BUILDING OVER TIME

Designing for adaptability, disassembly, and material loops
in prefabricated wooden structures.

Nina Falk Danauskis
Chalmers University of Technology
Department of Architecture and Civil Engineering

Examiner: Paula Femenías
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Nina Falk Danauskis
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Chalmers University of Technology
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Examiner: Paula Femenías
Supervisor: Walter Unterreiner
Contact Derome: Anders Carlsson

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CHALMERS
UNIVERSITY OF TECHNOLOGY

ABSTRACT

A building is often focused on the first-time user with very little thought on the second user and the possibilities to adapt to their needs. The energy in buildings is embodied in the building components and materials and if these would be put in a circular system instead of discarded as waste, the total energy use and CO2 emissions would reduce. The environmental footprint of a building is affected by which materials are used in the construction and the emissions connected to the production of them. The aim of this thesis is to explore the possibilities to improve the adaptability of the floorplan and design for disassembly features in a specific and existing prefabricated wooden building system. Adaptability is used as a strategy to meet different kind of needs and respond to changes. Design for disassembly is used to make physical changes possible and to separate components and materials when the building finally reached its technical limit, to enable material loops. The research inquiry is explored in two prefabricated building systems in wood for multi-storey residential buildings from the company Derome. One of the building systems are explored further with the goal to present an improved system.

This thesis is divided into three parts with an initial research part based on literature studies, a second part with an inventory of the building systems based on drawings from and interviews with Derome, and the third part consisting of a design proposal explored through sketches, drawings, and digital models.

The design proposal presented is a building system where the apartments could change both in size and number of rooms to adapt to different users' needs and respond to changes over time. Adaptable strategies of elasticity, flexibility, and generality are applied in the system and transformations are possible by adding or removing walls, keeping within the frames of Derome's original system. The adaptable features of the design proposal result in larger apartments compared to apartments based on the system from Derome. The modules are possible to screw apart into components or specific materials.

Key words: Adaptability, design for disassembly, prefabrication, material loops, wooden structures

PREFACE

This is my master's thesis for my degree in architecture at Chalmers University of Technology. My studies started in 2014 and I am now in my fifth year with a one-year gap with an internship at an architectural firm between the bachelor and the master. This thesis has been done between January and May 2020.

This thesis takes departure in my interest in wooden building that has grown during the education and the interest in housing; how it is used, how it could change or be designed in different ways for a variation to meet people's needs. The thesis will be a further investigation of these subjects.

I would like to thank Derome and especially Anders Carlsson who has provided me with the material that I needed regarding the building systems and answered all of my questions, my supervisor Walter Unterreiner for his expertise in wooden buildings, my examiner Paula Femenías for constructive feedback, and everyone at and outside Chalmers that have supported me and given me feedback.

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1. INTRODUCTION

BACKGROUND

A major part of the energy in a building is embodied in the components and building materials, when a building is demolished and if the materials are discarded, the embodied energy in forms of raw materials extraction, processing and manufacturing as well as the transportation of the material or components, gets lost as well (Crowther, 1999). The waste produced in the building and demolition industry are the largest, measured in volume (Europeiska komissionen, 2015). If instead the material would be reused, the total energy would be reduced and a correspondingly reduction of environmental impact of emissions from CO2 (Crowther, 1999). Resources available must be reused to the largest extent possible and put in a circular system instead of the current linear to minimize waste. A viable strategy towards this goal is to design buildings, structures, and systems that facilitate easy dismantling without damages for possible reuse (Europeiska komissionen, 2015). This is possible through design for disassembly. Design is important in a circular economy to minimize waste and pollution (Ellen Macarthur Foundation, 2020). The European commission report Paketet om cirkulär ekonomi: frågor och svar declares that we must minimize the production of waste and use the resources more efficiently for a more sustainable future (Europeiska komissionen, 2015).

Energy use in buildings reduces when building passive houses and importance of the amount of energy used in manufacturing of the building materials increases and is a larger part of the total energy consumption. The choice of structural material then has a large impact of the building's environmental footprint (Sveriges träbyggnadskansli, 2007). To use wood as a construction material with a negative emission number by binding CO2 will contribute to lower emissions. It requires low energy consumption when refining and is a renewable and biodegradable resource (Bergkvist, Ekdahl, Gross, Jermer, & Johansson, 2013).

Buildings are often demolished, in some form, due to obsolescence, even if the building has a longer physical life and an even longer lifetime of the components and materials (Crowther, 1998). Crowther (1998) presents five kinds of obsolescence; locational, functional, technical, physical, and fashionable obsolescence. The buildings are often focused on the first users need and very little on the second one and the amount of work needed to adapt to their use. In for example housing, the residentials needs differ appreciable (Drexler & El khouli, 2012). The focus in this thesis is to prevent functional obsolescence with housing as content. 83% of all municipalities in Sweden indicates a lack of housing (Boverket, 2019). Fashionable obsolescence is explored in the context of prefabricated buildings.

Derome is a large building company in Sweden that are known for working with wooden structures. When I started this thesis, I wanted to see how a company as Derome worked with adaptability and design for disassembly in their wooden multi-storey buildings and contacted them via email. When I explained what I wanted to investigate, they were interested to see how these concepts could be applied in their existing building systems and to see how the systems could be used in a different way. Derome have not given me any frames to work within, so I have been completely free in my investigations except from taking departure from their two building systems; space modules and flat-pack.

AIM

The aim of this thesis is to explore the possibilities to improve the adaptability of the floorplan and design for disassembly features in a specific and existing prefabricated wooden building system. The buildings are often constructed to meet the first-time user and are difficult to adapt during its lifetime. Constellations in apartments differ from every household and changes over time, the buildings should be able to change corresponding to this. Adaptability is used as a strategy to meet different kind of needs and respond to changes. This thesis presents a design proposal where the building and its apartments could change both in size and number of rooms over time. Design for disassembly is used as a strategy to make physical changes possible and to separate components and materials when the building finally reached its technical limit, to enable material loops.

The research inquiry is explored in two specific prefabricated building systems in wood for multi-storey residential buildings. One of the building systems is explored further. The goal is to present an improved system.

RESEARCH QUESTION

How can adaptability and design for disassembly be understood and improved in an existing prefabricated building system?

METHODS

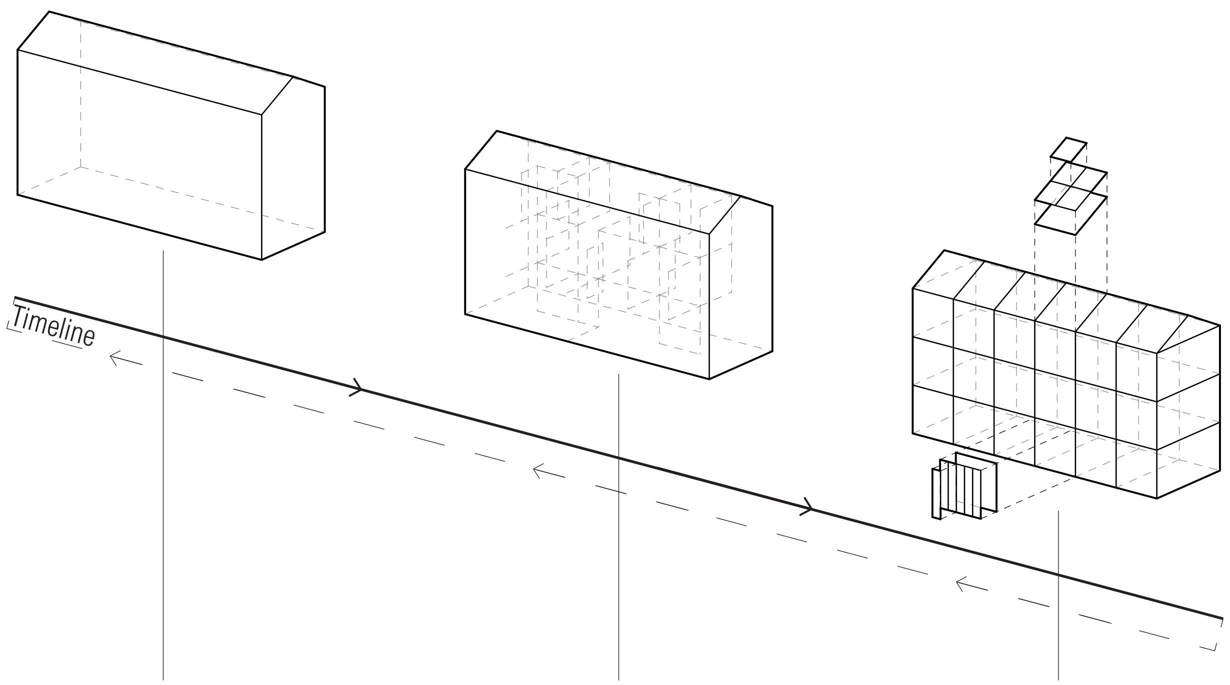
This thesis consists of three parts; an initial research part, an inventory part of the two building systems from Derome, and a third part where one of the two building systems are explored further based on the knowledge from the research, and finally presented as a design proposal of an improved building system. The research is based on literature and case studies to increase the knowledge about relevant subjects. The second part; the inventory of the building systems are based on an initial presentation of Derome and their building systems, interviews during the semester, and analyses of drawings and details. In the beginning of the thesis I went to one of Derome's factories in Värö for a study visit where I also got a presentation of the company and their two building systems. After the introduction I have talked to my contact at Derome; Anders Carlsson, Head of Research and Development, on skype or similar approximately once a month. If I had questions outside Anders's area of expertise, he connected me with another person at the company. The design proposal as the third part of this thesis is where one of the building systems are explored further and adaptable strategies as generality, flexibility, and elasticity are applied. The analysis of the existing system was the starting point of the design proposal where I explored how different changes could or could not be possible and how these transformations would affect the construction, the walls, the floor etc. Strategies from the research and references were applied and compared to understand how these could work in a modular system with a pretty defined boundary of each module and how the modules could be used, connected, or divided in different ways. From the inventory I had the knowledge about how the space modules and buildings was constructed, joined etc. The design proposal was developed through sketches, drawings, and digital models.

DELIMITATIONS

This thesis focus will be on multi-storey buildings. The two building systems that are investigated are the two systems Derome have. No other material than wood will be investigated. This thesis does not focus on the devastation of the forest and what would happen if all buildings would be built in wood today. Documentation, identification, and a deconstruction plan is important for design for disassembly, but not the focus in this thesis. Locational obsolescence and moving the building would contribute to emissions and are not investigated. Physical and technical obsolescence are dependent on the maintenance which will not be investigated in this thesis. The focus is on new production and to enable loops of materials and components of the building systems. It will not investigate circular design further regarding infrastructure or legal issues. Business models for circular economy will not be investigated. Reuse is not included in the proposed design even if it is important for circular design and to reduce emissions. The buildings lifetime is dependent on the contexts as well (Kohler & Yang, 2007) but this thesis focuses on solely the building and the system. Due to limited access to feedback from Derome on the design proposal, it is not fully investigated how the proposal would be constructed in practice.

READING INSTRUCTIONS

The thesis is divided into three parts. The first one is a research part based on literature and case studies. The second part is an inventory and comparison of the two building systems; space modules and flat-pack. The third part consists of further investigations in one of the building systems and is presented as a design proposal of an improved building system. The design proposal is presented in blue in difference from the other drawings in black.



To lower the emission in the building industry, building materials should be reconsidered. In this thesis wood are investigated as a more sustainable material, with lower emissions, in prefabricated building systems.

In this thesis the focus is on keeping the building in on site for as long as possible. For the building to be possible to respond to changes during its lifetime with different needs of the residentials, adaptability is used as a strategy. The adaptable transformations are enabled by design for disassembly.

When the building reached its technical limit, the components and materials should be possible to be separated to enable material loops; reuse, repair, remanufacture, or recycle. Design for disassembly are used to enable the separation of components and materials for material loops, but not the focus in this thesis.

2. RESEARCH

MATERIAL LOOPS

The circular economy is presented as a more sustainable economy compared to the current linear (Europeiska komissionen, 2015). In a circular economy are renewable resources used and placed in closed material loops. Products and services are transformed to eliminate the environmental impacts and problems of waste (Kozminska, 2019). If the material is discarded, as most of it often are in a demolition, the embodied energy is lost, but if the building material could be salvaged for reuse the embodied energy would instead be recovered along with the material. A reduction of energy use will reduce correspondingly to the emissions of CO2 (Crowther, 1999). The transition to a circular economy is not only a technical challenge, key elements in the value chain of the building is missing which are crucial for the material to be reused. Manufacturers in solely a few cases are taking their products back and enables them to be sold again. Leasing is not yet developed in the building industry (Guldager Jensen, et al., 2018). Ellen Macarthur Foundation (2020) states that design is a large part in a circular economy for minimizing waste and pollution.

The components must be cleanly separated for reuse, which is possible by design for disassembly (Guldager Jensen, et al., 2018). The focus in this thesis will be to enable separation without destroying the material to enable a material loops and further investigate design for disassembly to enable this. The materials should be reconsidered and of high quality to ensure that they could be reused to retain the value in materials and/or be more feasible for reuse or recycling. Non-toxic and pure materials are easier to recycle (Guldager Jensen, et al., 2018).

European commission presents a five-step waste management ladder (2019):
Prevention
Preparing for reuse
Recycling
Recovery
Disposal

The focus is in this thesis on adaptability to prevent the building from being demolished through changes to meet the needs of the residentials. All the materials in the building system should be possible to separate for future reuse, recycling, recovery, or disposal.

DESIGN FOR DISASSEMBLY

Design for disassembly ⟶ Construction ⟶ Use ⟶ Disassembly ⟶ Reuse/Recycling of building materials

Design process

Based on (Kozminska, 2019). Enabling material loops.

Design for disassembly is a strategy to enable a building to be dismantled in parts or in whole to facilitate future changes and to contribute to minimized environmental impacts with zero-waste and closed-loops of material through reuse, repair, remanufacture, and recycle, also maximize economic value. Flexibility improves when designing for disassembly as well as maintenance and operation during its lifetime. The most important thing when designing for disassembly is to make the connection between two components reversible without damaging the components. This is easier with a mechanical joint than a chemical, and it is important to make the connection visible and accessible (Guldager Jensen, et al., 2018).

Type of Connection	**/Advantages**	**/Disadvantages**
Screw	/easily removable	/limited reuse of both hole and screws, cost
Bolt	/strong, can be reused a number of times	/can seize up, making removal difficult, cost
Nail	/speed of construction, cost	/difficult to remove, removal usually destroys a key area of element - ends
Friction	/keeps construction element whole during removal	/relatively undeveloped type of connection, structural weakness
Adhesives	/strong and efficient, deal with awkward joints, variety of strengths	/virtually impossible to separate bonded layers, cannot be easily recycled or reused
Rivet	/speed of construction	/difficult to remove without destroying a key area of element – ends

Based on (Guy & Ciarimboli, 2005).

Different joining methods are possible, these have different properties. The screw is easily removed but more expensive than a nail for example. It is possible to reuse, though to a limited extent.

In this thesis design for disassembly is used to enable adaptable solutions and when the building finally reached its technical limit, possible to separate the building into its components or single materials. The focus is on connections, materials, and layers even though other strategies are important too.

Strategies when designing for disassembly:

Connections
Reversible connections; preferably mechanical connections (bolted, screwed), avoid chemical (glue, binders) and welded connections. In case of using chemical, use dissolvable ones. Make connections accessible visually, physically, and ergonomically.

Size
The size of components should be suitable for dismantling.

Standardization
A modular and/or prefabricated structure will be quicker and more secure to assembly and disassembly. Use a simple structure and form that are compatible with other system and possible to exchange and standard equipment.

Materials
Use high quality materials and ensure that they could be reused. Retain the value in materials and/or be more feasible for reuse or recycling. Use non-toxic materials and pure ones will be easier to recycle.

Layers
Allow changes in elements without affect the long-lasting ones. Separate MEP (mechanical, electrical, and plumbing) systems.

Documentation
It is important to have documentation of the building in terms of materials and methods of deconstruction with a labelling system and a deconstruction plan. It is important to update the documentation when changes in the building are executed.

Identification
Identify what materials or components it is and what procedure to use.

Deconstruction
Enable concurrent and parallel disassembly of components with a good material flow. Safety is important during dismantling and the access to the right equipment.

Based on: (Guy & Ciarimboli, 2005), (Guldager Jensen, et al., 2018), (Cruz Rios, K. Chong, & Grau, 2015), and (Crowther, 1999)

SHEARING LAYERS

Brand (1997) is defining six shearing layers with different lifespan. The site and the structure have the longest lifespan and are affecting the capacity of change the most. Building components with shorter lifetime needs to be easily exchanged without demolishing the longer lasting layers. When applying adaptability in a building, it is useful to separate layers such as finishes and supporting structure which allows for spatial changes with less effort without affecting the construction (Drexler & El khouli, 2012).

This thesis will focus on changes within the boundaries of the building, the structure and site, since these layers are the ones with the longest lifetime. The intention is to keep the building useful on site for as long as possible. The focus will be to enable changes in the space plan to achieve an adaptable building and to create rooms that are possible to use and to furnish in different ways – filled with different stuff. The skin is reconsidered in an aesthetic approach in a prefabricated context. The shafts should be easy to access but services will not be investigated further in the structure of the building.

Site >building
Geographical setting, urban location, legally defined lot
The site with context and boundaries could easily outlast the building or even buildings.

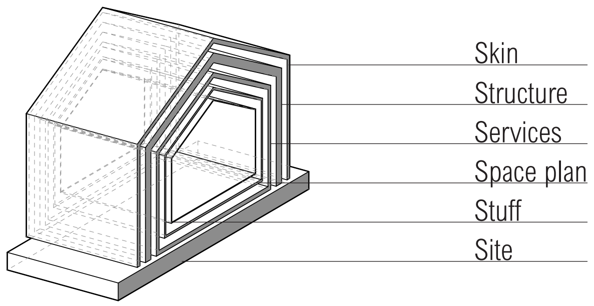
Structure 30-300 years
Foundation, loadbearing system
Both the foundation and structure are the least accessible in a building. For other reasons than the lifetime of the structure, few buildings make it past 60 years.

Skin 20 years
Exterior surfaces
Can change for replacement, reparation, or appearances due to the exposure of weather, to keep up with fashion, or technology.

Services 7-15 years
Electrical wiring, plumbing, heating, ventilation, moving parts – elevators, etc.
If the outdated system is deeply embedded in the building, it could cause demolition of an entire building or prevent alterations.

Space plan 3-30 years
Interior layout – walls, ceilings, floors, etc.
Needs to adapt to the occupants use and can range widely from a commercial setting to residential.
Flexibility of the walls and technical systems are important.

Stuff 1-30 days
Furniture, decorations – all the things we put inside a building.
Should not interfere with the flexibility and reuse of the resources.



Based mostly on (Brand, 1997), other references (Guldager Jensen, et al., 2018), and (Guy & Ciarimboli, 2005).

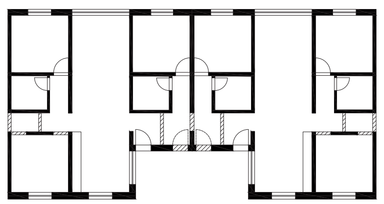
ADAPTABILITY

The buildings are often focused on the first users need and very little on the second one and the amount of work needed to adapt to their use. In for example housing, the residentials needs differ appreciable (Drexler & El khouli, 2012). A flexible building could respond to the unpredictable and predictable changes, all the changes of the users in a building affects the requirements of space (Estaji, 2017). Adaptability as a design strategy will change the focus towards a more time-based approach on design of buildings and will enable the physically built to respond to the changes over time instead of seeing the buildings as completed work. The buildings are in constant transition and are evolving to respond to the changes in society (Schmidt, Eguchi, Austin, & Gibb, 2010).

Braide (2019) presents different concepts of adaptability; generality, flexibility, and elasticity:
Generality: A general room in an apartment does not have a specific function and could be filled with different use. A square space is considered to offer a wider variation of use. The size is also important where Braide (2019) presents a room of 4x4 m and Femenias and Geromel (2019) writes about the size of a general room as larger than 15,4-16,4 sqm and a specific room under 8 sqm, the width of at least 3,1 m for general use and for specific under 2,2 m. Internal rings combined with rooms in sequence are more likely to enable different use.
Flexibility: To change the arrangement, number, and sizes of the rooms within the apartment which could be possible by demountable or moveable walls or furnishing (Braide, 2019).
Elasticity: the space in an apartment could both contract and expand in size (Braide, 2019).

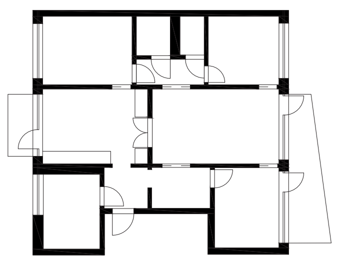
Femenías, Holmström, & Jönsson made a survey investigating refurbishment in apatments. They discovered that modern apartments are renovated to a large extent. Some of the changes were made for normal maintenance, but a common ground for changes where poor materials and low-quality equipment, and in some cases building error. The most common changes are; inner walls, storage, kitchens, flooring, finishes on walls, and appliances. Trends today is toward a more specific and function-controlled apartments with small bedrooms that cannot change in function, an open plan with combined kitchen and living room, and apartments reaching the other rooms from the living room instead of a neutral hallway. Apartments with a more complex shape is more often rebuilt then a simpler plan (2018). Some principles or solutions are presented; Reconsider materials, white goods, techniques, and design that lasts over time. Design floorplans with a time perspective and rethink alternative solutions with socket outlet, openings and window placement that could support this. Storage should not be placed in the bedroom, which would make the adaptability easier and limits the unnecessary exchange of wardrobes. Instead larger storages collected in one place, walking closet can turn into a part of the room. Floorplans that are area-efficient limits a general use of spaces and will make them difficult to furnish (Femenías, Holmström, & Jönsson, 2018).

ADAPTABILITY REFERENCES
The drawings are not in the same scale.
The drawings in a larger scale are presented in Appendix B.



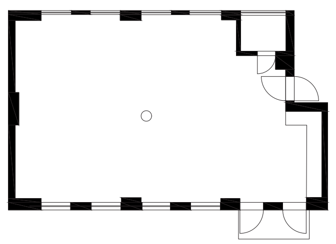
Herti V in Zug, Switzerland 1994.
Kuhn Fischer Partner Architekten.

In this project it is possibile to switch rooms between the apartments. The floorplan has a clear division of the private and closed rooms, in contrast to the social areas, such as kitchen and living room, that are more open. The middle room would be small for a separate apartment but could possibly be rented out as a smaller part of the larger apartment. The private rooms are of the same size which does not create a hierarchy between them.



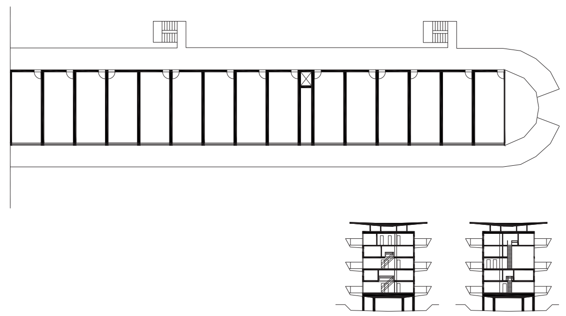
Lillatorpsgatan 17–19, Göteborg, Sweden 2007
Ulla Antonsson & Ola Nylander.

In this apartment it is possible to reach the different rooms in different ways which creates internal rings. Some of the rooms are specific where you must pass through one room to get to another, these would be more public; the living room and the kitchen. The private rooms are similar in size and spread out in the corners.



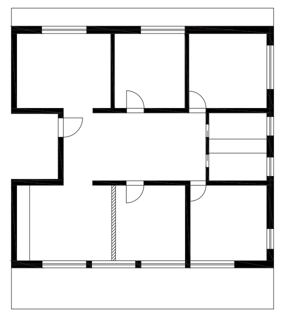
Modulatorsgatan 15-17, Göteborg, Sweden 1953.
Tage and Anders William-Olsson with Lars Ågren.

The apartment is possible to divide in different ways by moveable inner walls. This makes a variation of floorplans possible to create with different amount of rooms and sizes. The façade allows the divisions in different ways due to the placement of the windows. A fixed kitchen is placed in one of the corners. The apartment itself cannot change in size.



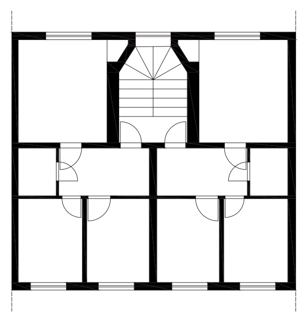
Nemausus1, Jean Nouvel,
Nimes 1987

All units are connected to the entrance balcony. The connection to the balcony makes it possible to connect or contract the different units and makes the apartment possible to extend or shrink. Within the unit it is possible to create different floorplan for each resident, though then a specific floorplan for their needs. Different ceiling height and connections vertically are possible as well with different levels within the unit.



Siedlung Bockler, Zürich, Switzerland.
Christoph Haerle & Sabina Hubacher 2007.

With almost the same sized rooms the content is not specific – it is general. Two rooms are a bit larger and open towards the hallway which makes them more specific. One of the rooms is decided as the kitchen and it is possible to remove a wall to extend the kitchen into a larger room. All the rooms are accessed through a neutral hallway, this area is though big and dark.



Landshövdingehus, Sweden

These apartments could alter rooms in between the apartments and connect two apartments for one larger. The two smaller rooms could be connected and if so, the rooms in the apartment would have similar sizes which enables the use to shift between the different rooms. It is also possible to divide the room into two smaller ones.

PREFABRICATION

Prefabrication is an industrial way of producing buildings. There are many ways to build in prefab, in this thesis the focus is on two building systems;

- Flat-pack; modular elements with free-bearing floor elements and loadbearing walls, typically two-dimensional elements and transported as large flat panels.
- Space modules with the entire volume built off-site and transported to the location where the modules, services, and other systems are connected.

(Atichson, 2018)

Prefabricated buildings are constructed fast on site because of the off-site indoor production which will save time, labour, and costs (Atichson, 2018). The off-site production enables a more sustainable building process and uses materials and resources efficiently while providing a good working environment. It is a controlled fabrication indoors which gives a high precision and improving the quality of the building components as well as improvement of predicting material utilization and minimizing waste. With a smoother working flow, efficiency is improved and avoids delays that would increase the costs (Albus, 2017) (Adolfi, et al., 2005). When building wooden constructions, the assembly are dependent on the weather due to the deformations that could happen if it would rain. A quick assembly is preferably to not risk the construction, and this is possible with prefabricated buildings.

Prefabricated buildings have advantages but comes with some limitations too. Late changes are difficult to make in difference to on site building. The architectural flexibility and creative freedom are limited when building in space modules and tend to appear monotonous with a standardised design (Albus, 2017). The size of the building elements are limited due to transportation regulations that will affect the measurements in the buildings, for example ceiling height which could affect the use. Buildings of the space modules have double walls and ceiling/floor.

WOOD

Timber is a biobased building material and is renewable and biological degradable (Europeiska komissionen, 2015). It requires low energy consumption when refining and produces lower emissions compared to concrete, steel, and bricks. CO2 is captured in the wood and when producing the material, during disforestation, transportation, and processing, it produces a low amount of emissions which gives the material a negative emission number (Bergkvist, Ekdahl, Gross, Jermer, & Johansson, 2013). Energy use in buildings reduces when building passive houses and the amount of energy used in manufacturing of the building materials gets more important and a larger part of the total energy consumption. The choice of structural material then has a large impact of the building's environmental footprint (Sveriges träbyggnadskansli, 2007). When wood no longer is possible to reuse, it is used as energy through combustion as shown in the figure below. It is a local material here in Scandinavia which will shorter the transportations (Bergkvist, Ekdahl, Gross, Jermer, & Johansson, 2013).

Renewable resource > Reuse > Recycling > Energy recovery > Landfill
Figure based on (Bergkvist, Ekdahl, Gross, Jermer, & Johansson, 2013)

Wood is both hard and elastic, because of the different strength and deformation properties in different directions. Longways the stem, in the fibre direction, the wood is considerably stronger and stiffer than across the fibres (Adolfi, et al., 2005). The lightness and flexibility of wood is well suited for industrial production and makes the assembly time on site shorter and the transportation easy because of the light construction (Sveriges träbyggnadskansli, 2007). The lifetime of wood is usually increasing when painting but limits the potential of reuse or recycling (Guy & Ciarimboli, 2005).

3. INVENTORIES OF DEROME'S BUILDING SYSTEMS

Derome was founded 1946 and is today the largest family owned timber industry in Sweden and have around 2200 employees. They work in the whole chain from timber to building, but do not own any forest themselves. Derome has sawmills where they produce products for the buildings and factories where they construct the two different prefabricated building systems for multi-storey buildings, villas, and trusses. The factories and sawmills are spread over the country. The two building systems for multi-storey buildings are space modules and a flat-pack system. 90% of the buildings Derome build in these building systems are multi-residential buildings, but they have also built offices in the flat-pack system, though this is not the main use of the system. The both building systems are presented on following pages in drawings, pictures, and diagrams.
The two building systems are prefabricated to a different grade. This affects the time of assembly on site and the freedom when creating the buildings. A building built in Kvillebäcken in Göteborg of six floors in the flat-pack system took around eight and a half months from first day of assembling the prefabricated elements to the finished building. A corresponding building in the space module building system would take around half of the time. The space modules are though more specific in the floorplan and the flat-pack freer, but the flat-pack system is more expensive than the space modules.

Waste from production are sorted in the factories and recycled or brought back to the producer. Prefabrication makes it possible to calculate what is needed material wise and therefore minimize the waste. There are more different kinds of waste when producing the flat-pack system due to the larger variations of materials used because of the greater freedom the system offers.

In both systems it is possible to add different facades with different expressions and colours in wooden panel, bricks etc. If a brick façade is chosen it must be placed on site. The roof, balcony size and railing, and windows are possible to alter in the design. In the flat-pack system the sizes and placement of the windows could vary in difference to the space modules.

Derome's both building systems are made of light wood-frames. Light wood-frame building systems uses lumber efficiently and is possible to reuse with the appropriate joints, but uses a large number of nails or screws that requires a lot of time when disassembly and has rather small dimensions which limits the possibility of reuse (Guy & Ciarimboli, 2005).

SPACE MODULES

Derome has developed a system for residential buildings of the space modules named AdderaPluss. The modules are placed next to each other along the long side up to four floors. The building systems maximum height is limited due to stabilizing reasons in the construction and increasing fire regulations over four floors.

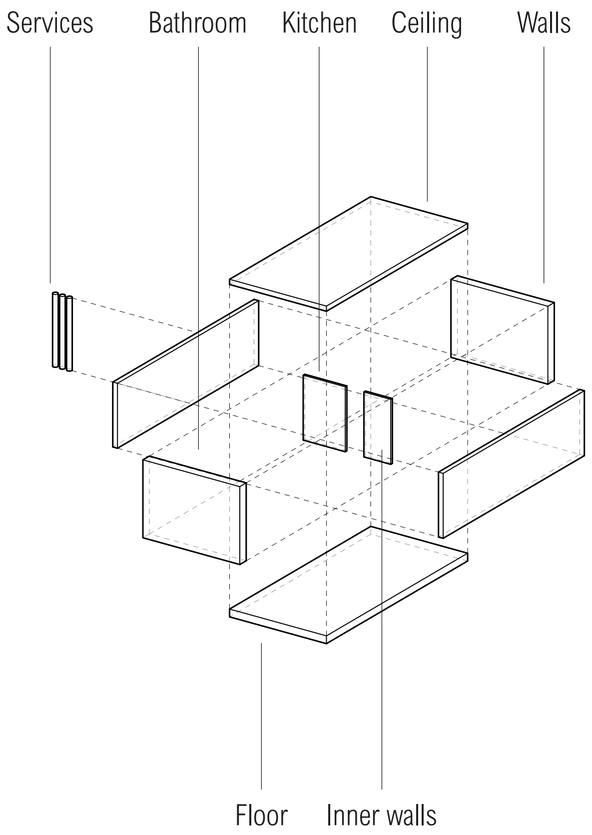
The apartments are reached from the entrance balcony and gives the possibility to make the buildings longer and shorter which makes it easier to adjust a building to a specific site and its measurements. The entrance balcony is though usually not so appreciated by residentials and will make the rooms facing the balcony pretty dark and easy to look into from the outside. In the Swedish climate, these untampered balconies are not so well used.

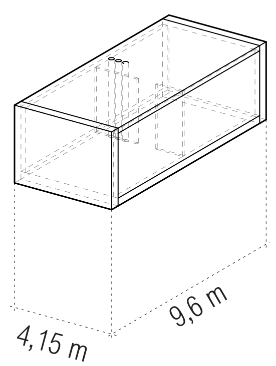
The modules are 9 m long and between 2,6-4 m wide. The maximum size of the modules are 9,6 or 12 m long and 4,15 m wide. This is because of regulations of transportation. The maximum length of 9,6 m makes it possible to transport two modules/truck + trailer. The longer modules of 12 m are only possible to transport one module/truck.

The space modules are prefabricated to approximately 85% in the factory. On site the modules need to be placed and joined, the gaps in the façade left for joining them needs to be covered with panel. The services (water, ventilation, etc) needs to be connected, balconies and the roof are added as well.

ASSEMBLY
Pictures from Derome

THE BUILDING SYSTEM



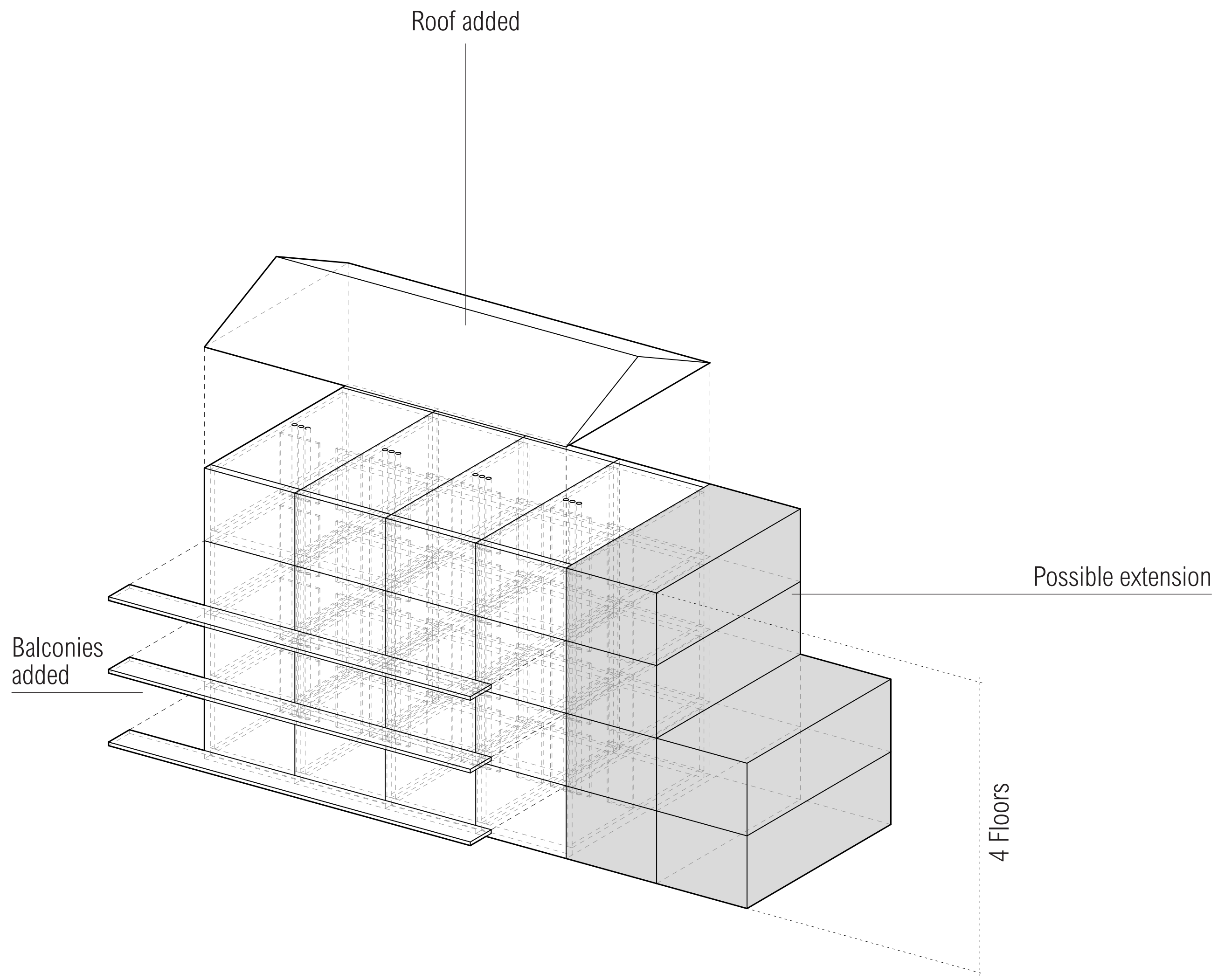


Size limited by the truck / transportation

The space modules consist of modular element. The walls, ceiling, and floor are produced separately before putting it together as a three-dimensional space module.

85% produced in factory

Produced in factory



The space modules are transported as a three-dimensional object and stacked on site to create a building.

Four floors are the maximum height due to fire regulations and structural reasons.

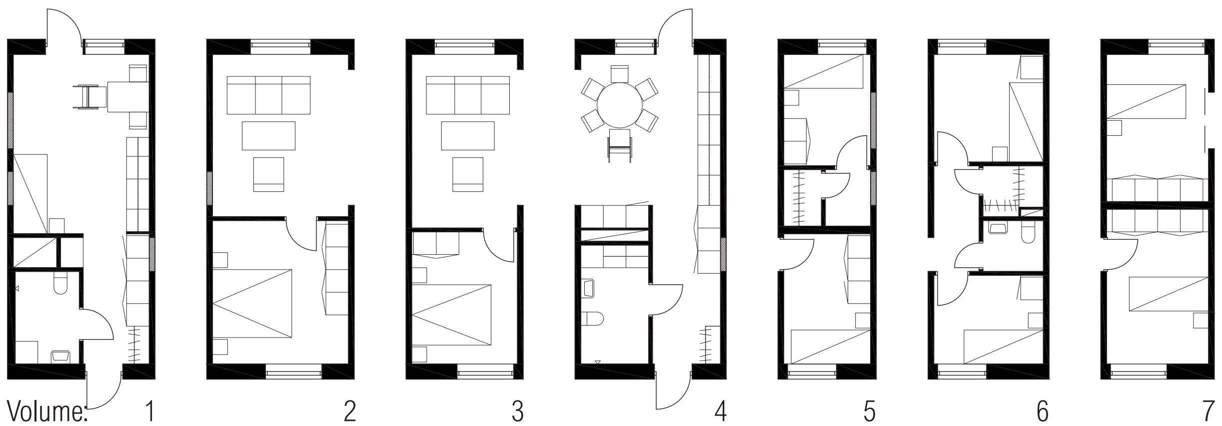
On site

MODULES

There are seven different modules that could be combined in different ways to make ten different apartments. The modules have different functions and different sizes. The combinations possible to make are depending on the where the openings are positioned. The floorplan is limited to the ten apartments, and the façade to where the openings are placed, further explained on page 44-45. Different façade expressions could be made with windows in different styles with window bars etc. Other possibilities to make different expressions are with different wooden panel (horizontal, vertical etc) or even using bricks. The façade must be built on site if using bricks. Different roofs are possible to add as well.

The seven different modules. There are two "base modules", module 1 and 4, that contain kitchen and bathroom where you then add modules with bedroom/s and living room in different sizes, modules 2, 3, 5, 6, and 7. Module 7 contains two bedrooms but for two different apartments.

This system offers a variation of different apartments in the planning stage, but when the building are built, the apartments are fixed.



Volume:	1	2	3	4	5	6	7
Sqm:	28,1	29,6	23,2	29,0	10,4/8,0	23,7	10,5/10,9

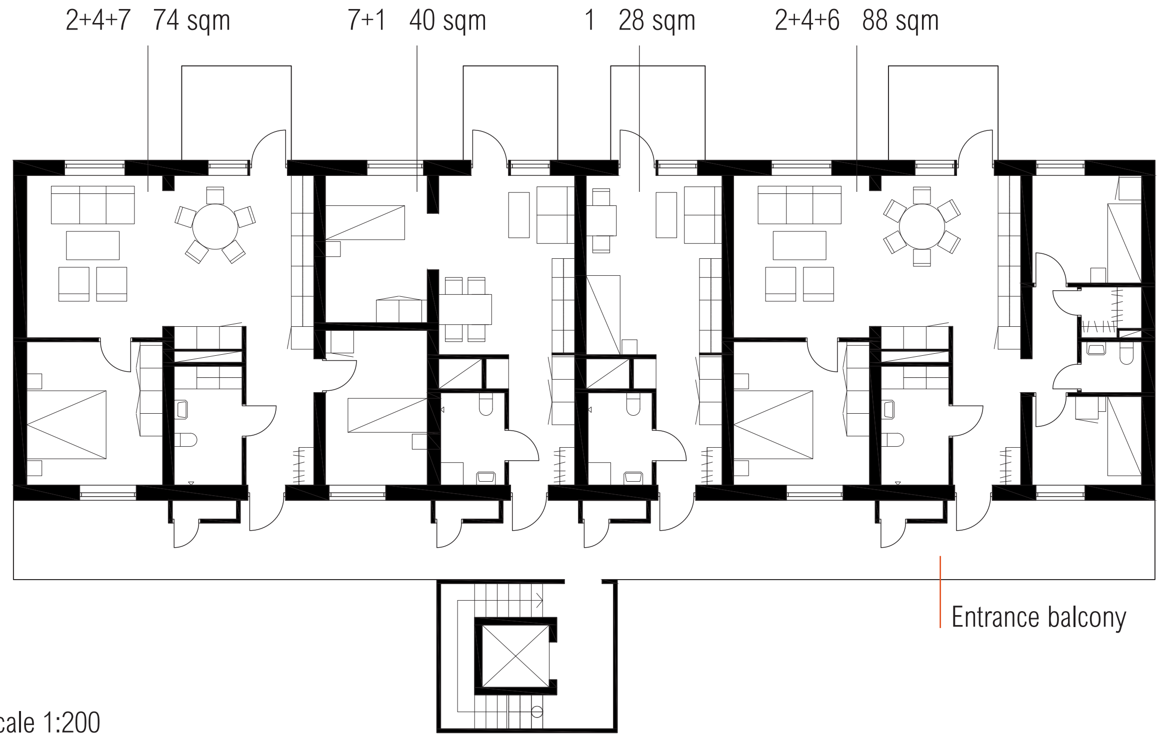
Scale 1:200

POSSIBLE APARTMENTS

Scale 1:200

BUILDINGS IN THE SYSTEM

Two example buildings from Derome are presented with different numbers of floors, length of the building, and different kinds of façade expression. The façade could be in different colours, with a different panel, and different windows, for example with or without window bars as long as they have the same outer measurements. Different floorplans are possible to create with the different modules and the buildings could contain different sizes of apartments as shown in these projects.

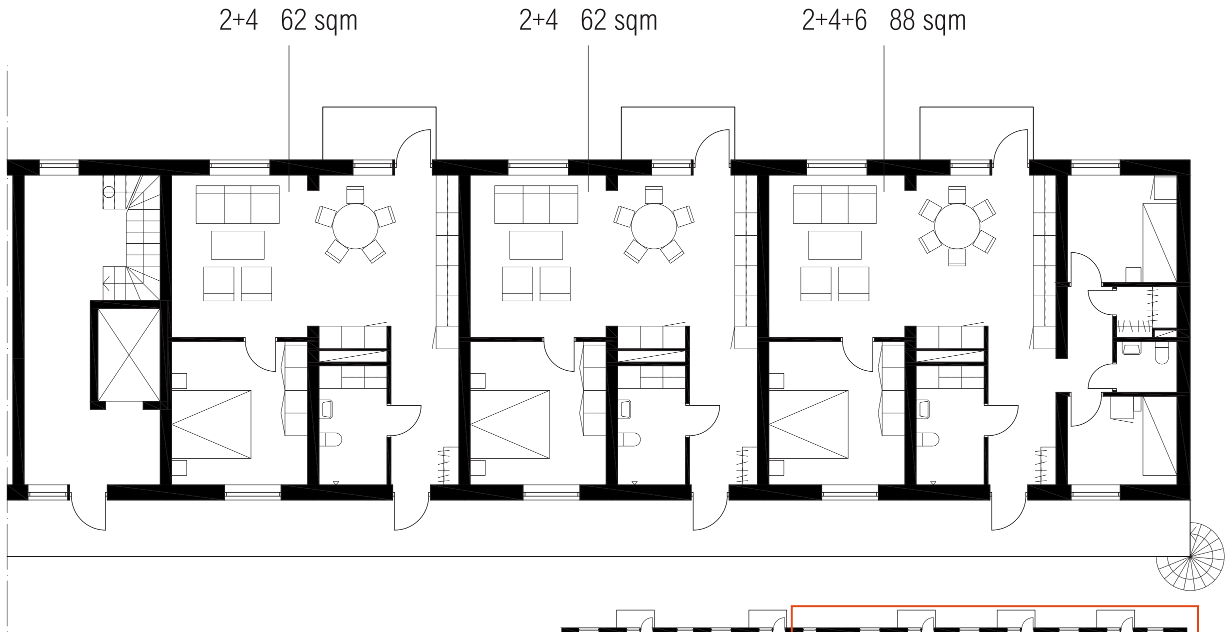


Scale 1:200

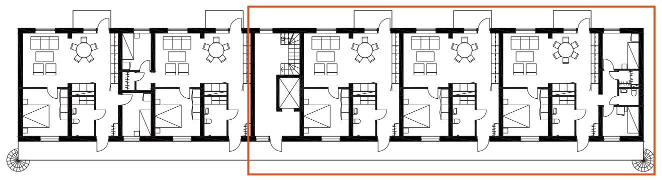
Rendering from Derome

Limbacka, 3 floors
Example building

Scale 1:400



Scale 1:200



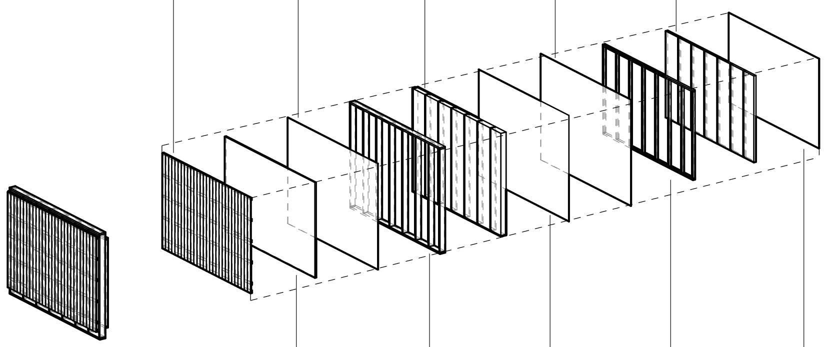
Scale 1:600

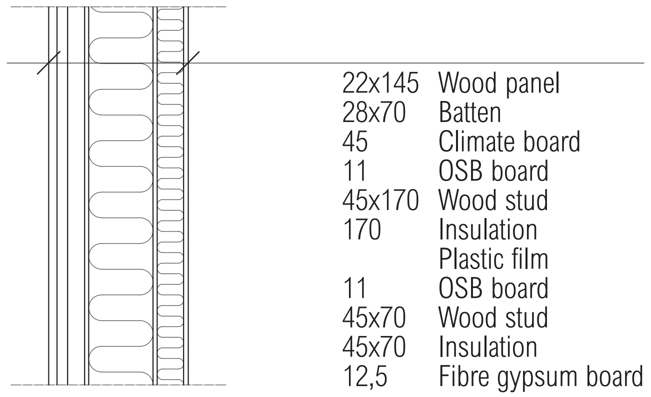
Scale 1:400

Rendering from Derome

Tollvik, 4 floors
Example building

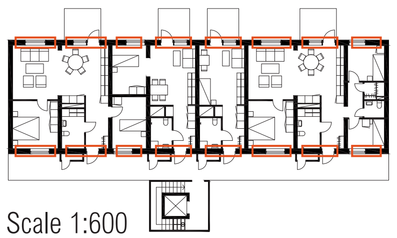
PART OF MODULE - EXTERNAL WALL / SHORT SIDE





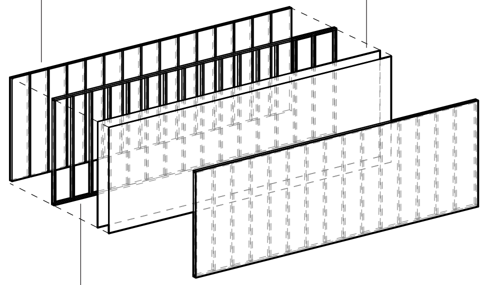
Scale 1:20

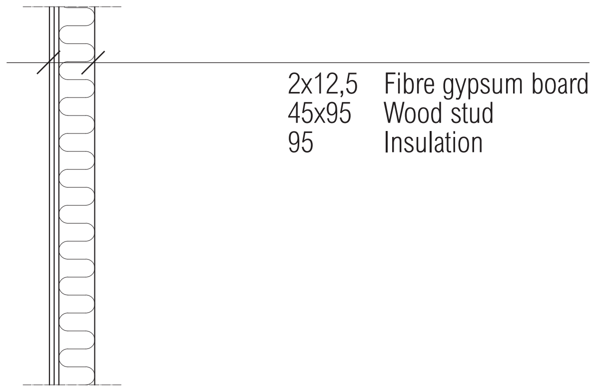
22x145	Wood panel
28x70	Batten
45	Climate board
11	OSB board
45x170	Wood stud
170	Insulation
	Plastic film
11	OSB board
45x70	Wood stud
45x70	Insulation
12,5	Fibre gypsum board



Scale 1:600

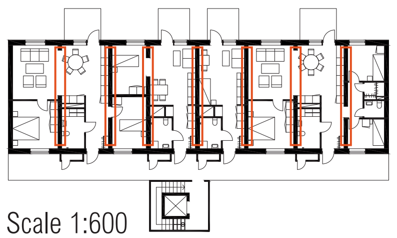
PART OF MODULE - APARTMENT OR ROOM SEPARATING WALL / LONG SIDE





Scale 1:20

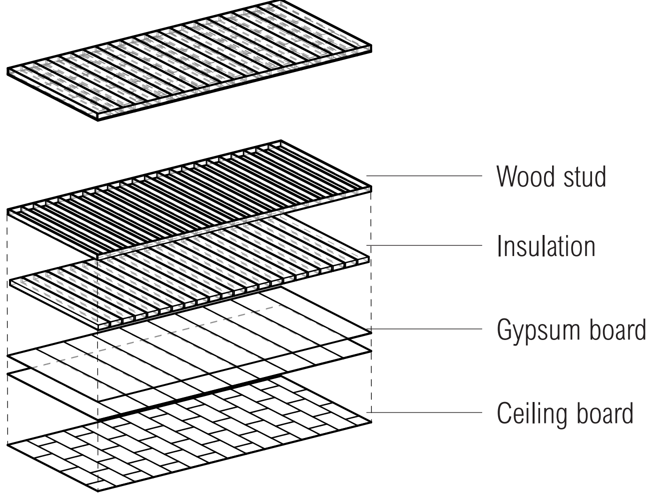
2x12,5	Fibre gypsum board
45x95	Wood stud
95	Insulation

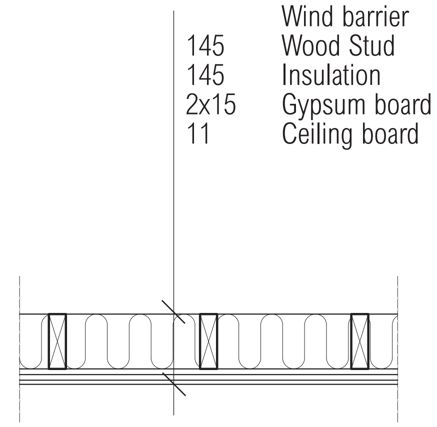


Scale 1:600

PART OF MODULE - CEILING/ FLOOR

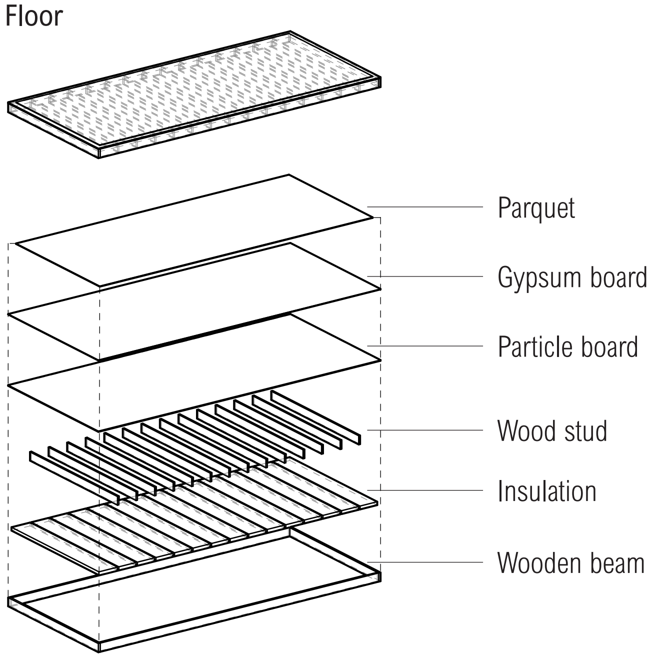
Ceiling

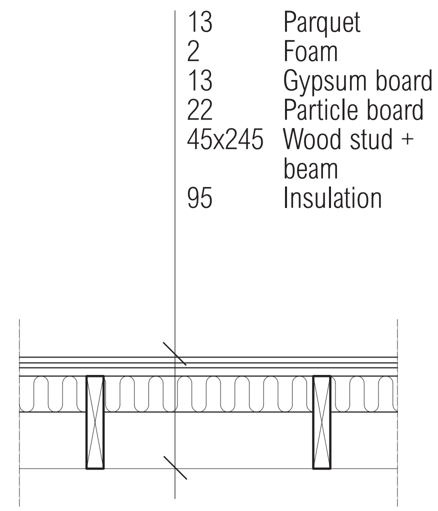




Scale 1:20

Floor

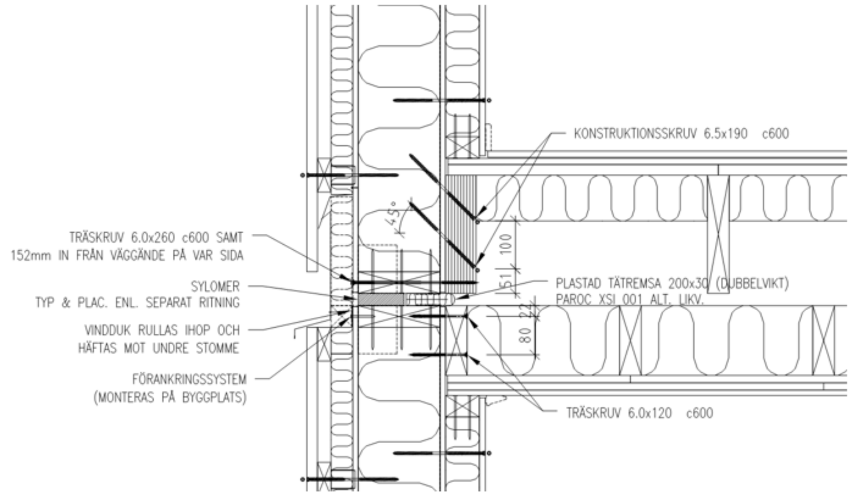




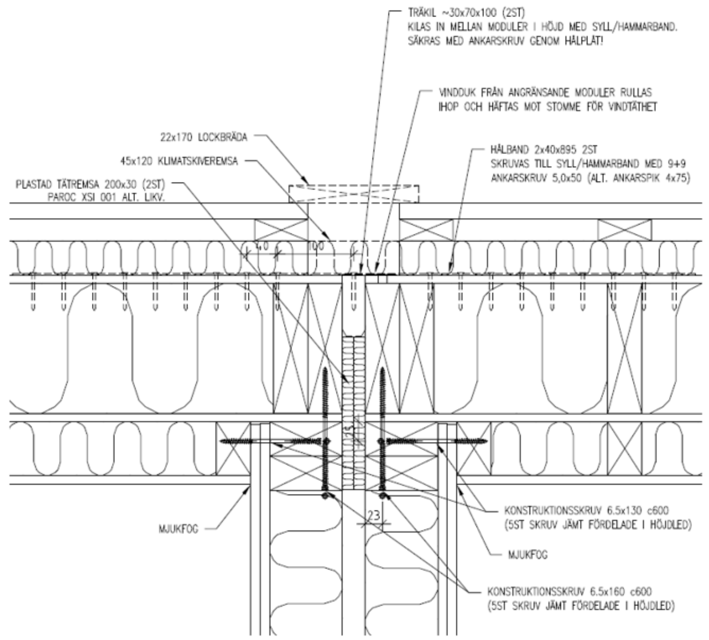
Scale1:20

JOINTS
Drawings from Derome.

The space modules are placed on site and joined with a wedge in between to keep an airgap between the modules for sound reasons.



Vertical / joint between volumes



Horizontal / joint between volumes

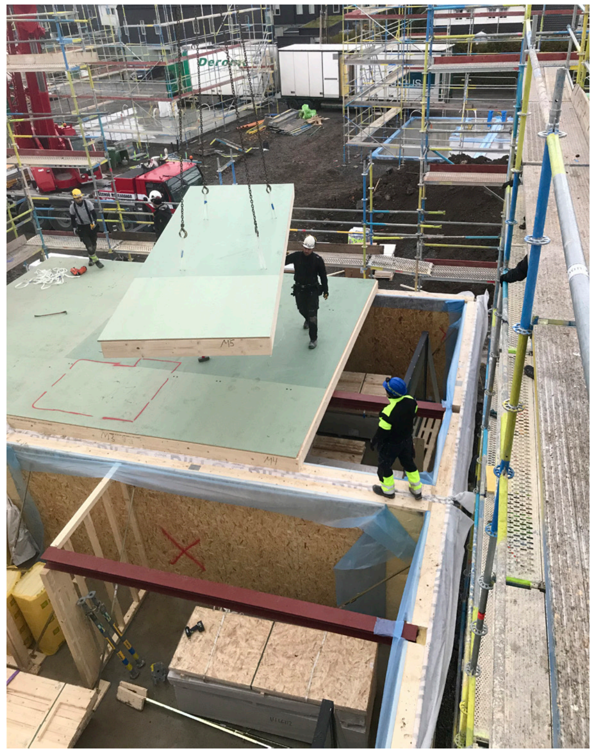
FLAT-PACK

The building system is consisting of elements as loadbearing walls, inner walls, and cassettes. This system is mostly used in residential buildings, but have been used in other buildings as well, for example in offices. The possibility to create different floorplans are possible but limited to the free span of 6 m due to the measurements of the cassette. If a steel beam is added it is possible with a longer free span in the building.

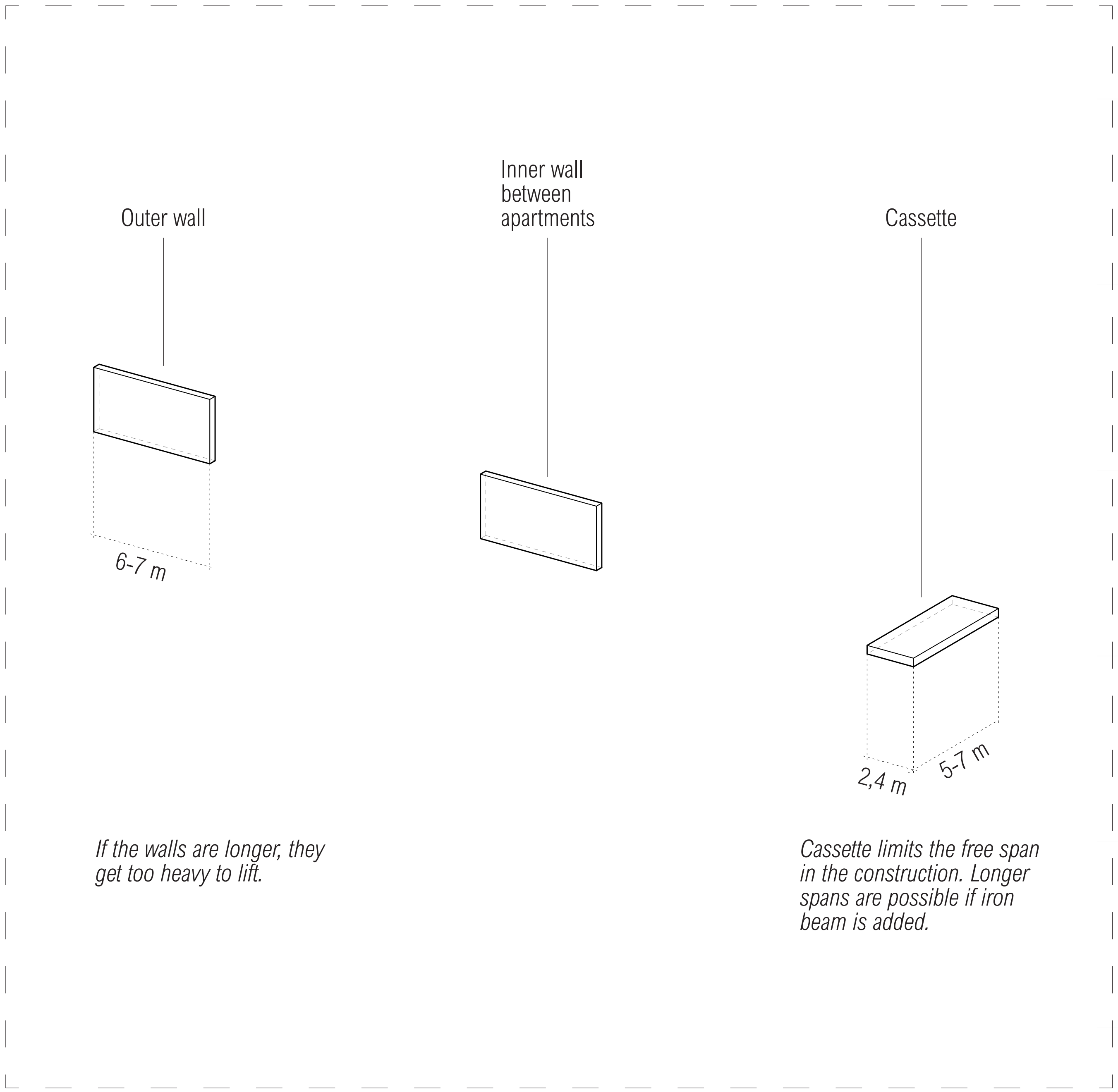
The maximum height of buildings in this system is eight floors, but for economic reasons better to build in six or seven floors. The numbers of floors are limited due to stabilizing reasons in the construction and increased fire regulations over eight floors.

The wall element could be up to 6 m long, if its longer, it would be too heavy to be lifted in the factory and the maximum height is 3,1 m due to transportation regulations. The cassettes have a measurement of 6x2,4 m. It is possible to put five walls on the same truck or seven to eight cassettes when the elements are transported to the building site.

ASSEMBLY
Pictures from Derome

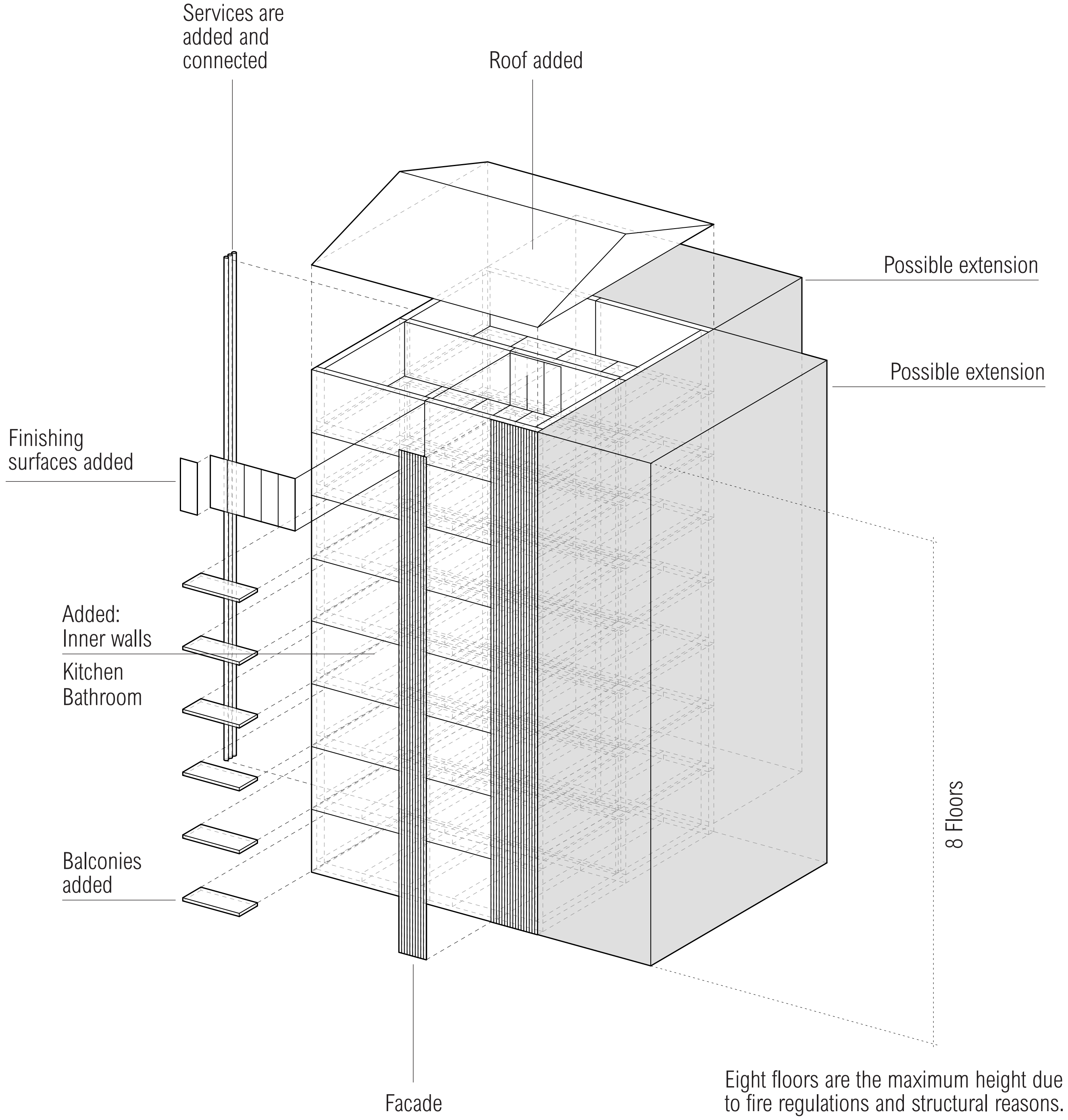


THE BUILDING SYSTEM



Produced in factory

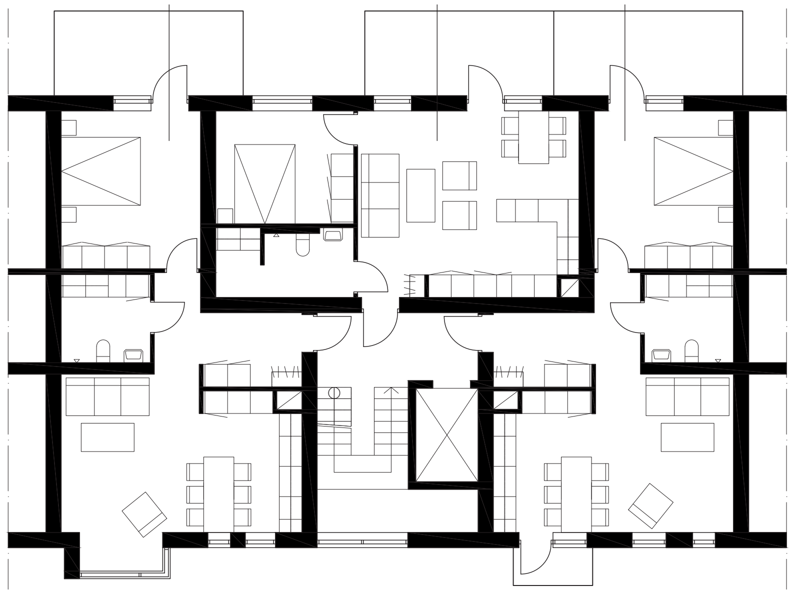
The elements are transported as two-dimensional elements and assembled on site to a three-dimensional building



The facade could be added on site or in the factory.

On site

BUILDINGS IN THE SYSTEM

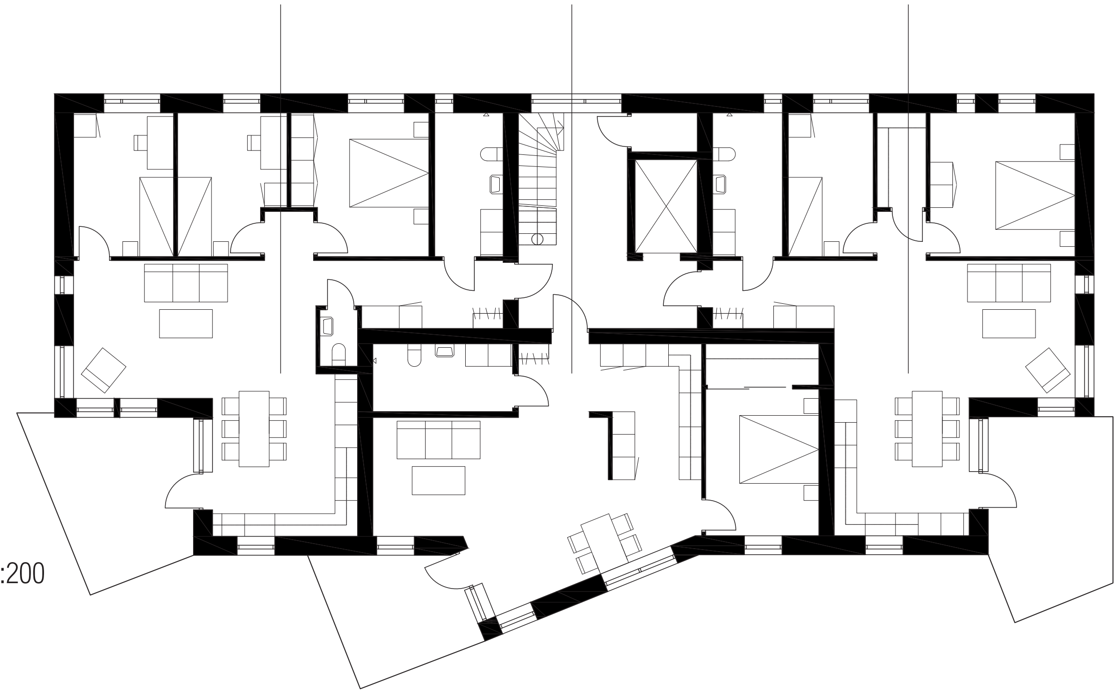


Scale 1:200

As the two buildings here shows, the variation in floorplan and expression in façade are wider than the space modules. The two buildings have different façade materials, different shapes of the building volume, different balconies, and different numbers of floors.

Scale 1:400

Trädriket
Kvillebäcken, Göteborg
2013-2016
Six floors / Residential building
Rendering from Derome

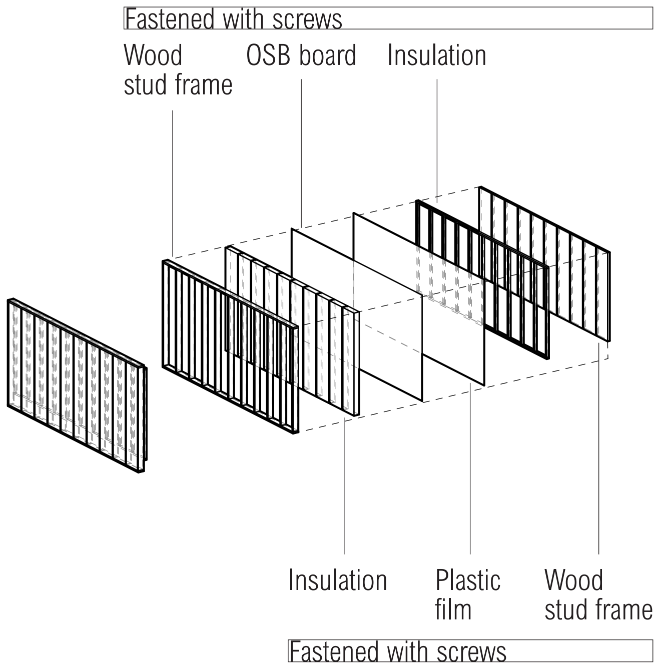


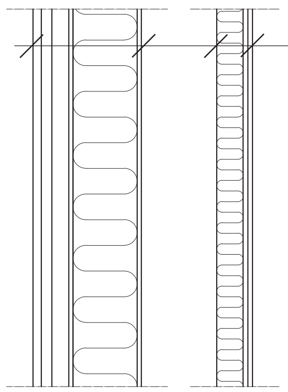
Scale 1:200

Scale 1:400

Kv Kungsäpplet
Varberg
2017
Five floors / Residential building
Rendering from Derome

PART - EXTERNAL WALL

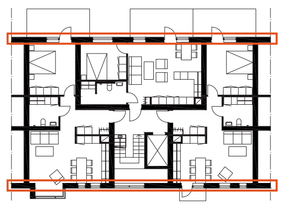




22x145	Wood panel
28x70	Batten
45	Climate board
11	OSB board
45x170	Wood stud
170	Insulation
	Plastic film
11	OSB board
-	
15	Air gap
-	
45x70	Wood stud
45x70	Insulation
2x15	Gypsum board

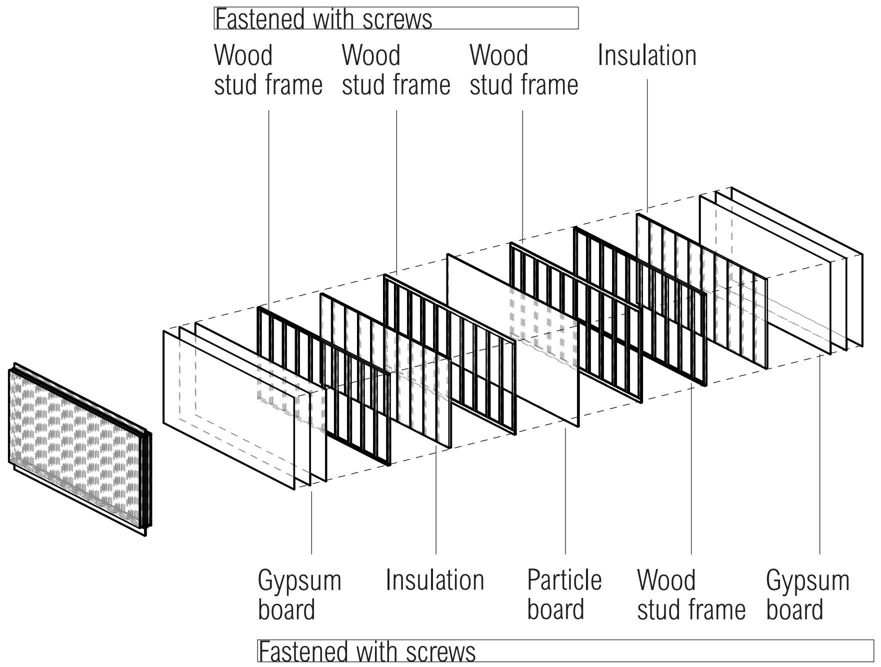
Prefabricated / On site

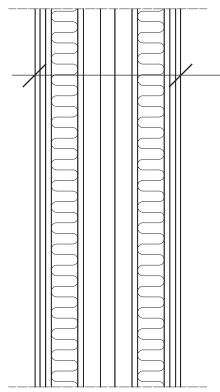
Scale 1:20



Scale 1:600

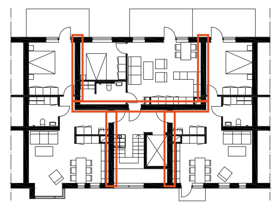
PART - APARTMENT SEPARATING WALL





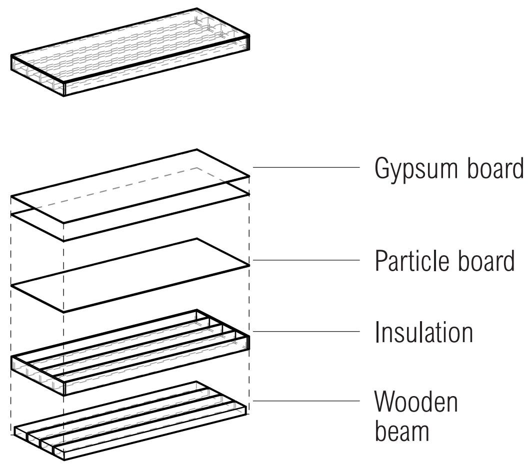
13	Gypsum board
2x15	Gypsum board
45x70	Wood stud
70	Insulation
15	Air gap
45x95	Wood stud
38	Particle board
45x95	Wood stud
15	Air gap
45x70	Wood stud
70	Insulation
2x15	Gypum board
13	Gypum board

Scale 1:20

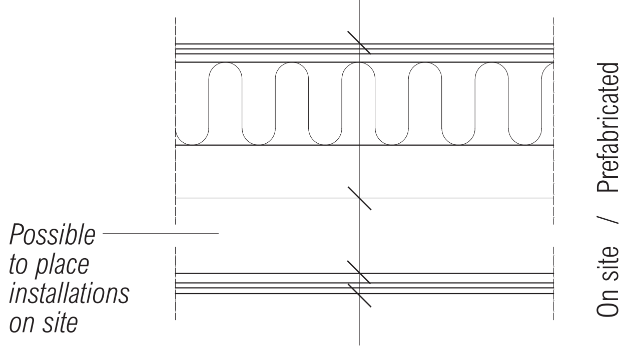


Scale 1:600

PART OF MODULE - CASSETTE



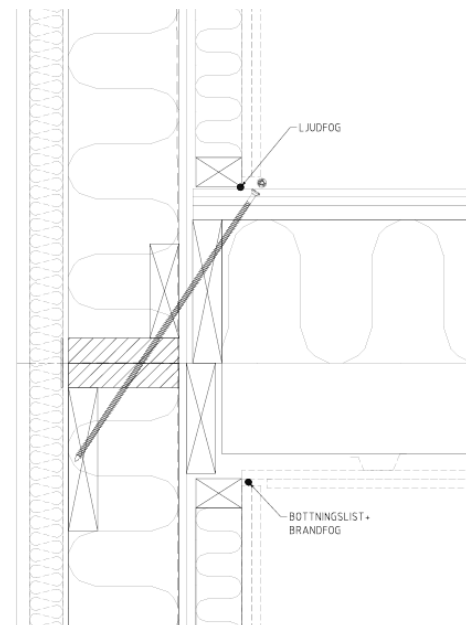
2x13	Gypsum board
22	Particle board
360	Beam
220	Insulation
-	
25	Acustic batten
13	Gypsum board
15	Gypsum board



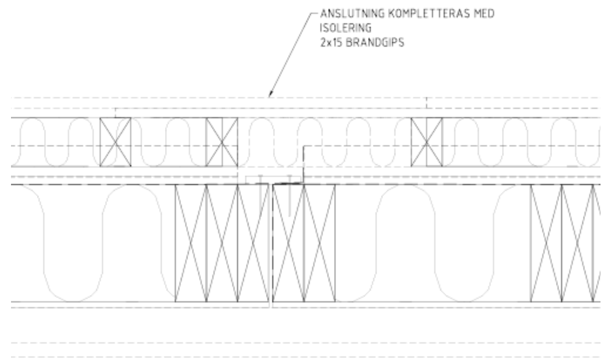
Scale 1:20

JOINTS
Drawings from Derome.

The elements are joined with many and long screws of 500 mm. This makes the elements hard to disassembly and screw apart because of the screws which could be hard to find and remove, they could break.



Vertical / joint between outer wall and cassette



Horizontal / joint between panels

SUMMARY

The two building systems have their differences regarding possibilities and limitations. To start with the grade of prefabrication; the space modules are prefabricated to a higher grade of approximately 85% and the flat-pack system is not prefabricated to the same grade. A consequence of this is that the time for finishing the building on site from the first day of assembly to the day the building is completely done is longer for the buildings in the flat-pack system. The flat-pack system offers though a greater freedom in design of the floorplan and facade. The floorplan itself could be more or less adaptable, depending on the size of the apartment and rooms, layout, placing on functions, connections, and loadbearing walls. The space modules are more limited in floorplan and focuses on the possibility to offer a variation of apartments when planning the building but when its built, the apartments are fixed. The space modules are limited in the architectural freedom and the flat-pack buildings gives a larger freedom for each building. The flat-pack system are more expensive to build in than the space modules.

The systems have because of their different structures, different ways to be joined. The space modules could quite easily be separated both module to module, but also in the module itself, mostly using screws for joints and are “looser” in the construction than the flat-pack system. The elements in the flat-pack system are joined with long and many screws and which makes the elements difficult to separate, both when finding all screws and get them out without breaking them. The building systems have different capacity in number of floors. The space modules can be up to four storeys and the modular elements up to eight.

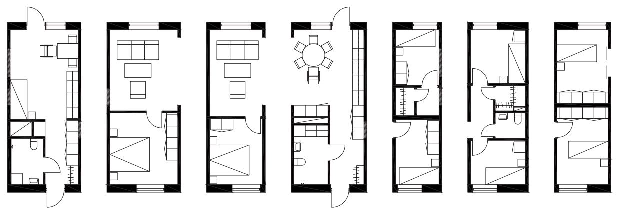
The finishing surfaces, the fibre gypsum boards, are attached with brackets which would make it hard to remove the board without destroying them. The formats of the boards are also optimised for prefabrication and are in a large format, 3 m long which would be hard to handle with only a human’s strength.

The system that I am continuing investigating are the space module system. Due to the limitations of the systems I think it would be interesting to investigate how the system would work in an adaptable way. It has a high grade of prefabrication that are beneficial in costs and working conditions but limited to each module in floorplan and the façade expression.

Investigations of the space modules will include arrangement of the modules, how the apartments are connected to the staircase, measurement, openings connecting the different modules, placement of fixed functions, different uses, and the possibility to separate different layers or components. The aesthetics of the building are also explored.

ADAPTABILITY IN THE SPACE MODULES

The buildings could consist of ten different apartments. The focus in this system is to provide a varying range of apartment, but this in the planning stage of the building, not during the building's lifetime.

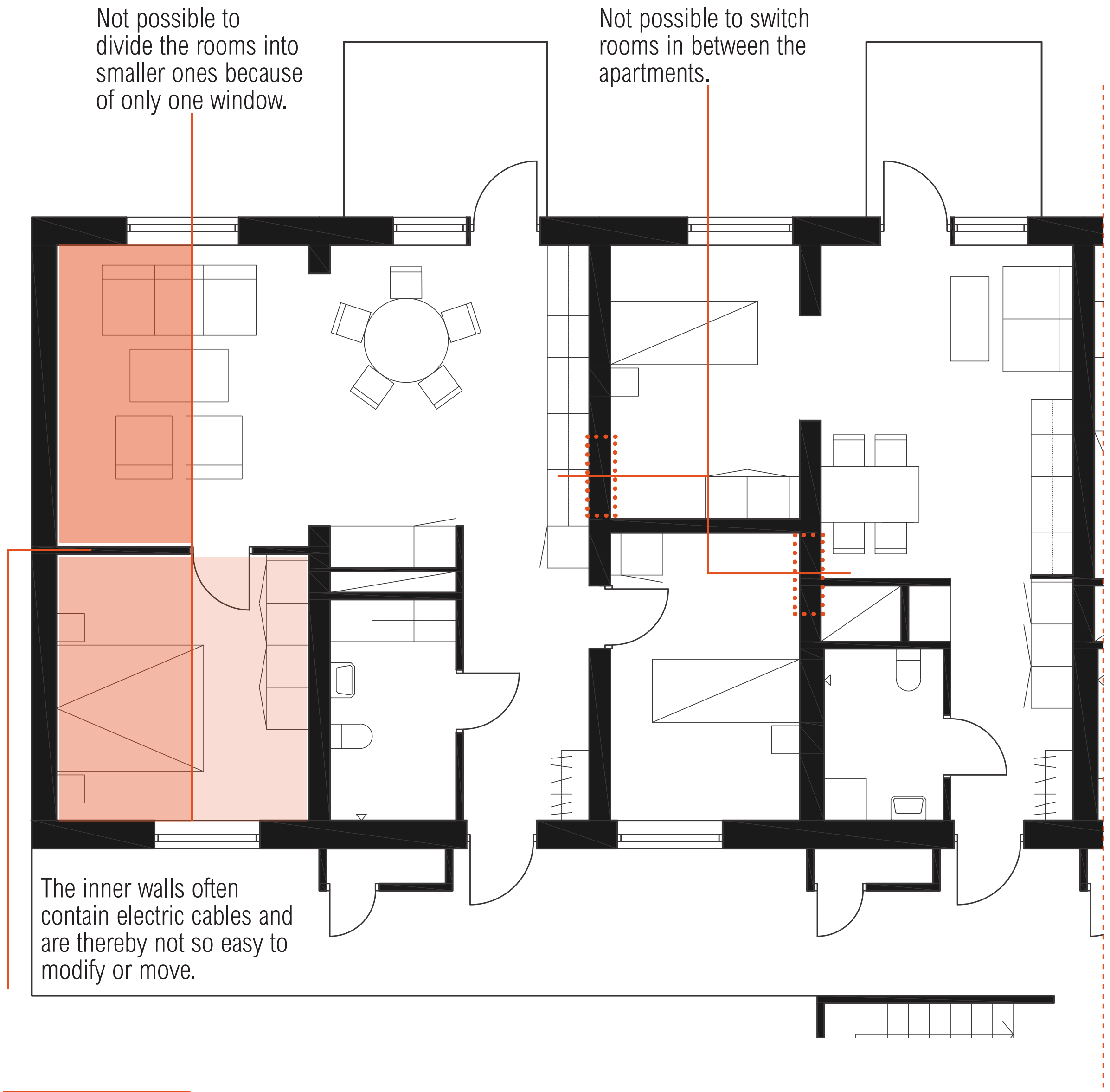


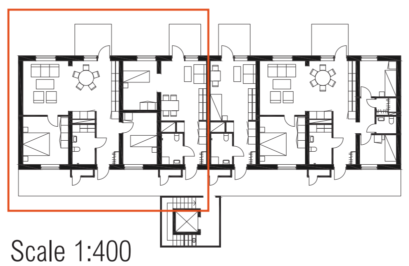
Seven different modules.

The modules are possible to be combined in different ways to create ten different apartments.

Drawings presented in a larger scale on pages 24-25 .

The focus in this thesis is the possibility to adapt during the building's lifecycle. The system is fixed in many ways as it is now.





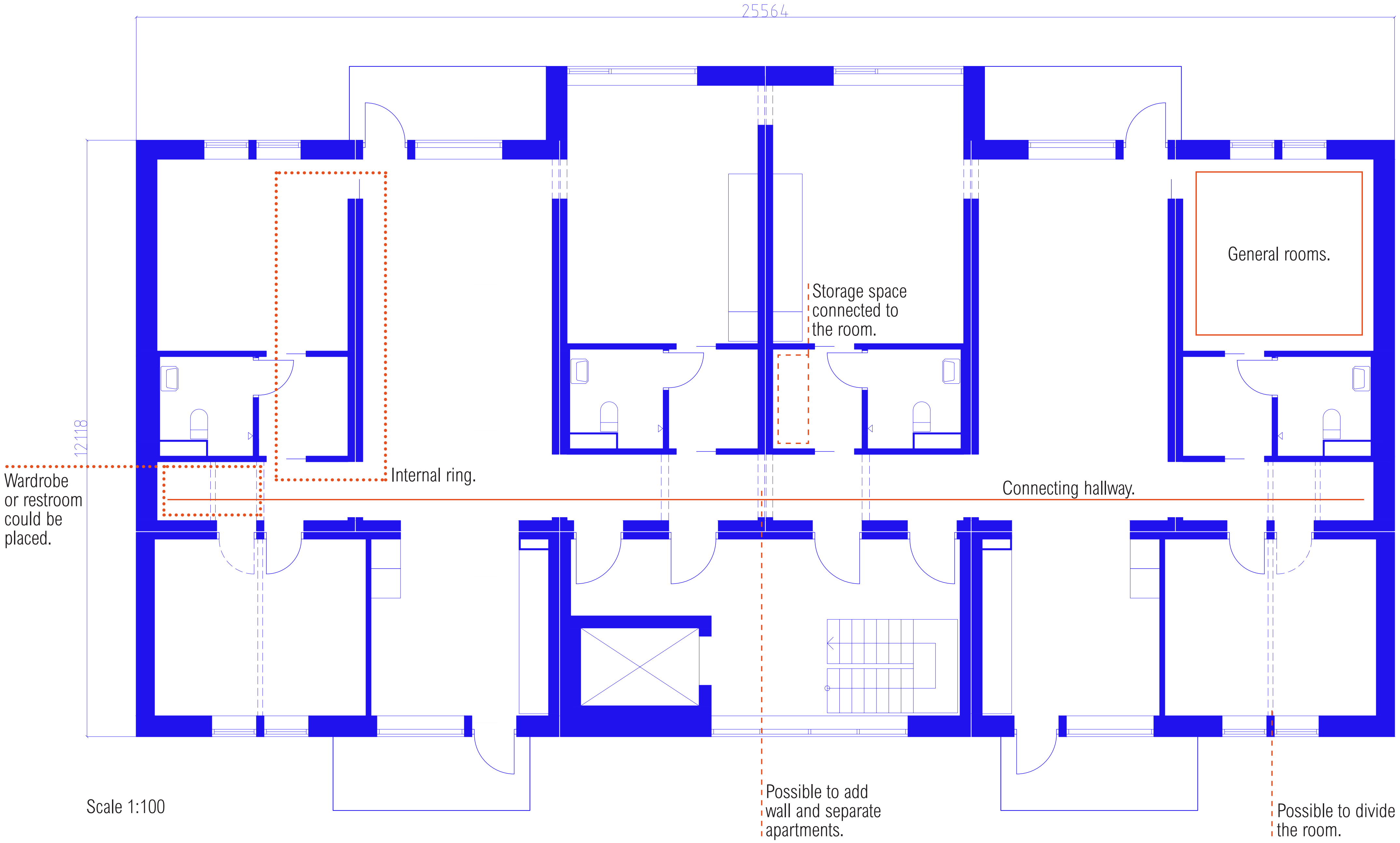
Scale 1:400

The proposed system will be similar to this system in some cases. The goal is to make the size of rooms and apartments similar and accommodate the same functions, this also according to the Swedish standards.

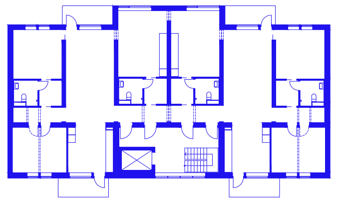
This proposed building system has a focus on a building that is possible to change over time. If the needs of the residentials changes, the apartment could respond to this by shrinking or growing in the sense of adding or contracting rooms from adjacent apartments and dividing rooms into smaller ones. This could make the residentials stay in the building even if changes happen. To be able to stay in the same apartment is important for the residentials to keep the social network in the neighbourhood, connections to different activities and work, for the children to not change school which could be difficult if moving etc.

Three adaptable strategies are applied; elasticity, generality, and flexibility. The strategy that are applied to the largest extent in the design proposal are elasticity, due to the focus on a transforming building with adding or contracting rooms and shrinking or growing apartments, as a response to the changing needs of the residentials and number of people living there. The building system developed in this thesis, have some similarities with the existing system and Derome's apartments with sizes and number of rooms.

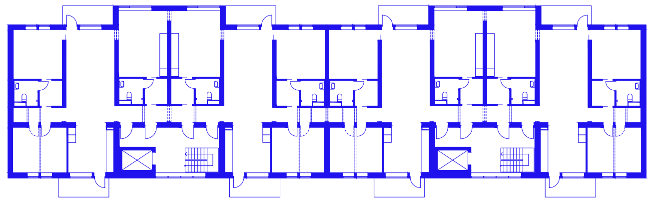
One building consists of nine modules, presented on page 51. Buildings are possible to connect to create a longer building.



Scale 1:100



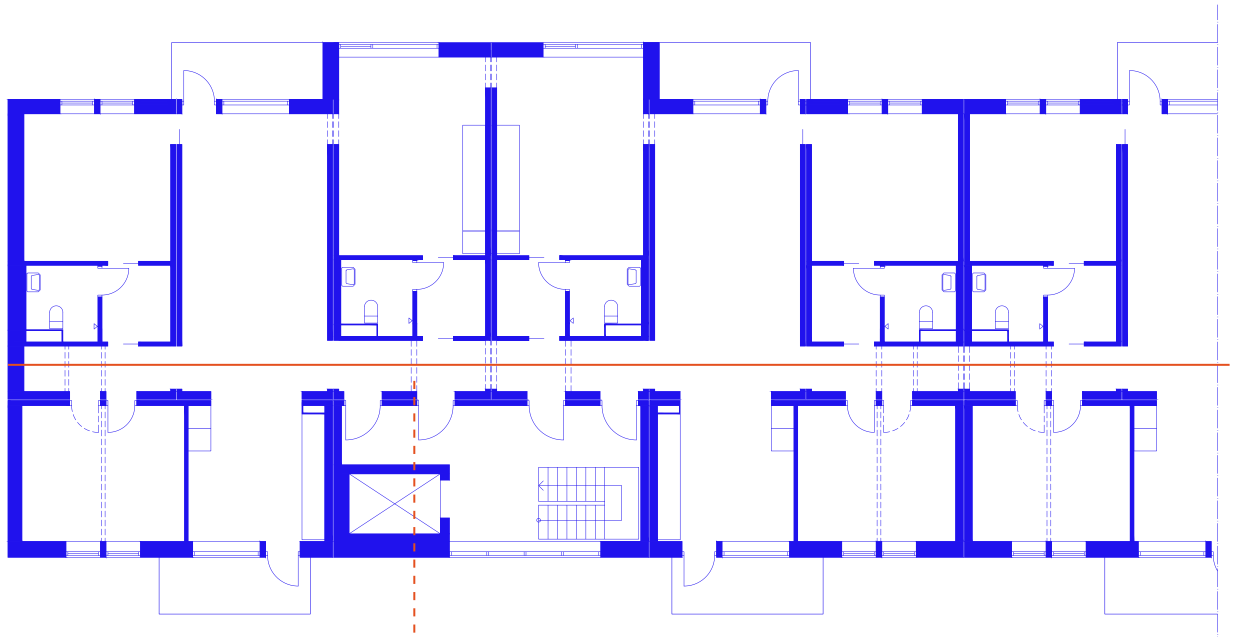
Scale 1:600 *One "building".*



Two "buildings" connected into one longer.

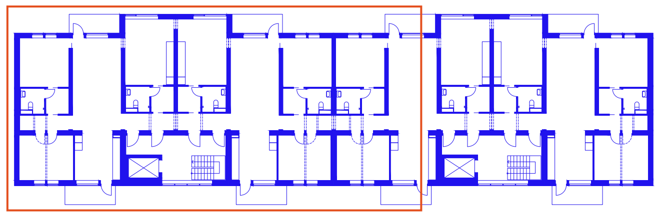
ELASTICITY

This system enables the apartments to grow and shrink. All modules are connected through a hallway in the middle in the building. By dividing or connecting the hallway the apartments could add or contract rooms. Details of dividing the hallway is presented on pages 66-67.



Scale 1:200

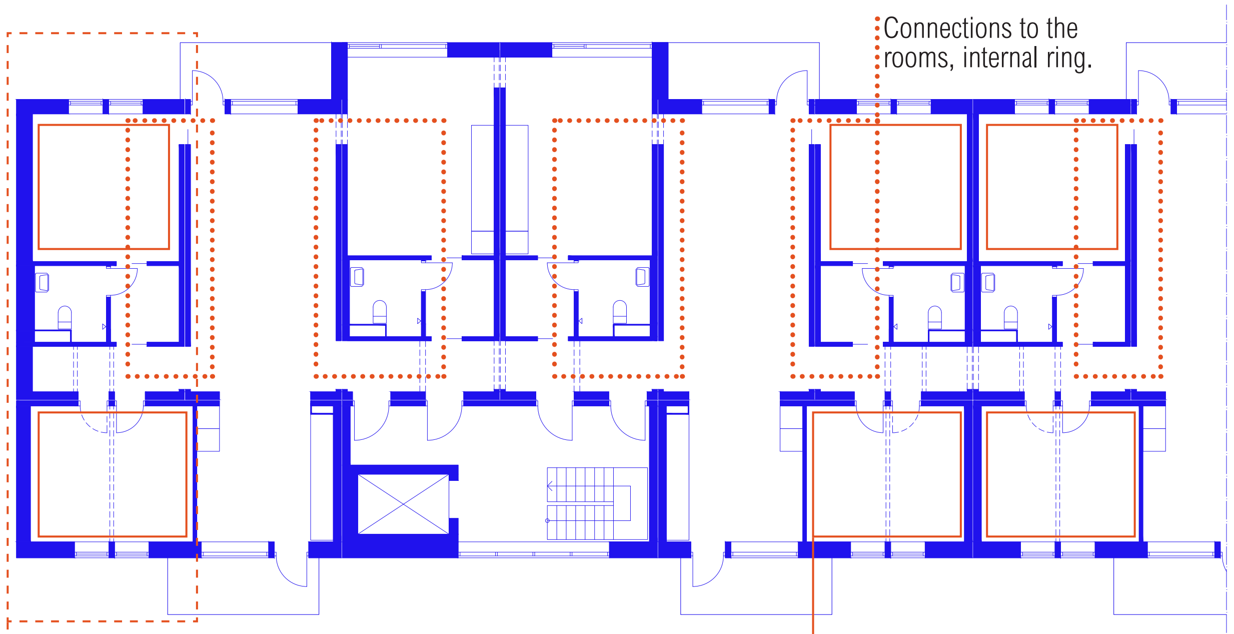
The different possible apartments when connecting or dividing the hallway are further explained on page 54-57.



Scale 1:600

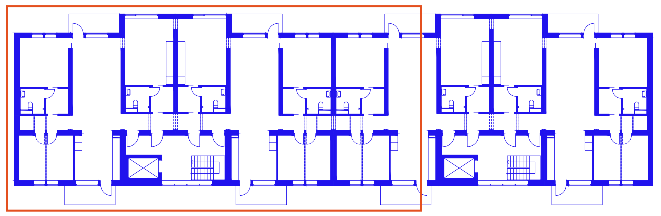
GENERALITY

The more private rooms are almost the same size and have a square shape for a general use such as bedrooms, a working space for a home office etc. The both rooms are reached through a neutral hallway. One of the rooms has two ways of accessing it, one more private through the hallway and one more public through the living room. This could both give the room a more public or private content and the openings creates an internal ring. The sizes of the rooms are 15,4 sqm and 15,1 sqm.



Scale 1:200

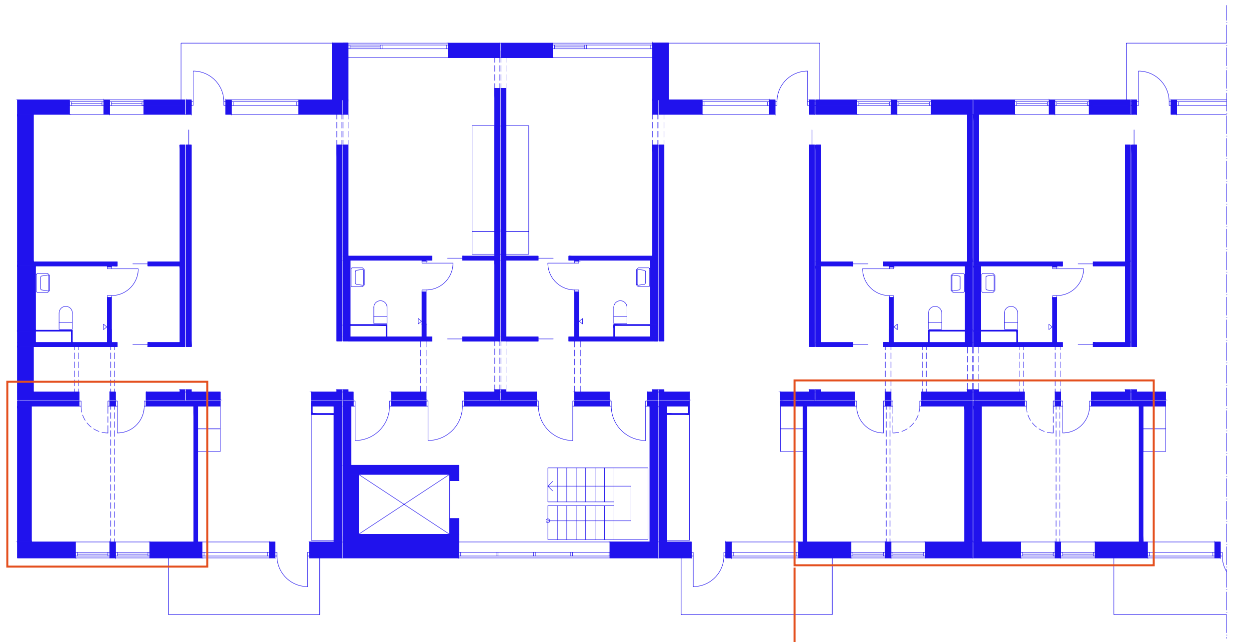
Different ways of furnishing the general rooms.
Scale 1:400



Scale 1:600

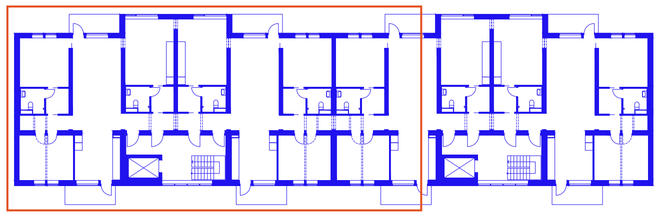
FLEXIBILITY

The room next to the kitchen is possible to divide into two smaller ones by adding a wall. The both rooms are quite small 7,5 sqm but has the width of 2,1 m which makes them accessible as a bedroom with a single bed. These rooms could for example be used as two smaller bedrooms or a bedroom and an office space. How the room is divided is further explained on page 68.



Scale 1:200

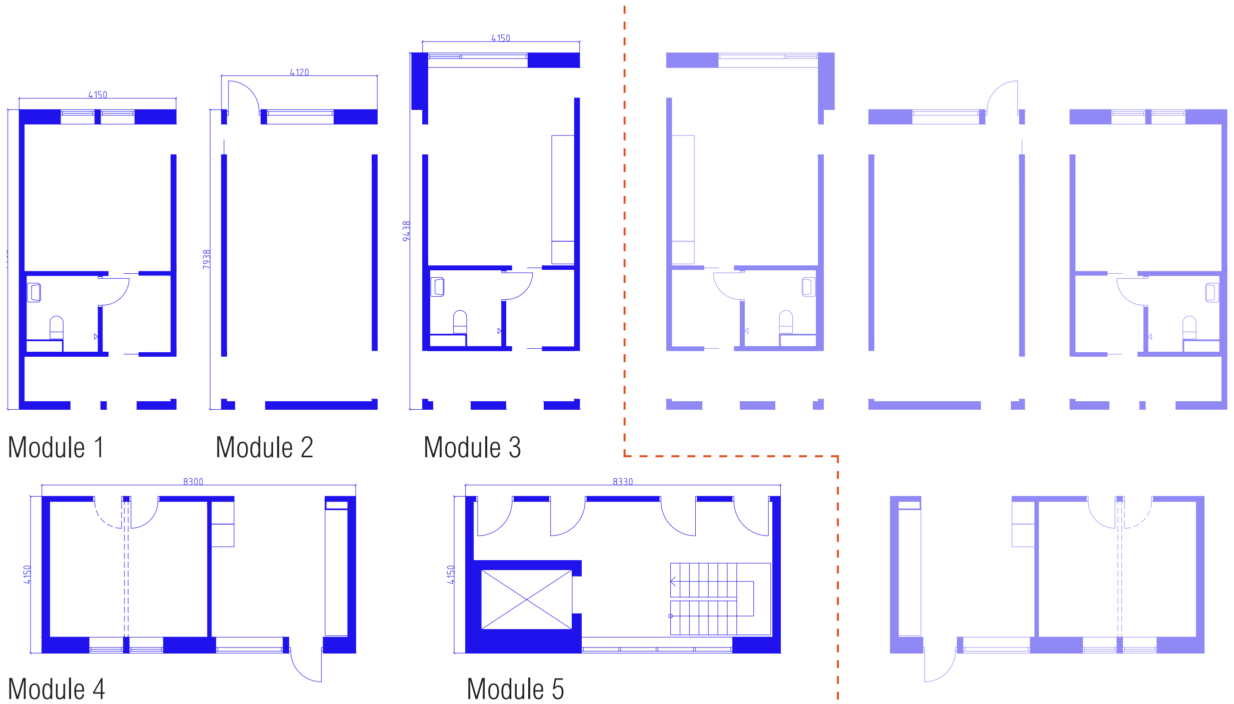
Possible to divide the rooms into two smaller ones.



Scale 1:600

MODULES

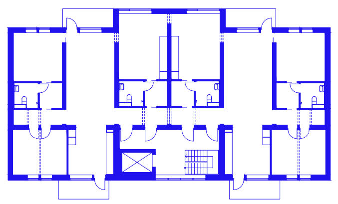
The building is consisting of five different modules, where module 5 is the staircase and integrated in the building instead of the existing entrance balcony. Module 1-4 is mirrored, which means that one floor of one building in total consists of nine modules.



Scale 1:200

General structure created with five modules where one of them are the staircase. The other four modules are mirrored to create the whole building. Module 5 is the staircase

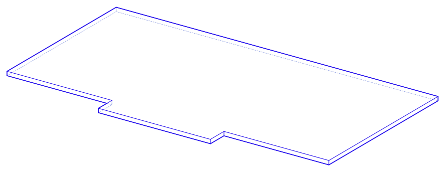
Mirrored modules 1-4



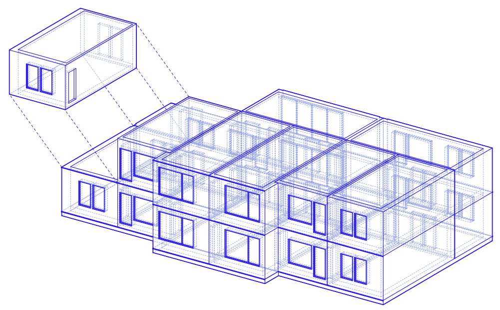
Scale 1:600

ASSEMBLY

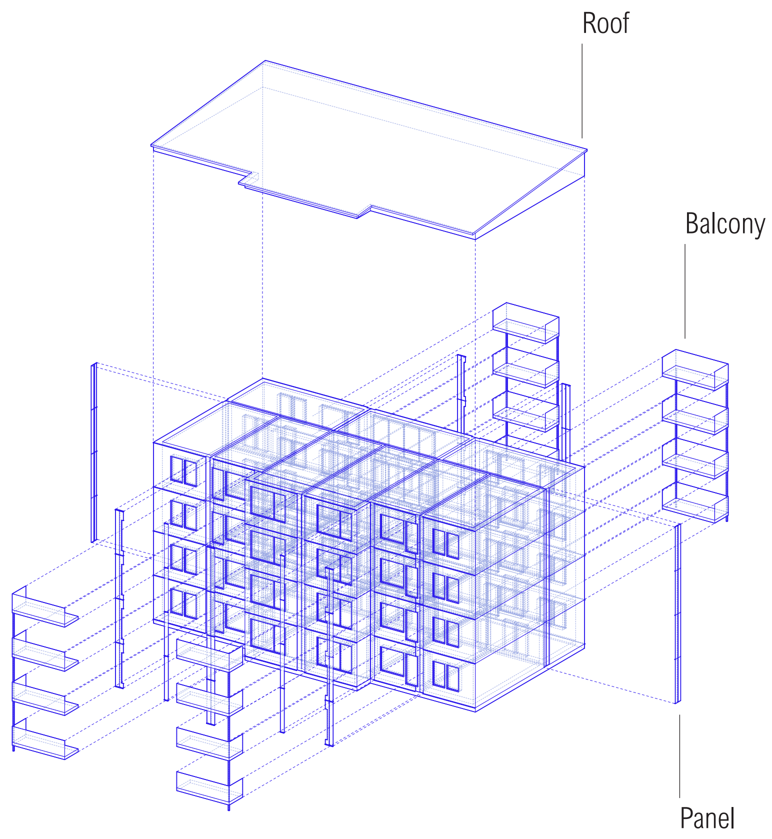
Example of a building in the system with four floors. The buildings in this system could maximum be four floors due to fire issues and structural reasons.



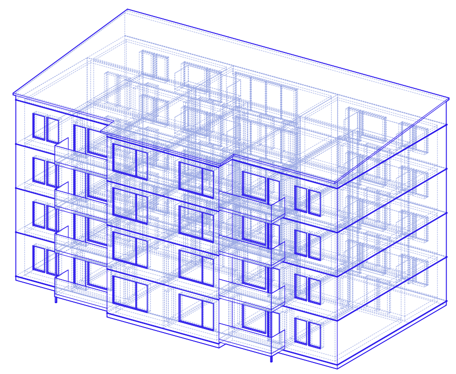
Foundation on site.



Placing modules with a crane and joining them.



Adding roof and balconies. Connecting services and adding the missing panel for covering the joints.



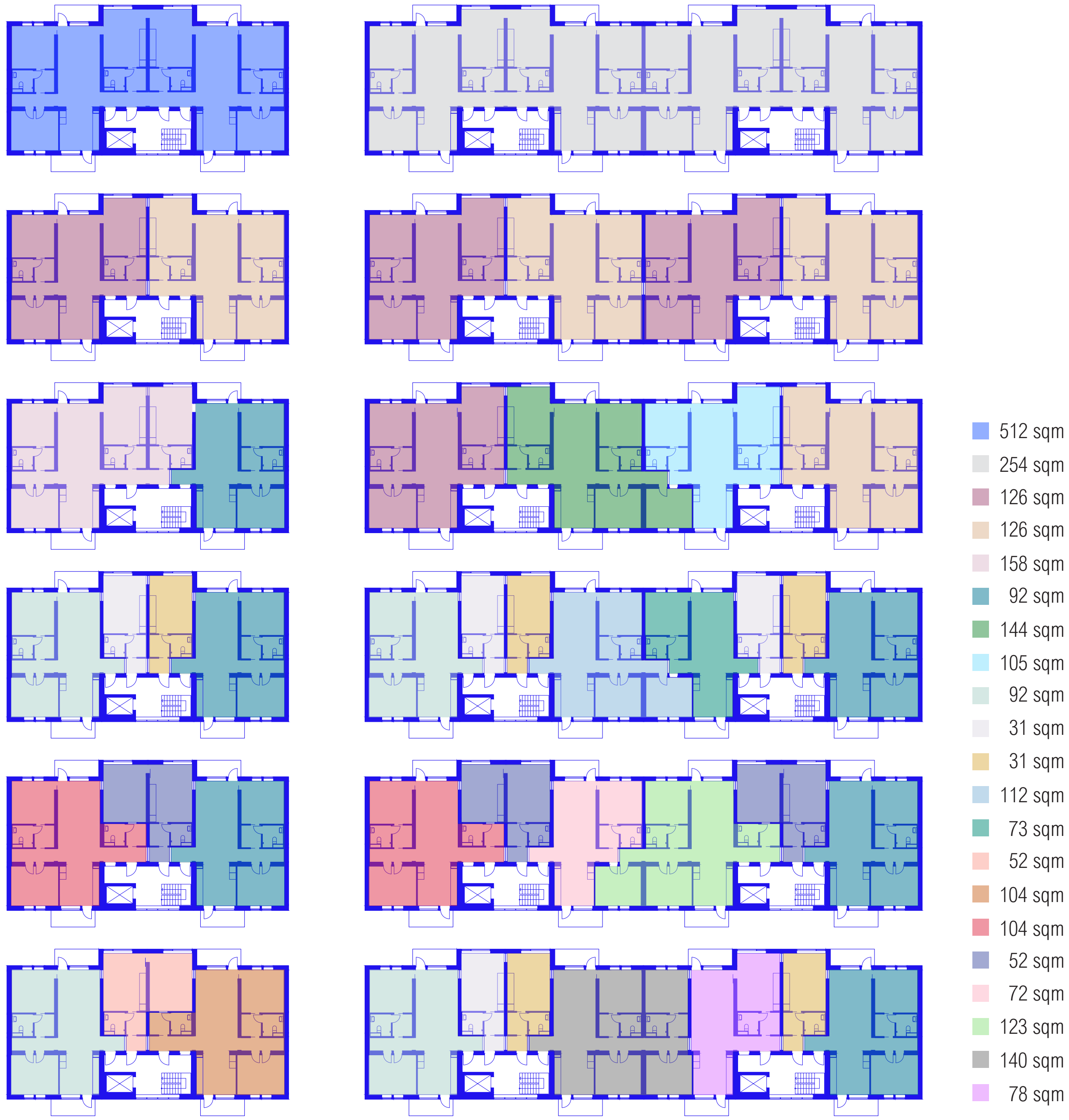
Finished building.

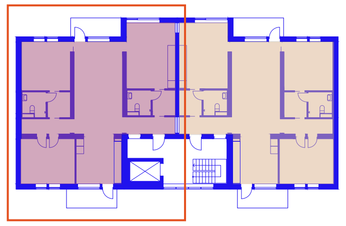
POSSIBLE APARTMENTS

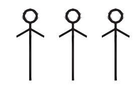
Different apartments are possible by connecting or contracting rooms. Presented on this page are possible apartments in both one building or two buildings connected. How many apartments every floor contain is depending on how the spaces are connected and the sizes of the apartments. It is possible to connect an entire storey.

One building:

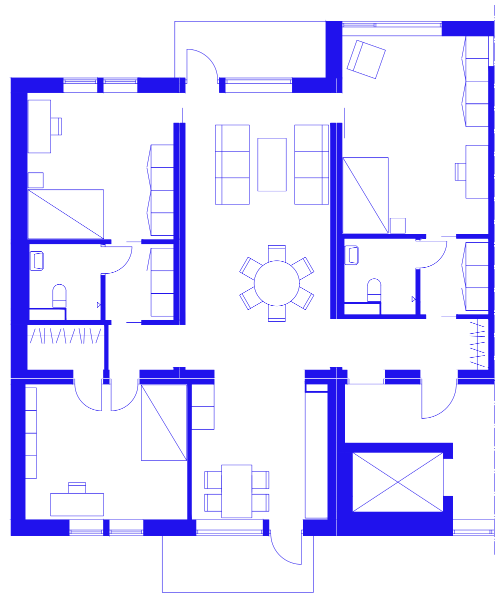
Two buildings:

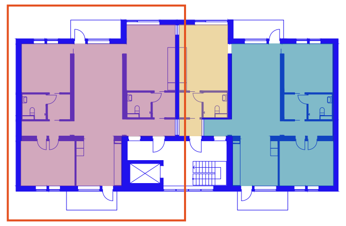


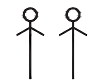




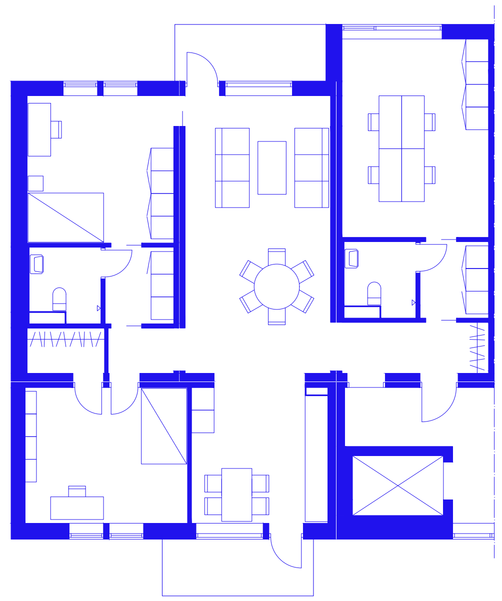
Three friends are living together. They have their own bedroom but share the kitchen and living room.

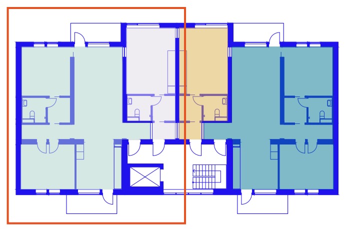


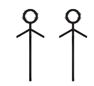




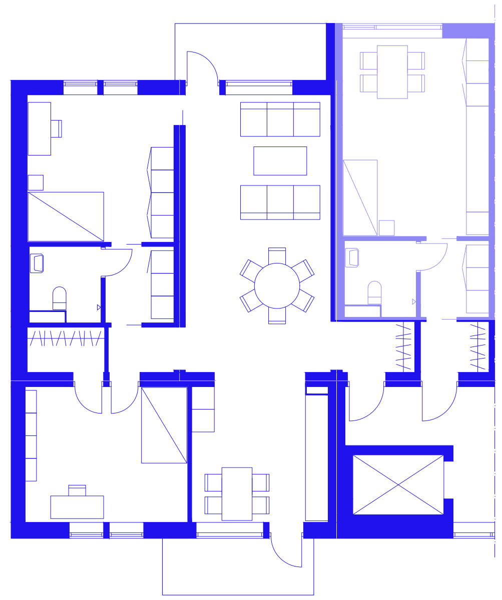
One of the friends moves out. The two remaining turns the now empty room into a small office.



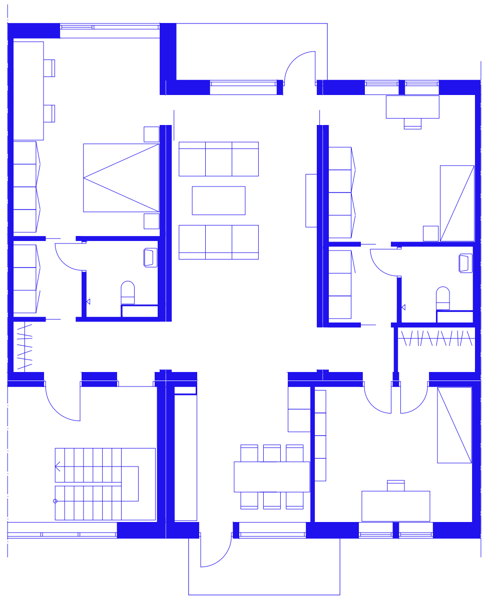


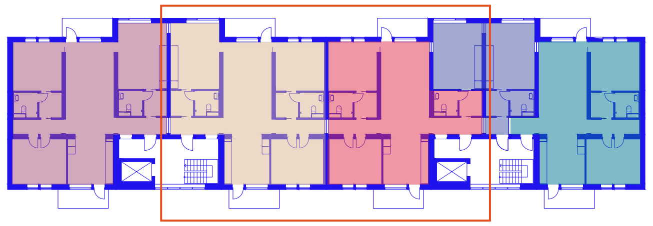


The office is no longer needed and turns in to a separate apartment. A room is cut off and the apartment is shrinking.

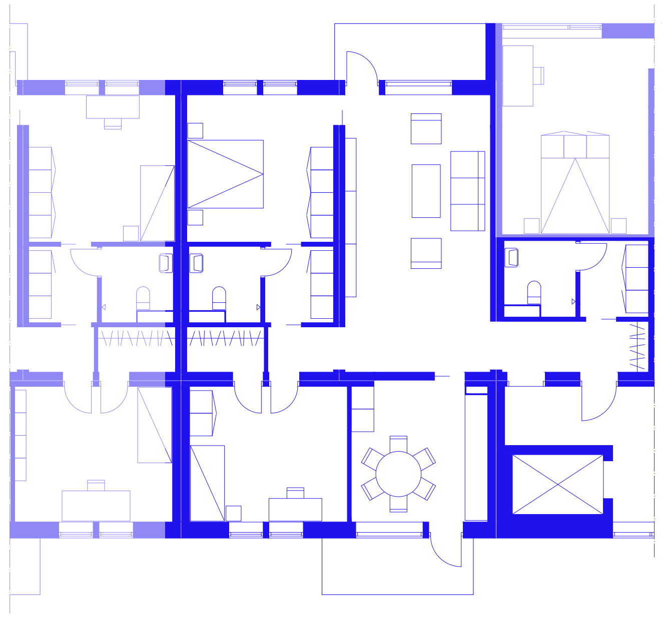


Two parents with two children lives here. Both children have their own rooms and the parents share the larger room.

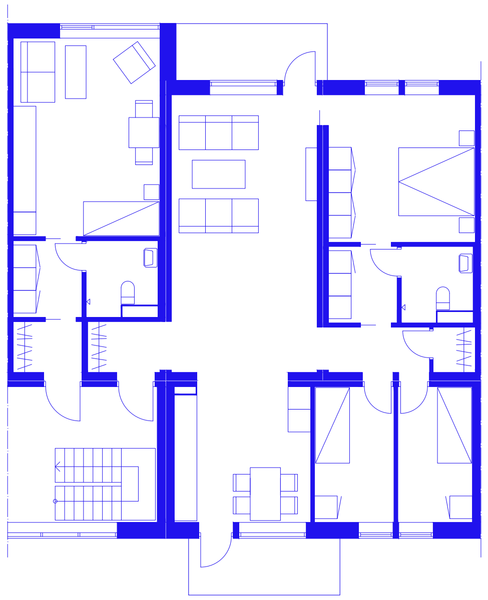


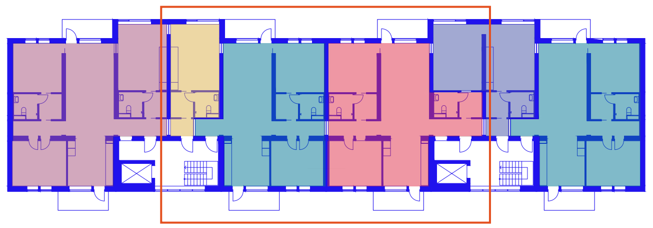


One couple lives here with their child.

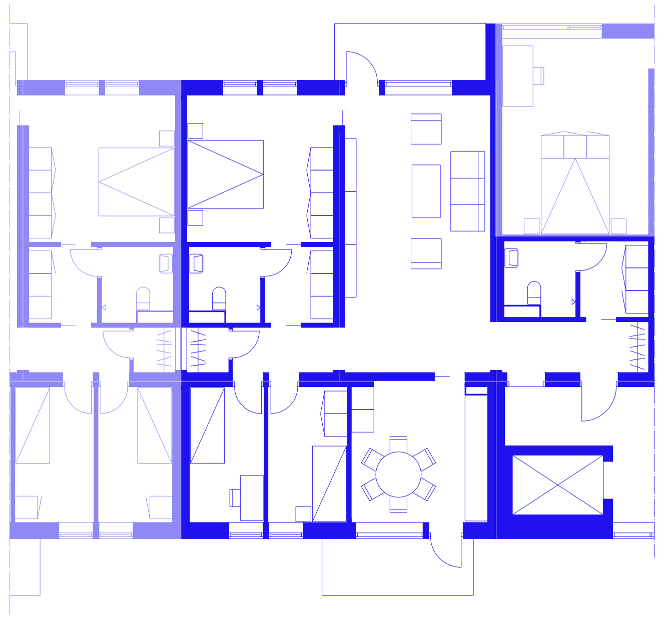


The parents get divorced and the larger rooms get cut off and turned into a separated apartment for one of the parents who will still live close to the children. One of the bedrooms are divided into two smaller ones, one for each child.

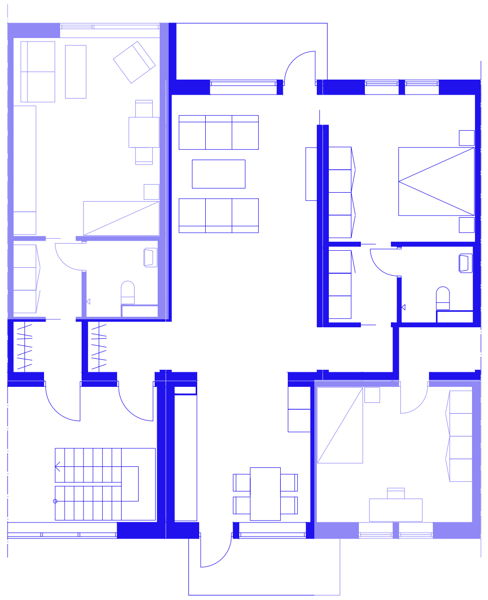


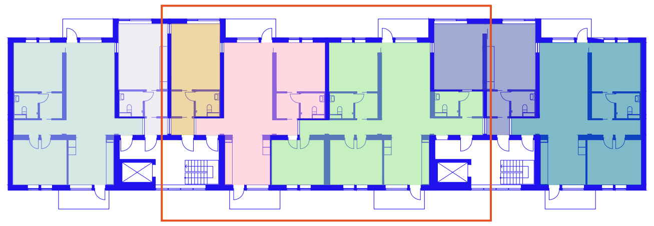


The parents get another child and divides one room into two smaller bedrooms.

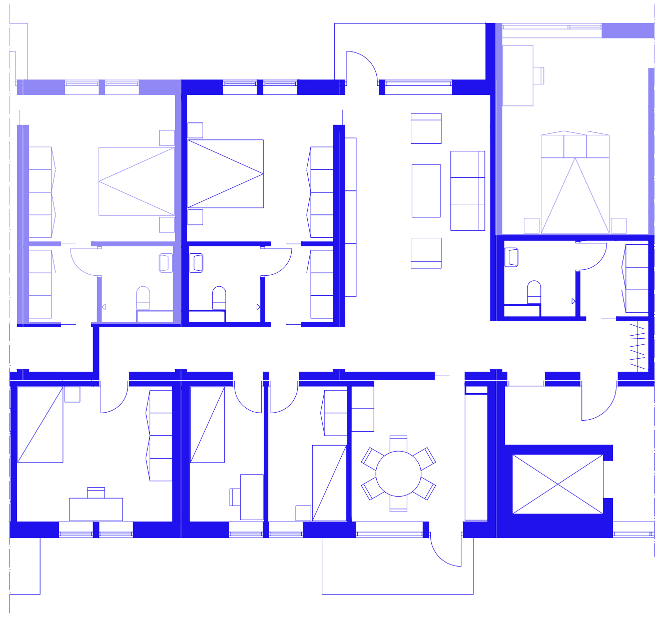


The children move out and their bedrooms are turned into one larger room and given to the apartment next to it. The other parent moved away.



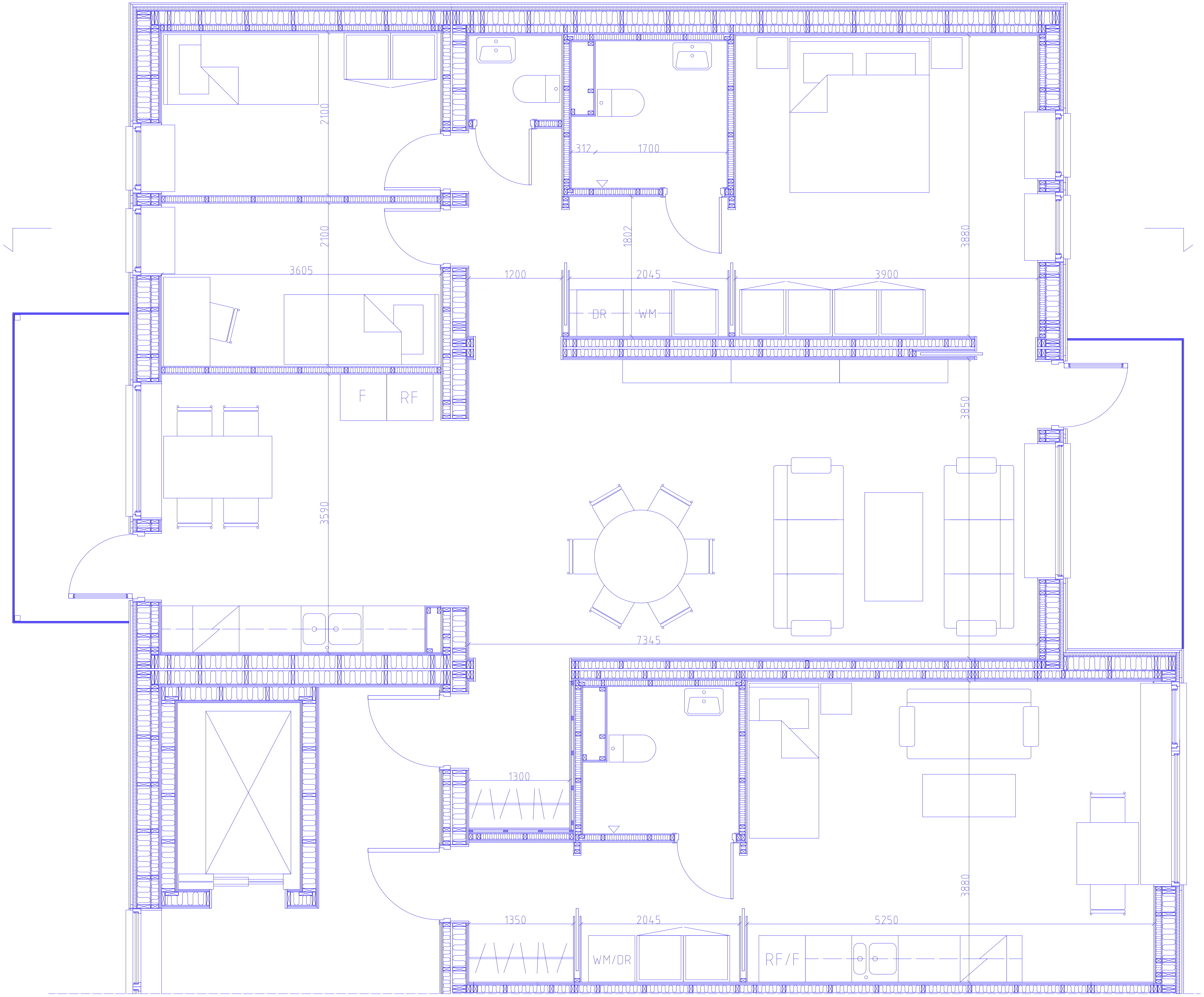


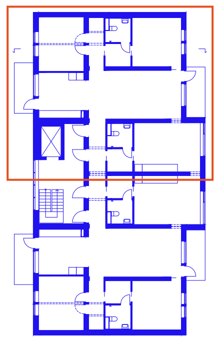
The couple gets a third child and the oldest child gets its own larger room when the apartment expands, and another room is added.



FLOORPLAN 1:50

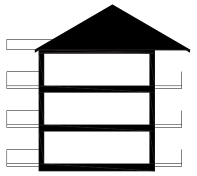
A floorplan of two apartments, one large and a separate smaller one. The larger apartment has three bedrooms, one larger and two smaller ones, and an added bathroom in the hallway.



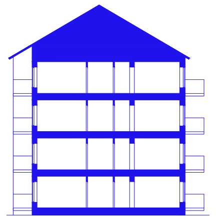


Scale 1:600

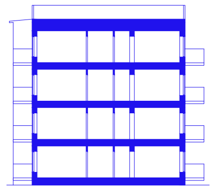
SECTION 1:50



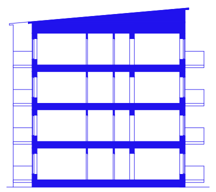
Section of Derome's building with a gable roof and the entrance balcony on one side and balconies for each apartment on the other side.



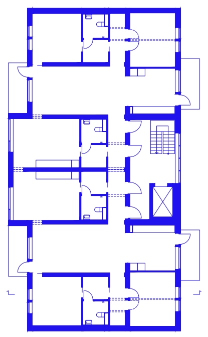
Gable roof.



Flat roof with a possible terrace.

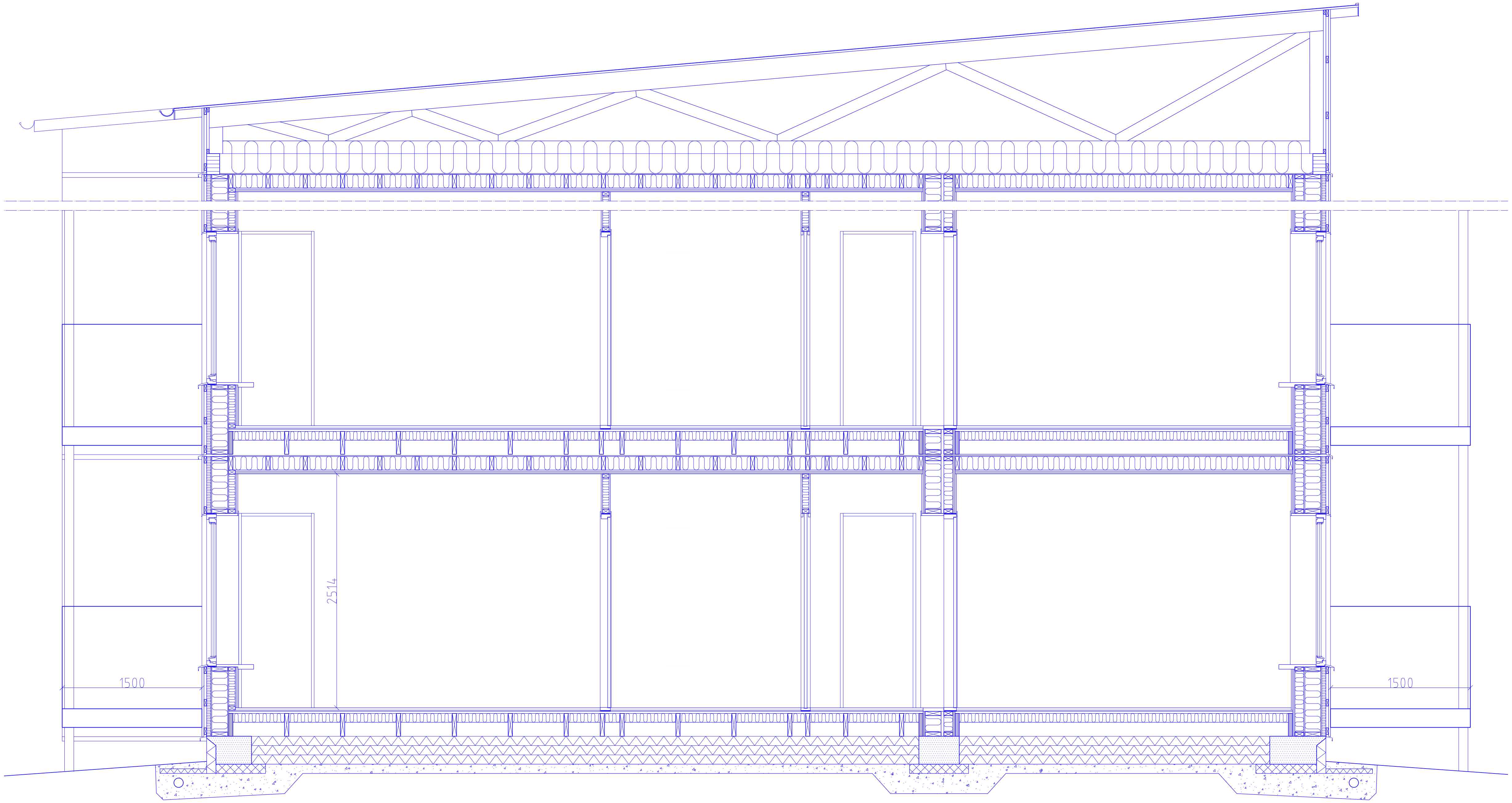


Single-pitch roof.

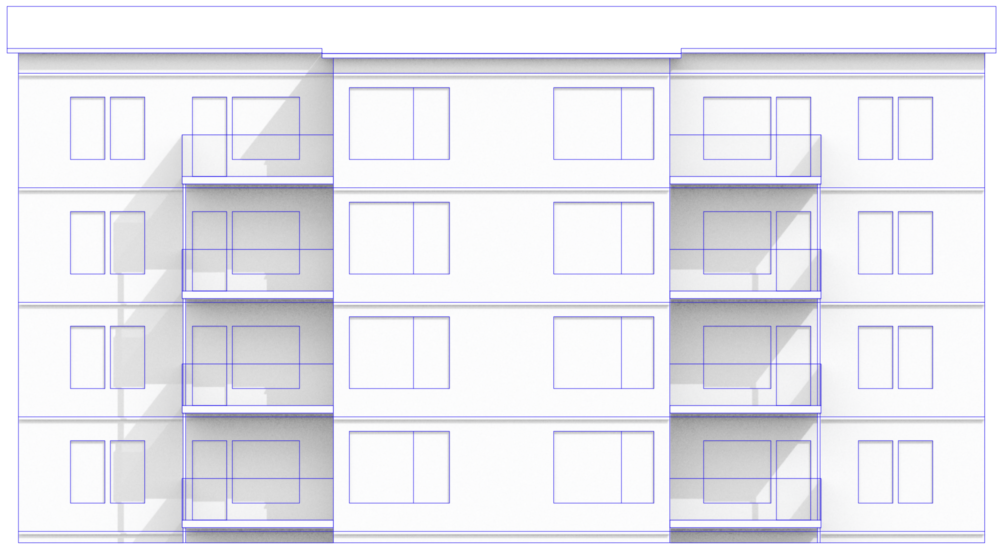


Scale 1:600

The section cuts through the two general rooms, the hallway, and the storage space. In this case the building has a single-pitch roof. Other roofs could also be added, such as a gable roof or a flat roof with a possible roof terrace.

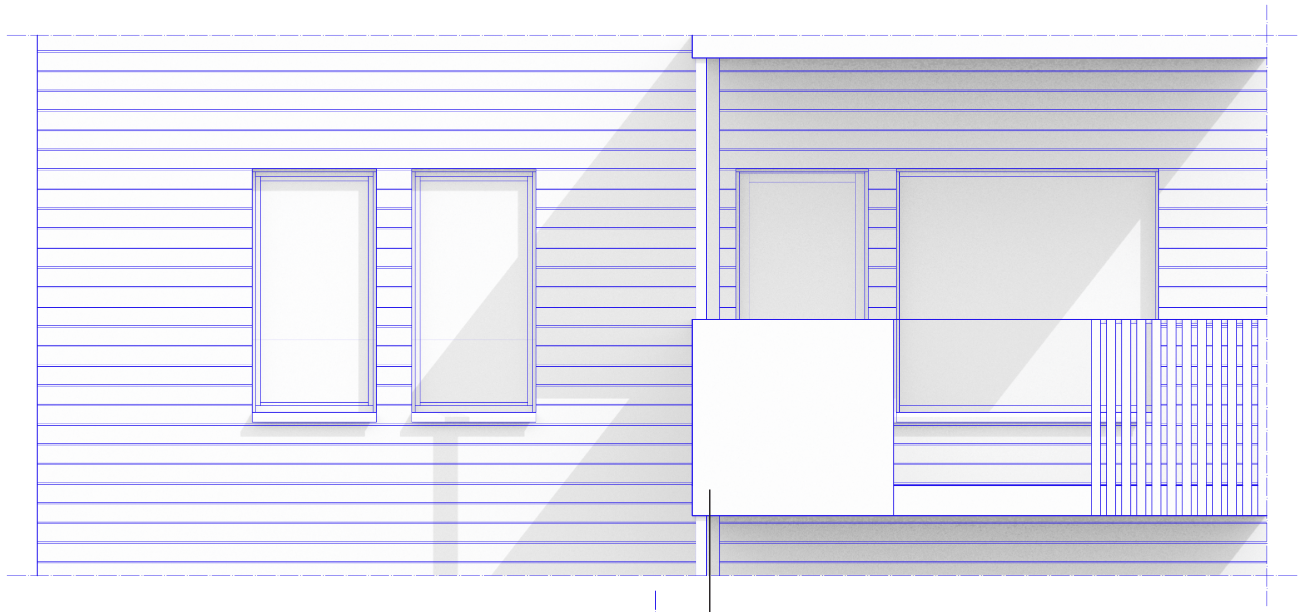


FACADE

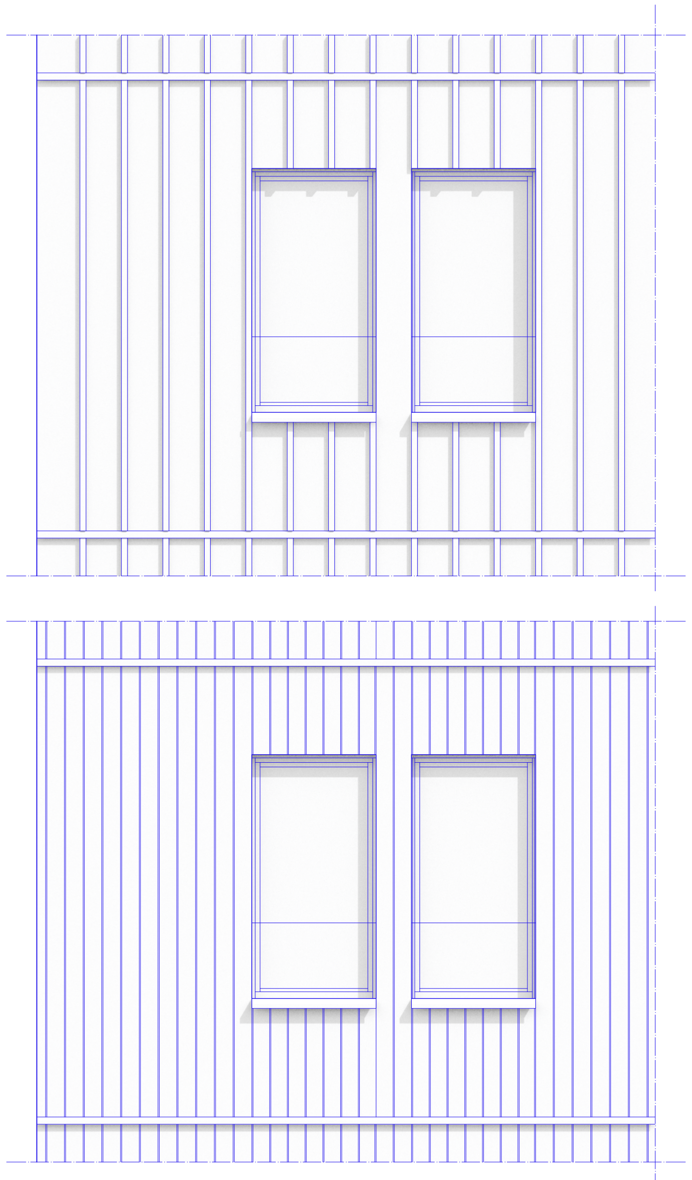


Scale 1:200

Scale 1:200



The balcony could have different railings; corrugated steel, glass, and wood.

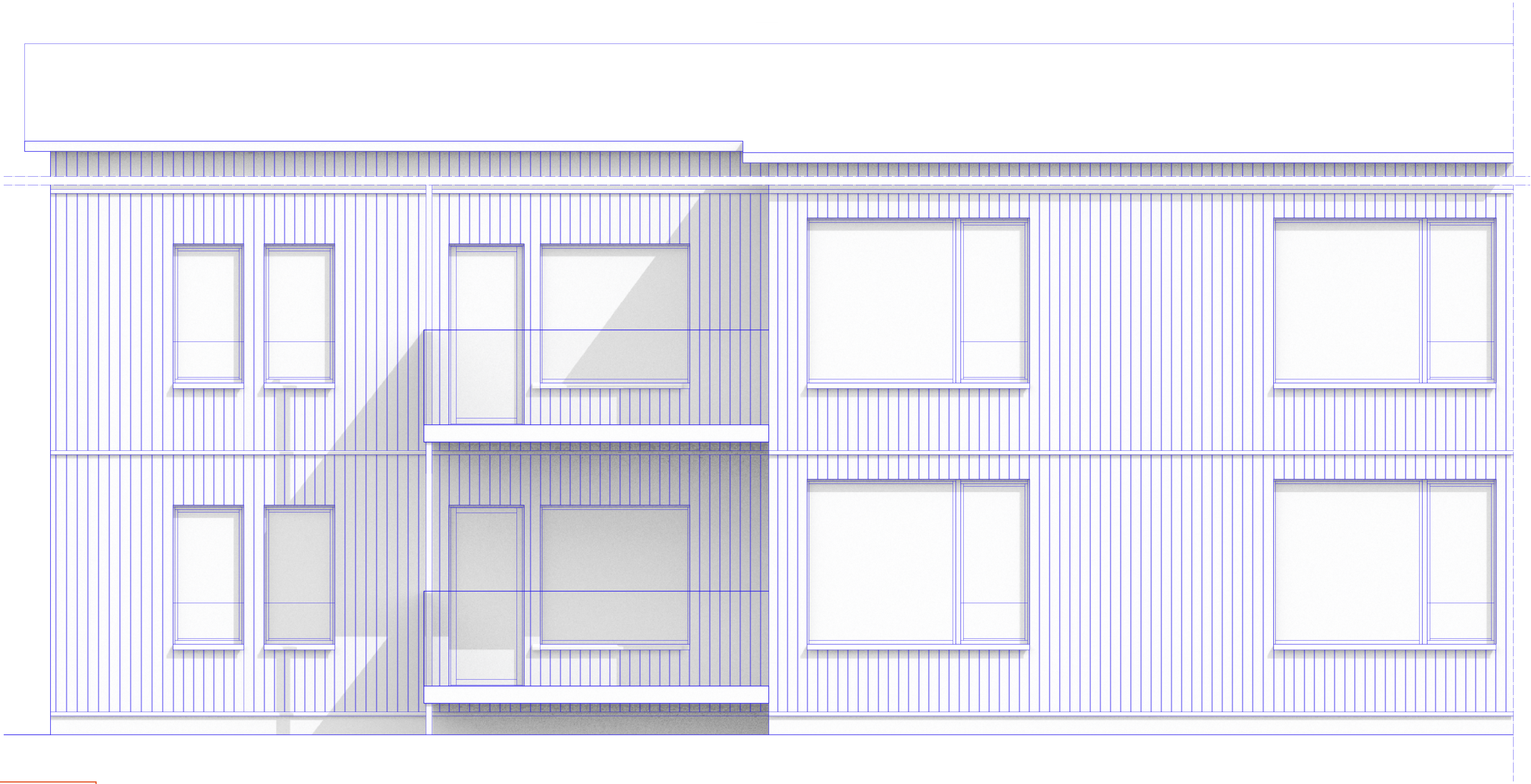


Different panels could be used.
Scale 1:50

The façade in the design proposal a more varying expression than in the existing building system. The windows are larger for more daylight and are changing for the different rooms and apartments. The general rooms have two smaller windows for the possibility to divide the room into two smaller ones. The extended module in the middle of the building gives the volume a difference in depth and a more protected space for one of the balconies. Without the entrance balcony the rooms that would have been behind it gets more daylight now. Both the living room and kitchen have access to a balcony.

Possible changes for different buildings of the same building system are the expression in the façade with different kinds of panel, for example horizontal and vertical. The balcony could also have different railings such as; corrugated steel, glass, and wood.

ELEVATION 1:50



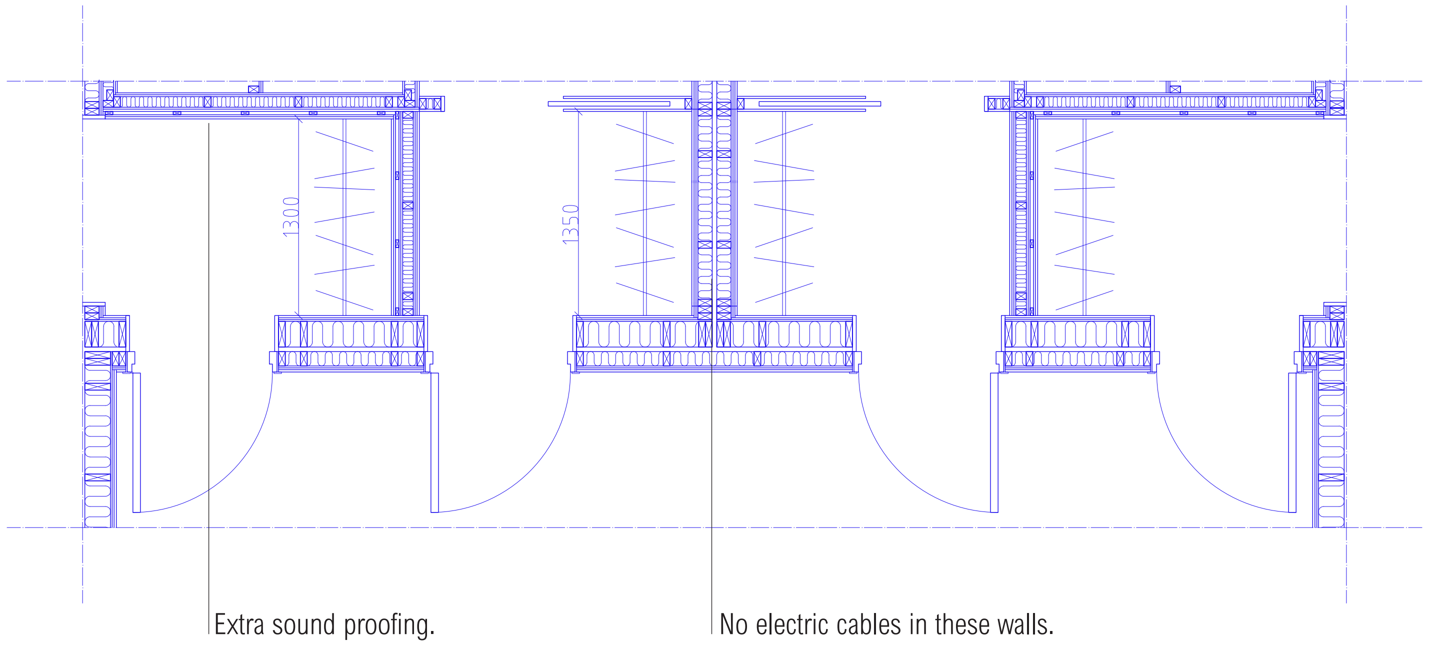
Scale 1:600

Here is a part of the façade with a vertical panel and a balcony railing of glass for transparency.

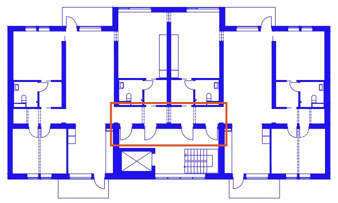
SEPARATING AND CONNECTING APARTMENTS

The apartments or modules are possible to connect or divide through the hallway. This is possible by adding or removing walls constructed of a wooden stud frame, gypsum boards, plywood boards, and insulation. Adding or removing walls in the hallway are quite small changes and therefore not so expensive which would make them feasible. The problems connected to these changes would be fire issues and excessive noise spreading through the construction between the apartments. The dividing walls are placed in the hallway where the excessive noise would be spreading, the noise would though be limited to this are and not the biggest issue, it would be worse in for example a bedroom.

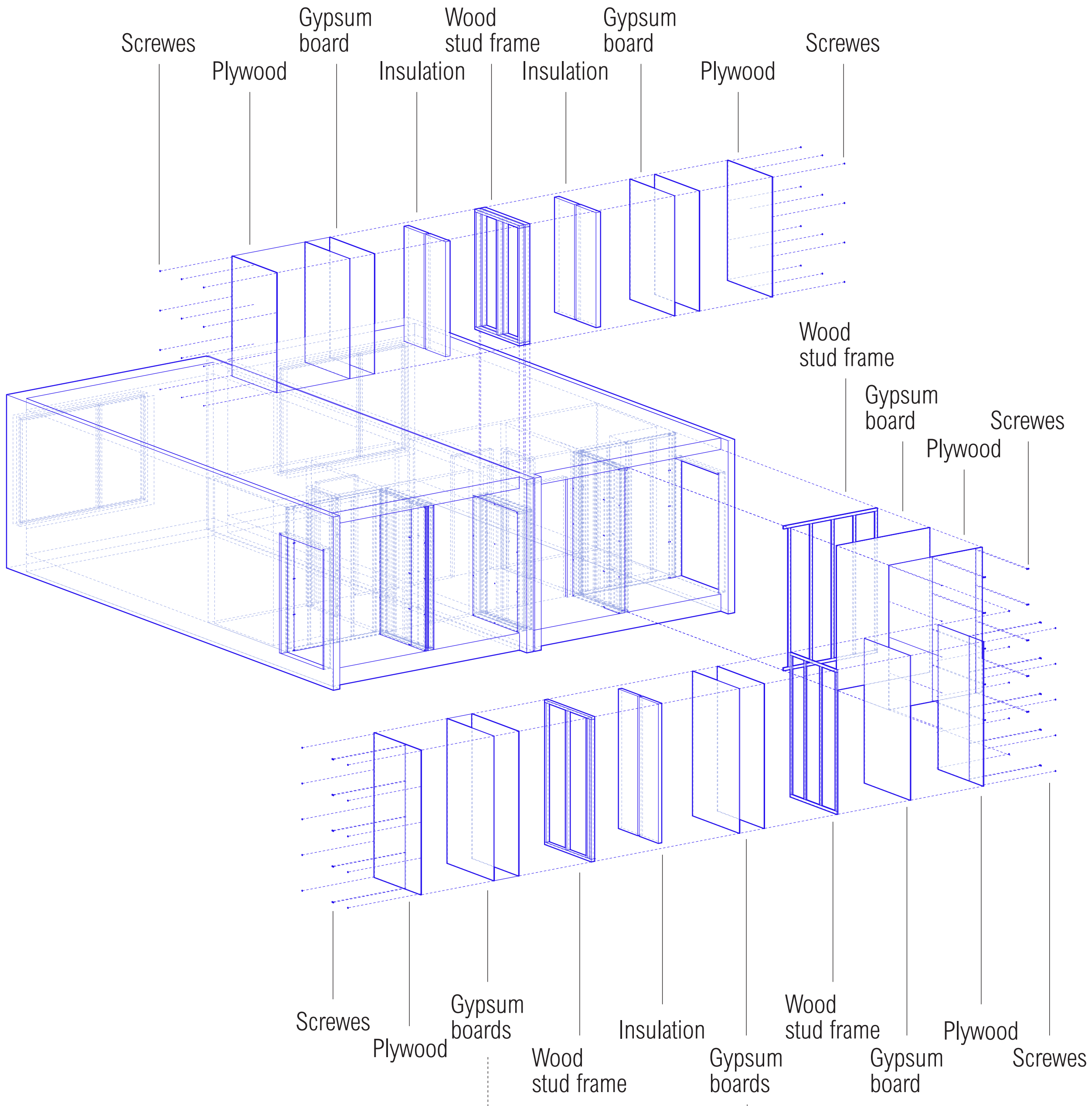
The wall separating the apartments cannot contain any electric cables for easy dismantling. Extra sound proofing would need to be added on the wall connected to the bathroom. Openings with pre-cut gypsum and plywood boards will make them easy to remove. Due to fire issues the cuts of the gypsum boards should not be on the same place or if they are an aluminium tape could cover the cuts of the boards for fire proofing.

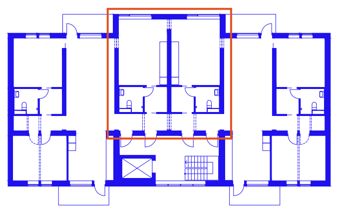


Scale 1:50



Scale 1:600



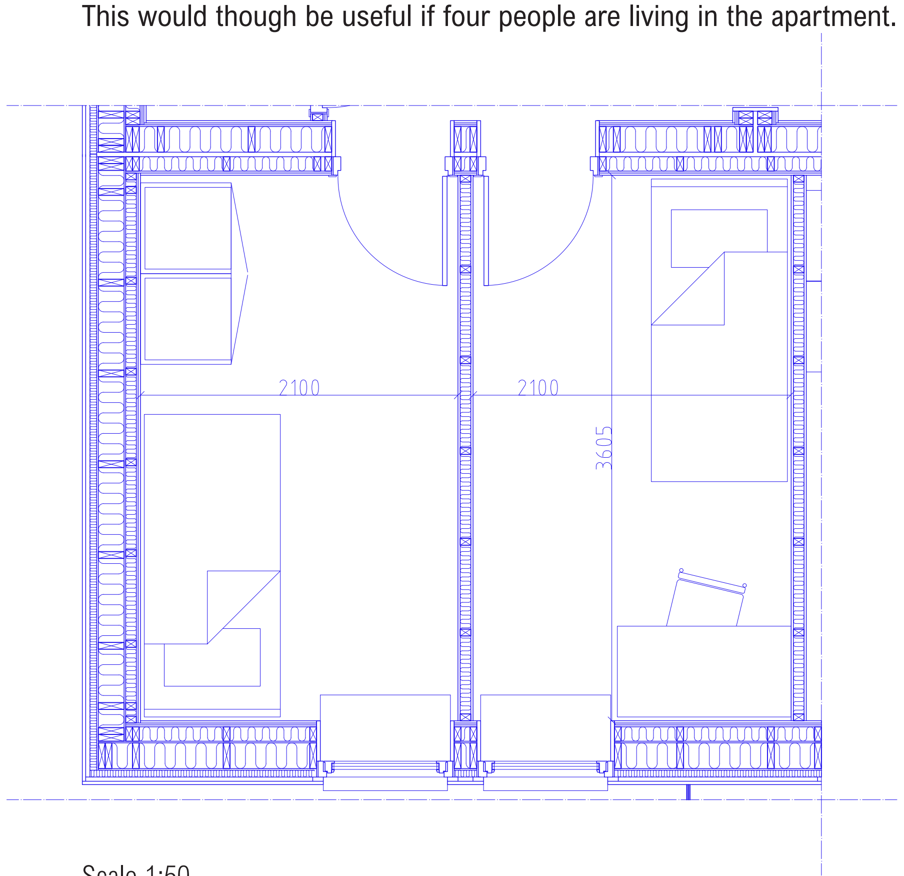


Scale 1:600

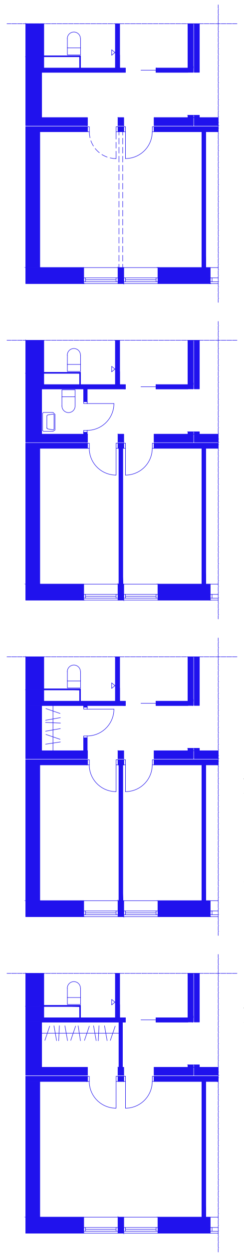
DIVIDING ROOMS

Temporary interior walls are possible to add to divide one room into two smaller ones. The inner wall is a wooden stud frame screwed into the walls, floor, and ceiling. The screws will leave marks, but small and few which would not be that visible and it is possible to cover the wholes if the wall is removed.

If the room is divided in two, the hallway could be used in different ways. A smaller adjustment would be to turn the hallway into a wardrobe or storage. A more extensive adjustment would be to add a bathroom. This would though be useful if four people are living in the apartment.



Scale 1:50



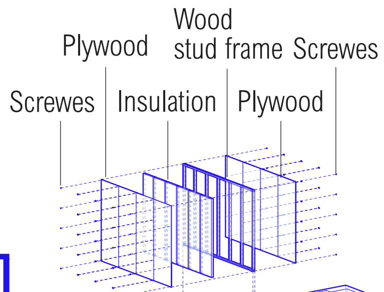
Structure.

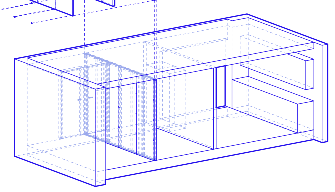
Added bathroom.

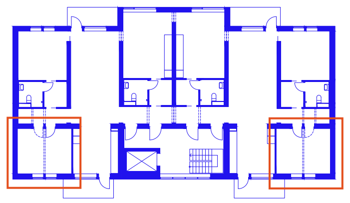
Added wardrobe/ storage accessed from the hallway.

Added wardrobe/ storage accessed from the room.

Scale 1:200





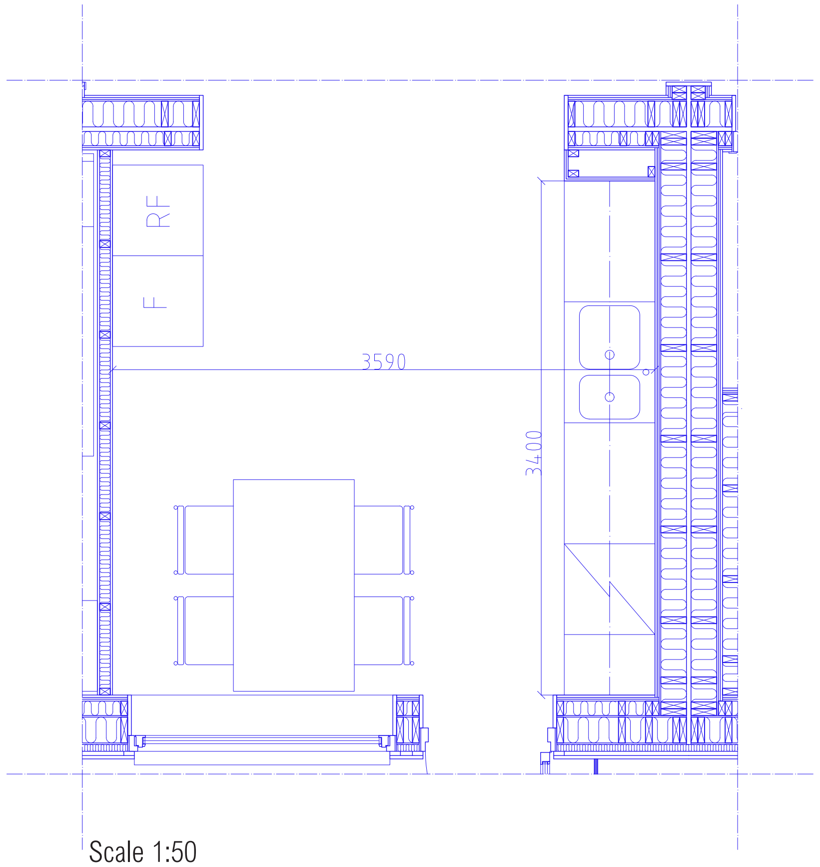


Scale 1:600

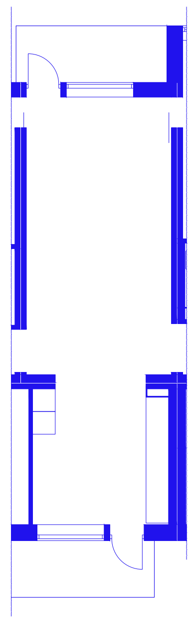
CONNECTION KITCHEN AND LIVING ROOM

The apartment could have a connection between the living room and the kitchen, or if a wall is added these would be two separate rooms.

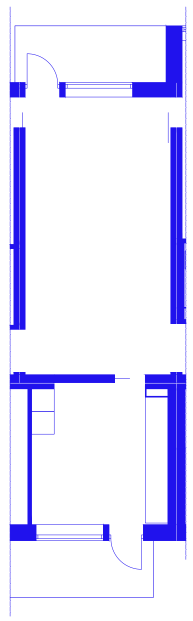
Kitchens are often renovated, and one strategy to limit this could be to have as little as possible placed in the kitchen from the beginning and then the residence can decide how the kitchen could expand or not.



Scale 1:50

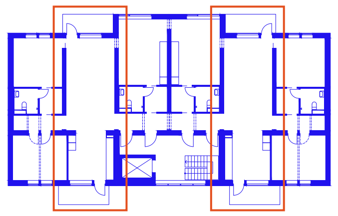


Connected kitchen and living room.

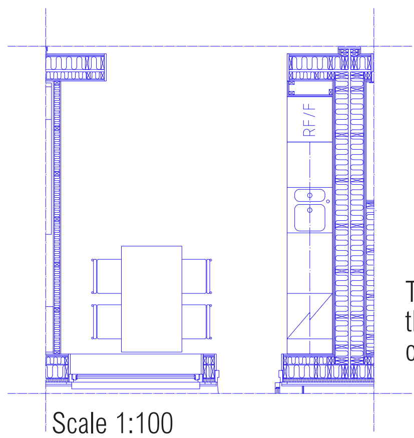


Separated kitchen and living room.

Scale 1:200



Scale 1:600



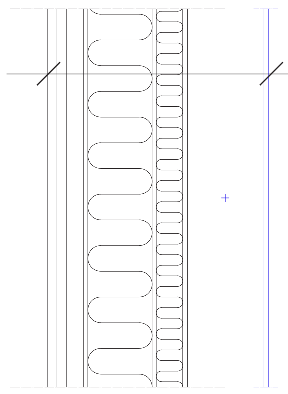
The kitchen with the minimum of cabinets etc.

Scale 1:100

MATERIALS

WALL

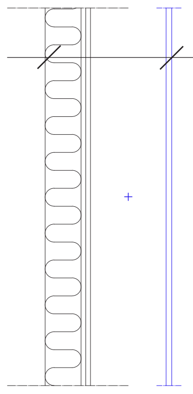
A plywood board is added on the wall. This for a wooden surface in a wooden construction and for the boards to be easier dismantled. If the wall is not apartment separating, the plywood could replace a gypsum board.



22x145 Wood panel
28x70 Batten
45 Climate board
11 OSB board
45x170 Wood stud
170 Insulation
Plastic film
11 OSB board
45x70 Wood stud
45x70 Insulation
12,5 Fibre gypsum board

+
15 plywood

External wall
Scale 1:20



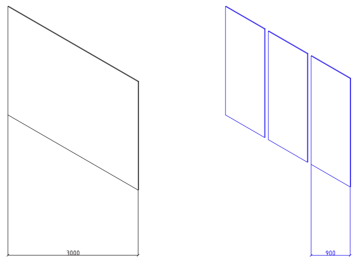
2x12,5 Fibre gypsum board
45x95 Wood stud
95 Insulation

+
15 Plywood

Apartment separating wall
Scale 1:20

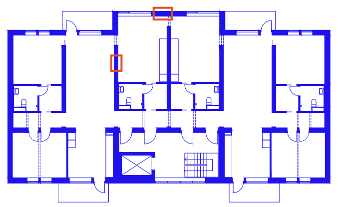
BOARDS

The gypsum boards are optimised for the prefabrication and has a large format of about 3000 mm. For the boards to be easier to handle for a human they should be according to the standards of 900 mm.



FLOOR

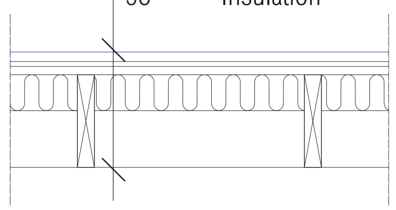
Instead of using a parquet floor that needs to be replaced ever 25 years, equally multiple times during the building lifetime, because of its bad quality, a massive wooden floor is placed. The massive wooden floor needs maintenance, unlike the parquet floor that would be replaced instead, and is more expensive but has a higher quality and will hold for a much longer time.



External and internal walls are marked.

Scale 1:600

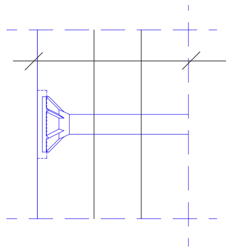
25 Massive wood floor
2 Foam
13 Gypsum board
22 Particle board
45x245 Wood stud
95 Insulation



Scale 1:20

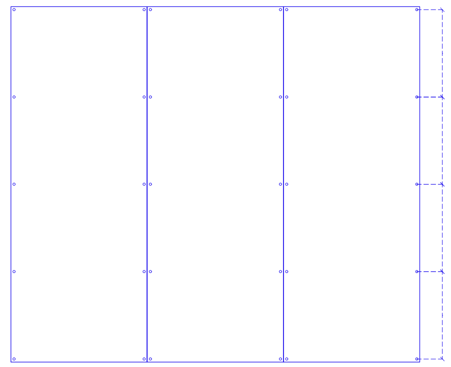
JOINT

The space modules are quite easy to separate from each other because of the connections with screws. The boards as the finishing surface within the space modules are though attached with brackets and the boards would be destroyed if dismounted. To enable the boards to be removed without destroying them, screws are used instead of brackets in the design proposal. A plywood board is added, and the screw head could be lowered to not be that visible. The screws should be placed on an even distance for aesthetic reasons. The gypsum boards could be screwed on without the plywood but then the screw gets covered with smoothing compound before painting the surfaces which is needed with the gypsum boards and this would make the screws hard to find and remove. Plywood are more expensive that gypsum so it might not be feasible, but it would ease the removal of the boards and the boards does not need to be painted which gives then a wooden surface in a wooden building and would be appealing.



15 Plywood
2x 12,5 Gypsum boards

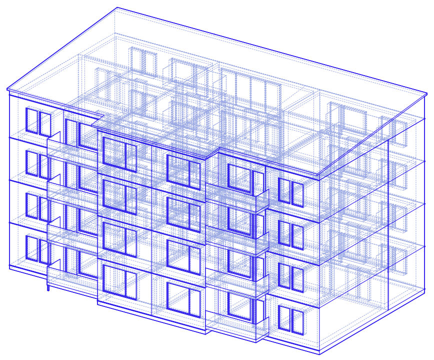
Scale 1:2
A screw with the head lowered in the plywood.



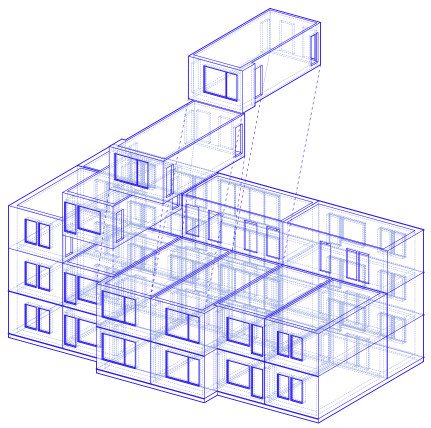
Scale 1:50
The screws on an even distance, attaching the plywood boards.

Two examples of where plywood boards as finishing surface are attached with screws on an even distance. The screws are visible, but with the pattern in the wood it is not be that noticeable. The distance between the boards differ.

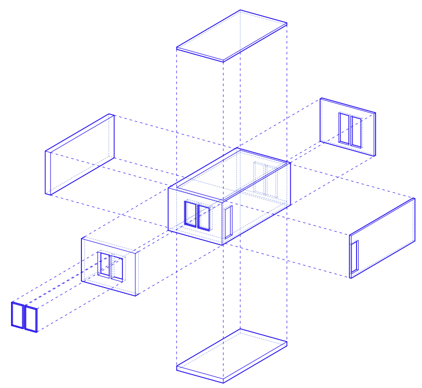
MATERIAL LOOPS



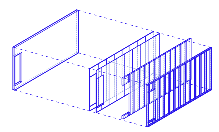
Building that has reached
its technical lifetime



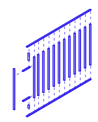
Module by module is
removed



Components – walls, floor,
ceiling – could be reused if
possible



Materials can be separated
for reuse, remanufacture,
recycle, or combustion –
possible to separate by
screwing apart.



Wooden stud frame
possible to screw
apart to single stud

5 FINAL SUMMARY AND DISCUSSION

In this master's thesis adaptability and design for disassembly have been applied in an existing prefabricated wooden building system for multi-residential use. The intention of investigating these concepts has been to enable changes in the building to meet the residentials varying needs and to prevent obsolescence. An adaptable building has social, environmental, and economical benefits when meeting people's needs and use the resources/buildings for as long as possible on site when making changes instead of demolishing or moving them.

Three adaptability strategies are applied; elasticity, generality, and flexibility. By applying the strategy of elasticity, the outcome in the design proposal is that the apartments in the building could shrink and grow by adding or contracting rooms from the apartments next to it. General rooms are used in some places to enable different uses and not specify functions, exceptions have been the living room, the kitchen, and the bathrooms because of the fixed functions or the size of the room. Flexibility as a strategy is embodied in some places where one room is possible to divide into two smaller ones. The strategy that are applied to the largest extent in the design proposal are elasticity, due to the focus on a transforming building with adding or contracting rooms and shrinking or growing apartments, as a response to the changing needs of the residentials and number of people living there. Summarized the application of all these strategies gives the possibility to change the size of the apartments, amount of rooms, and decide the functions in certain spaces. To be able to stay in the same apartment is important for the residentials and their social network established in the neighbourhood, so the children could stay in the same school, the connection to work or activities etc.

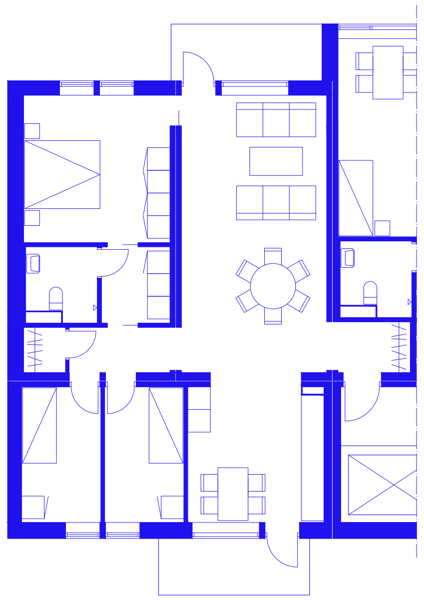
Design for disassembly has been used as a strategy to enable the adaptable transformations in form of adding or removing walls to connect or divide apartments. The focus has been on connections, standardisation, and layers to enable transformation and reuse, recycling etc of the materials. To enable that the different materials could be separated from each other without destroying them, connections has been important and, in this design proposal, using screws.

The design proposal differs from the existing building system both regarding floorplan and façade structure. The building volume of the design proposal varyies in depth where the modules are extended to create a difference in the façade and a more protected balcony. Instead of the entrance balcony and an entrance from the outside, the staircase is placed as a module and the entrances to the apartments are from the inside of the building. The windows are larger to give more daylight, differing in size for a varying façade expression, and placed in some cases so that the room could be divided by adding a wall. In floorplan the apartments are possible to change in size and amount of rooms when the building is built in difference to the existing system with fixed apartments.

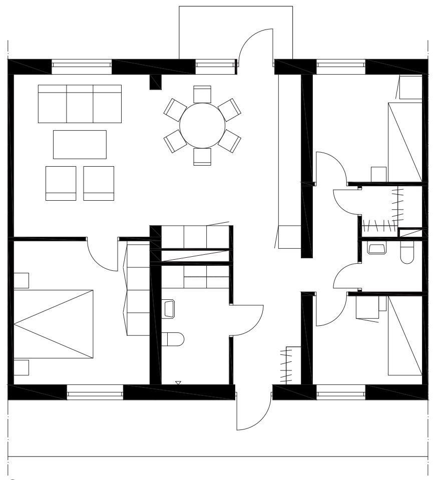
Some issues have occurred when investigating adaptability. For example, when applying general rooms, the problems has been related to the divergency where certain functions are more fixed than others (such as kitchen and bathroom) and the size needed for some of the functions. The general rooms of 16 sqm could be quite big for a bedroom, but too small for a living room. The consequence of this is shown in the design proposal with a specificness in some of the rooms; in the living room which is larger and more open, and the kitchen and bathroom which are specific due to the fixed functions. Another issue working with general rooms is that the total area of the apartment tends to get quite big.

The thesis concludes that adaptable apartments built with this building system need more space. If two similar apartments are compared, one from the design proposal and one from the existing system and Derome, they are only differing four square meters from 92 sqm to 88 sqm, which is not a major difference. Both apartments have a kitchen, a living room, one larger bedroom and two smaller ones. Though, if the room in the design proposal would not be divided, the apartment would only contain two bedrooms instead of three and this would be a large apartment. This is a consequence of the large general rooms and the room that is possible to divide into two where the primary room needs to be big enough for the divided rooms not be too small and therefore non-useable. The connecting hallway, which is running through the building and makes it possible to connect or contract the different rooms, is also contributing to the increased area in the apartments and makes the building deeper compared to the existing building system from Derome. A smaller apartment, optimised in size, is often explained as more sustainable, for example during its time of operation where a smaller area needs to be heated and less amount of energy is used, or during constructing the building where less amount of material is needed. The rooms and spaces in smaller apartments are often optimized and specific for a certain function and through a sustainable view in an adaptable way, the apartments need space for diverse use and possible transformations.

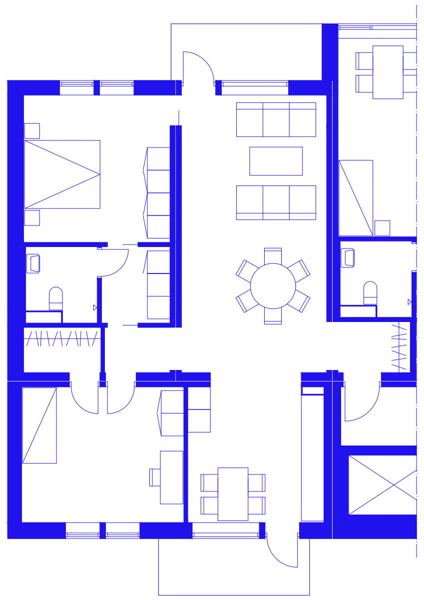
The adaptable strategies make it possible to combine the rooms into different apartments that could fit for different constellations or enable changes so the people living there could stay instead of having to move if more or less space is needed. The added or contracted space would probably be connected to an increasing or decreasing rent and then be decided by the income of the people living there, this could limit the people with less income to expand, if they cannot afford it and this would be a social issue.



Scale 1:200
The design proposal with an apartment of 92 sqm a living room, a kitchen, and three bedrooms - one larger and two smaller ones.



Scale 1:200
An apartment from the original building system and Derome of 88 sqm with a living room, a kitchen, and three bedrooms - one larger and two smaller ones.



Scale 1:200
The design proposal with an apartment of 92 sqm a living room, a kitchen, and two same sized bedrooms.

The concepts of adaptability and design for disassembly has been applied without changing the wooden building systems of Derome, it has been made within the frames of it. The changes presented with openings and adding walls are quite small adjustments and if they are prepared for it could be possible and feasible. Technical problems that could occur regarding these walls are fire issues and excessive noise spreading through the structure between the different apartments.

The design proposal suggests plywood boards as surface material on inner walls. Adding material as the plywood will increase the total amount of materials in the building and it could also be expensive. The benefits are the visible wood as material, on walls and ceiling, in a wooden construction and making the boards possible to remove. Massive wooden floor is a material with a longer lifetime compared to the parquet floor which must be replaced multiple times during the building's lifetime. Massive wooden floor is more expensive but can last for a longer time, which we should reconsider when choosing materials for minimizing waste in the buildings. This is though depending on if the residentials change materials in the building themselves which is quite common today. The mindset of renovating everything only because of a personal preference and style needs to change as well for the products and materials to be used for as long as possible and minimize waste. We should use good quality materials and products for as long as possible, that age nicely, and does not have to be replaced because they break easily.

REFERENCE PROJECTS

Ölzbündt, Dornbirn - HK Architekten
Wooden prefabricated building with a horizontal wooden panel, more glazed areas and steel railing on the balconies. The apartments are reached form an entrance balcony.

Affordable housing – Andreas Martin-Löf Arkitekter
Details and materials are reconsidered. Modular housing, but small apartments and fixed use.

Impulszentrum Graz und Mühlweg 3 – Hubert Riess
Modular arrangement of indoor and outdoor spaces.
Housing on Lisbjerg Hill, Vandkunsten

Flexible living space, possible to adapt to the changing needs of its inhabitants. Partly wood construction, prefabricated, laminated timber structure, joined with metal joints to enable easy disassembly and reuse of the elements.

Helical plc – Morris + Company
Dividing façade in different ways – could hide the splices between modules.

CIX (Cirkularitetsindex) – Ett11, Riksbyggen, Bengt Dahlgren, Lokalförvaltningen Göteborgs stad
Ongoing
Investigation of circular economy in buildings. Case study in one of Riksbyggens buildings.
Inner walls easy to move, façade explored where windows could be.

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APPENDIX A - SUMMARY OF THE INTERVIEWS

200124 Derome, Studiebesök Värö
Anders Carlsson
Tobias Persson

Har den längsta kedjan från skog till hus.
Ca 2200 anställda. Grundat 1946. Äger ingen skog.
Derome Timber – Halland sågverk 5 st. Gran som träslag i hus.
Byggvaror och träteknik
Hus
Mark och Bostad: a-hus, varbergshus (lösvirke) och plusshus
Förvaltning

Har som mål att vara klimatneutrala, få bort sitt fotavtryck.
70% av Sveriges yta är gjort av skog. Skogen växer snabbare nu pga klimatförändringar (varmare och fuktigare)

Två olika system – volym och panelelement.
Båda system används för flerbostadshus.

Volym: max 4 våningar
Panelelement: max 8 våningar, 7 är det som är byggt nu.

V: går att prefabricera i hög grad, mer ekonomiskt och bättre arbetsförhållanden.
P: mindre prefabricering och dyrare, väderkänsligt att montera (fuktkänsligt). För bra arbetsförhållanden går tält att montera som skydd, men blir dyrare.

V: begränsning av lastbilsmått, ca 9,6 m lång är optimalt (går med 12m, men sämre vid transport som har med svängradie på lastbil och hörn på modulerna).
P: mer flexibelt i användande. 7 m djupa för spännvidd.

V: hela volymen som element, allt monterat i fabrik. Fasad kan monteras i fabrik eller på plats. På plats blir det skarvar som täcks av med täckbräda, ger olika uttryck beroende på stående eller liggande panel. Om annan panel ska göras än trä eller träpanel utan skarv så görs det på plats.
P: väggar som element och bjälklag som element. Fasad monteras på plats. Går att göra olika fasader utanpå.

V: addera pluss - 7 olika varianter på moduler som kan bilda upp till 10 varianter på bostäder 1–4 rok. 2 moduler har kök och badrum. 85% kan göras på plats (beroende av fasad osv). Volymer används till boende.
Lasterna går i ytterväggarna på modulernas kortsida och byggnadens långsida. Fibergipsskivor används för brandskydd och finns i stora format, denna häftas på plats.

Akustikproblem i träbyggnader, hanteras på olika sätt i systemen. Ena har en luftspalt mellan och den andra har två luftspalter mellan.

200210
Anders Carlsson, Derome
Telefon

Volym - balkar tvärs
4 våningar max – sitter ganska löst därmed lätta att ta isär, men om det ska byggas högre så måste det dras åt hårdare.
Hål ca mått 3,6 m går att ta upp. Balk behövs vid öppning.
Fibergips skivor stora – fabriken gjord efter att hantera stora skivor och därför monteras stora skivor i fabrik. Ca 3000 mm

Panel element
Kontor har byggts – egen regi till Derome, men deras fokus är bostäder.
Kassetter som bjälklag.
12 m långa spännvidder går att göra, använder en I-balk av stål för långa spännvidder.
Kassetterna är 2,40 m breda och 6,20–7,20 långa. Staplas i en hög och går ca 7–8 st per last.
Väggar 3 m höga och 6–7 m långa – 5 per paket på lastbilen. Om de är längre blir de för tunga att lyfta i fabriken.
Bara gips som skiva, skillnaden är att de monteras på plats och då behöver de vara mindre – 900 mm. Om det hade varit gjort för fabrik skulle de antagligen vara stora format.
Installationer är delvis infällda i bjälklaget + schakt + gubbe i taket
Panelsystemet har många och långa skruvar. Det kan vara svårt att hitta och få ut. Konstruktionen skruvas åt hårt för att hålla. Det gör det svårt att få ut skruvarna och hitta.

200303
Anders Carlsson, Derome
Skype

Innerväggar går att plocka bort (om inte bärande), men innehåller oftast el.
El går att stoppa in i alla väggar, men vill oftast in ha det i lgh-skiljande väggar eftersom de kan leda ljud.
Strömbrytare sitter oftast vid dörr + eluttag.
Går att få hela volymen fri – väggarna runt om volymen är dock avgörande för stabilitet
Stora öppningar kan ge problem med stabilitet.
Garderober går att flytta och har golv under.
Maxhöjd på är 3150 som går att lasta på lastbil vilket ger en takhöjd inuti på ca 2500 mm och om de skulle vara högre skulle specialtillstånd behövas.
Längsta möjliga volym går att köra 12 m men då endast en per bil, om de är 9,6 m går det att köra två stycken – en på bilen och en på släpet. Lastbilskran används vid montering.

Samma mängd avfall eftersom prefabricering går att planera och därmed beräkna åtgång. Dock mer olika avfall av panelerna eftersom de har fler olika varianter. Avfallet sorteras i fabriken – isoleringen tillbaka till försäljaren som river upp och sprutar in på vind som lös isolering, trä blir till biobränsle, gips tillbaka till leverantören, plast och metall sorteras.

200409
Anders Carlsson, Derome
Skype

Hade varit möjligt att göra lösningar om det är förberett för detta. Ekonomiskt möjligt – mindre förändringar. Brand också möjligt, men kritiskt med dubbla skarvar i gips – gärna omlott. Problem i detta – ljud och brand. Ljudproblem att sätta upp lgh-skiljande vägg i samma modul. Klampljud.
Helst då separera sammanbindningen i konstruktionen. En golvskiva – helst dela av den också för bättre ljud. Göra en förstärkning som gör förändringen möjlig. Överväga vart dessa hamnar – som i hall kanske inte så avgörande. Värre i sovrum tex.
Hål i bjälklag går att göra, men måste förstärka runt om. Med sarg. Se till att inga installationer ligger där.

Transport går att få fossilfritt – bara beroende på vad som tankas med.
Ca 20–25 volymer om dagen sätts ihop på plats– transport som kommer dagligen då med 10-12 lastbilar. Om större yta finns runtomkring går det att ställa av innan och med truck flytta runt.

Panel element - 6–7 våningar ekonomisk – dela på trapphus och grund. Tekniskt möjligt att göra 8 våningar.
Det som begränsar tekniskt är styvhet i elementen. Om det ska vara högre bör de vara mer styva för laster – vind etc.
Högre brandkrav efter 8 våningar.

Volym
Laster och brand begränsar. Väggen måste justeras. Styvheten för laster. Det är högre brandkrav över 4 våningar.
Hyresrätter mindre pga energikrav för statligt bidrag.

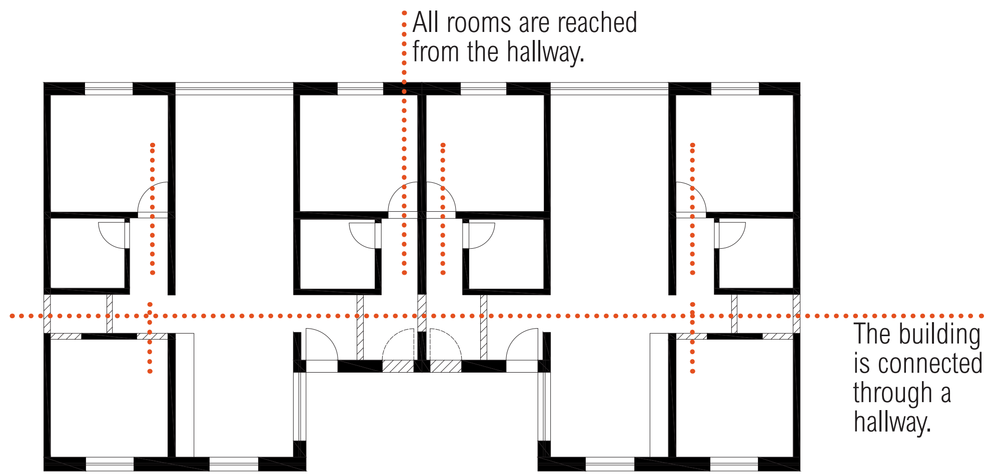
Material-
Mest valt för funktion och ekonomi.
Massivgolv är dyrt. Underhållsfråga och produktionskostnad.
Går att sätta upp lätta väggar på golvet.

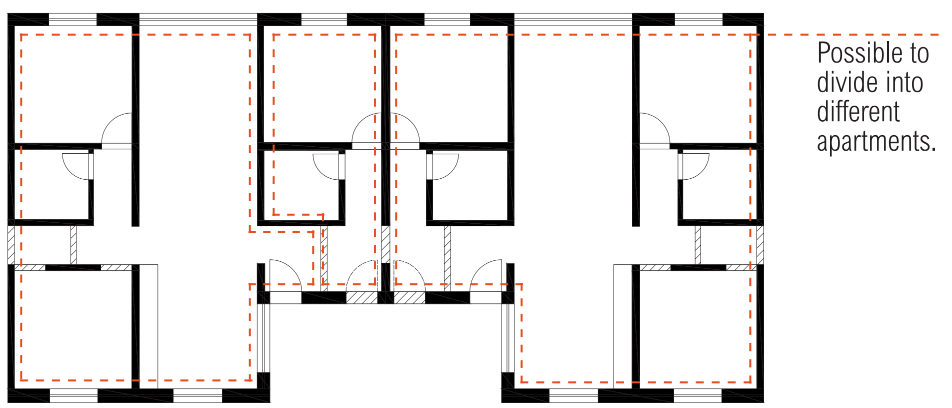
200420
Helen Johansson, Derome
Skype

Konceptet med loftgång är det som fabriken i Värö är utvecklad för nu. Volymen görs helt färdig i fabriken – svårt att ändra eller flytta om, väl på plats. Begränsningar med systemet är transport, tillgänglighet, hur det är möjligt att bygga – konstruktion.
Byggnaderna styrs av marknaden, lägenheter utformas i relation till detta. Nu jobbar de mycket med hyresrätter och då är storlek viktigt. Minimera ytor, men samtidigt så användbara som möjligt. Upprepning som volymkonceptet går ut på, med samma insida, men olika utsida. Hur utsidan kan ändras för att få ett annat uttryck med kulör och panel.
Så mycket standard som möjligt i volymerna och behålla dem som de är i projekten. Saker som är mer fria är tak etc.
Öppen planlösning passar eftersom lägenheterna är så små. Dagsljus är viktigt att lösa. Miljöcertifiering sätter högre krav. Hålla sig till begränsat antal fönster för ekonomiska skäl (5 olika). Fasader med samma öppningsmått men med olika fönster.

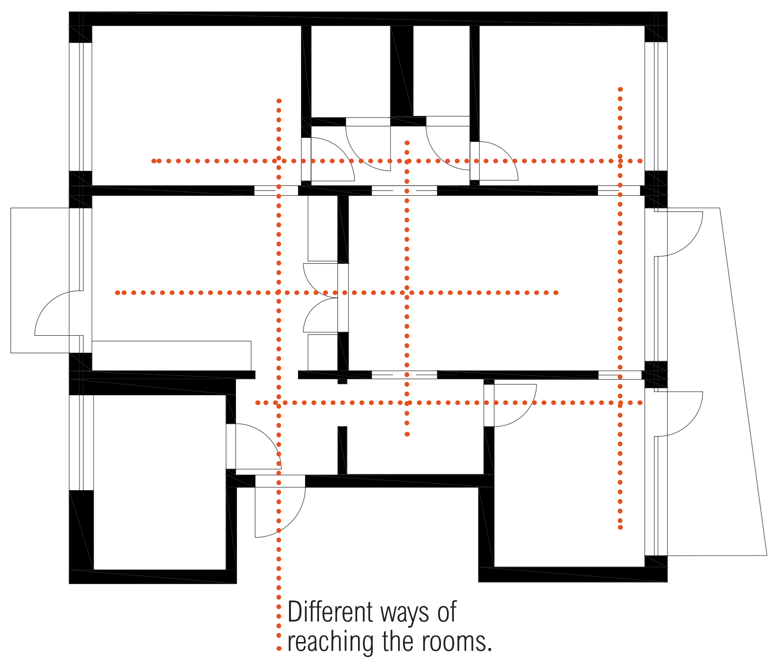
APPENDIX B - REFERECES ADAPTABILITY

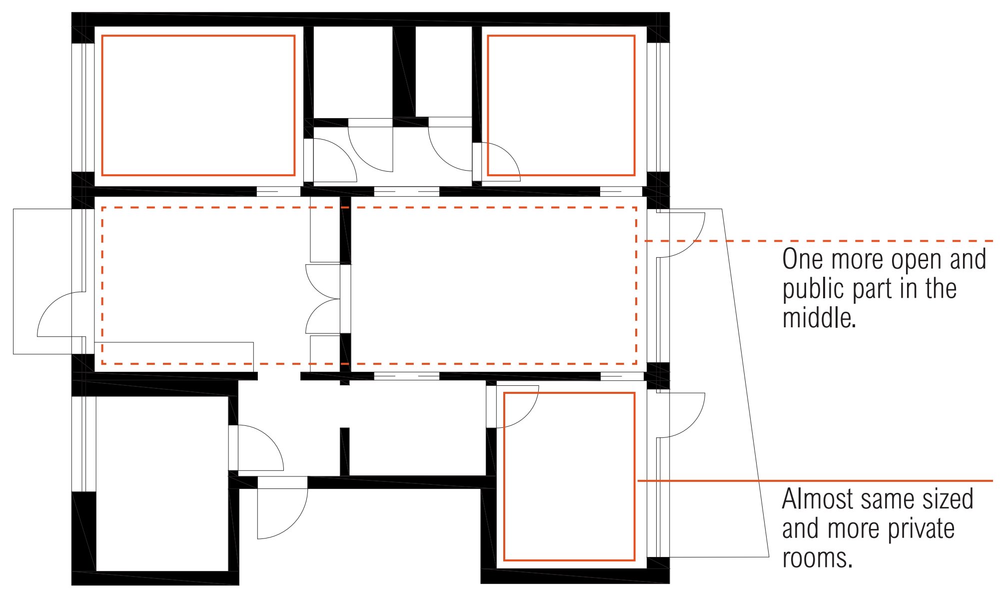
Herti V in Zug, Switzerland 1994.
Kuhn Fischer Partner Architekten.



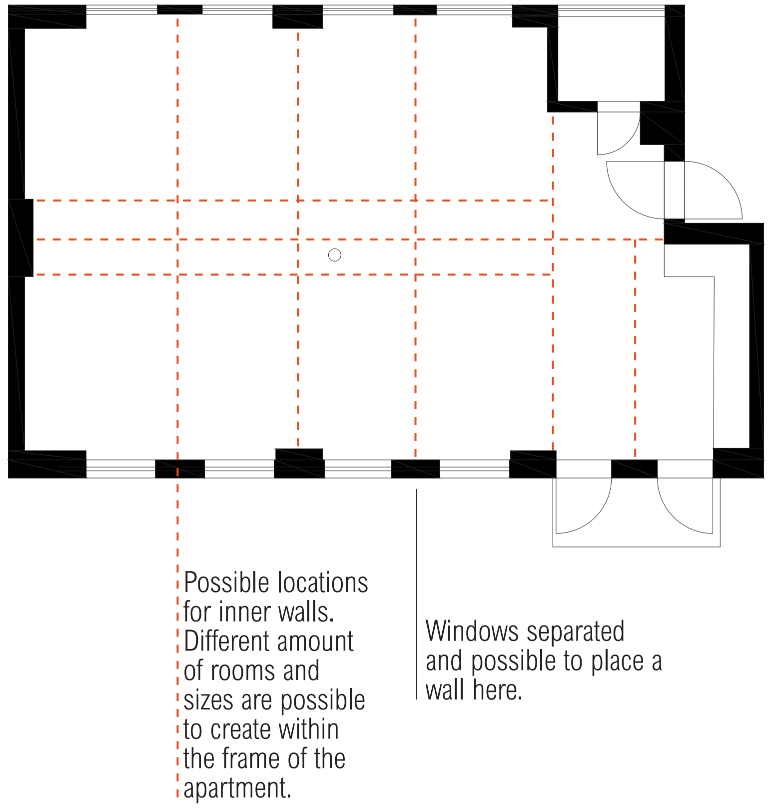


Lillatorpsgatan 17–19, Göteborg, Sweden 2007
Ulla Antonsson & Ola Nylander.

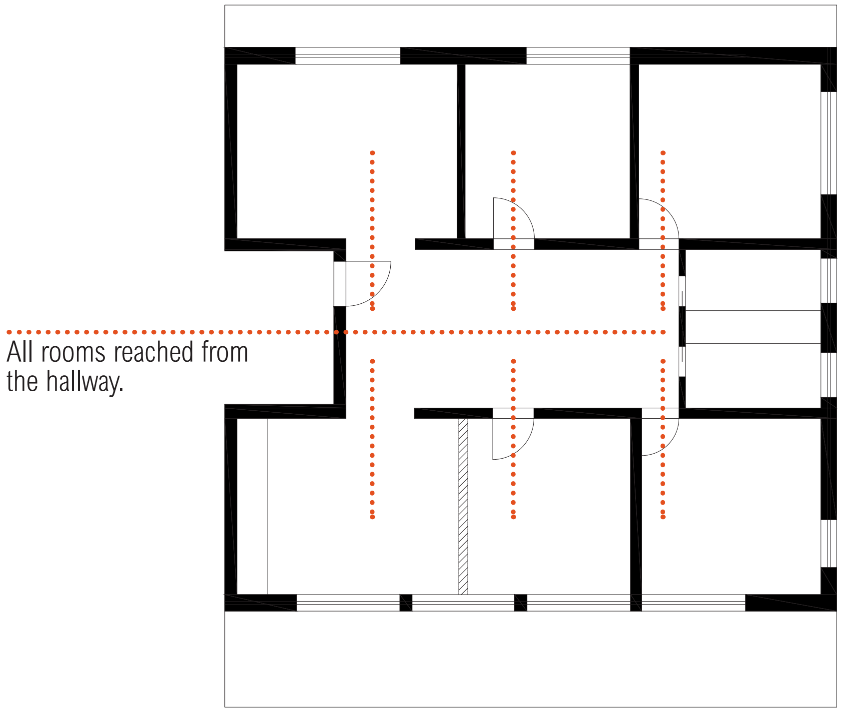


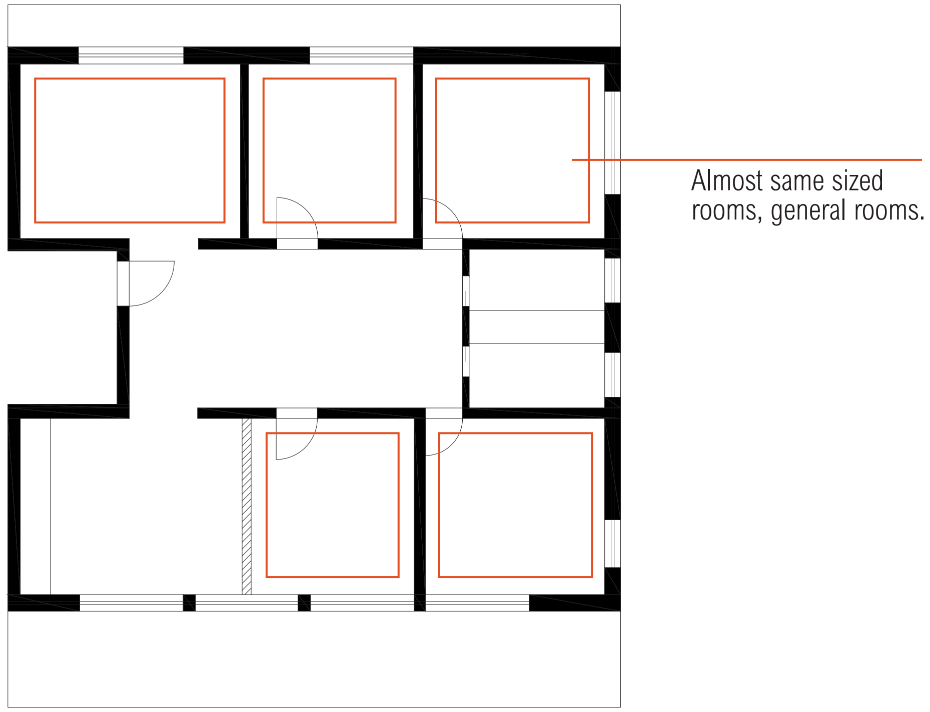


Modulatorsgatan 15-17, Göteborg, Sweden 1953.
Tage and Anders William-Olsson with Lars Ågren.

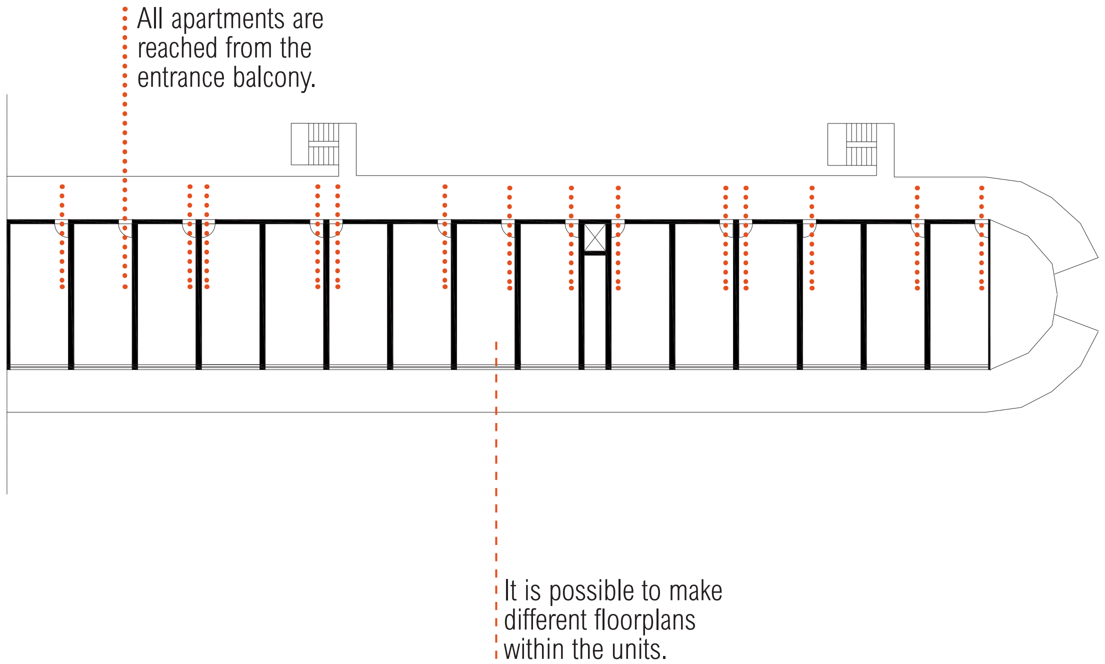


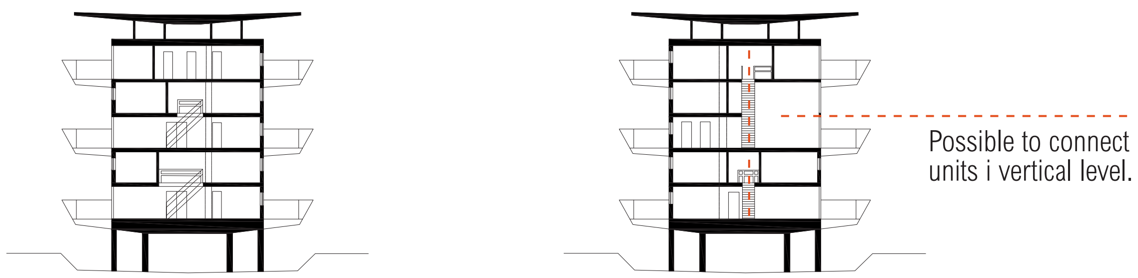
Siedlung Bockler, Zürich, Switzerland.
Christoph Haerle & Sabina Hubacher 2007.





Nemausus1, Jean Nouvel,
Nimes 1987





Landshövdingehus, Sweden