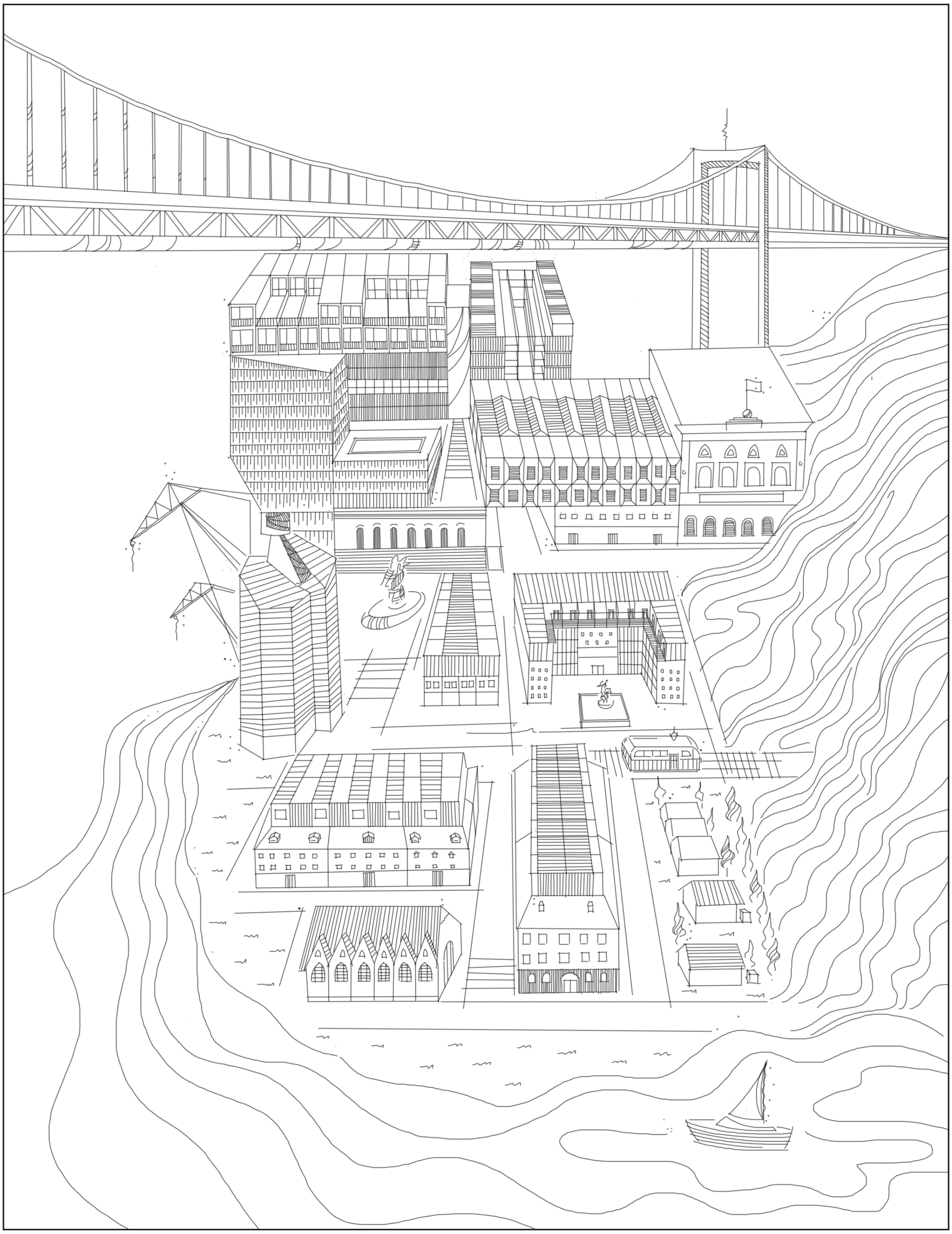

A LANGUAGE FOR CLOUD NINE

An investigation on volumetric modular rooftop extensions as sustainable multifamily housing

Mahsa Mohammadi

Chalmers School of Architecture
Department of Architecture and Civil Engineering
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Examiner: Anna Braide
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ACKNOWLEDGMENTS

First and foremost, I wish to express my sincere appreciation to my supervisor Jan Larsson, for his enthusiasm, constructive supervision and support.

Thank you to my supportive friends for their insightful feedback on my work and their encouragement to keep going.

And above all, I am thankful to my family for their great love, support and trust in me.

ABSTRACT

As an outcome of growing populations, high demand for housing is increasing the cost of building for us and our planet, therefore, it is crucial to use the spaces and technologies available wisely in our cities. The construction industry in Sweden faces a great need for more housing, but the progress has not been on par with the need. Rooftop architecture is a solution which offers the opportunity of using the existing infrastructure to create more functional spaces in the city, including but not limited to residential buildings. In this thesis, the modular building method has been explored for this purpose.

Three research questions drive the thesis:
1. How can prefabricated volumetric CLT modules be designed efficiently for rooftop housing?
2. How can a catalogue of possible compositions of prefabricated volumetric CLT modules be designed and composed together to form multifamily rooftop housing that is adaptable to a variety of contexts?
3. Which buildings in the city would be suitable options for rooftop extensions?

Literature and case studies form the foundation of the design process, afterwards, design strategies are drawn from them to explore design solutions for the concept of volumetric building method with CLT for rooftop housing. Initially, a limited number of modules are introduced, and then they are expanded into multiple apartments and arranged into compositions. In the final step, these compositions have been implemented on two different sites in Gothenburg.

The findings consist of conclusions drawn from this design process for best practices. In summary, the main findings are as follows:
It has been determined that using several modules with different lengths will be more effective in terms of the limitations in the dimensions of the existing building as well as providing to a mix of target users for each case. Furthermore, because of the structural durability of CLT as the main building material, along with the flexibility of organizing the apartments built with modules in diverse compositions, spaces between them can be adjusted according to the requirements for the site.

Keywords: rooftop architecture, modular housing, prefabricated CLT volumetric modules, volumetric construction, timber structures

AUTHOR

Architecture has been a medium of expression and a tool for contributing to shaping the surrounding environment for me. Along this journey, I have become more interested in the topics related to sustainability in an architectural context. With a background in similar directions, this thesis was an opportunity to build upon and expand my knowledge concerning themes of housing, wooden structures, prefabrication and modularity.

Contact

Mahsa Mohammadi
mhsamohammadi6@gmail.com

August 2020 - June 2022
Gothenburg, Sweden

Chalmers University of Technology
MSc. Architecture and Urban Design

Completed courses:
Healthcare Architecture,
Housing Inventions,
Building Climatology,
Architectural Competitions,
Material & Detail,
Sustainable Development and the Design Professions

September 2015 - February 2020
Tehran, Iran

University of Tehran, School of Architecture
Bachelor of Architectural Engineering

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01. INTRODUCTION

OVERVIEW

This booklet is the presentation of the work that has been done for this proposal. The contents are divided into four chapters followed by conclusion and discussion. The first chapter, introduction, states the purpose and aim of the thesis. Research questions are introduced and methods that have been used in the process are explained. Lastly, a clarification of the limitations and reading instructions are addressed.

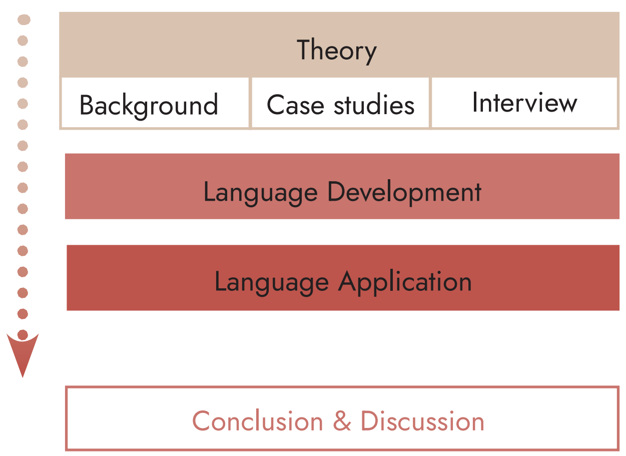
PURPOSE & AIM

The purpose of this thesis is to explore the opportunities in designing prefabricated volumetric modules built with cross laminated timber as the main material, for multifamily housings built on rooftops of existing buildings in the city as extensions, in terms of the design of the modules and their composition.

Through close contact with the builder and understanding the limitations and possibilities of building with prefabricated volumetric modules, architects can generate a realistic design that fits the needs and preferences of the end user.

The hope is to showcase the possibility of creating more multifamily housings, using prefabricated volumetric modules, on potential surfaces, in the city. Perhaps more architects, clients and planners would consider this method of building in the future as well.

After collecting background information on the core topics, the aim is to introduce a limited set of modules and design diverse apartments that suit different residents with different needs by assembling these fixed modules. In the next step, these Apartments will form larger building blocks. Finally, two sites in terms of relevant qualities are analyzed and a solution using the layouts created in the previous steps is composed that fits the sites.



RESEARCH QUESTIONS

Question 1:
How can prefabricated volumetric CLT modules be designed efficiently for rooftop housing?

Question 2:
How can a catalogue of possible compositions of prefabricated volumetric CLT modules be designed and composed together to form multifamily rooftop housing that is adaptable to a variety of contexts?

Question 3:
Which buildings in the city would be suitable options for rooftop extensions?

METHOD

The method for this thesis has been research on, for and by design.

Research on and for design includes literature studies, case studies, and interview. This is placed in the chapter on theory. After theory is presented, conclusions are drawn. Four main topics have been the subject of theory for the clarification of the process. In this chapter a foundation of information is presented on these topics:

1. Sustainable building and circular economy
2. Prefabricated volumetric building method
3. Rooftop architecture
4. Housing aspects

The literature study provides a framework for developing the design proposal. It starts by explaining the current situation in the housing industry and the need for circular design solutions and follows with relevant scientific articles and reports on the topics of prefabricated construction. Challenges of adding rooftop extensions on buildings are discussed and aspects of housing that need to be considered in the design are stated.

Case studies are examples that have demonstrated the method of building introduced here or have similar concepts. They have been analyzed in terms of construction techniques as well as architectural qualities. A summary of the findings from the case studies is in included in the chapter on theory and an extensive analysis of each case can be found in the appendix.

On the chapter of Language Development, for research on design based on prior knowledge and newly found information illustrations and drawings are produced and spatial explorations are conducted to decide on the efficient design for the apartments. In this chapter the apartments are introduced, how they will be placed and form building blocks are illustrated and construction details are explained or illustrated.

In the final step, on the chapter of Language Application, research by design is carried out by placing the apartments on site which will reflect the challenges and opportunities in the process of this project. The findings have been summarized in the conclusions and discussions.

DELIMITATIONS

A city is a complex living organism. It is made up of layers of functions, cultures, history and different dynamics that take place between them. It is a matter of debate whether to add anything to historical buildings or keep them untouched. In this thesis, these aspects have not been elaborated on and mostly the structural attributes of the building that will be used as a surface to build upon are discussed. However, the debates are acknowledged. Second, rooftop architecture is not limited to residential and living spaces. Many other functions such as sporting and leisure facilities, restaurants and green spaces for urban agriculture can be placed on existing buildings. This thesis is focusing on housing in particular following the other challenges portrayed in the bigger picture and uses rooftop architecture as a possible solution to the housing shortage in cities, especially in Gothenburg, Sweden.

READING INSTRUCTIONS

This section explains the specific terminologies used throughout the text for a better reading experience:

Existing building
The chosen building on top of which the extension will be assembled

Extension & Addition
The rooftop architecture that will be assembled on top of the existing building

Volume & Module
The prefabricated volume

02. THEORY

OVERVIEW

This chapter is the background framework of the proposal and is an investigation into the topics that play an important role in defining the context and current conditions of the proposal. First, the problem is formulated and afterwards, the topics are explained separately. There are four main topics, which include sustainable building and circular economy, prefabricated volumetric building method, rooftop architecture and housing aspects. A summary of the case studies and the interview are included. At the end of the chapter, conclusions are drawn based on the theory.

BACKGROUND | PROBLEM FORMULATION

This section introduces the main current issues that have formed the foundation of this thesis. They are challenges and trends within the housing industry as well as issues that involve broader scales.

By connecting these challenges based on their common points, the solution is formed and this project is further developed.

POPULATION GROWTH

From the year 2001 the population has grown from 0.3% increase per year to an average of 1% in 2020 in Sweden. (SCB, n.d.)

The majority of this population is focused around urban centers; in Västra Götaland County, the population per sq.km in Gothenburg is 1301.5 which is significantly higher than its surrounding municipalities. (Regionfakta, 2021).

In the regional housing market report published by Boverket - The Swedish National Board of Housing Building and Planning - in 2017, it is mentioned that following the sharp increase in construction rates parallel to the increase of population, the need for providing more housing opportunities is still present and apartments of various sizes are in demand. (Boverket, 2017)

CLIMATE CHANGE

Different human activities have accelerated global warming, including building construction. This section was responsible for 38% of global carbon dioxide (CO_2) emissions in 2015. The climate goal is to reduce carbon emissions to zero by 2050, however, even if this goal would be achieved several consequences of the current conditions such as flooding will continue at the same rate for decades. (IPCC, 2020)

Another important contributor to climate change is excessive use of natural resources, and the construction industry plays a significant role in this area as well. A total of 3 billion tonnes of raw materials are used every year to manufacture building products worldwide. (Breene, 2016)

However, the problem is mainly the linear cycle of produce-use-dispose which puts a lot of pressure on the planet. Circular economy is the contrasting idea to linear economy that requires establishing a plan for the life cycle of the materials that are extracted and used to help them be used and reused in more ways than one.

NEED FOR CHANGE IN THE INDUSTRY

Following the previous section, although in general buildings are difficult to adapt for reuse or deconstruction for recycling and reusing materials in cost-effective ways, it is evident that the smallest changes in the building industry that are done intentionally can make a significant difference in the bigger picture and long term.

Although some notions related to circular thinking have been present in the industry for decades, the built environment has had a slow progress in adopting the latest technologies and streamlining their processes. (Lemmens & Luebkeman, 2016)

Looking into timber and prefabricated methods of building with timber, it is clear that this could be a great option for achieving the goals in place for the future of the building industry.

LIMITED GROUND IN THE CITY

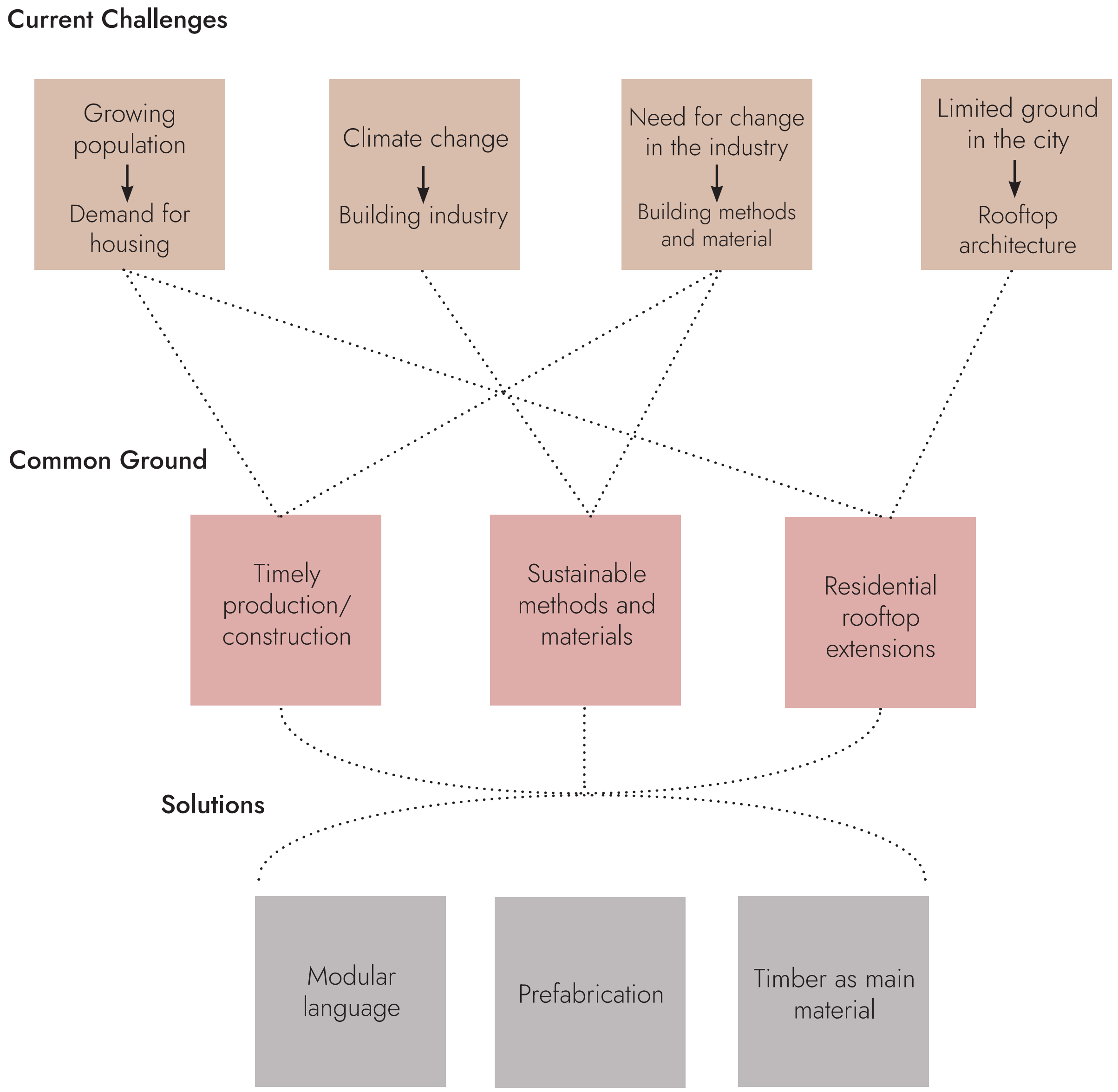
As mentioned before, while the population grows, demand for housing increases with it. However, the urban environment is also filled up, at least at ground level. Expanding the city to the surrounding land might be inevitable but rooftop extensions can become a solution for providing more spaces for activities in the city including living spaces.

This vertical form of urban growth can have positive effects on its immediate environment and neighborhood, in addition to bringing a low environmental impact approach.

PROBLEM FORMULATION

A summary of the paragraphs in the previous section is depicted in the diagram below, from challenges to the solutions that are aimed for in the thesis.

The first row identifies the current challenges and where the building industry comes into play. In the second row, the common areas between them are listed, and finally, the solutions that will be pursued are outlined.



SUSTAINABLE BUILDING & CIRCULAR ECONOMY | CLIMATE CHANGE

According to the sixth assessment report published by IPCC which addresses the most recent understanding on the subject of climate change, It is evident that human activity has heated up the atmosphere, ocean and land. Global surface temperature increases due to human activity are likely to be 1.07°C. (IPCC, 2021) In the majority of the future scenarios envisioned by this report, reducing greenhouse gas emissions is a key aspect to mitigating the pace of global warming. Assuming net negative CO_2 emissions were to be achieved and sustained, the global CO_2 induced surface temperature increase would be gradually reversed, however, other climate change consequences would continue at the same rate for decades to millennia. (IPCC,2021)

The climate goal is to reduce carbon emissions to zero by 2050 and cut global emissions by 45% by 2030, this has been a difficult task and there is still much to be done. (UN, 2020)
As reported by the 2021 global status report for buildings and construction, the construction and operation of buildings accounted for 38% of global carbon dioxide (CO_2) emissions in 2015. By 2020 this figure was reduced by 10%, mainly due to the conditions caused by the COVID-19 pandemic, but also continuous efforts in the sector. Nevertheless, this reduction will be temporary as recovery from the pandemic is taking effect slowly. (UNEP, 2021)

In Sweden, in the proposal for a roadmap and limit values, Boverket - The Swedish National Board of Housing Building and Planning - states that construction and real estate industry account for approximately one fifth of Sweden's greenhouse gas emissions, and one third of this comes from construction of new buildings and demolition of existing buildings. The long-term emissions target adopted by the Swedish parliament is that by 2045, Sweden will have zero net greenhouse gas emissions into the atmosphere. (Boverket, 2021)

LIMITED RESOURCES

Planet Earth has limited natural resources to offer. These resources include hydrocarbons, coal, lignite, ores, various rocks and minerals, soil, and clean water. (Maissner, 2002) These are vital to human survival, one of which is using them for shelter, simply put, using them for the building industry.

As stated by Spiegel & Meadows (2012), in accordance with the law of conversion of matter, matter cannot be created or destroyed, but goes into cyclical transformations, from physical to biological systems and back again. In the end, all we have is what we inherited, permanent, renewable, or non-renewable except for solar energy. Since matter cannot be created, nothing is created anew and nothing discarded is truly erased, yet, what human activities have an impact on is the quality of resources and their transformation cycles. In other words, we waste our natural resources to the point of disturbing the balance between them which creates dangerous conditions that can lead to extinction of ecosystems.

A total of 3 billion tonnes of raw materials are used every year to manufacture building products worldwide. Valuable minerals, metals, and organic materials are lost in this waste stream, therefore any small change and positive improvement can have a great impact on the final result. (Breene, 2016)

Consequently, with the growing population, resources become harder to access and more expensive. (Lemmens & Luebkeman, 2016) The combination of competition over local resources, and rise in waste and air pollution, along with climate change and the natural disasters caused by it, heightens tensions and conflicts, especially among fragile states and amplifies the gap between the rich and the poor. Nevertheless, even seemingly stable states can be pushed towards fragility if they are under intense pressure. (Rüttinger, Smith, Stang, Tänzler, & Vivekananda, 2015)

CIRCULAR ECONOMY

As mentioned previously, the built environment has a significant part in the share of climate change and consumption of resources. For many years the procedure of consumption has followed a linear form meaning that at the end all that has been used would be discarded, creating waste and landfills. Circular economy is a concept based on designing this procedure deliberately in a closed loop

As defined by the Ellen MacArthur Foundation, circular economy is a framework consisting of systemic solutions that are utilized to address global challenges such as climate change, biodiversity loss, waste disposal, and pollution and has three core principles: decreasing waste and pollution, circulation of products and materials and regeneration of nature. (Ellen MacArthur Foundation, 2021)

According to Lemmens & Luebkeman (2016) in a circular economy the biological material are taken from renewable resources but their regeneration and safe return to the biosphere will be guaranteed. In the circular economy, man-made products that have been used for their original purpose and cannot be repaired, are designed in a way that can be broken down into their main components and reused or remanufactured into other products. Resources return to the starting point of the cycle, or are in flow in a different form. In contrast to this approach, in a linear economy, when the product is no longer of service, it will be disposed after use. (Figure 1)

Extracting raw materials, transporting, processing and shaping them is already using large amounts of energy and producing green house gas emissions, therefore, the circular economy ensures that our best efforts are made to use them as whole, or in parts and reduce negative externalities as much as possible in the process.

On a report published by UNEP and UNDP (2020) it has been acknowledged that circular economy is the key for a more sustainable transition to consumption and production patterns as outlined in the 2030 Agenda for Sustainable Development.

The circular economy also requires more labor than the linear. Turning towards the circular economy could create 6 million new jobs by 2030, according to the Labor Organization. (Soezer & Areden-Clarke, 2020)

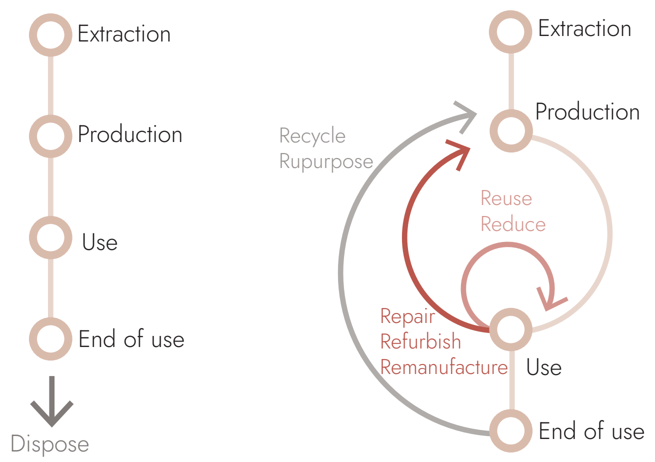


Fig. 1: Linear economy vs. Circular economy adapted from UNEP (2019)

CIRCULAR THINKING IN THE BUILT ENVIRONMENT

As mentioned before, construction of new buildings has one of the highest shares of greenhouse gas emissions in the industry next to demolition, and new buildings will certainly be built. Therefore, it is crucial that architects look deeper into their creations and make conscious decisions about the materials used in their buildings and the processes they have to go through, as well as what occurs after the design is produced and put in place.

In Boverket's report for a proposal for legislation on climate declarations for buildings, which has been intended to take effect from January of 2022, Boverket requires that construction of new buildings are accompanied by a climate declaration on the life cycle analysis of certain building components. (Boverket, 2021) This report has introduced modules within the stages of a building's life based on European standard EN 15978 issued by the European Committee for Standardization. (CEN, 2011). (Figure 2)

The end of life stage typically represents a very small share of a building's overall climate impact. (Boverket, 2021) However, purposefully choosing the materials, selecting more sustainable construction methods and more convenient reuse and refurbishment methods could have a large impact on the end result, since as mentioned before, the building industry makes up a large share of the climate impact.

Many principles associated with circular thinking, can be found in the industry dating back to centuries. These principles include maintaining, reutilising, upgrading and repurposing infrastructure and buildings, nonetheless, the built environment has been slow to streamline its processes and use the latest technologies. Using circular approaches can help reduce the sector's environmental impact as well as reduce increasing costs, delays, and other negative effects of a volatile market. (Lemmens & Luebkeman, 2016)

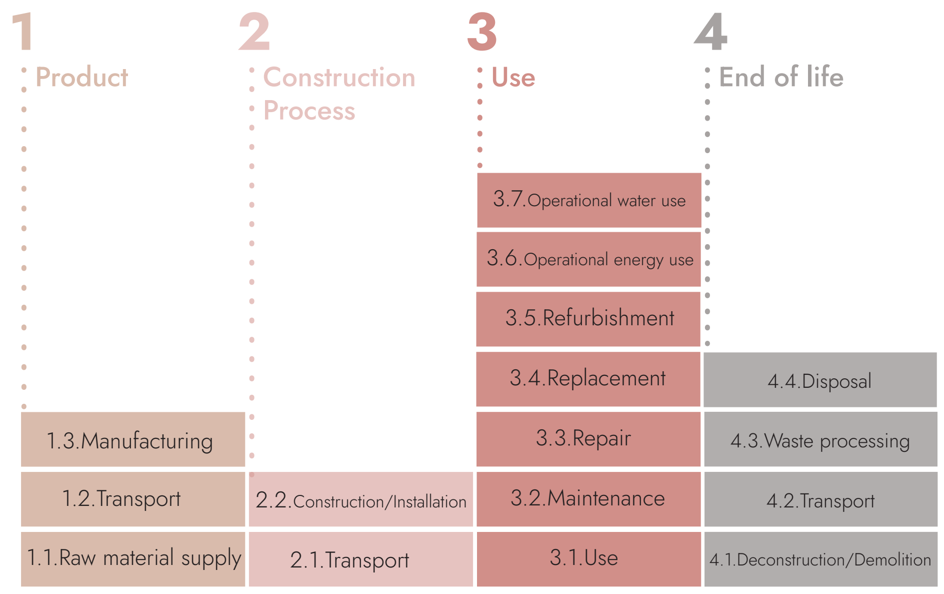


Fig. 2: Building life cycle adapted from Boverket (2021) & CEN (2011)

DESIGN FOR DISASSEMBLY

In short, circular design requires the creator to design a product with regard to its whole life cycle from use to disposition, reuse and recycling, therefore, design is a crucial part of the building process. Following circular thinking in the built environment, management of maintenance, recovery and end of life scenarios of buildings has unfolded into the concept of design for disassembly.

In a guide to close-loop design and building for architects and designers, Guy & Ciarimboli (2005) introduce design for disassembly, the need for it and challenges that come with it. Design for disassembly or DFD is portrayed here as a concept in design that focuses on reducing the need for consuming new material for new buildings and ensuring that the building components are designed and connected in a manner that can be easily reused, or renovated in the future. DFD is a crucial part of designing for the environment and allows for the addition, subtraction, and conversion of whole buildings. (Guy & Ciarimboli, 2005)

In introducing a circular economy index for building design, O'Grady, Minunno, Chong, & Morrison (2021) have chosen the factors of disassembly, deconstruction and resilience in a design. The difference between deconstruction and disassembly is noted here as deconstruction being removing structural elements or sections of a building for rebuilding whereas disassembly refers to the end of life. And finally, resilience in a building means if it is robust enough to withstand events such as relocation. Furthermore, this paper breaks down the possible scenarios of decommissioning of a building. (Figure 3)

A number of strategies mentioned for achieving DFD are:

- Using lightweight material
- Using standard structural grids
- Separating structure from cladding
- Reducing the number of different materials
- Avoiding composite materials
- Designing connectors that are easy to detect

(Guy & Ciarimboli, 2005)

According to Lemmens & Luebkeman (2016) designing the building components and structures in a way that they can be repurposed and reused further down the line will guarantee their circulation in the industry. Hence, modularity and disassembly are favored in this attitude.

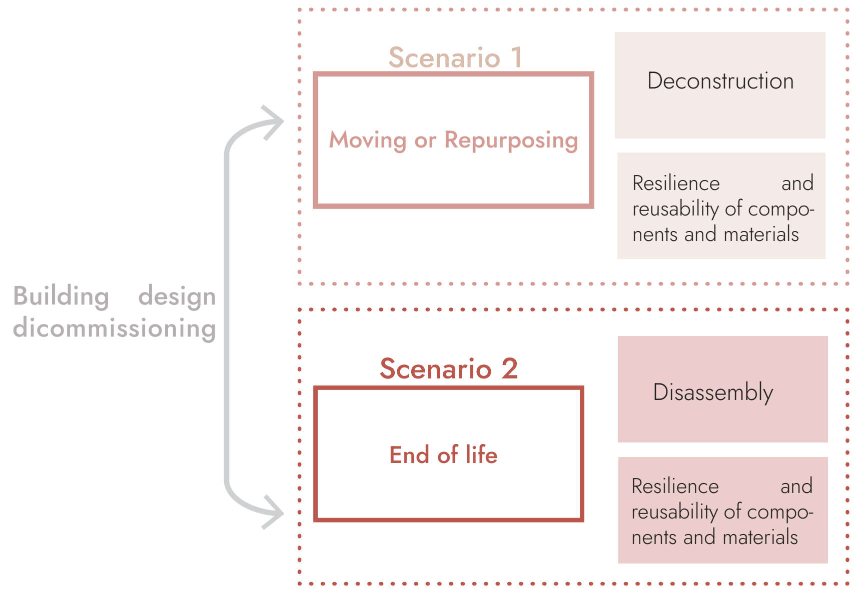


Fig. 3: Building decommissioning scenarios in the circular context adapted from O'Grady et al. (2021)

LAYERS OF CHANGE

Buildings last for varying amounts of time, nonetheless the components that shape the building also have different life spans, and this brings limitations with it. The components, as introduced by Brand (1997) can be categorized into different layers. (Figure 4) Brand has introduced these layers in the six S's system of:

1. Site: The setting and location
2. Structure: Foundation and load-bearing elements
3. Skin: Exterior finishes
4. Services: Utility and HVAC systems
5. Space Plan: The interior partitions or cabinets
6. Stuff: Furniture, appliances

The layers are described as shearing layers of change, because of the variation in their life expectancy. It is important to note layers that go through change rapidly are in control of the slow layers and cannot alter freely. (Brand, 1997)

This is a crucial point to have in mid while designing the building components and elements, and it means that the elements that are in need of a more constant change should be accessible if the hope is that the whole building system should function for a long time. As mentioned in previous section Guy & Ciarimboli (2015) also mention separation of different building elements such as cladding and structure as a strategy for DFD.

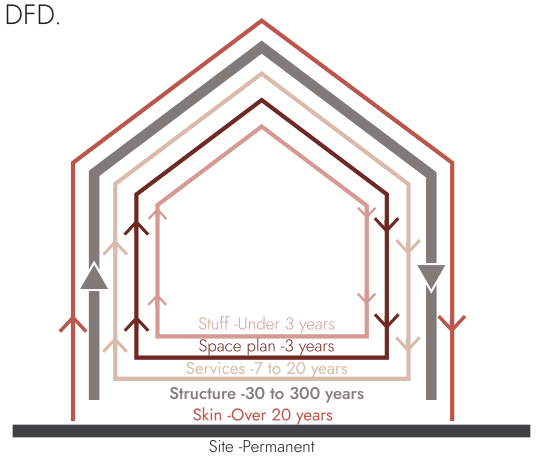


Fig. 4: Six S's diagram adapted from Brand (1997)

TURNING TO TIMBER

According to Spiegel & Meadows (2012) getting an understanding of the relative eco-friendliness of a material can be achieved by taking a number of qualities into consideration:

- Not including synthetic chemicals in byproducts
- Possibility of being locally obtained
- Potential for including input of recycled material
- The amount of energy it requires for production
- Potential for recycling or reusing

(Spiegel & Meadows, 2012)

Following these characteristics and with the rise of topics surrounding circular economy, sustainable design and the need for encouraging sustainable building methods, timber has attracted attention. As a natural building material, it has qualities that correspond to sustainable needs as well as offer great flexibility due to diversity of the products that can be produced by it. Wood is a natural and recyclable material, it has great strength and durability and carbon compounds are stored within wood material throughout its lifetime.

When considering a building's impact on the environment over its lifetime, the manufacturing and construction processes become increasingly significant. Analyses of the life cycle of built objects indicate that using wood in structural frames as opposed to other materials reduces emissions. (Gustafsson, 2019)

Cross laminated timber or CLT, is a timber product made of glued boards or planks layered alternately at right-angles. CLT can be manufactured in an energy-efficient manner, and its by products can be used further on, additionally the raw material can be reused. Similar to regular wood, CLT is a natural product that is strong and durable while acting as part of nature's ecocycle when used properly. It can then be repurposed in new structures or incinerated to produce energy. (Gustafsson, 2019)

CROSS LAMINATED TIMBER OR CLT

Cross laminated timber or CLT comprises of at least three layers of glued wooden boards or planks, and each layer is placed at 90 degrees angle to the next. (Figure 4) (Gustafsson, 2019)

As an engineered timber product, CLT has several properties that make it an exceptional material for modern timber buildings, from high rise, to different types of commercial and industrial buildings and residential.

USAGE

CLT is majorly used for structural components (wall and floors) in the Nordic countries. In the frames of multi-storey buildings, schools, and industrial buildings. Large panels of CLT are often used as surface components such as walls and floors. However, the versatility of CLT allows it to be used in various applications. CLT is an engineered material that has had extensive prefabrication of its components, making it suitable for architecture in industrialized settings. (Gustafsson, 2019)

STRENGTH

Due to its great strength and stiffness, cross-laminated timber can compete with other traditional structural materials in high-rise building construction. CLT panels can support more weight than most other building materials in comparison to their own weight. They can be used for large spans, however, in housing, since the spans are usually smaller and the internal walls act as supports the ceiling can be self-supporting. (Gustafsson, 2019)

FIRE PROOFING

Behavior of wooden structures in case of fire is predictable, however the details must be designed cautiously. Different degrees of fire proofing can be achieved through using different compositions of materials in the walls or floors. In housing fixed ceilings usually comprise of one or two layer of plasterboards over battens and insulations. (Gustafsson, 2019)

SOUND & ACOUSTICS

In general, as a rather lightweight structure, in CLT structures low-frequency noise is challenging to insulate. It is important to design the floor structure accordingly. Double structures have been advised to be used in the floors and they have extremely high sound insulation qualities. Double structure refers to double sheets of CLT panels, separated with cavity partially filled with insulation. Similar to stud walls, CLT panel walls are considered lightweight compared to materials such as concrete and bricks, but using double structures, with a minimum distance of 100mm can bring acceptable sound insulation. (Gustafsson, 2019)

THERMAL PROPERTIES

Due to its low thermal conductivity, wood also makes surfaces pleasant to touch. The use of CLT structural frames brings many benefits in terms of both indoor climate and energy efficiency. The energy consumption for heating can be reduced by a considerable amount when compared with stud walls and light-weight floor structures. CLT panels are usually used with insulation and facade layer as exterior walls, that is because although wood has good thermal properties, additional insulation is needed to meet modern requirements. (Gustafsson, 2019)

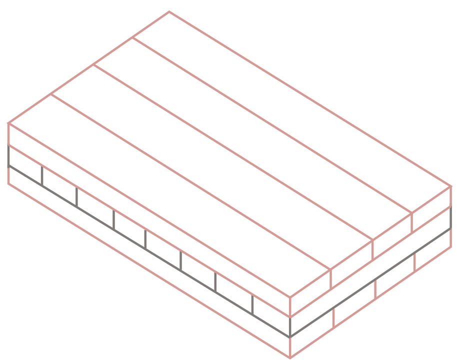


Fig. 5: Illustration of a CLT panel composed of three layers

PREFABRICATED MODULAR BUILDING METHOD | PREFABRICATION SYSTEMS

Prefabrication refers to the act of manufacturing parts of a building system off site and in some cases in controlled conditions in the factory, and transporting them in an almost finished state to the construction site.

The general categorization of level of prefabrication is as follows:

1.Components
2.Panels
3.Modules

It is more efficient to manufacture larger components, panels and modules to the highest degree of finish before transporting to site. (Smith & Timberlake, 2010)

COMPONENTS

This level of prefabrication has the most flexibility in the design phase, yet when brought on site, the components are numerous and a good organizing system is needed, which makes the process more similar to "typical" construction processes. To assemble the components, joints and connection should be carried out on site which heightens the risk of mistakes, weathering and leads to overall reduction of the quality. (Smith & Timberlake, 2010)

PANELS

Panel refers to planar elements such as wall, floor and roof, load-bearing or non-load-bearing. According to Smith & Timberlake (2010) prefabricated panels have finished levels of 60 percent when brought onto site. This category includes wall panels with integrated insulations, interior partition walls, curtain walls and different types of cladding systems.

MODULES

As mentioned by Smith & Timberlake (2010) today the modular method is favored for reducing the duration of construction and high quality of product. Modules have the highest degree of prefabrication and can be completed from 85 to 95 percent. The remaining work is left for foundation works on site and utility hookups.

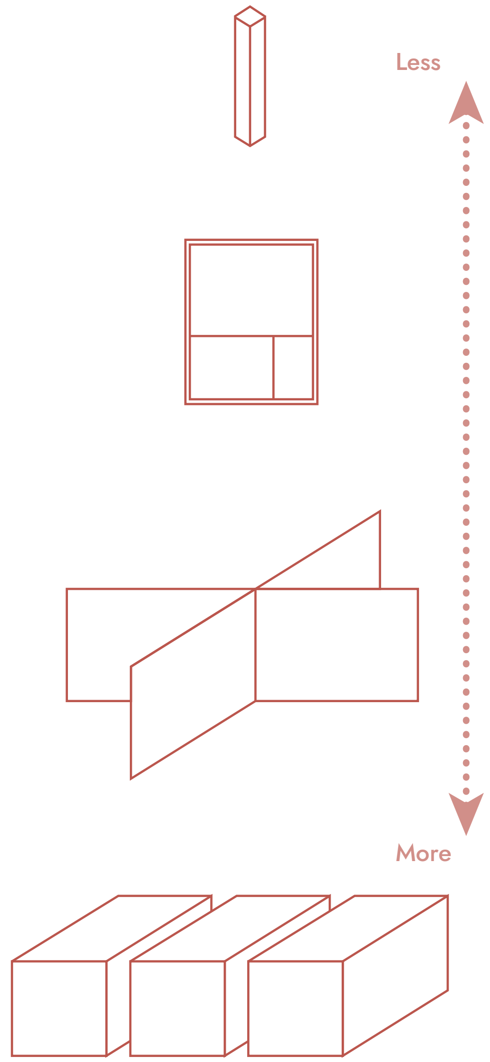


Fig. 6: Degrees of prefabrication adapted from Smith & Timberlake (2010)

PREFABRICATED MODULES

The word module is referred to a standard volumetric unit. According to Smith & Timberlake (2010) in the 1960s precast modules were supposed to be the solution to achieving timely construction, nonetheless, nowadays wooden and steel frame modules are more common.

Smith & Timberlake (2010) describe the process of building a conventional wooden module as follows (Figure 7):

1. Floor of the module that is constructed in the factory, is sheathed and put on skids

2. Panel walls of the module that are constructed in the factory, are sheathed and tilted onto the floor of the module

3. Roof of the module that is constructed in the factory, is craned onto the walls

4. The modules is wrapped

5. Windows are installed

6. Exterior and interior finishes are installed

After this the modules are wrapped and loaded on trailer, transported to site and put in place using cranes

Some challenges in this method could be that the modules cannot be transported to the site due to large height, width or length, or that sloped roofs have to be transported as separate elements. In these scenarios knocked down methods are used which means that the components of the module are propped and tilted or put flat so that they can be erected on site. (Smith & Timberlake, 2010)

Transport conditions have one of the greatest impacts on construction and assembly costs. It is considered to be the most efficient and economic to design the modules in a way that can be transported to site as quickly as possible and reduce transportation time.

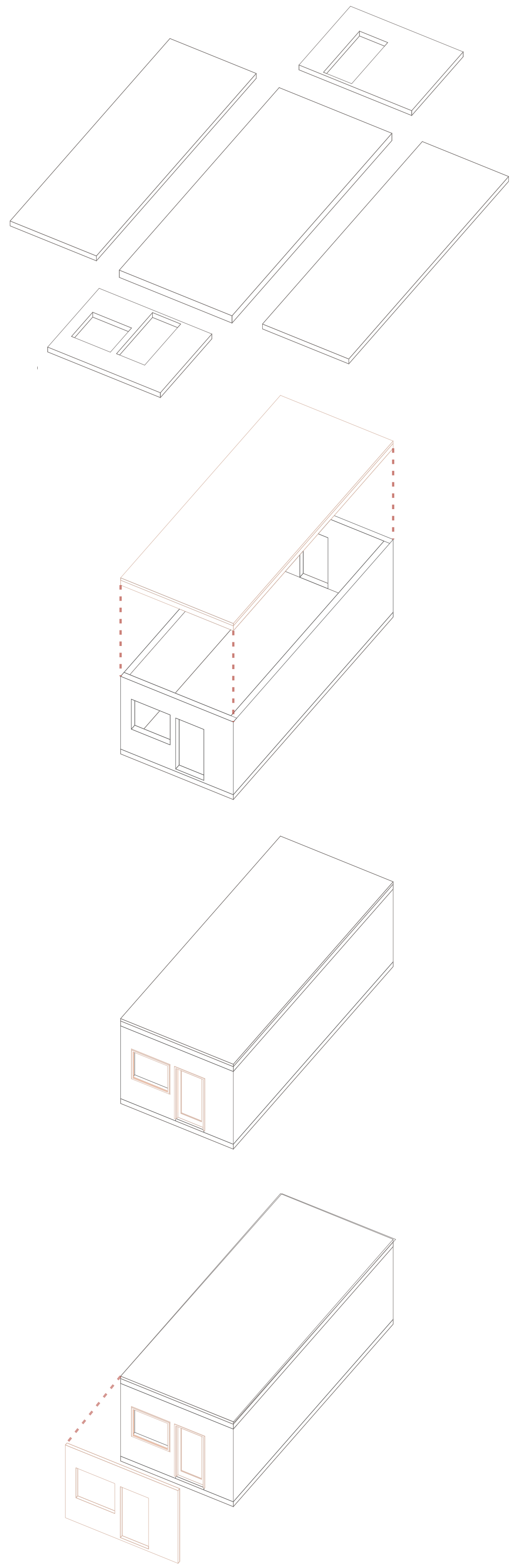


Fig. 7: Illustration of fabrication of a module in the factory

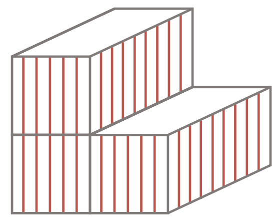
PREFABRICATED TIMBER MODULES

As mentioned previously, modular building, means the placement of entire finished modules on site. (Smith & Timberlake, 2010)

For timber modules, this method of construction can be divided into three main categories in regards to the materials and the building method that are used for assembling the modules.

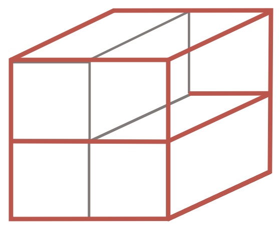
- Stud frame
- With a supporting structure
- CLT modules

The information regarding the characteristics of each building method, shown in the table below, has been acquired through the interview and diverse resources. (Stenberg & Rosenberg, 2020; Davallou, 2021; Lindbäcks, 2020)



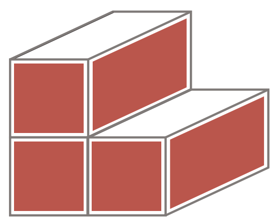
Stud Frame modules

- Modules built with a regular wooden system
- Less use of wooden material
- Lightweight and easier to transport
- The volumes are load-bearing and are mounted on top of each other



Supporting structure

- Modules are placed into a supporting structure, such as post beam frames
- The volumes are not completely load-bearing



CLT modules

- Modules built with CLT panels
- More use of wooden material
- Heavier in weight
- The volumes are load-bearing and are mounted on top of each other
- Stronger and durable against harsh construction conditions such as wind

DIMENSIONS

Transport restrictions determine the dimension requirements for modular construction, considering that it is most efficient and economic if the whole volume fits into the truck at once.

As displayed in figure 8, the maximum length for vehicles on Swedish roads is 24 meters, with a height of 4500 mm and width of 4150 mm. (Trafikverket, 2011)

CLT can be used in large formats. As acquired from the CLT producer that has been interviewed, CLT elements are made up of 3, 5 or 7 layers, with a thickness between 60mm up to 300mm, and they can be produced in 3 meters to 12 meters long.

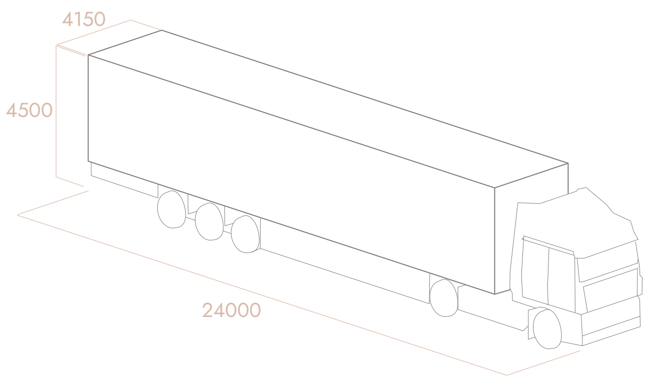


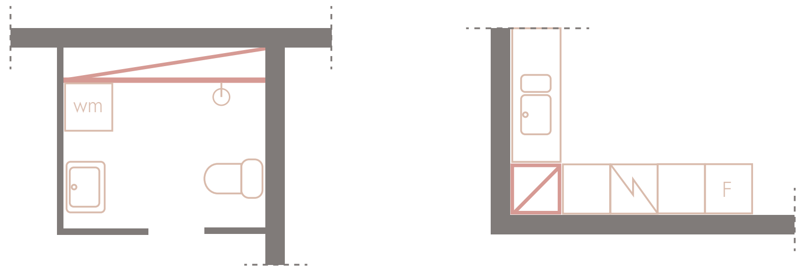
Fig. 8: Maximum dimensions allowed for transportation

TECHNICAL SPECIFICATIONS

It is important to have access to the shafts (water, ventilation, etc.) both during and after construction.

In the cases when the kitchen and bathroom are completed in the factory, the shafts still need to be accessible.

Lindbäcks (2020) describes situations that the placement of shafts are not favorable in the design of the volumes. (Figure 9)



Positioned between the bathroom pod and the exterior wall on the construction site, the shaft is inaccessible

As the kitchen is finished at the factory, the shaft is no longer accessible

Fig. 9: Examples of unsuitable placement of shafts adapted from Lindbäcks (2020)

CONCEPT OF MODULARITY IN PRODUCT

According to Jablan (1997) modular systems are the manifestation of the universal principle of economy in nature: the possibility of creating diverse structures that result from a limited set of basic elements. Modularity in art is also described as a combination of modules that lead to a variety of structures, such as ornamental brickwork.

According to Gershenson, Parasad & Zhang (2003) modularity is achieved by decomposing a product into parts and components, and because components are more easily standardized, there is a greater variety of products available. In this paper it is discussed that the notion of "being made up of modules" is the only concrete consensus about modularity across different fields and it is concluded that there are three fundamental aspects to modularity:

1. Components are independent of outside components
2. Similarity of components with respect to their life cycle
3. Absence of similarities to outside components

In regards to these three aspects, Gershenson et al (2003) suggests that products can have different degrees of modularity depending on how many of these factors they oblige to, and that an ideal modular product exists although it is difficult to achieve.

Introducing a three dimensional approach Fine, Golany & Naseraldin (2005) compares modularity to integrality on three points of product, process and supply chain design and concludes that an ideal modular product will be created through a modular process and supply chain. (Van Oorschot, Halman & Hofman, 2021)

In this context, modular products are made up of standardized components which are interchangeable, as opposed to integral products that are customized for only one product. Additionally, modular process means that It is possible to manufacture modular products at different locations independently. (Van Oorschot et al, 2021)

Fine et al. (2005) then proceeds to assign modularity and integrality to supply chains, and explains that an integral supply chain is shaped when the components of the supply chain are close to each other in terms of geography, organization and culture, but in contrast, in a modular supply chain the components are scattered with few organizational ties that connects them together. (Figure 8)

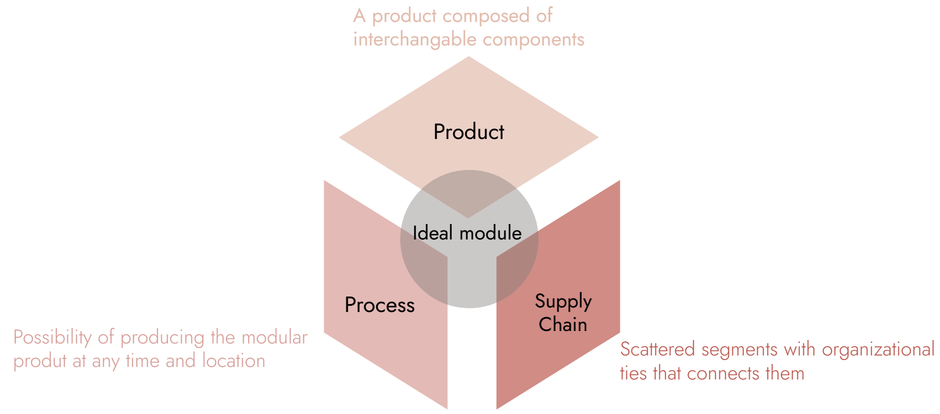


Fig. 10: Three dimensional approach to modularity based on Fine et al. (2005) & Van Oorschot et al. (2021)

MODULARITY IN THE BUILT ENVIRONMENT

In an investigation by Viana, Tommelein & Formoso (2017) it is also showcased that the theory of modularity explained by Fine et al. (2005) can be implemented in prefabricated building systems and modular solutions, to enable the adoption of mass customization and reduce its complexity. Viana et al (2017) explains that using modular design results in the reduction of time spent in the schematic design phase and reduces the need for turning back to them and makes it feasible to have an accurate outlook on time and budget.

Van Oorschot et al (2021) has examined the factors that can influence the adoption of green modular innovations in the housebuilding sector in case studies in the Netherlands. Based on the three dimensional approach to modularity introduced by Fine et al. (2005) the adoption, or failure, of green modular innovations is explored. The subject of study for green modular innovations in this scenario are subsystems of a house (Modular renewable energy system, Modular bathroom pod and a modular photovoltaic integrated roof), however the findings could be deemed relevant on a wider aspect.

This research concludes that a modular product is created when design rules and standards come together with the supply chain integration, and although setting the initial agreements and standards are time consuming, there will be less need for future management and time will be saved. Furthermore, it is shown that modular innovations in housing projects require coordination between the supply chain partners to develop shared knowledge and understanding on what is to be designed.

Ultimately, as discussed in the mentioned papers, modular products take a longer time to be designed, since a footprint of possible scenarios should be considered in the schematic design phase, but when it comes to conduction, the time spent on the creation of the modules is redeemed due to rapid implementation and the fact that they make the process more convenient.

MODULARITY & SUSTAINABLE DESIGN

As mentioned by Van Oorschot et al (2021) the main economic incentives for utilizing modular innovations in the housing industry are improving productivity and increasing industrialization, however environmental impact is also a subject that is usually brought up when referring to modules.

In a literature review, Sonego et al (2017) states that general literature represents modularity as a method that serves the environment; although the context of which modularity is used in and the users that the product is designed for play an important role in how the environmental impact can be articulated. In this paper, the intersection between modularity and sustainable design is investigated from the perspective of the product life cycle (production, use, and disposal), and it is concluded that research is mainly focused on the production and disposal phase, while the usage phase which is a deciding and critical phase in the life cycle of the product, needs to be further explored. (Sonego et al, 2017)

In summation according to the previous sections regarding the notion of circular economy in the building industry, modularity and prefabrication have been pointed out as effective solutions, due to the possibility of being disassembled and used as whole or broken down to subcomponents.

ROOFTOP ARCHITECTURE | ARCHITECTURE ON CLOUD NINE

In this thesis, the design concept strives to occupy rooftops in the city, rather than erecting new buildings at ground level. Rooftops are addressed as cloud nine here. Since the invention of elevators, rooftops became as easily accessible as the bottom levels, therefore the opportunity of using and inhabiting these spaces was created. (Melet & Vreedenburgh, 2005)

A NEW WAY OF URBAN GROWTH

According to Melet & Vreedenburgh (2005) in the past the city was a dense point with housing, workplace, recreation and markets placed in it, surrounded by greenery. This typology of layered city changed in the next hundred years when residents, large companies and industries left the city to move to the outskirts due to the desire to possess more land and easy access. This has resulted in the creation of different areas with specific characteristics, such as exclusively residential or industrial districts. The city occupies more space as these heavily used areas become increasingly crowded.

Rooftop extensions are becoming popular for creating new homes within already consolidated cities. (Aparicio-Gonzalez, Domingo-Irigoyen & Sánchez-Ostiz, 2020). Therefore it is crucial to consider the notions and possibilities surrounding the topic.

Urban planning frameworks such as zoning plans determine whether additional storeys can be built.(Melet & Vreedenburgh, 2005) An analysis of urban context including distance between buildings, height, street type and existing vegetation should be carried out as well. Existing buildings can be impossible to build upon if they have a monument status or are completely structurally unsound. (Melet & Vreedenburgh, 2005)

LOW ENVIRONMENTAL IMPACT SOLUTION

As mentioned before, the population is growing and the need for providing more space within the city is growing with it, especially for housing. Considering this new dimension in the city as a site to build on means that urban growth can take place without spreading the city out and invading new land. (Melet & Vreedenburgh, 2005; Bellini & Mocchi, 2019)

To build on a rooftop, no new land is being purchased and the urban infrastructure (except for parking space) is already available. (Melet & Vreedenburgh, 2005)

Nonetheless, the capacity of the infrastructure should be examined to be certain that installations, services and free spaces can support higher density of population in the area. (Aparicio-Gonzalez et al, 2020)

REVIVING THE NEIGHBORHOOD

Rooftop architecture can cover a variety of functions. It can be the same function as the existing building (if it is still in use) or have a completely different function. Nonetheless in the case of housing, Melet & Vreedenburgh (2005) suggests that a slightly different housing stock will lead to a more diversified neighborhood composition, since the interaction between old and new residents is inevitable.

Additionally, the need to examine the regulations regarding rooftop extensions, can lead to deeper research into the existing conditions of the site and makes the further development of the area possible in an intentional manner. (Given, 2019)

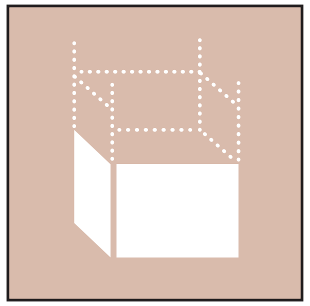
BENEFICIAL FOR THE EXISTING BUILDING

Following the previous point on strengthening the neighborhood and area due to bringing new attention and possibilities to it, on a smaller scale, it can also be deemed as a positive opportunity for the existing building, if done right.

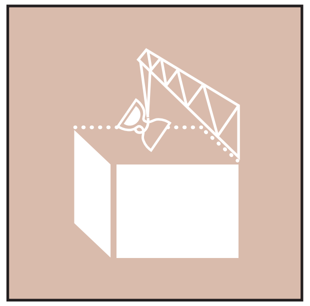
Renovation of building stock is being slowed down because of the high costs of renovation. According to Aparicio-Gonzalez et al (2020), profits from selling the new homes can be used to renovate the existing buildings.

CHALLENGES OF ROOFTOP CONSTRUCTION

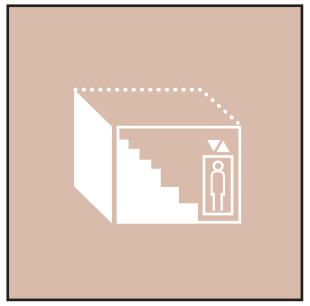
Rooftop construction brings limitations and challenges, which can be categorized into several assortments:



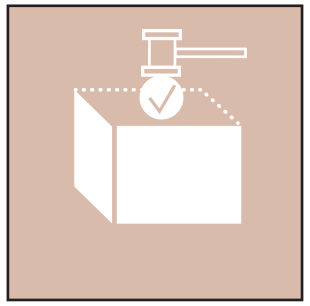
EXISTING BUILDING
The first challenge is the site, or in other words the existing building. It determines dimensions, structural capacity, and regulations in fire safety issues. (Melet & Vreedenburgh, 2005)



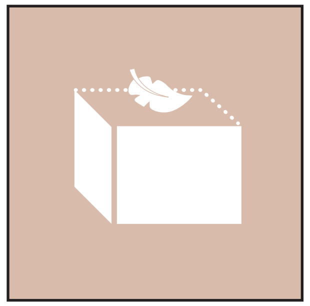
SHORTER CONSTRUCTION TIME
Due to working conditions that can be dangerous, simple work operations and low maintenance solutions are required. (Melet & Vreedenburgh, 2005; Bellini & Mocchi, 2019)



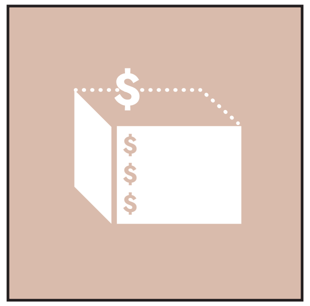
ACCESS
Lack of direct access to the street means that current elevators require extending or new ones should be added. (Melet & Vreedenburgh, 2005)



REGULATIONS
The addition should follow regulations of a newly constructed building, which can be more demanding than the regulations for renovations. (Aparicio-Gonzalez et al, 2020)



STRUCTURE
In most cases rooftop construction requires lightweight systems such as light and easily movable structures, temporary elements and prefabricated blocks and modules. (Bellini & Mocchi, 2019)



HIGH COST
Rooftop construction is expensive. Significant costs go toward strengthening the roof to withstand the additional weight. (Melet & Vreedenburgh, 2005)

RELATIONSHIP WITH THE EXISTING BUILDING

Rooftop architecture has been referred to by various names. Rooftop extensions, rooftop additions, topping up or even parasitic architecture. Whether these names have one meaning or are different, is a topic of discussion and these phrases have been categorized across different aspects that have one main common point, the relationship of the extension with the existing structure.

Bellini & Mocchi (2019) categorize the connection between the existing building and rooftop architecture based on diverse aesthetic, visual and structural attributes in regards to the relationship with the existing building. In the next two sections adaptation of these assortments are illustrated.

RELATIONSHIP WITH THE EXISTING BUILDING: FORMS & EXPRESSIONS

The extension can take on various forms on top of the existing building. The form can be respecting towards the boundaries of the existing building, it can hide from sight, or completely take over the scene. (Bellini & Mocchi, 2019)

These categorizations are also determined by other aspects such as the structure of the extension and the building method used for them. Nonetheless, depending on the function of a rooftop design and the goal that is decided for it, the extension can take many forms and affect the building and the urban landscape in different ways to diverse degrees.

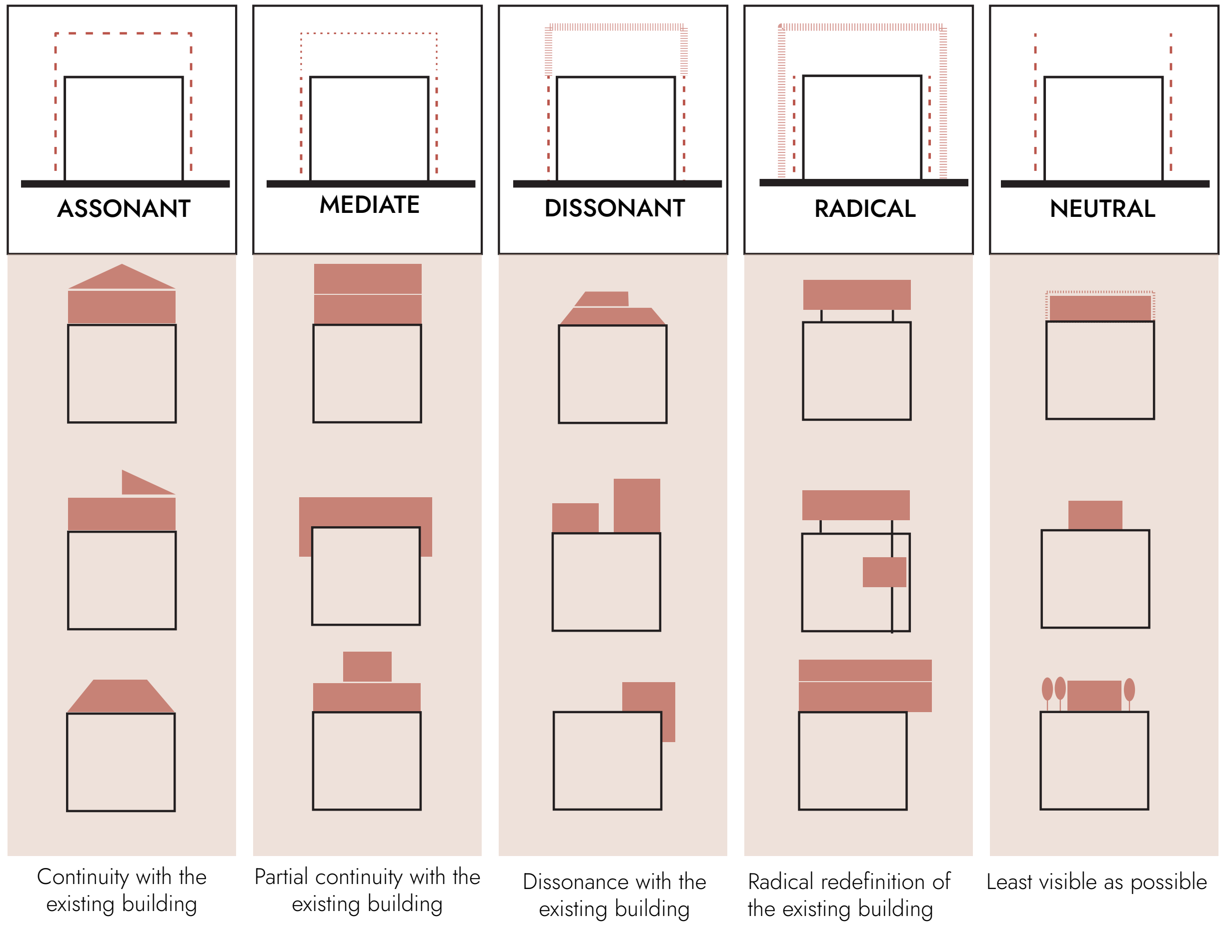
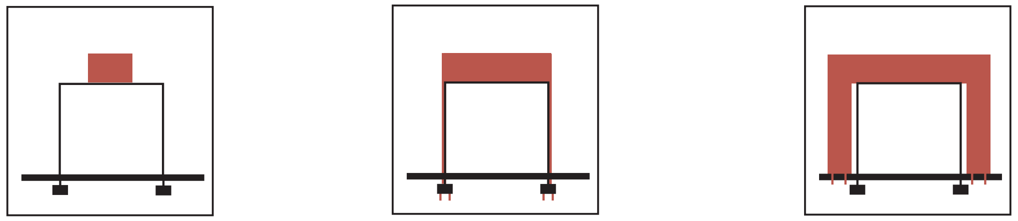


Fig. 11: Forms of an extension adapted from Bellini & Mocchi (2019)

RELATIONSHIP WITH THE EXISTING BUILDING: STRUCTURE

Depending on the form and structure of the extension as well as the structure of the existing building, different types of structures might be needed. It is possible that the extension is completely supported by the existing building. In some cases, for the extension to be supported, the existing building needs additional reinforcement. It is also possible that the extension is completely independent with separate structures that connect to the ground. (Figure 12)

As for the modular building method, although it might be possible for the modules to be placed directly on top of the roof of the existing building, in most cases a foundation over the rooftop of the existing building will be needed, however calculations regarding the structural capacity of the existing building against the weight of the extension should be conducted to determine if it needs extra reinforcements.



The extension is completely supported and the existing building is not altered. The addition is built without structural reinforcement, on the last cooperating floor.

The extension is placed on the last cooperating floor while vertical reinforcements, support the existing building's foundation.

The extension is placed on an independent floor, and is supported by independent vertical reinforcement.

Fig. 12: Examples of types of structure of an extension adapted from Bellini & Mocchi (2019)

RELATIONSHIP WITH THE EXISTING BUILDING: BALANCE

A relevant and balanced relationship must be formed between the addition and the existing building in which the existing building's characteristics and qualities affect and are affected by the addition.

According to Melet & Vreedenburgh (2005), two of the criteria mentioned by Rotterdam local authority, for an initiative aimed at promoting building new houses are as follows:

1. The existing building must benefit from the addition due to its improved image, or an elevator being installed or other improvements made to it.

2. The addition must harmonize with the existing structure, although this does not mean more of the same. As long as respect is shown for the existing structure and the surroundings, the architecture can be different and challenging.

This question on aesthetics and architectural balance with the existing building and its surroundings, could be addressed in forms and materials of the extension.

DIFFERENT OR THE SAME

Melet & Vreedenburgh (2005) introduce topping up as adding more of the same without any differentiation with the existing and with the goal of increasing volume. They urge to make a distinction between topping up and rooftop architecture. Here it is argued that improvements to the programme in the neighborhood are not part of topping up and this method is targeted to the same users as the ones that already inhibit the existing building.

Sim (2019) discusses layering and stacking in the context of general urban buildings. Layering means placing different functions and types of accommodation on top of each other, whereas stacking is putting similar types of accommodation on top of each other. In this view, what makes an urban building ideal is that it consists of different layers in correspondence to the differing qualities of space as lighting and access conditions vary when moving up.

In addition, it is noted that the ground floor and the top floor both have distinct characteristics that can be used as a means of attracting a variety of target users. Furthermore, it is suggested that layering works best in enclosed, medium-height buildings since they have proportionally more ground floor and top floor than taller buildings. (Sim, 2019)

In the diagram below, similarities and differences between different approaches mentioned for densifying and building vertically in the city are depicted. (Figure 13)

From the previous paragraphs it can be concluded that the first step to adding an extension is to be aware of the current conditions regarding the users and target audience in the existing building. The housing extension placed on top of the building should aim to invite a more diverse user group to the neighborhood, and this can be done by introducing different architectural qualities than the ones already in place.

Secondly, layering can be interpreted in two different ways. One is adding a different layer from the existing, for instance adding housing to a building which has a different function. The other one is to implement layering in the extension itself, for instance using a different type of accommodation on the top floor of the extension in comparison to the other floors.

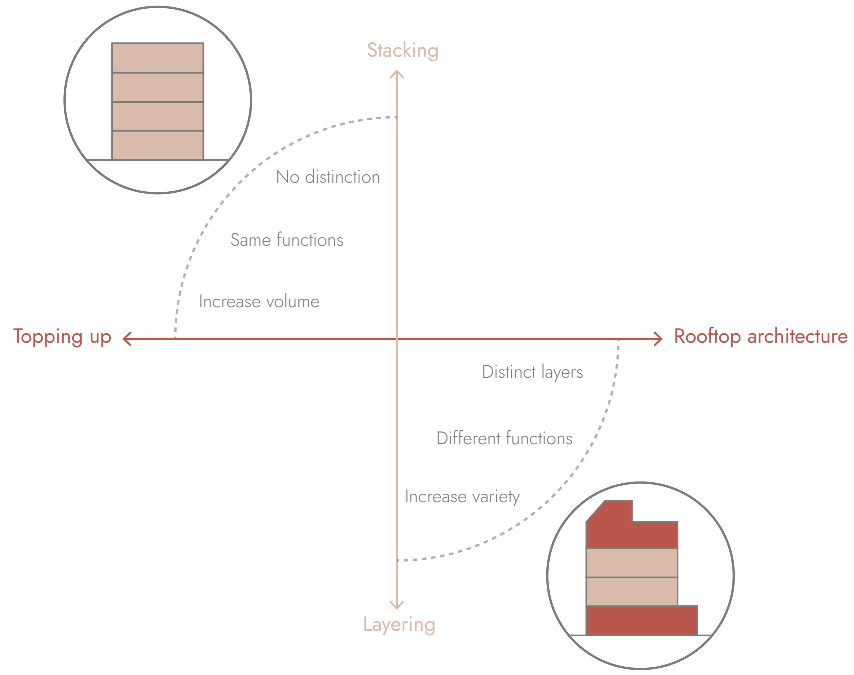


Fig. 13: Different or the same adapted form Sim (2019) & Melet & Vreedenburgh (2005)

HOUSING ASPECTS | QUANTITATIVE VALUES

The idea of including all the essential functions of a home in one volume with fixed sizes leads to the notion of compact living. Although the aim of this thesis is to include different types of apartments in the building blocks, the smallest apartments that is comprised of one volume will be affected by this concept.

In a study on the domestic space needed by solo dwellers (One person household) in the Helsinki metropolitan area Tervo & Hirvonen (2019) determines that the minimum living space for a solo dweller should be 30 square meters, but concludes that this finding is not valid for micro apartments.

According to Heckmann & Schneider (2017) in micro apartments through recognizing the varying spatial scenarios throughout the day, and multi functional furniture like adjustable tables, folding beds, and compressible wardrobes, the facility attempts to minimize the amount of space needed for each individual.

Furthermore, it is stated that these homes are based on the hotel industry's serviced apartment concept and are suitable for one person. As the residents might not be able to furnish the apartments themselves, the living situation is considered impersonal; and asocial, since there is limited space for inviting guests over. (Heckmann & Schneider, 2017, p 38)

In a Swedish context the project called Optibo is a 25 sq.m compact home demonstration unit that aims to include all the functions normally found in a three-room (75 - 80 sq.m) apartment. This concept is aimed at a couple without children as users. The furniture in the Optibo apartment can be moved up and down into the 60 cm space under the floor. However, the participants in this project concur that in order for these apartments to become commercial in the future, further work in the development of the techniques implemented needs to be carried out. (Boverket, 2013)

QUALITATIVE VALUES

Nylander (1998) introduces seven non measurable architectural qualities in the house. These properties are closely related and affect each other as well. They influence the residents perception of their house and are the key aspects that turn a house to home for them.

MATERIAL & DETAIL

Residents perception of the authenticity of the material in the building affects their relationship with their home. The authenticity in the material means that its origin, use and finish is readable in the traces. (Nylander, 1998)

In the design of the modules the material that will be used is CLT panels. Using water sprinkling system in the building allows for the surfaces to be left as they are covered with a layer of oil.

AXIALITY

Axiality and sight lines in the home help to relate the spaces and make way finding easier. (Nylander, 1998)

In the design of the modules, straight sight lines in the apartment can make the space appear larger especially in the smaller apartments.

ENCLOSURE

An enclosed space holds the attention in one space while openness invites connection from the surrounding spaces. Open or enclosed spaces can determine the degree of privacy in a space. (Nylander, 1998)

MOVEMENT & CIRCULARITY

Elements such as the staircase are clearly linked with movement, however, contrast in lighting or attractive forms can also induce movement in a space. Movement is closely related to axiality. Furthermore, the possibility to move in a circular pattern in a home adds to the flexibility of use in the rooms and spaces. (Nylander, 1998)

Having the ability to move between rooms makes the house feel more spacious as well as catering to the flexibility of use in the rooms.

QUALITATIVE VALUES

SPATIAL FORM

This is referred to as the form of the space and in general the volume of the space. Some properties in a space can affect how it is experienced, including: the size of the room, symmetry in the openings and light. (Nylander, 1998)

As shown in the figure below the type of opening between the volumes can change the perception of the connection between them and create a different atmosphere.

LIGHT

When discussing light, it is important to remember that natural light is the focus. As mentioned earlier, light is crucial in the home. It creates a sense of direction and reinforces the public or private character of the spaces in the home. (Nylander, 1998)

SPATIAL ORGANIZATION

Schematic layout and circulation patterns are included in this section but the focus is on the interface between the indoor and outdoor. It is stated that a sense of security in the private space for residents is crucial for claiming the public area that surrounds it. (Nylander, 1998)

A major part of the focus in the housing extensions will be on this aspect of housing and it is expanded upon in the following section.

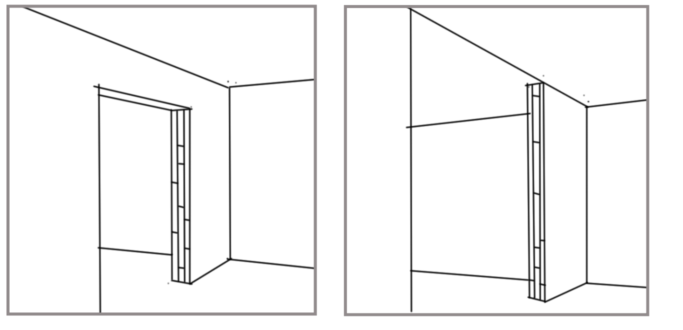


Fig. 14: Types of openings between volumes adapted from Lindbäcks (2020)

OUTDOOR & INDOOR

OPENINGS

When building on rooftops a connection between outdoor and indoor of the house is crucial and plays an important role in adding value to the extensions. It is likely that an extension built on a rooftop will be positioned higher than the neighboring buildings and will have a view of the city. To take advantage of this quality, the building must be equipped with openings and balconies. The residents of the extensions might not have access to their own gardens, therefore including balconies is important in creating enclosed outdoor spaces that help them connect to the outside.

Sim (2019) mentions that even a small detail can make an irreplaceable difference when it comes to connecting people to the outside world.

INTERFACE & IDENTITY

According to Sim (2019) the hierarchy of spaces starts in the home from open spaces such as the kitchen and living room to private rooms. The next layer is the group of the apartments placed next to each other. In particular, edge zones outside homes are important for the residents to express their identity.

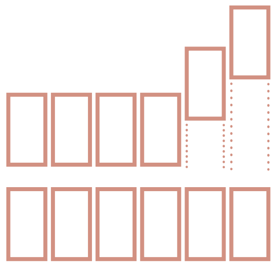
These identifiable spaces can vary from a recessed step in the doorway or a private balcony in front of the house, but they allow the residents to express themselves by the way they want to use these spaces. This could be done by placing a potted plant or deciding to use the space for social functions. (Sim, 2019)

CASE STUDIES

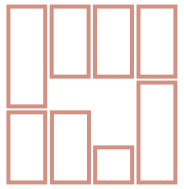
The case studies are examples of projects that have been analyzed regarding different characteristics that are in focus in the thesis. All built projects are located in Sweden. (Refer to appendix for an extensive analysis of the individual cases.) These characteristics are:

- Modular building method
- Rooftop extension
- Housing qualities

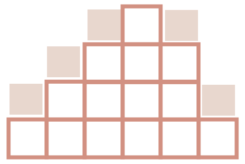
From the projects that follow the modular building method, based on the vision of creating affordable and economic housing (Case no.1, Boklok & Case no.2, Snabba hus västberga) or creating temporary housing (Case no.3, Gibraltar guest house) it can be concluded that the building blocks are compact, and seek to maximize the living space. In these cases usually the variety of modules is limited to simplify the process of construction.



Case no.4, O2 Orminge, introduces a wider variety of apartments using several modules and showcases the possibilities in creating different types of modules. In this example the units form a building block.



In contrast, Case no.5, 79 & Park uses only one module and creates unique apartment types. It is notable that the choice of the modules in these two reference projects might be influenced by the concept and the overall form of the buildings.



In this project the offset repetition of modules has created the opportunity for including private balconies. This shows that experimenting with the placement of modules next to each other can create more possibilities in providing private and enclosed spaces for the residents.

The competition project (Case no.8), which is also a rooftop extension, is one example of the many possibilities of creating voids and other communal functions using a fixed set of modules. It is worth mentioning that these proposals might not be on par with reality of costs and regulations.

Case no.6, Skäpplandsgatan taklägenheter is a built and realized rooftop housing extension that showcases one story apartments on top of existing residential buildings. From this case study the importance of including windows and balconies on the rooftop extensions and in particular emphasizing on sight lines between openings can be realized.

Case no.7, Brf Viva has been included as an example of apartments that are accessed through entrance balconies but has managed to create more functional and social possibilities at the entrances.

INTERVIEW

The Interviewee is a producer of cross laminated timber elements at the Swedish company Södra. During this interview the qualities of CLT as a building material and its advantages were discussed.

The CLT elements produced by Södra are 3, 5 or 7 layers, with a thickness between 60mm up to 300mm, and they can be 3 meters to 12 meters long.

During the discussion it was mentioned that the material of CLT has the lowest CO_2 impact. The material produced by Södra has 34 kilo CO2 equivalent per cubic meters, which means that compared to concrete the CO_2 can be reduced by 80 percent, therefore, CLT is an excellent material to use in modern housing.

Another benefit of producing CLT panels is that it can be a very well defined product, and it is possible to produce the panels with millimeter precision.

Compared to the traditional timber frame, CLT is more rigid and durable, and the building is more stable in the construction phase. As for the total output of usable area compared to building area, especially in 3 to 8 stories, CLT is most effective. Timber frame uses less wooden material than a CLT structure, however, there are a variety of other materials present as well in the construction, and the walls would be thick when building higher with timber frames, as a result, some of the living space would be lost.

A hybrid of timber frame and CLT can also be a solution, where CLT would be used in the load-bearing parts and the timber frame in the non-load-bearing areas.

Following the topic of modularity, the interviewee stated that building with modules is a great alternative for low cost production.

It is also mentioned that in the volumetric building method, the costs of construction and assembly are most affected by the transportation conditions. Designing the modules in a way that they can be transported to site as quickly as possible and reducing the transportation time can be deemed as the most economic solution.

Regarding the expression of the building, the usage of CLT panels as the traditional flat elements would provide greater freedom in construction, while modular building limits this freedom.

CONCLUSION

Through connecting current matters and extracting their connection to the built industry, a theme for the solutions proposed and the goal of this master thesis has been illustrated.

In this section, based on the four topics explained in the theory, conclusions are drawn as to what has been established through the theory for the development of the project.

CIRCULAR DESIGN & MODULAR BUILDING

The principles of circular economy translated into the building industry require choosing the materials and the building method with care.

Designing for disassembly enables the possibility of reusing and repurposing products. The modular building method can allow for this when the elements of the volumes are assembled with reversible techniques. Furthermore, the volumes can also be assembled. As for the material, the volumes will use CLT panels. CLT is a byproduct of timber which can be manufactured using efficient methods. Additionally, it can be reused and repurposed.

ROOFTOP ARCHITECTURE & MODULAR BUILDING

Prefabricated CLT modules have qualities that make them suitable both for a sustainable approach in building as well as rooftop architecture.

Rooftop architecture is a current topic in the development of cities, however, it brings challenges with it. The method and materials chosen for the development of this project, are compatible with this building method.

CLT is a rather lightweight material (compared to its weight) and is a suiting option for densification and vertical expansion projects. This is also beneficial when transporting and lifting the structures. (Gustaffson, 2019)

Furthermore, the prefabricated modules allow for ease of assembly and reduced duration of construction time on site. This makes industrial building methods a logical choice for rooftop construction.

The concept of modules that are designed cautiously and can be put together in different ways has proven to be cost effective in most cases. This manner of industrialization, as mentioned, reduces the construction time, has a higher quality product and provides a more realistic estimate of time line and budget.

Considering the expression of the extension on the roof of an existing building, the connection between the existing and extension and how it is viewed from the pedestrian point of view, the aim in this project is for the modules to depend on the roof of the existing building as the foundation, therefore no supporting structure would be touching the ground from the sides of the rooftop. However, additional staircase and elevators might be added to the existing buildings. The height of the extension depends on the structural capacity of the existing building and it will be most effective on how it will be perceived.

The addition and the extension need to form a dialogue with each other where perhaps the qualities of the extension is complemented. This balance could be sought in architectural aesthetics of the extension and the existing.

Regarding the characteristics of the existing buildings in the city that can be beneficial to build on, it can be said that certain types of buildings serve well for this purpose. These are parking garages, industrial buildings, and shopping malls.

Calculations that determine the structural capacity of the existing building should be made for each particular case.

According to previous discussions on layering and stacking in an urban context, for the development of a sustainable city, it is most advantageous to have buildings layered with differing characteristics. Therefore, in this proposal buildings that have functions other than residential will be chosen for the implementation of the project.

CONCLUSION

As mentioned in the delimitations, in this thesis, argumentations regarding if extensions should be added on top of buildings that have a historical or symbolic background have not been elaborated on, yet, the challenges are acknowledged. With that being said, any building that has good structural capacity along with other reasonable criteria could be an option considered for rooftop extensions.

Furthermore, it is important to consider the effect that the extension may have on the neighborhood. For this reason, the modules should cater to different types of households to bring in different types of movements and users into the area.

In regards to the composition of volumes on rooftops when they form a building block, the dimensions of the existing building determine the way the modules can be placed. Another deciding factor is the location of the existing vertical connection points or the new connection points if a staircase and elevator need to be added.

HOUSING ASPECTS & MODULAR BUILDING

In terms of dimensions, due to the limitations in transportation and for an economic way of producing the elements in the factory, it is more efficient to introduce modules with different lengths but fixed widths. Taking this into consideration, as seen in the case studies, there is a lot of flexibility when assembling modules, and they can be put together to make a variety of types of apartments.

As argued by Melet & Vreedenburgh (2005) when adding a house or office extension, while the disadvantages of the rooftop extension such as the price, lack of a garden and a direct opening to the street could be compensated with the location or the view, the architectural qualities are imperative. As a result, on the smallest scale, the objective for the design of the CLT volumes and the apartments created by them will be for them to provide sufficient living space and suitable and satisfactory living conditions.

In the design of one module as one apartment, which will be suitable for one person, it is critical to design the volume in a way that does not feel crowded but includes all the necessary functions.

Following the qualitative design aspects mentioned earlier, the relation between the outdoor and indoor is crucial in adding value to the extensions. Creating enclosed outdoor spaces, will provide an interface and connection between indoor and outdoor as well as bringing identity and opportunity for more social functions in the house. The opportunity of having more social spaces in the house is important for all apartments but especially important to the smaller apartments for one person.

In the larger scale of composition of the modules and how the apartments would be put together and form building blocks, from studying the reference projects, it is evident that when the modules are designed more clear an with fixed characteristics, putting them together is more straightforward an convenient. Consequently, this leads to a more manageable produce line in the factory.

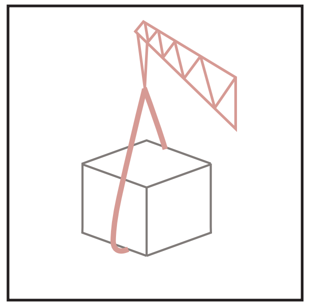
The effort in this project will be towards creating balance between the degree of complexity in the modular language of the apartments and the living qualities in such a unique setting, on cloud nine.

03. LANGUAGE DEVELOPMENT

OVERVIEW

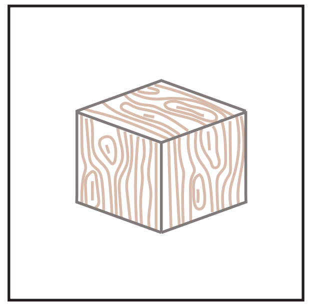
In this chapter based on previous knowledge and new-found information on the topics, the modules are defined and the apartments are designed. Based on the categorization of the apartments, the footprint of building blocks are provided and possible compositions on rooftops are illustrated.

DESIGN STRATEGIES



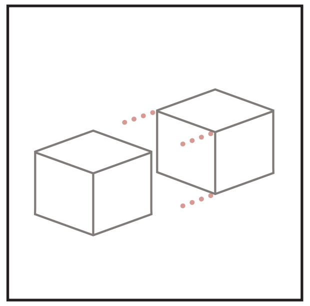
TRANSPORTABLE MODULES

The modules should have dimensions that allow them to be transported to the site from the factory as one whole unit.



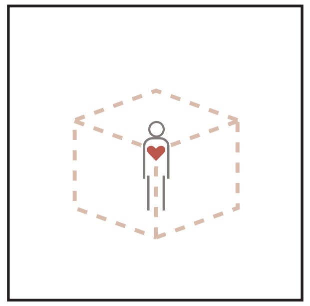
PRIORITIZING USE OF WOOD

In this design the aim is to use wood and its by products such as CLT in as many areas as possible in the module, for instance in the structure and cladding.



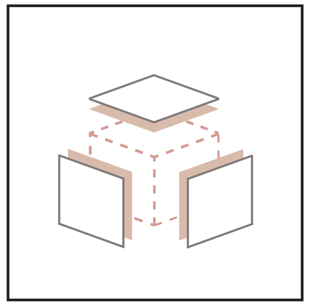
SYSTEMS THINKING

As part of accelerating the production of apartments, a limited set of modules should be used and repeated for expansion into iterations.



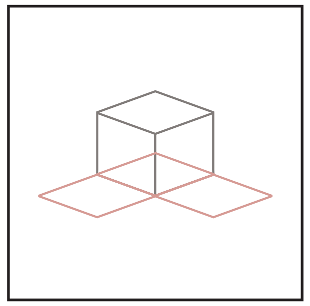
A HOME FOR RESIDENTS

In the design of the apartments, qualitative design aspects such as axiality and light, and creating sufficient outdoor spaces are factors that can make the residents feel more secure in their homes.



DESIGN FOR DISASSEMBLY

Designing for disassembly leads to a more efficient use for the life cycle of the building materials and components, since they can be reused or repurposed in the future.



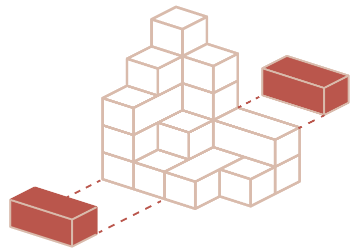
STANDARD SPACES

It is crucial to include spaces with standard dimensions that can be adapted to diverse needs of different users.

DESIGN CONCEPTS

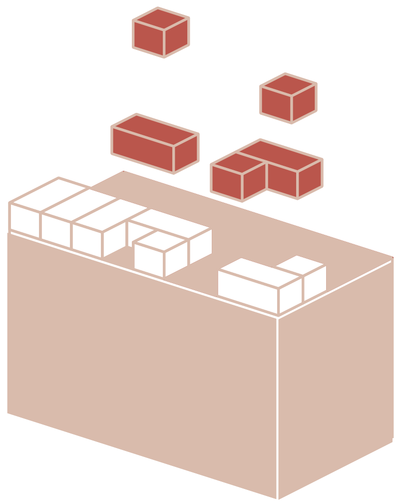
SPEAK THE SAME LANGUAGE

The design of the apartments stems from a fixed set of modules and different iterations of them. The iterations are limited and follow fixed principles such as dimension. As a result, the apartments can be produced conveniently in the factory, and the final product can be predicted precisely.



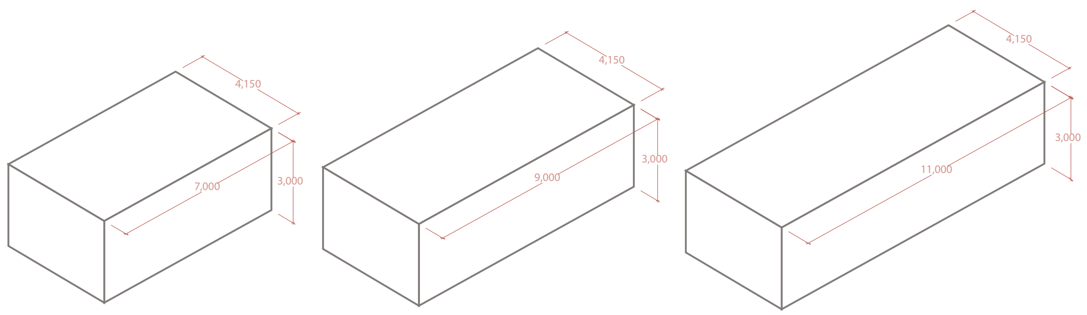
A LANGUAGE FITTING ALL?

There is no one-size-fits-all formula for every rooftop, yet, what if through proposing different types of apartments, which follow the same principles, rooftop multifamily housing can be designed functionally and quicker.



DIMENSIONS OF THE MODULES

Three modules are introduced in this project. They are comprised of CLT panels as floor, wall and roof elements. They are 4150 mm in width and 3000 mm in height, with the varying lengths of 7000, 9000 and 11000 mm. This decision is made in order to be able to choose from two primary building blocks when dimensions of the existing building are restricting.



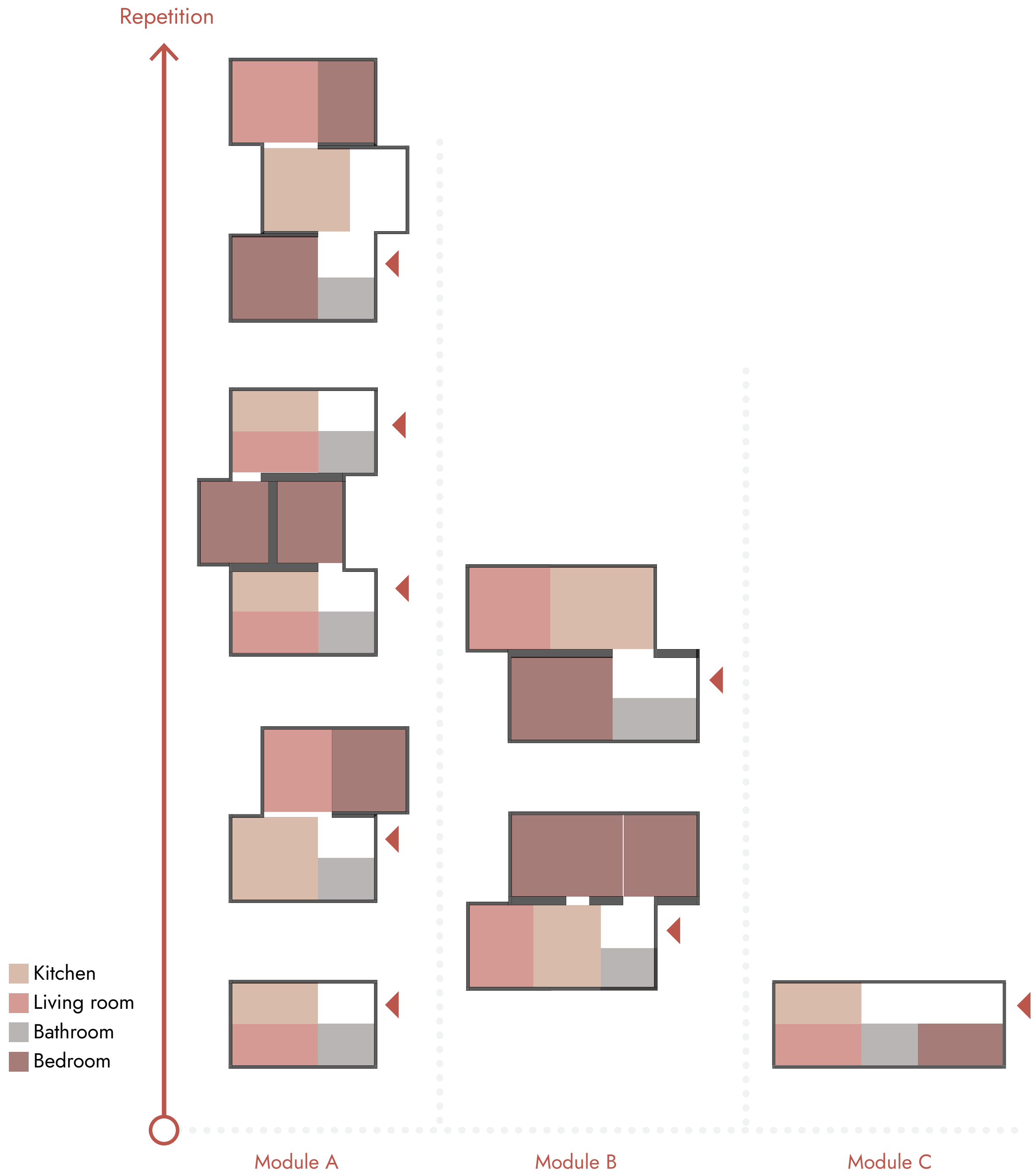
Module A Module B Module C

LAYOUT DEVELOPMENT

The organization and layout of spaces inside the modules commence from the design of the smallest module which is a studio apartment (Apartment A).

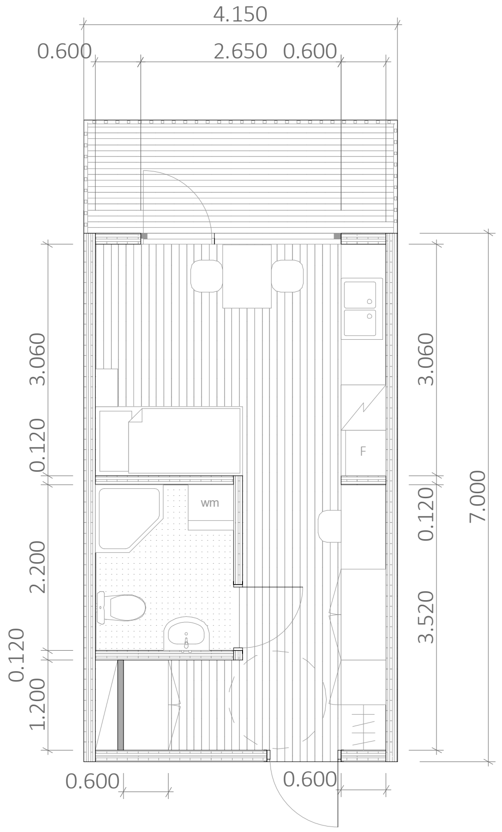
As shown in the diagram below, the fixed modules are then expanded following a similar layout in the organization of spaces.

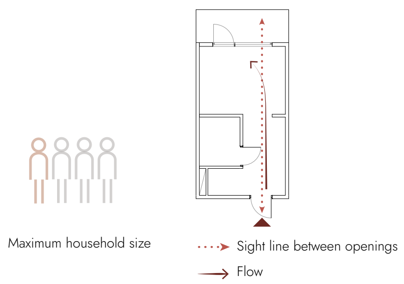
As a starting point, the bathroom, kitchen and living room are placed in the entrance module. As the modules are repeated and the apartments expand, the living room and kitchen are expanded and in some cases moved to the other modules.



BASE MODULE

With an area of 25 sq.m this base module is suitable for one person.
A straight line of view to the window and balcony from the entrance makes the room appear larger. The function wall to the side of the apartment is designed to include closets, a desk and the kitchen units. With its balcony, the apartment boasts more social spaces.





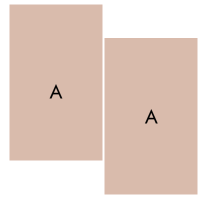
Apartment A, 25 sq.m
1:100

Perspective-section of apartment A

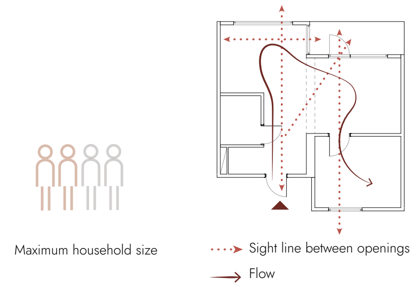
APARTMENTS

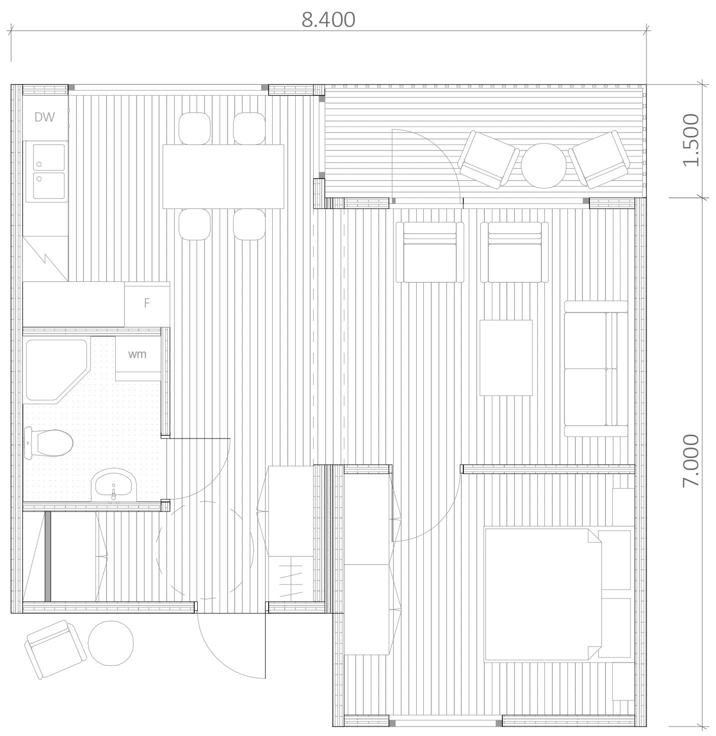
As the apartments expand by combining more modules, they follow a similar layout as in the base module (Apartment A), with more standard rooms and spaces for different households.

Apartment AA1 is composed of two "A" modules, with one being shifted 1500 mm on the long side. This shift in the composition of the modules allows for a private and enclosed balcony on one side as well as seating spaces along the entrance of the apartment on the other side.



Assembly footprint

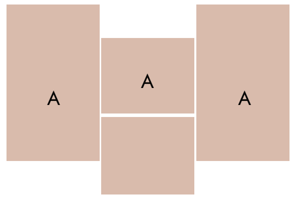




Apartment AA1, 52 sq.m
1:100

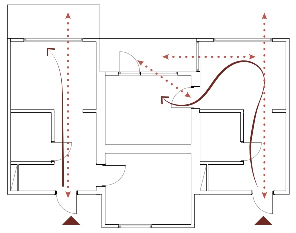
APARTMENTS

Apartment AA2 and AA3 are composed of one and a half "A" modules, with the middle module shared by both which holds the bedrooms. The apartments both have sitting spaces at their entrance and private balconies.

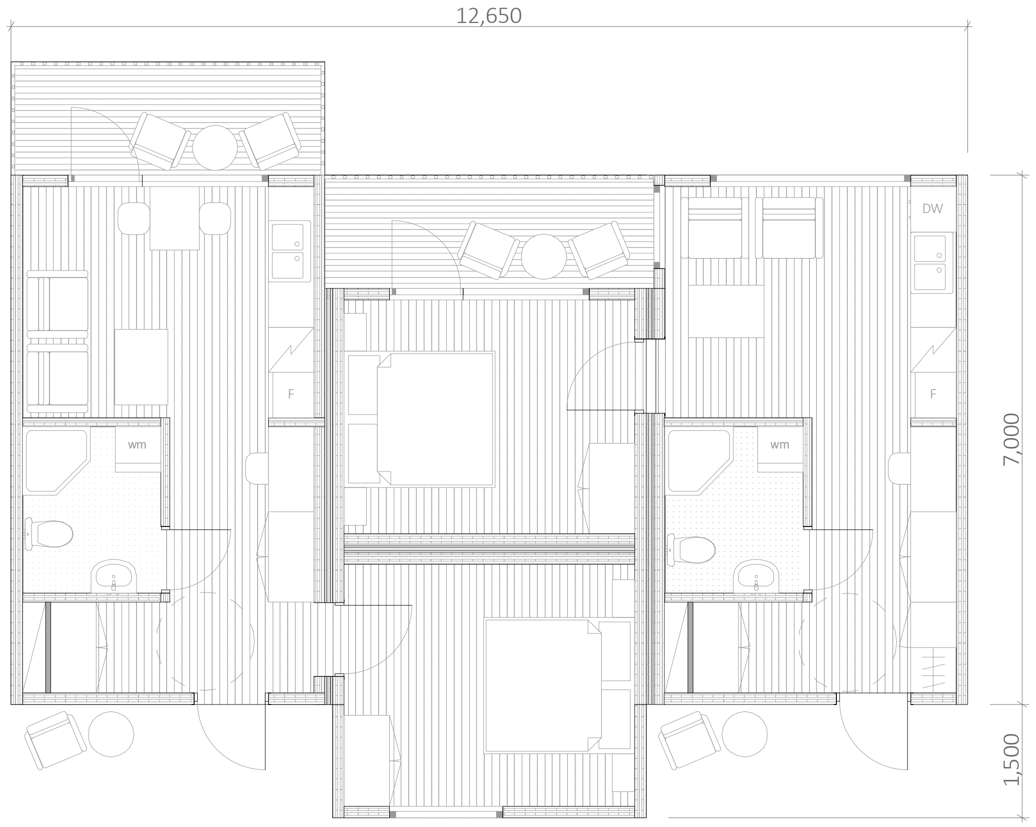


Assembly footprint

Maximum household size



Sight line between openings
Flow

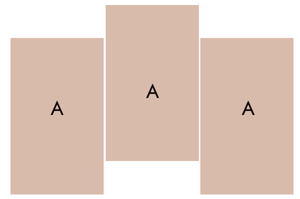


Apartment AA2, 38 sq.m
1:100

Apartment AA3, 38 sq.m
1:100

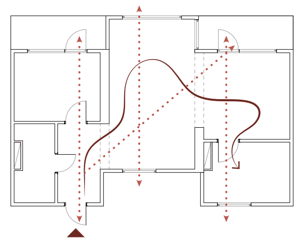
APARTMENTS

Apartment AAA is composed of three "A" modules, with two bedrooms and open kitchen and living area. There are two separate private balconies accessible from the apartment. The shifted middle module allows for sitting space along the entrance balcony.

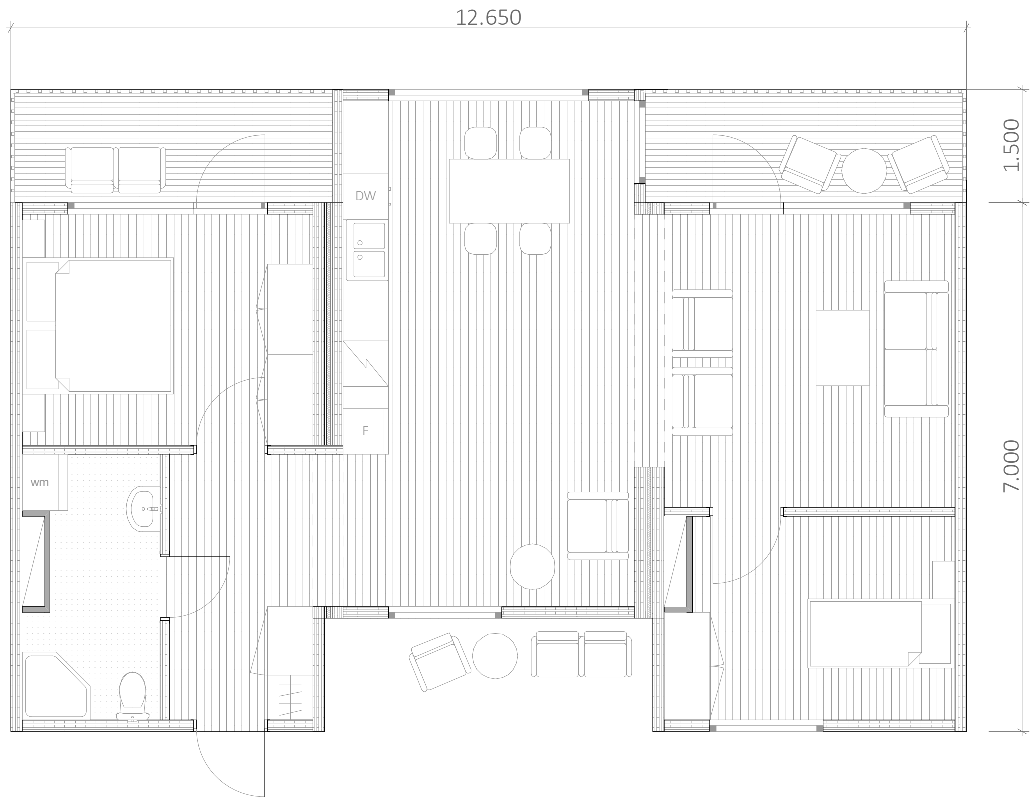


Assembly footprint

Maximum household size



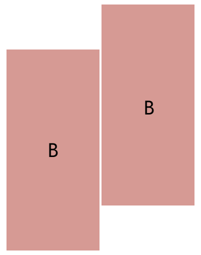
Sight line between openings
Flow



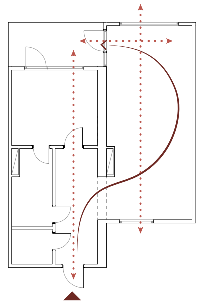
Apartment AAA, 76 sq.m
1:100

APARTMENTS

Apartment BB1 is composed of two "B" modules, with one being shifted 2000 mm. This larger apartment follows the same principles in the previous apartments in the interior layout. In addition to the balcony that can be accessed from the bedroom or living room, sitting space is included at the entrance balcony.



Assembly footprint



Maximum household size

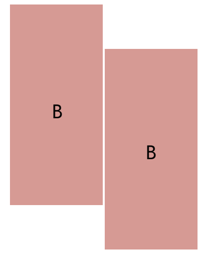
Sight line between openings

Flow

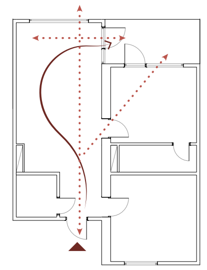
Apartment BB1, 68 sq.m
1:100

APARTMENTS

Apartment BB2 is composed of two "B" modules, with one being shifted 2000 mm. However it is mirrored on the long edge compared to apartment BB1. In this apartment two bedrooms are included.

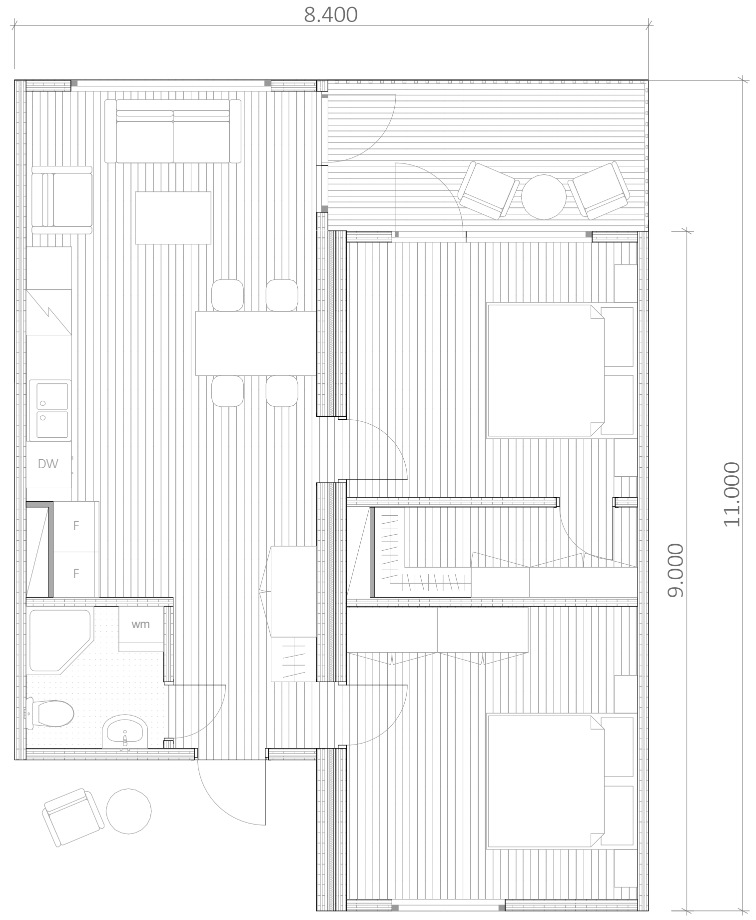


Assembly footprint



Maximum household size

Sight line between openings

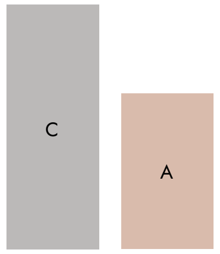


Apartment BB2, 68 sq.m
1:100

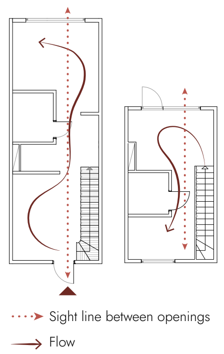
APARTMENTS

This apartment is created by putting together module "C" as the first floor and module "A" as the second floor. The first floor has a combined living room and kitchen with a corner bedroom which can be separated with a partition wall. The space under the staircase provides more storage.

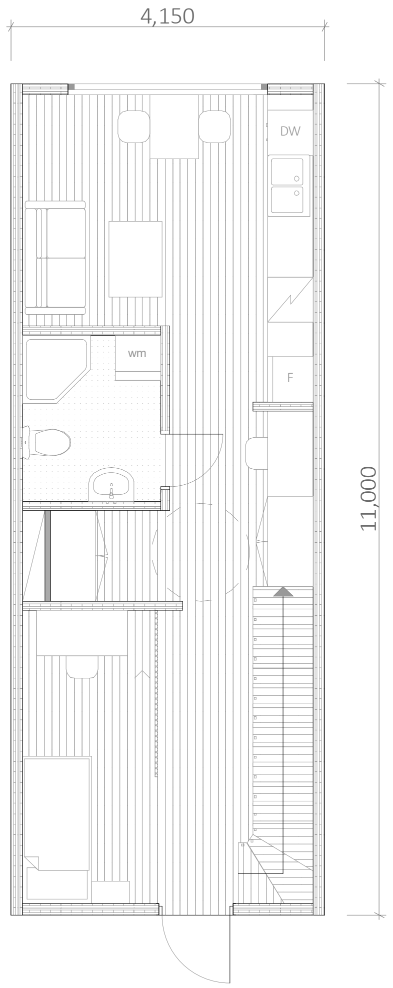
A larger balcony is accessible on the top floor, when the smaller module is put on top.



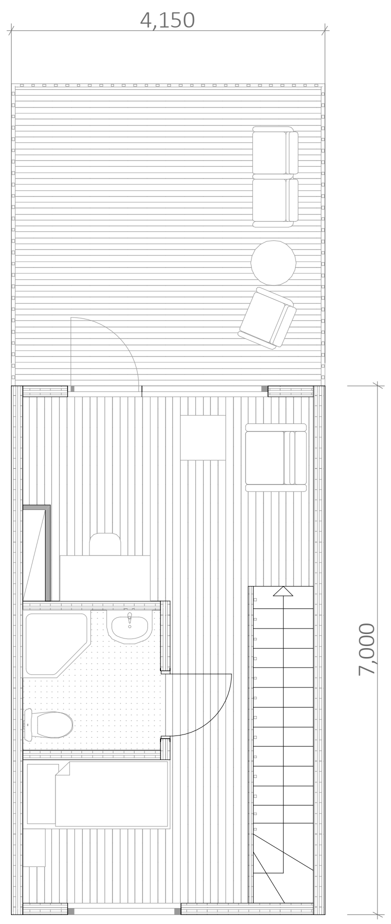
Assembly footprint



Maximum household size



First floor

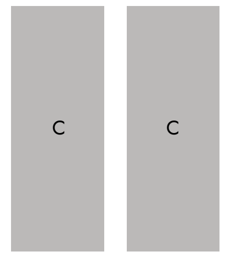


Top Floor

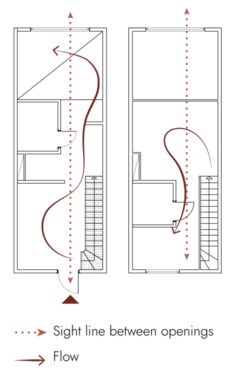
Apartment CA, 65 sq.m
1:100

APARTMENTS

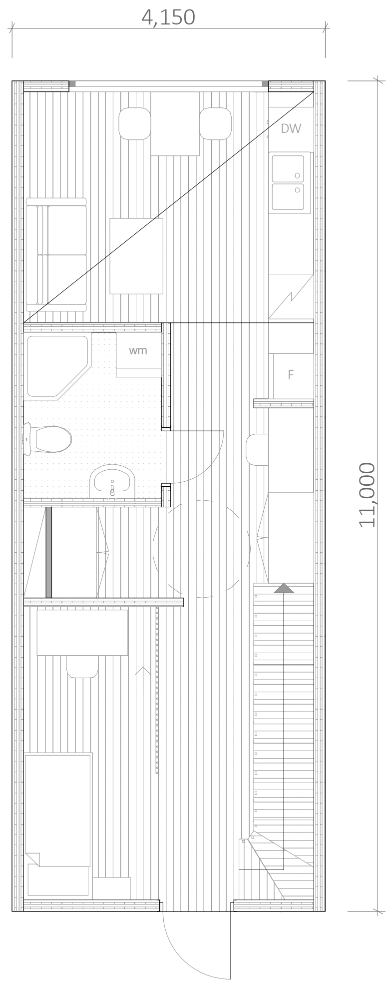
This apartment is created by putting together two of "C" modules. The first floor is similar to the previous apartment, while the staircase leads to an open loft on the top floor.



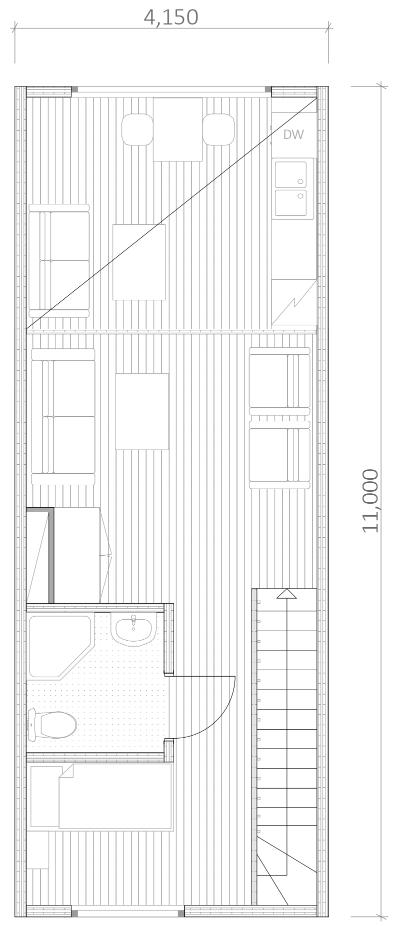
Assembly footprint



Maximum household size



First floor



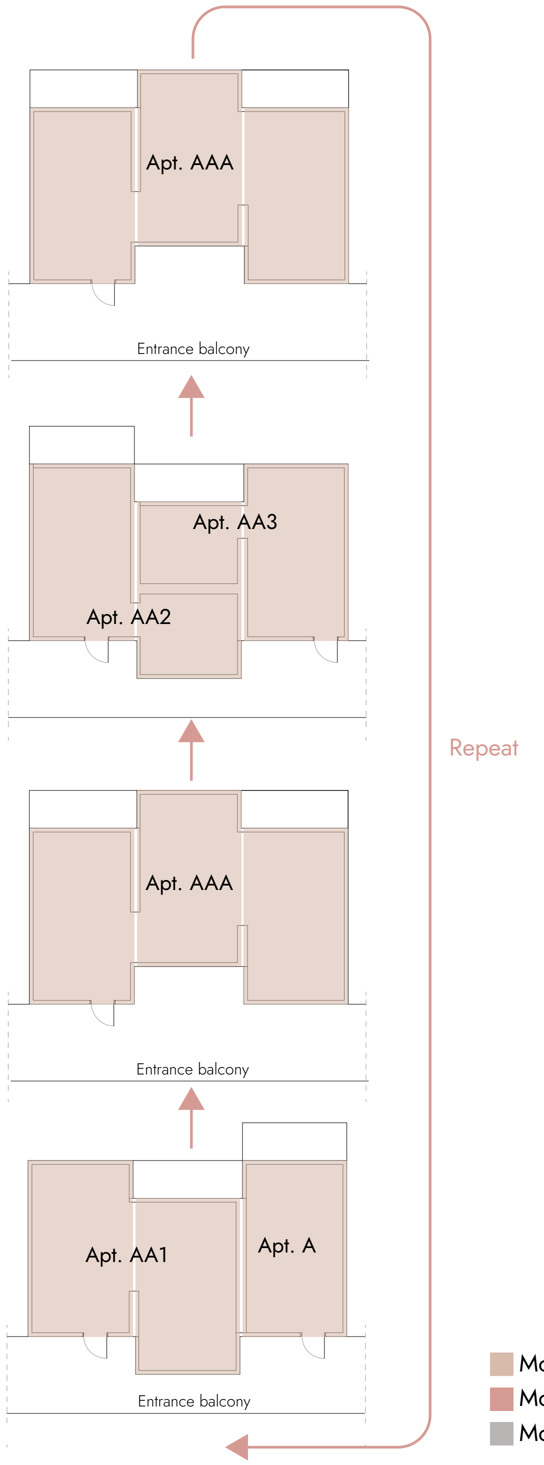
Top Floor

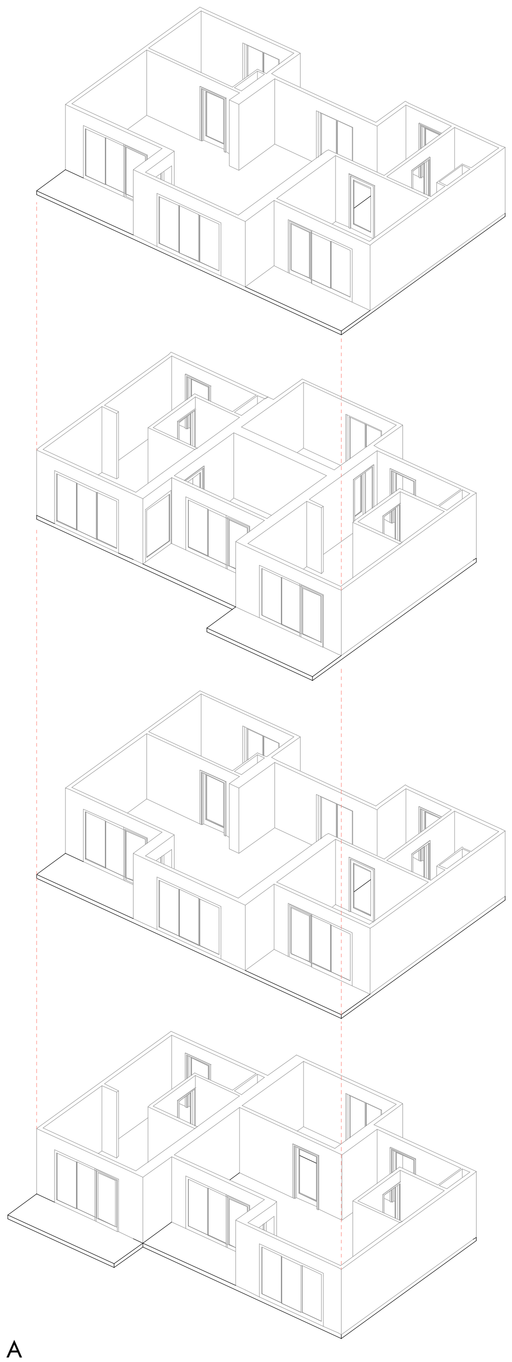
Apartment CC, 65 sq.m
1:100

BUILDING BLOCKS

As mentioned earlier different modules were introduced to be able to choose from two primary building blocks according to the conditions of site and the dimensions of the existing building.

The following diagrams illustrate the order in which the apartments are to be placed on the floor levels. Building block no.1 comprises of apartments designed with module "A" and building block no.2 comprises of mainly modules "B" and "C".

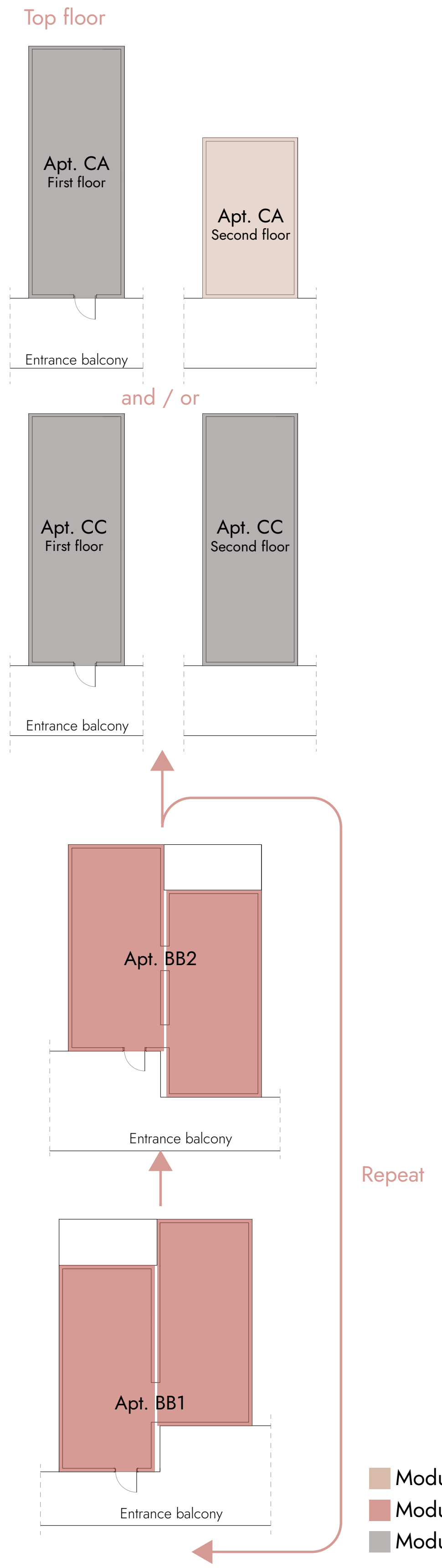


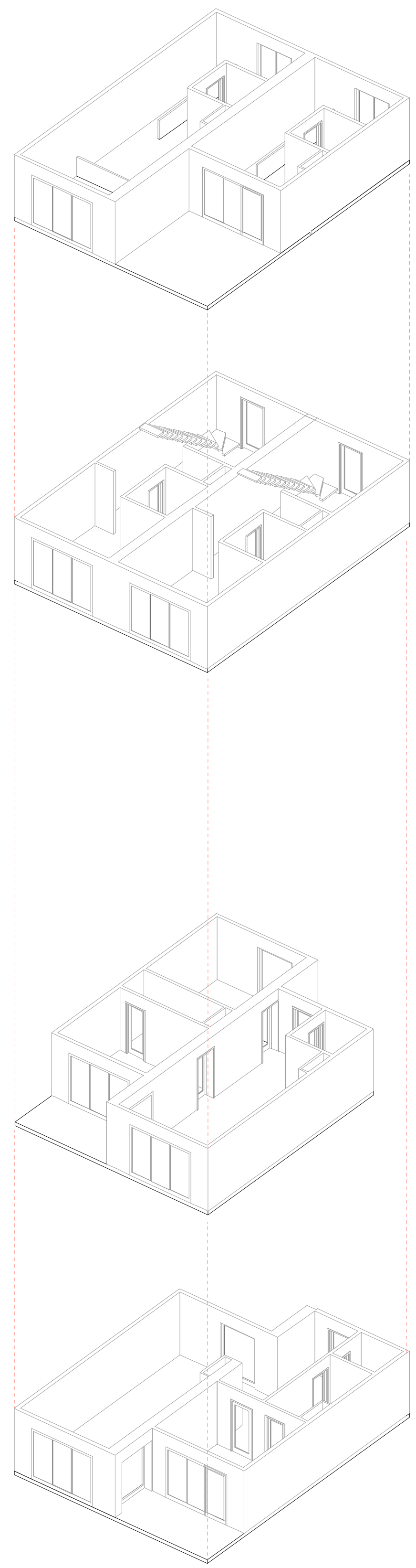


Module A
Module B
Module C

Composition of apartments in levels for building block no.1

BUILDING BLOCKS



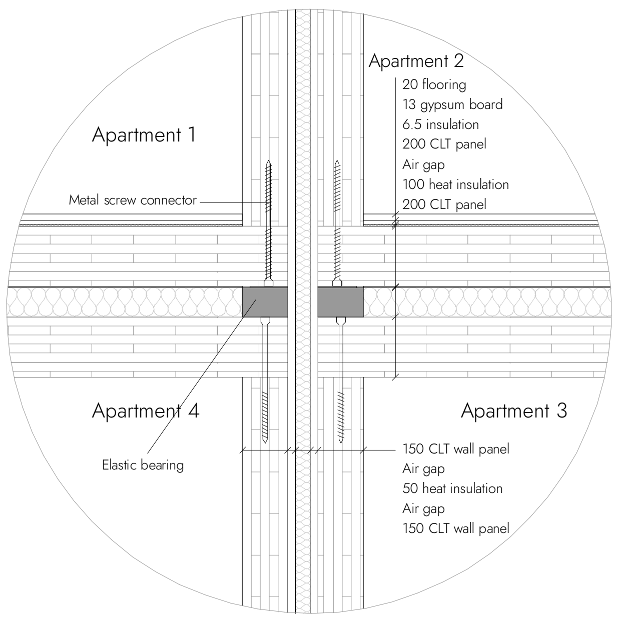


Module A
Module B
Module C

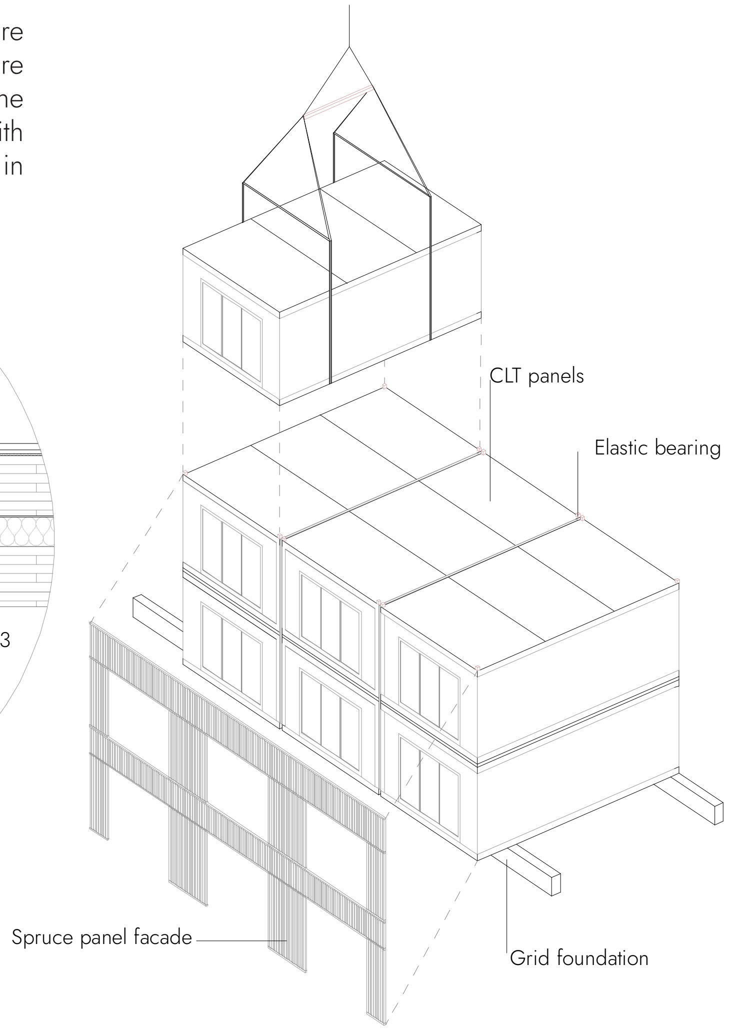
Composition of apartments in levels for building block no.2

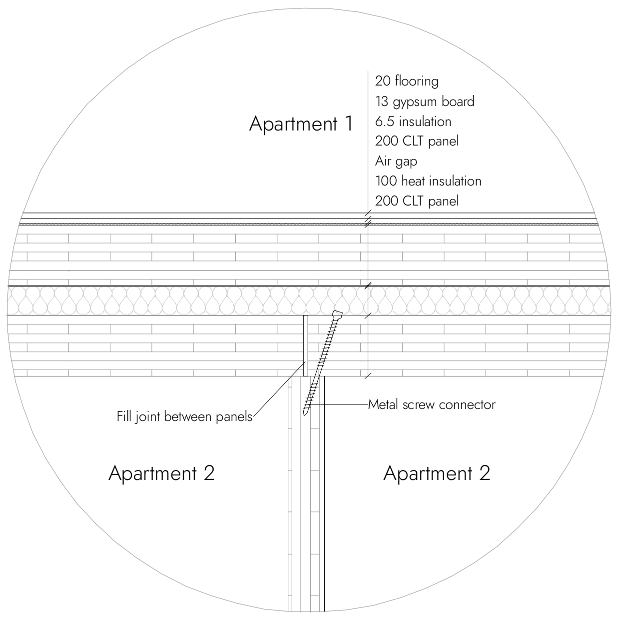
ASSEMBLY PRINCIPLES

Walls, floors, and roofs in each module are constructed from CLT panels. The panels are connected using screw connections. The modules are mounted on top of each other, with elastic bearing points and layers of insulation in between.

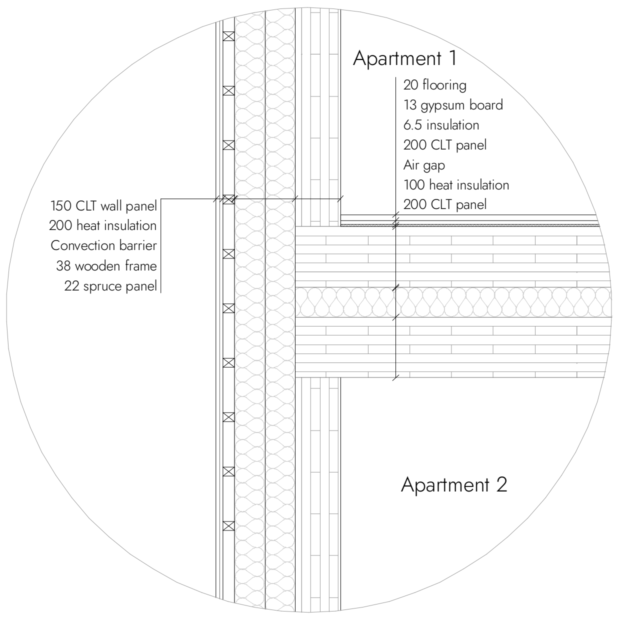


Connection between modules
1:25





Connection between ceiling and interior wall
1:25



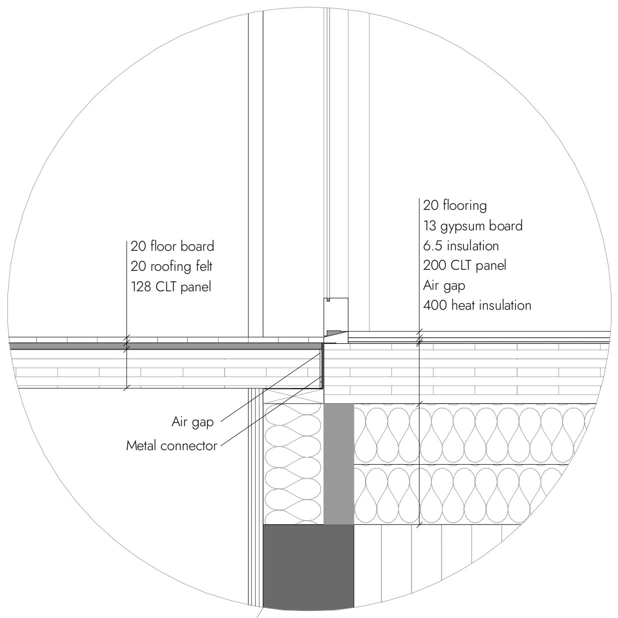
Exterior walls of the module
Scale: 1:25

SECTIONS

The apartments are placed on the grid foundation which is built on the rooftop of the existing building and then mounted on top of each other accordingly.

Although it might be possible for the modules to be placed directly on top of the roof of the existing building, in most cases a foundation will be needed to distribute the forces evenly from the extension to the load-bearing structure of the existing building. The proposed foundation system is a wooden beam frame.

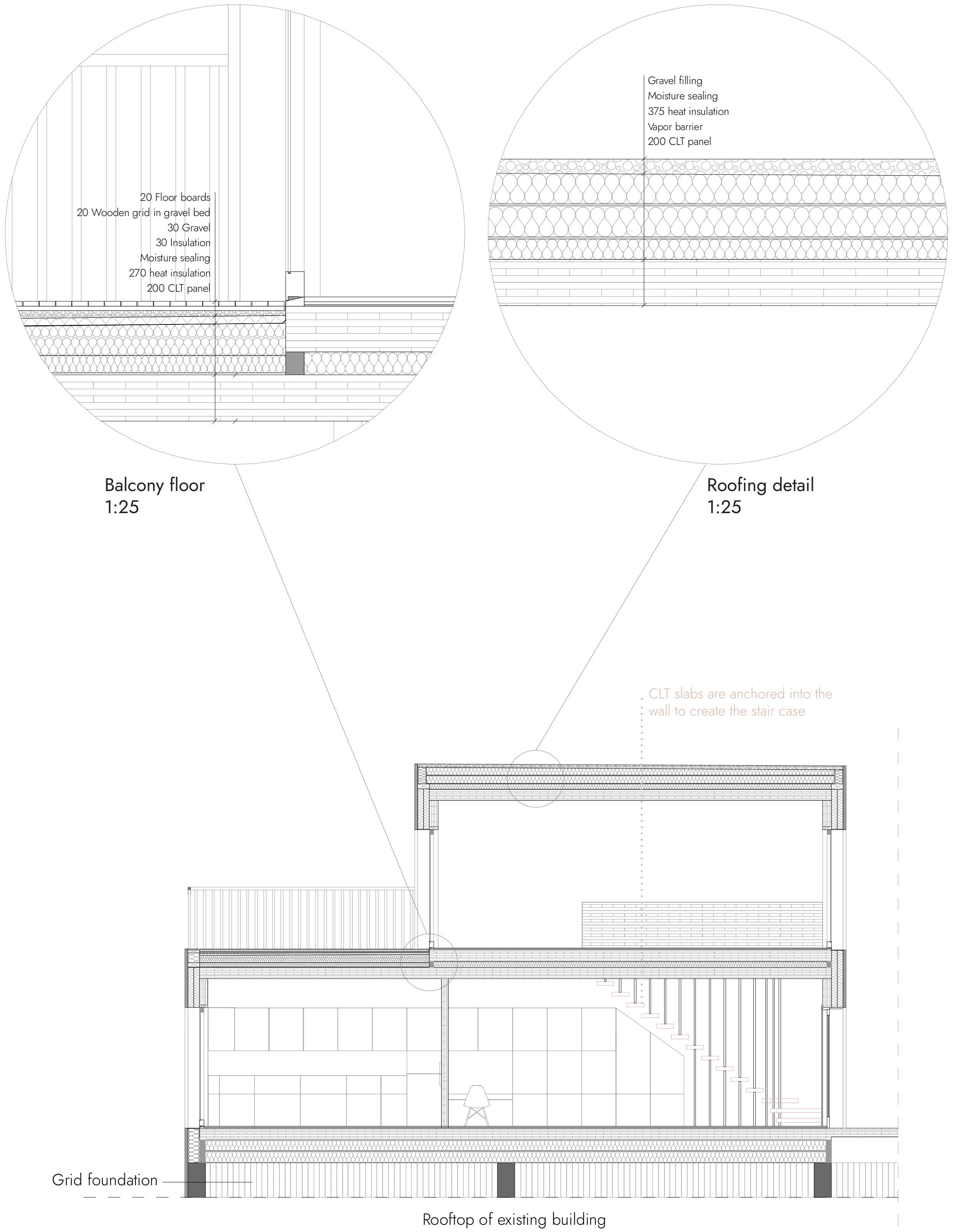
The apartments are accessed through an entrance balcony and on the other side have private balconies. The entrance balcony is supported by a glulam structure of pillars and beams.



Connection between module and extruded balcony
1:25

Section of building block no.1 (comprised of module A), 1:100

SECTIONS



Section of apartment CA, placed on an example rooftop, 1:100

Interior of apartment CA
CLT slabs are anchored into the wall to create the stair case

Interior of apartment AA1
There is an open connection between two modules in one apartment

FACADE

CLT panels are fairly robust, and they can sustain any type of cladding that is put on the exterior of the building.

The choice of type of cladding has been influenced by factors such as the overall expression of the volumes when placed on top of each other. With timber as the main material, the goal has been to create harmony with the surroundings while conveying a sense of warmth.

For these reasons, a natural wooden facade in spruce panels is selected, which is mounted on the volumes in the factory. The spruce panels on the facade will be heat treated and preserve a gray natural look as time passes.

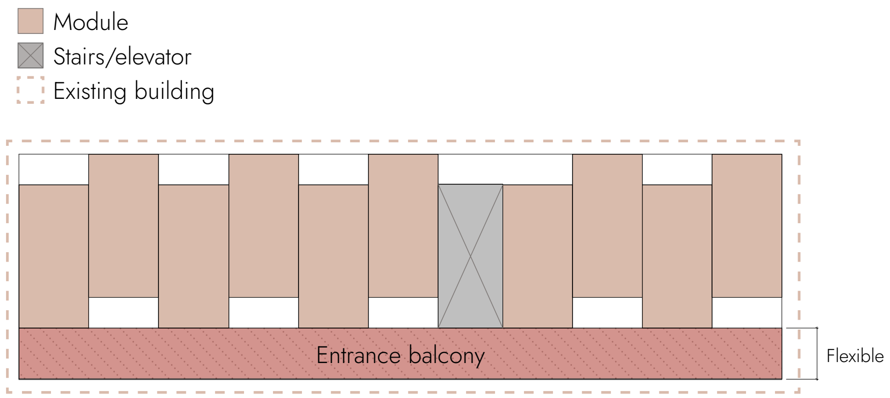
Facade composition of building block no.1 (Comprised of module A), 1:100

COMPOSITION ON ROOFTOP

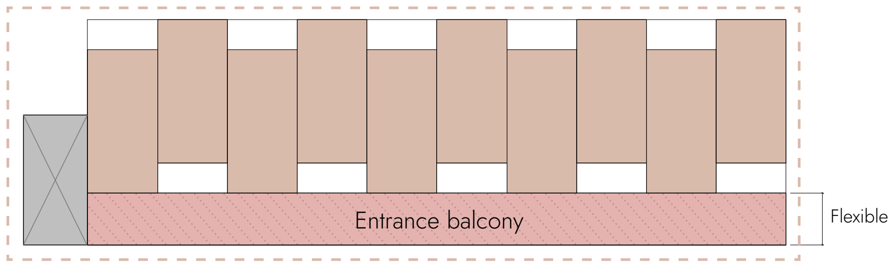
When placed on rooftops there could be two options for the placement of the staircase and elevator. Either the vertical connections are placed inside the boundaries of the existing building and extend up to the roof, or, the vertical connection are added outside the boundaries of the existing building.

Another factor to be considered is the dimensions of the existing building and more specifically its width which allows for one or two rows of apartments to be placed facing each other.

In this section diagrams of several general scenarios for the composition of the modules on the existing building based on the variables mentioned above are proposed for the apartments. When the building blocks are placed on the site, the idea will become more clear in the following chapter.

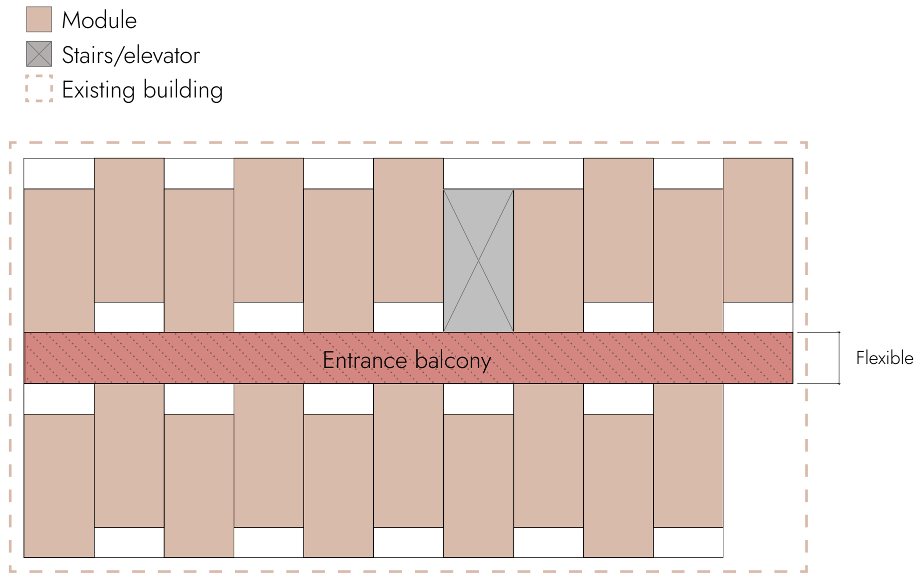


One row, vertical connections within the boundaries of existing building

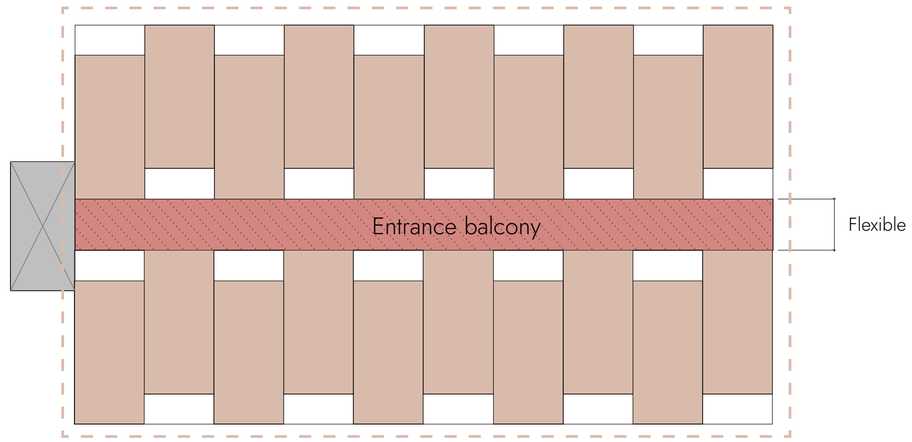


One row, vertical connections outside the boundaries of existing building

COMPOSITION ON ROOFTOP



Two rows, vertical connections within the boundaries of existing building



Two rows, vertical connections outside the boundaries of existing building

03. LANGUAGE APPLICATION

OVERVIEW

In this chapter the building blocks are placed on two example sites in Gothenburg, Sweden, in order to execute and experiment with the modules and to determine how they would be carried out on site.

SCENARIO ONE

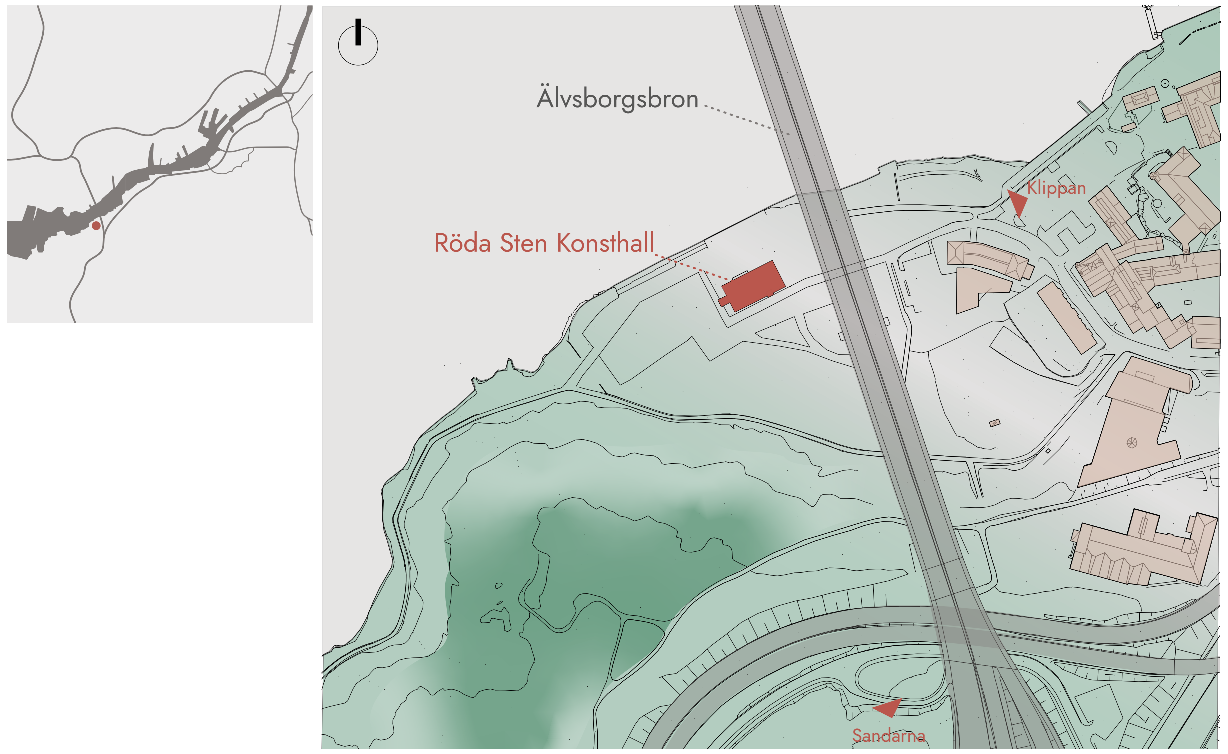
SITE

On the bank of Göta älv in Gothenburg, Röda Sten art gallery sits under the Älvsborg bridge. Formerly used as a heating plant for nearby industries, this boiler house was turned into an art gallery in the 1990s when it was threatened to be demolished. (Röda Sten Konsthall, n.d.)

Located in the vicinity of the old Klippan area and Sandarna district, there is a strong industrial background present on site. Some of the industries include Banehagen's rope warehouse, Carnegie sugar factory and Carnegie porter brewery. In 1847–60 the sugar factory and the brewery built an area for their employees with 10 residential buildings, a church and a school. This area expanded into larger residential areas with accommodating functions up to 1900s. (Svensson, 2020)

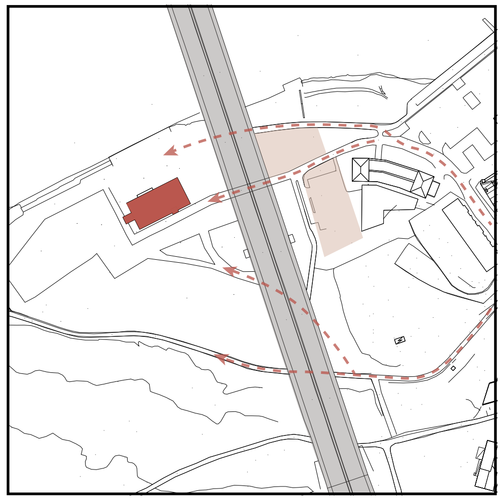
In close proximity of the area in Sandarna district as part of BoStad 2021, about 1400 new apartments with new schools, a nursing home and a mix of cultural buildings and restaurants are being planned where the Fixfabriken was previously located. Through this planned programme a mixed-use urban development will be created in the area. (Göteborgs Stad, n.d.)

By developing multifamily housing on this plot, the neighborhood will experience a broader variety of movement from different households interacting with one another.



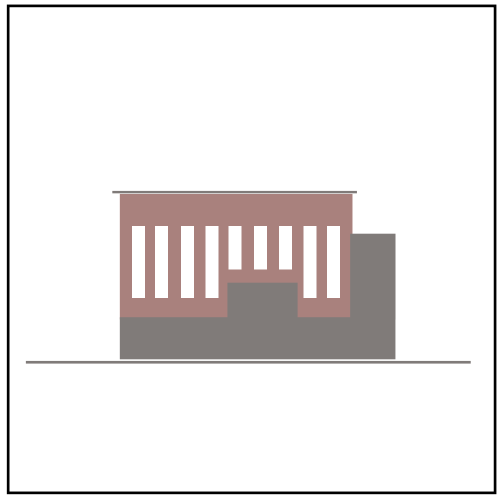
Röda Sten art gallery, approximate location in Gothenburg and zoomed in, 1:5000

SCENARIO ONE



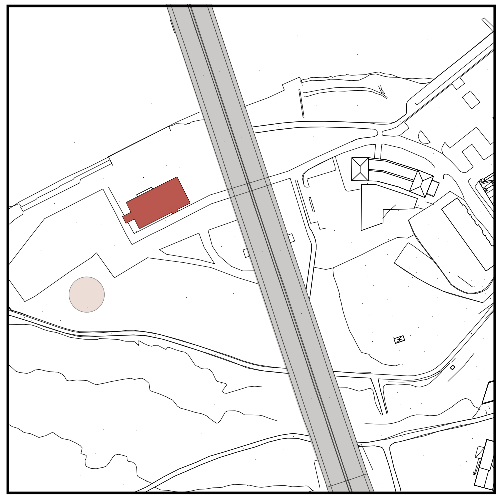
ACCESS

Tram and bus stations are located about 750 meters away to the east of the plot, allowing pedestrian access. Cars have easy access to the plot, and there is a nearby parking area.



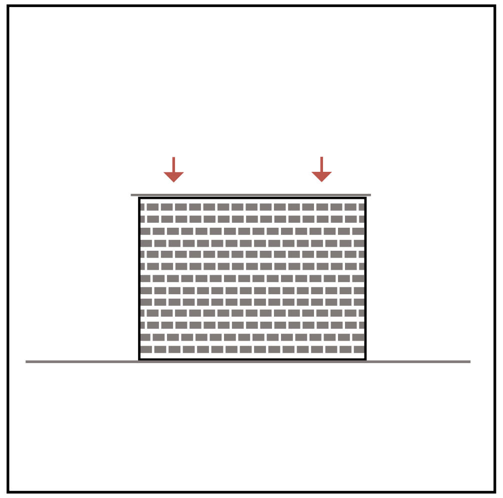
HISTORICAL LANDMARK

Standing alone in a plain area, the building is quite distinctive with its red bricks, and a rich history has been woven into its identity through the years. However there is potential in adding another layer of function over this building so as to invite more mixed users to the area.



SURROUNDING FUNCTIONS

Currently, the contemporary art gallery and its coffee shop and restaurant are frequented by many visitors. It is a popular spot for admiring the view of the water, or for taking a walk.



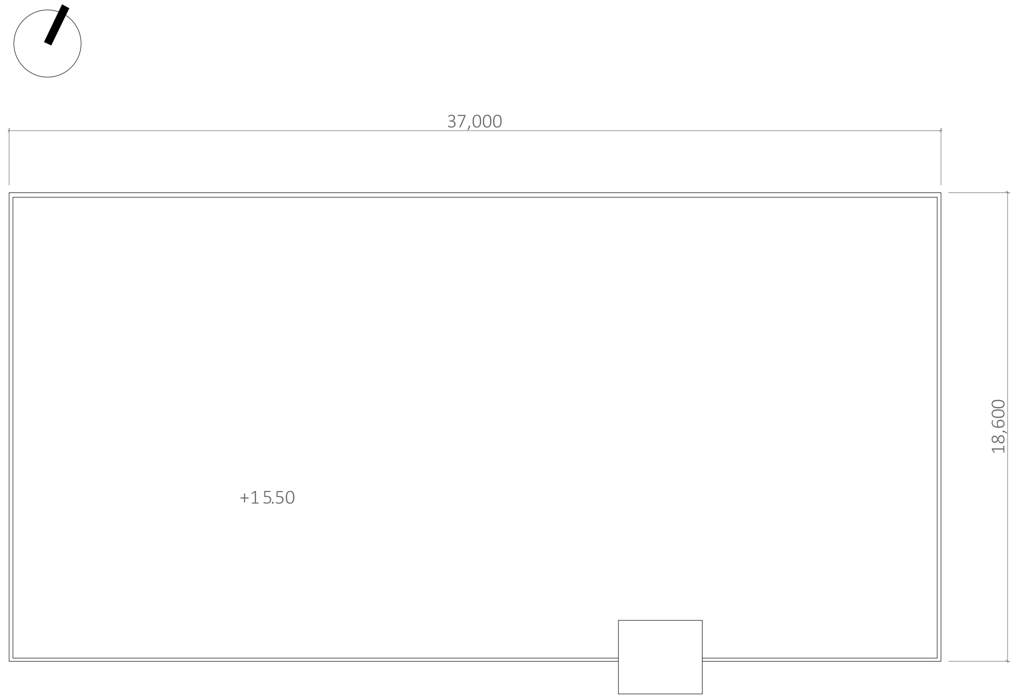
STRUCTURE

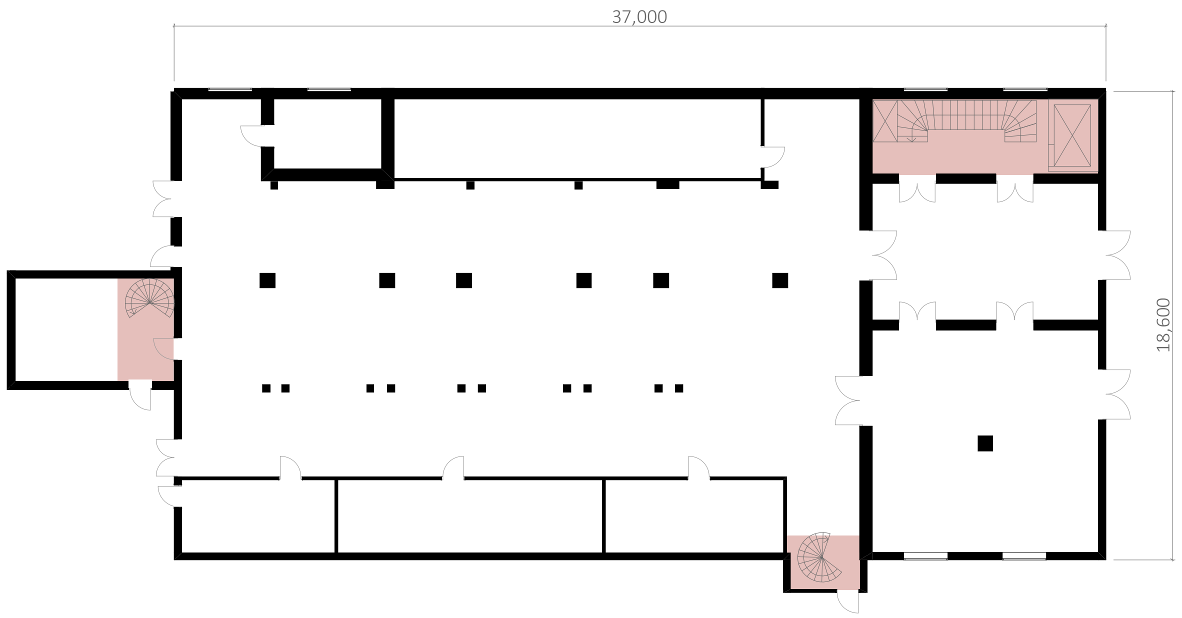
With a robust structure there is potential for adding a housing extension on the roof of this building.

SCENARIO ONE

DIMENSIONS & ACCESS

The rooftop dimensions of Röda Sten art gallery is 37 by 18.6 meters and currently vertical access points are located on three spots around the building.





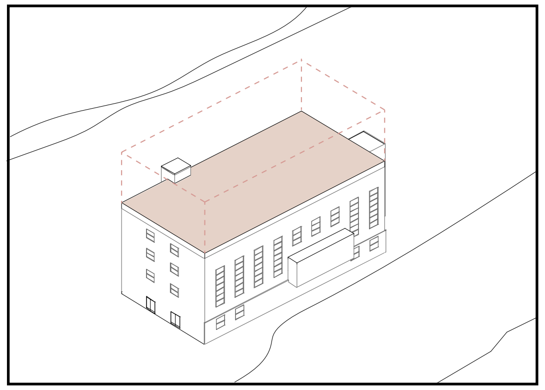
Rooftop of Röda Sten and existing vertical connection points, 1:300

SCENARIO ONE

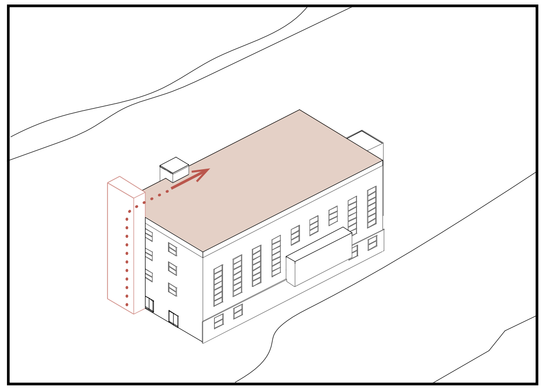
SHAPING THE BUILDING

The extension's general form starts with defining the boundaries within which it can be placed onto and the visual impact it has on site and on the existing building.

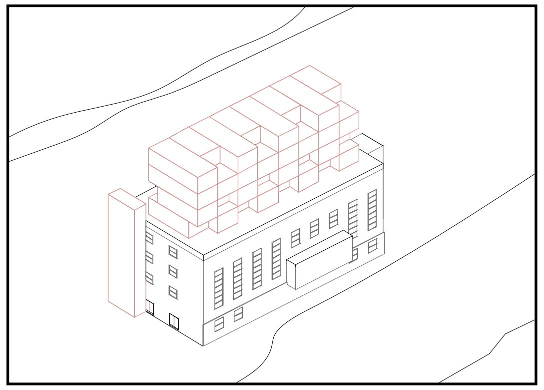
For the plot of Röda sten art gallery, the aim is that the addition does not collide with the existing building and respects the boundaries of the existing building. This also applies to the height of the extension in comparison to the art gallery.



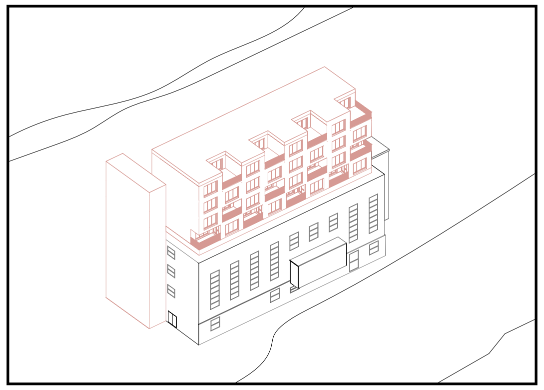
In the next step, depending on the placement of vertical connections, the entrance balcony will be positioned. In this case, due to the function of the existing building, a new staircase and elevator will be placed outside the building.



Finally, the modules are placed along the entrance balcony. In this instance, it is possible to place modules B and C on the side of the entrance balcony. The private balconies face the river.



	4st	Apt. BB1	68 sq.m
	4st	Apt. BB2	68 sq.m
	4st	Apt. CA	65 sq.m
	4st	Apt. CC	65 sq.m
Total	16st apartments		1064 sqm

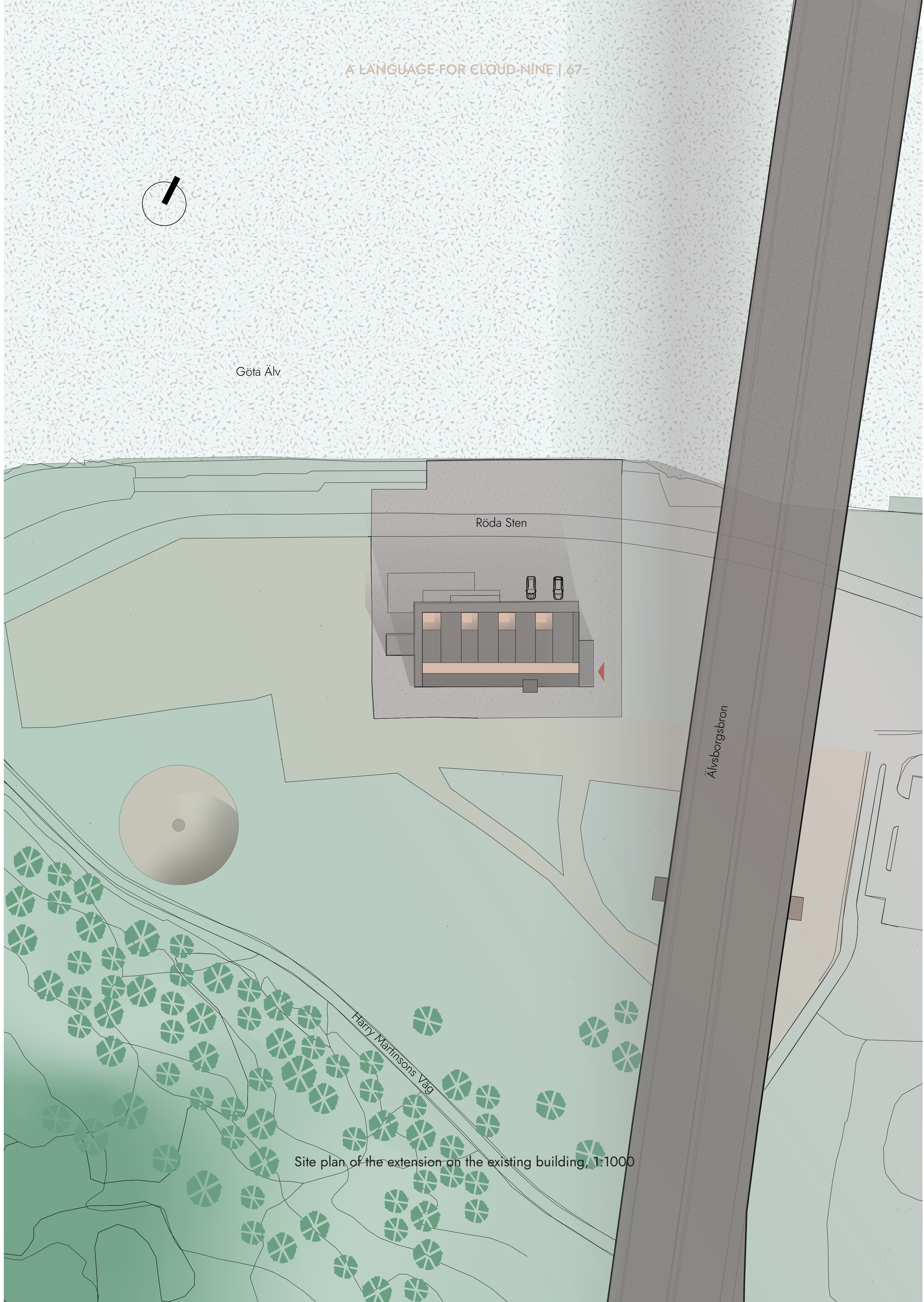


SCENARIO ONE

View towards the building from north

SCENARIO ONE

View towards the building from south



Site plan of the extension on the existing building, 1:1000

SCENARIO ONE

As mentioned before, the challenges of adding an extension over a symbolic building are acknowledged. A drastic change to a historically significant building might be difficult for the public to accept, however adding additional residential units to this building is a thought-provoking idea. Numerous visitors stop by the contemporary art gallery, as well as its café and restaurant, and enjoy the surrounding nature and views, therefore the area has the potential to hold more users and a residential layer could be added to the recreational nature of the neighborhood, bringing a mixed variety of users and movements.

Furthermore, the contrast between wood and brick, old and new in such a unique location can bring new connotation and value to the identity of the area.

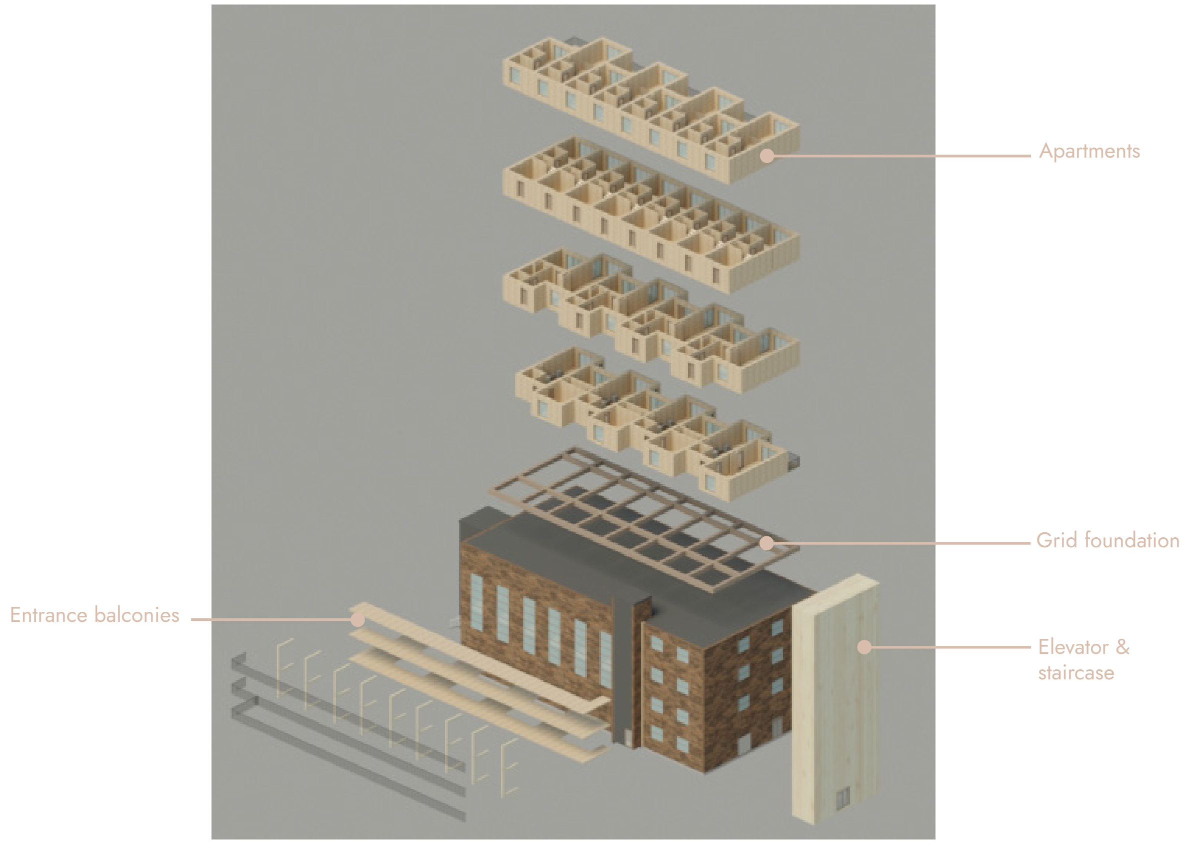
THE EXTENSION

Building block no.2 which is comprised of the two larger modules is implemented on this building. The choice of using larger modules is to maximize the living space on the rooftop.

The extension is placed on the building in four floors and is almost the same height as the art gallery. Vertical connection to the floors is made through a separate elevator which is added to the building and the existing staircase and elevators are left untouched to avoid disturbance in the necessary flows required for the art gallery and restaurant. From there, the apartments are accessed through an entrance balcony.

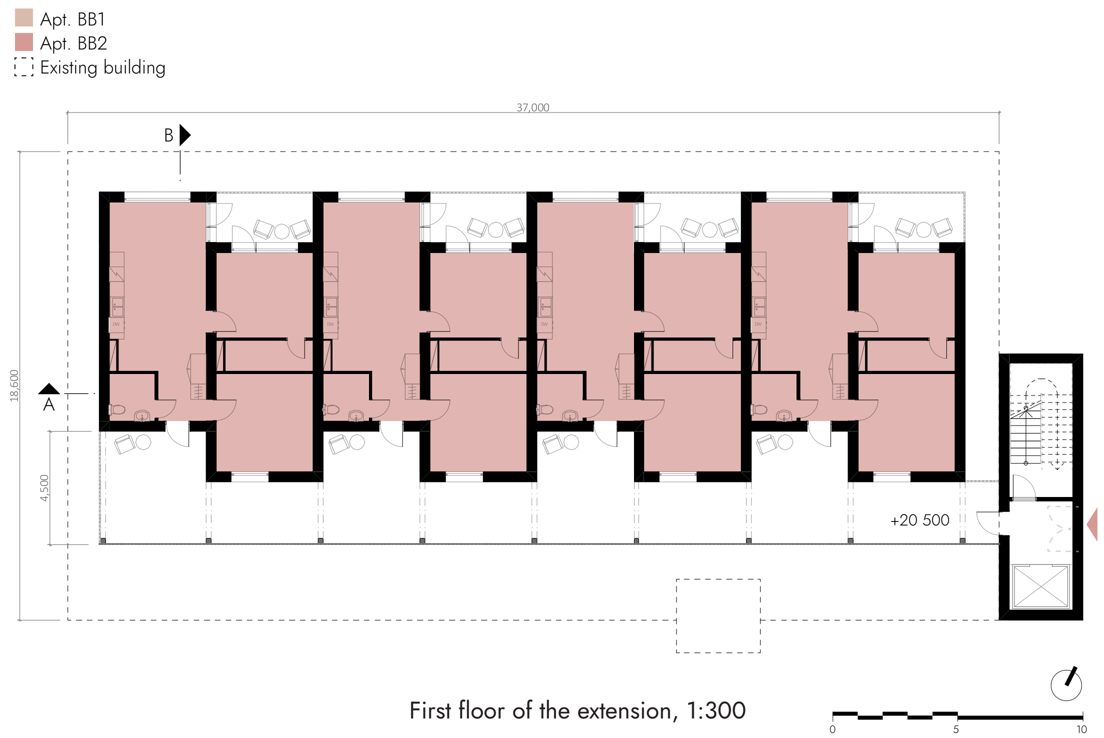
The composition of apartments next to each other forms the recessed spaces in the corridor and on the private balconies, which creates enclosed and private social spaces for the residents and breaks a straight entrance corridor.

The extension is almost fully supported by the existing building, placed on a primary foundation on the rooftop. The form of the extension on top of its host can be categorized as mediate; while it is respecting of the existing boundaries, and in terms of proportions resembles the art gallery, it is visible from a pedestrian point of view.

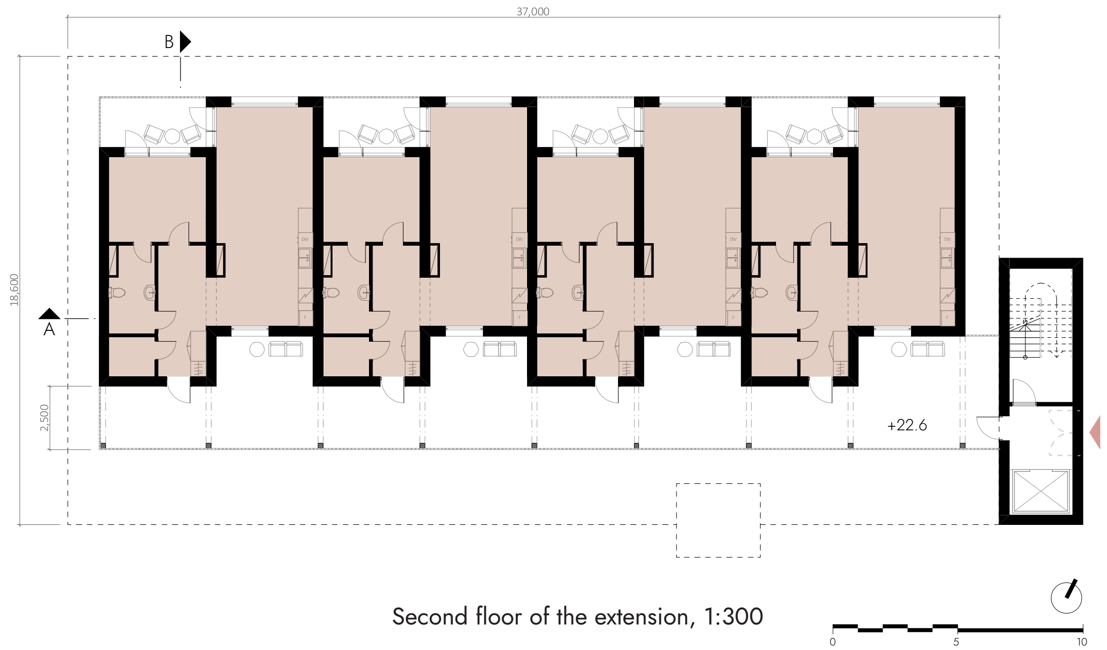


Exploded axonometry of the extension over the rooftop

SCENARIO ONE

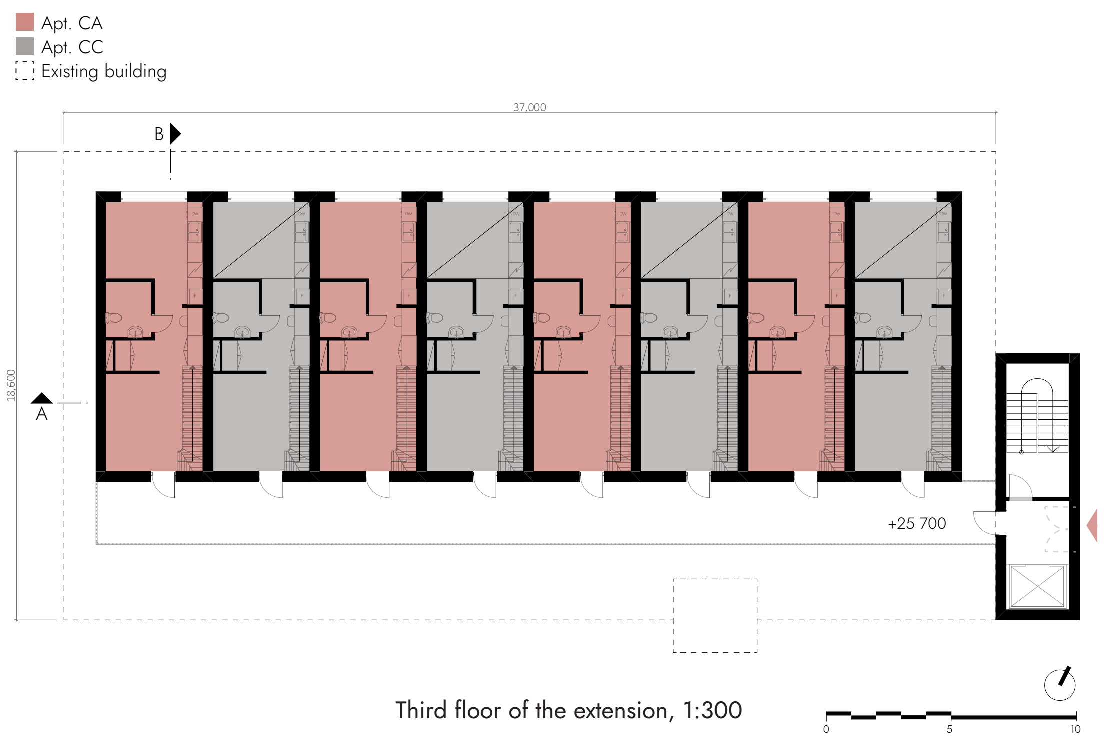


First floor of the extension, 1:300



Second floor of the extension, 1:300

SCENARIO ONE



Third floor of the extension, 1:300

Fourth floor of the extension, 1:300

SCENARIO ONE

North elevation, 1:300

South elevation, 1:300

SCENARIO ONE

Section A-A, 1:300

Section B-B, 1:300

SCENARIO TWO

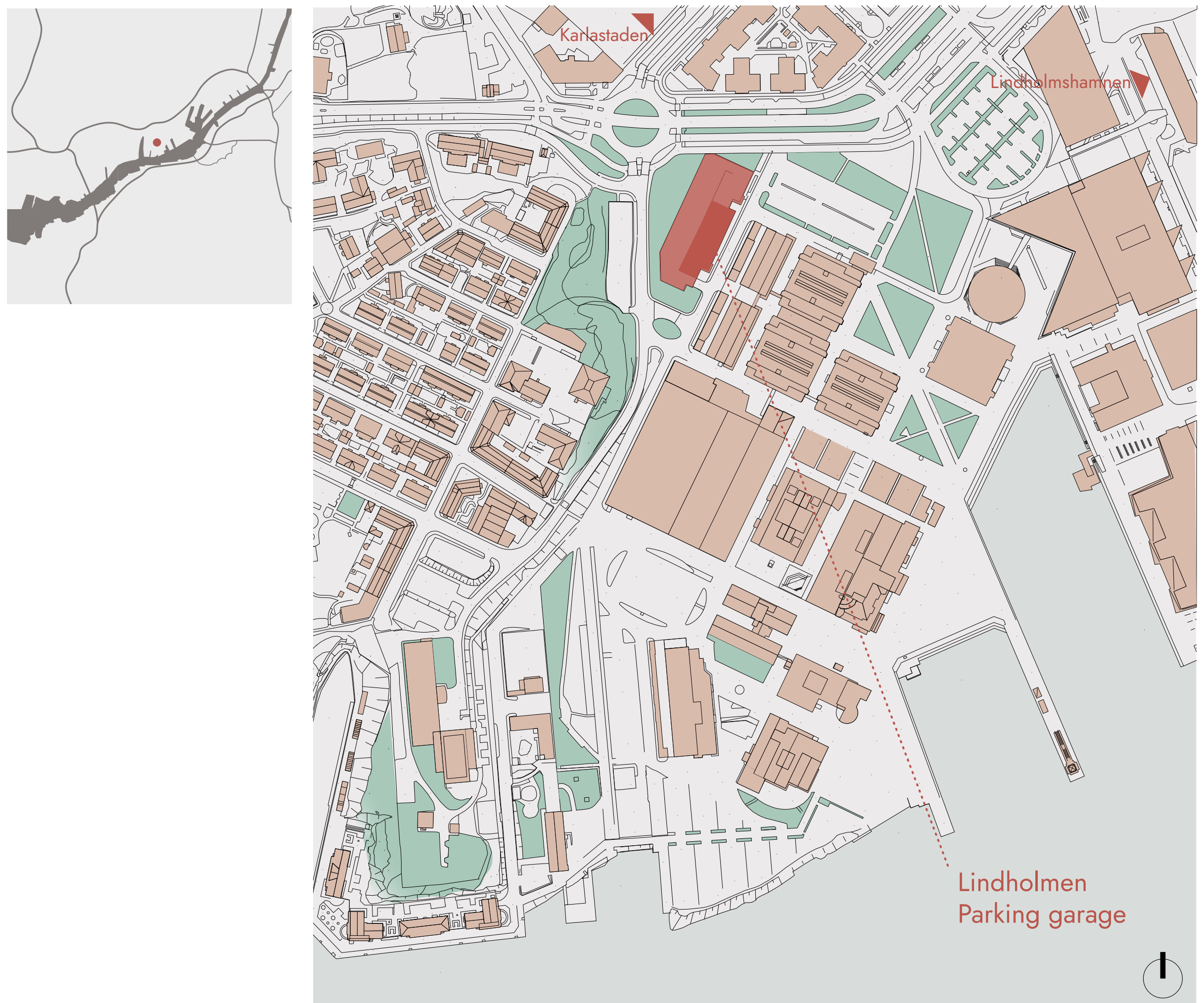
SITE

Built in 2004, Lindholmen parking garage is a multi-storey carpark for Chalmers campus on Lindholmen. (Chalmersfastigheter AB, n.d.)

The Lindholmen area was initially a shipyard and industrial district which gradually housed companies and educational institutions.

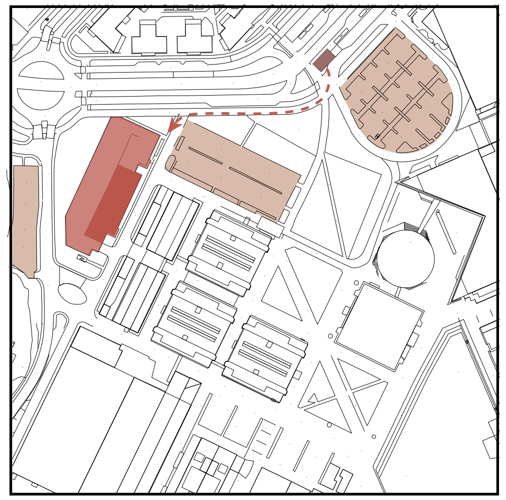
According to Göteborgs Stad (n.d.) as of yet, Lindholmen is home to diverse companies, educational and research centers, but relatively few homes, however, in order to create a sustainable city, different functions need to co-exist. Currently, city of Gothenburg, along with private developers are working to provide extra housing, offices, preschools, cultural centers and parks and restaurants for the area. Karlastaden and Lindholmshamnen are two planned residential areas that will be home to new residents. (Göteborgs Stad, n.d.)

Incorporating a residential addition, on the top floor of this parking garage, could bring new opportunities in achieving the densification goals for the future of this district. In this proposal, the addition is meant to provide housing for the students studying at Lindholmen campus.



Lindholmen parking garage, approximate location in Gothenburg and zoomed in, 1:5000

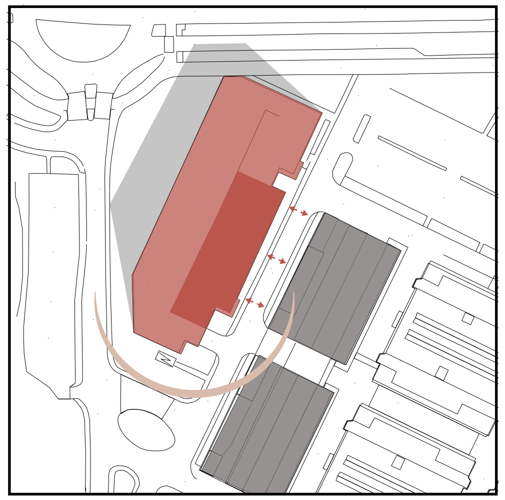
SCENARIO TWO



Lindholmen parking garage
Car parking
Bus station
Pedestrian

ACCESS

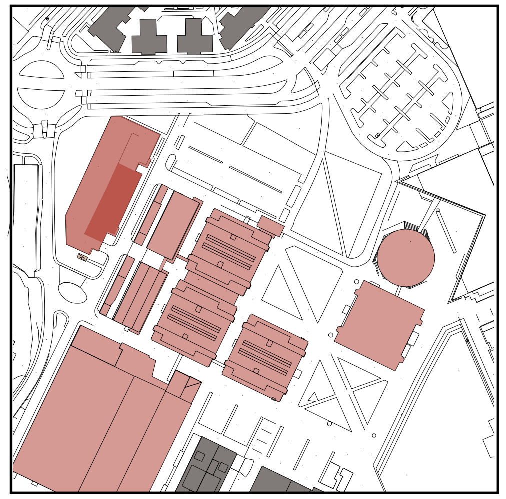
Pedestrian access is available from the nearby bus station. In addition to the plot being a parking garage, there are many parking areas around the plot.



Lindholmen parking garage
Adjacent buildings
Sun path

SUN & SHADOWS

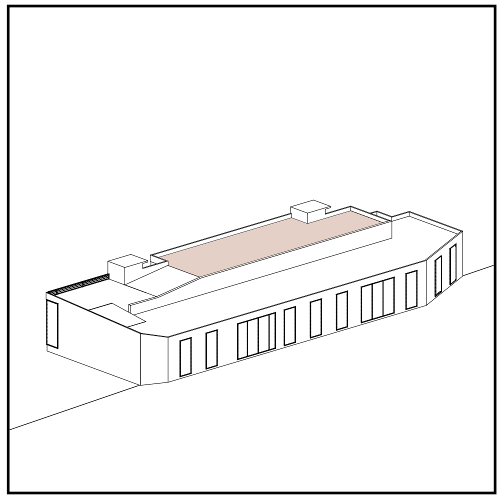
Except for the university buildings at the south-east, the site is relatively open.



Lindholmen parking garage
University buildings
Other company premises

SURROUNDING FUNCTIONS

The area is populated with different businesses, educational and research institutions.



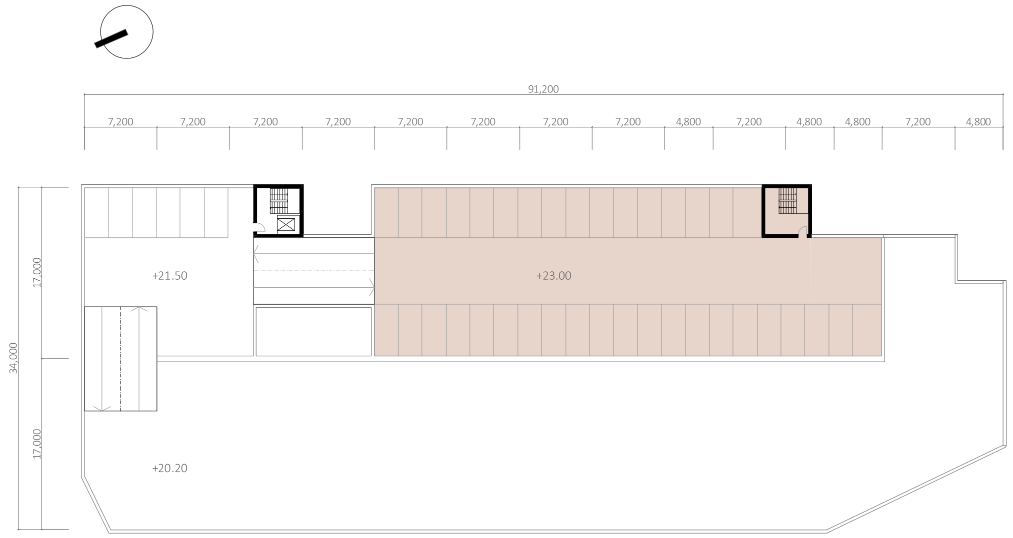
SURFACES OF THE ROOF

The rooftop of the parking garage is made up of three levels, however the area chosen as the base of the project is the highest level on the roof.

SCENARIO TWO

DIMENSIONS & ACCESS

The part of rooftop designated for an extension in this proposal is with dimensions of 17 by 51 meters. (Colored section on the floor plan below) Vertical connections takes place in the internal staircase and elevators which will also be used as they are, for the proposal, but extended upwards to reach all floors of the extension.

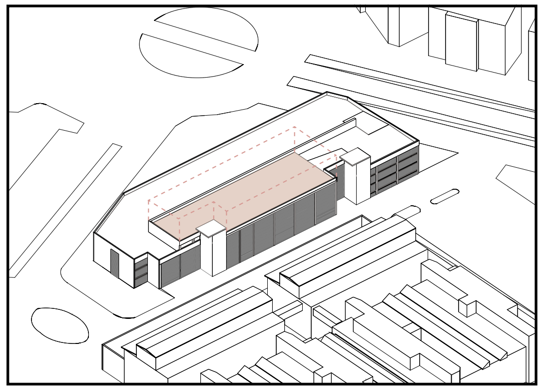


Rooftop of Lindholmen parking garage and the selected area, and vertical connection points, 1:750

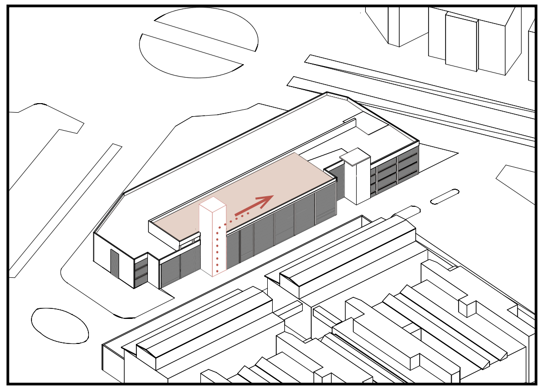
SCENARIO TWO

SHAPING THE BUILDING

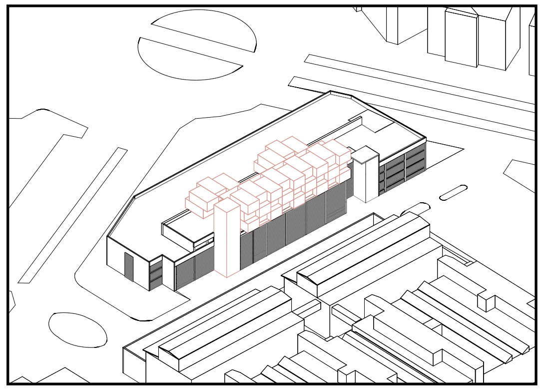
On this plot, the aim is to populate the highest roof surface of the parking garage. Currently, this section is also used as carpark, and in this proposal it will turn into the base for the residential building block.



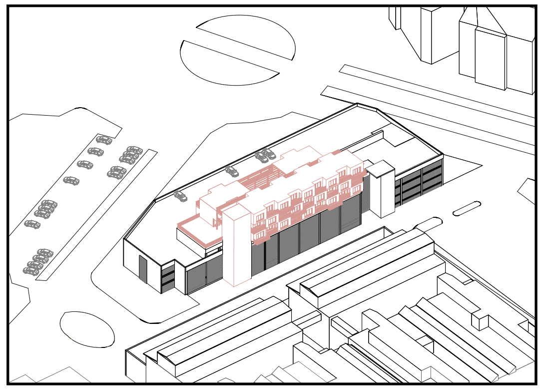
In the next step, as mentioned earlier, one of the existing staircases will be extended upwards to provide access from the street.



Finally, the modules are placed along the long sides of the roof with a 1500mm overhang. This is done to provide a more spacious entrance area to the apartments. In this case building block no.1 which is comprised of the smaller modules is used. The extension has three floors on one side and two floors on the other, with an open air public space between the modules.



	5st	Apt. A	25 sq.m
	5st	Apt. AA1	52 sq.m
	2st	Apt. AA2	38 sq.m
	2st	Apt. AA3	38 sq.m
	6st	Apt. AAA	76 sq.m
Total	20st apartments		993 sq.m



SCENARIO TWO

View towards the building from north west

View towards the building from south west

Site plan of the extension on the existing building, 1:1000

SCENARIO TWO

On the edge between the educational and office buildings and a residential area, the concept of adding modules to this parking garage could be a possibility to create more housing opportunities for students of Chalmers.

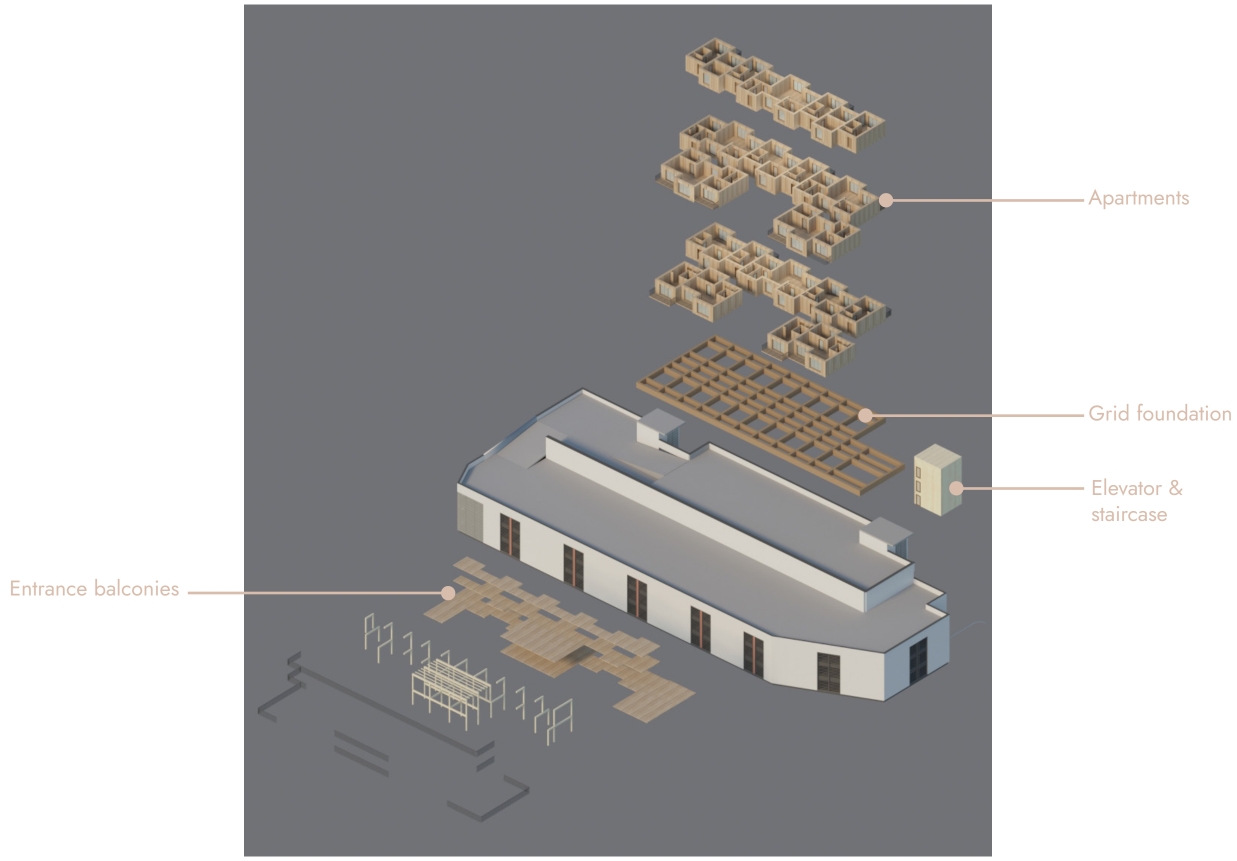
THE EXTENSION

Building block no.1 which uses the 7 meter modules is implemented on this building. The choice of using this module is to maximize the number of apartments as well as allowing for more social spaces integrated into the building.

The extension is placed on the building in two rows, three floors on one side and two floors high on the other side. Vertical connection to the floors is made possible through the existing staircase and elevators while their primary function is not disturbed. From there, the apartments are accessed through corridors and entrance balconies.

In this proposal in addition to the composition of apartments next to each other which forms the recessed spaces in the corridor and on the private balconies, the open space allows for more social spaces within the building, as well as opening up the building block to more daylight.

The extension is supported by the existing building, placed on a grid foundation on the rooftop. The form of the extension on top of its host can be categorized as mediate; although it is not entirely within the existing boundaries and is visible from a pedestrian point of view, it maintains continuity with the existing structure since it is not higher than it.



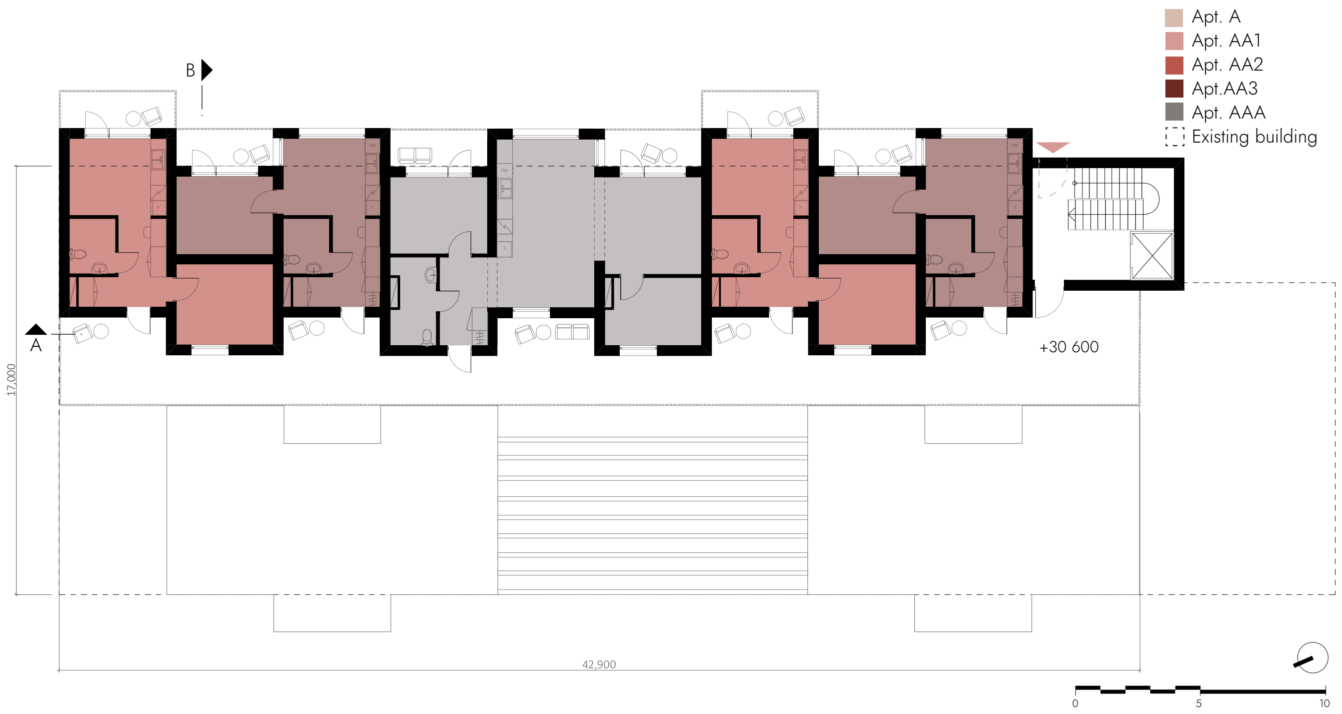
Exploded axonometry of the extension over the rooftop

SCENARIO TWO

First floor of the extension, 1:300

Second floor of the extension, 1:300

SCENARIO TWO



Third floor of the extension, 1:300

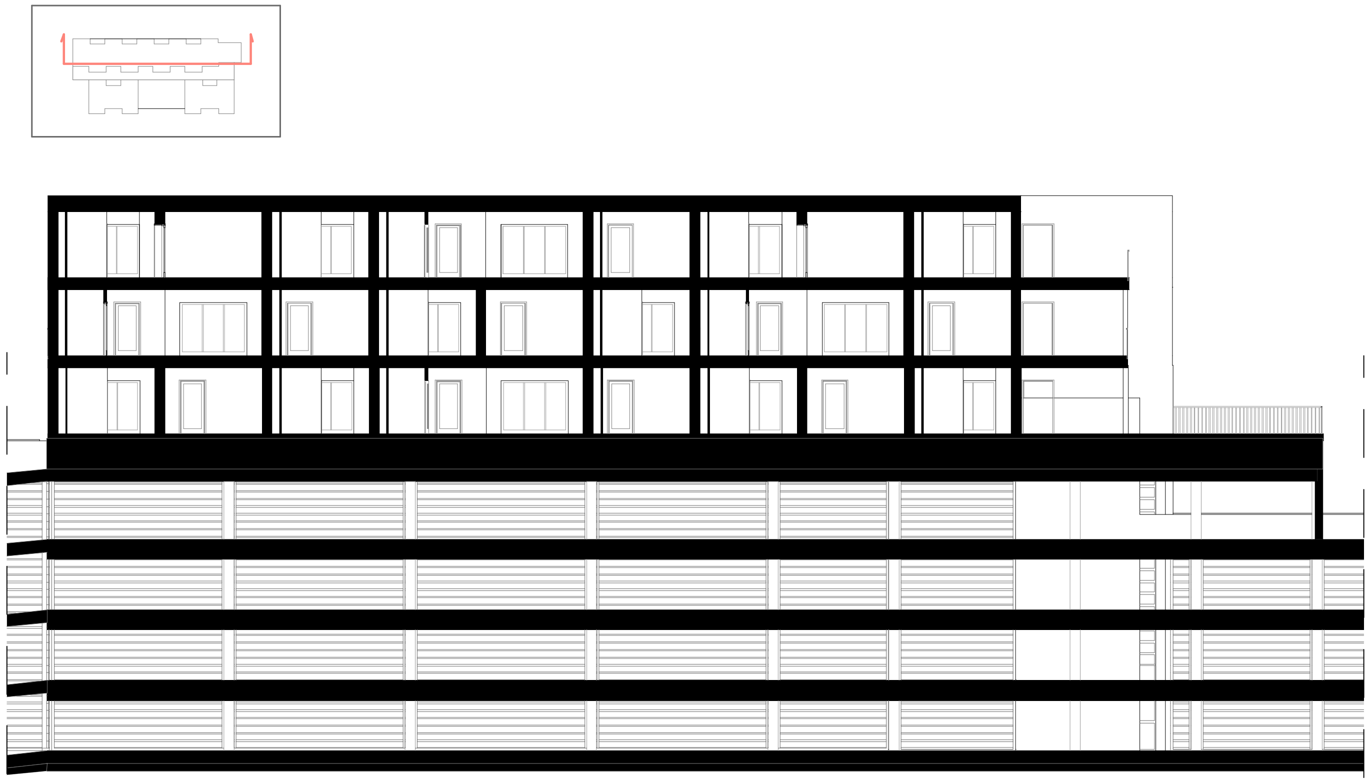
View of the open space on the second floor of the extension

SCENARIO TWO

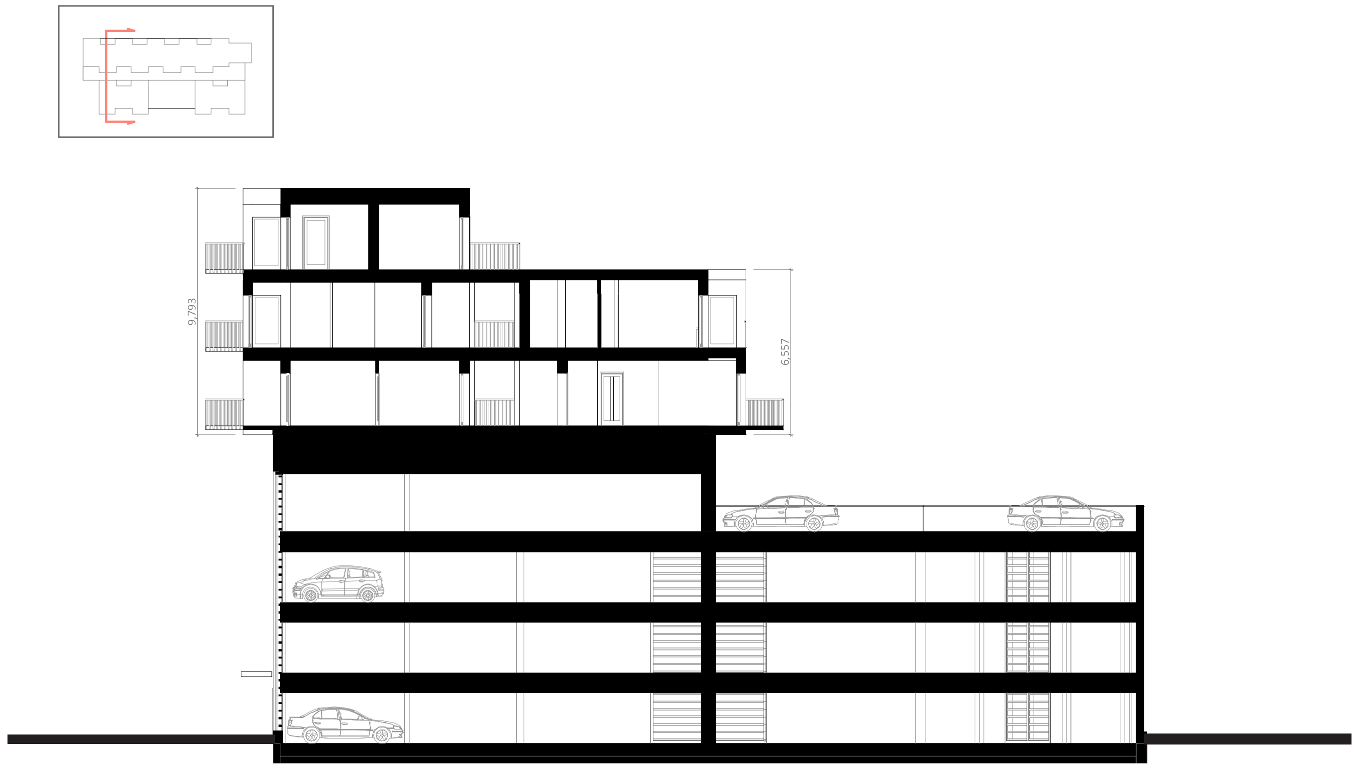
South east elevation, 1:300

North west elevation, 1:300

SCENARIO TWO



Section A-A, 1:300



Section B-B, 1:300

CONCLUSION & DISCUSSION

OVERVIEW OF THE PROCESS

This thesis proposes a prefabricated modular framework for building residential extensions on rooftops in the city.

In the chapter on theory, the problem is formulated which consists of the current topics in the building industry and is followed by the solutions that outline the project in this thesis. Later in this chapter, four main relevant topics are explained that are essential for the further development of the project.

In the Language Development chapter, design strategies and concepts clarify the goals and visions. Then, the apartments are designed using three different modules.

In the smallest apartment, with a living area of 25 sq.m which is comprised of the smallest module, essential functions for one person have been provided while the living space does not feel overcrowded. Utilizing large windows has allowed maximum light to be brought into the module. This opens up the space and makes it appear larger as well. In the design of this apartment, as with the other iterations, balconies are included to provide more space.

The iterations are designed with attention to creating standard rooms and spaces in the apartments so that the users can use them according to their needs and preferences. They vary from 38 to 76 sq.m.

In the arrangement of two modules and three modules next to each other, shifting the modules on the long side provides space for private balconies for each apartment as well as creating a rhythm on the outside. This pattern is also effective on the inside, adjacent to the entrance balconies, creating recessions along the straight corridors where the residents can have their own space to use as they please. This brings a sense of identity to the interface between private and public.

Two building blocks are introduced. Building block no.1 comprises of apartments designed with module "A" and building block no.2 comprises of mainly modules "B" and "C". Apartments may be repeated in the order that is presented and there are no height limits for the buildings.

The compositions of the apartments, provide a guideline for placing the apartments on rooftops in the city based on the dimensions of the existing building and vertical connection points available on site. To achieve the best results in different compositions of iterations, simplicity and clarity were important factors in the design of the apartments.

In the chapter on Language Application, two plots in Gothenburg are chosen for the implementation of the apartments on site.

The first plot, Röda Sten art gallery on the bank of Göta älv, has an open surrounding and is close to nature, while the second plot, Lindholmen parking garage is more enclosed.

Based on the conditions of the existing buildings, the apartments are placed on them following the basic compositions that are proposed in the previous chapter.

RESEARCH QUESTIONS

This thesis has been guided by three research questions:

1. How can prefabricated volumetric CLT modules be designed efficiently for rooftop housing?

2. How can a catalogue of possible compositions of prefabricated volumetric CLT modules be designed and composed together to form multifamily rooftop housing that is adaptable to a variety of contexts?

3. Which buildings in the city would be suitable options for rooftop extensions?

In the last pages of the chapter on theory, initial thoughts and conclusions were drawn on the questions, and through the process of the design of the apartments, in the chapter of Language Development and their implementation on sites, in the chapter of Language Application the research questions were explored more thoroughly.

CONCLUSION & DISCUSSION

Firstly, on the smallest scale, the objective for the design of the CLT volumes has been for them to provide sufficient living space and adequate living quality.

Since the concept of adding extensions on rooftops is a particular condition, this project has been working towards providing architectural qualities that are valuable to a resident's perception of their house. These contain private balconies, large windows and attention to axiality and sight lines in the apartments.

The relationship between the outdoor and the indoor plays a critical role in adding value to the extensions on rooftops. Creating enclosed outdoor spaces will provide an interface and connection between indoor and outdoor as well as bringing identity to each household and the opportunity for more social functions in the house. It is important to have more social spaces in every apartment, but especially in small apartments that can only accommodate one person.

It was determined that introducing different modules that make up the apartments in different ways would be most effective in terms of the limitations of the existing building as well as including different types of apartments that fit different users.

Regarding the second question, on the larger scale of composition of the modules and how the apartments would be put together and form building blocks, if the modules are designed with fixed characteristics, putting them together is more straightforward. This refers to the shape of the apartment when two or three modules are placed next to each other and placement of shafts; which are both important in the vertical organization of the building block. Consequently, this leads to a more manageable and convenient production line in the factory. This section proved to be most challenging when designing without a specific site in mind.

The other factor influencing the composition of the building blocks on rooftops is the dimensions of the existing building and the placement of vertical connections of staircase and elevators for the extension.

The height or the number of the floors of the extension is influenced by the stability and the capacity of the existing building, and the apartments have been designed in a way that can be repeated, however, they might require supporting structures in higher blocks.

And finally, considering the characteristics of the building to be built on, structures in the city that have sufficient rooftop surface and are robust are suitable for this purpose. Among these buildings are parking garages, industrial buildings, and shopping malls. Nonetheless, calculations that determine the structural capacity of the existing building should be made for each particular case.

In this proposal the existing buildings that were chosen to be built on have roofs with flat surfaces, and the modules are placed on a grid foundation which is placed on the roof of the existing building, however, this foundation could be designed to be placed on other types of roof as well.

As noted in the delimitations, arguments regarding whether extensions should be added to historic or symbolic buildings in this thesis were not elaborated on, however, the challenges are recognized. Considering this, any building that has a good structural capacity and meets other reasonable criteria can be considered for a rooftop extension.

For the development of a sustainable city, buildings layered with differing characteristics are most beneficial, as outlined earlier on layering and stacking in an urban context. Therefore, in this proposal buildings chosen for the implementation of the modules have functions other than residential. As explained in separate sections for each plot, adding a residential extension on these plots, introduces a mix of different user groups to the area and neighborhood.

CONCLUSION & DISCUSSION

SCENARIOS

The area surrounding Röda Sten art gallery has a recreational function in nature, and a dense building block no.2 which uses the larger modules is placed on the building in four floors to maximize the living space. The apartments are accessed through an entrance balcony on one side, where the residents can have small seating spaces on the corridor. In this scenario the extension is inside the boundaries of the existing building.

On Lindholmen parking house, building blocks no.1 which use the smaller module are placed on part of the rooftop of this building in two rows, to maximize the number of the apartments. In this scenario the extension is 1.5 meters overhang from the sides of the parking garage, and it is not inside the boundaries of the existing building.

On one side the apartments are in three floors and the other in two rows with an open seating space in between. This illustrates that with the flexibility of combining modules in different ways, the open spaces between them can be adjusted to suit the requirements and programme of a specific site.

FUTURE INVESTIGATION

When adding an extension to an existing building, a balance between the existing and addition where they form a dialogue with each other and complement the unique qualities that each one have is necessary. In settings where the extension is more visible on the plot, this aspect will gain more significance accordingly.

The apartment modules that are designed as rooftop extensions in this proposal are fixed in qualities such as the character of the facade. Further investigations can be done to identify the qualities that the modules bring with them and introduce more variables to the design of the modular framework of the apartments that can complement and balance the qualities of the existing building in each case.

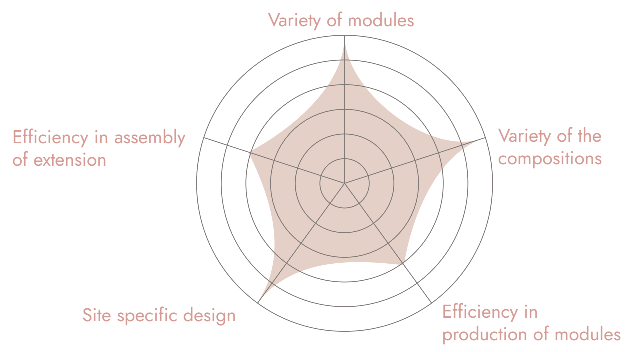
CONCLUSION & DISCUSSION

FINAL THOUGHTS

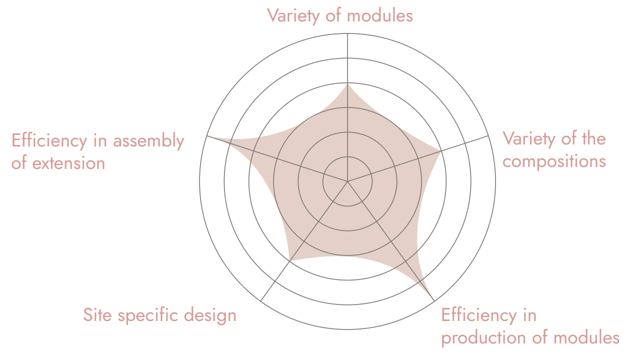
In the catalogue of apartments designed during this process, 8 types of apartments were designed for rooftop residential extensions using 3 modules. As shown in the following diagrams, the way in which the apartments are designed for rooftop extensions directly affects efficiency in the process of assembling the extension on site and the efficiency of production of modules in the factory. Introducing a wider variety of modules in different dimensions or increasing the variety in which they are composed together to form the apartments would lead to a larger category of building blocks.

This would make it possible to have more options for designing rooftop extensions according to the more specific needs of the plot. On the other hand, it will increase the complexity of factory processes and costs for building and assembly of the extensions, which could lead to less demand in the market.

During this project, the effort has been concentrated on bringing balance between the degree of complexity in the language of the apartments designed using the modules and living qualities in such a unique setting, on cloud nine. Nonetheless, further research can be carried out to improve and enhance the apartments.



Increasing the variety of modules and variety of the compositions will result in a more site specific design for the extension but reduce efficiency in production and assembly of modules



Reducing the variety of modules and variety of the compositions will result in a less site specific design for the extension but increase efficiency in production and assembly of modules

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FIGURES

All figures are personal illustrations. The adaptation sources have been listed here or throughout the text.

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Figure 11: Adapted from Bellini, O., & Mocchi, M. (2019). Rooftop architecture and urban roofscape: designing the new vertical city. TECHNE - Journal of Technology for Architecture and Environment(17), 264-277. doi:https://doi.org/10.13128/Techne-24021. p 269.

Figure 12: Adapted from Bellini, O., & Mocchi, M. (2019). Rooftop architecture and urban roofscape: designing the new vertical city. TECHNE - Journal of Technology for Architecture and Environment(17), 264-277. doi:https://doi.org/10.13128/Techne-24021. p 268.

Figure 13: Adapted from Sim, D. (2019). Soft city: Building density for everyday life. Island Press. Stacking vs. Layering. p 46. & Melet, E., & Vreedenburgh, E. (2005). Rooftoop Architecture: Building on an elevated surface. Rotterdam: NAi Publishers.

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Chalmers Geoportal

Göteborgs Stad, Stadsbyggnadskontoret

White architects AB

APPENDIX

OVERVIEW

Analyses of the case studies are included in the appendix. They are explained briefly under the section of case studies on the chapter of theory. The case studies are reference projects that have specific characteristics that are in focus in this thesis such as the modular building method or are analyzed in terms of their general housing qualities.

CASE STUDY NO.1: BOKLOK

IKEA and Skanska
Modular building method
Location: Sweden, Norway, Finland, UK
Year: Started in the 90s

Scope: Single and multifamily housing

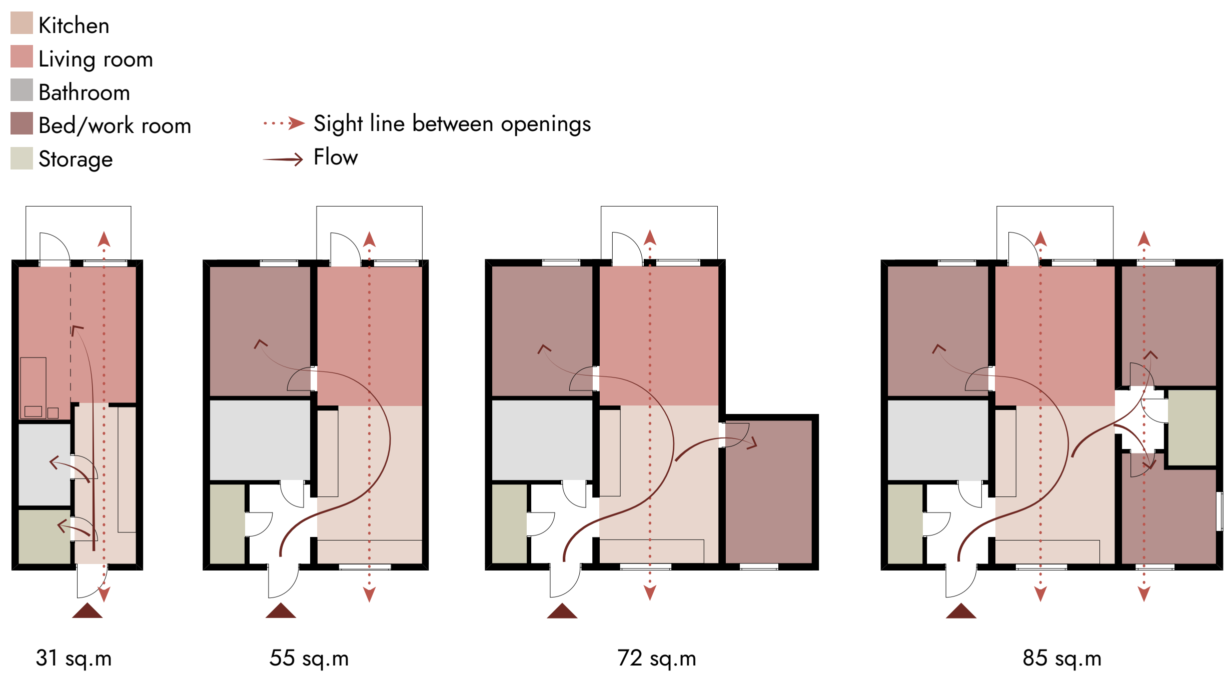
This project is an example of designing standard modules that can work in many locations.

As a concept for sustainable and affordable housing, these homes are built through an industrialized process using factory built modules which are brought onto site. Additionally, the entire value chain, from product development, project development and manufacturing in the factory to sales are conducted by Boklok. In addition to the modular construction method Boklok implements a wide variety of green solutions, such as solar cells and solar panels to achieve more sustainability in energy use. (Boklok, n.d.)

The apartments built with this modular building method have various sizes, and they are all composed of modules. A studio apartment is made up of one module, a two-room apartment consists of two modules and a three-room apartment consists of three modules and so fourth. Modules are put together by assembling the individual parts and joining them together in the modules, and each module is completed in approximately a week. In addition to the tiles, all installations are completed in the kitchen and bathroom. (Boklok, n.d.)

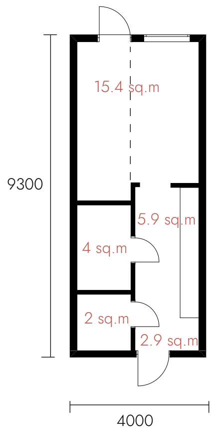
In order to make the buildings harmonious with their surroundings, the materials used in the facade are diverse in color and expression, which gives each building a unique identity.

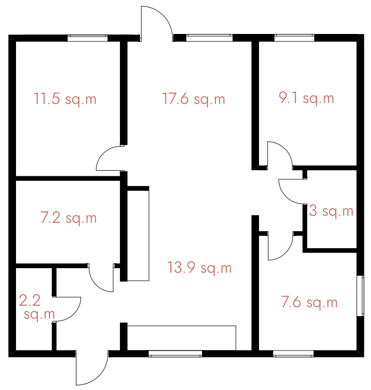
The base module with one room is 31 sq.m and has the alternatives of balcony, no balcony or french balcony. The two room apartments are 55 sq.m and have the alternatives of balcony and no balcony. The three room apartments are 72 sq.m and are made up of two and a half modules, and depending on their placement, their mirrored version can complement each other. And finally, the four room apartments are composed of three modules with the area of 85 sq.m.



Sample of Boklok's apartment types and organization of spaces, in Odenvallen, Östersund adapted from Boklok (n.d.)

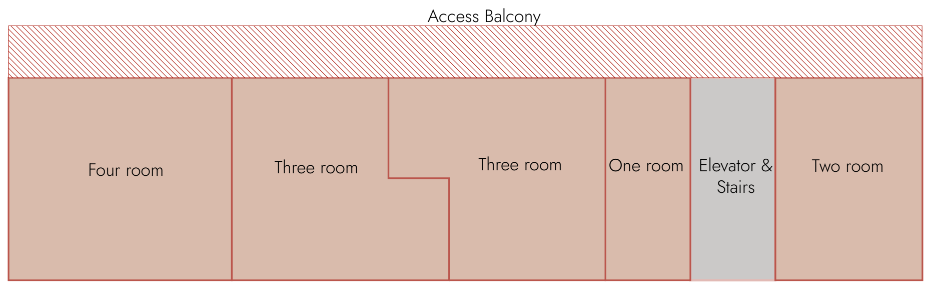
CASE STUDY NO.1: BOKLOK





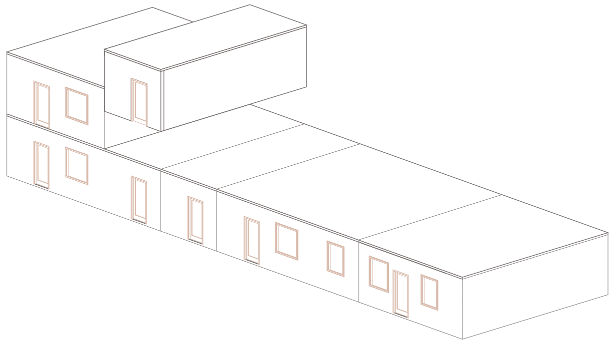
The approximate dimensions of the base module are 9300 by 4000. The organization of spaces is straightforward and the open axis view from the entrance to the other short side provides a broader viewpoint and an open atmosphere.
The 2 sq.m storage space by the entrance provides good functionality to the apartment, however, if it would be removed and the bathroom was smaller in size, the area by entrance could have another purpose.

When three modules are placed together, three more rooms are added, however, instead of the extra storage space between the two rooms including another bathroom could make the apartment more flexible.
Finally, in these building blocks the two short sides of the building can have windows which creates more opportunities.



Arrangement of Apartments in a block of Boklok, Odenvallen, Östersund adapted from Boklok (n.d.)

In in Odenvallen, Östersund, the multifamily housing is created by placing modules on top of each other in blocks of four stories high. The apartments are accessed through an access balcony facing the public outdoor area. The three room apartments with half modules fit together and allow for an organized expansion in the composition of the layouts. As mentioned before the modules are brought to site and mounted on top of each other.



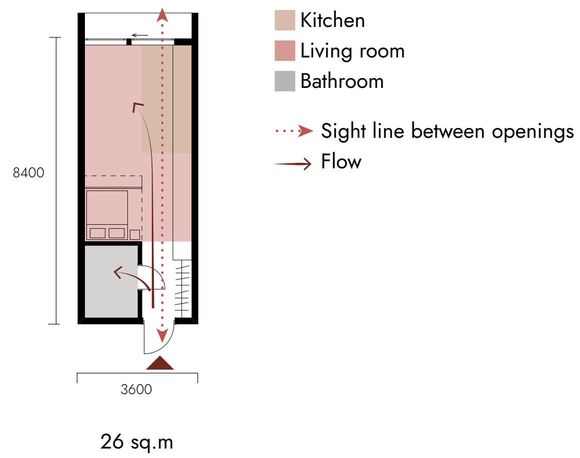
3D illustration of a block, Odenvallen, Östersund adapted from Boklok (n.d.)

CASE STUDY NO.2: SNABBA HUS VÄSTBERGA

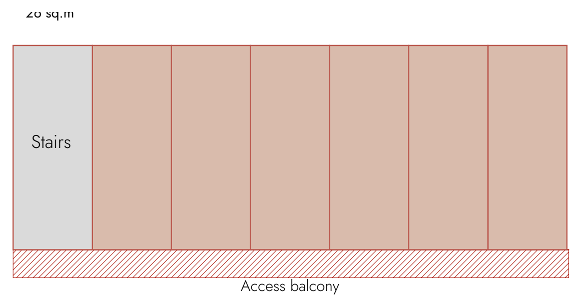
Andreas Martin-Löf Arkitekter
Modular building method
Location: Stockholm, Sweden
Year: 2016
Scope: 280 Apartments, 6 buildings, 8 stories

This apartment building is one of the snabba hus projects introduced as affordable housing for the youth done by Andreas Martin-Löf Arkitekter. Prefabricated apartment modules are placed in a prefabricated concrete structure. 6 building blocks face a private courtyard. The compact apartments have balconies and generous glazing towards the courtyard and are accessed from the opposite side with semi-external access balconies. The ground floor of the building blocks house larger family apartments and shared functions such as laundry rooms and bicycle parkings. (Andreas Martin-Löf Arkitekter, n.d.)

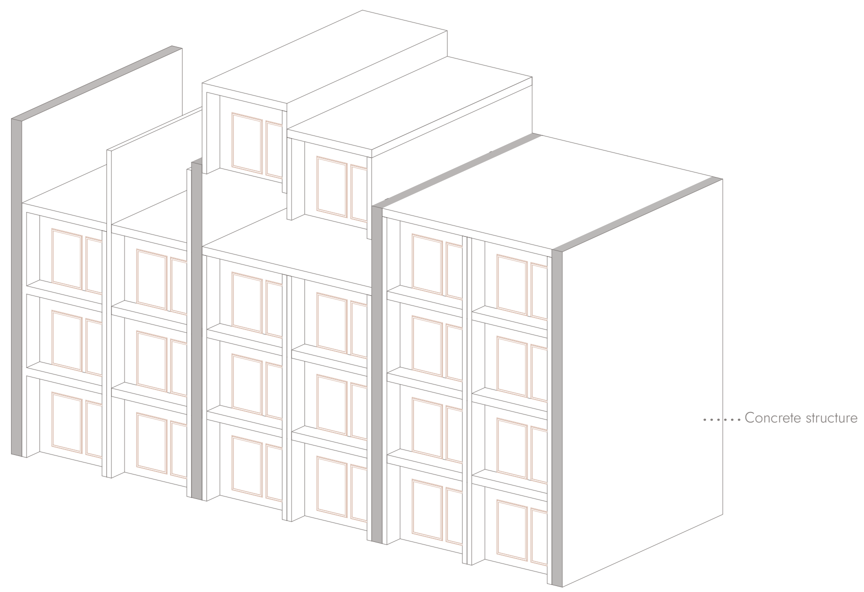
The base module apartment can accommodate up to two people. However, compared to the previous examples they are smaller in size due to shorter width, and comfort may be an issue for two people.



Snabba hus västberga's apartments and organization of spaces adapted from Andreas Martin-Löf Arkitekter (n.d.)



Arrangement of apartments in a block of Snabba hus västberga adapted from Andreas Martin-Löf Arkitekter (n.d.)



3D illustration of Apartments in Snabba hus västberga adapted from Andreas Martin-Löf Arkitekter (n.d.)

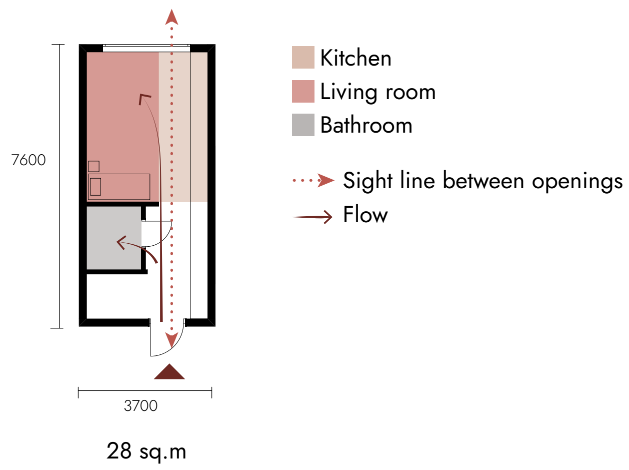
CASE STUDY NO.3: GIBRALTAR GUEST HOUSE

Bornstein Lyckefors
Modular building method
Location: Gothenburg, Sweden
Year: 2018
Scope: 100 Apartments, 6 stories

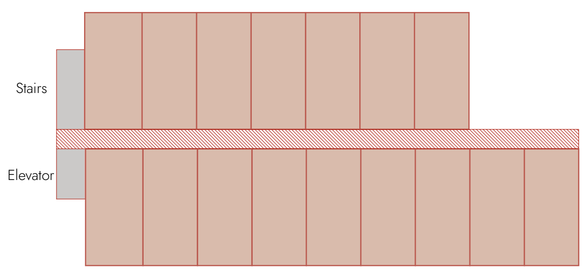
This temporary housing block, has been constructed using a hybrid method of building. First an 18m high glulam frame was erected an then the prefabricated modules were placed on top of each other inside the frame. The fixed furniture that come with the modules have made them more practical and the detailing on the windows add another dimension to the facade. (Bornstein Lyckefors, n.d.)

All the apartments are studio apartments with an area of 30 sq.m. They do not have balconies but generous windows open up the apartment to the view. A specific user group residing in these apartments has made it possible to design the interior furniture on the function wall for their specific needs.

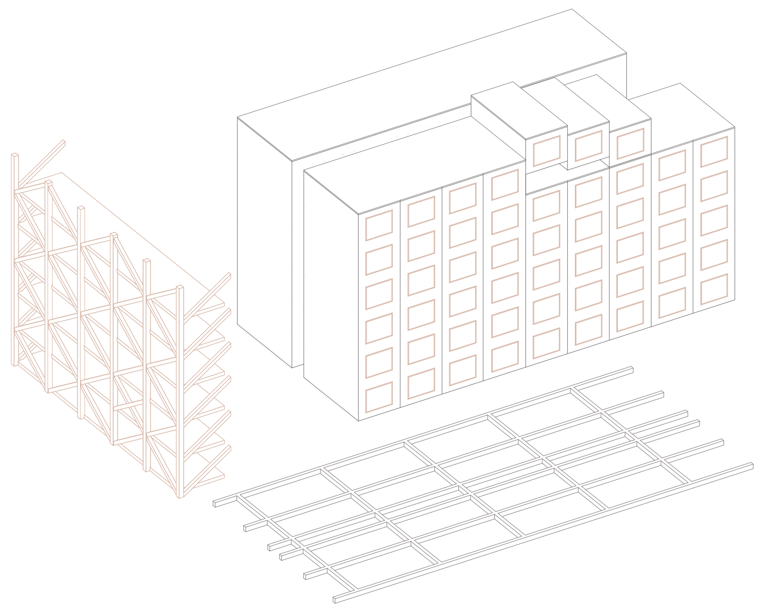
The apartments are accessed through a shared corridor in the center of the block. The modules are placed on top of each other, and are put on a temporary pillar and beam foundation on the ground.



Gibraltar guest house's apartments and organization of spaces adapted from Bornstein Lyckefors (n.d.)



Arrangement of Apartments in Gibraltar guest house adapted from Bornstein Lyckefors (n.d.)



3D illustration of Apartments in Gibraltar guest house adapted from Bornstein Lyckefors (n.d.)

CASE STUDY NO.4: O2 ORMINGE

Dinell Johansson
Modular building method
Location: Stockholm, Sweden
Year: 2016
Scope: 260 Apartments

All 9 building block vary from 4 to 7 stories, and they share the same set of apartments. The wooden modules are produced in the factory and brought onto site. Different sets of volumes have created a system that produces different types of homes. The apartments start from a functional one volume apartment with 29 sq.m and expand to 100 sq.m. (Aros Bostad, n.d.)

The apartments are designed in a way that fit together like puzzle pieces and create the building blocks. In some cases they have been mirrored.

In most iterations the entrance module holds the bathroom and a living room and/or kitchen, however there is no general rule governing the placement of the spaces that can be identified.

The bedrooms vary from 16 sq.m to 7 sq.m in size. Access to spacious balconies from the living room and kitchen as well as bedrooms, has increased the quality of spaces and also expanded the living area.

Sample of O2 Orminge apartment types and organization of spaces adapted from Aros Bostad (n.d.)

CASE STUDY NO.4: O2 ORMINGE

Sample of O2 Orminge's apartment types and organization of spaces adapted from Aros Bostad (n.d.)

Arrangement of a building block of O2 Orminge (Building block number 5) adapted from Aros Bostad (n.d.)

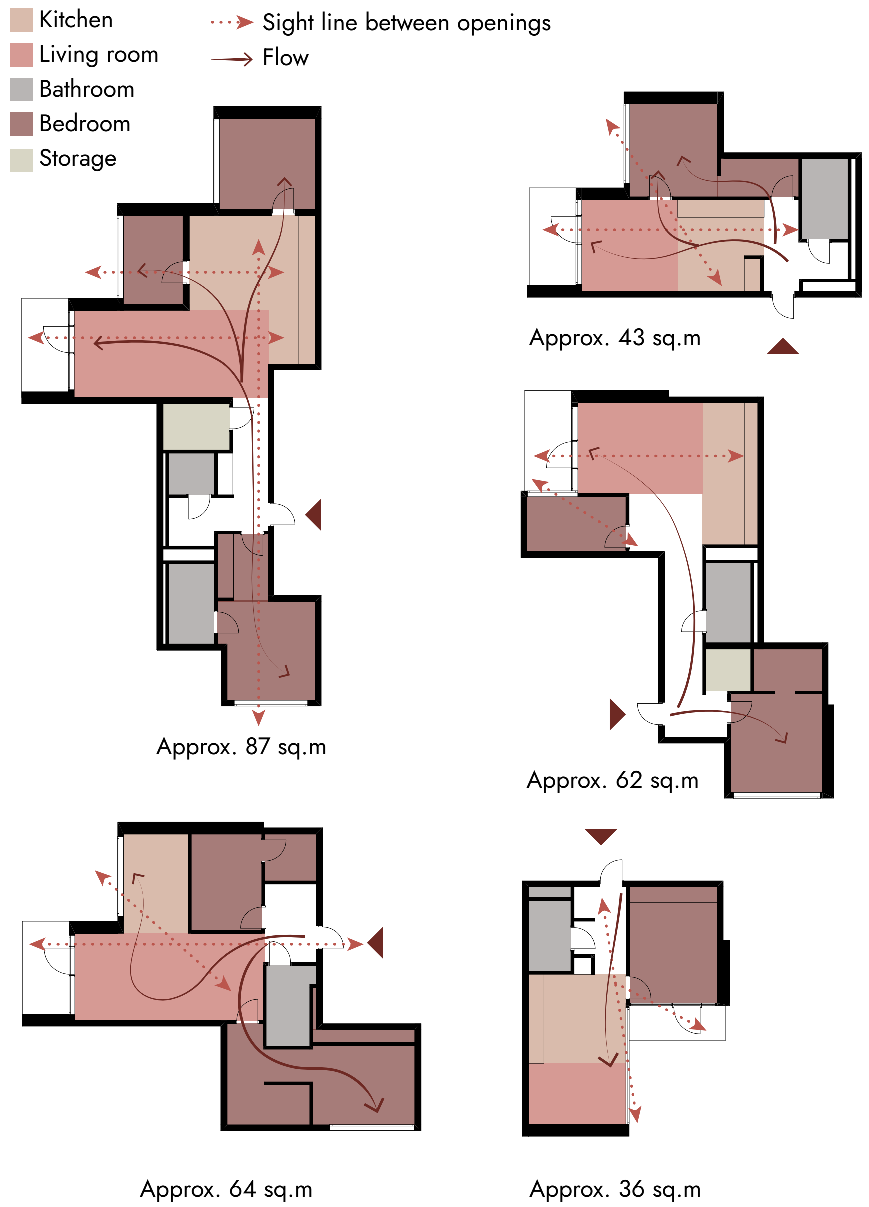
CASE STUDY NO.5: 79 & PARK

Bjarke Ingels Group
Modular building method
Location: Stockholm, Sweden
Year: 2018
Scope: 169 apartments

3.6 by 3.6 meter modules have shaped the form of an enclosed hillside at the edge of Stockholm's national park, Gärdet. The buildings tallest corner with 35 meters in height slopes down to 7 meters. The apartments have unique layouts and invite different types of users.

All dwellings have access to private and shared open spaces. (Bjarke Ingels Group, n.d.)

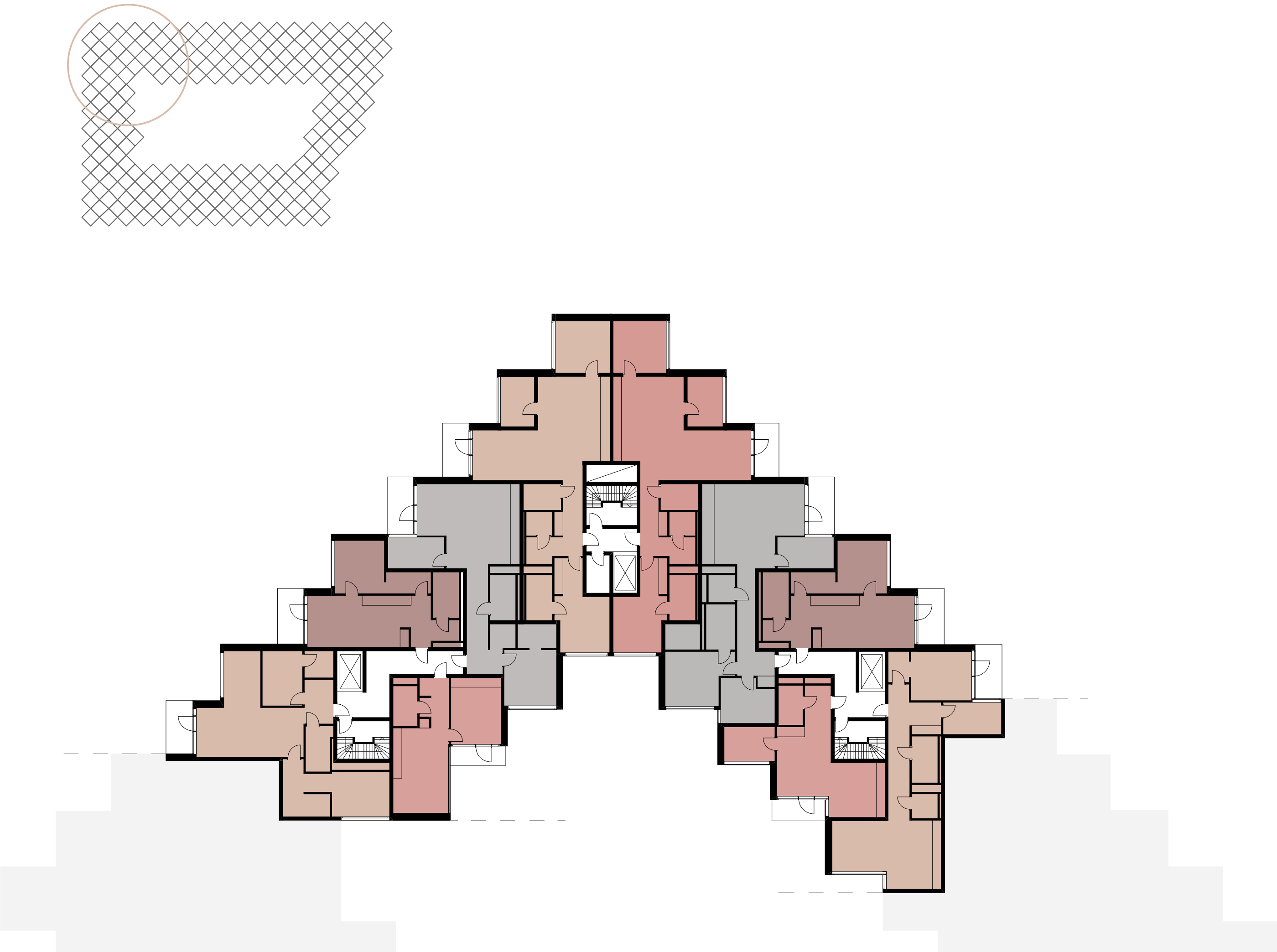
The apartments are not repeated in most cases and have diverse and different layouts. The general principle in the design of apartments is an entrance hallway connected to an open plan kitchen and living room and bedrooms.
The offset repetition of modules has created the opportunity for including private balconies.



Sample of 79 & Parks Apartment types and organization of spaces in 79 & Parks adapted from Bjarke Ingels Group (n.d.)

CASE STUDY NO.5: 79 & PARK

Using smaller modules allows for great freedom in shaping apartments with different qualities. By choosing to shape the form around an enclosed garden most of the apartments get windows and balconies from two directions.



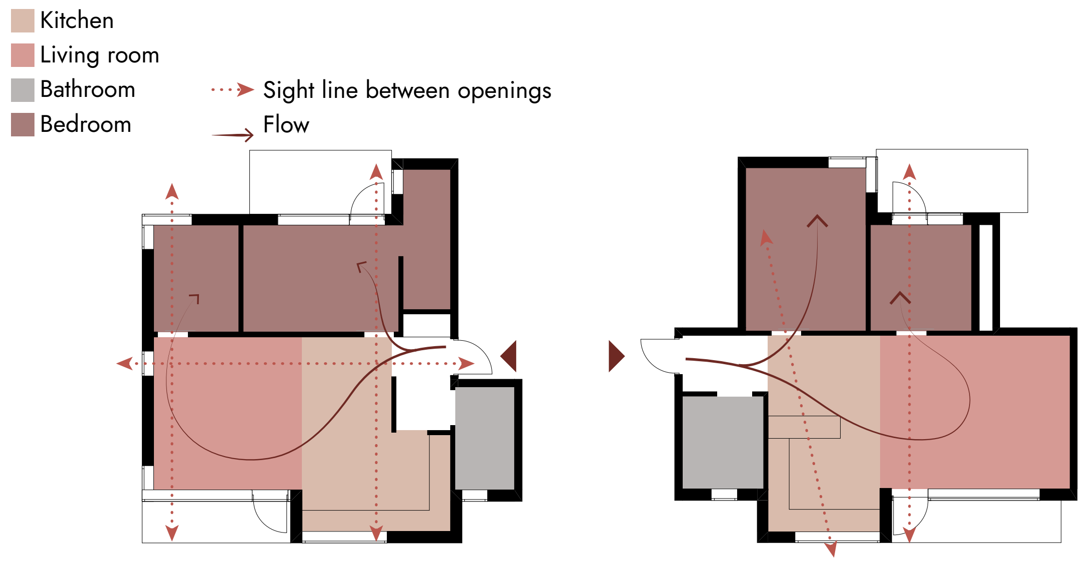
Pattern of the modules and the arrangement of apartments in 79 & Parks (Third floor) adapted from Bjarke Ingels Group (n.d.)

CASE STUDY NO.6: SKÄPPLANDSGATAN TAKLÄGENHETER

Ferrum Arkitekter
Rooftop extension
Location: Gothenburg, Sweden

New rooftop housings are added on top of the 9 floor residential apartments. The houses gain light from two directions and all the rooms including the bathrooms have windows.

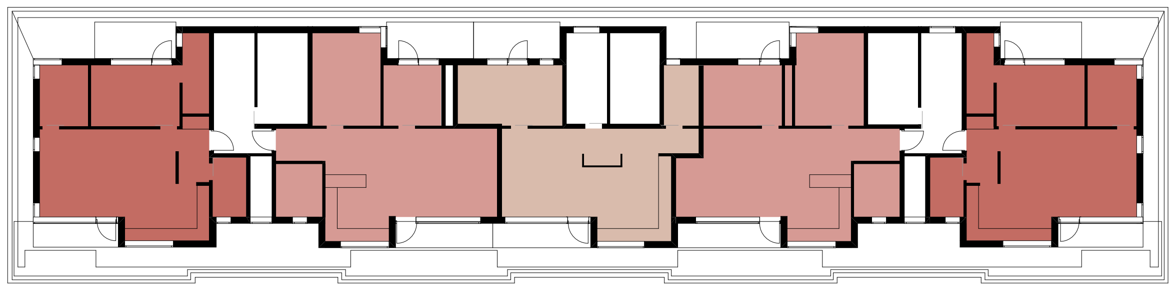
In regards to how the extensions are perceived, they are only one floor and placed on an already high building, therefore they do not have a strong presence from a pedestrian point of view, Furthermore, due to the use of another form and material in contrast to the existing, they give the sense that another layer has been added to the building rather than just added volume.



Approx. 66 sq.m

Approx. 66 sq.m

Apartment types in Skäpplandsgatan taklägenheter adapted from Ferrum Arkitekter (n.d.)



Arrangement of apartments in Skäpplandsgatan taklägenheter adapted from Ferrum Arkitekter (n.d.)

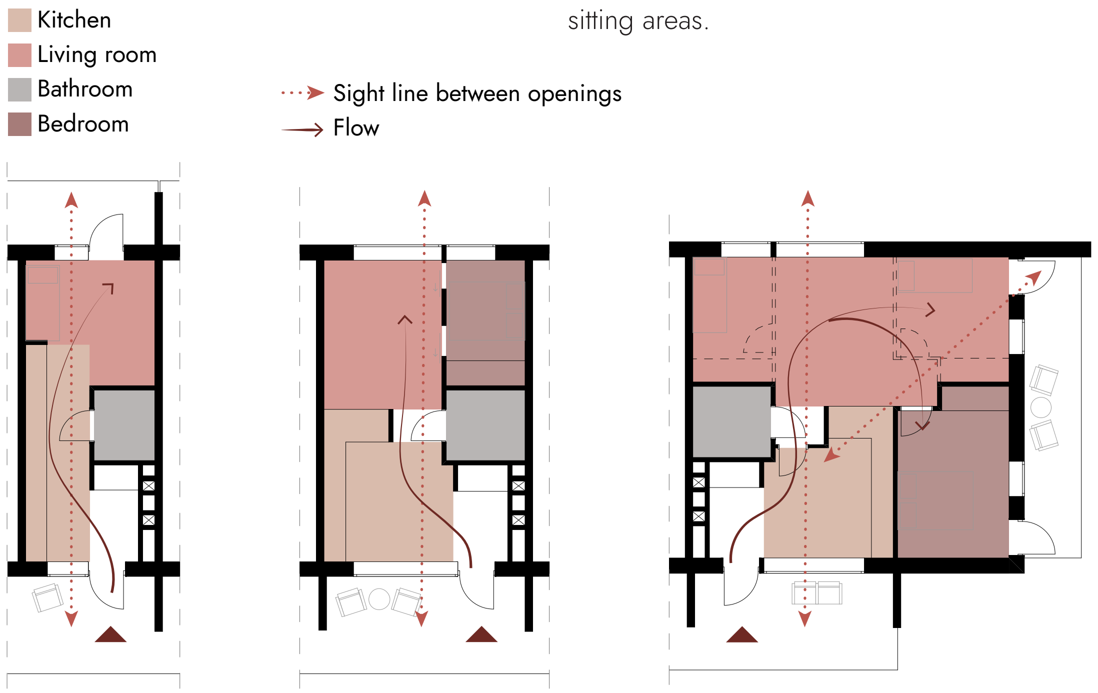
CASE STUDY NO.7: BRF VIVA

Malmström Edström Arkitekter Ingenjörer
Housing qualities
Location: Gothenburg, Sweden
Year: 2019

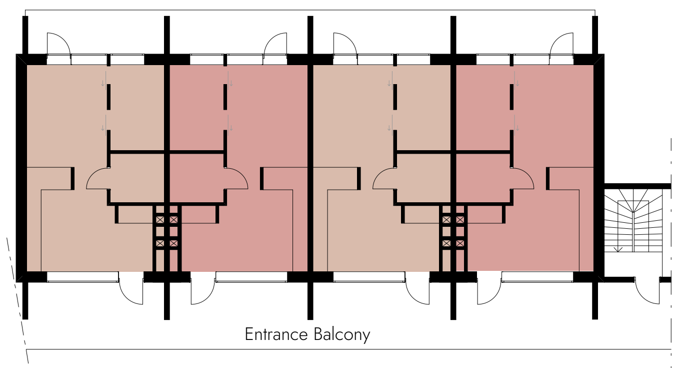
Placed on a steeped slope, each 2 of the 6 building blocks are placed around a courtyard. In addition to functional residential environments, public spaces such as bicycle rooms and grilling areas are also included. (ArchDaily, n.d.)

In the 30 sq.m studio apartments, the kitchen is placed in the center of the wall which allows for a larger living room. In the other apartment types the kitchen is at the entrance and open to the living area.

Although the apartments are accessed through an entrance balcony, there is enough space for sitting areas at the entrance of each apartment. A sense of comfort and privacy is offered to residents through the walls separating these sitting areas.



Brf Viva Apartment types and organization of spaces adapted from ArchDaily (n.d.)

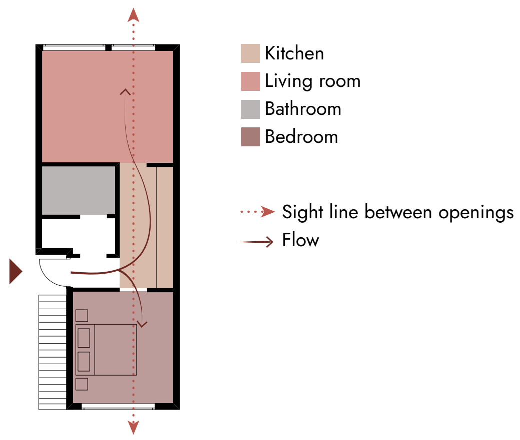


Arrangement of apartments in Brf Viva (Fourth floor) adapted from ArchDaily (n.d.)

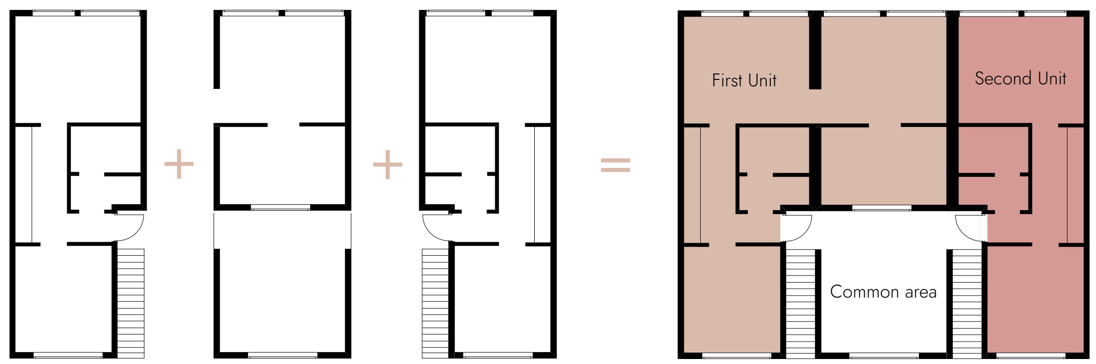
CASE STUDY NO.8: COMPETITION ENTRY

Modular building method
Roftoop extension
Location: Sorbonne, France

This competition entry proposes rooftop building on top of the Sorbonne university with prefabricated CLT modules. The base module designed is sufficient in length to allow for a bedroom as well. (White architects AB)
By combining different variations of the base module that adds extra space to the Apartments as well as common and public functions, such as common terraces and bike parks, more social values have been added to the housing apartments.



Base module and organization of spaces



An example of arrangement of modules and formation of Apartments