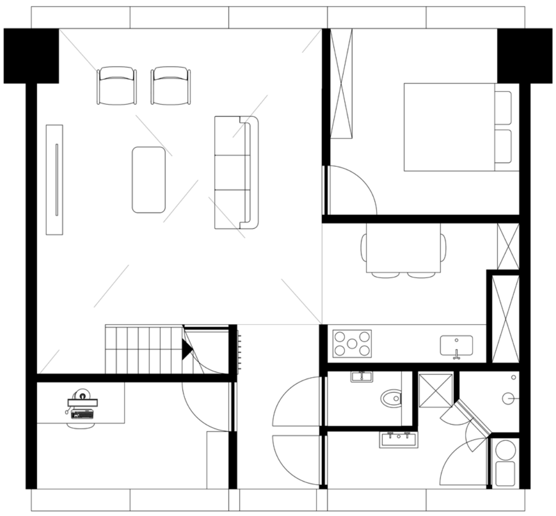
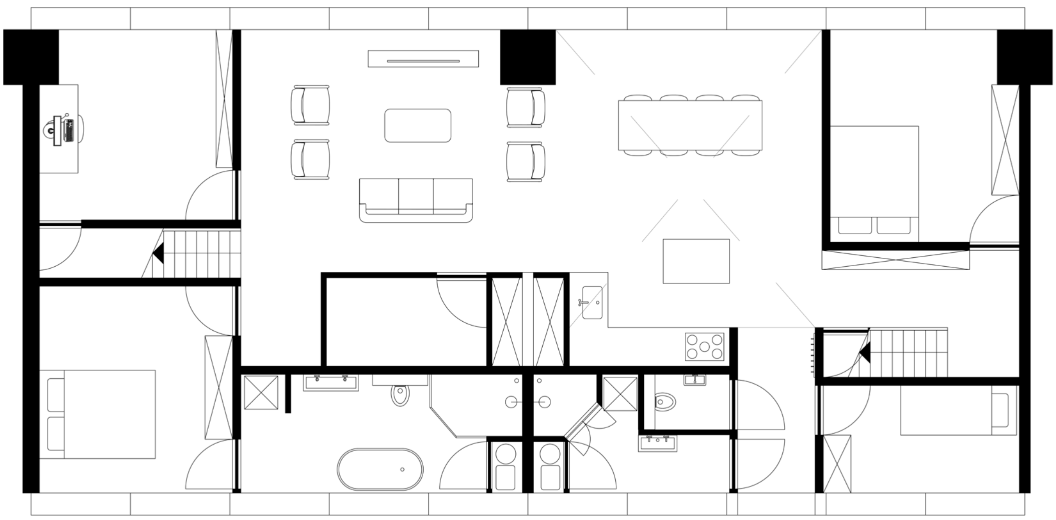
Floor p type 4



Scale 1 : 50 (scaled to fit)

Floor plan type 5

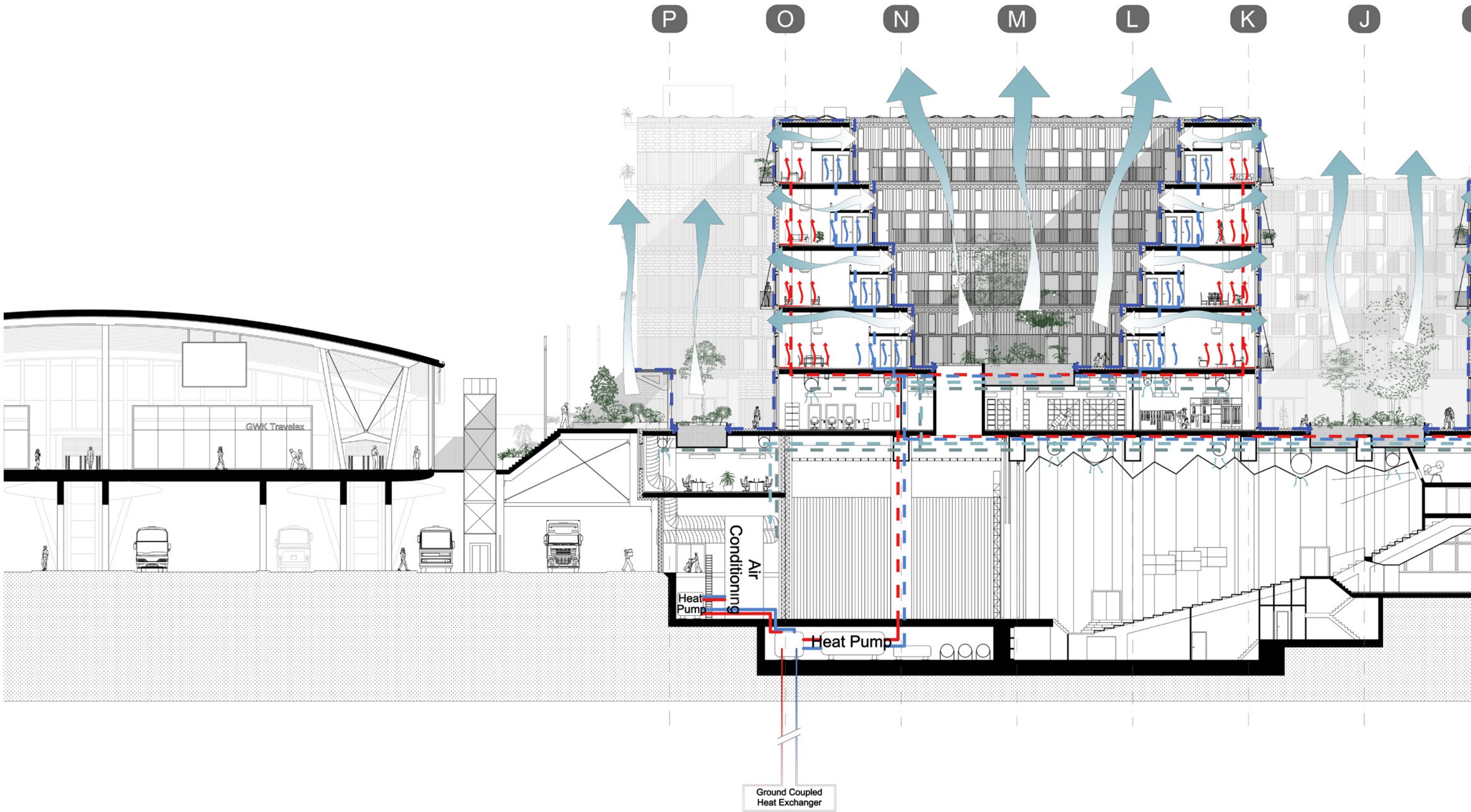


Scale 1 : 50 (scaled to fit)

Fig. 3.28: 4 possible dwelling layouts with the fifth serving as a layout for a double unit dwelling. Drawing by Author.

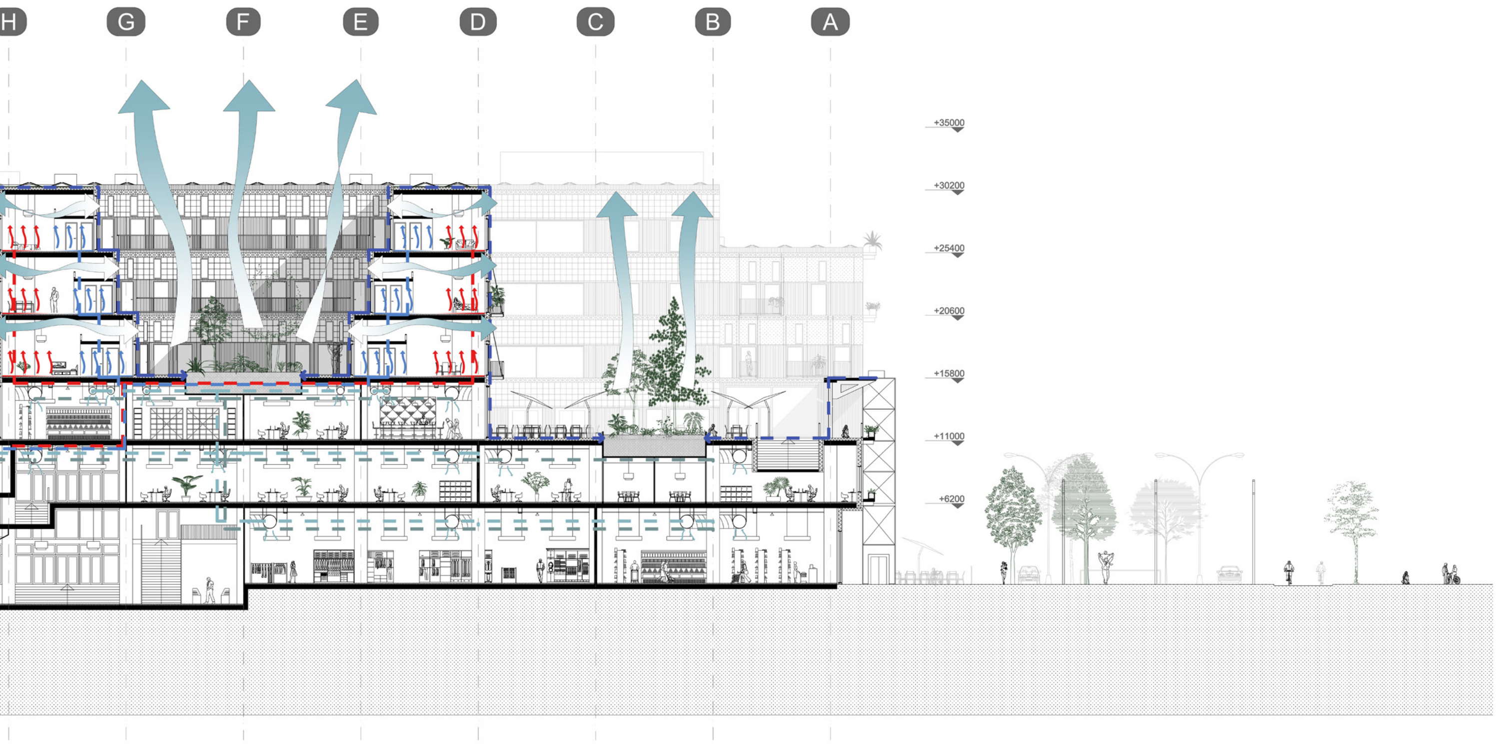
3.5 | Technical and detail drawings

Fig. 3.29: CAD drawing of longitudinal section with the climate design displayed. Subjects treated are the darker blue (cooling), red (heating) and light blue (ventilation) accents. Drawing by Author.



Climate design

Goal of the buildings climate design is to do as much climate control passively as possible. The approach can therefore be considered 'low tech'. See figure 3.29. Because of the principle of all dwellings have sunlight entrance from at least two directions, the dwellings are suited to be cooled with cross ventilation by operable windows. The greenery helps create local micro climate that cool the building all around through evapotranspiration. For the other programs in the building, this is a larger challenge. This is because these programs like offices and retail have larger spaces further away from the facade. This means that these programs cannot completely rely on ventilation through the facade. That is why these programs have a ventilation system that supplies and retracts the air with an air conditioning unit capable of heat and cooling recovery. Although drastically



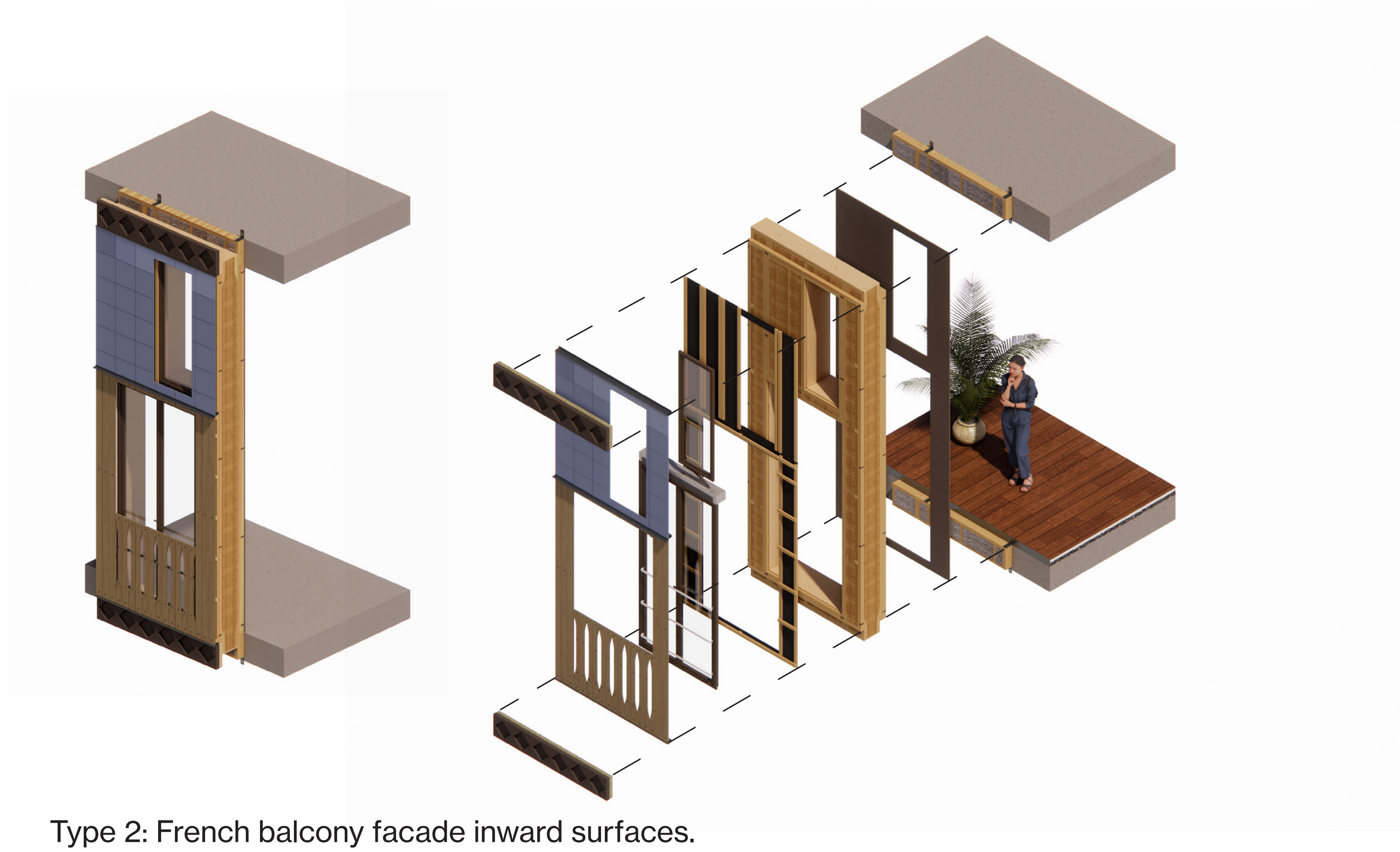
Scale 1 : 500 (scaled to fit)

reducing energy consumption in doing so, this is not enough as efficiency of the airco is 90% at the best moments. Additional heat and cooling is provided by an electrical heat pump with a water medium. This heat pump uses water pre-heated or cooled from a ground coupled heat exchanger. The same ground couped heat exchanger is used by the dwellings, that supplies the pre heated or cooled water to another electrical heat pump, which in turn provides warm or hot water to floor heating/cooling systems of all dwellings.

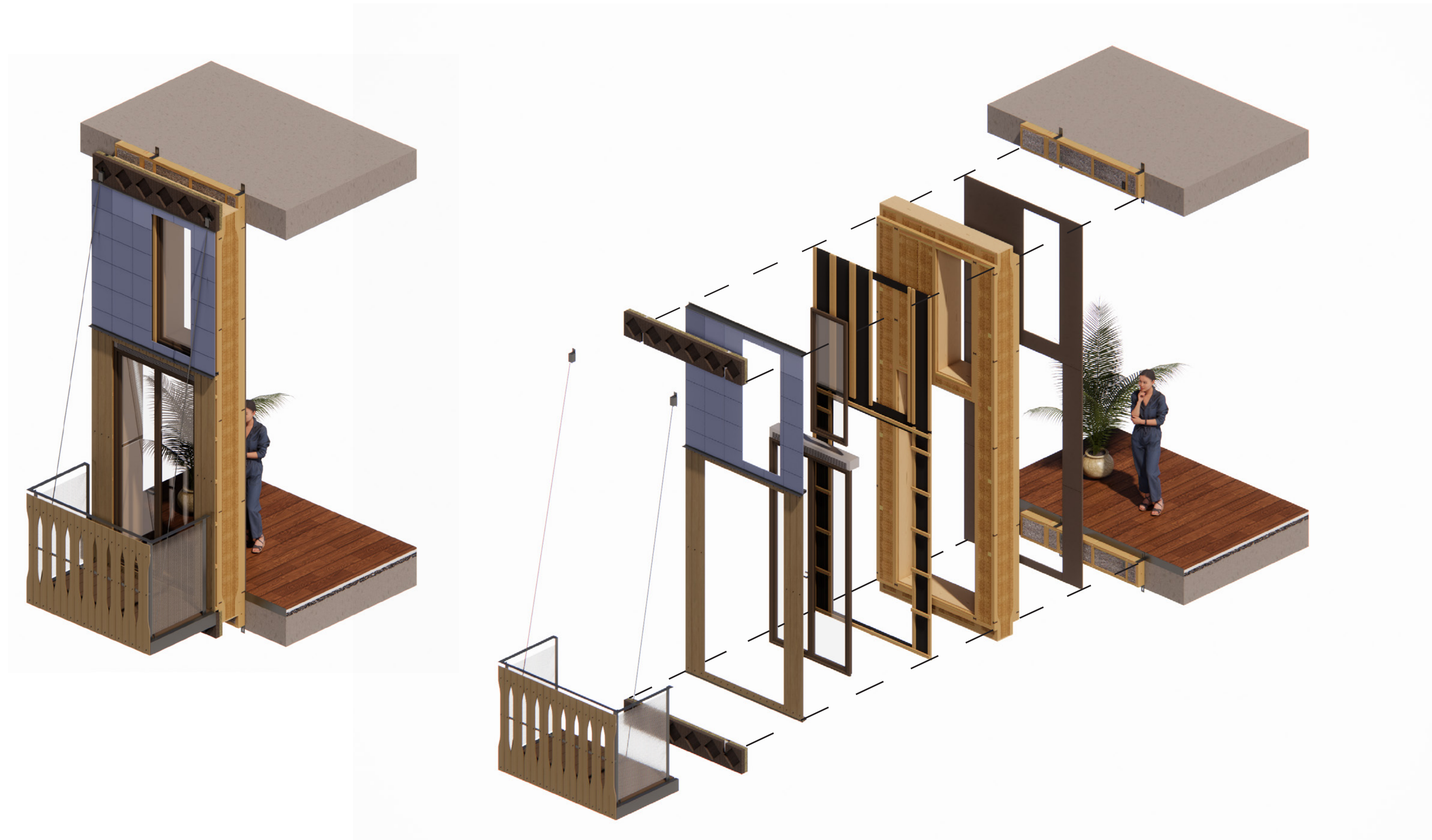
Facade typology

The facade design is of course an important part in this chapter, as it tests the applicability and feasibility of the research into the design assignment. The design approach starts at the urbanistic scale. From the moment of the first design ideas and sketches (paragraph 3.3) was played with the idea of preserving the existing outward image of the building by keeping the floor edges and industrial elements like concrete. The facade design builds on this. In addition to some concrete elements like floor edges and galleries, it will reuse the aluminium profile sheets that currently serve as facade finishes on a large part of the whole building (figure 3.30, type 1).
On the new, 'carved out' inward facade facade surfaces however, will the new facade finishes as stated in the research be applied. In doing so, the building will have a nice contrast of a more industrial outward appeal with a more renewable and warmer materiality inwards (figure 3.30, type 2 and 3). Type 2 and 3 are here shown with the options of a (French) balcony, because only the inward facing facade surfaces will provide outside space for the dwellings looking over the internal streets in the design. This is not done on the outward facing facade and courtyard as space is reserved for galleries.

Fig. 3.30: Axonometric renderings of the different facade types developed from the facade system. Continues on next page. Drawing by Author.



Type 2: French balcony facade inward surfaces.



Type 3: balcony facade inward surfaces.

Ornamental typology

Within the inward facing facade types, a greater distinction can be made concerning ornaments. As stated before, are here all materials applied found in the research. They are structured according to the order of the different u-shaped blocks. On the one hand, they share a universal finish of vertical wooden cladding, to unify the design. On the other hand is around the same height in every block on every floor surface area reserved for a ornamental material that is unique to each specific block. This not only helps in wayfinding in the large building, but also aims to provide residents an increased sense of place and identity. See figure 3.31 and figure 3.32 for the division and renderings of the ornaments.

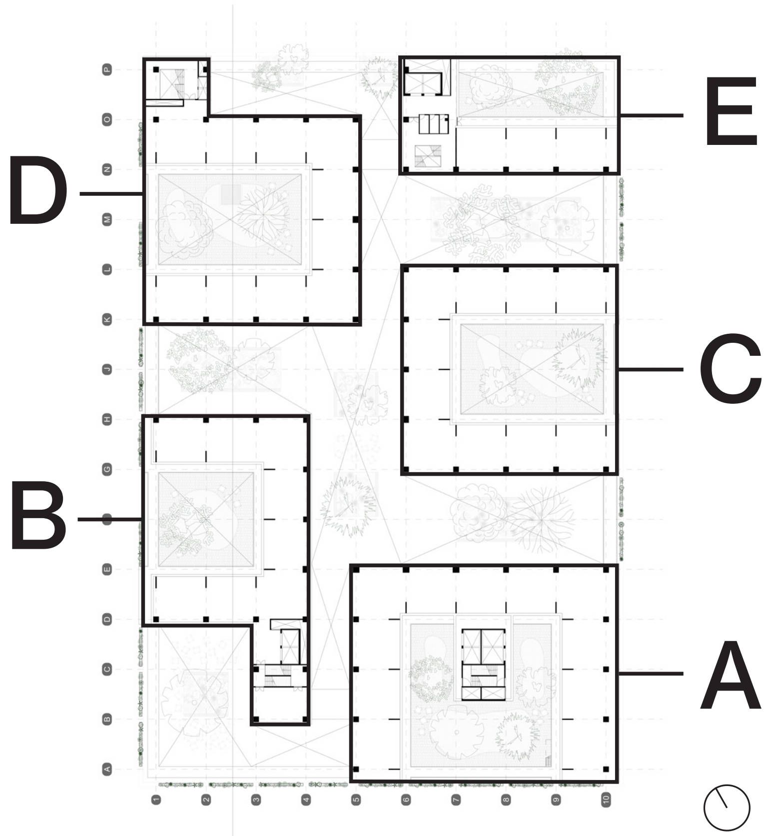
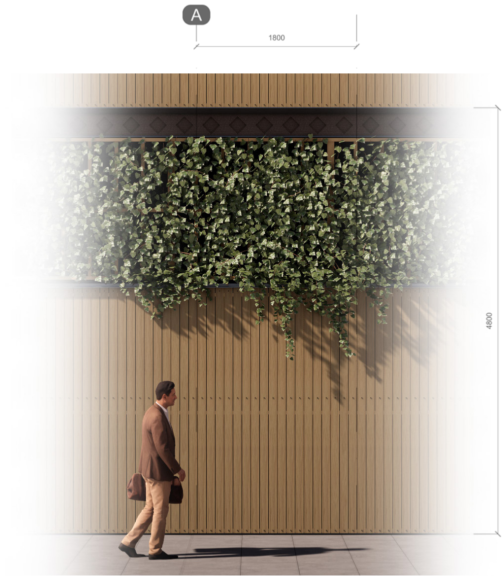
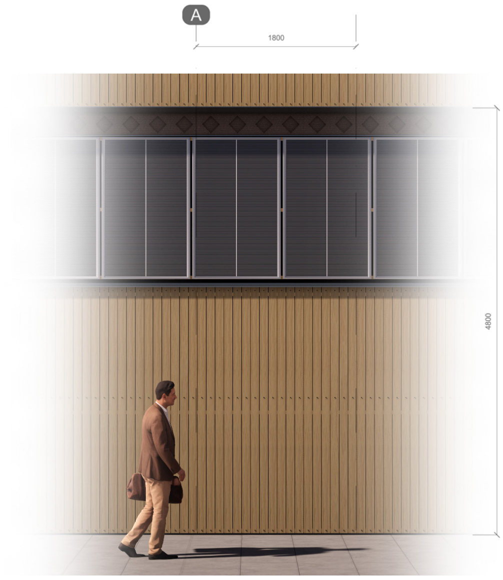


Fig. 3.31: Simplified floor plan overview of the different u-shaped blocks and their location in the building. Drawing by Author.

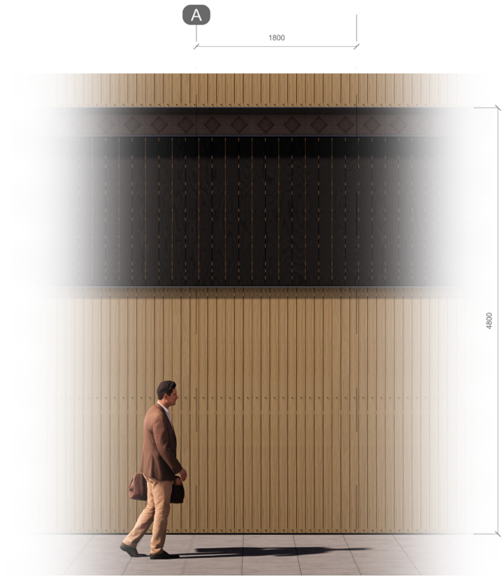


Facade type block A
Vines

Facade type block B
Biocomposite tiling

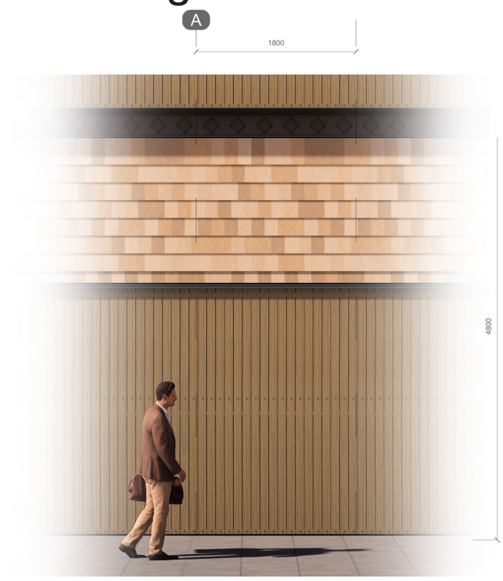


Facade type block C
PV-panels



Facade type block D
Shou Sugi Ban

Fig. 3.32: Renderings of the different ornament types for the inward facing facade surfaces. Block A: vines, Block B:biocompositie tiling, Block C: PV panels, Block D: Shou sugi Ban cladding and Block E: chestnut shingles. Drawing by Author.



Facade type block E
Chestnut shingles

Facade in relation to dwelling

As almost all dwelling units cover the grid size of 9 meters, they will each have a prefab facade panel consisting of 5 cassettes on each side (so 10 cassettes in total per dwelling on average, see figure 3.33). As shown in the research in chapter two, is within each cassette the possibility for customization. Standard options are type one: an enclosed facade or type two: one with openings. In type two, the standard cassette types two and three from chapter two are combined. This is in line with the facade design language of the universal facade finish of vertical wooden cladding and the ornamental strip on top. The wooden cladding covers conventional floor height of 3 meters, while the remaining height of 1,8 meters has the ornamental finish with a smaller ornamental window to allow for even more daylight entrance.

Fig. 3.33: Axonometric drawing of a typical dwelling fitout with a possible prefab facade panel removed, having enclosed and open surfaces as well as a large balcony. Drawing by Author.

Facade fragment and 1 : 5 detail connections

Because the construction, production and assembly of the facade system is already deeply discussed in chapter two, do these details not bring any new information. They are made to bring a complete overview of the facade buildup, especially in relation to the more specific design of the transformation of the Bearixgebouw. They show how the facade relates to the other layers as defined by brand (1997), like the precise attachment to the floor edges and columns of the Beatrixgebouw. It also shows how infill elements like partition walls and floors can be made in a similar fashion of timber and straw products. Whilst windows and door are not specifically part of the facade system design (it was stated in chapter two to have triple glazing and a ventilation grille on top), here is chosen for a hardwood frame from sustainable FSC forestry as it is more sustainable in a CO2 emission LCA related comparison. The setback of windows and door in the facade is also visible in the details (figure 3.34 and 3.36), allowing for less direct sun heat entering the dwellings in summer while allowing more to enter in the winter.
For the courtyard and gallery a floor insulation of cellulose mats was chosen, similar to the one used in the interior ribbon of the facade system (figure 3.35). These are not pressure resistant, but are topped by a heightened tiling system. Pressure resistant insulation made from biofoam (renewable) is used only on the roof and around the soil containers for the greenery.
Lastly, will the floors in the dwellings be topped by a layer of biofoam, gravel and another layer of biofoam to house the floor heating/cooling piping (figure 3.36. detail 2). The floor finish can be chosen by the residents, but require to be suitable with the floor heating.

Corner dwelling with balcony and French balcony:
1. existing concrete column
2. Enclsed pressed timber-straw casette with interior clay board and exterior wood fibre board and wooden cladding
3. rain pipe
4. Pressed timber-straw cassette with facade opening and balcony. Teak, single door, triple glazed window frame. steel and wooden balustrade
5. Pressed timber-straw cassette with facade opening and French balcony. Teak, double door, triple glazed window frame. Steel and wooden balustrade

Scale 1 : 5 (scaled to fit)

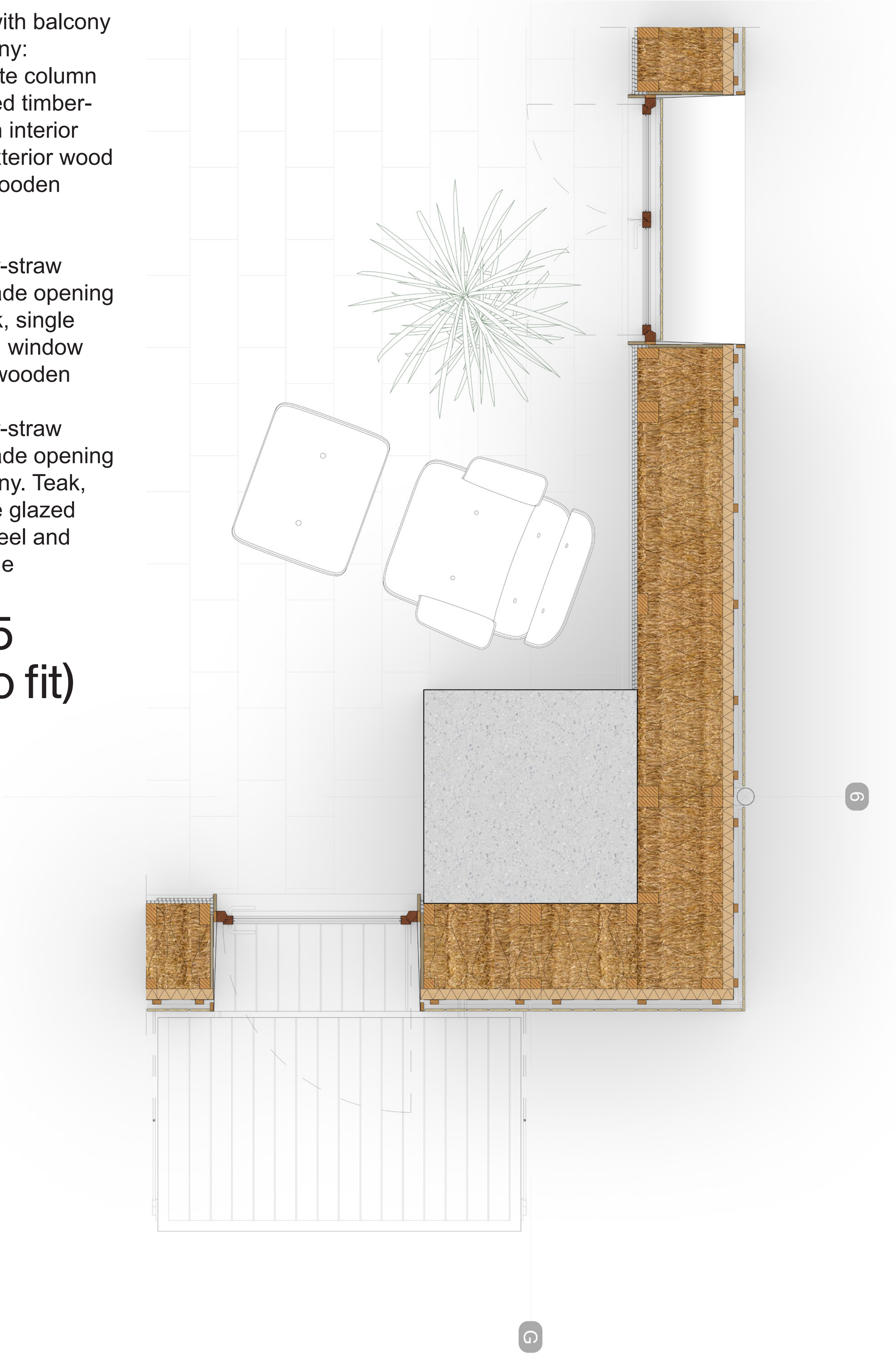


Fig. 3.34: Horizontal 1: 5 detail of the corner connection in the facade system of a dwelling. Drawing by Author.

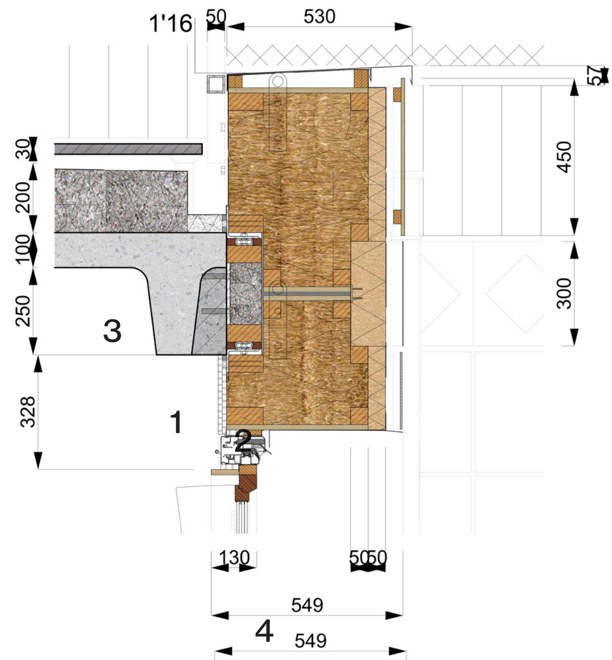
Fig. 3.35: Facade fragment taken at the courtyard of one of the u-shaped blocks. Drawing by Author.

Facade Fragment

Scale 1 : 20 (scaled to fit)

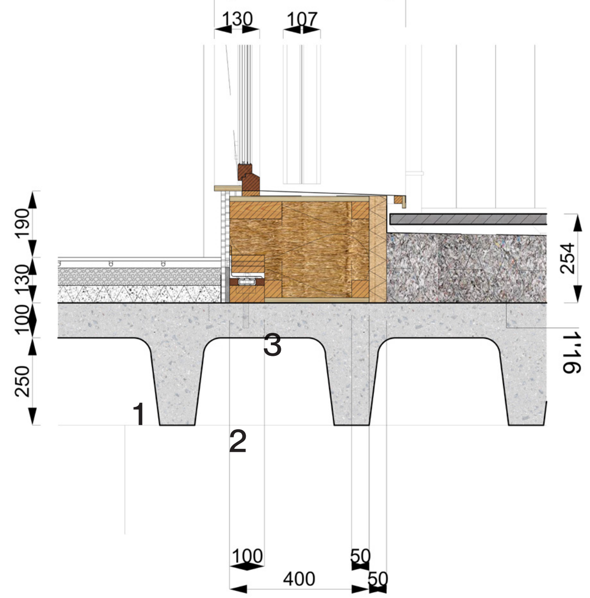
Details of connections

Scale 1 : 5 (scaled to fit)



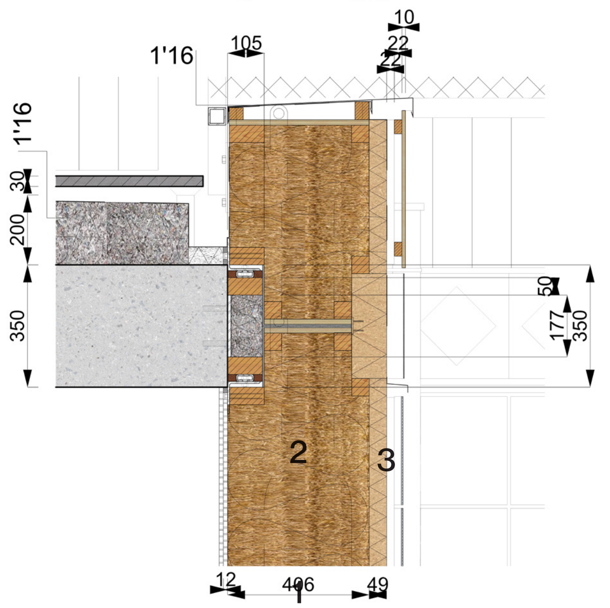
Detail 1

Gallery edge connection with facade opening:
1. concrete cassette floor with healed concrete floor edge
2. Double timber frame floor edge ribbon with cellulose fiber insulation for cassette attachment
3. Hightened reused pavement for gallery slabs with cellulose insulation
4. Timber-straw cassette with operable window and ventilation grille



Detail 2

Dwelling facade connection to gallery with facade opening:
1. Concrete cassette floor with Biofoam EPS and gravel in carboard honeycomb structure, with floor heating and cooling
2. Single timber frame floor edge ribbon for cassette attachment
3. Pressed timber-straw cassette with operable triple pained window frame of teak and aluminium sill



Detail 3

Gallery edge connection with enclosed facade:
1. Enclosed pressed timber-straw cassette with wood fibre board.Vertical timber cladding and Nabasco biocomposite as facade finish
2. Wool felt between cassette for wind and water proofing
3. Wood fibre board ribbon with nabasvo biocomposite finish on outside as secondary sealant

Fig. 3.36: Three vertical 1 : 5 details of several connections from the facade fragment in figure 3.35. Drawing by Author.

3.7 | Model documentation

An important part of the design (process) was making the 1 : 1000 scale urban model. This model is necessary to uderstand the relation of the design with its direct urban environment better, by using a physical tool. Although being made relatively late in the design, it still gives some valuable insights on the design that were taken into account. It mostly helped in relazing how to succesfully settle the building into the urban environment. First, with the aid of 3DBAG and openstreetmaps, a 3d digital model is developed with the Beatrixgebouw and the Jaarbeursplein at the center. Then some quick renderings are made to test materiality and visual representations (figure 3.37 and 3.38). The choice of wood in combination with cardboard was quickly made because of the contrast of warm and cooler tones emphasizing differents aspects of the model. Moreover, does the accents of steel wire on the location of tram and train tracks remind the viewer of the vicinity of the many transportation facilities closeby.

Fig. 3.37: Rendering of the complete urban model. Rendering by Author.

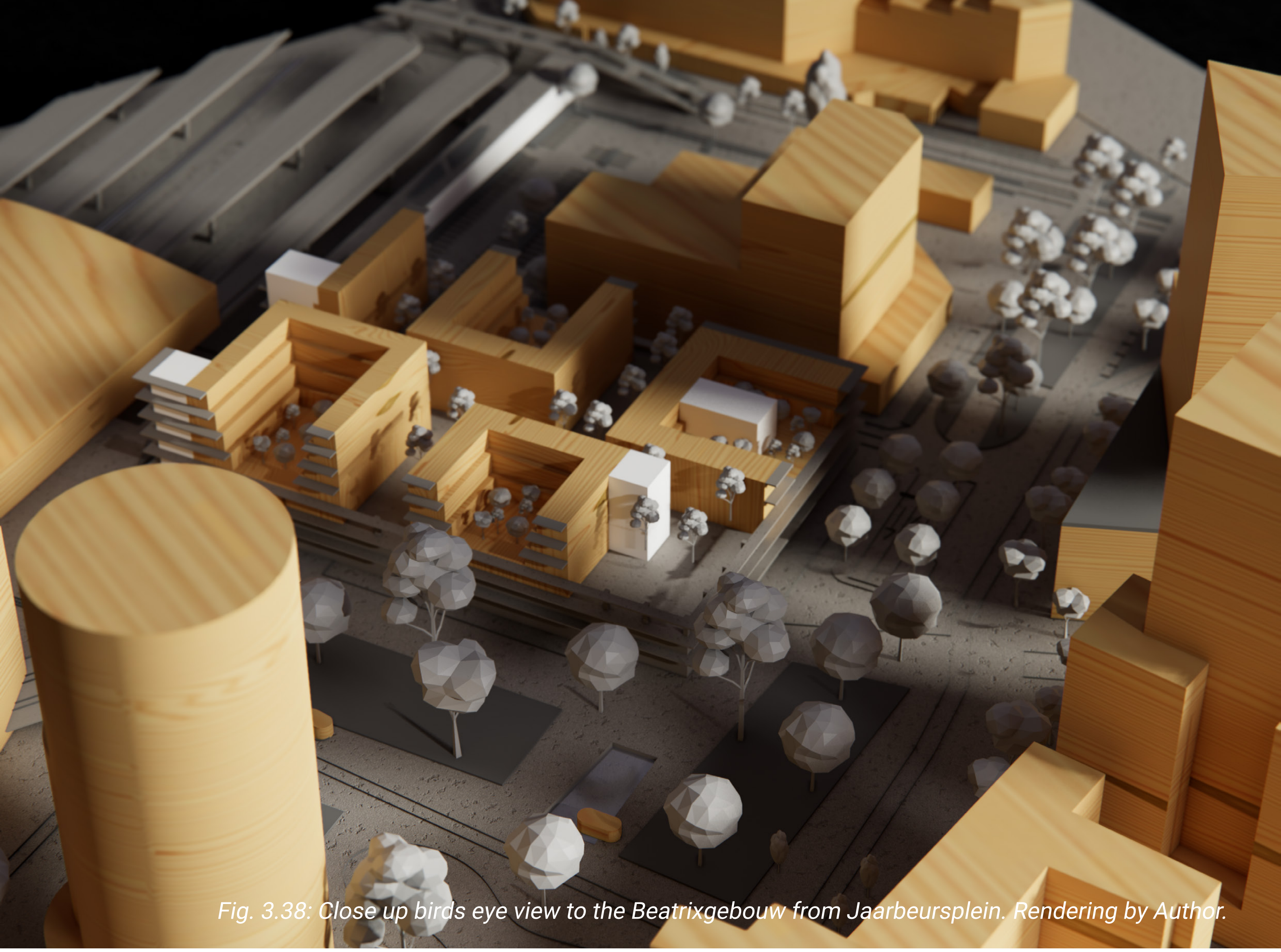


Fig. 3.38: Close up birds eye view to the Beatrixgebouw from Jaarbeursplein. Rendering by Author.

Model making process

Making the model was quite time consuming, and took approximately 75 hours. Although many things were planned beforehand, a couple things were adjusted. The first being the baseplate, that gained more thickness so the nails for the tracks could fit in completely (figure 3.41). Another adjustment was the model of the Beatrixgebouw. It was decided while making that the building should have some other color to attract the attention. This was eventually accomplished by staining the wood with a darker brown color. Secondly, it first had the galleries made from cardboard glued directly onto the model, was removed later. This was done because the carboard was cut by hand and looked sleazy. It got improved by adding some silver cardboard to the building perimeter (referencing the old, reused aluminium profile cladding) and by replacing the carboard with paper for the galleries (figure 3.40). The silver cardboard also added some contrast to the wood.

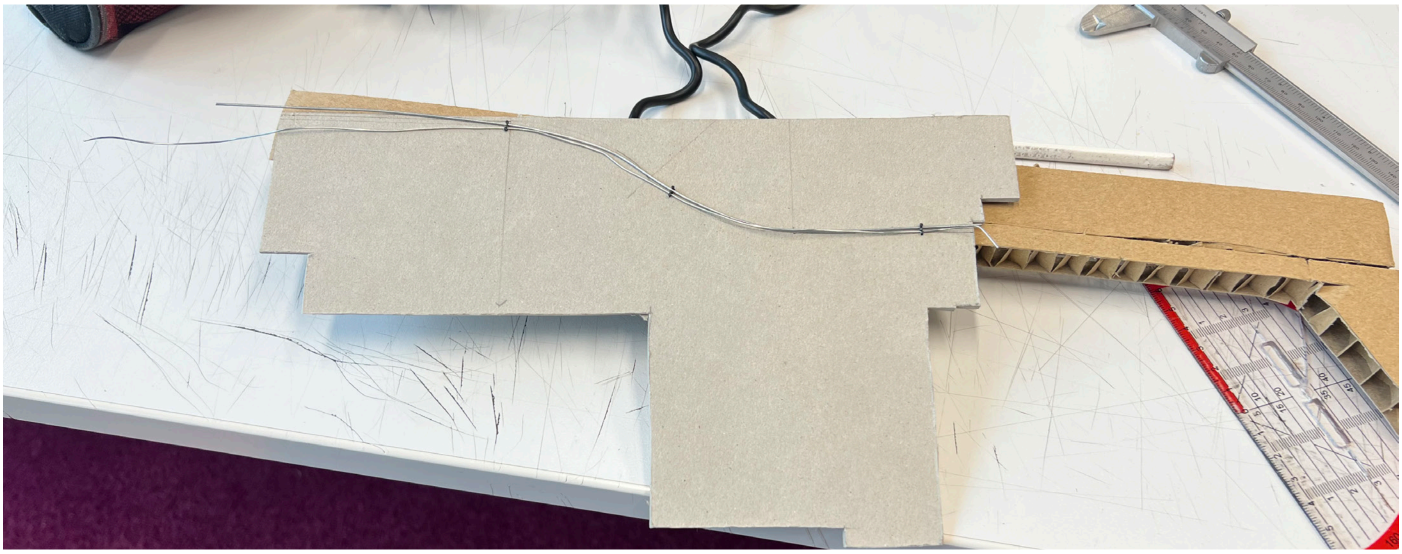


Fig. 3.39: Testing the placement of steel wire on a cardboard surface with nails as a reference to the tram and train tracks. Photo by Author.

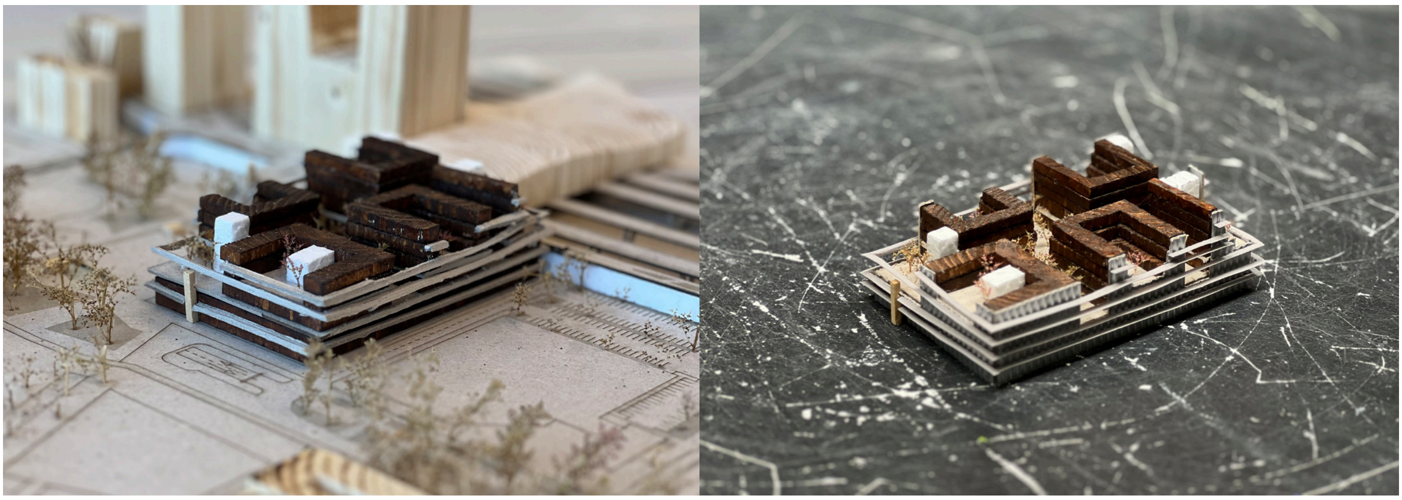


Fig. 3.40: . The model of the Beatrixgebouw with the sleazy cardboard gallery glued on directly (left), and the more precise model after adjustments with paper and silver cardboard (right). Photo by Author.

Final product

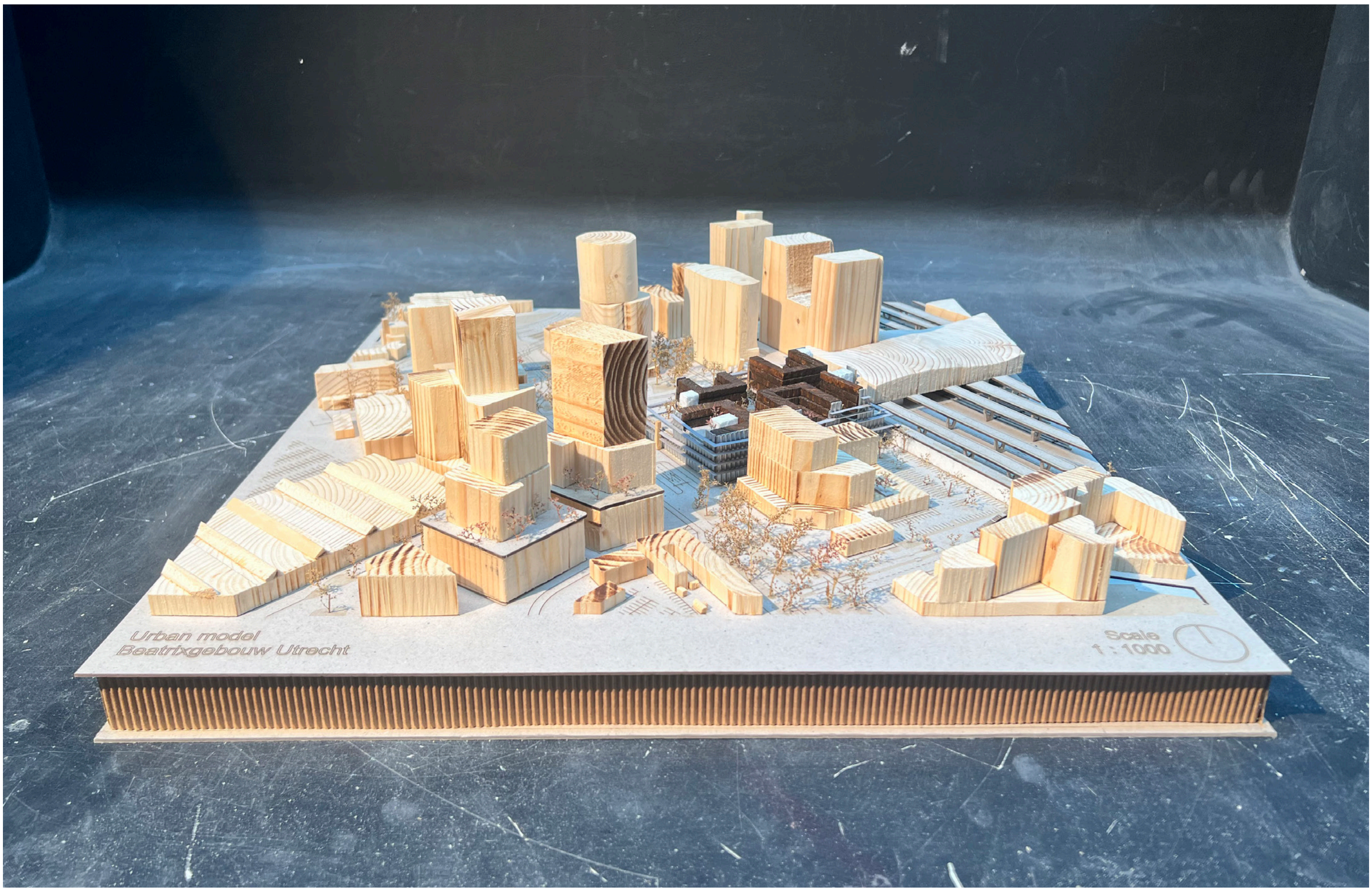


Fig. 3.41: Complete urban model from the front looking north. Photo by Author.

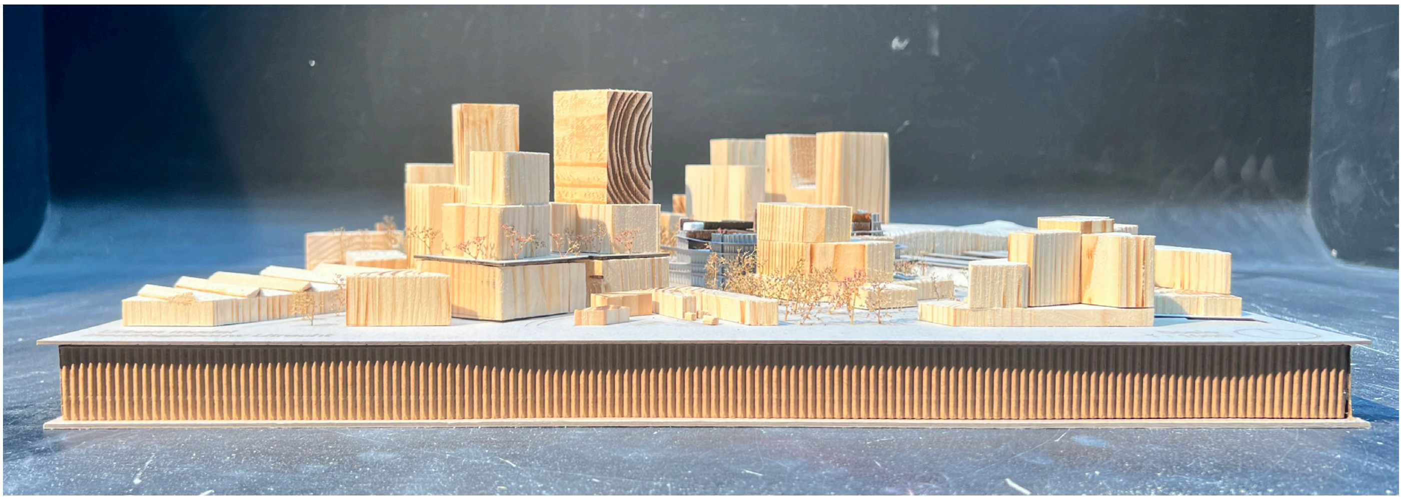


Fig. 3.42: Complete urban model from the front showing the skyline. Photo by Author.

Fig. 3.43: Top view of the urban model. Photo by Author.

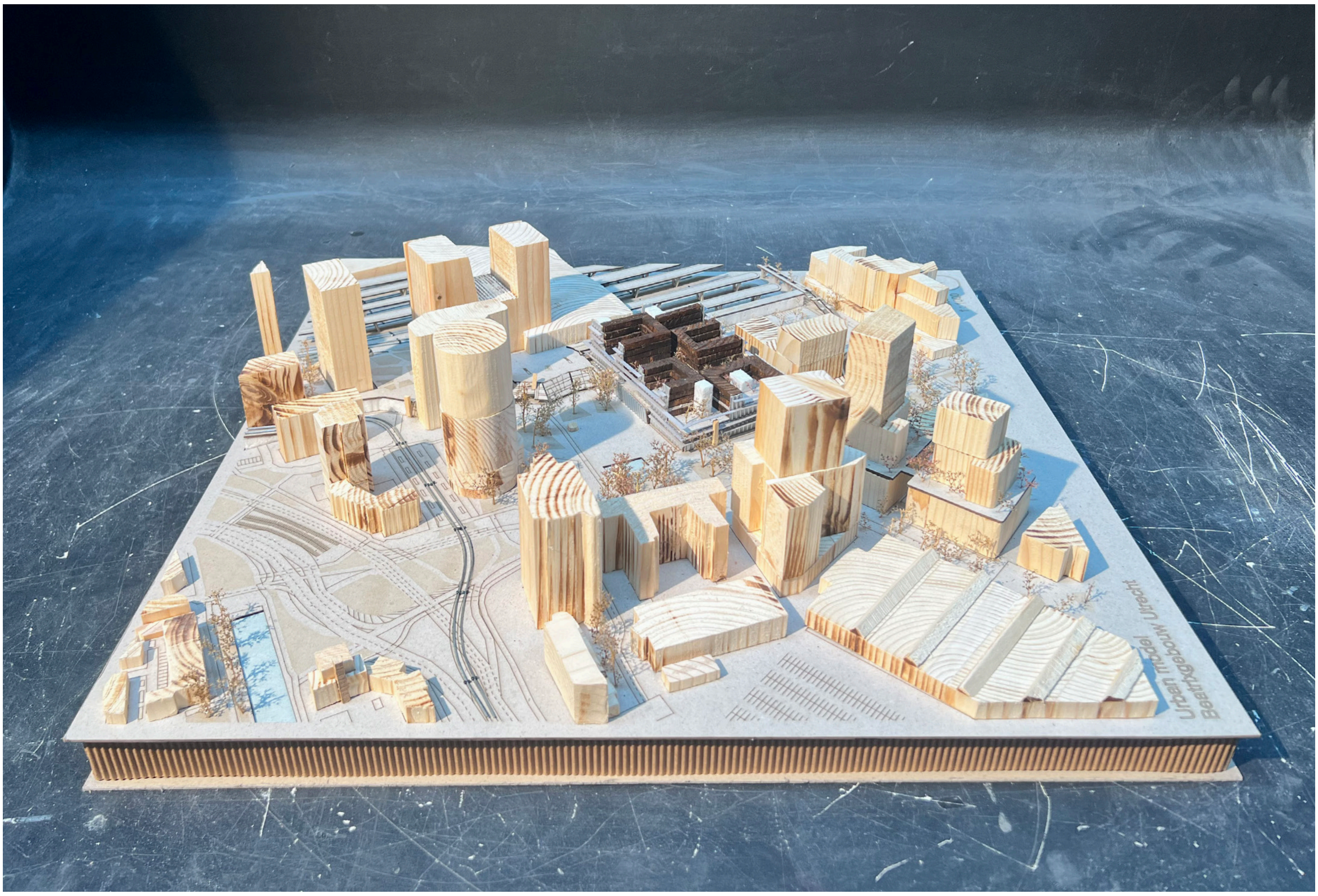


Fig. 3.44: View from the west of the urban model, showing connection of the Beatrixgebouw with Jaarbeursplein. Photo by Author.

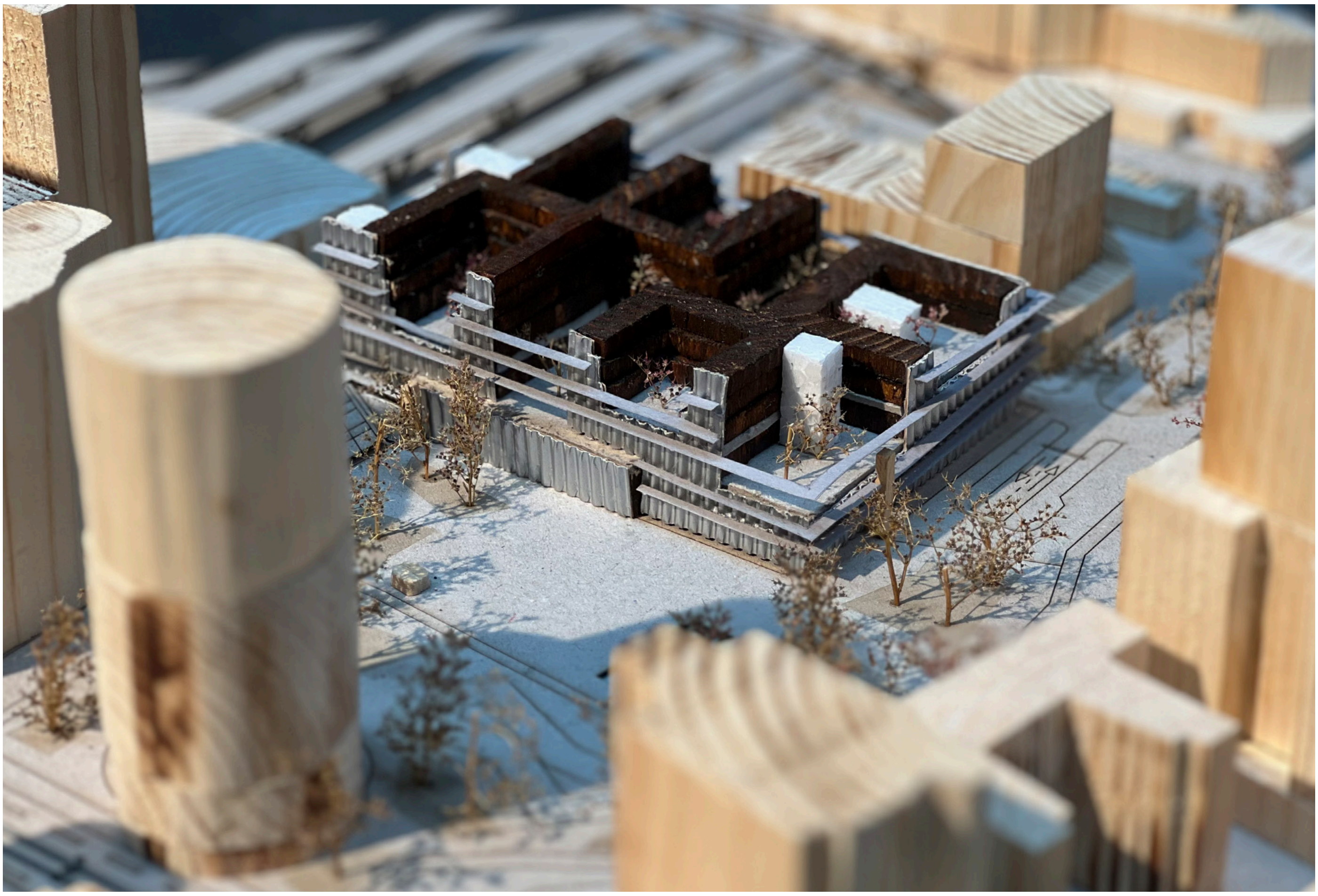


Fig. 3.45: Close-up of the Beatrix gebouw connection to Jaarbeursplein, surrounded by greenery. Photo by


Fig. 3.46: Close-up of the Beatrix gebouw from the Southwest showing the blocks stepping up in height towards the north. Photo by Author.

Fig. 3.47: Close-up of the Beatrixgebouw and the open west corner towards Jaarbeursplein, seen in between the highrise building Amrath hotel (left) of Wonderwoods (right). Photo by Author.

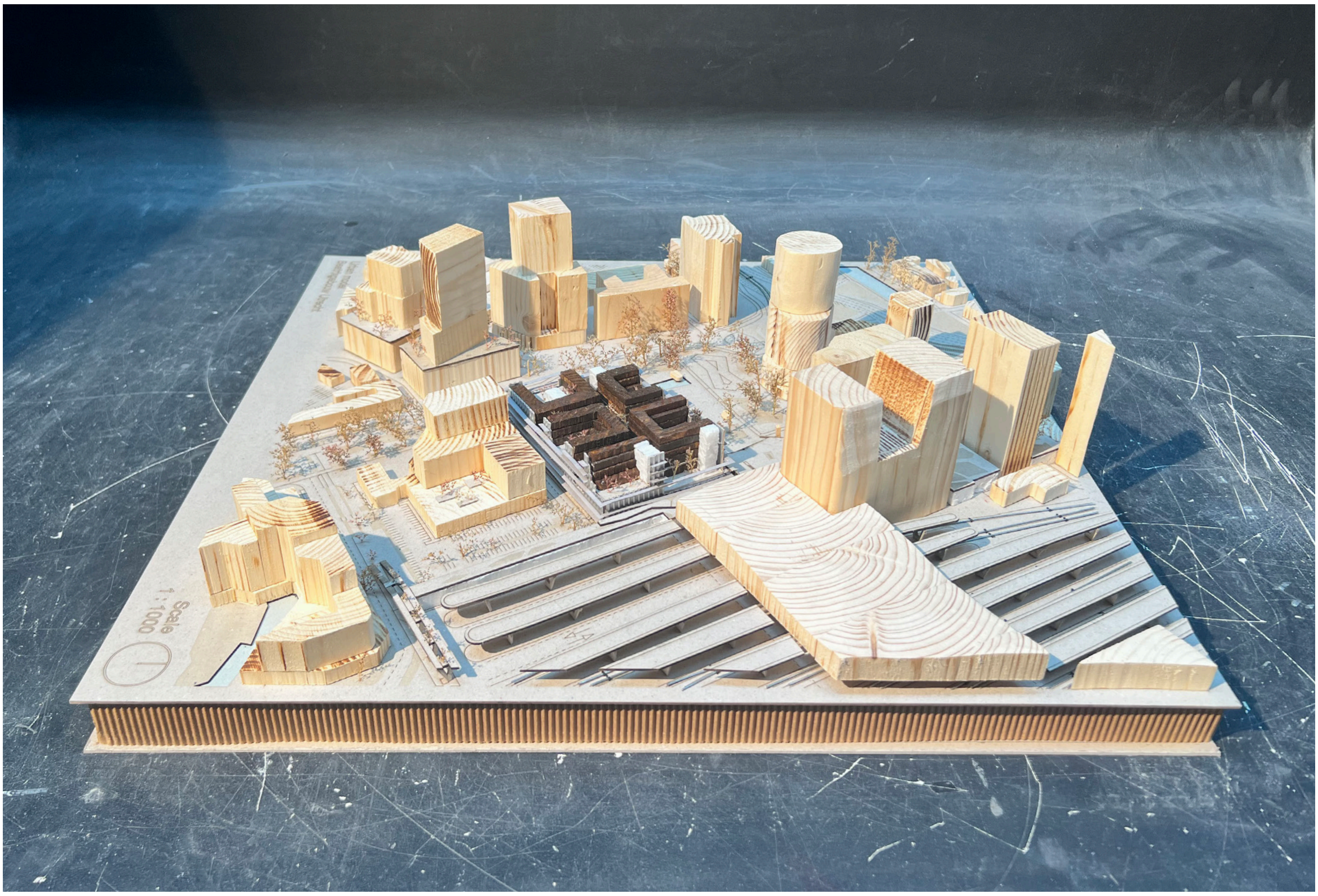


Fig. 3.48: Complete urban model viewed from the east, showing the connection of the building to the raised walkway and central station. Photo by Author.

3.8 | Impressions

Four perspectives were chosen to develop renderings from to show as some final visual representations of the design. These perspectives, all from eye level, were chosen upon some key design characteristics. They show a typical interior of a dwelling, the view of the building from jaarbeursplein, a typical courtyard layout and the heart of the raised urban level.

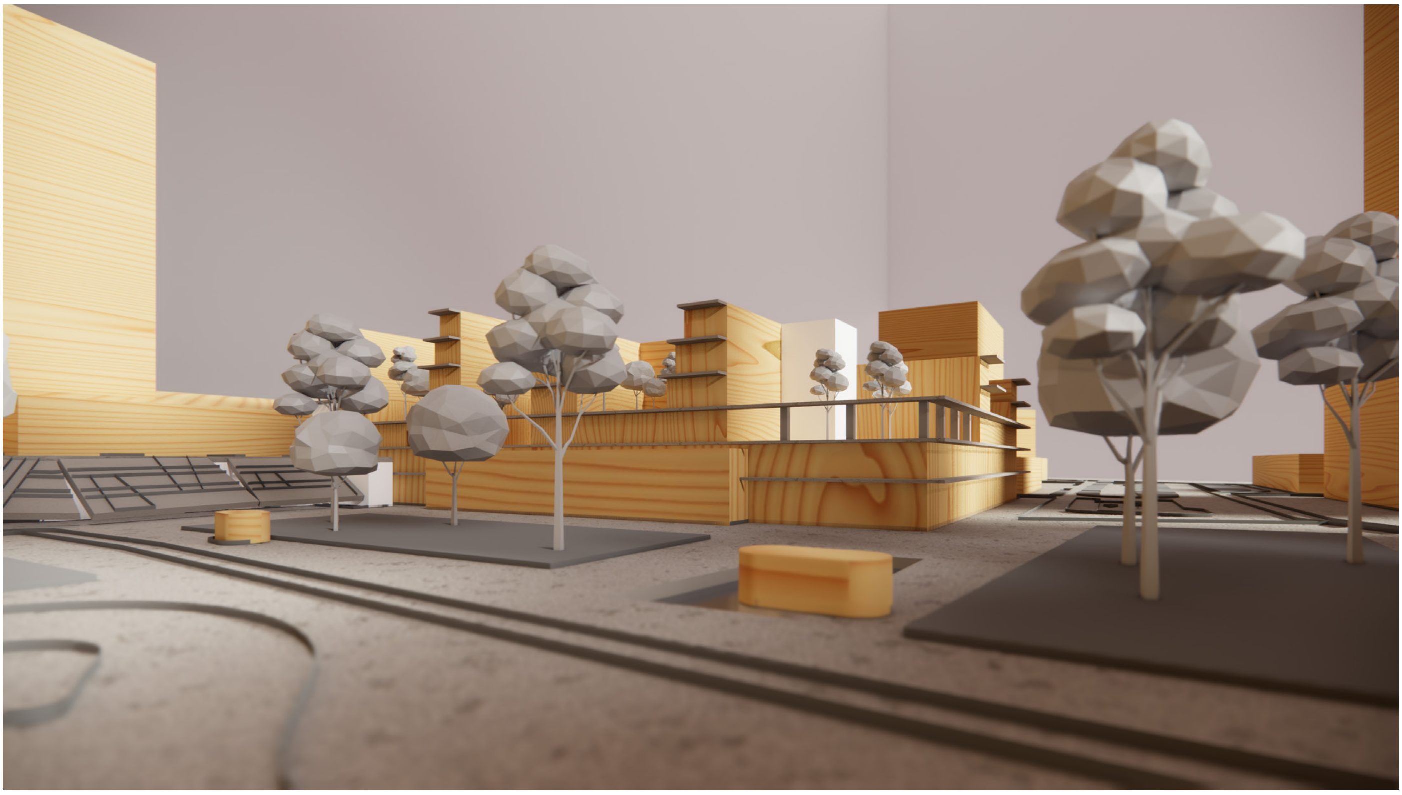


Fig. 3.49: Sketch render from the urban digital model of the view from jaarbeusplein.

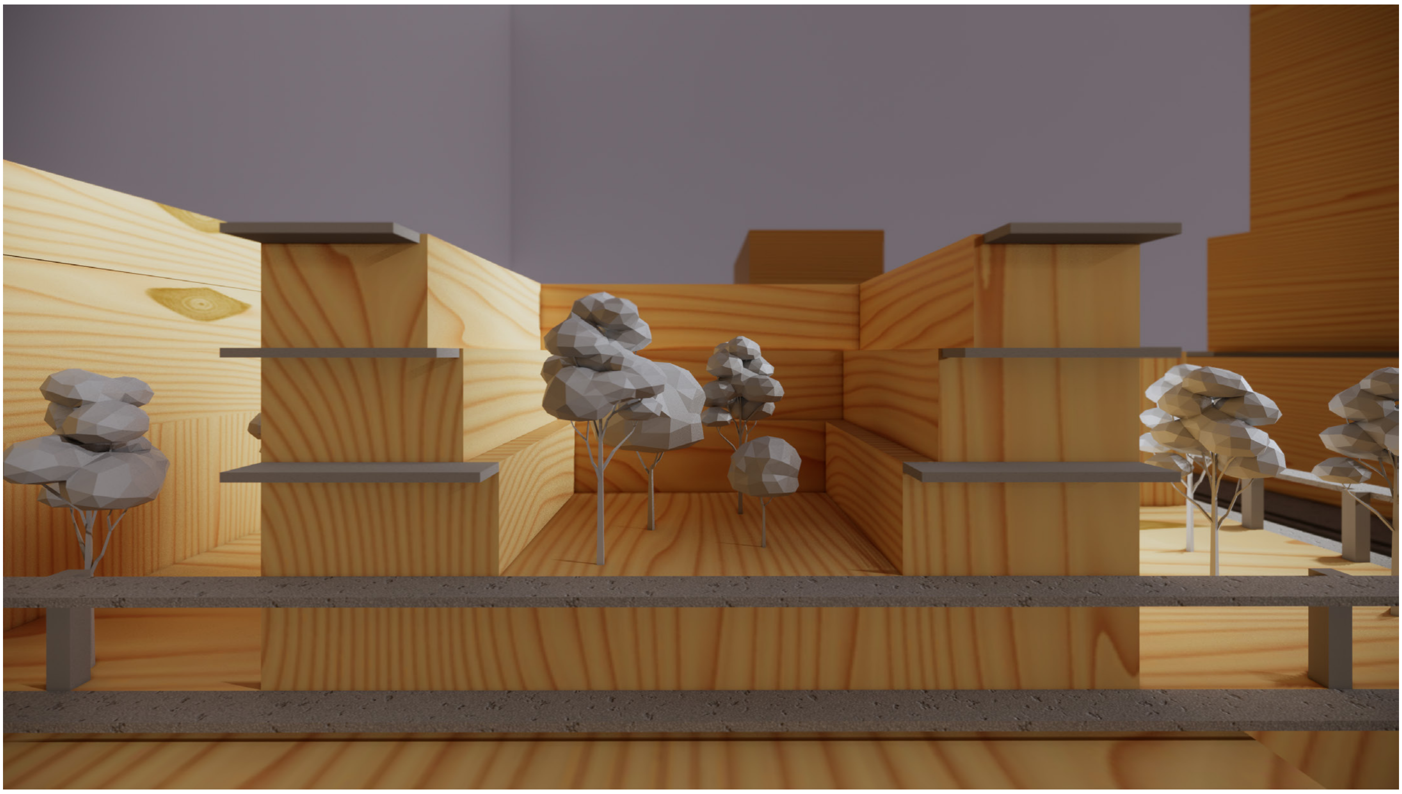


Fig. 3.50: Sketch render from the urban digital model of the view towards one of the courtyards.

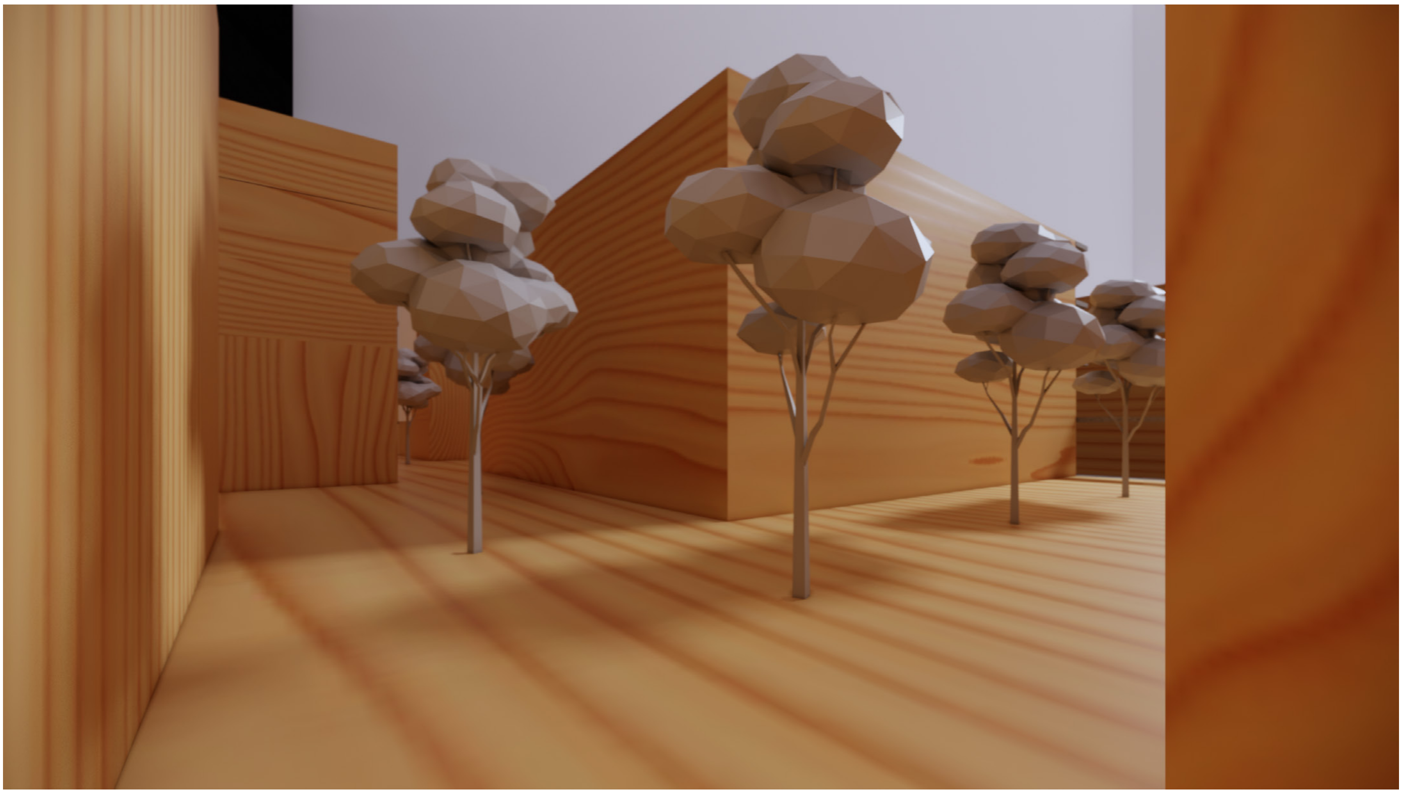


Fig. 3.51: Sketch render from the urban digital model of the view from the raised urban level.

Fig. 3.52: Interior Perspective. Render by Author.

Fig. 3.53: Courtyard perspective. Render by Author.

Fig. 3.54: Jaarbeursplein perspective. Render by Author.

04 | Reflection

04 | Reflection

1. *What is the relation between your graduation project topic, your master track (A, U, BT, LA, MBE), and your master programme (MSc AUBS)?*
Relation between:
Graduation project topic – master track Architecture
The façade is one of the most visual and aesthetic aspects of a building, form both the interior and exterior viewpoint. In designing the façade system, the eventual focus is on both technology and aesthetics. The outcome is on the interplay between both, and in this regard the architecture produced creates a design language as a result of the technology.
Graduation project - master programme AUBS
Additionally, the graduation work touches upon topics of urban design and building sciences in respect to their relation with façade design. Through different scales, it delves into the intersection of façade and building technology, public/urban space, building management and landscape design. Some topics were investigated during the research, like the economic constructs like PaaS ask for new managerial attitudes, as a part to the shift towards the circular economy. Other aspects were treated later in the process, during the research application. For example: the flexibility of the façade system posed by the research can accelerate the renovation rate in urban areas, which in its part transforms the urban playing field as well: when a building changes program the urban space around changes with it. Retrofitting the Beatrixgebouw also allowed to increase vegetated areas in and around the building. These aspects were taken into consideration during the design.

2. *How did your research influence your design/recommendations and how did the design/recommendations influence your research?*
Already within the research plan during Q1, some limitations in the design phase were foreseen. An example of this is that, to be suitable for the façade system, the to be designed/transformed building had to be linear in shape (i.e. without curves), with a relatively plain structure and an easy demountable facade. Additionally, by determining the programs of use in the research early on, a program of requirements was subsequently easily created when the design started.
Because the design phase is quite separated from the research phase, the design did not influence the research as much. However, during the design some challenges arose that were not accounted for in the research and that require further investigation, like the potential use of hempcrete as façade finish or how to deal with cantilevers in the support structure of a building.

3. *How do you assess the value of your way of working (your approach, your used methods, used methodology)?*
The used methodology was effective. This is due to the use of different methods and research/design tools bringing in different insights about the project. On of the most valuable methods was prototyping. Here, the knowledge about the material and technology and paper became tangible. It also revealed some elements that failed in the process of making, like the wooden cross brace that snapped. Overall, however, the process of making the façade cassette went according to plan.

Another significant method was the use of climate calculations during the development of the façade system. In theory the system was tested for vapor regulation, sound insulation, thermal conductivity and more. Although it complied with the set criteria on paper, unfortunately there was not enough time to test this thoroughly in practice.
The architectural tectonics framework offered a paradigm to structure the literature research on, but often it felt difficult to break the multifaceted technological process down into plain text. If this aspect would have been improved, the overall design and research could have been more clear and

Figure 4.1: the timber cross brace that broke during the processing of all parts. Photo by author.

coherent. The use of CAD-drawings in the appendix helped to some extent visualize the process as an additional explainer.

4. *How do you assess the academic and societal value, scope and implication of your graduation project, including ethical aspects?*
Social relevance: the goal was to apply the developed façade system to new construction, as well as renovation projects aimed at housing, office space and commercial space. In doing so, the work aims to contribute to resolve the Dutch housing crisis by urban densification and renovation. Considering the size of the graduation project, was opted to only apply the façade system to the renovation of the Beatrixgebouw (if it works for renovation, it will work for new construction). Moreover, modularity and open building principles allow changes in building program relatively easily, responding to specific program demand changes. However, research into the economical and organizational implications of the flexibility was not part and could raise more practical challenges. Professional relevance: the graduation project comprises work based on the latest trends and insights in the construction industry. The results were be applied to existing building stock, which currently can be considered as the larger construction challenge of the Netherlands. The use of biobased materials is in line with the material transition in the professional field, which has to ramp up to 30% in 2030 (NABB). Academic relevance: the graduation work explores the potential of upscaling and industrializing the use of straw-cassettes as the core modular system. It attempts to construct a framework on which industrial processes and biobased materials can be integrated, closing in the research gap between them. Here it is important to eventually test the façade system for its performances, something that unfortunately was not possible during the graduation project.

5. *How do you assess the value of the transferability of your project results?*
Because the research results are relatively separated from the design, they can be generalized to a great extent. As mentioned earlier, was the façade system only applied to a renovation project (Beatrixgebouw), but it is important to note that it also works for new construction. To offer an architect or contractor a sustainable facade tool in their design has always been the approach. Nevertheless, has to be said that every project is different and faces unique design challenges. During the application of the system onto the Beatrixgebouw these challenge arose as well and needed some custom solutions.

6. *Are there any specific things you would have done differently? (own question)*
The timeframe in which we had to do the research (Q2) was underestimated and there was no advantage taken of beginning the research in Q1 already. In retrospect, having started earlier could have allowed for a bit more in-depth of a research. For example; the prototyping started in Q3 and was actually planned for Q2. However, the Q1 period in the aE studio is meant for exploring one's interest and research topics, and the topic altered a few times. That is, of course, also part of the process and laid a good foundation for the research. It began with a modular and demountable pavilion, followed by a biobased factory for biobased construction materials, to finally result in a modular and biobased façade system.
7. *How was the feedback translated into the work? (own question)*
After each tutoring session, all the feedback was written down in a notebook. The feedback formed a list, that was added to the to do list and was processed every week. In doing so, the processed feedback could be shown to the tutors next week to build on. These adaptations are also mentioned in the presentations, to make the design process more visible, rather than a static end result.

Semester 1																						
Site analysis	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	2,1	2.2	2.3	2.4	2.5	2.6			2.7	2.8	2.9	2.10
Month	September				October					November				December				January				
Date	2/9 - 6/9	9/9 - 13/9	16/9 - 20/9	23/9 - 27/9	30/9 - 4/10	7/10 - 11/10	14/10 - 18/10	21/10 - 25/10	28/10 - 1/11	4/11 - 8/11	11/11 - 15/11	18/11 - 22/11	25/11 - 29/11	2/12 - 5/12	9/12 - 13/12	16/12 - 20/12	23/12 - 27/12	30/12 - 3/1	6/1 - 10/1	13/1 - 17/1	20/1 - 24/1	27/1 - 31/1
Delivery	Design tutoring every Tuesday Research tutoring every Wednesday									P1	Design tutoring every Tuesday Research tutoring every Wednesday						Christmas Holidays		Design tutoring Research tutoring		P2	
01 | Introduction																						
	Composing research plan																					
02 | The research: towards sustainable facade culture																						
Part A							Collecting relevant case studies				Analyze facade climate											
												Analyze biobased materials										
													Analyze structures									
Part B															Experimentation & facade design				Experimentation & facade design			
03 | The design: transforming the Beatrix gebouw Utrecht																						
Site analysis															Site selection				Site selection			

Figure 4.2: the self-made planning for Q1 and Q2, with a relatively long period for 'composing research plan' and relatively little time for the actual research itself. Table by author.

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