

# **Evolving Urban Housing**

**A prefabricated system for urban mix-used housing which  
could adapt over time**

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## **Abstract**

This research develops a prefabricated housing system that can respond to labor shortages in construction, fast-changing urban living demands, and the increasing need for adaptable rental housing in Eindhoven. Through an analysis of existing prefabricated systems and open building strategies, the project identifies the lack of short-term adaptability during the use phase as a key limitation. The proposed system combines a demountable timber support structure with manually assembled 3D-printed earth-based infill and modifiable facade, enabling reconfiguration with minimal intervention. This infill system is not only flexible and sustainable, but it also provides unusual spatial experience with curved design. The design is applied to a mixed-use site in Eindhoven's station district, where changing household compositions and co-housing scenarios can be tested through adjustable boundaries between private and shared spaces, and interior and exterior. By positioning the building as an evolving platform rather than a fixed product, the project outlines a strategic framework for balancing permanence and changeability, and provides a basis for future research on adaptable and open housing systems.

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# **1. Introduction**

## **1.1 Problem Statement**

### **1. Labor shortage in construction**

According to the Netherlands Business Survey reported by Statistics Netherlands (CBS) in April 2025, the construction sector faces the worst labor shortage among investigated sectors. Over 80 percent of businesses in the construction sector indicated that they are experiencing staff shortages.

One of the solutions to this problem is prefabrication and automating more tasks. With automation and the help of advanced digital fabrication technologies thriving in recent years, prefabricated construction systems improve productivity in a traditionally manpower-intensive industry. Moreover, off-site manufacturing in controlled environment also provides a safe working place for construction workers, which encourages more people to enter the construction industry.

### **2. Shorten building life span due to fast-changing building use**

The construction sector accounts for around 37% of global carbon emissions. Buildings are frequently renovated and demolished in response to fast-changing factors. These changes can be related to social and local factors (e.g. users' preferences and changes in building functions), environmental motives (e.g. climatic changes), technical requirements and functional performance (e.g., to embrace technological improvements), and stakeholders' interests.

Nevertheless, they are usually designed and constructed as rigid, fixed, monofunctional structures, which disable any type of change. (Askar et al., 2021) As a result, many structures require extensive refurbishment or face premature demolition as user preferences shift, effectively shortening their life cycles. This leads to significant costs and large volumes of waste, causing large amounts of CO2 emission.

Although standardization brought advantages of higher quality control and the economies of scale, standardized construction systems lacked geometric

flexibility and therefore the ability to adapt to different internal and external conditions. (Kriega & O. Lang, 2019) Reversible building design can help to improve the adaptability of buildings by enabling rapid and cost-effective changes to the building's layout and structure, and by allowing for the reuse of building components through design for disassembly. (Mlote et al., 2024). Therefore, development of prefabricated construction with a demountable design becomes a topic in urgent need of research.

### **3. Substantial future population growth in Eindhoven**

Eindhoven is expecting substantial population growth. The population increased from 223,209 in 2015 to 249,035 in 2025 and is estimated to reach 300,000 by 2030. This is because of the developments in the high-tech industry and the planning for the Brainport high-tech region.

Recently, ASML plans to start construction on a new campus near Eindhoven Airport, with clean rooms and offices built in phases, which could potentially bring 20,000 new employees to the region. (NL times, 2025) Moreover, ASML will provide significant financial support to four new construction projects that in total will deliver 1,085 affordable homes in Veldhoven, Eindhoven and Helmond. (ASML, 2024) There are also plenty of new housing projects in the city center of Eindhoven, such as the station area.

As for the household type, according to the Woononderzoek 2024–2040, Eindhoven has many small households, and the average household size is 1.9 people. In the city center, a household consists of an average of 1.4 people. Also, of all the homes in the municipality, almost 60% are rental homes. This indicates an increasing need for new housing in Eindhoven, especially small rental households due to the main influx of population are young employees working in the high-tech industry. Moreover, the report also shows that there is increasing desire for shared facilities such as a communal kitchen or laundry among home seekers to prevent loneliness, which also opens an opportunity for new living styles such as co-housing and efficient use of limited housing resources.

## 1.2 Project Objectives

To respond to the rising demand for prefabrication systems while upgrading current systems to better align with the principles of circularity, meanwhile fulfilling increasing housing demand resulting from population growth in Eindhoven, this research aims to discover the possibility of a new prefabricated system for mix-used housing which could adapt to various scenarios.

There is a large amount of research on demountable design for the end-of-life scenario, and these circular building parts could be applied to a different context once being demolished. However, the short-term adaptive scenario is often not fully considered, resulting in time-consuming renovations which cause considerable waste. For the most demanding housing type in Eindhoven, which are small rental households, the short-term change due to personal preferences of individual will occur more frequently. Therefore, the adaptive scenario of this research would focus on two main aspects:

1. Mixed-use housing which could adapt to changing building use
2. Changeable layout based on users' preference and experimental framework for co-housing

Mixed-use housing is for the future possibilities of decreasing housing demand and renewal urban plan in a fast-changing urban area. Changeable layout based on users' preference and experimental framework for co-housing is suitable for short-term rental homes for the increasing population in Eindhoven. This type of housing values the publicness of space, providing a customized and abundant living style under a restrictive context. In usual cases, the negotiation of deciding the proportion of shared space often slows down the process in achieving co-housing. The experimental framework could help accelerate the process with changeable layout after construction and during use.

As a result, the research questions are established as follows:

## **How to develop a prefabricated system for adaptable mixed-use housing and provide an experimental framework for urban co-housing?**

With the following sub-questions organized in categories:

- **Adaptable building:**

What are the existing open building strategies that could allow for reconfiguration of buildings?

- **Existing prefabricated housing system:**

What kind of prefabricated housing systems are currently used?

What could be improved in the current system?

- **Mixed-use housing:**

What kind of mixed-used program would be suitable in the station area, and promote the lively urban environment?

- **Changing layout and Co-housing unit:**

How to design a flexible support and infill system for experimenting with the suitable proportion of shared space within single co-unit and between co-units?

What kind of infill system will accelerate the process or provide maximum flexibility?

- **Automation and digital fabrication methods:**

What are the adding values of emerging digital fabrication methods and how to implement them into the manufacturing process of adaptable housing construction?

### 1.3 Project context

In Eindhoven, there is a massive undergoing transformation of the station area. By 2040, this area will be a residential area with residential facilities, recreation, and more green space along the Dommel River for 16,000 new residents. Early-stage planning of the selecting site includes 7,500 housing units, however whether there will be mix-used program is not yet clear.

The site is chosen due to its location close to the major public transportation hub, including the central station and the public bus stop location for future brainportlijn, which is the significant bus line connecting the ASML related offices and campus. The district is also connected to Dommel River and the TU Eindhoven campus, which makes it an important public gathering place and a suitable site for rental apartments in this area.

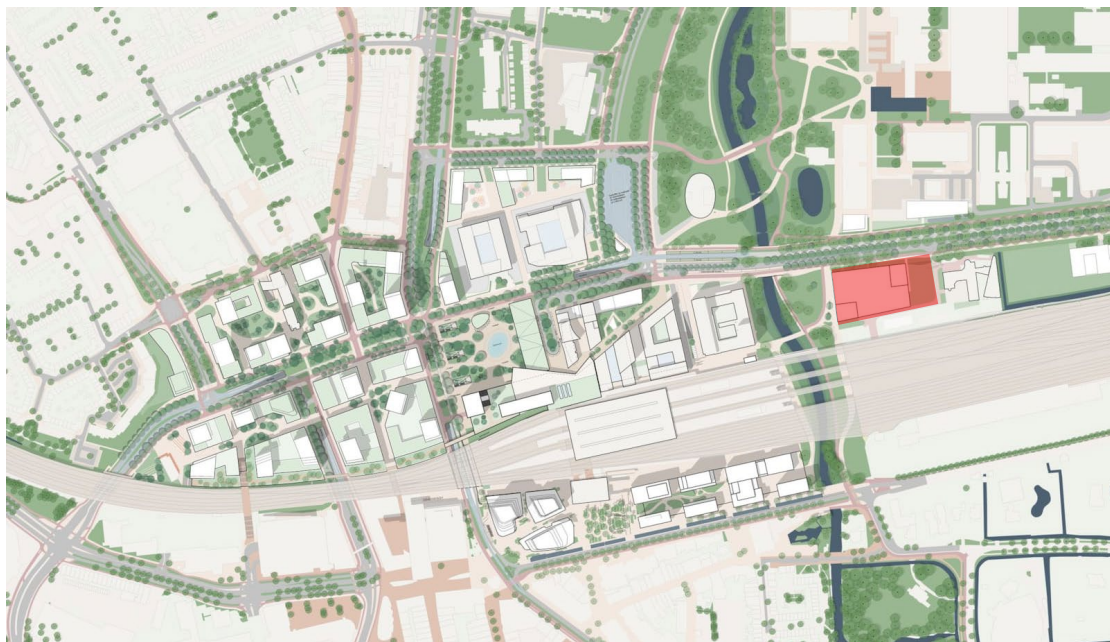


Fig 1.1 Site location

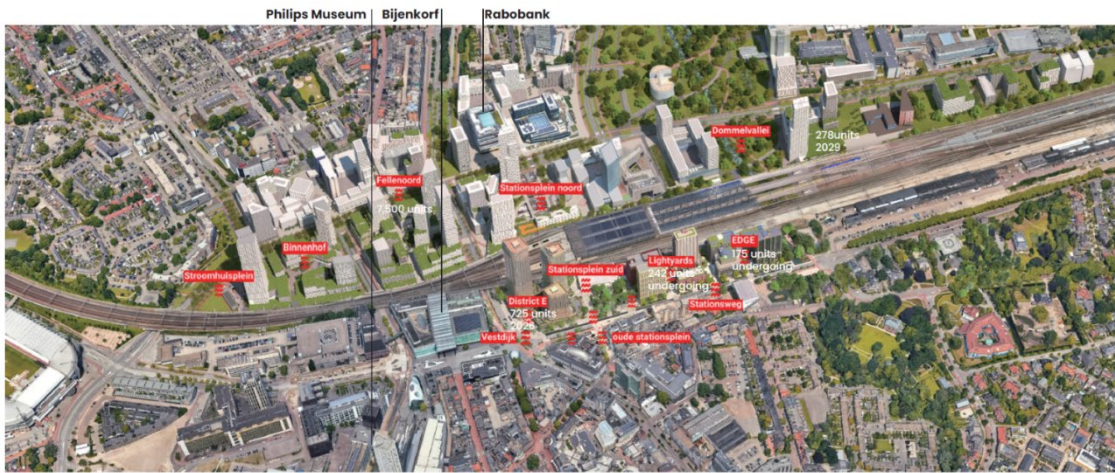


Fig 1.2 Future plan of central station area

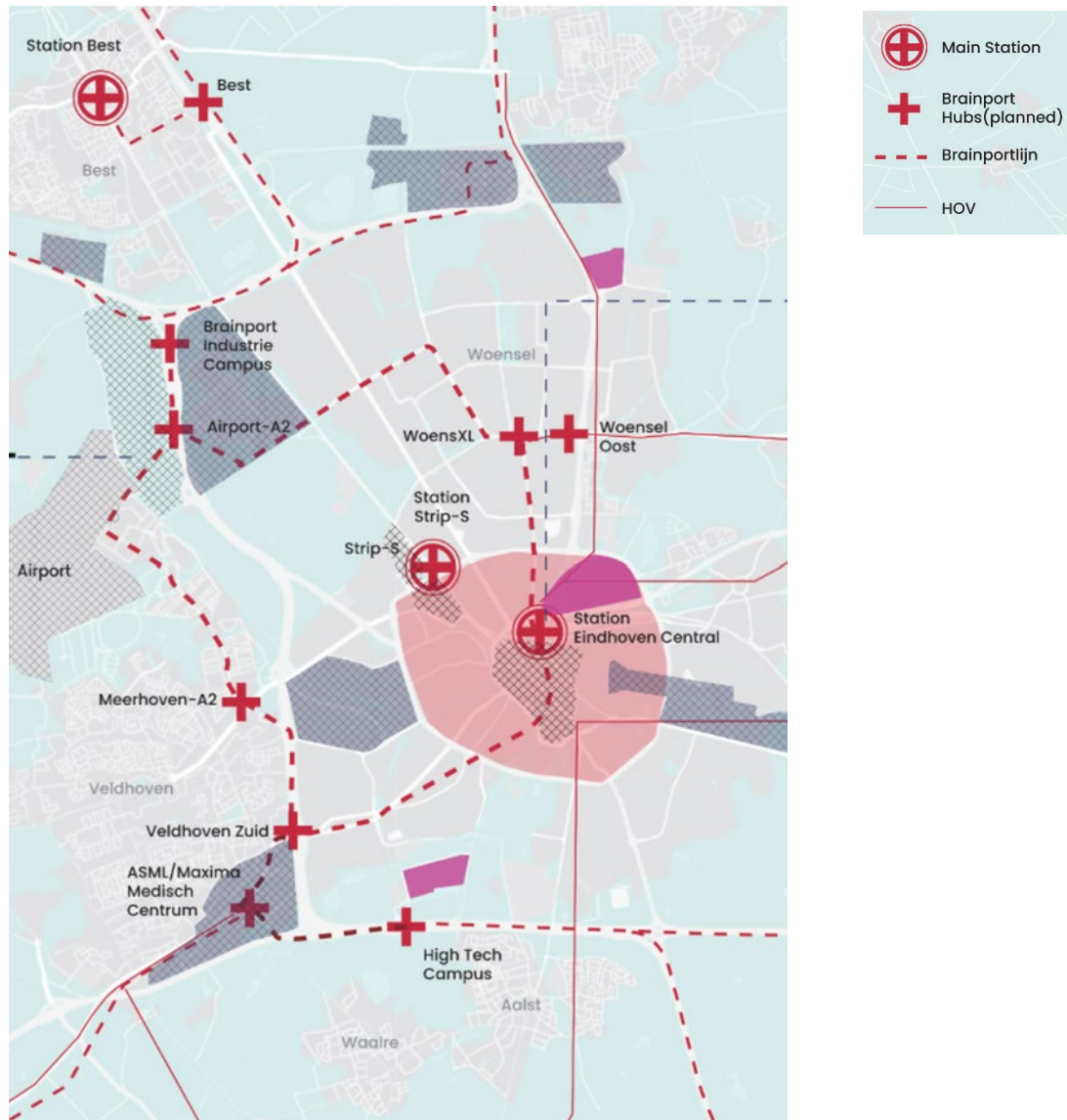


Fig 1.3 Brainportlijn

## 2. Methodology

### 2.1 Analysis of adaptability of current prefabricated system

In order to analyze the adaptability of current prefabricated system, literatures reviews related to adaptability of buildings are conducted. These papers carried out a systematic literatures review reflecting on the field of adaptability of buildings, which helps to set criteria to evaluate current prefabricated systems and identify the existing strategies and disadvantages of these systems.

As a result, the design strategies and approaches for achieving adaptability of buildings can be classified into these categories: modularity, extendibility, flexibility, convertibility and recyclability. (Askar et al., 2021, Askar et al., 2022, Mlote et al., 2024). This analysis framework of adaptability strategies will be used to evaluate selected case studies.

Table 2.1 Analysis framework - Adaptability of building

Modularity (Design Phase)	Percentage of prefabricated and standardized components that are used in the system.
Flexibility (Design Phase)	<ul style="list-style-type: none"><li>● Open-plan layouts and movable partitions.</li><li>● Different configurations according to site.</li><li>● Feasible building span.</li><li>● Feasible floor height.</li><li>● Diverse façade design. (aesthetic/ change with climate/ change with orientation)</li></ul>
Extendibility (Use phase)	<ul style="list-style-type: none"><li>● Vertical: Structural rigidity. The possibility of adding more floors.</li><li>● Horizontal: Fast and feasible connection to new floor.</li></ul>
Convertibility	<ul style="list-style-type: none"><li>● Demountable joints between building layers. (Site/</li></ul>

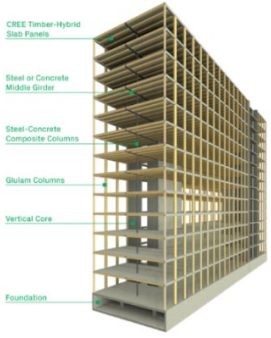
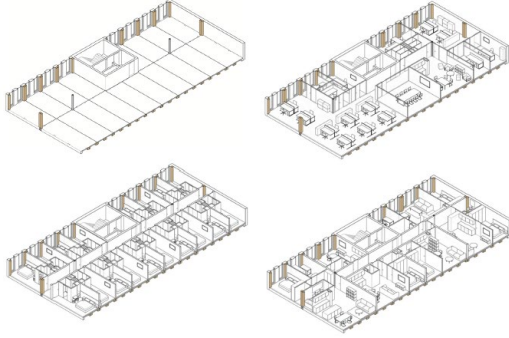
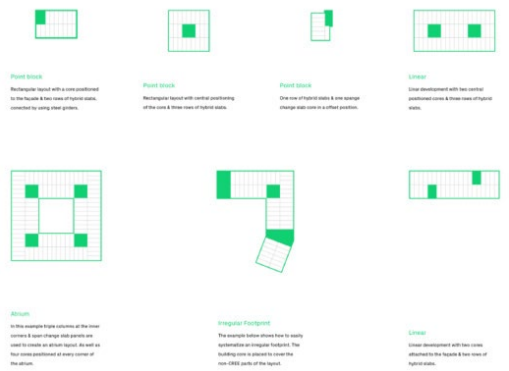
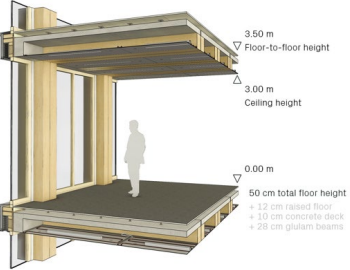
(Use phase)	<p>Structure/ Space plan/ Skin/ Services)</p> <ul style="list-style-type: none"> <li>● Movable partitions while in use and energy efficient process.</li> <li>● Reconfigurable MEP system.</li> </ul>
Recyclability (End of life)	<ul style="list-style-type: none"> <li>● Demountable components which could be possibly used in other buildings.</li> <li>● Bio-based material.</li> </ul>


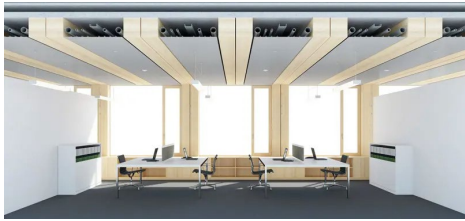
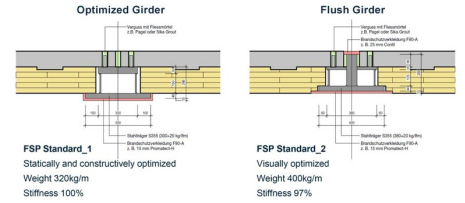
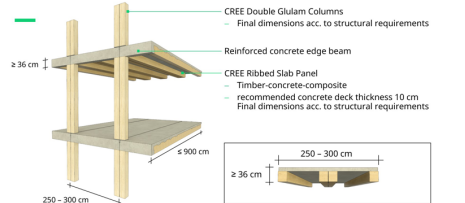
With the criteria presented, a comparison of two prefabricated housing systems using different structure systems is conducted. The selected cases enable multi-story construction to fit in an urban context and had been used as housing.

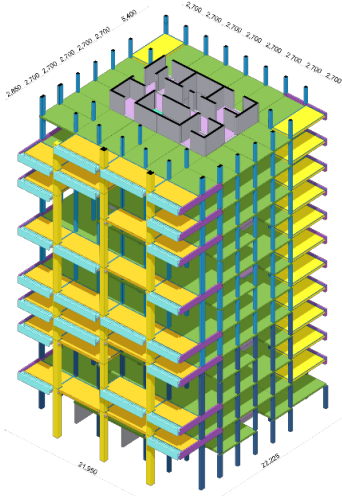
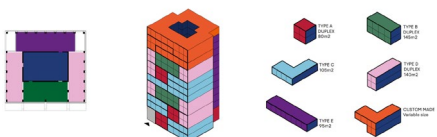
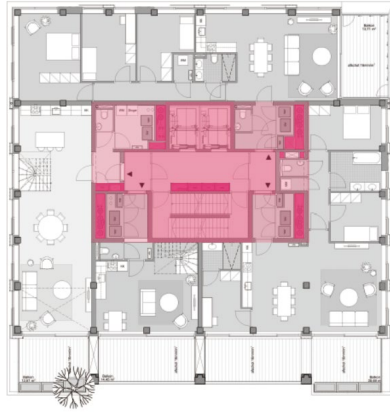
Fig.2.1 Selected project using prefabricated system



<p>CREE (Timber) (Column and beam)</p>	<p>Superlofts Hoorn (RC) (Column and beam)</p>

Table. 2.2 Adaptability analysis of current prefabricated system

<b>CREE</b>		
Modularity (Design Phase)	Percentage of prefabricated and standardized components that are used in the system	Except for concrete core, foundation and infill. 
Flexibility (Design Phase)	Open-plan layouts and movable partitions	Allow for different uses and layouts. 
	Different configurations according to site	
	Feasible building span	8.1m
	Feasible floor height	3.5m 

	Diverse façade design	Maximum opening width limits by 2.7m span on the façade. Applicable for various cladding.
Extendibility (Use phase)	Vertical	Possible. Claimed possible floors: 30 floors.
	Horizontal	Façade and column are connected as panels. Opening is also determined from beginning.
Convertibility (Use phase)	Demountable joints between building layers	Combined columns and façade panels for fast assembly. 
	Movable partitions while in use and energy efficient process	Façade is unchangeable during use phase. Partition wall could be removed but could not be reused.
	Reconfigurable MEP system	Possible between beams. 
Recyclability (End of life)	Demountable components which could be possibly used in other buildings.	Mostly fixed with mortar. 
	Bio-based material.	Glulam Column and timber hybrid slab panel. 

<b>Superlofts Hoorn</b>		
<p>Modularity (Design Phase)</p>	<p>Percentage of prefabricated and standardized components that are used in the system</p>	<p>Except for concrete core, foundation and infill.</p> 
<p>Flexibility (Design Phase)</p>	<p>Open-plan layouts and movable partitions</p>	<p>Allow for different uses and layouts.</p> 
	<p>Different configurations according to site</p>	<p>Relatively inflexible because of a centralized layout, with all units using part of the core as service space, creating an efficient yet irregular unit shape.</p> 
	<p>Feasible building span</p>	<p>5.4m. Mostly suitable for housing.</p>
	<p>Feasible floor height</p>	<p>Around 6m. Suitable for most functions.</p>

	Diverse façade design	Maximum opening width limits by 2.7m span on the façade. 
Extendibility (Use phase)	Vertical	Possible.
	Horizontal	Hard because of a centralized layout
Convertibility (Use phase)	Demountable joints between building layers	Not specially addressed. Façade allows for replacement.
	Movable partitions while in use and energy efficient process	Partition walls could be removed but could not be reused.
	Reconfigurable MEP system	Vertical shafts in every corner of the core. However, there is no further adjustable design.
Recyclability (End of life)	Demountable components which could be possibly used in other buildings.	Demountable column and slab. 
	Bio-based material.	No bio-based material.

In conclusion, most existing prefabricated system performance well when it comes to modularity of main support. Both timber and precast concrete structure are well developed. However, for the partition wall, traditional walls are mainly applied.

These systems also both allow for open layout to a certain degree in the design phase. However, the flexibility of multiple layouts is strongly influenced by the

arrangement and design of the vertical circulation. A linear solution is more flexible than a centralized core layout. As for facade, there are various options for prefabricated facade design, but the design freedom will also be strongly influenced by main structure. Also, the replacement of façade in use phase will be limited because of the initial fast assembly façade design.

Both systems do not emphasize the change during use phase as main design consideration. Disassembly and reconfiguration during use phase could be time-consuming to carry out and lead to extra waste. Also, the reconfiguration of MEP system within units is not presented, which could lead to the difficulty of changing layout. The partition walls are both considered as non-reusable infill in both cases.

As for the end-of-life phase, both prefabricated systems are demountable since the building parts are made for dry assembly initially.

## 2.2 Adaptability: Open building strategy

Open Building is an approach to architecture and urban design that emphasizes flexibility, adaptability, and long-term usability of buildings. It advocates separation of support and infill. Support is building components such as load-bearing walls, floors, façades and roofs which are intended to last at least 100 years. Infill components are partitions, stairs, parts of façade and other equipment and their associated piping and wiring. They are installed and later reassembled to allow changes without disturbing the Support construction or other private domains. (Van der Werf, 2026)

The concept of open building is highly related to the objectives of this research, therefore through case studies, several core strategies for the realization of open building are listed, which help to achieve the adaptability of the buildings.

### 1. Identity of the building

- Molenvilet / Papendrecht, NL (1976)

Method: Structures theme which can be recognized as a whole

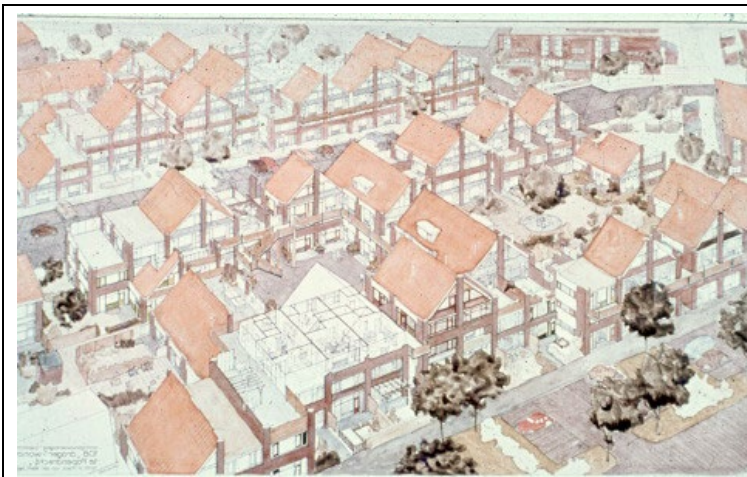
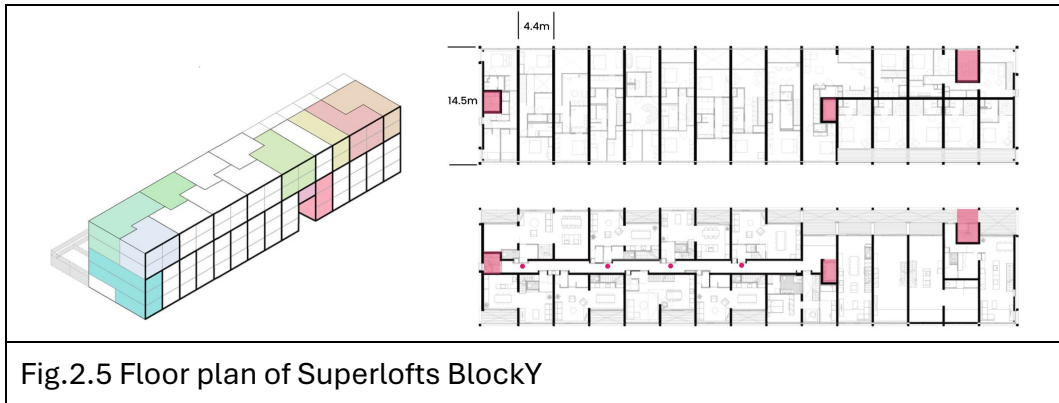


Fig.2.2 Drawings of Molenvilet

Pitched roofs continuing around the corners, roof terraces and galleries around courtyards provide a strong characteristic for this project. The façade has bay frames, within which Infill components can be assembled in different ways and can be painted in colors from a given palette, at the individual choice of the users. The designed frame and palette give a diverse yet united feeling from the exterior.





The span of 14.5m allow for both one side and middle corridor layout.

- Next21/ Osaka, JP (1994)

Method: Detached vertical circulation

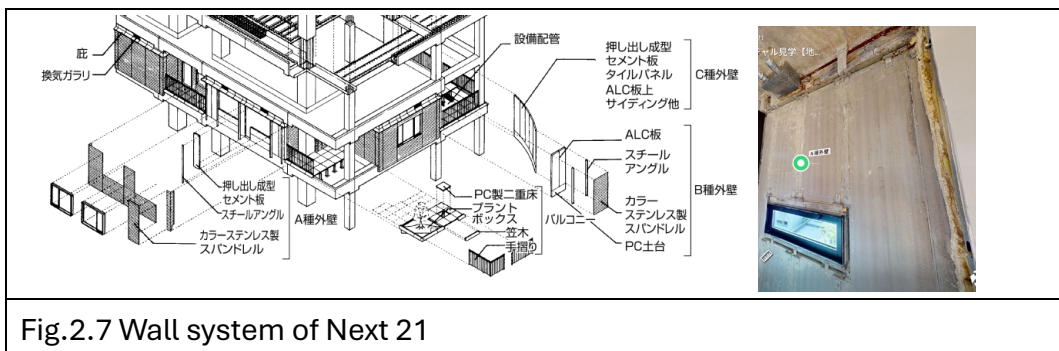


With a detached vertical circulation away from the corridor and dwelling units, the combination of different dwelling units is more likely to be achieved.

#### 4. Changing boundaries between indoor and outdoor:

- Next21 / Osaka, JP (1994)

Method: Modular exterior walls as infill



The exterior wall is modularized, allowing for relocation and replacement.

They can be installed from the interior or carried out from the balcony.

## 5. Compatibility between support and infill:

- Next21 / Osaka, JP (1994)

Method: Modular grid

NEXT21 uses a 30-centimeter modular grid to coordinate its four independent subsystems: structure, cladding, infill, and services. This framework ensures dimensional coordination across components, enabling precise compatibility and flexible reconfiguration with minimal intervention.

## 6. Easily changed and modified MEP system

- Patch22 / Amsterdam, NL (2016) & Next21 / Osaka, JP (1994)

Method: Raised floor

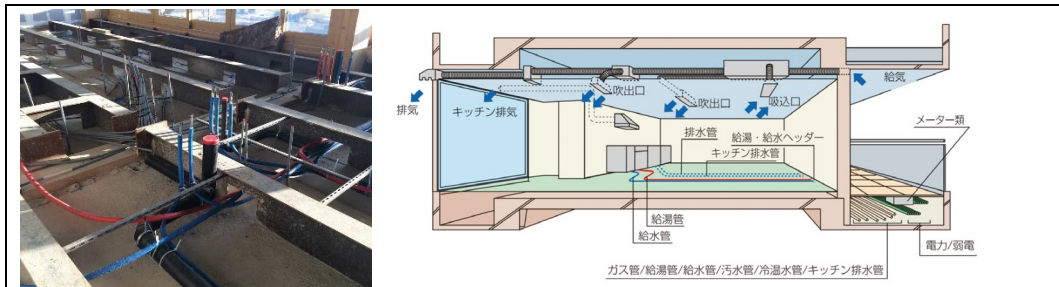


Fig.2.8 Floor system of Patch 22/Floor system of Next 21

- Molenvilet / Papendrecht, NL (1976)

Method: Vertical shaft in each unit

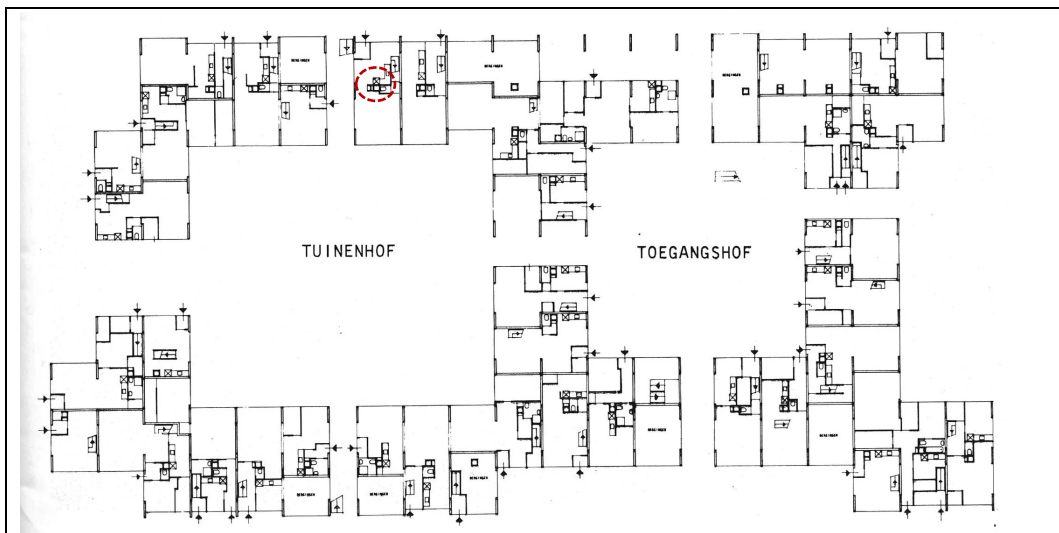


Fig.2.9 Location of MEP shaft






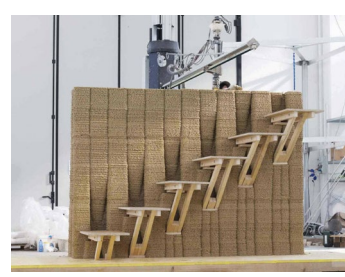
The MEP shaft located at the center of each dwelling unit, housing ingoing and outgoing pipes. And the cooking and sanitary area are located around it, providing certain flexibility for the layouts.

## 2.3 Prototyping of reconfigurable infills

The main goal of the prototype is to develop a reconfigurable infill system which could be changed during use phase, manually, with minimal intervention to the main support. This plays an important role in the realization of adaptable buildings. To enable precise compatibility between the infill and the support, the connection and assembly sequence between them should also be examined in the making of the prototype.

3D printing technology is chosen due to its potential to replace traditional labor-intensive tasks and the ability to provide customized bio-based building parts with least waste during production. The adding values of 3D printing are preliminary sorted and classified from case studies, which reveals the potential of 3D printing.

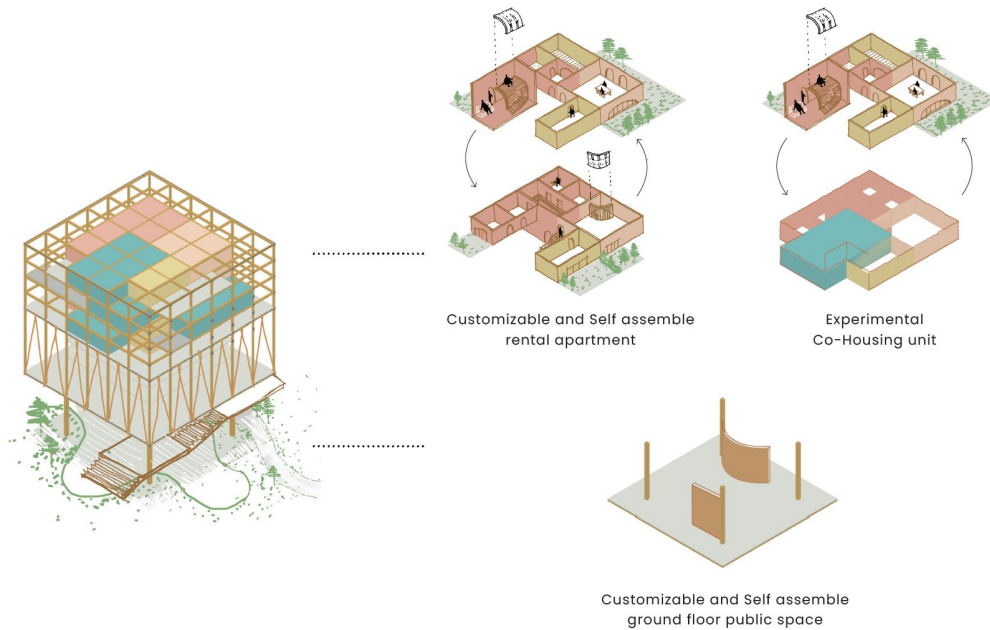
Fig.2.10 Adding value of 3D Printing:

<b>Complex form</b>	<b>Structural integrity of unusual bio-based loose material</b>	<b>Optimization: less material/ more lightweight</b>
		
The Warp pavilion	The Eggshell Project	Tor alva
<b>Reduction of formwork waste</b>	<b>On site automation: 3d printer/ robot arm/ drone</b>	<b>Complex building components and highly customization</b>
		
TECLA	PERI 3D Construction	Embedded staircase

### 3. Result

#### 3.1 Adapting Scenario and configuration

##### 1. Strategy

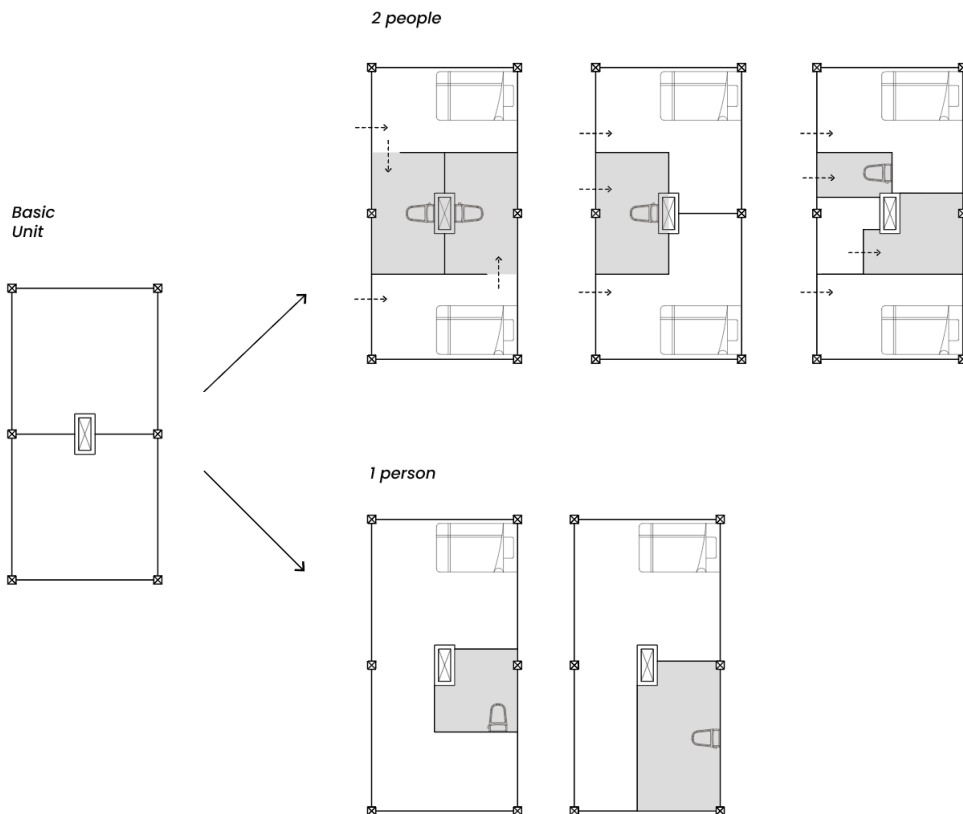
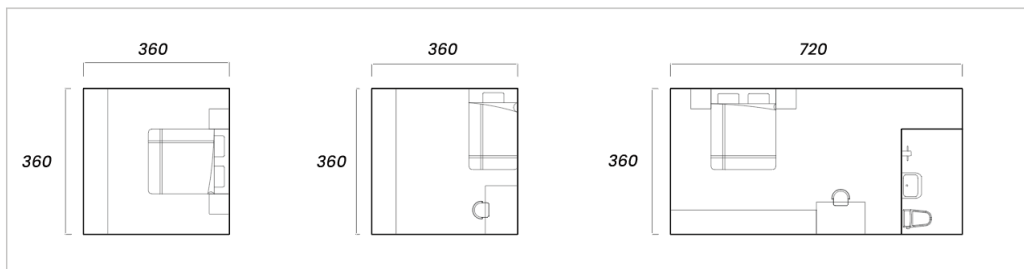


The upper part is set for experimental co-housing units which allow for change of shared space, inhabitant numbers and indoor-outdoor boundary within single co-unit. There is also possibility of combining adjacent unit for a larger shared space or changing the co-unit to purely separate private housing for future need.

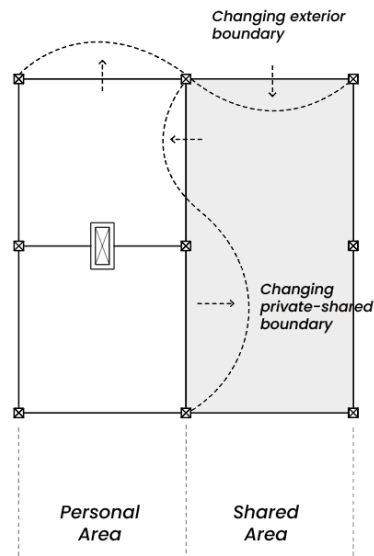
This system will allow a free framework for exploring the use of co-housing, and the degree of shared space within single co-unit, which is the main reason for the time-consuming design process when it comes to co-housing. This will also bring the purpose of open building design to not only allow customized layout within private housing, but also to discuss the level of publicness by changing the boundary between private room and shared space, and between shared space of different co-unit.

## 2. Design of basic unit

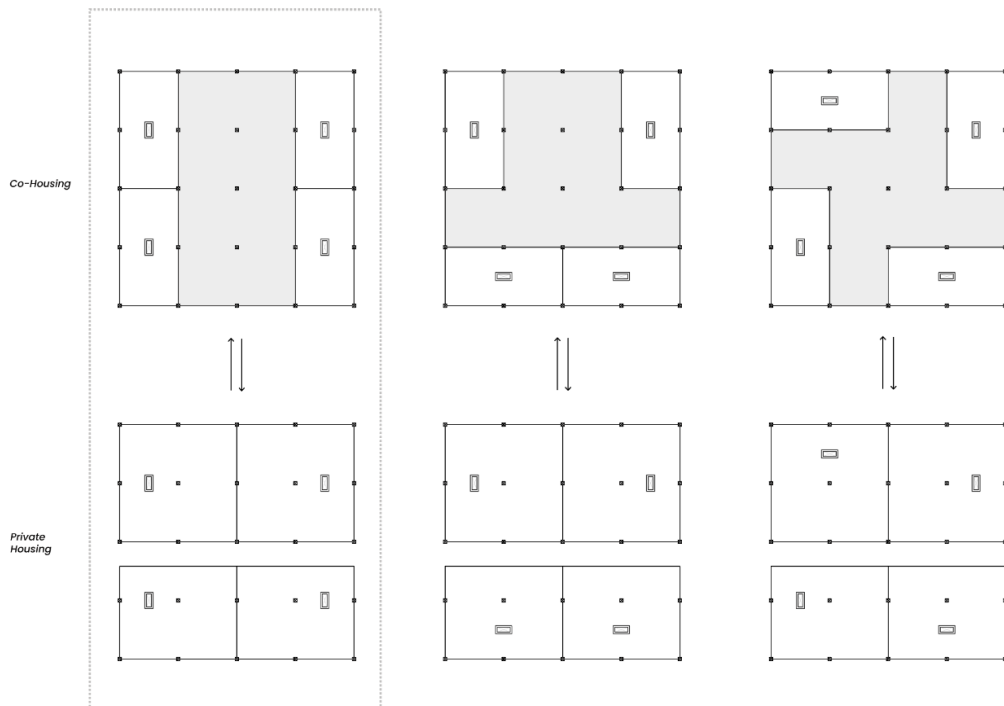
The basic design of the unit starts with a 360 by 360 square, and two of the squares will combine and contain one shaft. This unit could be turned into diverse combinations of rooms. This dimension is adjusted for structural and spatial need in the further design development.



*Basic Unit*



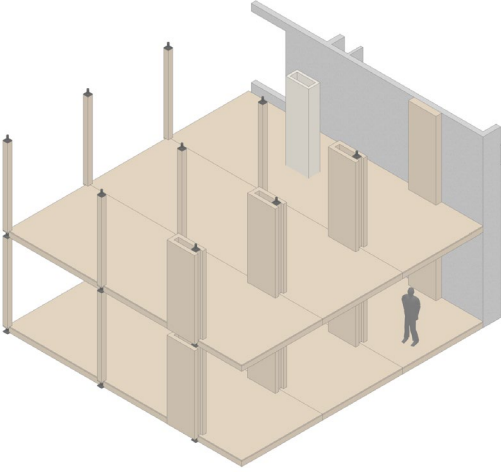
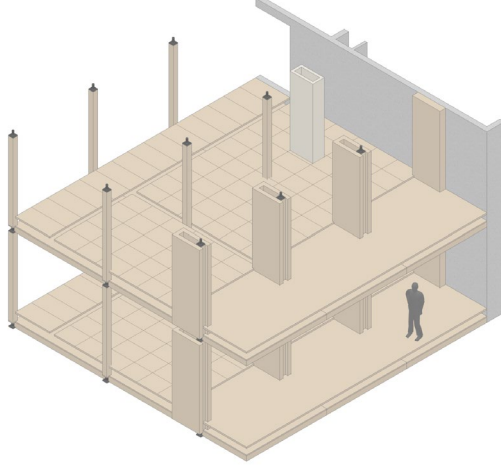
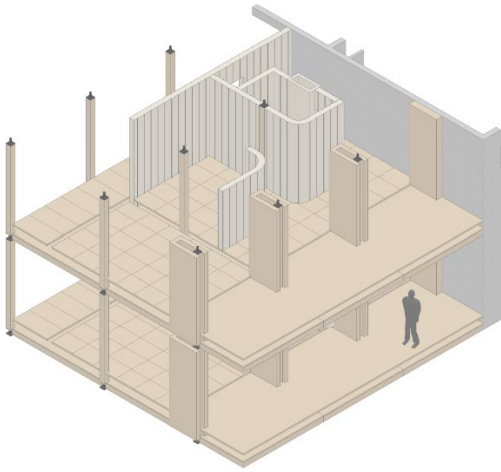
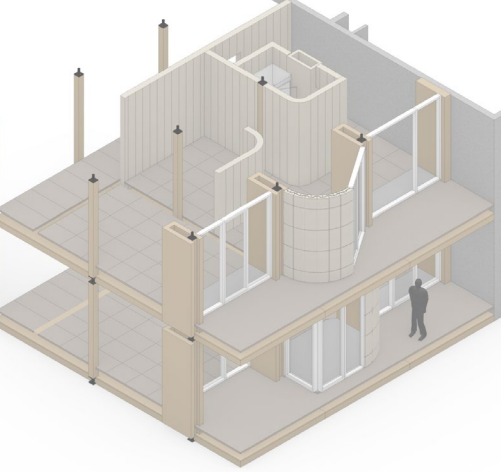
By adding one span, the basic unit contains half space for rooms, and the other half for shared or living area. The goal is to allow users to change the boundary in between, and the boundary between interior and exterior.



Four of these units are combined into one co-housing space. The first configuration could switch between co-housing and private housing, while the other have the shaft too close to the exterior façade when it becomes private housing.

### 3.2 System design

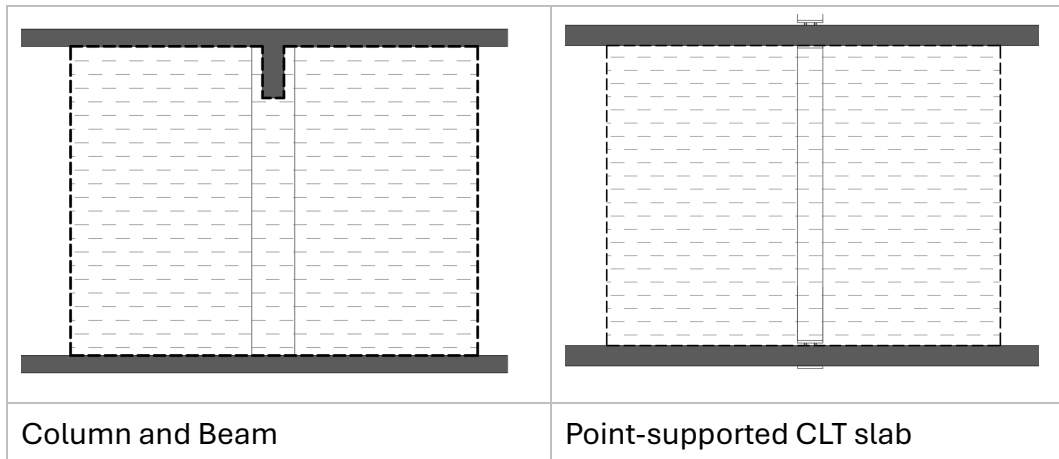
#### 1. Housing system design

	
<p><u>Fixed</u> Point-supported CLT slab /Vertical Shaft/Fixed Exterior Wall</p>	<p><u>Changeable</u> Raised floor</p>
	
<p><u>Changeable</u> 3D printed earth based interior wall</p>	<p><u>Changeable</u> Exterior Facade</p>

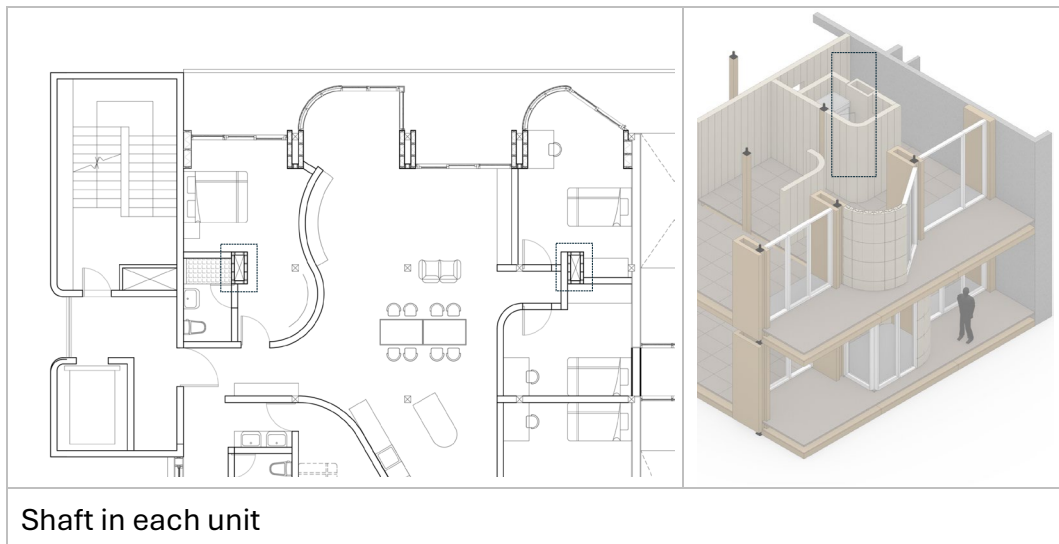
The housing system is developed to realize the previously mentioned layout diversity. The fixed part includes main structure, shaft and exterior wall. The changeable part includes raised floor, 3D printed earth based interior wall and exterior façade.

## 2. Support: The fixed

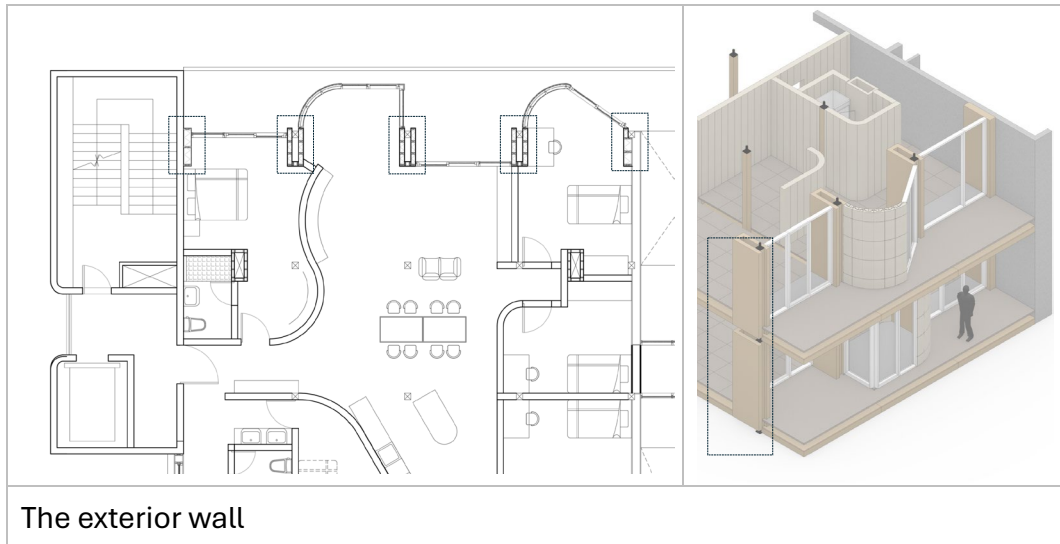
To allow the maximum flexibility and the easy assembly of the infill, the point-supported CLT slab is applied. This enables a beamless interior space, and the infill could be designed as modular and be installed freely in the provided space. This structure is also demountable in an end-of-life scenario for circularity.



Another fixed part is the shaft mentioned previously. Through a combination of shaft and raised floor, the system allows the user to move the wet area freely as needed.



Lastly, the exterior wall is to provide a zone in each span to change the façade panel freely. The façade is made into 4 types, which will be explained further.

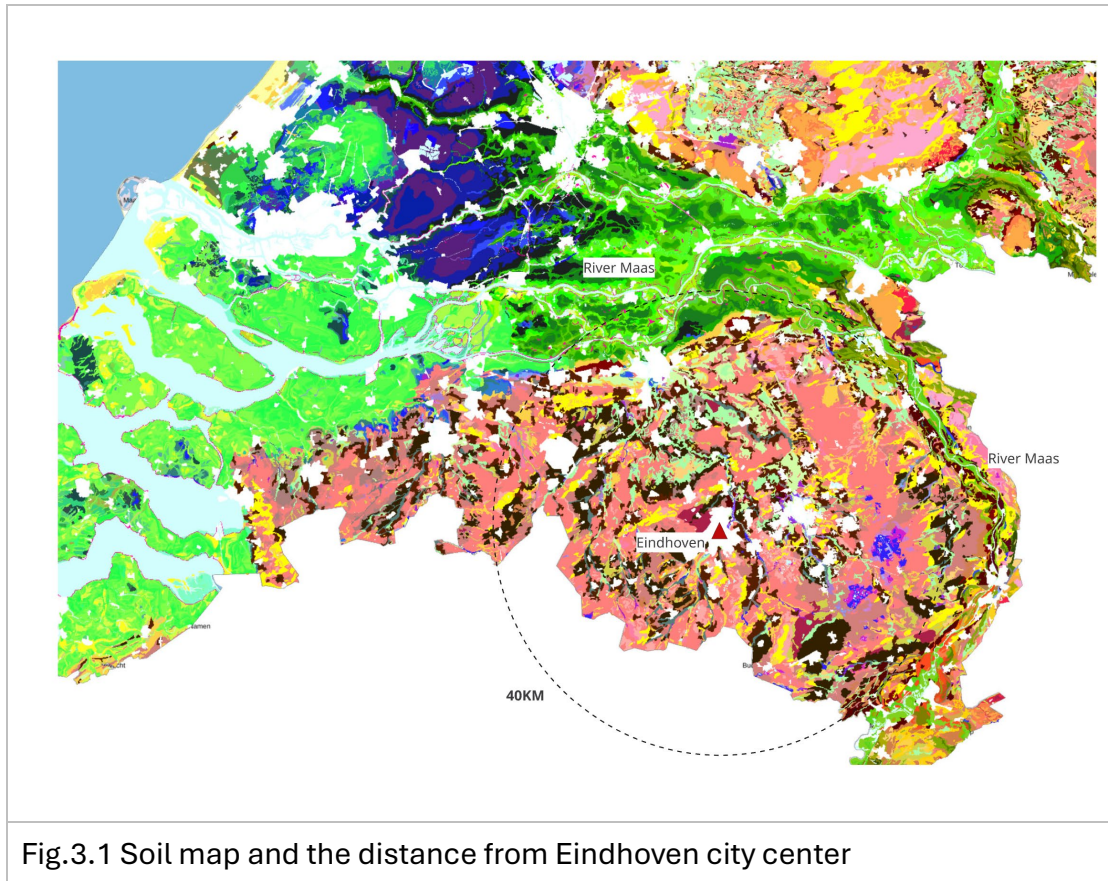


### 3. Infill: The changeable

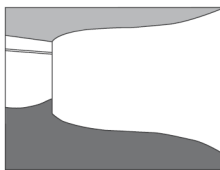
To reach the goal of a reusable wall system, the infill principle for interior wall is set as follows:

1. Maximum percentage of mono material
2. Manually demountable and remountable during use phase
3. Bio-based and less waste

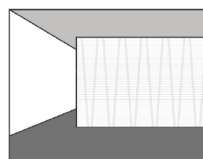
To achieve this principle, a modular system made of earth-based material is used for the interior partition wall. Earth based material used for construction includes clay, sand and fiber, and the most important material is clay, which is a natural binder and provides structural strength. The river Maas to the north of Eindhoven city center constantly supplies clay every year, and there are still multiple brick factories in this area. This provides a sustainable and continuous supply of material for the making of the system.



With the application of 3D printing technology, the infill system is expected to reach the following goals:



Aesthetic Free form



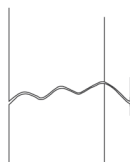
No finishing Needed



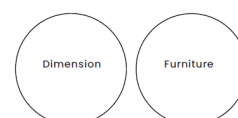
Recyclable & Bio-based & No-waste production



Light Weight (compared to block made by mold)

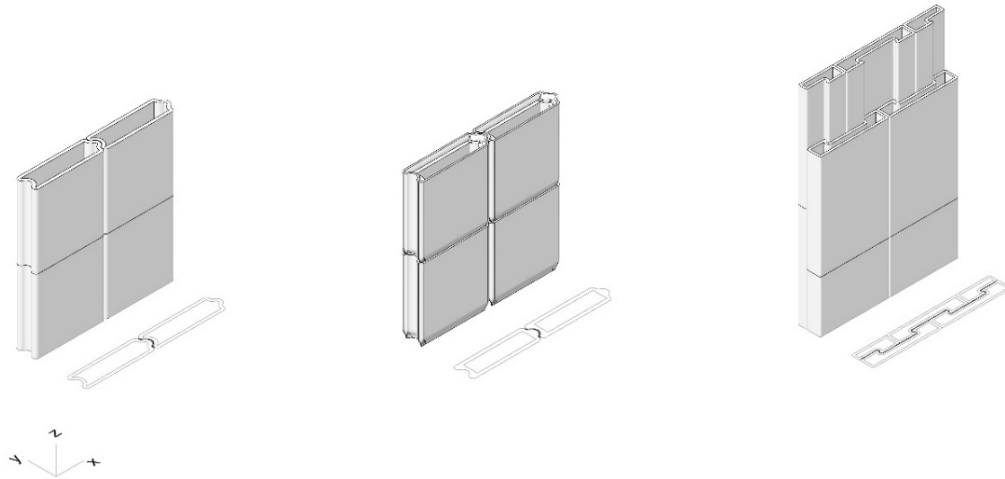


Interlock Connection with mono material



Customizable On site fabrication

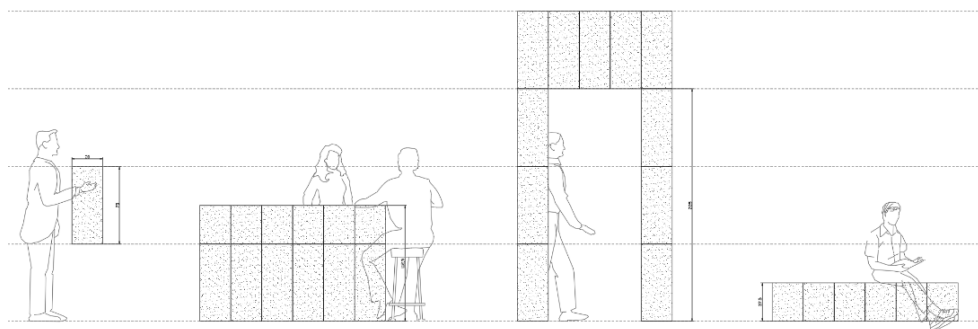
The basic block design starts with single layer and simple interlocking. However, it is only stable in one direction (the left one), and if the interlocking of another direction is added, it will require support in the printing process (the middle one). The final design is an interlocking system on all x, y, z axis, therefore it is expected to require no further joint between the blocks.



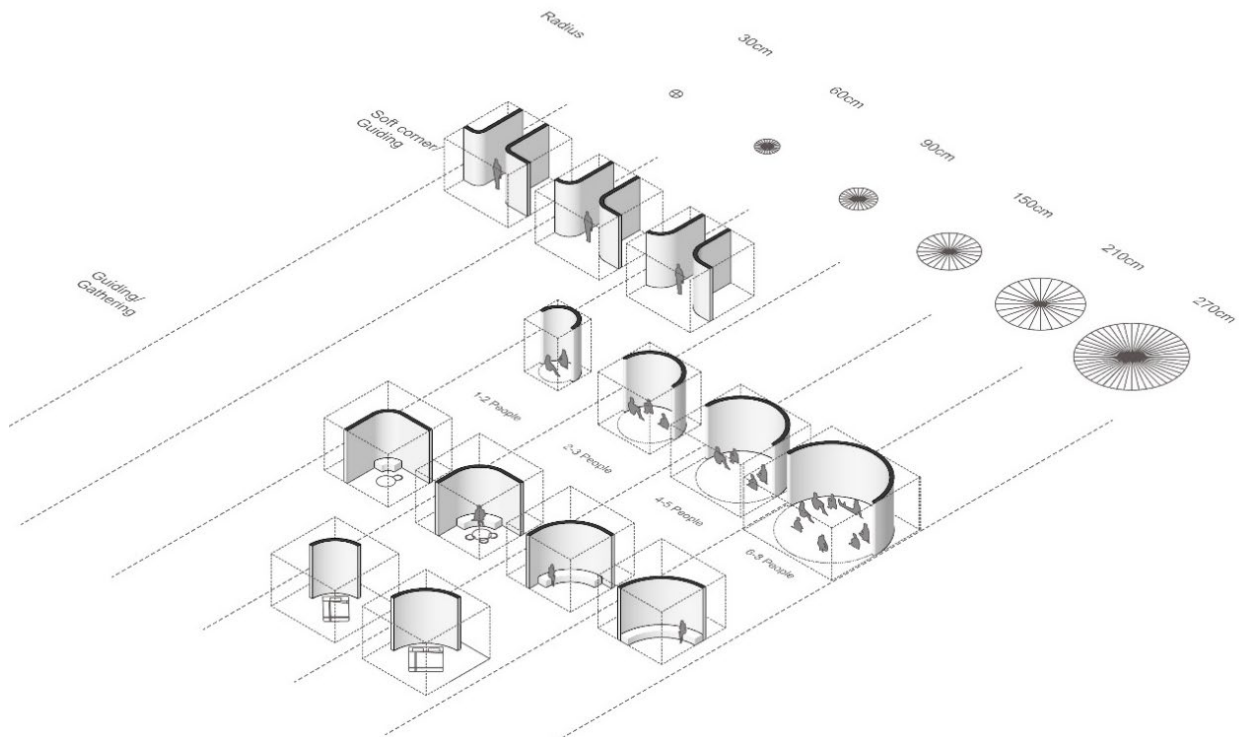
The dimension of the single block is determined by the following analysis:

- Size

The height is determined by dimension related to the door, bar table and seat. Moreover, one single block should be carried manually.



- Radius of curved walls



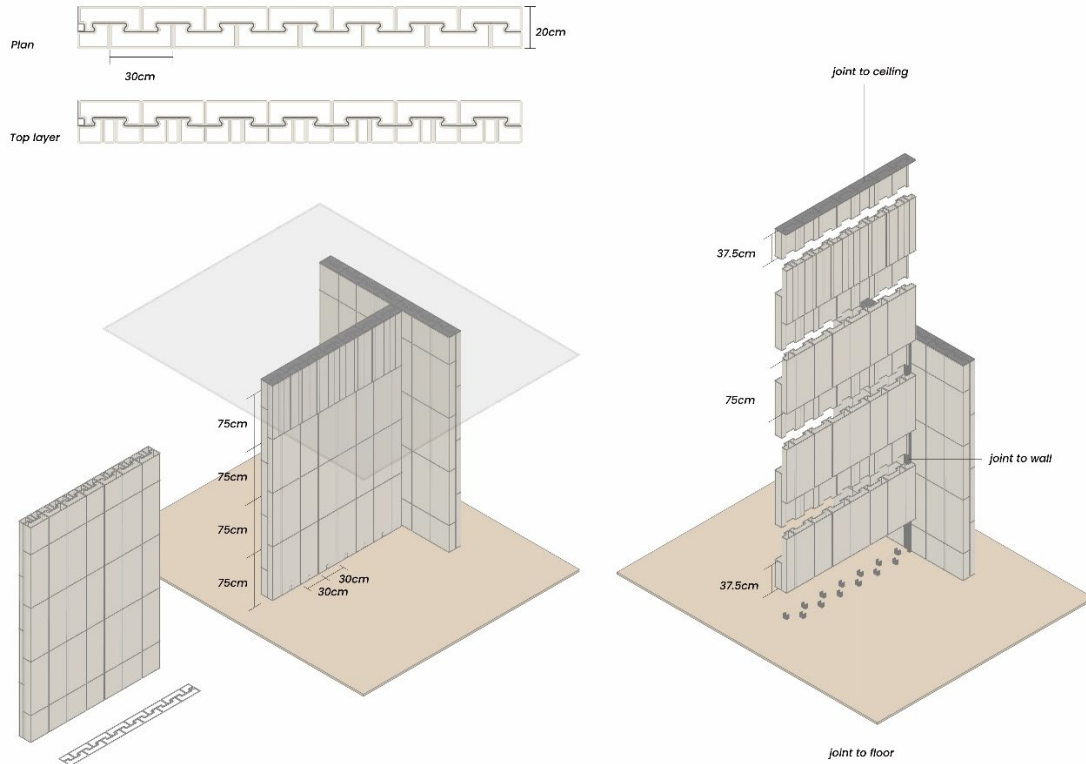
To enable a more playful interior space, curved wall with various functions is added to the modular. The final selected radius is 30, 60, 90, 150, 210 and 270 cm. Certain radius for different functions are shown as follows:

- Weight and thickness

Material	Unit weight(kg/m <sup>2</sup> )
Brick, 12cm	220
Gypsum Block Wall (10cm), 1/2" Gyp Board Each Side	85
ALC (10cm), 1/2" Gyp Board Each Side	76
Wood Studs, 2x4, Plastered Two Sides	98
Wood or Steel Studs, 1/2" Gyp Board Each Side	39
Designed system (20cm), 1.5cm thickness	131
Designed system (20cm), 1cm thickness	88

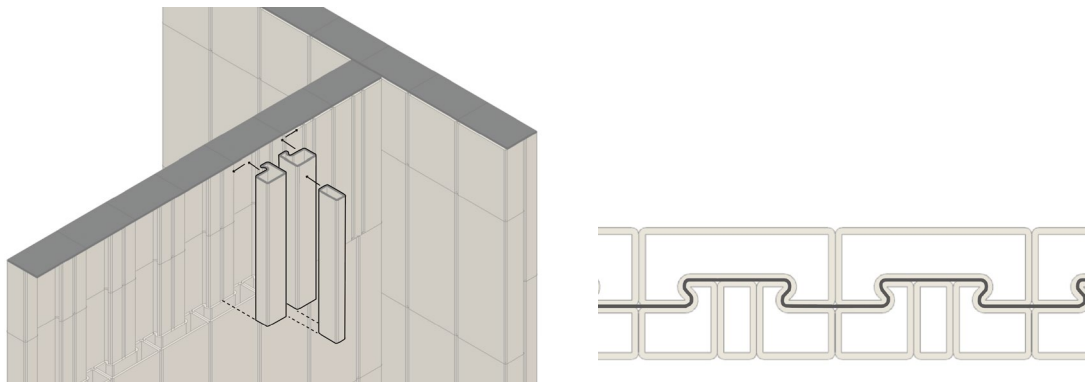
Table 3.1 Comparison with other partition wall

The thickness of the final designed block is 1cm, which makes the weight similar to the common lightweight masonry wall system, and significantly lighter than the traditional brick wall.

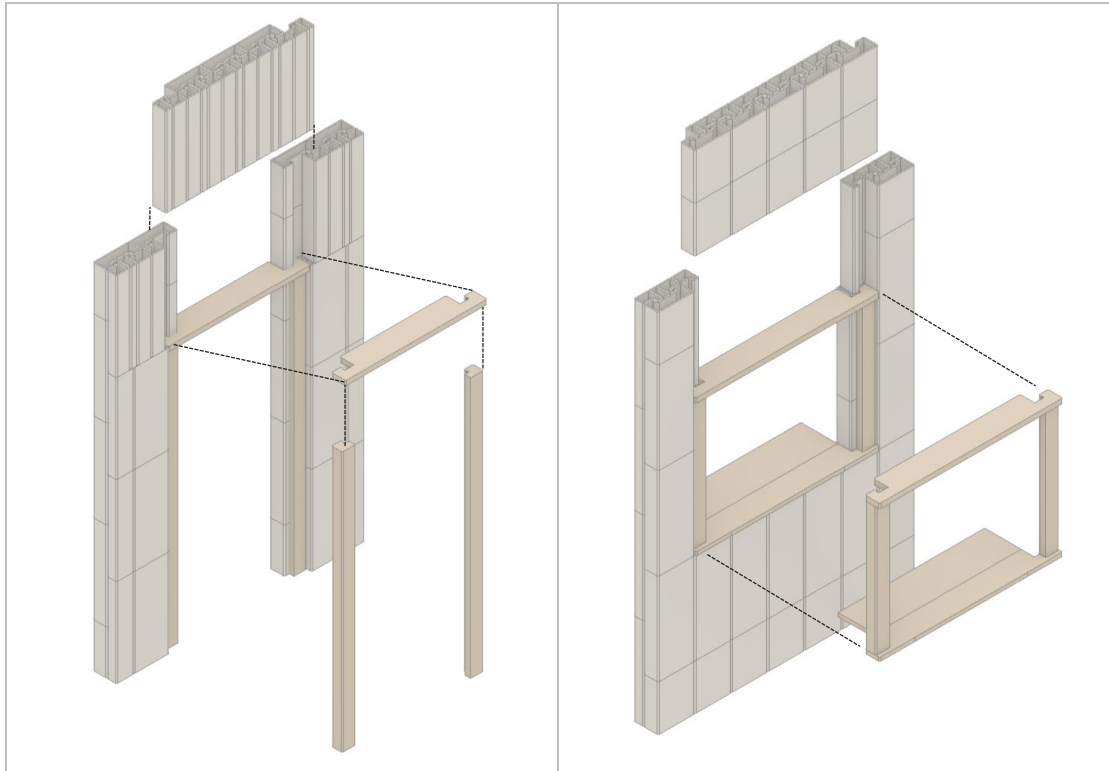


The final dimension is shown as follows, the normal width of each block is 30cm by 75cm, and the end and bottom modular are with different dimensions. Curved modular has different widths but are the same height.

The block close to the ceiling is not installed from the top but is installed from the side and fixed by the middle pieces. Also to improve sound insulation, sound insulation material is fixed on every block.

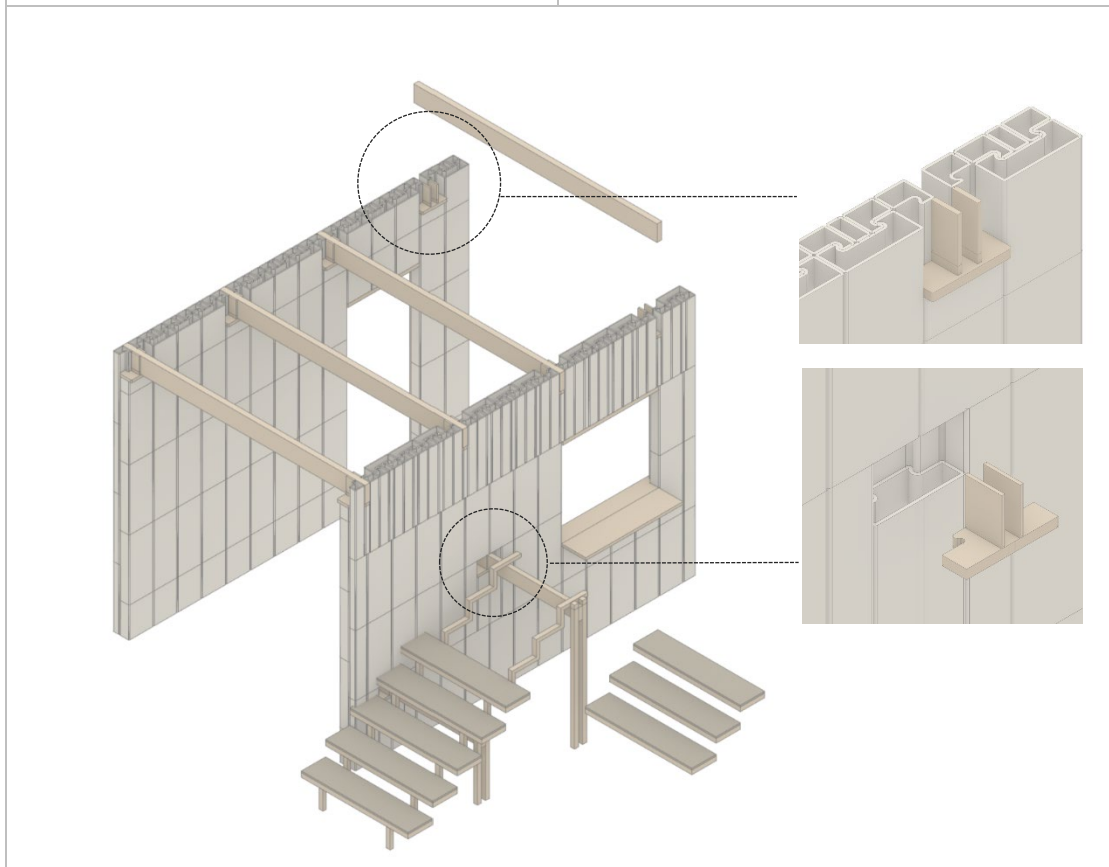


The prototype of door, window, stairs, mezzanine and curved wall:

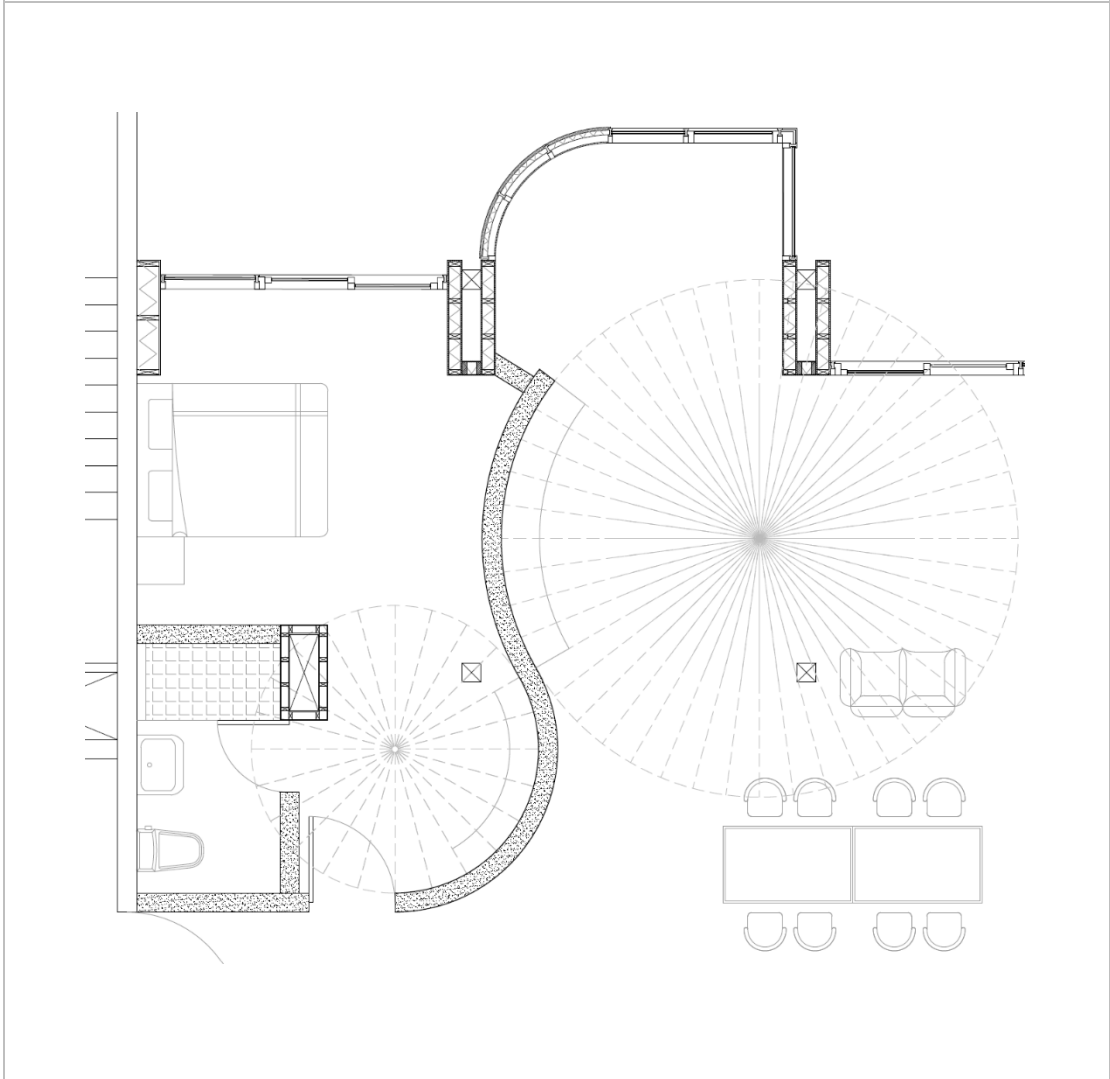
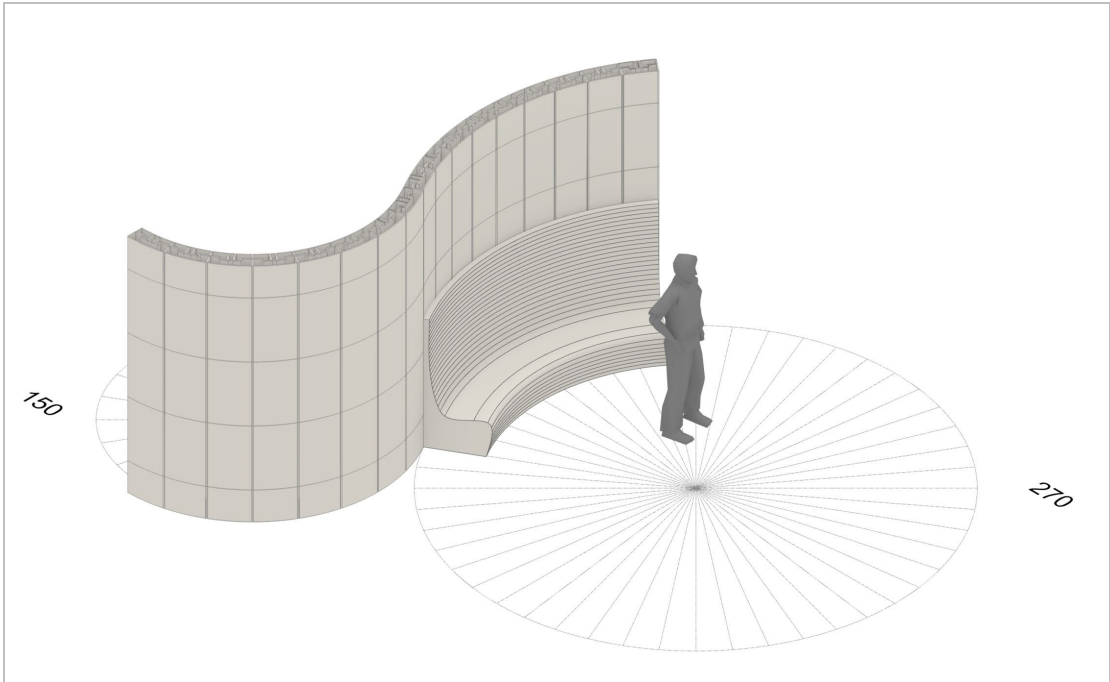


Door

Window

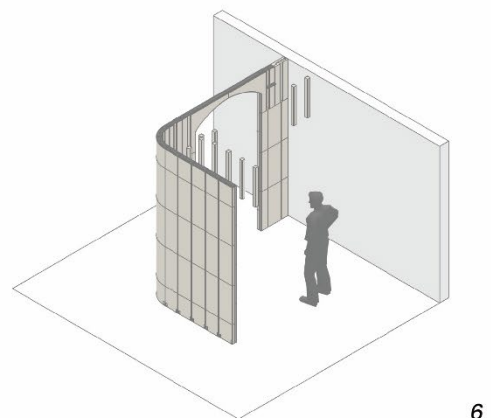
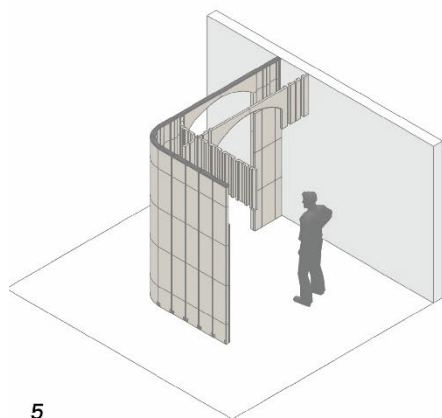
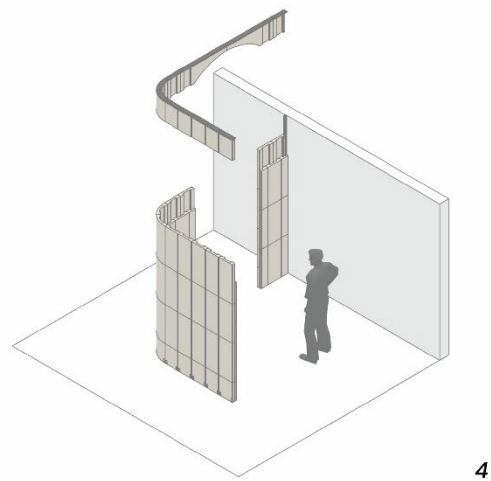
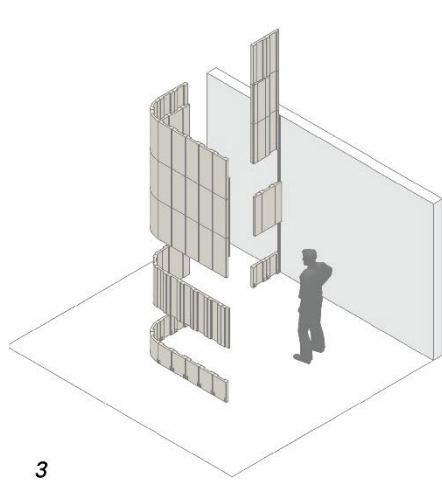
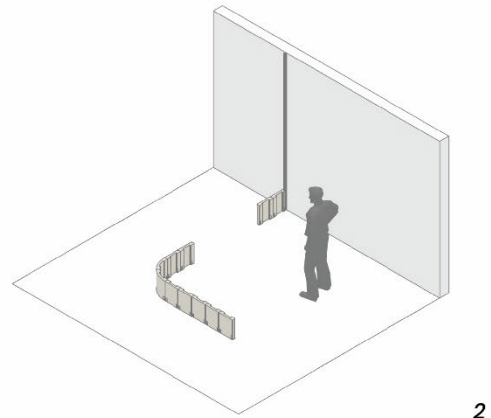
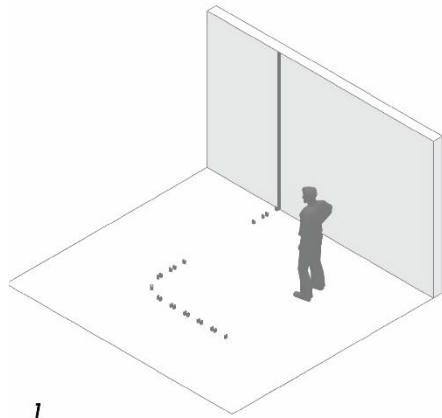


Stairs and mezzanine

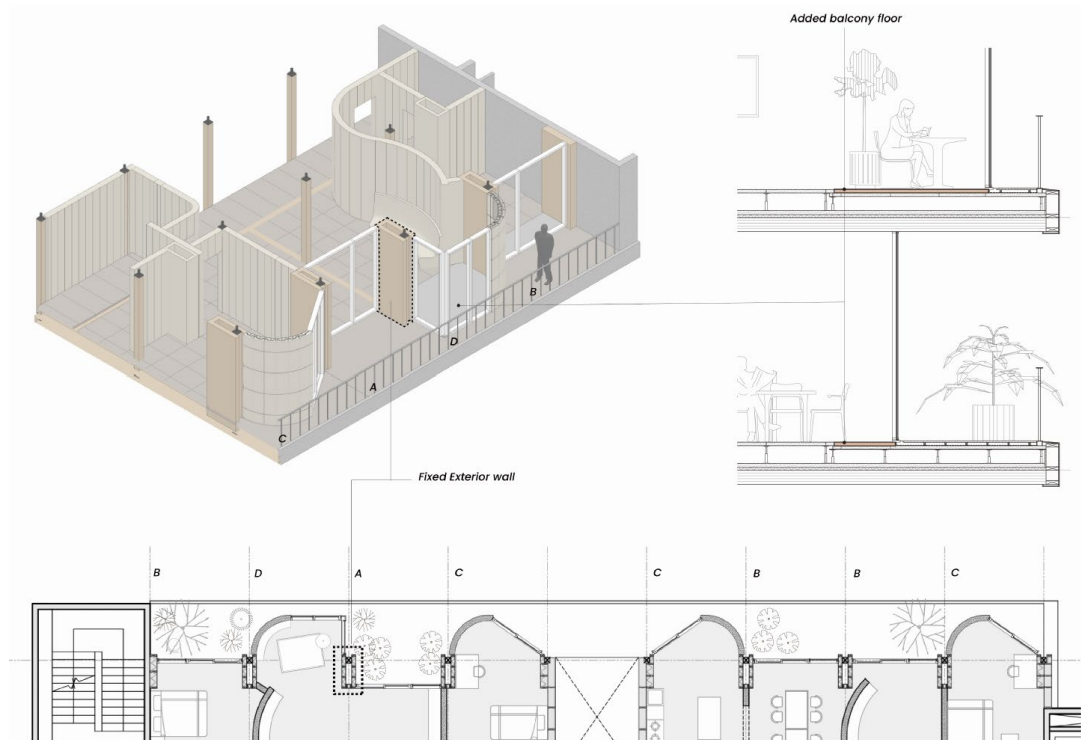


Curved wall

The assembly sequence of one curved wall:



The other changeable part is the exterior facade, and four types are set for standardization.



### 3.3 System in context

#### 1. Site Plan and urban relationship



Site location



Site Plan

To promote a lively urban environment and maintain a sense of openness and spatial continuity from the nearby riverside, there is an inner courtyard bringing greenery into the site. Open space is preserved at the southwest and northwest corner to welcome the pedestrian flow moving along the river. Parking and open space for the daycare is located on the east side of the site.

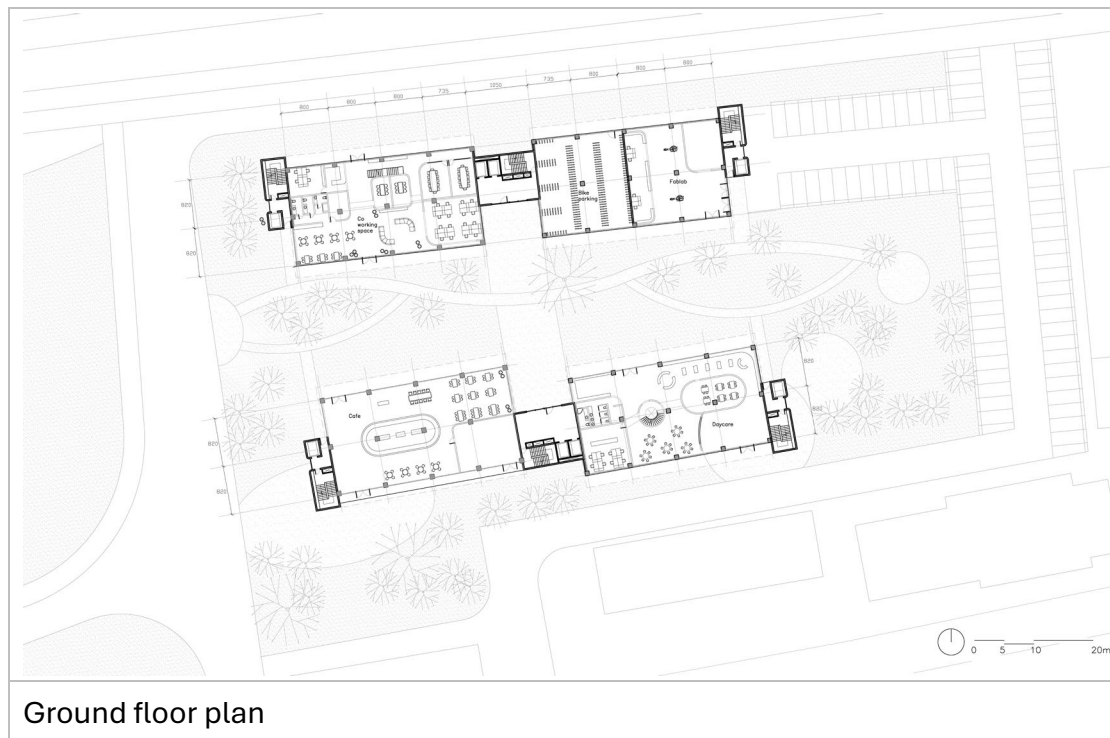
The current plan is to build a high-rise in the chosen site for a rising demand for housing, but to better respond to the surrounding nature, and as a transition from the high-density central station area to the surrounding low-density campus and residential area, a lower mass is applied in the site.



Isometric perspective

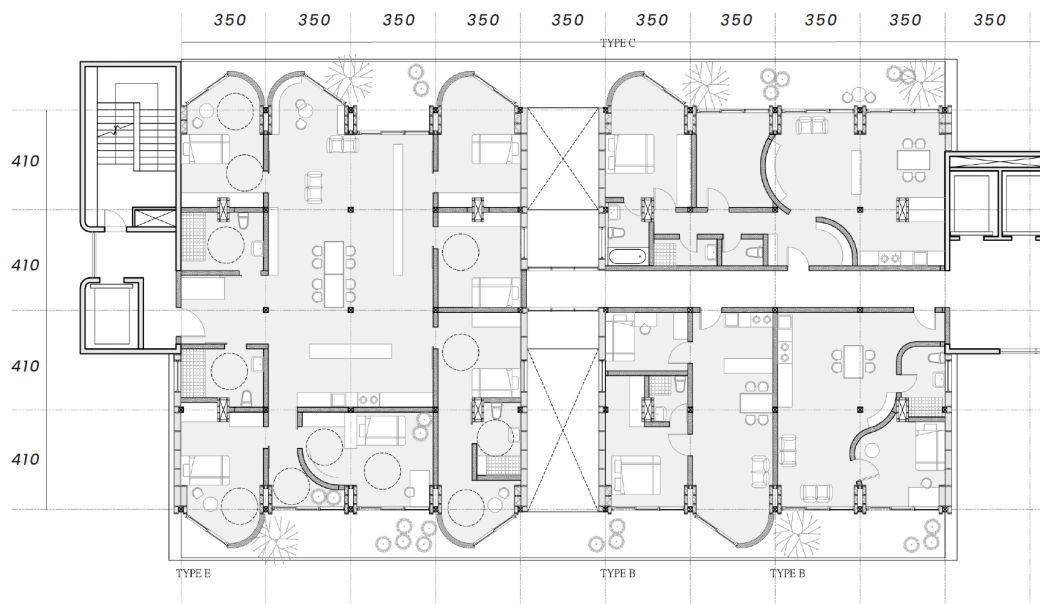
## 2. Building design

The lower part allows for various functions which have a strong connection to the urban environment and change rapidly. Due to the most needed dwelling type in Eindhoven is single or small household or co-housing unit, the target group of the housing is single or small family who are expats, starters, young professionals, researchers and the elderly. The program on the ground floor will provide the essential space for these groups, such as co-working space and daycare. Moreover, commercial programs are introduced along the Dommel river to create a recreational atmosphere and activate the area as a vibrant urban gathering space.





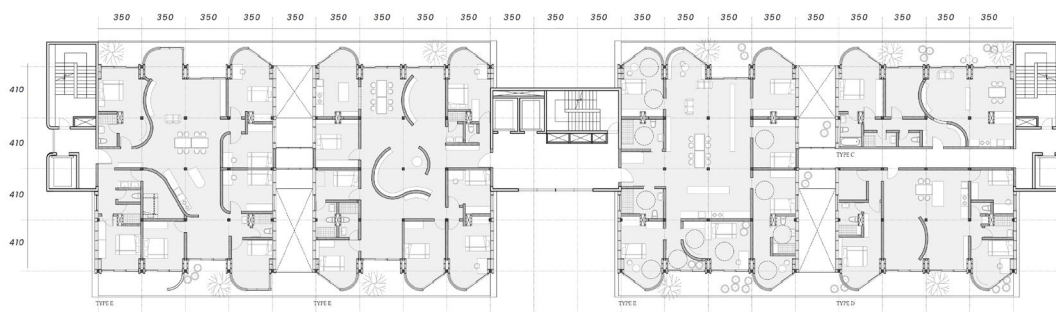
First floor plan-block A



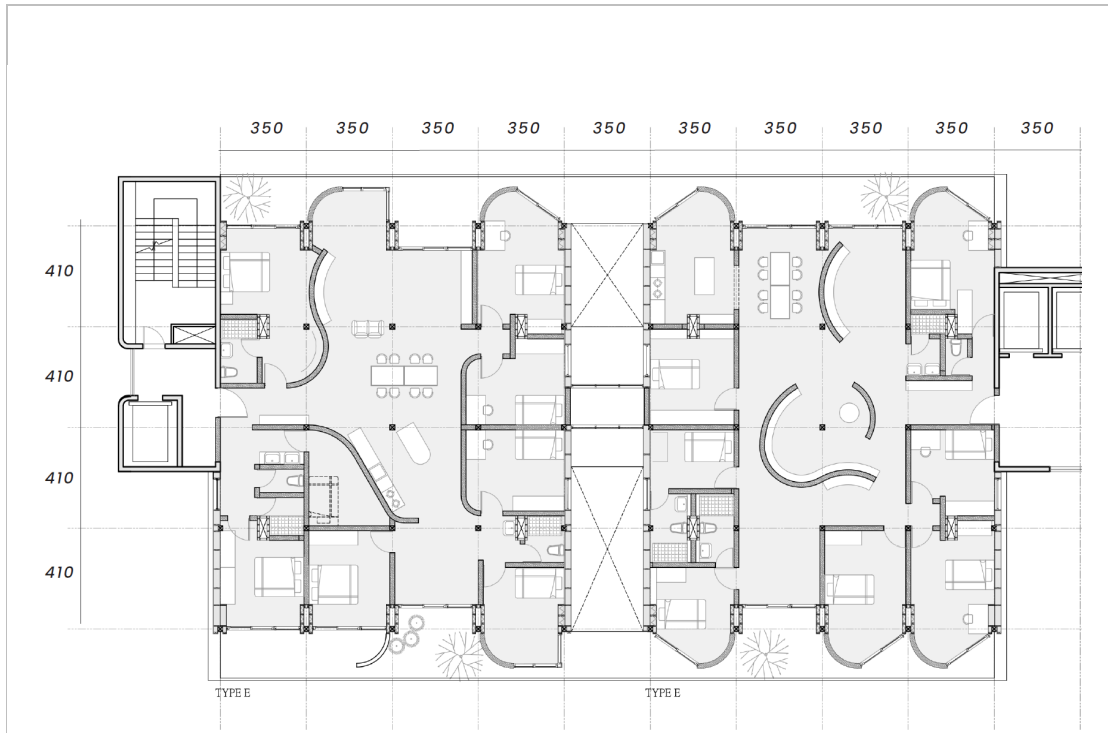
First floor plan-block A (Left)



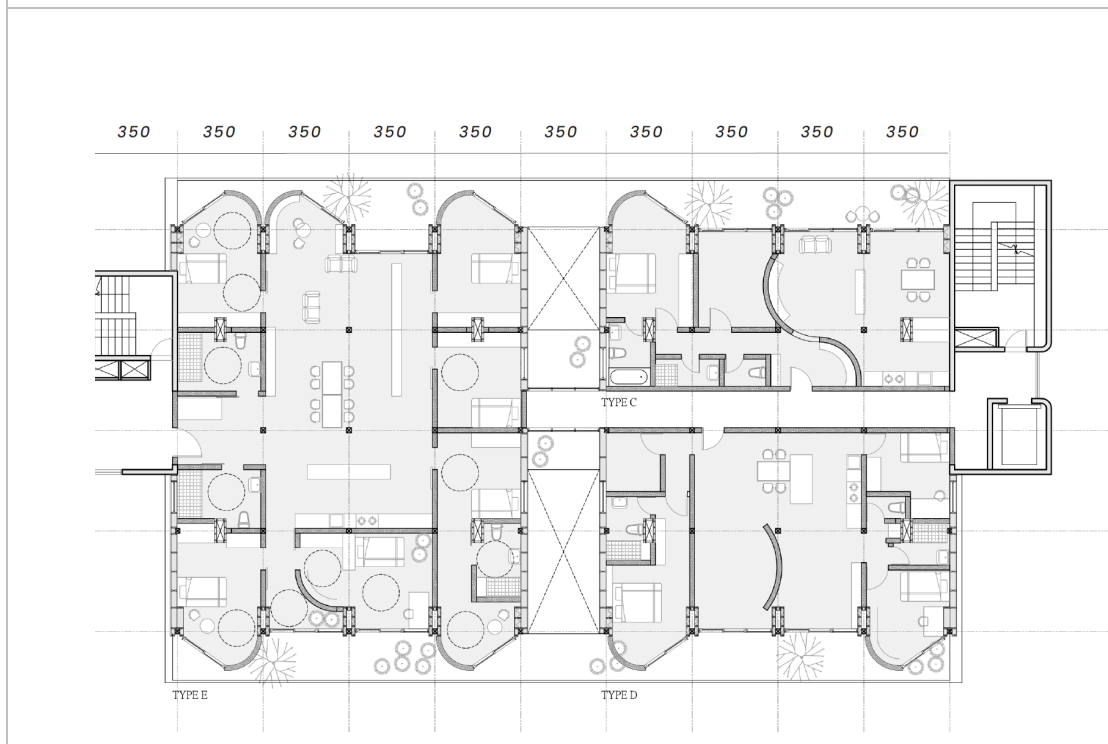
First floor plan-block A (Right)



Second floor plan-block A

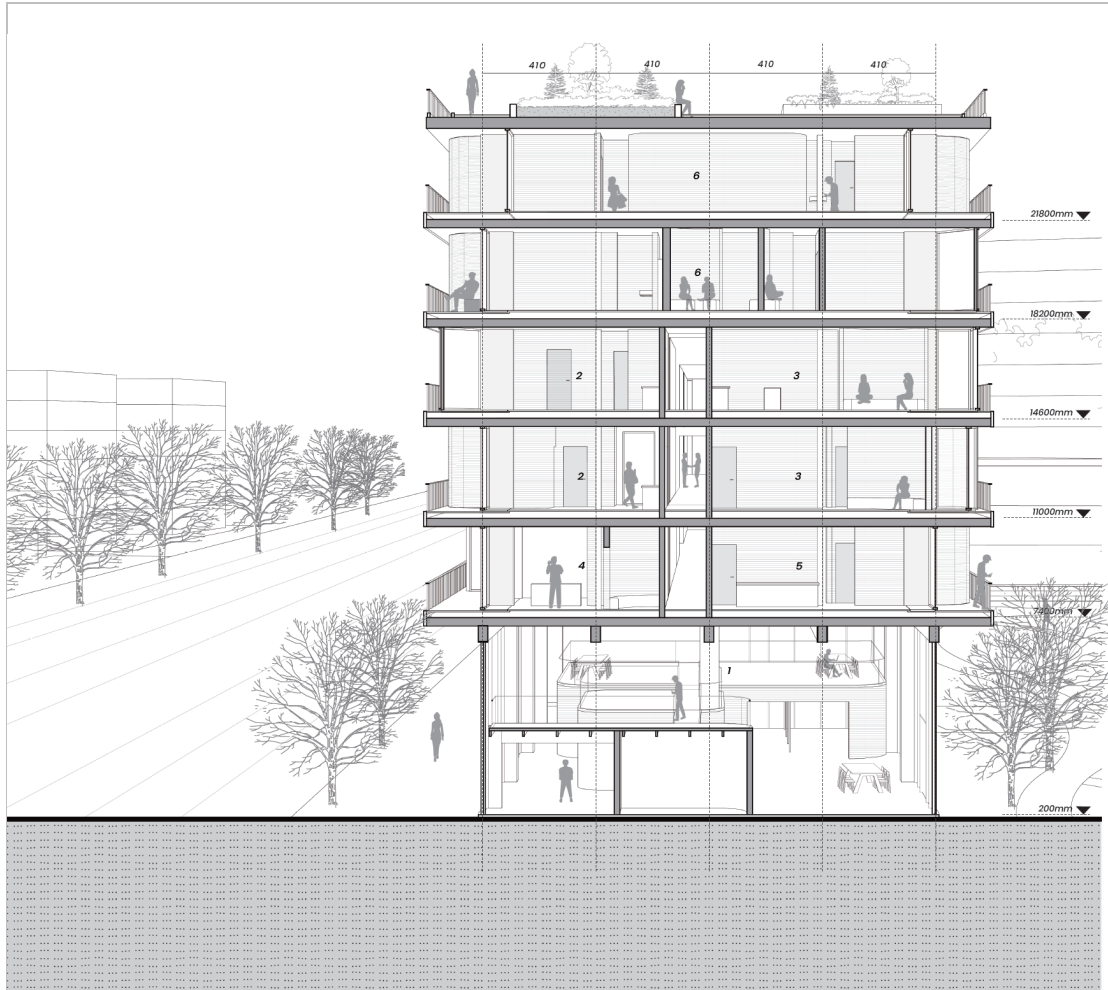


Second floor plan-block A (Left)



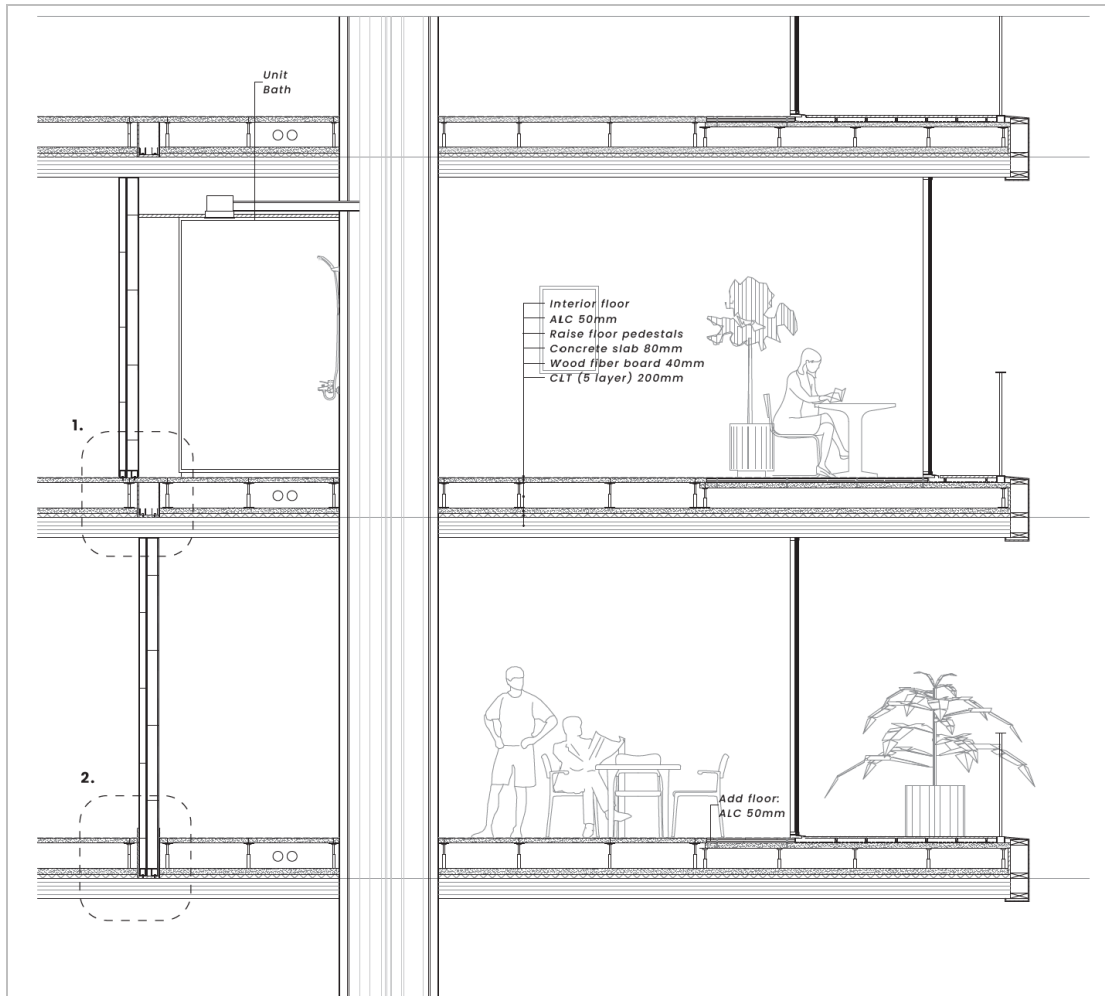
Second floor plan-block A (Right)

The exterior boundary will change based on the user's presence. Therefore, the appearance might be different in few years. The set of curved exterior walls controlled the variation and provided constant architectural language.

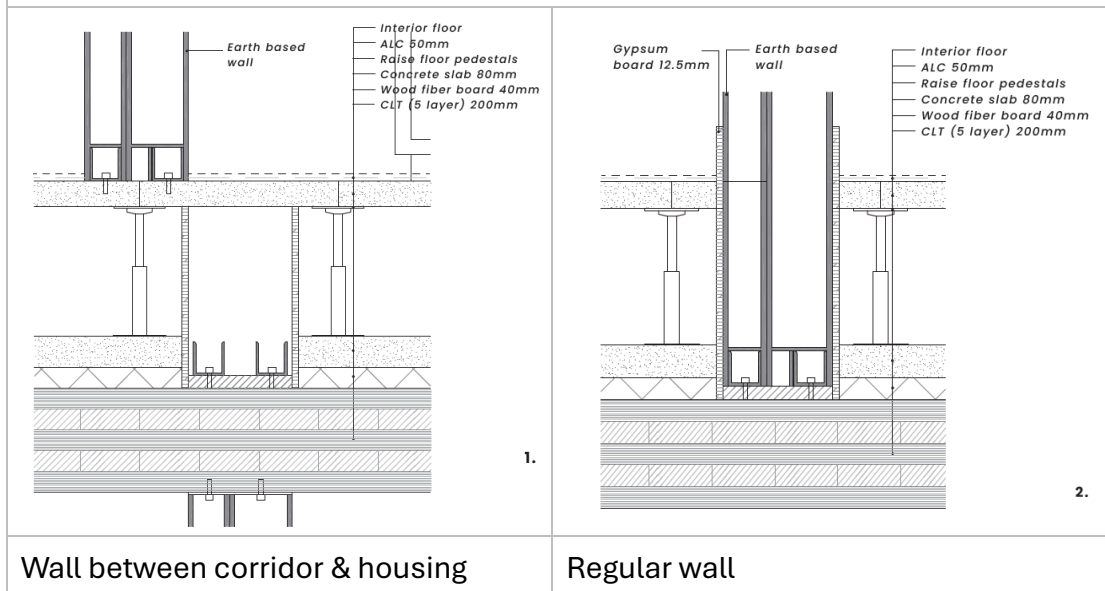


- 1. Co-working space
- 2. Type A housing
- 3. Type B housing
- 4. Type C housing
- 5. Type D housing
- 6. Type E housing

Section



Section



## 4. Conclusion

### 4.1 Conclusion

In responding to the three main problem statements, the final design presents a solution for mixed-use urban housing which could constantly and rapidly respond to different user preferences and evolve over time, especially under the context of a mix of co-housing and small rental apartments in the city center. To understand the adaptability of the designed system, Table 2.1 is used for a final systematic assessment.

Table 2.1 Analysis framework - Adaptability of building

Modularity (Design Phase)	Percentage of prefabricated and standardized components that are used in the system.
Flexibility (Design Phase)	<ul style="list-style-type: none"><li>● Open-plan layouts and movable partitions.</li><li>● Different configurations according to site.</li><li>● Feasible building span.</li><li>● Feasible floor height.</li><li>● Diverse façade design. (aesthetic/ change with climate/ change with orientation)</li></ul>
Extendibility (Use phase)	<ul style="list-style-type: none"><li>● Vertical: Structural rigidity. The possibility of adding more floors.</li><li>● Horizontal: Fast and feasible connection to new floor.</li></ul>
Convertibility (Use phase)	<ul style="list-style-type: none"><li>● Demountable joints between building layers. (Site/ Structure/ Space plan/ Skin/ Services)</li><li>● Movable partitions while in use and energy efficient process.</li><li>● Reconfigurable MEP system.</li></ul>
Recyclability (End of life)	<ul style="list-style-type: none"><li>● Demountable components which could be possibly used in other buildings.</li><li>● Bio-based material.</li></ul>

First, the system is highly modular in both main structure and infill.

Prefabrication along with digital fabrication, in this project the 3D printing technology, is applied for the making of both the partition wall and changeable façade. However, for structural stability of demountable timber structure, the non-modular concrete core is used to achieve lateral force balance.

For flexibility and convertibility, with a considerate arrangement of vertical shaft and core, and the application of raised floor, the modular wall system and the façade system allow for free interpretation of space by the user, and with an adding value of curve design, a more playful design could be achieved by the system. The system is also designed to be manually modified and easy assembly due to the modular design, therefore enabling changes during the use phase and reducing the need of construction professionals. However, because of the coordination with the developed wall system, application of a structure system without beam is used. This has caused a relatively small span which is more compatible for housing use. With a feasible floor height of 3.6m and with the raised floor system, the possibility of changing the building to public function such as office and hotel remained.

Moreover, with the demountable structure system, the timber structure is reconfigurable in different locations. The remaining concrete ground floor structure with a generous building height, and the uninterrupted space between remaining concrete core allows for a variety of public use such as library or other public function since the location of this building plays a significant role in urban experiences of Eindhoven.

As for extendibility, the vertical and horizontal extension is not fully addressed in the project. Vertical expansion is possible but further details about adding floors to the concrete core and the demountable design of roof required further development. Lastly, for recyclability, the wall systems using earth-based material is a sustainable approach, and the modularity provides a reuse scheme for the usual discarded building parts. And as mentioned above, the timber structure could be demounted and rebuilt in desired location.

## 4.2 Reflection

This project applied research by design methodology, and the founding in the design process is addressed, including several improvements and potential research direction for related topics:

### 1. The earth-based brick

- Experiments on technical requirements:

The design provides an approach to using modular earth-based brick as partition wall. With the natural features of the material itself, it has a promising opportunity as partition wall and provides certain quality such as mass for acoustic and thermal performance, and ability for fire resistance. The interlock assembly also enhances the structural integrity and sound performance. However, there is a gap between the design and the implication since the technical requirements of partition wall are not tested. For example, the structural stability of the current designed connection to the structure, the acoustic performance difference if with different bio-based sound insulation material filling inside or added in between. And the performance with different proportions of clay, sand and fiber mixture. Also, the performance with or without lime mortar and the feasibility of reuse if the mortar is applied. Moreover, the design of an integration system to install all the MEP system could be further explored.

- Free form exploration:

To maximize the modularity, the system is designed with certain dimensions and a set of parts. Although the design aimed to provide maximum flexibility for playful design and space experience, there are limitations about dimensions, and the form is also limited. In this case, full potential of the use of 3D printing technology could be further explored since the material is highly recyclable. For example, on site printing of highly customized parts within the existing framework could be designed.

- Curved wall positioning:

The designed system has a characteristic of manual or self-assembling with

prefabricated kit of parts. However, the principle of positioning the curved walls is relatively complicated than orthogonal system. A parametric model, or a user interface for automatically generating layout options based on the needs of user using the system could be interesting for further exploration.

## **2. Housing layout and configuration:**

- Using the system for different sites:

To achieve a generous space for co-housing units and an uninterrupted space between vertical core for future diverse building use, the basic unit size for the co-housing unit is relatively big and not exactly flexible and repeatable enough to apply to various sites. Although the co-housing unit could be turned into private housing freely, and the private housing unit could be combined freely in different contexts, a more flexible and considerable configuration to achieve co-housing could be further explored. For example, the use of two floors as a single co-housing unit when there is not enough floor area.

- Arrangement of the fixed:

Arrangement of the fixed component is crucial to providing a basic framework for the changes. There are components that could be fixed in some projects and in the others changeable. One of them is the wet area. The common solution for this is fixed around the corridor or entrance of each unit, and for projects such as Next 21 and Patch 22, they are freely movable with the raised floor. This project aims to find flexibility in between, with a combination of raised floor and prefabricated bath unit. However, the placement of the shafts, although for several design consideration mentioned previously, is sometimes causing inefficiency of the space. A creative way of the arrangement of these fixed elements should be considered carefully in the beginning of design and could be an interesting approach and has potential as a design characteristic.

Overall, the projects explore a potential way for achieving a less waste future responding to the fast-changing demand when it comes to urban housing, and a manually assembling infill system allowing for a customizable layout under the context of increasing labor shortage. By integrating user-driven modular infill and demountable timber structures, the design shifts the building from a fixed product to an evolving platform for all kinds of dwelling preferences. With this system, flexibility could not only be achieved within private housing units but also shows in an instant testing ground for the co-housing living style. The strategic framework for balancing permanence with changeability sets an option for future research on open building. Furthermore, several research directions in the field of adaptable building are also provided for future exploration.

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