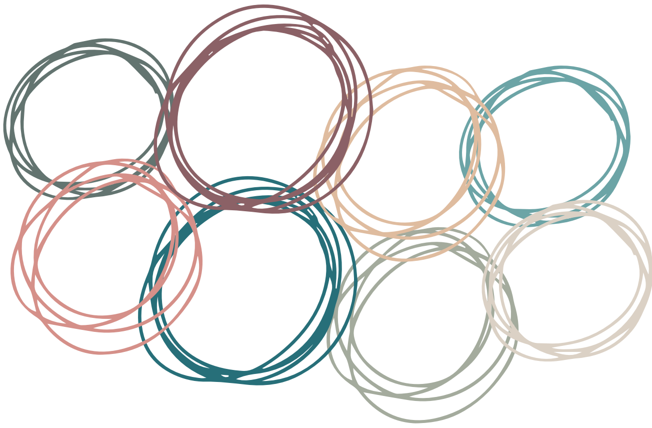
SUSTAINABLE HOUSING CONSTRUCTION
Modular details and typology

Building design for sustainability

Examiner : Paula Femenias | Supervisor : Walter Unterrainer



Chalmers School of Architecture
Department of architecture and civil engineering

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Modular details and typology

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Student background

Ideology

Architecture is a way of expression that allows me to show my interest in construction and sustainability. This thesis shows how both aspects come together in a project following some principle that I appreciate as a rational person: adaptability, modularity, and design for disassembly. With those, it is possible to design all sort of project that could adapt over time. Respecting our environment is crucial for our future and the generation to come, and I hope I will be able to bring that on my journey in the architecture world.

Acknowledgments

I would like to thank my tutor Walter Unterrainer and my examiner Paula Femenias to follow me during this research and help me along the way with the many challenges I faced. The feedback and comments helped me developed this project as it is now. I would also like to thank my friend and family for the support they gave me in my work.

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Fig 01. Diagram, Consumption of the planet resources. © Personal illustration.

01 Abstract

This thesis aims to explore the potential of flexibility in housing to endeavour to solve problems raised by waste of resources in the construction industry. The availability of resources and their usage after a building project raise many concerns. Various strategies can be carried out to improve these issues; in this proposal, the focus is to propose a building system for housing projects that could optimize material usage and building lifespan. Consequently the proposal will explore two areas: layout design and technical realization with details.

Exploring these different approaches, various methods will be used to pursue this research. For the building layout, reports, references, and experimentation in the subjects of dimensions and modularity will be examined. For the building system, there is a preliminary phase of prospection and inventory of existing solutions, then following these results, it will be possible to experiment while still performing research to complete the design. These parallel developments are then assembled and shown in a generic proposal.

Researching the subject of this thesis, many elements have been learned about construction solutions and possible assembly methods. The main achievement is the design of a building system made up of modules which allow a longer lifespan. There have been many challenges as the possibilities of solutions were endless and complex to attain the goal of disassembly and adaptability. The final proposition shows how those issues have been solved and arranged together. The building layout aspect was less challenging; however, it was still constrained by the dimensions of the construction. In the end, both aspects of the thesis work in cohesion to pursue a longer lifespan.

Using concepts of adaptability, design for disassembly and modularity in cohesion with architectural reflections on materiality and dimensions has helped to propose a system that is flexible and durable over time. The overall project shows that there are many possibilities to save resources and solve waste issues, using simple but efficient designs strategies.

Keywords: resources, waste, adaptability, design for disassembly, modularity, building system, layout.

02 Introduction

Problematic

50% of the world resources are exploited by the construction industry, producing 40% waste. (Australian Government - Department of the environment and heritage - Green house office, 2006). Consequently, the way human society is build will alternately become problematic. Since the beginning of human existence, man has constructed all kinds of shelters to provide protection from the environment and potential dangers.

However, we are now faced with issues of how to deal with our waste and to manage the available resources. New technologies and evolution have led to our planet suffering more and more from pollution. Some organizations are trying to solve those issues. For example, the project «the Ocean Clean-up" aims to eliminate 90% of floating plastic in the oceans. ("The Ocean Clean-up," n.d.). Even with those actions, the source of the problem is not taken care of. The problems will reemerge again.

Our society is created from materials, energy, and water. All those elements come from our only planet. For a few years now, movements highlight the fact that we are depleting Earth from its resources. We would need 1,75 planets to sustain our actual consumption. (McCarthy & Sanchez, 2019). In 1970, the overshoot day (the date when we have consumed the annual resources available) was the first day of the following year. In 2019, this day was on the 29th of July. The movement "#movethedate" makes us think about solutions to our over-consumption. ("Press Release July 2019 English", 2019). This demarche is trying to help preserve the environment. Our planet is renewing its resources at a fixed speed, and we are exceeding this speed with our actual consumption.

Although those problems are acknowledged, our society is not changing. As architects, we can propose new solutions to solve those issues and contribute toward giving a better future to the coming generations. In this thesis, there will be research and experimentation will be carried out to propose a sustainable housing proposal. It will explore ways to reduce resource consumption and waste production. One approach to figure out those issues is to work circularly. It can be tested in the project regarding the materials cycle, how we use them and how we subsequently leave them.

Purpose

This study aims to explore circularity to propose a sustainable housing project. The idea is to reduce resource consumption and waste production in the construction industry. Those elements will be explored using three concepts: adaptability, design for disassembly, and modularity. Those approaches will help the project to gain flexibility and longevity. It will be adapted to the user's needs over time while respecting the environment.

Research questions

How can a housing project attain sustainability, while enhancing material circularity and user comfort?

How can the concept of adaptability help to adapt a housing layout to the user's needs and promote its comfort at all times?

How can the concepts of modularity and design for disassembly be explored to propose a building system that adapts over time while respecting materials?

Objectives

As stated previously, the main goal for this thesis is to attain sustainability. However, this element cannot be rated. The proposal will focus on diverse ways to propose a housing project that respects the environment. For that, the lifespan of the building must be longer, the materials used must be selected properly, and the overall design must be adaptable over time. Therefore, the project aims to be modular in its layout and construction to provide a long-lasting shelter. Then, the diverse components should be designed and thought about in a way to be reused after serving their purpose in the project. Overall, the process behind this proposal aims to lengthen its life.

Reading instructions

This booklet represents a semester of work on a project. To follow this research, it has been separated into chapters. The first one state the structure of the booklet. The second one gives a beginning of research on how the process will be done. Then, in the third chapter, it is possible to find the research material along with the development of the diverse design. In the fourth chapter, the design is cleared and exposed as a final product. The fifth one shows the development of the design in a realistic condition with a project proposal. And the final chapter is about reflections on the whole process.

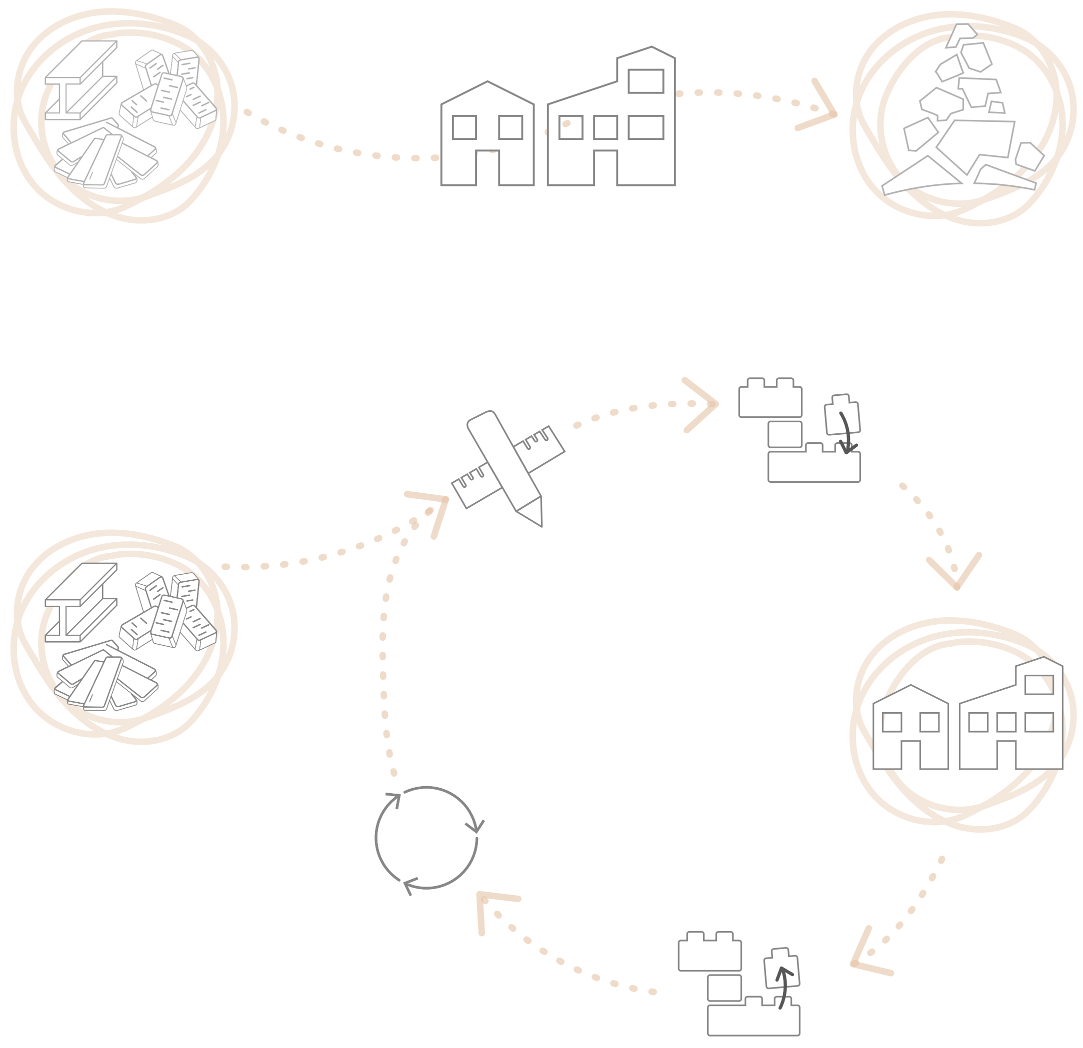


Fig 02. Diagram, Linear versus circular system. © Personal illustration.

Background
Introduction

This section will provide explanations on how the thesis will be developed through three concepts: adaptability, modularity, and disassembly. Using them, it will be possible to explore the idea of the evolution of the building in diverse ways. They have diverse strategies and are not applied in the same manner. For instance, the principle of disassembly concerns construction aspects more than the others. We now show how the concepts are working and how they could be used in this study.

Adaptability

Dictionary: the ability to adjust to different conditions or circumstances. ("Definition of adaptability | Dictionary.com," n.d.)

Architecture: the capacity of a building to accommodate effectively the evolving demands of its context, thus maximizing value through life. (Schmidt III, Eguchi, Austin, & Gibb, 2011).

Background: Adaptability concerns two concepts, time and change. In present days, designers tend to focus on aesthetics and functionality without thinking about what the design could evolve into or even how long it will last. Although, with a growing interest of our society for sustainability, it is fundamental to focus on how things will evolve in the future, and what building becomes after they serve their purpose. (Schmidt III, Eguchi, Austin, & Gibb, 2011). Therefore, reflections on strategies to make the situation change are essential. According to the American Institute of Architects, design for adaptability is about early engineering engagement in the process. They recommend using a stronger structural system with regular spaces between the elements and a generous floor-to-floor height. In terms of the structure, they recommend that the spans must be clear and the interior partitions should not be load-bearing. Then they state that the materials must be durable and assembled with mechanical fasteners and the systems should be clearly separated. Finally, they recommend clear and efficient documentation to propose a design that displays beauty and quality over time. (The American Institute of Architects, n.d.). With those elements in hand, designs can therefore evolve in typology or construction over their entire life span.

Those strategies are used in many projects. For example, Kitamura Naoya Architects and Planners employed some of them in the K House design. The spaces inside correspond to the needs of the household, although they can evolve in the future. The arrangement consists of a column and beam grid structure that follows dimensions from the Japanese standards. The ceiling height is generous, allowing the opportunity to use the space vertically. Therefore, it is possible to play with half levels and create spaces under and above others. As the architect said, the house showcases diversity in design and possibilities of expansion. There are diverse possibilities to change the space for future needs. (Pintos, 2020).

Fig 03. Picture, inside of K-House. © Takumi Ota

Fig 04. Picture, inside of K-House. © Takumi Ota

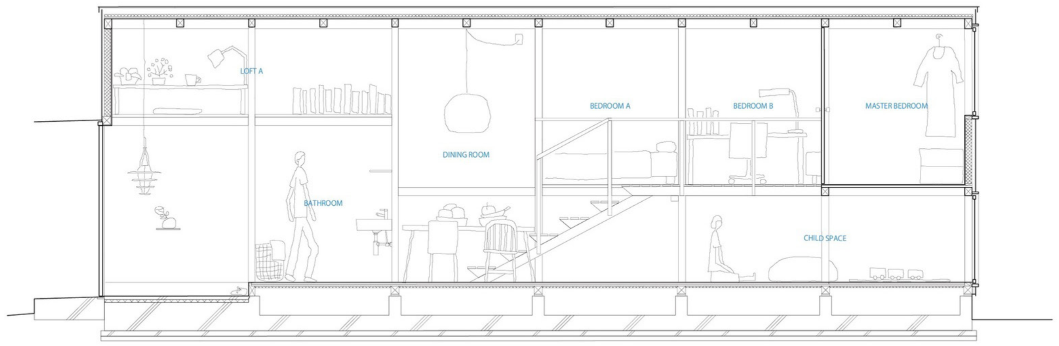


Fig 05. Drawing, «Section» of the K-House. © Kitamura Naoya Architects and Planners

Interpretation: The possibilities of evolution and adaptability from design allows for various approaches. It offers diverse design approaches for architects, and the project remains able to grow, change, and responds to future needs. However, it needs to be planned in the early stages of the design otherwise it will not be efficient. This concept enables the building lifespan to be extended. With our actual linear system in the construction industry, it now offers opportunities to extend it. The longer the building lasts, the less waste it produces. For instance, the building doesn't have to be demolished nor replaced by another construction that generates waste in turn.

As this concept offers sustainable development opportunities, it would be beneficial to use it in the thesis. There are many ways to employ it as we can see with the number of strategies. In this study, it would be interesting to use it for the building layout. The idea is to allow it to evolve with the users. For instance, if a family gets bigger or smaller, it will be possible to add or take away a room. However, to allow those design transformations, it is important to elaborate on all aspects so they can evolve smoothly. Therefore, the building components must be thought to be adaptable as well. If the transformation seems too complicated, the users will prefer to move or completely change the building. It is crucial to think of solutions that are user-friendly so the project will reach the goal of sustainability.

Modularity

Definition: *The use of individually distinct functional units, as in assembling an electronic or mechanical system.* ("Definition of modularity | Dictionary.com," n.d.).

Architectural meaning: System subdivided into smaller parts called modules that can be independently created and used in different systems. (Nady, 2021).

Background: The concept of modularity has been explored for decades by architects. For instance, in Japanese buildings room sizes corresponds to rice mats combinations. This was also made famous by Le Corbusier and the modulor. This concept is a challenge, with complex elements, however it also presents many advantages such as flexibility and cost efficiencies. (Nady, 2021). Modularity compared to adaptability or disassembly uses fewer strategies, there is only one, using modules. The modules should be similar and able to work alone or with others. Once the project is in service, it should be possible to add, replace, or take away modules without affecting the whole design and its characteristics. (Nady, 2021).

The idea of modularity is something that has been used for a long time in architecture. For instance, bricks are a module that forms a wall (or other sorts of elements) when it is assembled with others. As the bricks are prefabricated, a type of modular solution, the building process is made easier. However, during the standardization stage, this approach changed further. During mass production and industrialization, modular concept was taken so fat that creativity, beautiful and unique designs were left aside. Nevertheless, some elements of this period allows us to produce faster more efficient projects and should not be ignored. (Combes & Bellomio, 1999). Prefabrication is making a comeback, in "lego style" design. Façade modules are now the most popular modules and can be in diverse materials, and it does reduce the construction time considerably.

Time constraints are now crucial factor in new buildings. Here it is about making the construction process faster. With prefabrication, the building parts can be assembled more efficiently, as there are usually manufactured with controlled conditions inside a factory. Associating prefabrication and modularity is possible, although those two terms also work separately. (Wagner, 2016). The first houses to be prefabricated trace back to 1600 when England sent kits to the United States. A more modern version of those houses appeared around 2000. (Connors, 2020). Modularity was popular in architecture when Buckminster Fuller proposed some of these designs in new houses. As he went over budget the trial was classified as unsuccessful. However, the concept developed again in 1950. It was then trending. In 1967, Moshe Safdie made it popular with the Montreal International Exhibition. He proposed a project named Habitat 67 in which 354 concrete modules are stacked on top of each other. Those components formed a 12 story building where lights, air, and open spaces have been important. (Wagner, 2016). This project started as an experiment for a high-quality housing solution in an environment denser over the years. The architect worked with two objectives. First, the modularity, which brings a less expensive construction solution. Then the layout of the apartments where the idea was to create sub-urban houses in a high-rise building. (Merin, 2018).

Fig 06. Picture, Habitat 67. © Wikimedia Commons.

Fig 07. Picture, Habitat 67. © Wikimedia Commons.

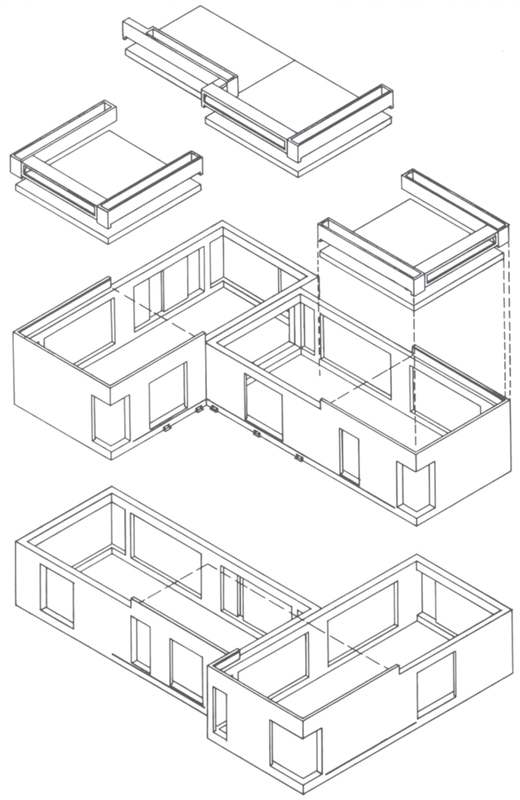


Fig 08. Isometry, Module. ©Canadian Architecture Collection, McGill University.

Interpretation: Modules can be used in various ways for a housing project. As the houses are going to evolve in size for the proposal, all components must follow those variations. Therefore, it would be interesting to think of them as modules. Thus, the dwelling can gain flexibility. As mentioned before, the concept of design for disassembly can also work in cohesion with the idea of modules. Then each module can be disassembled from the project to be moved.

As the proposal is to work towards improving buildings lifespan, it is therefore important to think about how the modules can work in this way. Each layer of the house is composed differently. Therefore, the lifespans of each of them are varied. It would be preferable to work all parts of the project as modular components: structure, skin, space, system, etc. Then the elements should work together when assembled. The different layers evoked here correspond to the famous "Shearing Diagram" by Frank Duffy, which was further elaborated by Stewart Brand in "How building learn: what happens after they're built". (Brand, 1995).

The proposal is now working in many ways to be able to evolve over time. However, style and preferences are also evolving. It would be interesting to think about this aspect in cohesion with the modules. For instance, the finishes could vary regarding the user's preferences. The modules are going to be used as long as they can, it is important to build them with pleasant aesthetic in mind. Once they are not able to pursue their function in the house, they should be dismantled and the materials should follow a sustainable path. For example, they can be reused, recycled, repurposed.

Design for disassembly

Dictionary: to take apart / to come apart ("Definition of disassemble | Dictionary.com," n.d.)

Architecture: Design of buildings to facilitate future changes and dismantlement for recovery of systems, components and materials, thus ensuring the building can be recycled as efficiently as possible at the end of its lifespan. (Cutieru, 2020).

Background: Disassembly is the most recent of all three concepts. Society is ever more engaged in these ideas as sustainable approaches gain momentum in the collective consciousness. A few projects have been built since it was defined in 1990. However, very little feedback exists concerning the different strategies to prove their efficiency. The office 3XN has been working on many projects using this concept to endeavor to enhance usability. According to 3XN materials must be carefully selected to ensure optimal performance and recycling. They insist the entire lifespan of the building should be at the center of all discussions around its design. They discuss ideas regarding the standard dimensions in projects to allow them to fit into systems. Then, they recommend using connections that can be dismantled and reused from a long-term perspective. Finally, they claim that planning the whole project with schedules for the assembly and disassembly phase is fundamental. (GXN, 2018). With those elements, it is possible to obtain a circular economy with a project. The entire process can even go further with materials listed with IDs and stocked in a database shared among planners.

This concept of disassembly is based on and reach principles to allow better maintenance and end-of-life management of a building. It is possible to obtain circularity when it is used properly. With this process, it is possible to reflect on how materials are used and how they serve after the primary usage. It pursues an integrated method where everything is thought to reduce energy consumption, resource looting, waste accumulation, etc. Consequently, the construction industry will work in a circular system instead of a linear one. Having a material bank is a strong approach to help alter the system in this industry. With it, the components of projects are listed and can be used and reused in diverse designs. ("Overview | Buildings as Material Banks (BAMB) Outcomes at the End of a Research Cycle," 2019). This strategy is increasingly developed in certain countries. It could be generalized in the following years as resources might become rarer.

Design for disassembly aims to relieve the scarcity of resources. This is one of its goals and to pursue it, the design should reflect on how components are assembled, and how they could be disassembled. This parameter requires to allow reversibility. Therefore, glue and other permanent fixing solutions should be avoided, as they could damage the building's components. It is crucial to reflect on those points during the design stage. For instance, the circle house project from GXN is following this principle. The design of the unit was conceived in a way to be disassembled into many components. They proposed a concrete slab system that can be separated and used for other projects. ('Circle House Demonstrator', n.d.).

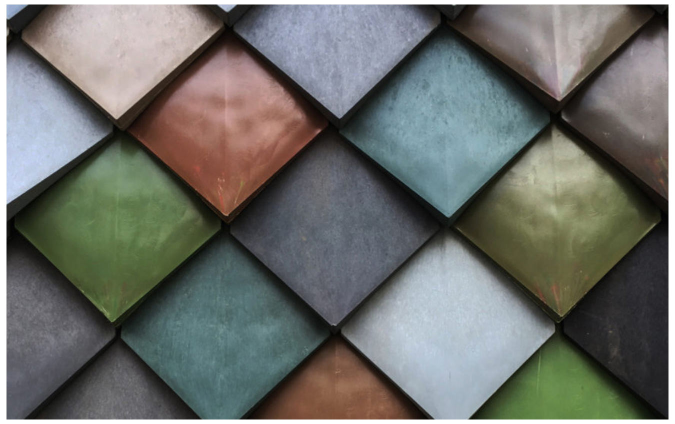


Fig 09. Picture, Circle house facade. © GXN.

Fig 10. Picture, Circle house concrete detail. © GXN.

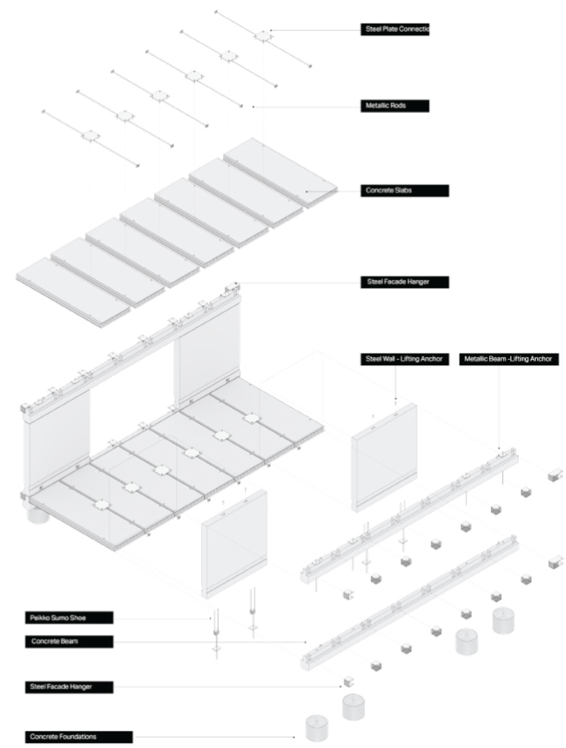


Fig 11. Isometry, Circle house assembly elements. © GXN.

Interpretation: The concept of design for disassembly offers many opportunities for constructive solutions. As mentioned before, the construction aspect needs to follow the adaptable strategy of the project. If it was using classic manufacturing methods, it would be impossible to disassemble it. Therefore, it is important to plan the different elements so that they could move following the layout of the building.

Dimensions are another strategy that benefits the project. If the constructive aspect has dimensions that fit the layout of the building, it would then offer multiple possibilities of evolution. Using the concept of modularity (see next page) in cohesion with design for disassembly could give many advantages to the project. Those two elements together could enable complete freedom to the project.

The concept of design for disassembly fits with the other ideas for the project and could bring many advantages. In this thesis, disassembly solutions will be studied to explore the diverse opportunities. This is an important point to focus on. Those elements can enhance the project and its lifespan. The less the materials are damaged, the longer they can remain in use in the project.

Thesis development

Introduction

This section will provide an explanation of how the project aims to be developed. As mentioned before, the problems of resources and waste are concerning. As architects, it is possible to think our design differently to propose new solutions. In this thesis, the approach consists of two elements: an adaptable building layout and a flexible constructive system. These elements are developed according to the following description; however, the focus of this thesis is based on the principle of modularity. This is the main element and it is visible through both aspects developed.

Building layout

The adaptable building layout development is about making various possibilities of dwelling sizes. In fact, once the room design is decided, it will be possible to arrange the diverse parts to form houses, apartment buildings, etc. The proposal will contain different types of rooms that can be attached to others to form a full home. If the user's needs change, it is possible to adapt the layout. This development is mainly visible in plans and focuses on the sizes. The spaces need to be comfortable to live in and to fit the general functions required in a housing project. Those elements will be studied in research for adequate dimensions.

Fig 12. Diagram, Building concept. ©Personal illustration.

Construction details

The flexible constructive system will be developed through modules. Those elements are then going to be assembled to follow the building layout. Once they have served their purposes, they will be disassembled from the main house, dismantled, and the materials will be used in another way. For instance, the diverse parts can be reused, recycled, repurposed, etc. This aspect is about the after-life of the building components. It is fundamental to think about those elements as it opens the opportunity to create loops, which means sustainability. This is how a circular economy can be achieved. However, this is not the main part of this study. The most important aspect to work on is the constructive details to provide efficient houses with climate in mind and to offer the possibility to move the elements with the possible evolution of the house.

Fig 13. Diagram, Constructive concept. ©Personal illustration.

Method

This thesis will be developed with research and experimentations. Many aspects should be studied to bring a strong knowledge core into the project. As the proposal will be developed with constructive aspects, it is important to define the materiality. Sustainability is crucial for the project. Therefore, diverse materials will be compared to find the one that respects the most this criterion. Then, the way to use this material must be explored to find the most efficient assembly solution in cohesion with the concept of design for disassembly. The two parts to be developed in this thesis, the typology and the construction, are related to dimensions. This aspect will also be explored regarding the actual requirements. The idea is to find measurements that can fit the needs of the users in a comfortable way.

A phase of experimentation can start now that research has provided the foundations. This stage consists of developing a building layout based on room elements, and construction details of modules that can be assembled in an adaptable way. Those two aspects can be developed separately as they rest on the same research. In the end, a catalog of solutions will be established to represent the multiple opportunities from both aspects. However, they must be exposed in a project to demonstrate their cohesion. This part consists of a proposal for a housing project. As all projects require a context, a suitable site in Göteborg needs to be found. The city is currently promoting a strong development with the interlinked city. Thus, the idea here will be to propose something outside of this development as a suburban project. However, the connection to the city remains crucial, so the context must include good commuting. This research will be developed later in the thesis. Once the site will be selected, it must be analyzed. For this aspect, the e-book of Tifa "Architecture student guide: Site analysis" will be used. (Tifa, 2020). To finalize the proposal, the settlement of houses will be designed regarding a diverse household community.

Fig 14. Diagram, Method. ©Personal illustration.

Delimitation

Although the thesis is exploring many paths, it will not cover some aspects. One of them is the engineering calculation. For instance, there is not going to be structural dimensioning. Instead, the project will refer to dimensions coming from previous experiences that are not optimized. Nevertheless, they correspond to a good range to make this project realistic. However, other calculation such as thermal values will be presented as it goes into a sustainable approach to make a project more efficient. Another element that is left out of the thesis is the budget. The economical aspect will not be calculated. Besides those elements, this paper aims to be precise and informative on the concepts explored.

02 Research development

Introduction

This section of the thesis will provide the information from the research phase. It consists of exploring the materiality opportunities and selecting one that will be relevant regarding sustainability. Then this option will be further analyzed to explore how to use the materials. After those research, the process will continue with explorations of assembly methods to research what can be employed regarding the selected material and how it can fit with the concepts explored in the background. Finally, there will be exploration regarding dimensions and measurement for housing regarding requirement and comfort. It will give us proportion to work with for the experimentation stage.

After finishing this research, it will be possible to test the results and try designing with them. Those experiments should be done for the building layout and the construction system. While realizing those explorations, it will be fundamental to keep in mind the sustainability goal. For instance, when designing the modules mentioned earlier, it is important to think about how the materials are used to optimize their quantity. Many approaches like this one must follow the process to make it sustainable in the end.

Materiality

In the construction field, there are many materials used. Three of them are more present in housing projects: brick, concrete, and wood. They are all presenting qualities; however, they are not especially sustainable. As this research aims to reach sustainability, it will be preferred to choose a material with less environmental impact. A comparison between the materials will be done to pick one. It will follow some criteria. First, there is the availability of the material. Some of them are finite resources that will be impossible to find in a few decades; therefore, it is important to choose a resource that does not vanish due to over-consumption. Then, the materials will be ranked regarding their ability to have a second life. It would be better if they could be reused, recycled, repurposed, etc. This criterion is crucial to reach the circularity goal. Next, it is the production and transportation of the material that will be studied. If the material involves a lot of emissions, it is not going to be suitable. Finally, the three elements will be assessed regarding the way they can be employed for construction. It must be reversible, otherwise, the materials can be damaged and become waste.

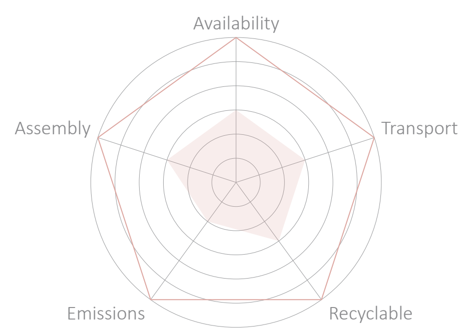


Fig 15. Diagram, Brick. ©Personal illustration.

The first material assessed is brick. They are usually made with clay. However, to assemble them, cement is required. This material uses sand and the process to extract it is damaging many ecosystems. Therefore, the availability of this resource can be not ranked very well. Consequently, cement is also impacting the evaluation for the emissions and transports. It is also impacting the opportunities of a second life for the material as the assembly is not reversible with cement. Solutions are now being explored to solve those issues, although they are not easy and they will consist of important investigations for this research.

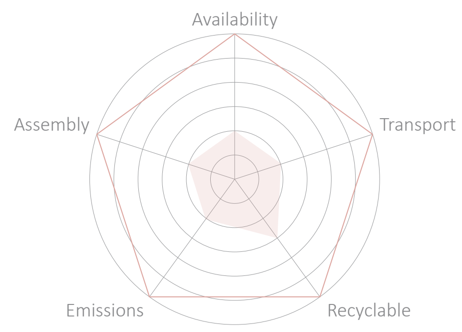


Fig 16. Diagram, Concrete. ©Personal illustration.

Then, there is concrete. This material is composed of sand, like cement. Therefore, it has a big impact on the environment which gives it a bad grade for availability, emission, transport. Similar to bricks, it also causes problems with the assembly. Concrete is usually put in a mold with iron to make it stronger. Then it dries and attaches to some parts to stay there until it will be demolished. Consequently, this material does not suit the concept of design for disassembly. However, it now can be recycled. Once a building is taken down, the gravel from the concrete parts can serve as a base for a new concrete building.

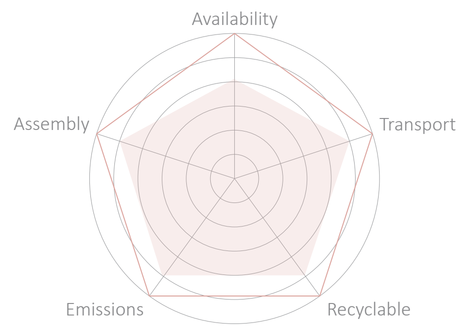


Fig 17. Diagram, Wood. ©Personal illustration.

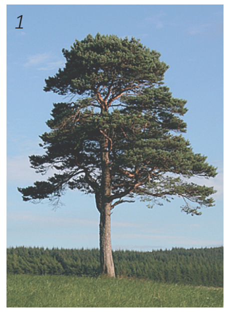
Finally, wood can be assessed. This material shows diverse opportunities. It can be grown which makes it an infinite resource for now. To collect and manufacture it, the emissions are low. Moreover, it is largely available in Sweden with a large amount of forest we can find there. Therefore, it does not require a lot of transportation. Another opportunity with this material is that it can be used for many things in the construction industry: structure, insulation, finishes, etc. Furthermore, wood elements can be assembled in many ways with solutions that can be reversible. Using wood is not only an advantage, it also requires thinking about waterproofing, air-tightness, treatment against parasites, etc.

The three materials presented here are the most common for buildings. However, do not present the same potential for sustainable constructions. As presented above, wood is the material that impacts the environment the least, therefore, this is the material selected for this study. It is present with diverse essences in the Nordic countries. From those, there are many options of hard and soft wood. Depending on this, the usage may vary. It is then important to choose the right type of wood regarding its usage. As mentioned in the wood analysis, there are also a lot of possibilities with wood as it proposes insulation, finishes, structure, furniture, etc. The assembly of those elements is also a variable and it may be possible to reverse it in many cases. It will be crucial to select fastening solutions that correspond to principles from the concepts of modularity and design for disassembly.

Now that wood is selected as the material to explore in this project, it is important to study the diverse options it offers. In the following section, this will be explored with research on tree essence, existing materials, etc.

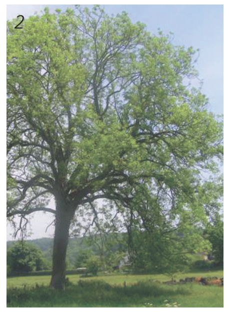
Wood essence

In Nordic countries, it is possible to find the most important producers of wood in the world. Those are Sweden (55% of forest), Finland (78% of forest), and Norway (37% of forest). The exploited forests are based on sustainable management to avoid deforestation. (NoltFolx, n.d.). Overall, there are 65 million hectares of forest across Northern Europe, and 55 million are possible to use for wood cutting. Most of the trees are coniferous. (Food and Agriculture Organization of the United Nations, 1997). In this family of trees, it is possible to find European pines (Scots pine) and European spruce (Norway spruce). Coniferous show many advantages for the construction industry. First, they are growing fast, which makes it easier to maintain de forest while using this resource. Then, it is a soft kind of wood, which makes it easier to cut and manufacture into specific pieces. Finally, the constructor prefers to work with it as it will be more flexible for various usage and simpler. ('How to use conifers – Commercial & other uses for conifers', n.d.).



1 - Fig 18. Pictures, Scots pine, ©Wikimedia commons.
2 - Fig 19. Pictures, Spruce, ©NatureHillNursery.

There are also some varieties of hardwood in the northern countries. For instance, it is possible to find European hornbeam, European ash, white birch, kvill oak, or common aspen. Those types of trees are still usable for construction. They offer more varieties in aspects than coniferous that look similar once they are cut. However, those are hardwoods which makes them harder to work with.



1 - Fig 20. Pictures, European Hornbeam, ©Wikipedia.
2 - Fig 21. Pictures, European Ash, ©First Nature.
3 - Fig 22. Pictures, Birch, ©Wikimedia commons.
4 - Fig 23. Pictures, Kvill oak, ©Wikimedia commons.
5 - Fig 24. Pictures, Common aspen, ©Tree guide UK.

Wood products

As mentioned before, using wood offers various possibilities. It was first used 10'000 years ago with a timber house in Britain. Throughout the Middle Age, wood was mainly used as structure and skin. Between the 14th and 17th centuries, the use of wood became more common. The watermill was invented to allow new usage of this material. (Log Cabin Hub, 2016). Since then, many other solutions have been developed using all the components of wood: bark, trunk, branches, leftover, etc. Each part of the tree can be used in some way. Most of them can be transformed into building components. For instance, it is possible to transform the bark to make some insulation with it. The process to achieve this product does not require additive and is nonpolluting as it does not produce greenhouse gases. With the wood fiber, it is also possible to propose various products: insulation panels, boards, etc. Moreover, when the wood is not strong enough for some structure, it is possible to reinforce it. The elements are then called glulam timber. It consists of many pieces of wood glued together to form a stronger component.

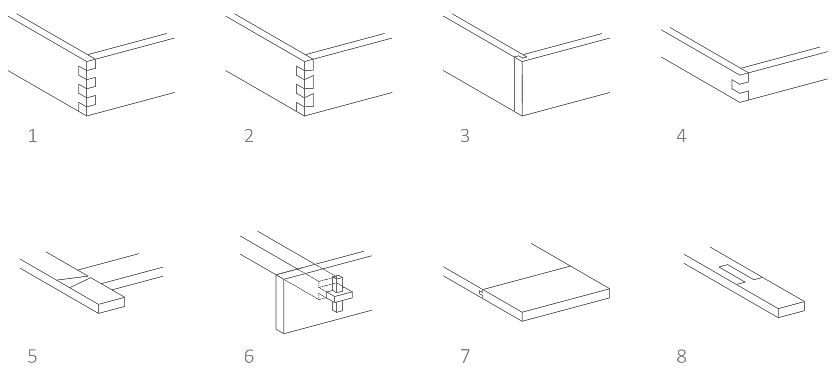
Wood can therefore be used in many parts of a building. There are plenty of ways of manufacturing wood. In the beginning, there were only saws to cut it. Now, it is possible to use a computer numerical control (CNC) machine to accomplish perfect cuts of specific elements. It can be practical for the mass production of a single element, like a module. However, it can become more expensive to use those technics. It is easier to use elements with standards dimensions. For structural timber, dimensions are usually the same with all resellers. However, with elements like insulation, the dimensions can vary from one factory to another one. In all cases, it is crucial to reflect on the size of the elements and the possible modules. The more the measurement corresponds, the less waste there will be.

Assembly

In this section, we will cover the different ways to assemble wood. As previously stated, wood is a great material for flexible usage. However, the fastening techniques are limited mainly three methods: woodworking joinery, mechanical fasteners, and carpentry connectors. Those three categories are gathering most of the technics used for wood joinery.

The woodworking connections are the oldest to fasten wood. This is a tradition coming from China, Japan, Europe, and India. Elements from Egypt and India are estimated to be 5000 years old. Techniques have developed over the years. In the Diderot Encyclopedia, it is possible to find more than 90 illustrations of woodworking techniques. Those assembly methods are still famous in some countries, where using mechanical fasteners is not possible. For instance, in China and Japan, the weather conditions are creating too many fluctuations for wood and fasteners are not able to follow those movements. Therefore, woodworking joinery is the most effective method as all elements move together as one. This is a strong feature of these countries architectural culture. (Wikipedia contributors, 2021).

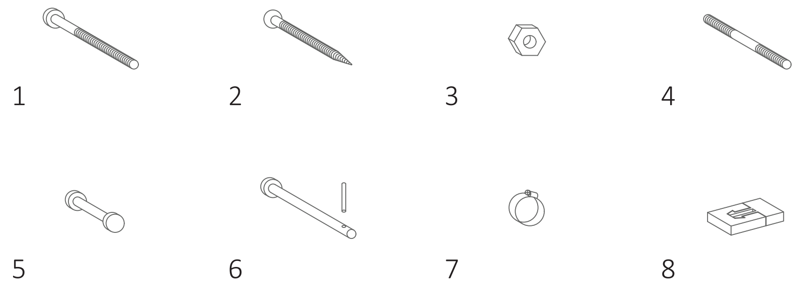
Woodworking joinery can be used for different functions: lengthening, widening, framing, etc. Those functions are bringing a lot of opportunities with wood. To achieve them, there are many joints techniques, corresponding to eleven categories: box, bride, butt, dado, dovetail, lap, miter, mortise and tenon, rabbet, scarf, and tongue and groove. Each of them contains several ways of realizing joints. However, to be able to produce them properly, it is necessary to have strong knowledge of wood and its characteristics. Each essence of wood acts differently and the joints are not fitting all of them in the same way. (Craftsman space, n.d.).



1- box joint
2- dovetail joint
3- dado joint
4- bridle joint
5- lap joint
6- mortise and tenon joint
7- tongue and groove joint
8- scarf joint

Fig 25. Drawing, Woodworking joinery. ©Personal illustration.

Mechanical fasteners is the method most used in the construction industry due to its simplicity of usage, this technique was also used in metal constructions and were subsequently developed for wood assembly. Most of them can be reversible. However, it is important to reflect on the impact they have on wood. For instance, once a screw is used in wood it will leave a hole that could impact re-usability. Therefore, nuts and bolts can be more effective for long term use of material, especially if it is pre-holed. (Throughton, 2008).

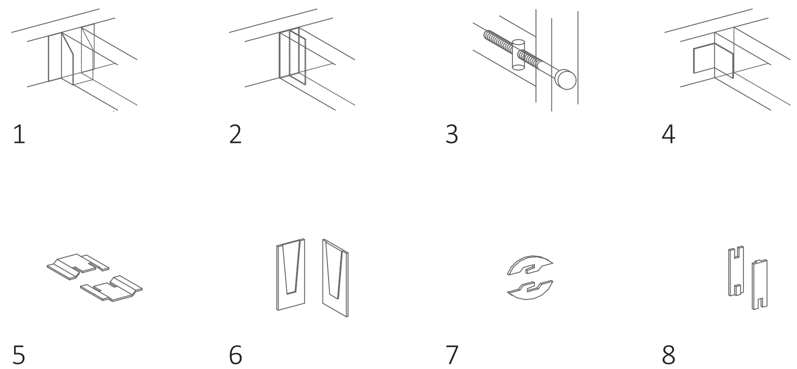


1- bolt
2- screw
3- nut
4- stud rod
5- river stud
6- pin clip
7- pipe clamp
8- snap fits

Fig 26. Drawing Mechanical fasteners joinery. ©Personal illustration.

Finally, carpentry connectors can be used in various shapes and dimensions. It is also possible to get them specifically for a project. The pieces are usually in metal. There are many innovative solutions with this type of connection. It is possible to have them hidden so they are not going to impact the aesthetic of the project. Most of them can be disassembled. However, it is here again important to think about the possible damage to the wood elements.

To use carpentry connectors, it often requires to use bolts or screws to fix the connectors on the pieces. By mixing those two categories, the possibilities of assembly become limitless. However, it is crucial to think about the dimensioning of those elements. In fact, they are here to enhance a project, but if they are too poorly sized, they might break and the design will be impacted. Those elements are fundamental for some projects, and they can be part of the aesthetic. It is important to consider them properly for all those parameters.



1- joist hanger
2- joist brackets
3- cross-dowel
4- angle connectors
5- interlocking connector
6- hooked connectors
7- simplex
8- knap connector

Fig 27. Drawing, Carpentry connectors joinery. ©Personal illustration.

Dimension

This section is about exploring the dimensions of housing buildings. Plenty of solutions exist for making housing comfortable. However, in this research, the focus is brought to rationalize a system to make it efficient through different aspects: layout and construction. Both aspects must fit together. To make this proposal livable, it will be necessary to respect the requirements from standards dimensions and to propose generous spaces for user's comfort. The first step will be to explore the recommendations from the Swedish government. Then it will be possible to experiment with the diverse spaces to find the perfect fit that could be used for the entire project. The size here must be relevant enough to fit all purposes as mentioned before.

In Sweden, regulations for building sizes do not exist. However, it is possible to find recommendations. The Swedish Standards Institute is proposing some of them for the interior dimensions of a housing building. Those measurements are respecting enough spaces to allow disabled people to have access to the diverse elements composing the rooms. (Swedish Standards Institute, 2006). Here are the recommendations they assess for interior design.

Now that the recommendations have been studied, it is possible to try them into various room sizes to evaluate the general measurements. As mentioned by Boverket organization, some spaces are essential in a house. Here are the spaces they recommend having in the house: space for hygiene, space to cook and eat, space for social contact, space to rest, space for outdoor clothes or storage, and space for laundry. (Boverket, 2019). Once all those elements are part of a building, it is possible to name it housing. Therefore, it is now time to experiment with the requirement to produce those spaces and create homes.

There are various possibilities to try out some room layout. Space can be a square, a rectangle, or any other shape. To have a clearer system to start with, the square is going to be the reference shape. It allows having a clear grid to add other rooms next to each other without having issues with the sides. It is also easier to progress with a constructive system with similar sizes in a project. Then the question that arises is about the size of the square sides. The spaces are going to be tried with three, four, and five meter side sizes. Those measures come from previous experiences in other housing projects. In fact, rooms can't be too small and with a three meter side size, it gives a surface of nine square meter which is just the size of a single person room. Here are the possible spaces created from those dimensions.

With these tests, it is obvious that some sizes will fit better than others. By evaluating each size, it will be possible to rank them and select one that fits better. Here are some criteria that will help proceed to the evaluation. First, there is comfort. Users should be able to move freely in their houses without feeling claustrophobic. Then, the adaptability. Spaces are designed in a certain way for the project. However, the users might want to use it a bit differently. They should be able to make those changes easily. Finally, there is the functionality. Each room is getting a function. Although, if the space feels too small or too big, the practicality of the space might be impacted. Here is the evaluation of the three dimensions according to those parameters.

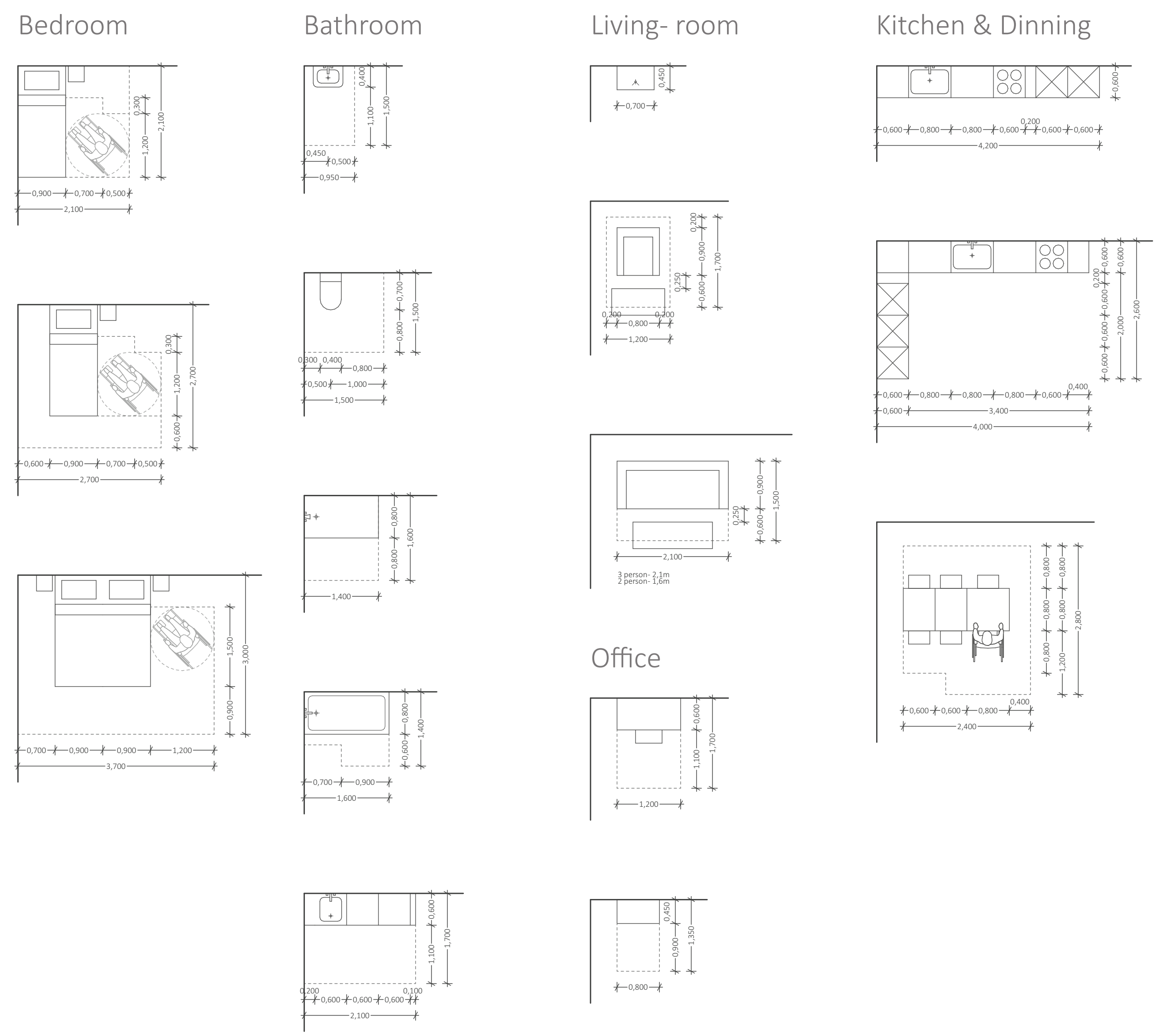


Fig 28. Drawing, Interior dimensions from the Swedish Standards Institute. ©Personal illustration.

Fig 29. Drawing, Comparison of sizes for rooms. ©Personal illustration.

When assessing three meter side spaces, it is obvious that necessary requirements wont be achieved. For instance, it is not possible to fit a double bed with spaces for disabled people properly in a three by three meter room. Then, the adaptability of each room is quite limited. There is not enough space to move things around. Finally, as the spaces are quite small, it is hard to get things done properly which impact the functionality of each room.

Rooms with four meter sides are easier to fit in various requirements and are fairly flexible. However, the space could be slightly larger for added comfort. The spaces are flexible; it is possible to change the layout if the users would like. To finish, the rooms have a good size and the layout that they possess can offer functionality.

Finally, it is time to evaluate rooms with five meter's side size. The spaces are large and fit all the purposes they should. It is too spacious for some of them. It feels like a waste of space; it is more than enough to get the required comfort. The adaptability parameter with this dimension is accomplished. There are various possibilities of layout due to a large amount of space. Finally, for the functionality, it is possible to make the spaces as efficient as they need.

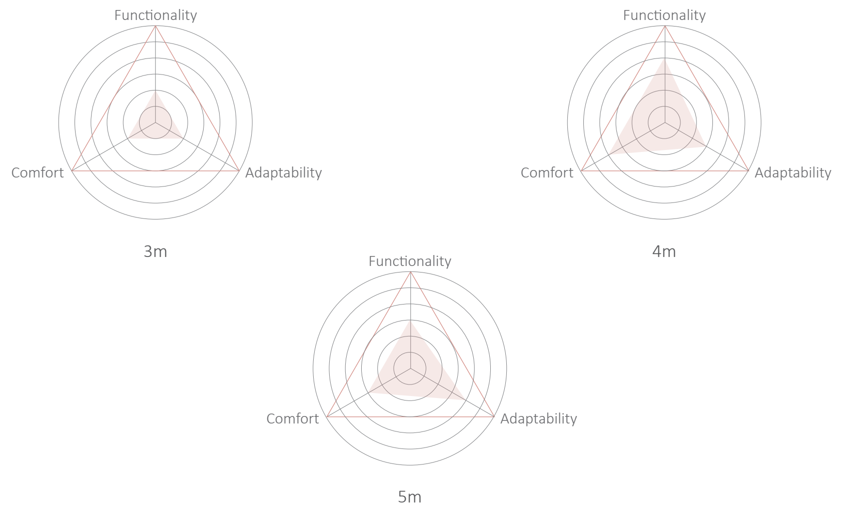


Fig 30. Figure, Room size comparison. ©Personal illustration.

Concluding this comparison, it is visible that the three meter side size rooms are too small for this purpose. The rooms of four meter sides are just enough for the purpose, although they could get some extra space. And finally, the five meter spaces are larger than what is required. Therefore, it would be preferable to explore the possibilities from an in-between solution. Now, there will be experiments with a room of four and a half meter side size. A few typical rooms have been created with these dimensions. Here are the results of this.

The trials with the dimensions of four and a half meter are conclusive. This space fits all the required rooms. It is even possible to combine some rooms together in one element. The spaces are neither restrictive nor extensive. The level of comfort is sufficient for a housing design. With those elements, it will be possible to experiment with modular houses. This part will be developed in the following sub-chapter "Building Layout".

Fig 31. Diagram, Sizes comfort comparison. ©Personal illustration.

Fig 32. Drawing, Rooms with a four and half size side. ©Personal illustration.

Building layout

Introduction

This section will provide a global vision of the building layout development. In the background chapter, the concept of adaptability is discussing the opportunities of flexibility for a floorplan. This approach needs to be explored while respecting the diverse requirements of space. With the previous research on dimensions, some rooms have been created that correspond to similar sizes of squares. Those elements work like modules that can be added or taken away from the full building. The proposal now needs to explore the combination possibilities of those square to see how houses can be created with diverse sizes.

Criteria

To develop this aspect of the thesis, it is also important to think about some criteria. Some elements need to be respected, or worked with, to make this project realistic. One of them is accessibility. It is crucial in our society to think about disabled people and how to integrate their needs into our design. Therefore, the project must be adapted. It means that the ground floor access needs to be though without steps, or with a ramp. Then inside, the space must be generous and all required rooms must be accessible, either on the ground floor or with a device to access the first floor.

Another criterion to think about is the capacity to grow. As mentioned previously, the houses must be adaptable. Therefore, it will be important to design a house that can grow or shrink with the user's needs. It requires thinking about the access to possible parts of the house, without disturbing the original layout. And if the house gets smaller, the elements that were making it bigger should not be missed by the rest of the house.

Finally, it is also necessary to think about the cohesion with the construction. The building system works with beams and pillars (see building system development). Therefore, the room sizes must respect this parameter. As the floor plan works with squares as the architecture frame, it is primordial to use those squares fully. It is not possible to use just half of it otherwise the constructive system will be impacted. Moreover, this space is considered useless and it consumes energy to maintain while serving for nothing.

Fig 33. Diagram, Criteria for house development. ©Personal illustration.

Experiment

Now that the boundaries have been established, it is possible to experiment with the rooms to create floorplans. At first, the idea is to develop a floor plan that is at the same time adaptable and accessible. To work out this proposal, it would be interesting to explore a ground floor that would remain the same, and then the first floor could contain more or fewer rooms regarding the needs. With this approach, it is possible to offer accessibility with the ground floor that must contain all required spaces for a house, and adaptability with the opportunity to have a first floor that grows. Here are a few experiments with this approach.

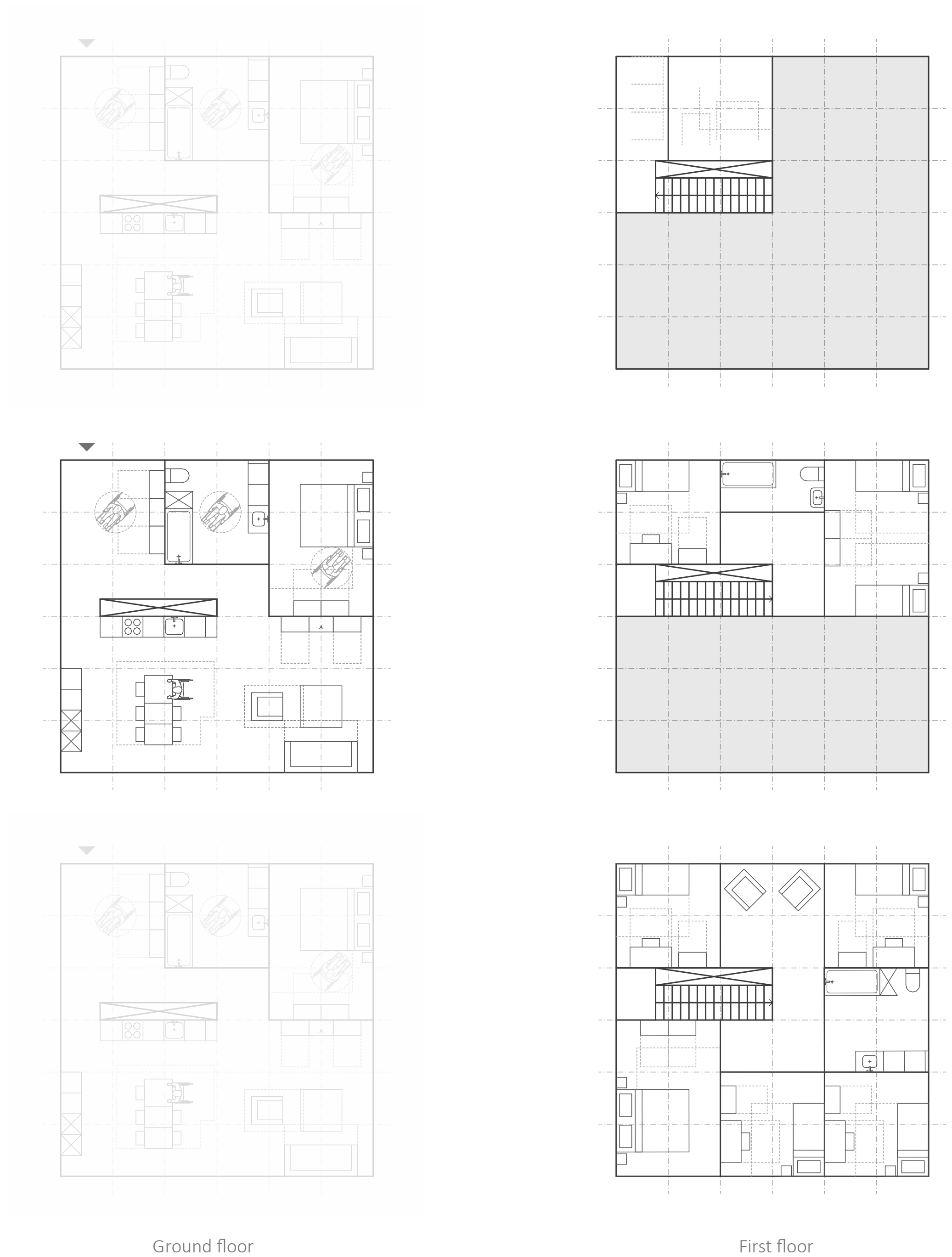
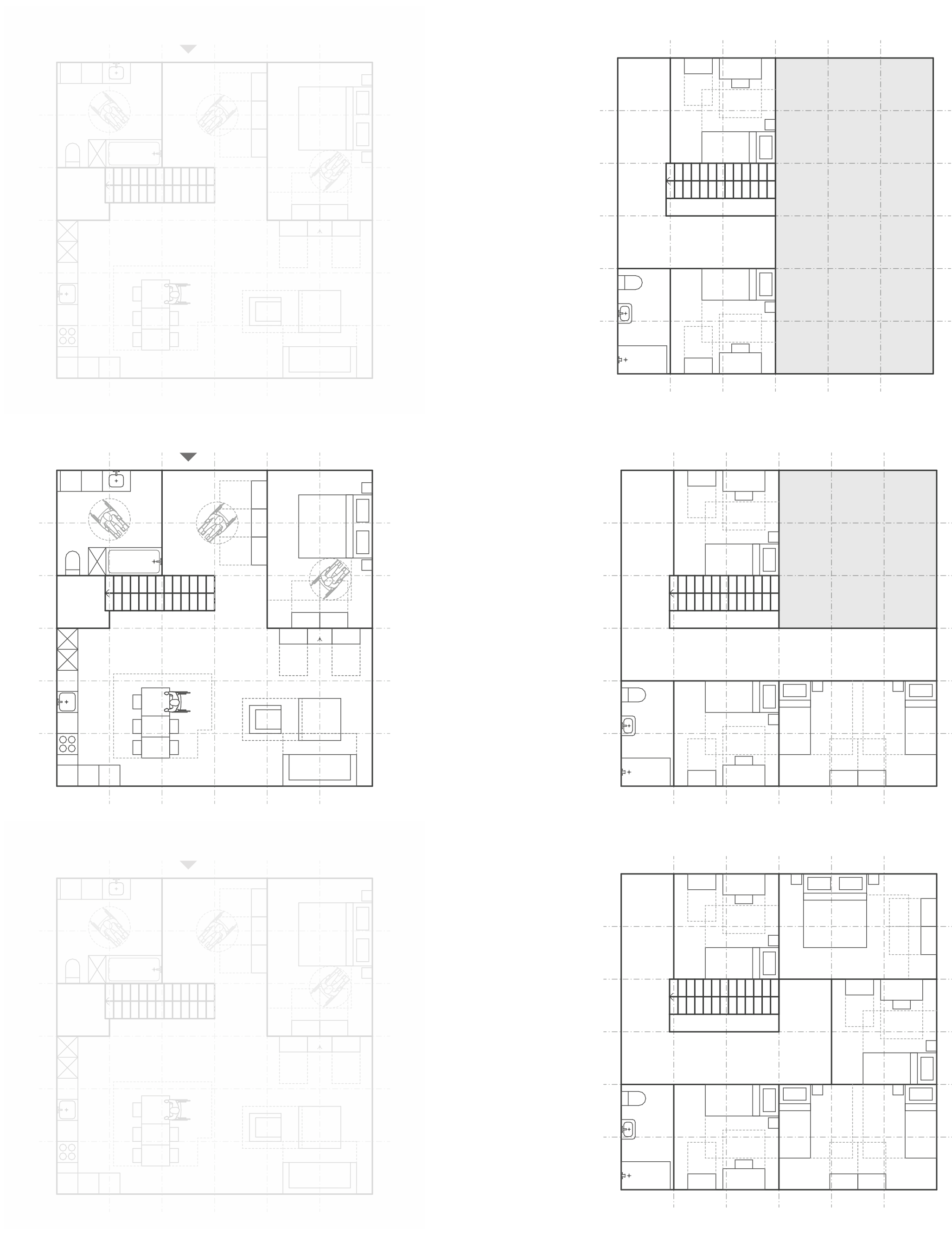


Fig 34. Drawing, Layour experimentation for various sizes of houses. ©Personal illustration.

The main idea of a common ground floor could function, however, the stairs in the house become an important element. With its size, it takes a good amount of space. The reflection around its placement should consider the area it impacts on the ground floor, but also the upper floor. The circulation must be coherent all over the house and it is influenced by the stairs. Another element that arises is the water management with the upper floor. It is not suitable to overlay the bathroom on both floors. There could be two approaches to this issue. The first one is to rearrange the upper floor around this parameter. Otherwise, it would be to integrate a shaft to take the water out where it will meet the others wastewater pipes.

Layout

With those diverse aspects to work on, it is to design another approach of the layout that would answer the issues. To proceed with this new version, the ground floor has been remodelled. In this version, the entrance became central in the layout, which allows the circulation to be more rational on this floor. The diverse elements proposed answer the accessibility requirement. And the stairs can be placed without affecting the layout. On the upper floor, rooms can be added easily. And there can be bathrooms too. However, space efficiency can be problematic. In fact, when only one room is added upstairs, it feels like it is a lot of work and it does not fit with the idea of sustainability. Therefore, if an upper floor is required it would be better to use at least two square frames to make it efficient.



Ground floor

First floor

Fig 35. Drawing, Layour experimentation for various sizes of houses. ©Personal illustration.

Another aspect that can be explored with the layout is the concept of working from home. It has increased in the last year due to the health crisis impacting the world. Therefore, a lot of households face issues to find a proper space at home to work which can be crucial to concentrate to work efficiently. However, it is not always easy to get. With the layout proposal, it could be possible to use one of the bedrooms as an office. Moreover, if the users required a client space in their home, it could even be possible to extend the house with one square frame to fit this need. If the bedroom downstairs is not required for accessibility purposes by the household, this one could also be used as an office, and it possesses direct access to outside, which could be convenient for clients.

Fig 36. Drawing, office integration. ©Personal illustration.

With those experimentations, it was possible to explore the floor plan in single house projects. However, the layout goal is to be as flexible as possible. Therefore, it should also be possible to use it for attached houses or apartment buildings. This aspect of the project can be developed with a common circulation area. Then the floor plans can be played with to create various shapes of buildings. However, the building system also needs to follow this aspect. The loads from a too high apartment building might not fit the proposed system. Therefore, if the proposal must be developed in a small apartment building, there will be a height requirement. There can't be too many floors to the building otherwise the system might collapse. The proposal for denser layouts will be visible in the catalogue chapter.

Overall, the layout proposal shows many flexibility advantages that fulfil some approaches from the concept of adaptability. Many floor plans are possible to explore, and they can adapt to the user's needs. Now that the layout has been established, it should fit the building concept. The experiments have been done for both aspects during the progress of the work. Therefore, adjustments have been made. The two concepts should now fit with each other. There will be a trial site with a housing settlement proposal to express the entire proposal and shows the possible development from it.

Construction details

Introduction

This section reviews the building system proposal. As mentioned in the background, there are two concepts to help this aspect of the research: design for disassembly, and modularity. With those approaches, it is possible to propose a system that should follow and enhance the adaptability principle of the building layout (see building layout development). For the building system, the main idea will be to develop modules for the house that can be assembled and disassembled along with the house evolution. Each component should be able to work on its own, and with others. Therefore, the project can sustain in all situations.

Criteria

Some criteria need to be established for this development. First, there have been some frames established with the dimension study and the building layout experimentations. The floor plan is based on a 4,5m dimension which should be followed by the constructive elements. It is possible to use the structure to express this frame in the construction. And then the other elements can correspond to those measurements be assembled. It is important to respect this element to be able to assemble the two aspects developed in this research without issues.

Another element to reflect on is the possibilities of structural systems. As mentioned in the delimitation part, there will not be architectural calculations regarding the loads. Therefore, the measure used for the structure will be influenced by experiences and previous knowledge. The rest of the construction should mainly be done in wood, which makes it be a lightweight construction. Therefore, there should not be issues for the structure to carry all the elements.

With the use of modules, it is important to think about how they behave in the project. As the project tend to evolve, they must function separately, which means an element should be able to be moved while the other stays in place. However, when each module tends to work on its own, there could be issues with some fundaments of the construction, like the water permeability. How can modules ensure a waterproofing characteristic when they are separable? It will be necessary to find solutions to implement construction necessities with the modules while still making them able to be disassembled.

In a project, there are many technical elements to integrate, such as electrical components, water piping systems, etc. With a classic construction, those elements are hidden inside shafts. With a modular construction that evolves, it is not always possible to integrate fixed shafts. Therefore, technical elements should be included in the modules and following a logical course in the building system. The floor plan layout integrates a technical room from which all elements must come or go, it will be a challenge to tackle for this project.

Another element to figure out with the modules is the thermal performance. This parameter can evolve wherever the project will be installed; however, for this study case, the system is planned to correspond to European standards. As each country has its recommendations, it is not possible to make a system that will correspond to all. In general, the U value should be around zero points two watts per square meters' kelvin. This is the value that will be used for walls, floors, and roofs in the building system, as a reference to attain to propose an efficient system.

The last criteria to work with is the aesthetic of the project. The project proposal shows one possible style for the building system; however, with the evolution of the project and the user's taste, it is not possible to propose only one aesthetic. Therefore, modules must be able to adapt to allow the users to feel comfortable. This aspect is developed in the catalogue chapter where diverse finishes and materials choices will be possible.

Now that the boundaries are settled, it is possible to explore the possibilities of construction for the building system. As mentioned in the assembly part, the project is going to be developed layer by layer to use the entire lifespan of each element. For instance, a wood structural system can last more than a century, while a façade must be replaced after a few decades. It is more profitable for the project to work with separate layers for the structure, skin, and systems. Referring to the "shearing diagram" from Frank Duffy, there are more layers to use; however, the site layer is not relevant here as the project adapts to any situation, the space layer is treated with the layout in the previous part, and the stuff one is considered as the furniture that comes from the users individually.

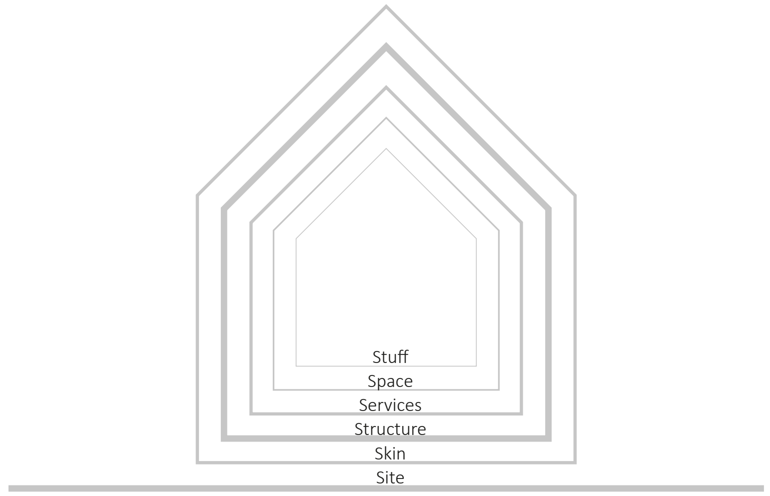


Fig 37. Drawing, Shearing diagram from Frank Duffy. ©Personal illustration.

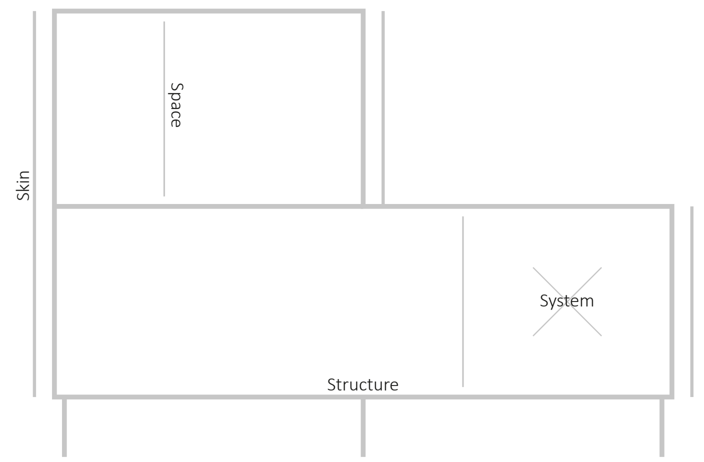


Fig 38. Drawing, Shearing diagram évolution. ©Personal illustration.

Structure

Experimentations start with the structure of the building system. This element of the design is the most durable, therefore it is crucial to plan it accordingly. It also represents the bones of the house as it carries all the other elements. As mentioned previously, the materiality of the project is mainly done with wood, which will be applied to most of the components. There are diverse opportunities to create a structure with wood: timber frame, balloon frame, platform frame, panel, log, and classic frame. There is one solution that stands out, it is frame construction. This system is inspired by the "columns and slab" technique used with concrete. (Deplazes, 2018). With this alternative, it would be possible to have a simple structure with columns and beams. Then a consolidation system must be integrated to avoid swaying. Nevertheless, with this system, it is possible to reduce the material needs compare to others without reducing the strength of the system.

There are a few possibilities to build the beams and columns. They can be done with timber wood, or with a glulam system that is stronger when it comes to carry loads. Dimensions must be thought according to the fact that those elements carry other modules. For the columns, a section of 1400 by 1400 millimetres will be used. This will allow strong pillars that are not too big. Constructively, this section size should be sufficient to carry loads of a housing project. The beam section that has been chosen for the project is 1400 by 3000 millimetres. Here again, it is a measure that must correspond to the needs. Those dimensions come from previous experience, although they are not exactly optimized for this project they could be explored more in-depth if the project would be built.

Now that the structural system is set, it is time to explore how it can be assembled. Various alternatives are possible to assemble those elements as shown in the "assembly" study inventory. With the need for disassembly, it would be better to choose a solution from the carpentry connectors section. At first, the system was assembled with joist hangers as it is an easy solution to assemble or disassemble and it can be invisible; however, it was not ideal to add columns on top of each other, and it requires a lot of elements all over the project. Therefore, a unique system tailored for the project still inspired by joist hangers has been designed. It consists of a single piece of metal making a cross, to fit in the pillars, from which metal plates go out to fix the beams. Then, it is possible to add as many plates as required for the pillars.

The structure needs to be integrated to the site in some ways. The design plan is to avoid the use of concrete; however, for the foundation, it is necessary to use something that will be durable over time. Therefore, it can be used to create a cylindrical element that comes out of the ground to support each column individually. Under the ground, this element is supported by a trapezoidal base. It is necessary to find a connector to fix the wood element on top of the concrete. In the beginning, the idea was to use a post holder; however, with the evolution of the structural system, it is more logical to use the same carpentry connector. Therefore, a cross-element comes down from the pillars to be fastened in the concrete element via a plate piece. This component also includes the beam connectors for the ground floor elements.

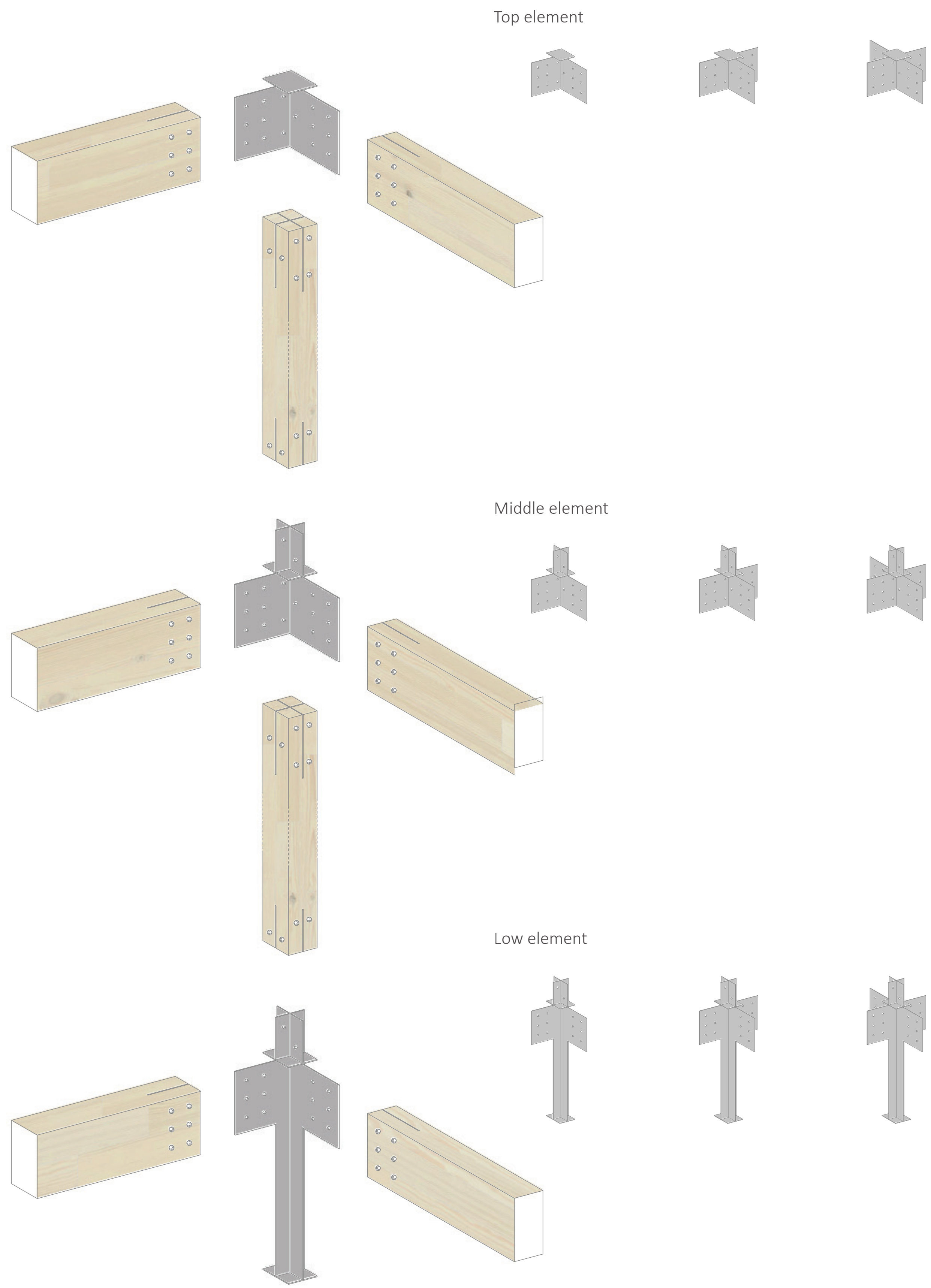


Fig 39. Drawing, Main structure axonometry with possible connectors. ©Personal illustration.

Slab

Now that there is a skeleton structural system for the project, it is possible to reflect on a horizontal structure to fill the gaps. There are some possibilities with wood to design slab elements. Two of them could fit the project. The first is to use secondary beams with simple flooring on top of them. This system should be installed all over the four-and-half meter frame and it cannot be made as a module. The other option is to work with a full slab system like cross-laminated timber (CLT). These systems show many advantages, like structural opportunities with high strength and self-weight materials. In fact, they can support themselves on a long scope without using secondary beams. They also act as a thermal insulation mass, which enhances the building system characteristics. The production of CLT slabs is a sustainable demarche that reuses waste as much as possible. (Swedish Wood, 2019).

From the two options, the most suitable one to fit the concept is the CLT slab as it can be made into modules that are ready to install with all finishes and insulation layers. The wood structure of these modules needs to be dimensioned, the thickness of the slab can vary with the scope of the slab. Here again, estimations will determine the measurements of the slab. Based on previous knowledge, the slab should be around twelve centimetres thick with five layers of wood. To fill each architectural frame of four-and-half meters, there will be three slab elements of one-and-half meters each time. This division corresponds to the layout reflections.

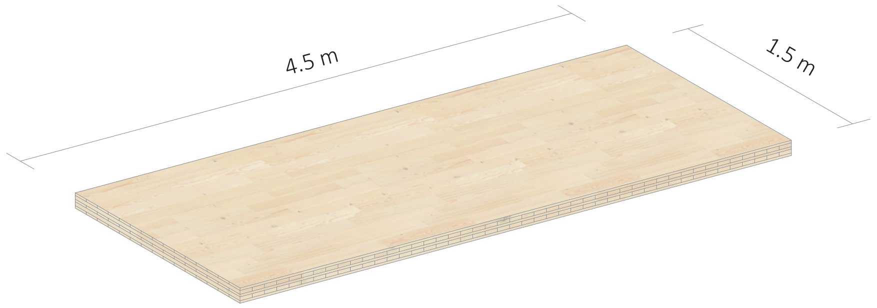


Fig 40. Drawing, Cross laminated timber slab element. ©Personal illustration.

Slabs can have different requirements depending on where they are placed in the project. For instance, a terrace element is not composed in the same way as a ground-floor element, the insulations and finishes will change. Each system will be developed in this section starting with the interior slab module. For this element, the main aspect to solve is the sound insulation to avoid hearing when people move on the floor above. Insulation in wood can be found in various ways. One of the most reputed is hard fibre panels. They act as a sound barrier and structure as they can carry the finishes layer on top without an additional structural stud, which would be necessary with other solutions. This panel has various thicknesses, for the project, it will be three centimetres thick. The last element to add to the module is the finishes layer, which is impacting the aesthetic of the design. Therefore, various elements are proposed in the catalogue, such as parquets, tiles, carpets, etc., so the users can select what they prefer to feel comfortable in their home.

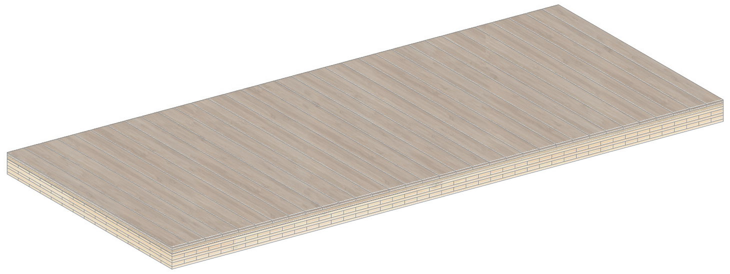


Fig 41. Drawing, Interior slab module. ©Personal illustration.

The other slab modules require more layers than the element developed before as they are in contact with outside and water. There are three other types of slab used in the project: roof, ground-floor, and terrace. For the ground floor slab, it is possible to use the same sound insulation and finishes as the interior slab module on top of the CLT structure; however, under it, it requires more insulation and a membrane to avoid water damages. This time, the selected insulation consists of soft fibre panels as they show better thermal performance. These panels are installed in between structural wood stud and covered with a waterproof membrane that will be the finish of the element as it is not visible.

Fig 42. Drawing, Ground-floor slab module. ©Personal illustration.

The roof slab module is more complicated than the ground floor one as it requires to consider evacuation of rainwater. A slope in the element could help solve this issue, it can be integrated into the wood fibre insulation panel as the panel is covered with a waterproofing membrane. As the slope is integrated into the element, there are fewer layers which make the composition simple to reduce the number of resources needed and waste. Once the water arrives down the slope, it will be collected with a drainage system that sucks the water that appears to be efficient with a small pipe dimension to evacuate the water.

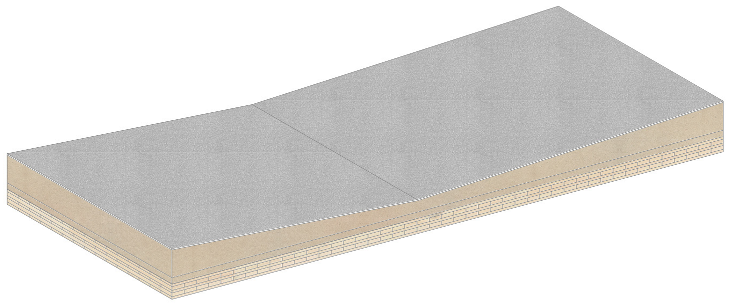


Fig 43. Drawing, Roof slab module. ©Personal illustration.

The last module of slabs is for the terrace. This one is similar to the roof for the requirement; however, it will need to get a walkable finishes layer. Moreover, to access the terrace, users should not have to climb a step, so the thickness of the slab needs to be reduced to correspond as much as possible to the one inside. A tolerance for a step of three to four centimetres is possible. The main element that could cause this lag is the insulation as it needs to fulfil the U values requirements. To solve this issue, it is necessary to install insulation that is more performant and thinner, the vacuum insulation. This element can show higher levels of performance with just two or three centimetres of thickness, which could help to solve the step. It will be used directly on the CLT slab, and then above it, there will be a thinner wood fibre insulation panel with a slope and a waterproof membrane. To make this terrace walkable, there can be wood boards installed on top of the whole system.

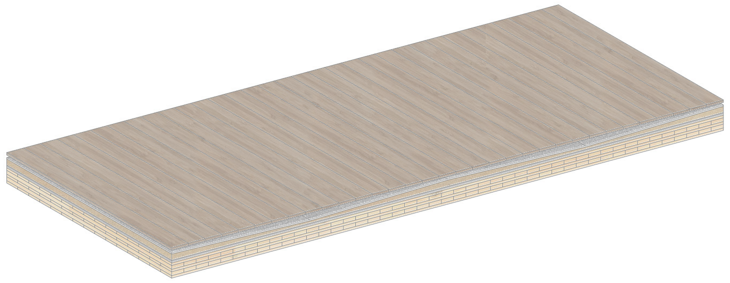


Fig 44. Drawing, Terrace slab module. ©Personal illustration.

The U value parameter mentioned with the last module has been calculated for each slab module that is placed towards the outside. All these elements are having U values under the requirement of zero points two watts per square meters' kelvin.

With those modules defined, it is now necessary to find how to assemble them with the structural skeleton. It is possible to use hooked connectors, concealed beam connectors, interlocking connectors, etc., all these elements work in two pieces to be fixed on the beam and module. Then it allows an easy connection solution that is also possible to disassemble. The selected fixation is the interlocking connectors as they secure the slab in both directions. Then, an additional compressible rubber band is added to create an air-tightness between all the components. This element is fundamental for acoustic performances, and fire regulations.

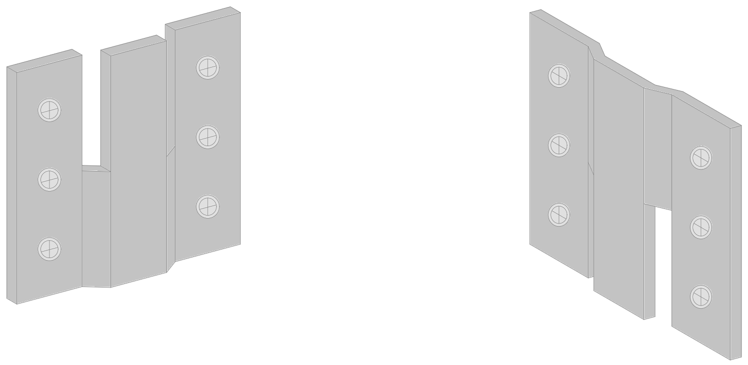


Fig 45. Drawing, Interlocking hanger for slabs. ©Personal illustration.

The slabs modules are made to be user-friendly. Once they are installed, there is nothing left to do as even the finish is installed with them. The assembly technique is also simple, which procure serenity to the user when he will need to renovate or modify his house.

The slab systems are easily assembled and disassembled from the main structure. They come as a complement to stabilize it vertically. As the demarche of this thesis is to reduce waste from the construction industry, the slabs modules are optimized regarding supplier's dimensions. This process is visible in the catalogue part, where each module is detailed with the diverse materials it uses.

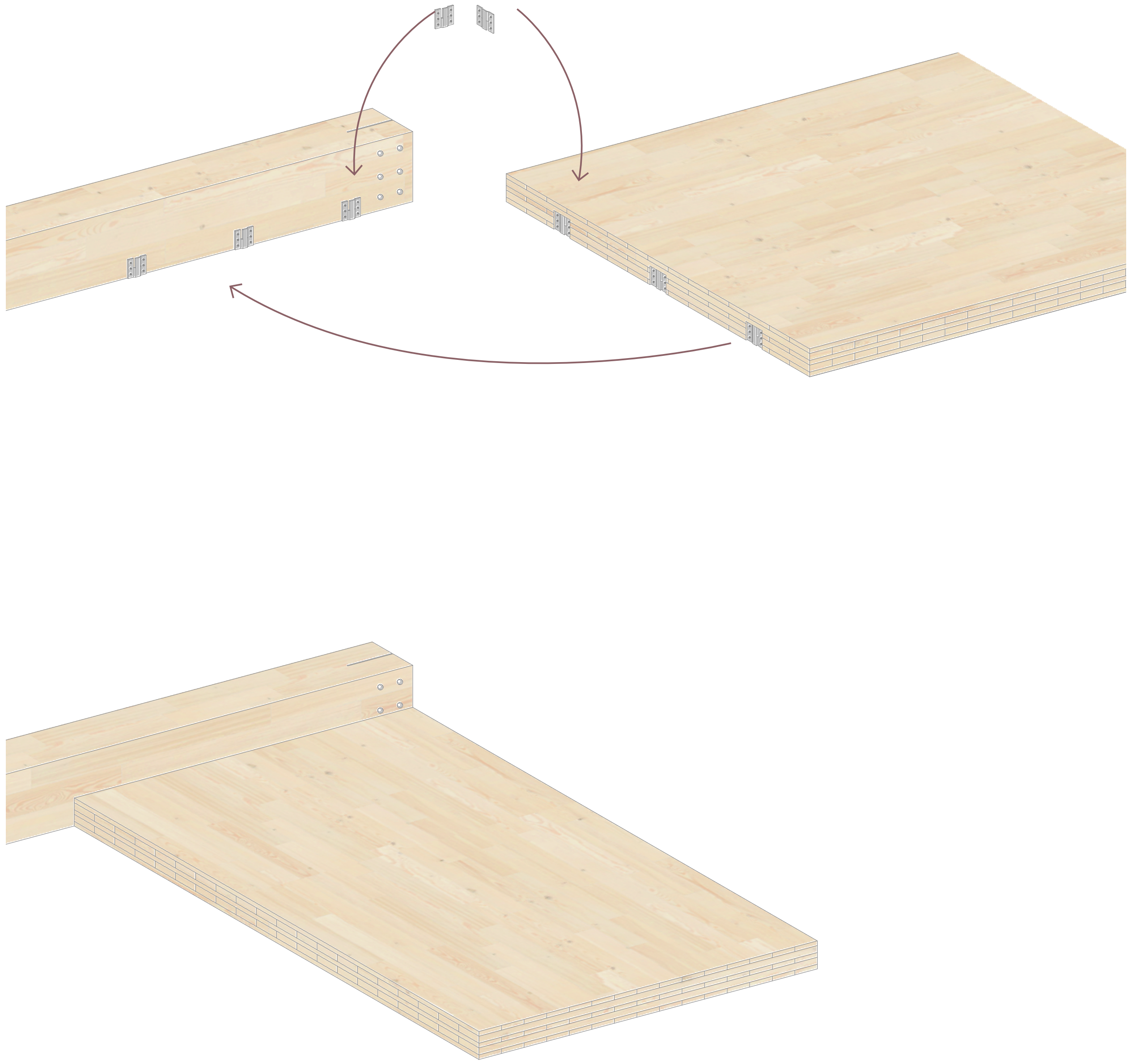


Fig 46. Drawing, Slab connection. ©Personal illustration.

Facade

To continue the envelope of the houses, it is necessary to add façade elements. As mentioned before, the architectural frame is divided by three to create one-and-half metres intermediate distances. The façade modules contain windows that might be smaller than one-and-half metre; therefore, these modules will measure fifty centimetres and can be combined to create bigger elements for larger windows and doors. The height of each module depends on where it is placed in the project; for instance, the ground floor module will be longer at the bottom to join the slab insulation, while the higher floor module will be longer on the top.

Despite the diverse dimensions of the elements, they are all composed in the same way. There is a structure for soft or loose insulation (can vary with the context). This part is closed with a wood fibre panel that comes as complementary insulation. Then, this panel can be covered with a waterproofing membrane and a finishes layer chosen by the users. On the other side of the main structure, there is a substructure of six centimetres, filled with insulation, that carries the inside finishes panels that can be selected as well. The thickness from this interior part helps to hide the technical system at the top and bottom, this will be explained further in the "system" part.

As these modules serve as a façade, it is necessary to include openings such as windows and doors that have various dimensions. For instance, smaller windows can be used in bathrooms for privacy purposes, while in the living room it is preferable to have larger windows to enjoy daylight as much as possible. The various possibilities of sizes are listed in the catalogue along with the finishes opportunities for both inside and outside the module.

The façade modules are lightweight construction; however, they cannot stand on their own and need fixations. As they cover one floor each time, they can hang on the beams. At first, they were fastened using interlocking connectors like the ones for the slabs, but it does not allow enough flexibility with the system and it was not possible to take modules away individually. A second option has been studied with angle connectors and this option allow the modules to be fixed on the beams up and down the module with no issues.

As mentioned previously with the slabs modules, it is required to provide air-tightness and waterproofing layer for the construction to be durable. It is possible to use a compressible rubber band in between the elements; however, it is not enough to ensure that the modules are waterproof. For this aspect, the membrane will overlap on the outer part of the component to avoid water to slip in between the elements.

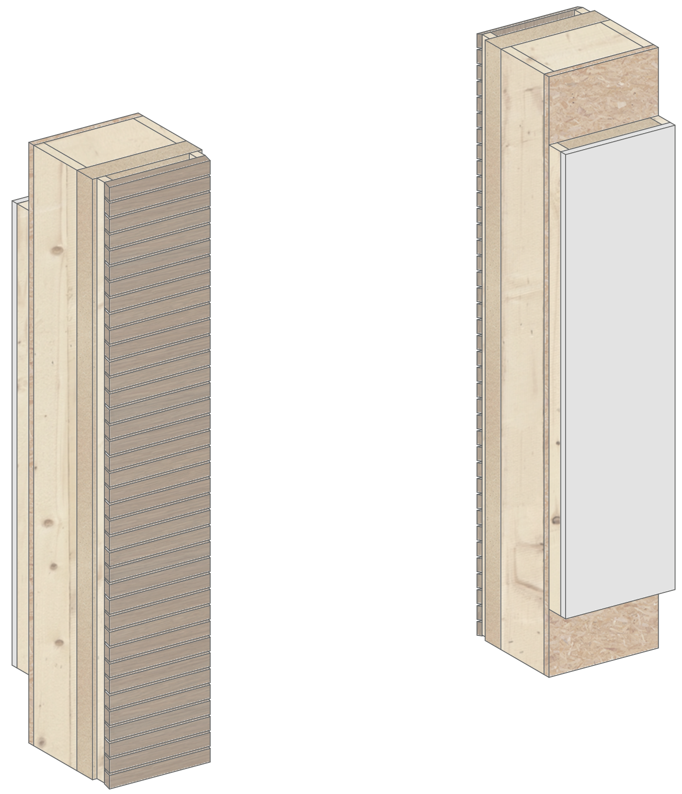


Fig 47. Drawing, Facade module. ©Personal illustration.

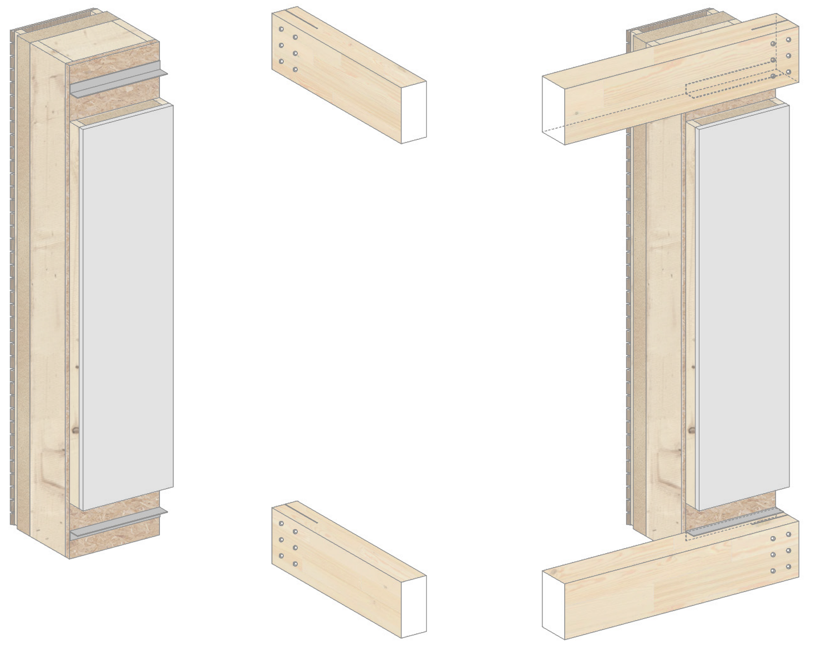


Fig 48. Drawing, Facade module connector. ©Personal illustration.

Interior partition

Now that the envelope is defined, it is possible to work on the elements inside the building. The different spaces planned in the "building layout" part need to be divided with interior partitions. Their dimensions need to correspond to the floorplan, so they can be installed every one-and-half metre. To connect the partitions together, a margin is required for the angles; therefore, each element will be less than one-and-half metre large. These modules need flexibility as the inside might vary over time, and they also need to contain openings to move freely from one space to another one. To attain adaptability, each module needs to be easy to separate from its support (the slabs); therefore, it cannot be as high as the floor to ceiling height, here again, it requires a margin. This parameter can be planned to match the one used in the façade to hide the systems.

The interior partition modules are composed of a few layers. There is a structural frame with wood studs that are filled with insulation, and on both sides of it, there can be a finish layer such as plasterboard, or wood board. This can be selected by the users as an aesthetic choice. Then each element is attached on the top and bottom with metallic angle connectors on the modules and the support that can be fastened together. Those elements are hidden by baseboards on both sides with complementary insulation on one side. A gap remains to let the system runs over the various spaces. The airtightness between the elements is also required here to attain the right level of acoustic insulation. It is again possible to use a compressible rubber band in between each element.

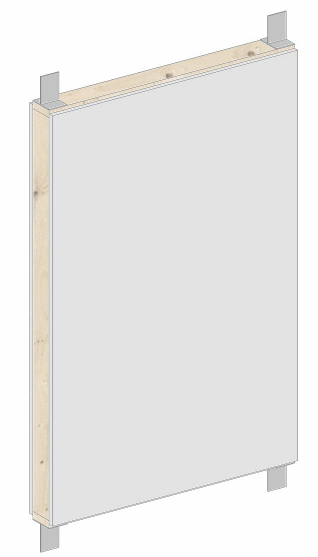


Fig 49. Drawing, Interior partition module. ©Personal illustration.

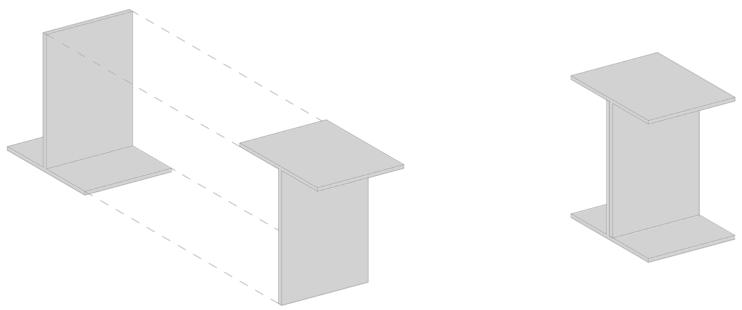


Fig 50. Drawing, Interior partition module. ©Personal illustration.

System

In all project, it is required to run electricity, plumbing, and ventilation elements. These components can be of different sizes regarding the needs in the building; therefore, it is crucial to plan enough space for them to circulate. As mentioned in the "façade" and "interior partition" parts, there are some gaps at the top and bottom of the modules to allow the circulation of the various systems in the project. The free space is at least fourteen centimetres tall and three centimetres wide. These dimensions are enough for a housing project; however, they could need to be bigger with a public building where needs are usually higher.

Once the cables and pipes run in these gaps, it is possible to create plugs or to install plumbing elements and connect them to the network. The alimentation for each flow depends on the location and context; for instance, there could be access to gas heating in some places, while not in others. The house can connect and react to various structure, and there is a technical room planned in each layout to install any technology that would be required. As this thesis aims to attain a sustainable demarche, it is even possible to have solar panels on the roof or as a façade finish. This research will not go deeper into the building technology integration as it does not correspond to the development in progress.

The systems are required in all the rooms of the space, but not all of them need to reach every space. The electricity is the most present one and needs to go to each part of the house, but the plumbing and ventilation are not required everywhere. For instance, they are mainly used in bathrooms and kitchen; however, the ventilation might need to be a bit more present depending on the location to propose a better air renewal inside the house.

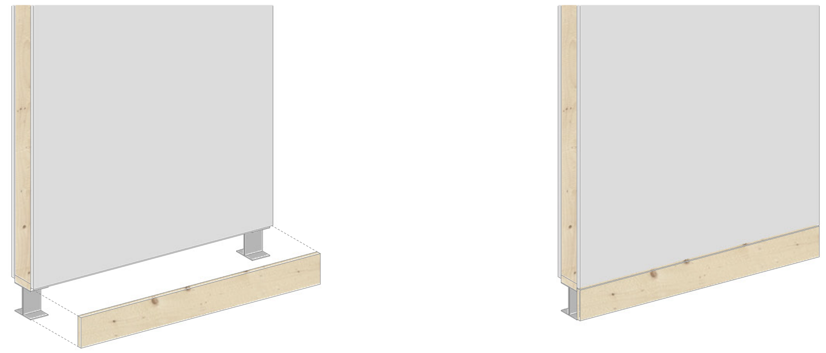


Fig 51. Drawing, System gap. ©Personal illustration.

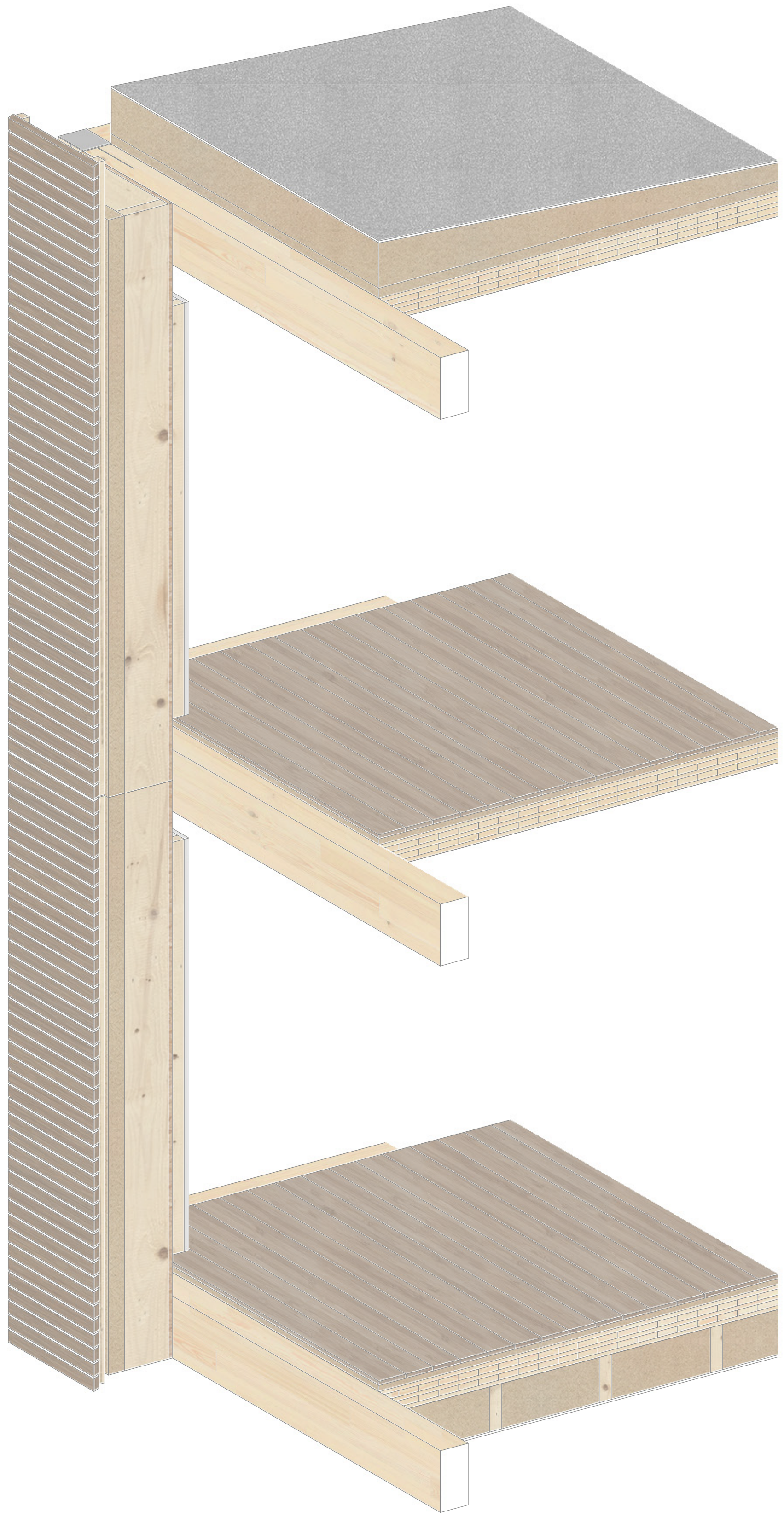
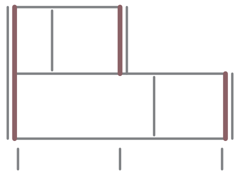


Fig 52. Drawing, Axonometry building system. ©Personal illustration.

04 Catalogue

In this section, the building system and building layout will be explained in more details, showing their characteristics and possible evolutions. A part of this chapter will review the outcome in term of sustainability from the building system with how the materials are used at their fullest and how they serve after their main usage in a building project. The technical aspects of each module will also be reviewed with how the entire system comes together with the various connectors, and how it should be maintained to ensure it lasts.

Main structure



The skeleton of the project is made from glued laminated timber beams and columns that are fastened with metallic pieces tailored for this design. To display the structure on the site, there are concrete bases coming out of the ground on which specific metallic components are fastened with the help of bolts. Those elements are the only ones using concrete and they represent a punctual foundation system that is economical in resources. Overall, this system allows a fast and economical use of materials to build a structure.

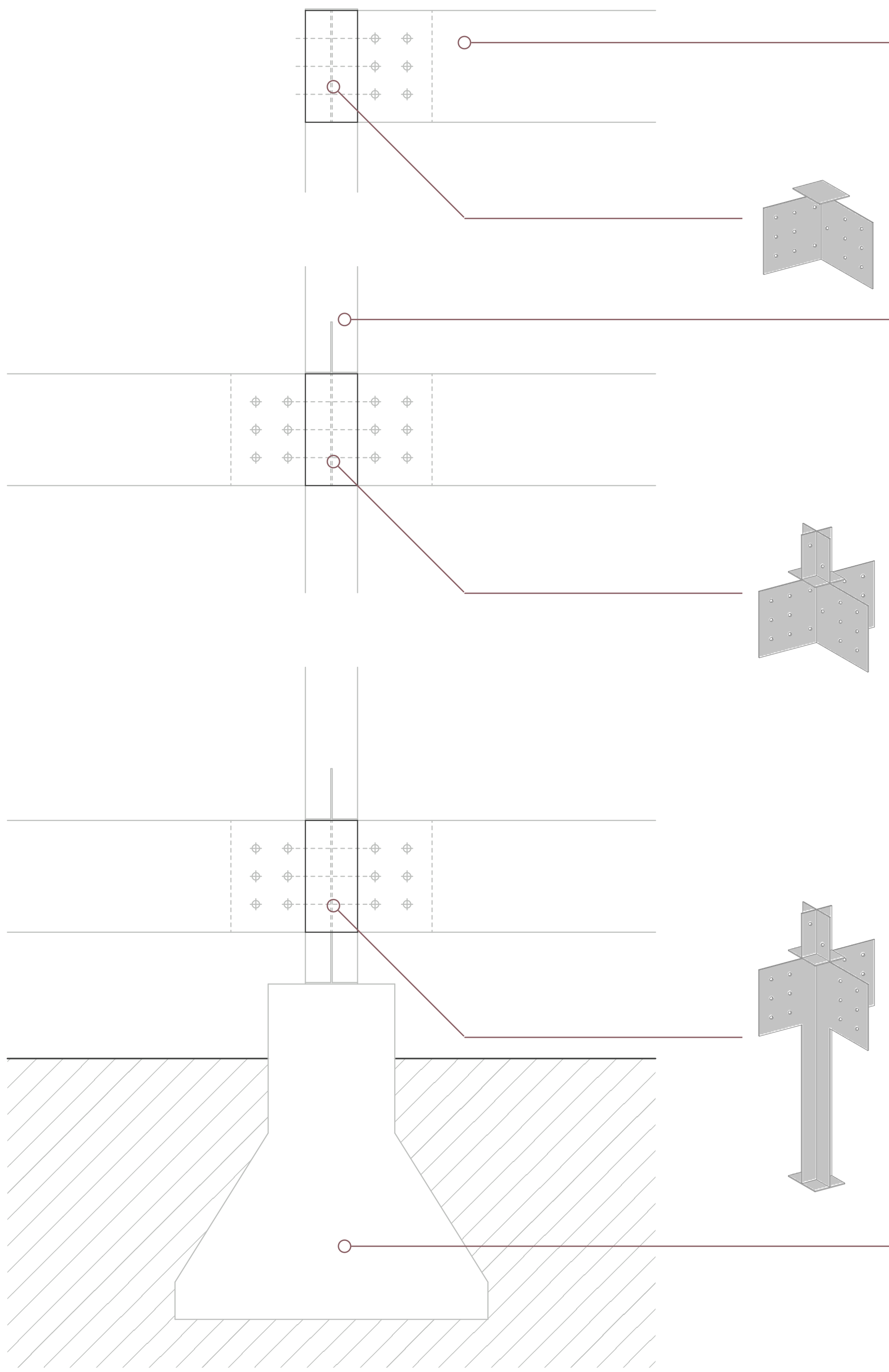
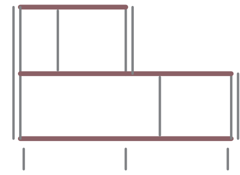


Fig 53. Drawing, Structure section - 1:20. ©Personal illustration.

Slab module



To fill the gap of the skeleton, it is needed to install a flooring system. It is composed of a structure in cross-laminated timber of twelve centimetres and complemented with various layers regarding its placement in the project. In the end, four slab systems are proposed. The finishes of some surfaces can be selected from a range of products to correspond to the user's tastes. With the various insulation used with the slab, the u-value of zero points two is attained to reach a high-performance level of the envelope.

ROOF SLAB COMPOSITION

Waterproof membrane	-
Fibre wood insulation panel with slope	100 - 220 mm
Fibre wood insulation panel	50 mm
Cross-laminated timber slab	120 mm
U- value	0,195 W/m².K - 0,118 W/m².K

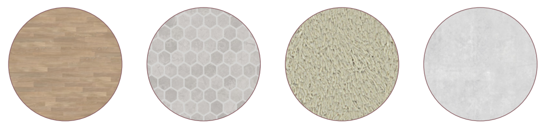
TERRACE SLAB COMPOSITION

Finish flooring	20 mm
Ventilation gap with sub structure	20- 50 mm
Fibre wood insulation panel with slope	20- 50 mm
Vacuum insulation	20 mm
Cross-laminated timber slab	120 mm
U- value	0,201 W/m².K - 0,172 W/m².K

INTERIOR SLAB COMPOSITION

Finish flooring	20 mm
Fibre wood insulation panel	30 mm
Cross-laminated timber slab	120 mm

POSSIBLE MATERIALITY FOR FLOORING



GROUND FLOOR SLAB COMPOSITION

Finish flooring	20 mm
Fibre wood insulation panel	30 mm
Cross-laminated timber slab	120 mm
Fibre wood insulation in between stud	220 mm
Waterproof membrane	-
U- value	0,122 W/m².K

MATERIALS LIFESPAN

CLT slab	≈ 60 years
Wood fiber insulation panel	≈ 20 years
Floor finishes	≈ 10 to 40 years
Waterproof membrane	≈ 20 years

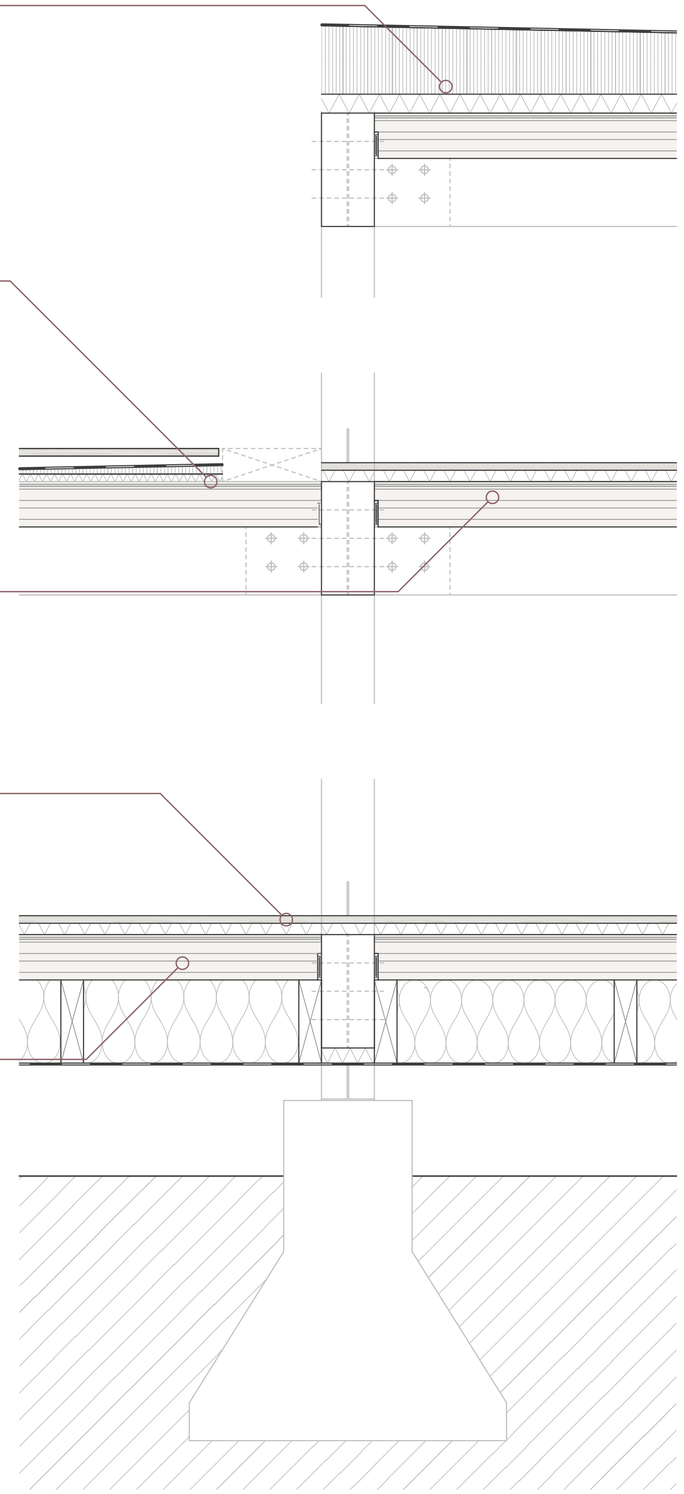


Fig 54. Drawing, Slab modules - 1:20. ©Personal illustration.

All modules have been planned regarding material factory dimensions. Here are the slab modules.

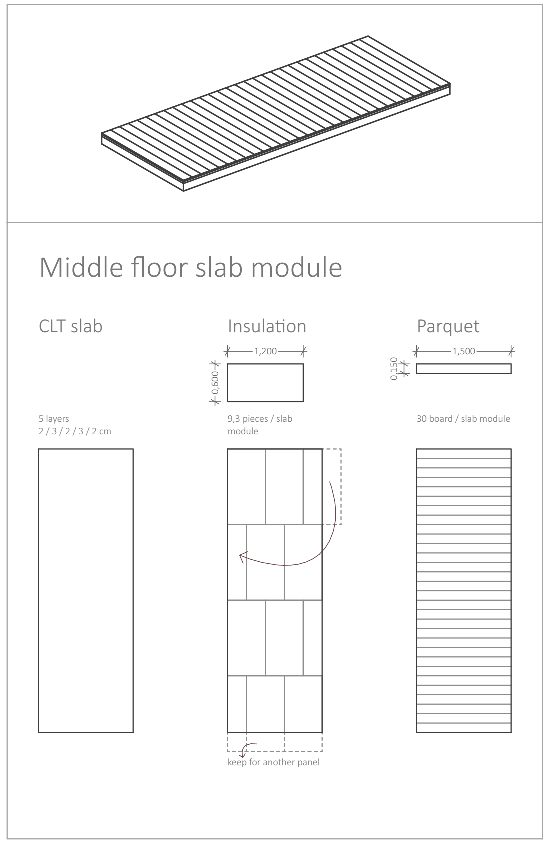


Fig 55. Drawing, Interior slab composition - 1:20. ©Personal illustration.

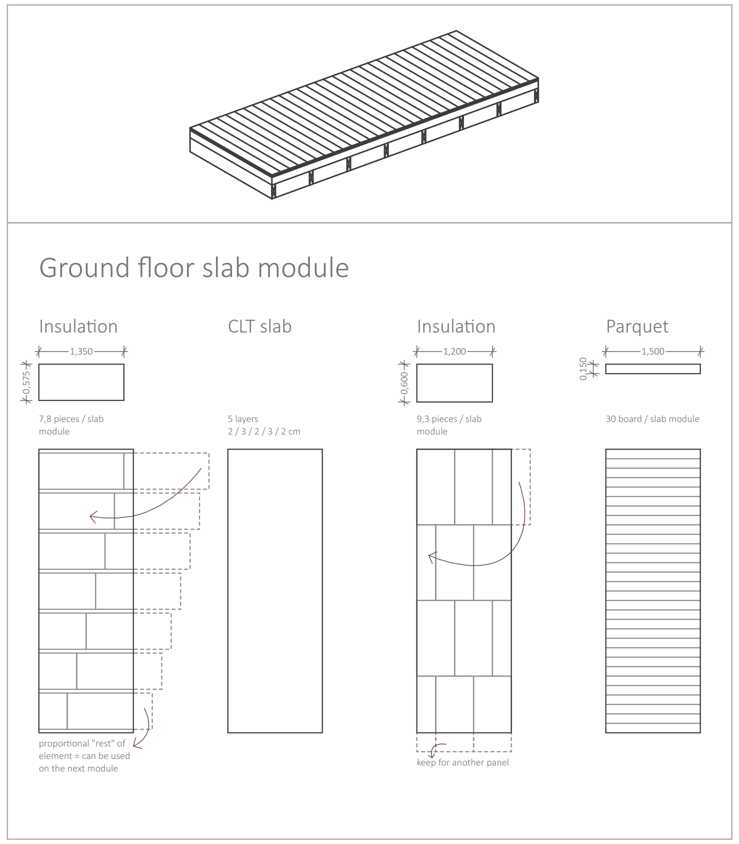


Fig 56. Drawing, Ground-floor slab composition - 1:20. ©Personal illustration.

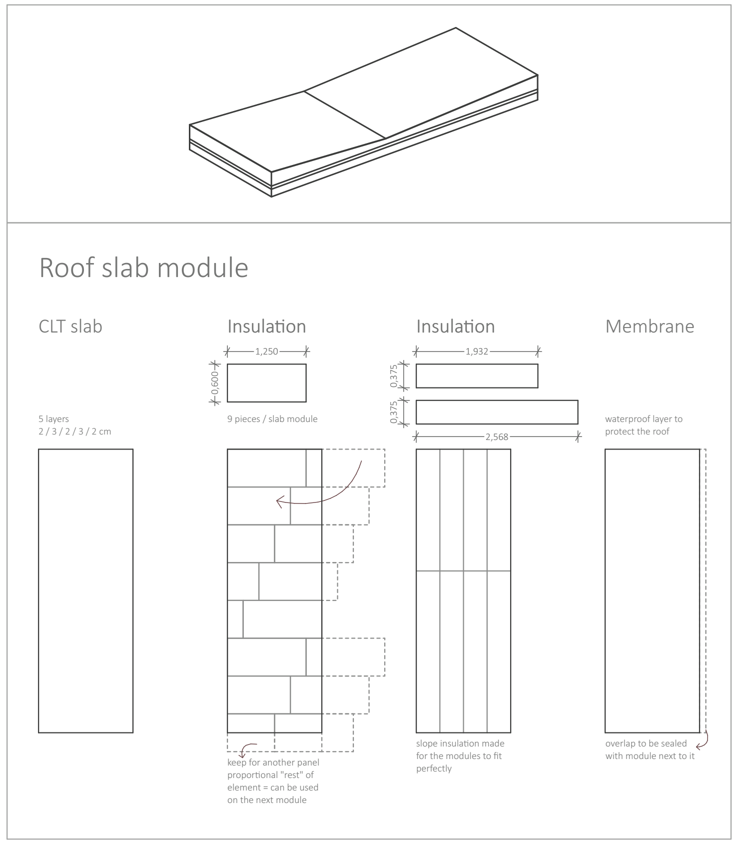


Fig 57. Drawing, Roof slab composition - 1:20. ©Personal illustration.

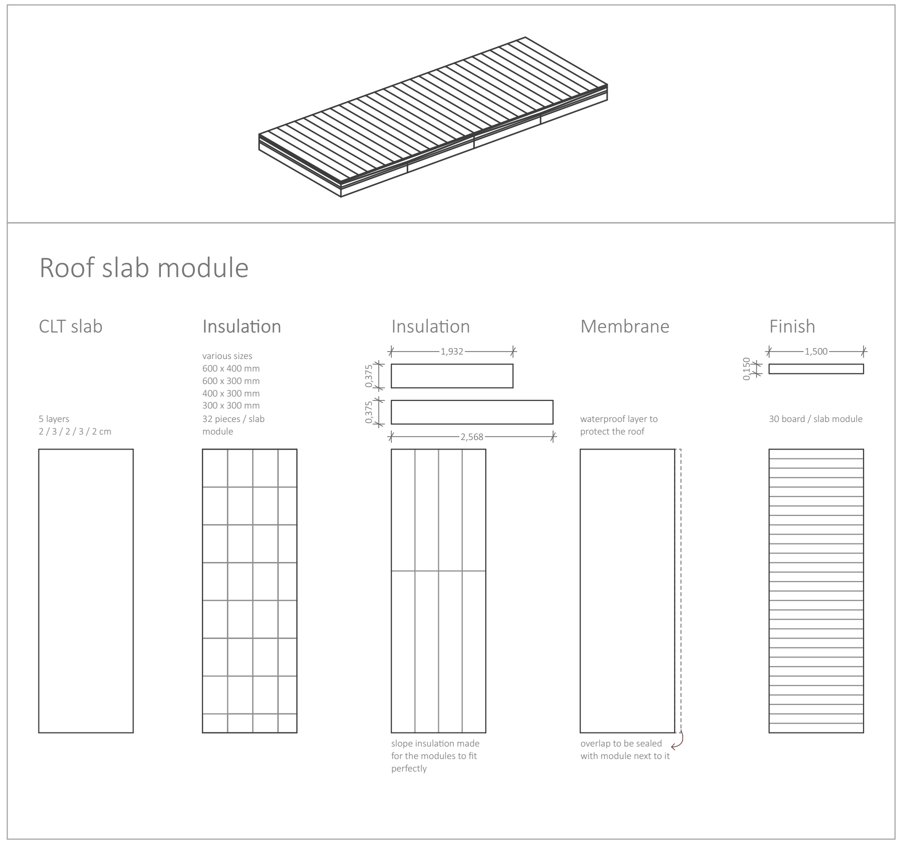
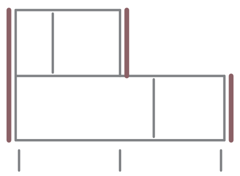


Fig 58. Drawing, Terrace slab composition - 1:20. ©Personal illustration.

Facade modules



To complete the envelope of the building, here are the façade modules. It works with a structure in wood and insulation, then on both side of it, the finishes can be selected by the user to match his taste. The modules come in different width from fifty centimetres to one-and-half metres to allow various possibilities of openings with windows and/or doors. Modules are dimensioned according to the floors they are; for instance, the ground floor module is not as tall as the last floor module.

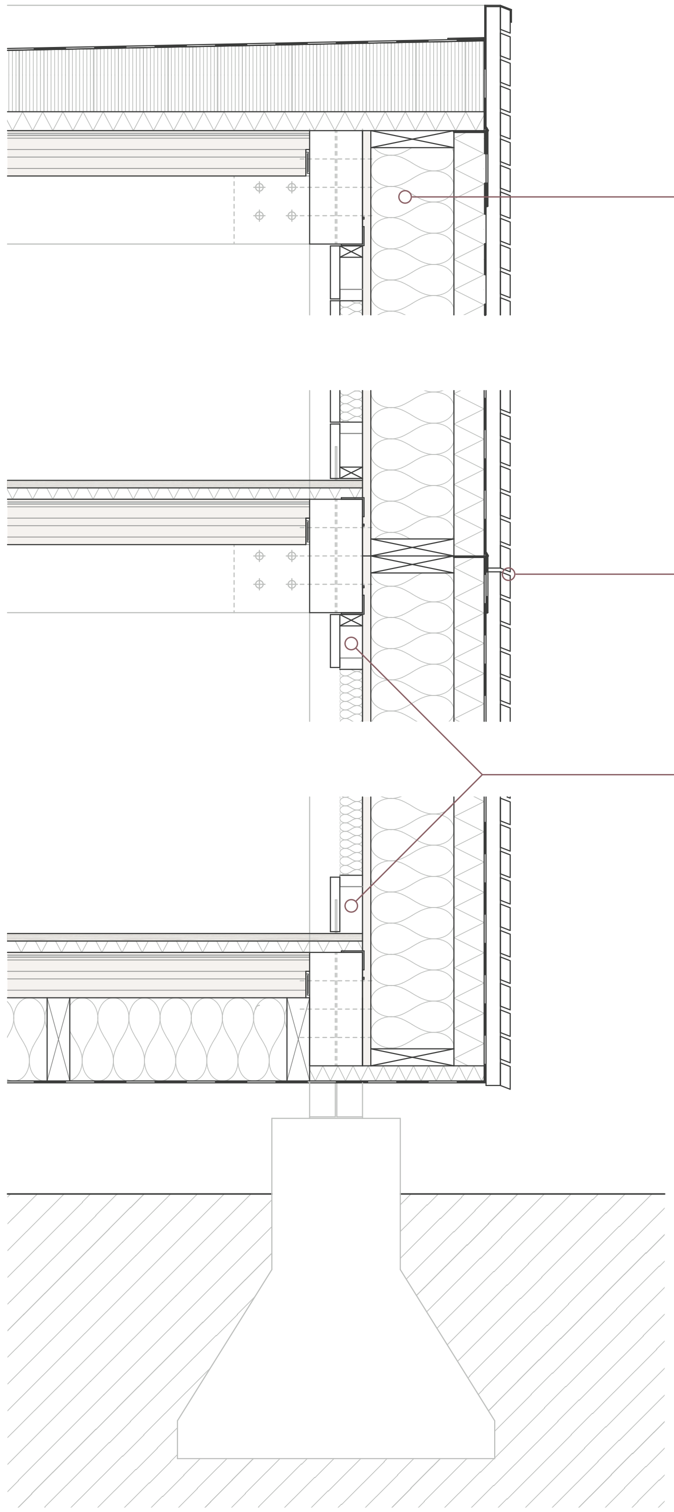
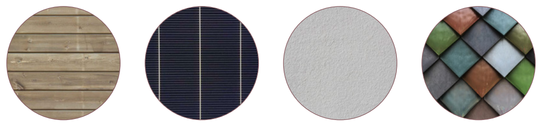


Fig 59. Drawing, Facade modules - 1:20. ©Personal illustration.

FACADE COMPOSITION

Finish layer	-
Wood stud & ventilation gap	38 mm
Waterproof membrane	-
Fibre wood insulation panel	80 mm
Loose cellulose in between structure	220 mm
OSB board	22 mm
Fibre wood insulation panel with studs	60 mm
Finish layer	-
U- value	0,108 W/m².K

POSSIBLE MATERIALITY FOR FACADE



Gap for technical systems

MATERIALS LIFESPAN

Cellulose	≈ 20 years
OSB board	≈ 60 years

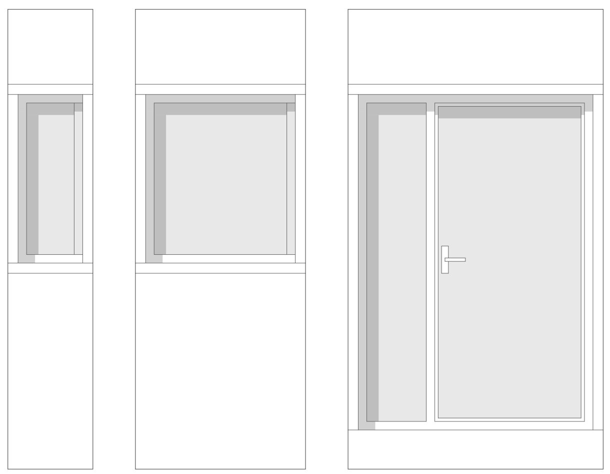


Fig 60. Drawing, Type of openings for facade modules. ©Personal illustration.

All modules have been planned regarding material factory dimensions. Here is the facade module.

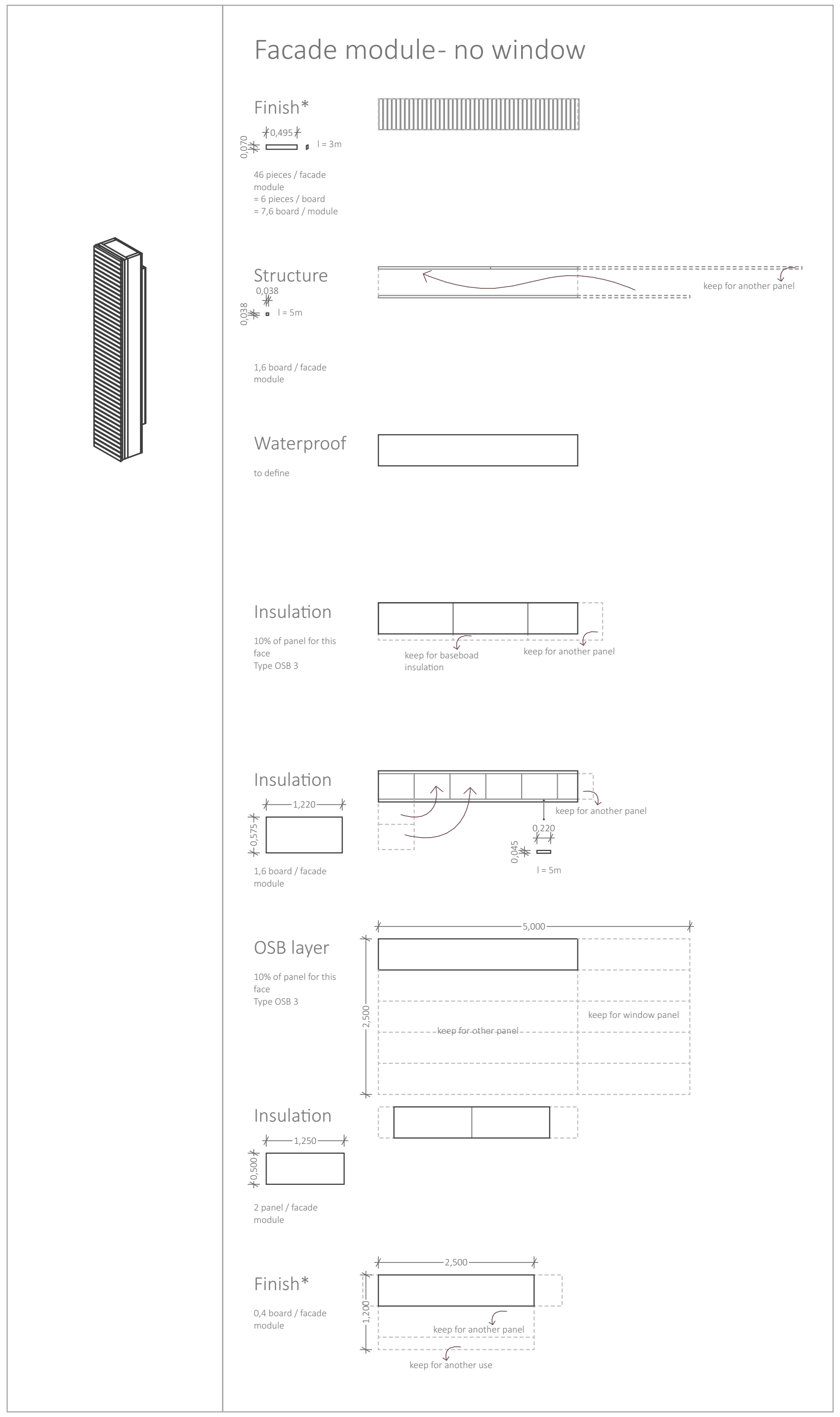
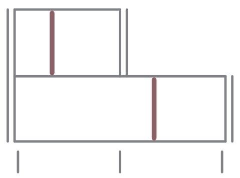


Fig 61. Drawing, Facade composition - 1:20. ©Personal illustration.

Interior parition module



Now the outer part of the building is completed, it requires some work inside to separate the diverse spaces. In a similar way as the façade, the interior partitions modules are designed with a structure filled with insulation and two possibilities of finishes on both sides. The structure is attached to the floor and the ceiling and can be moved to the will of the users. It is visible on the drawing below that there are technical gaps on the top and bottom of the elements, as mentioned in the development of the research.

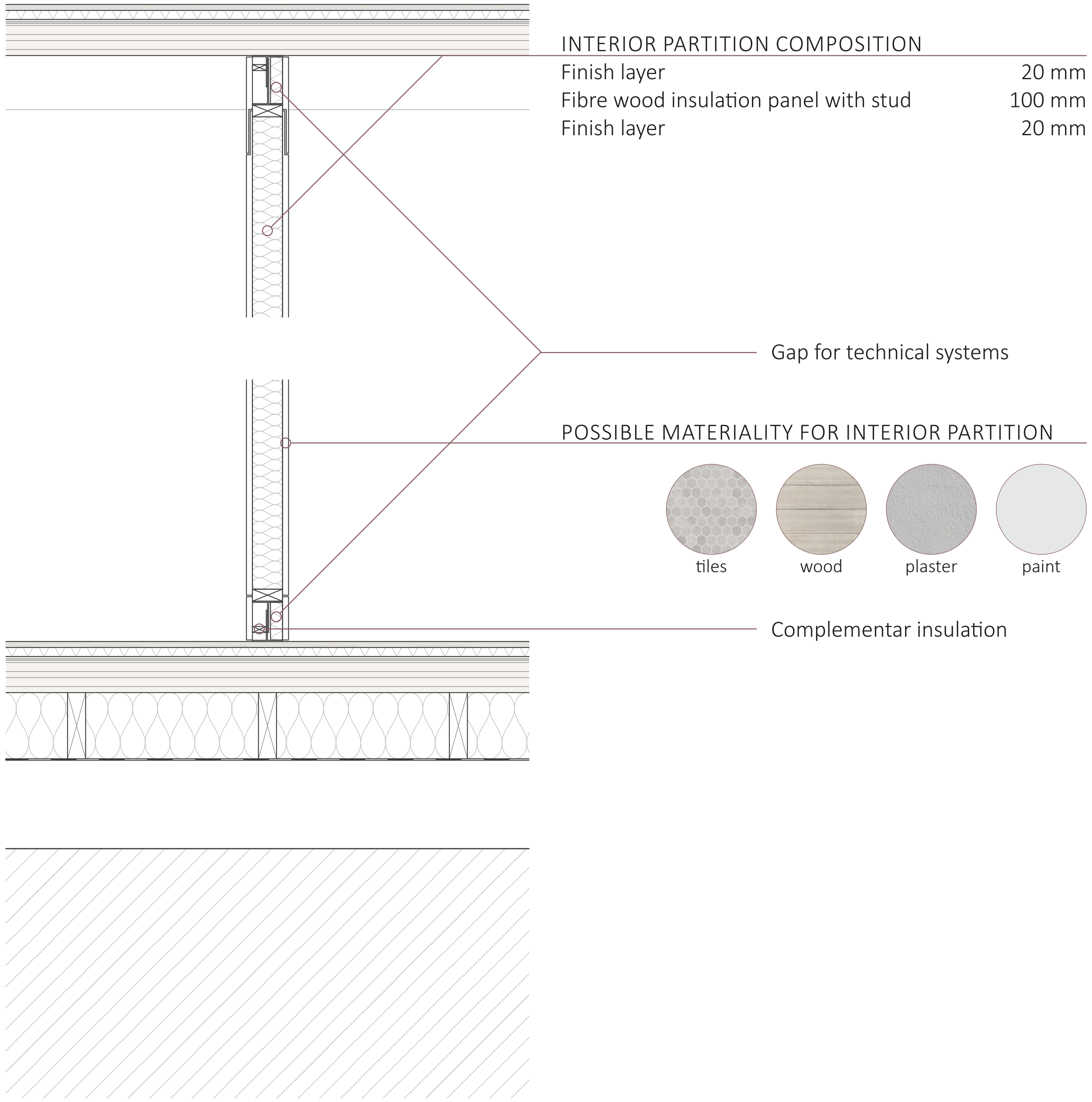


Fig 62. Drawing, Interior partition module - 1:20. ©Personal illustration.

All modules have been planned regarding material factory dimensions. Here is the interior partition module.

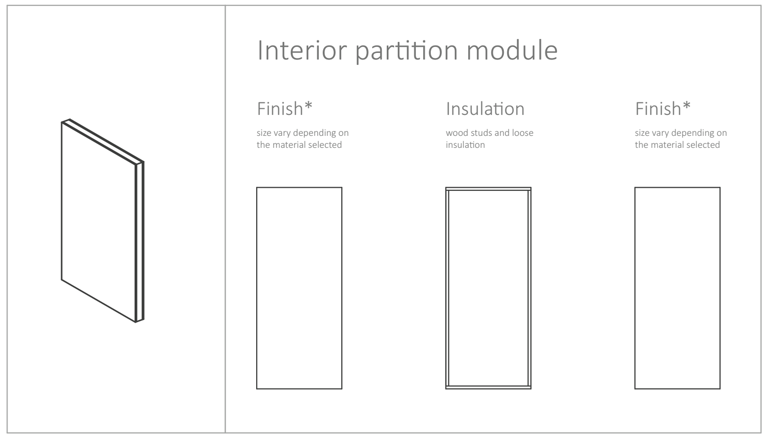


Fig 63. Drawing, Facade composition - 1:20. ©Personal illustration.

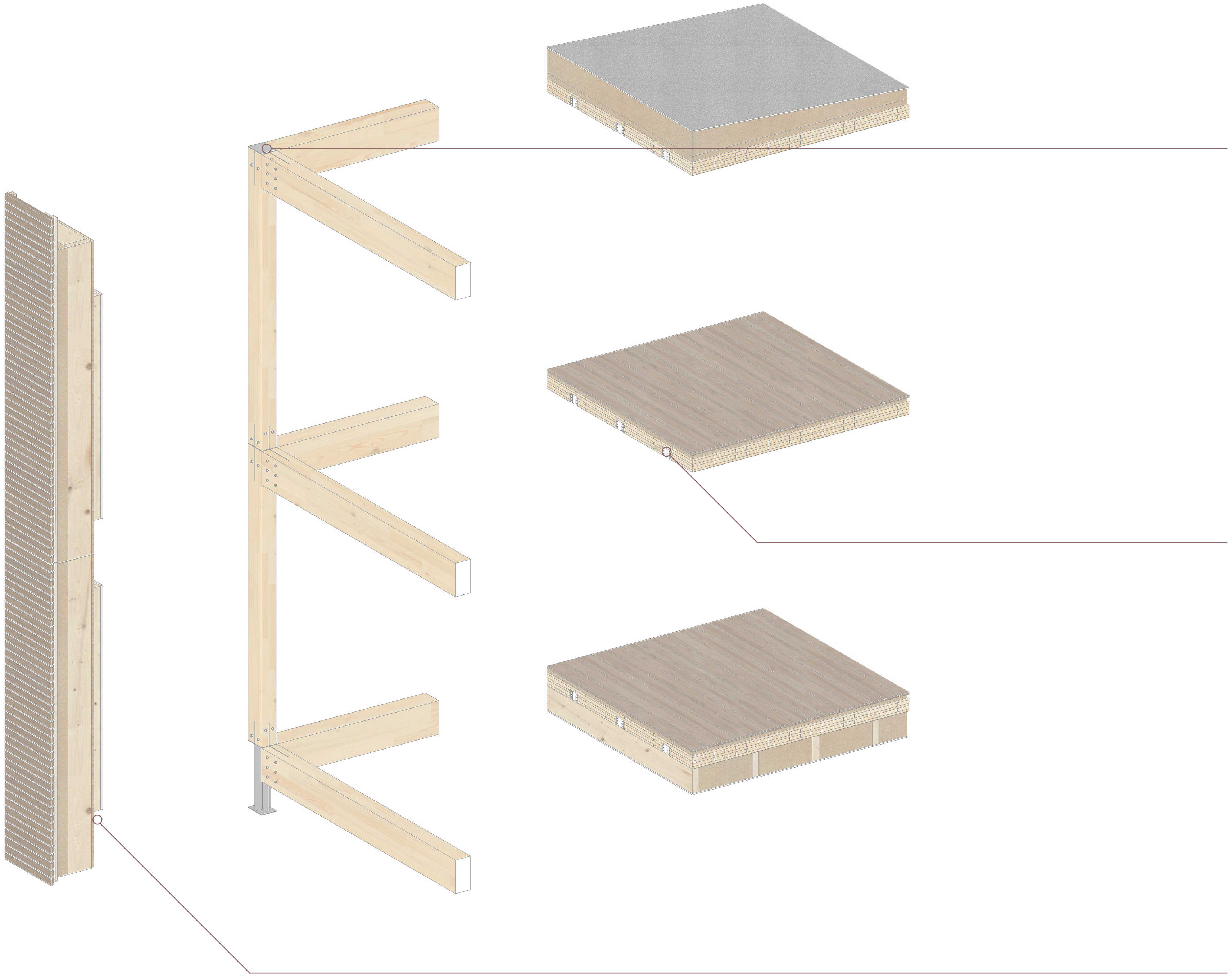


Fig 64. Drawing, Axonometry building system exploded. ©Personal illustration.

Connectors

As mentioned previously in the research, there are many ways possible to assemble elements together while still allowing to disassemble them in the future. The building system works in two steps, starting with the main structure assembly with the help of metallic connectors. Then, the diverse modules are fixed on this skeleton with various connectors (see below).

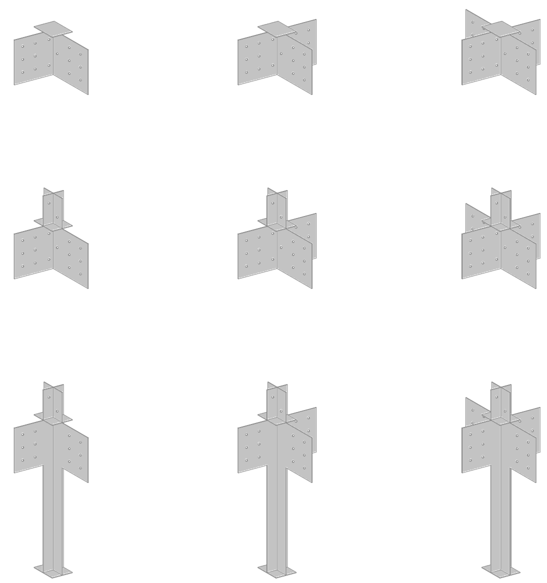


Fig 65. Drawing, Structure metallic connector. ©Personal illustration.

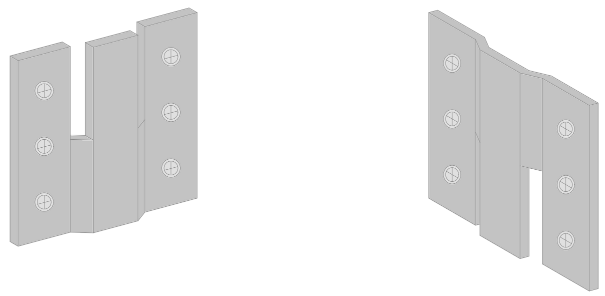


Fig 66. Drawing, Slab interlocking connector. ©Personal illustration.

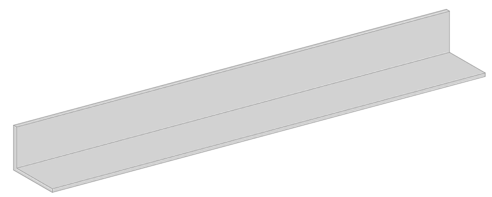


Fig 67. Drawing, Facade angle connector. ©Personal illustration.

Lifespan

Each module of the system has a specific lifespan. As the goal is to reduce resource consumption and waste, it is important to focus on how to attain the maximum lifespan for each element. Therefore, the modules must be maintained, partly replaced, and taken care of at the end of their life. Here is a timeline representing the duration for each element and how long the building can last until all modules have been replaced. These replacements can also encourage the evolution of the project. For instance, changing all façade could allow to grow the building and make the project answer to more needs.

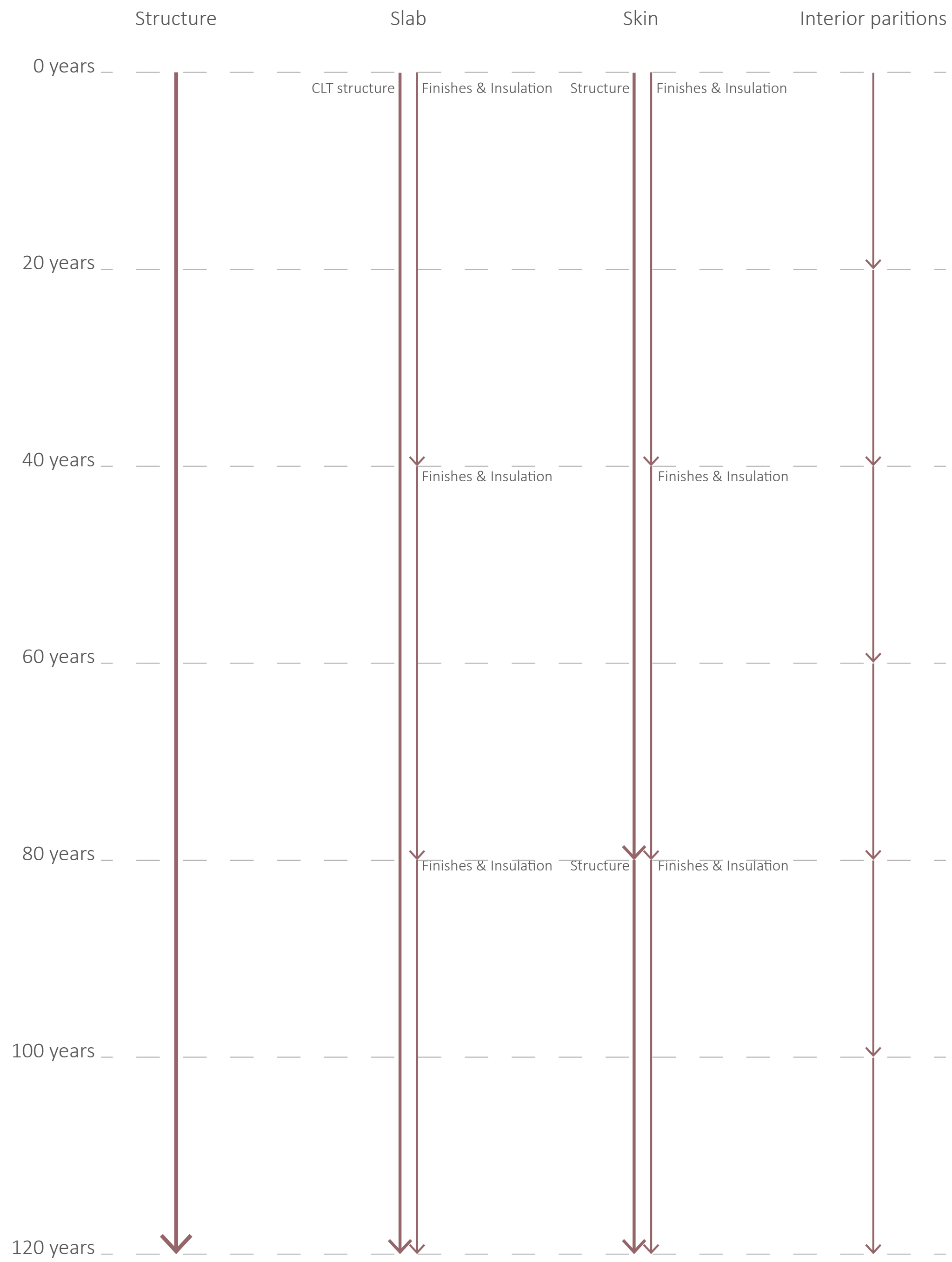


Fig 68. Diagram, Lifespan of modules. ©Personal illustration.

Materiality

As mentioned previously, one of the goals is to avoid waste and create circularity with the materials of the project. To accomplish this objective, it is possible to plan the "after-life" of each element so when they cannot serve their original purpose anymore, they would follow a new path and not become some waste. As most of the elements are made from wood, there are various possibilities to upcycle, recycle, reuse, etc. each component. In the end, there should be as little waste as possible to ensure the project respect the planet.

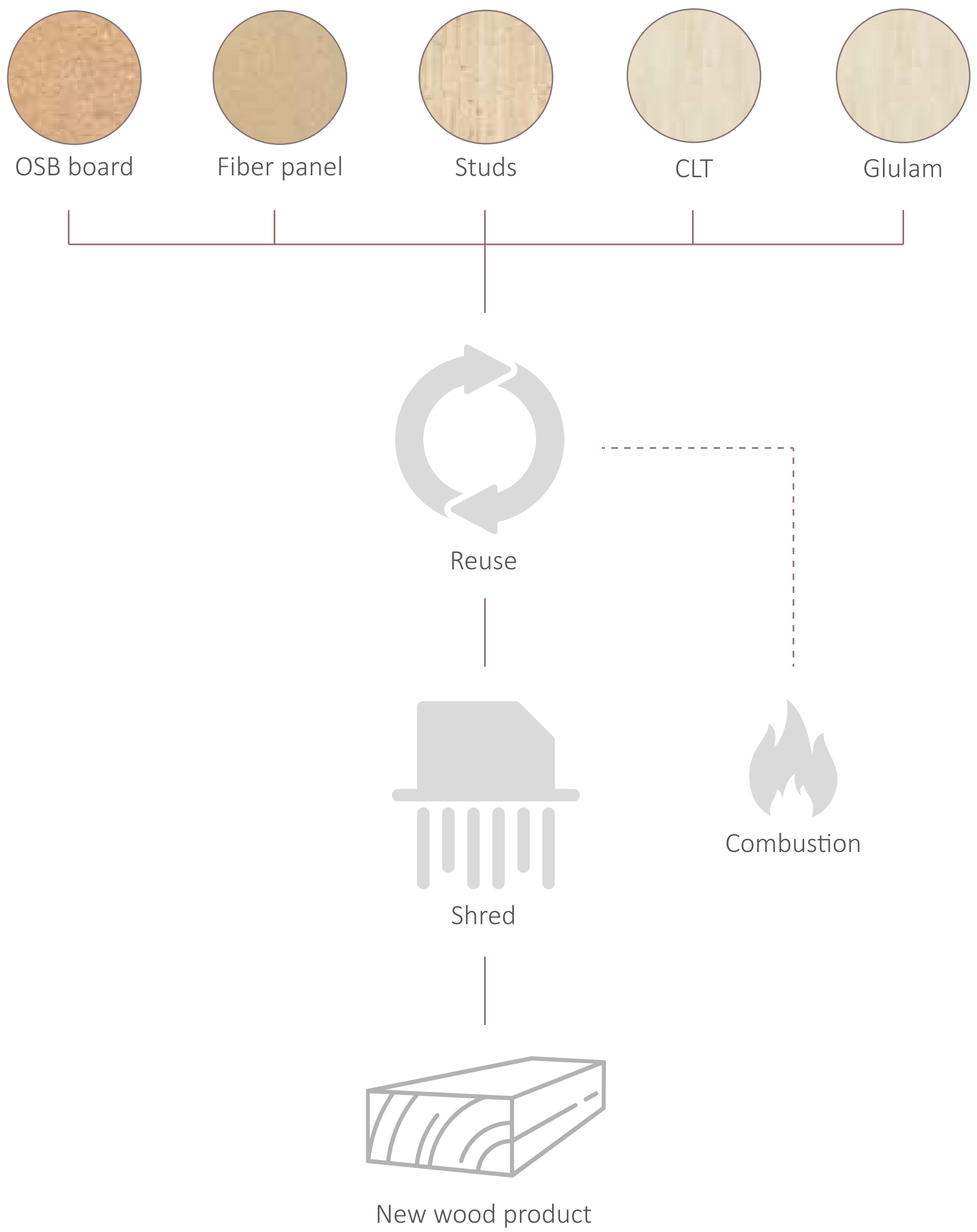


Fig 69. Diagram, Material usage after serving in the building. ©Personal illustration.

Building layout

The various possibilities of rooms have been shown in the thesis development chapter. This section will show how each floorplan looks like with the building system and how the design can evolve to be integrated into bigger buildings. The first aspect represented here concerns individual houses floorplan that can be separated into four sizes regarding the number of users. The first one shows the possibility of a one to two persons' house displayed on just one floor. The second option represents a house with two more persons on an additional floor. With the third version, the upper floor is growing for two more persons again. And the final version used the entire floor upstairs for three more persons this time, which give a total capacity of nine persons in this version of the house.

In the next section, there will be some examples of how the layout design can be adapted into bigger buildings. The focus is made on the circulation and access of each house. Those examples represent building that can be displayed on three levels, it is not sure how the structure will react with higher buildings as calculations were not realised; however, it could be possible to improve it to make buildings higher.

The development will not show the possibility of terraced houses as it is simply putting two houses next to each other; however, this option can be developed if needed. The first example of larger buildings shows a simple development of a rectangular floorplan, while the second one is more complex with a central circulation. Each building can then comport various sizes of apartments. The inconvenient with bigger buildings is that it is harder to evolve the spaces over time as they can be blocked by other apartments. However, it could be possible to exchange apartments within the building.

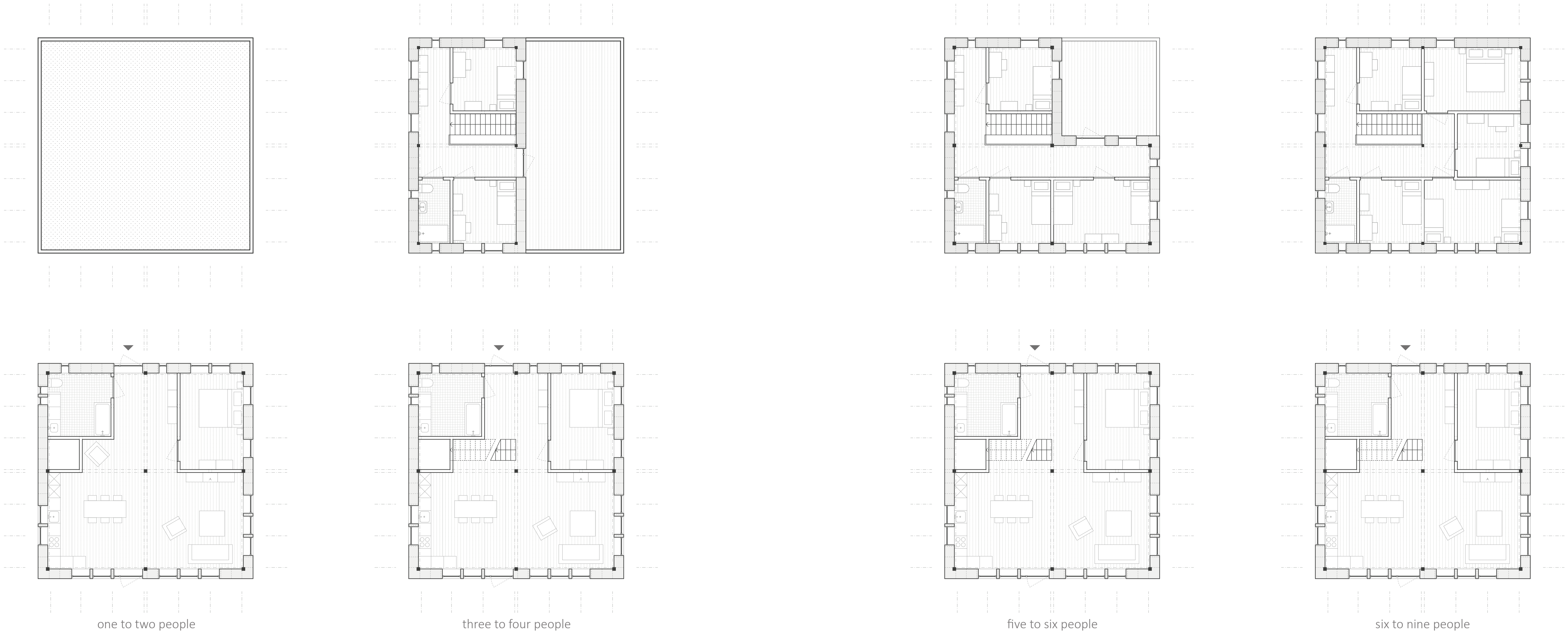


Fig 70. Drawing, Individual houses floorplans - 1:200. ©Personal illustration.

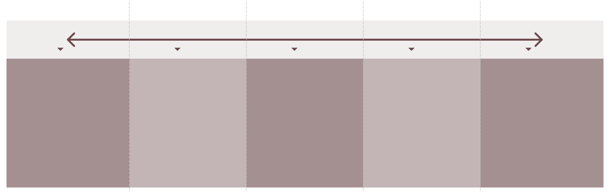


Fig 65. Diagram, Long building circulation. ©Personal illustration.

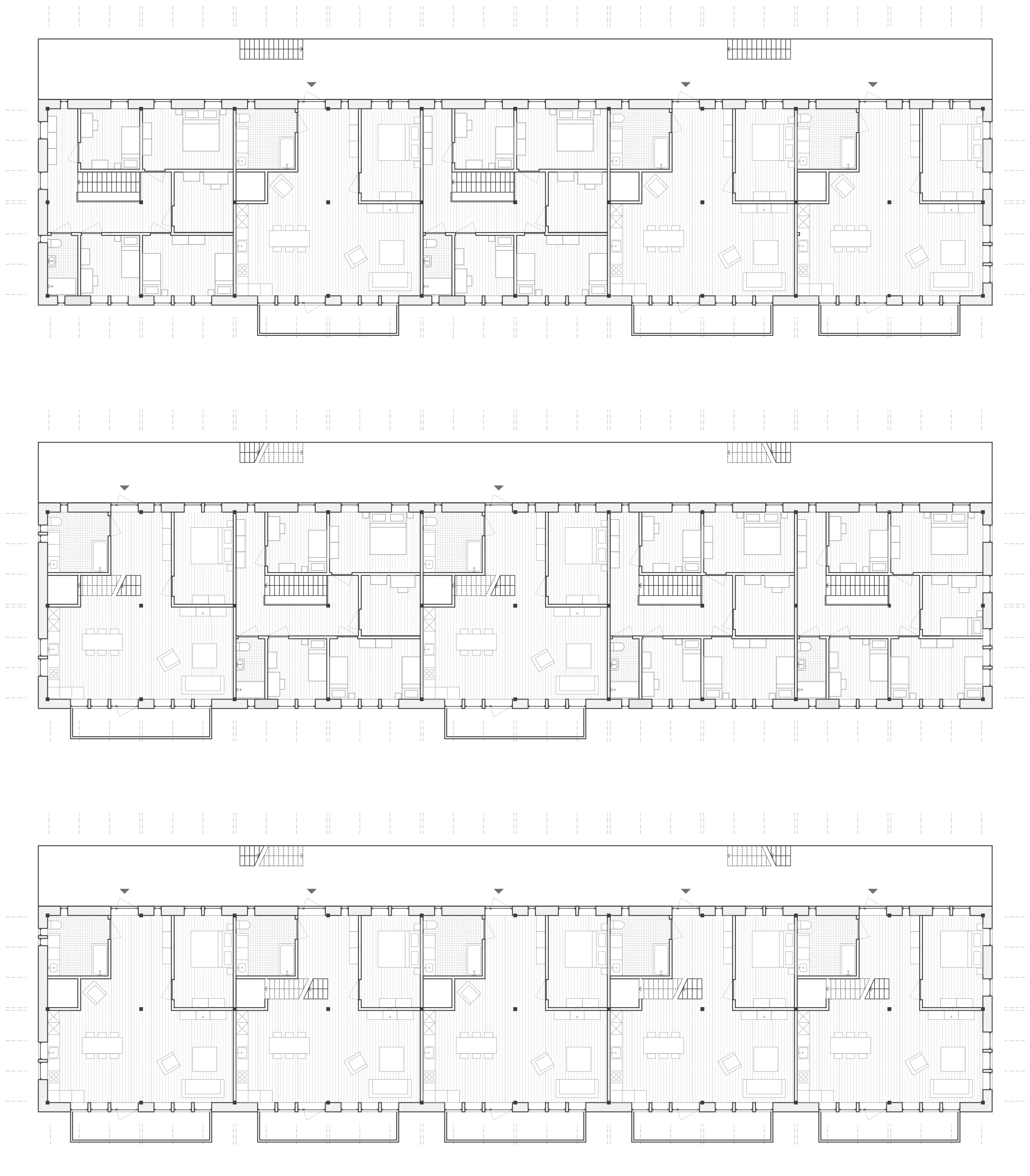


Fig 71. Drawing, Long building floorplans - 1:300. ©Personal illustration.

Fig 72. Drawing, Tower building floorplans - 1:400. ©Personal illustration.

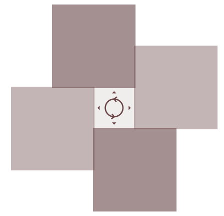


Fig 67. Diagram, Tower building circulation. ©Personal illustration.

05

Proposal development

Introduction

This section will review a proposal of project to illustrate the building system and layout together in a realistic context. This is a trial of the developed elements on a site; however, this location does not have importance for the project development, it could be developed on any site with different conditions. A promiscuous household community has also been thought of for the project to represent how it can adapt.

To select the site, the idea was to solve realistic situations that happen in the world. The one selected here concern the housing crisis that Sweden faces with its main cities. The exploration has been focused on the city of Göteborg and its possible development in the future. The idea is to propose a space where a settlement of individual houses could emerge not so far from the city centre so people could still commute every day; therefore, the commuting axis has been the main point to find the site. Then this location can be analysed and designed for the needs of the community. The concept of the proposal keeps the idea of evolution; in fact, it has opportunities for development in the future: densification, transformation into apartment buildings, etc.

Site selection

In Sweden, there is a housing crisis, and many people struggle to find a place to live in the cities or even close to them. Therefore, this project aims to propose more houses to help with this situation. As the city plans densification until 2050, the interlinked city, with plenty of projects. (Göteborg Stad, 2013), the proposal will be developed outside this perimeter with a sub-urban site close to the commuting axis.

Three commuting axes reach the centre of the city: Älvängen, Alignsås, and Kungsbacka, with Nineteen train stations outside of the interlinked city perimeter. From those, two of them are quite far and the time required to reach the city is too long to commute every day; therefore, they are not considered in the research. The selection between the remaining sites is influenced by criteria; first, there is the sustainability level of the site. If it is a preserved area or contains too much green structure, it will not be suitable. Then there is the proximity and accessibility to the train station. As the idea is to propose fast commuting to the city, the train should be easy to reach. Finally, there is the comfort of life. There should be commodities in the area to propose a good quality of life to future users.

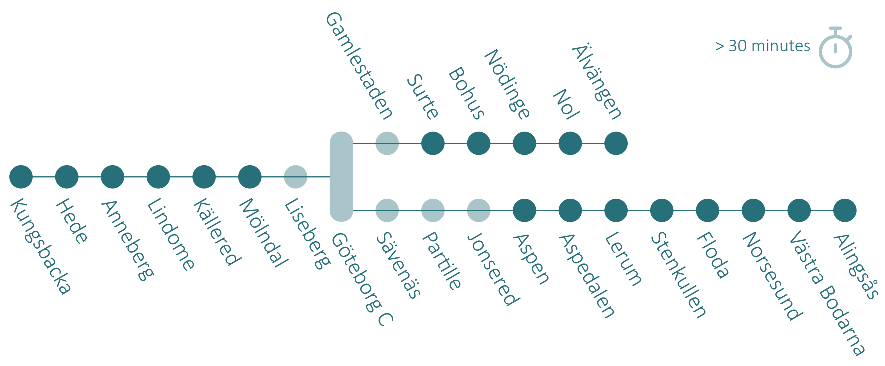


Fig 73. Diagram, Commuting axis. ©Personal illustration.

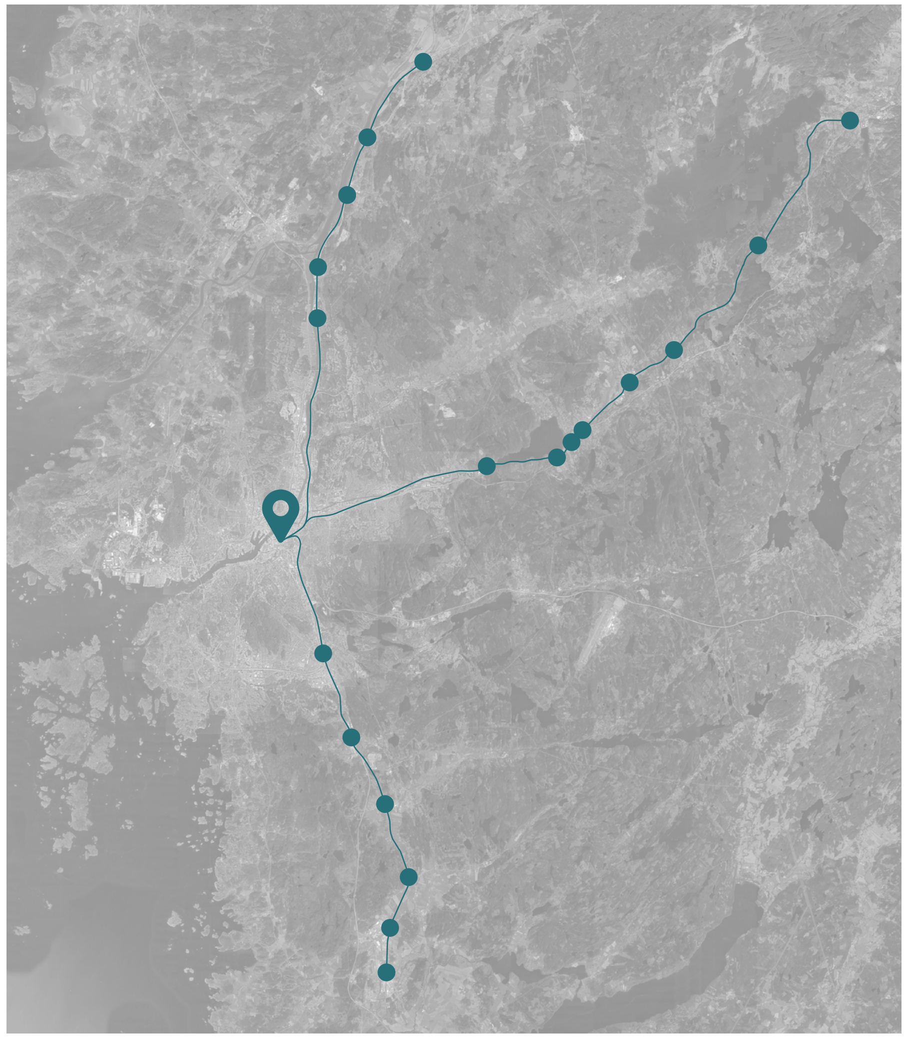


Fig 74. Map, Commuting axis and train stations. ©Personal illustration.

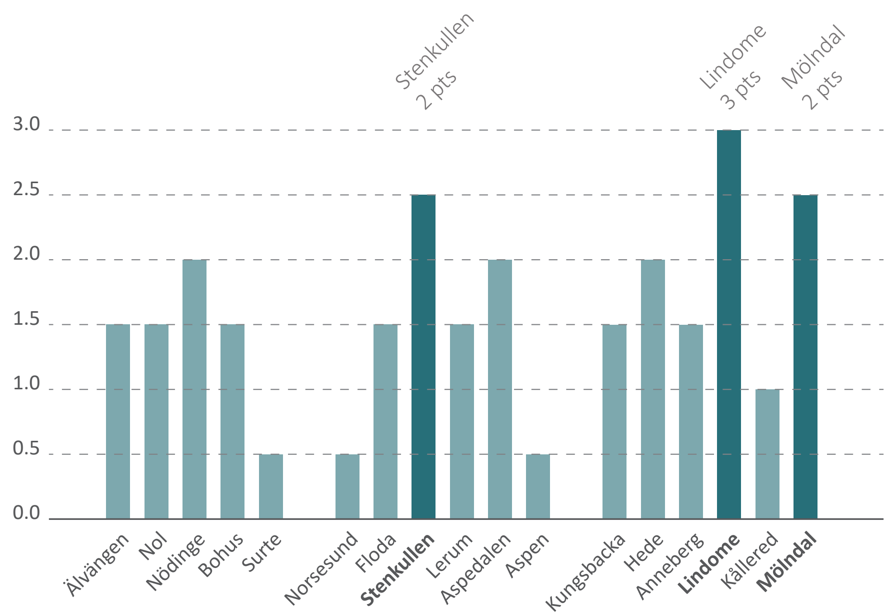


Fig 75. Figure, Site rating. ©Personal illustration.

After ranking the diverse site, three of them are standing out. They must be evaluated with more criteria that concern the surrounding of the possible plots. The focus here is to facilitate the integration of the project from a long-term perspective. First, the sites will be studied with natural structures to verify that there is not any preserved element on and around the plot. Then, the accessibility is evaluated with diverse types of transportation. Next, there is the social capacity of the site with infrastructure close to it for education, socialization, distraction, etc. Then the development potential is assessed with opportunities for extensions. Finally, the well-being of the users is ranked with the accessible commodities for essential shopping, health facilities, administrative offices, etc.

Fig 76. Map, Three sites. ©Personal illustration.

With the final evaluation, a site has been selected in Lindome. The site offers a lot of potentials and the surrounding contains many housing settlements. There are plenty of commodities with schools, shops, recreational centres, etc., that can bring an interesting comfort of life to the future site users. Furthermore, the site is planned to be developed by the municipality in the coming years. This site is a good fit for a housing project and it is now possible to start the next step: analysis. To proceed with this aspect, the plan is to follow parts of the method “Architecture student guide: Site analysis”. (Tifa, 2020).

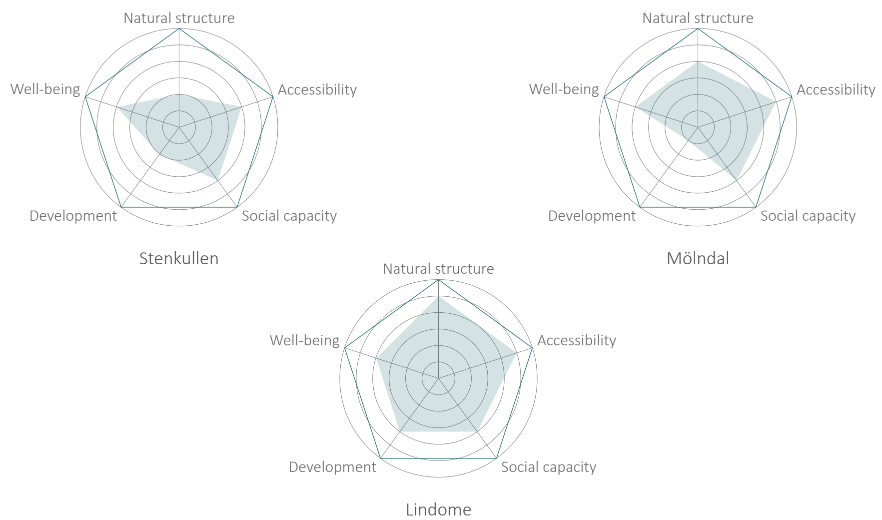


Fig 77. Figure, Site rating. ©Personal illustration.

Site analysis

In this section, the site in Lindome will be analysed with the help of the method previously mentioned. To start, it is necessary to perform a simple context reading that will provide the first impression of space and geometry. The site takes place in a rural area where most of the surroundings feel open due to many agricultural fields on the southern part. On the north, there are many settlements of individual houses with low buildings apart from school buildings on the western side. However, the views to the horizon are clear and it is possible to spot some hills in the background. Many natural elements are punctuating the landscape with trees in between parcels. Overall, the site feels like an empty page to write on with a lot of potentials.

The geometry of the site is irregular and does not represent any specific shape. There is an area of approximately fifteen thousand square metres to work with. All over the plot, there is a height difference of about five metres. This element is not visible as the plot is large and it can be considered relatively flat.

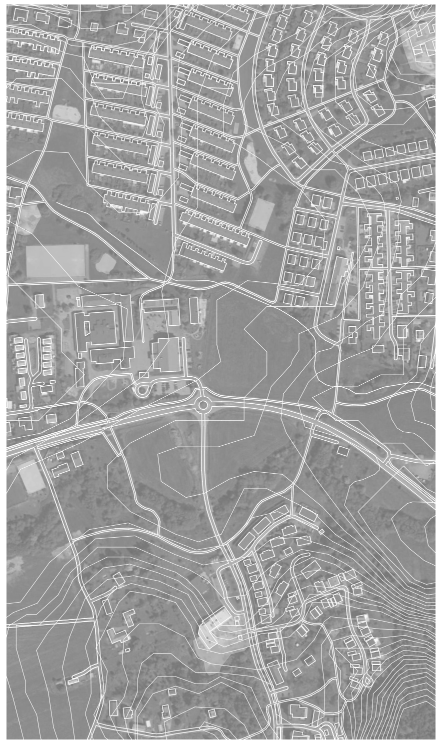


Fig 78. Map, Site plan. ©Personal illustration.

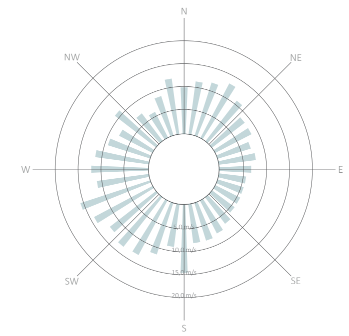


Fig 79. Figure, Wind path. ©Personal illustration.

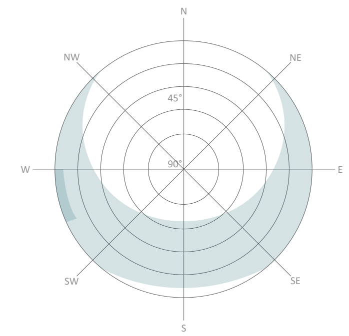


Fig 80. Figure, Sun path. ©Personal illustration.

The weather conditions on the plot are like the ones experiences along the western coast of Sweden. There is a hemi-boreal climate, which means that the temperatures are low in winter (around minus five degrees Celsius) and moderate in summer (around twenty-five degrees Celsius). It makes the four seasons distinctive from each other; however, the precipitations can occur all year with variable levels. There should not be flood risk on the site, although a small stream could overflow if there are heavy rains for too long. Another element to notice is that the sun path is quite low in the winter, although there is always some sunlight even for a few hours at the lowest point. Furthermore, the landscape does not create any shading, so the sun rays in winter can reach the project. The wind in the area is quite wild, it can come from all directions and with diverse intensities. It is a common condition on the west coast, although it could be possible to find ways to deviate it from the outdoor areas of the houses.

Natural structures are present around the site; although on-site, there is not much distinctive element. It is possible to find some tree settlements along the borders. There is also a small stream that goes from the south of the plot to the east. Around the small stream, a small tree arrangement is visible, it separates the plot from other house settlements.

There are building for diverse use in the surrounding of the site. On the north, there are mainly houses with some schools that punctuate the urban landscape. Those buildings are low (one or two stories) and embellished by shed roofs with a small slope. The houses create settlements that are composed of terraced or individual houses. Those elements will be studied further to get some size comparison to visualize the number of houses that could fit on the plot. There are two farms close to the site, one on the east and one on the west side. Going further east, there is the train station and some shopping facilities. It is possible to find more commodities on the other side of the railway.

Many circulation paths are present around the plot that compose a valuable transportation system. On the south, there is the main road for cars with a bike path that follows it. A roundabout allows a smaller road to get closer to the site. The bike lane crosses the field on the eastern side to reach the train station faster. This path is also walker-friendly. There are other walk paths around the sites that come from all directions.

Overall, there are many opportunities with this site, and it should be easy to develop a concept with all of them; however, the first step is to understand the capacity of the site. This will be done in the following section, with a comparison of the settlement in the surrounding to get data about the size of houses and gardens for each of them.

Fig 81. Drawing, Site analysis map. ©Personal illustration.

Size comparison

It is important to compare the site size with other of the same type to get numbers for the potential design, as it will help to integrate the proposal in the surrounding. For instance, the number of houses could be determined by knowing how big the houses are compared to entire settlements. It uses proportional rules to determine the number of dwellings to build on the site. The size of each house is already determined by the building layout development; however, it will be possible to compare this element to the surrounding and to see how much land area each house usually gets. To do this comparison, three other settlements will be measured, one in the south, one in the north, and one on the west side of the plot. Here are the measurements from each site.

Fig 82. Satellite picture, South site. ©Google maps.

This housing community contains thirty individual houses. They are all made of two stories, and it seems that there is one apartment per floor. Each one has a footprint of about a hundred square meters, and the entire land for each house is about five hundred square meters. The entire settlement possesses an area of fourteen thousand and six hundred square meters.

Fig 83. Satellite picture, North site. ©Google maps.

This settlement contains thirty-eight individual houses. Those are composed of one floor and their footprint on the yard takes one hundred and ten square meters. The entire garden areas are about seven hundred and eighty square meters each. Which gave a total community space of about twenty-nine thousand and five hundred square meters.

Fig 84. Satellite picture, West site. ©Google maps.

This last community of houses is composed of twenty-one houses. They are made of one story with some additional space under the roof as the pitch is quite high. They take around a hundred square meters of yard for a total of five hundred square meters allowed to each house. The entire settlement is about ten thousand and six hundred square meters.

Now that the surrounding has been analysed, it is possible to compare it to the actual site to get some ideas of how many houses can fit on the plot. Forty per cent of the entire space will be taken away for circulation and common areas. From the fifteen thousand square meters, it lets around nine thousand of them to plan houses. The average area of yards found from each of the communities studied is about six hundred and forty square meters, which gives us approximately fourteen houses to build on the plot.

Household

For the project proposal, there will be fourteen houses to design on the plot. To show the flexibility of the proposal, it will be related to a diverse community of fourteen households selected to "live" there. To be able to create them, it is first preferable to look at some data about the type of household members in Sweden. It would be more realistic to create those families with the help of realistic facts.

Statistics from Statista shows that there are about four point eight million households in Sweden. Forty per cent of those are composed of single people that live without children. About twenty-five per cent are families with children and twenty-four are collective without children. Then, there is about six per cent of single parents with children. And the remaining five per cent correspond to other types of families without children. (Statista, 2021). Now that the data are announced, it is possible to plan for the fourteen households.

The five first households will be single people without children. There is Tim a retired man that lives alone and is passionate about gardening. Then, there is Hayley a young influencer with her dog Cyrano. Next is Olle a young artist. Then it is Maya a sports teacher that gives classes from home. Finally, there is Jordan a businessman that works in the city.

Then, there are four households composed of couples with kids. There are Anna and Marcus with their kids Eric and Elsa. Then there are new parents Emma and Michael with their daughter Rose. Next, the couple Pierre and Adèle that will welcome their first child soon. And finally, Katarina and Victor with their kids Magdalena and Johana.

The next group of households is composed of people that live together without kids. They can be married, simple couples, or cohabitating. Here, there are Ida, Tina, and Jack that form a collective. Then, there is a couple of Agnès and Rosa. And finally, there are the married retired Ellen and George with their cat Mitten.

Then, there is one household with a single parent. It is Flora and her two children Marcus and Olivia.

And finally, there is a household classified as other. For this one, it is a composed couple with many kids and a grandmother that lives in the house with them. They are Emilia and Joe with their kids Julia, Gloria, Victoria, and Jim. And the grandmother is named Marta.

With those fourteen households, it is not possible to install the different houses on the site. The next step is to plan a site concept design with circulations and common areas. Then each household will get a house and it will create a variety of typology used.

Fig 85. Drawing, Households. ©Personal illustration.

Site concept

This section will review the proposal for the site concept. The main idea for this plot is to propose a design in cohesion with the rest of the research; therefore, it is based on the principle of evolution where the idea is that in the future, things could evolve and the site could be denser if it is required. There will be some elements to allow such development that will be reviewed. For instance, dimension reflections will be present to help the placement of the houses.

There are some criteria to follow to design the site sustainably and durably. One of them is the orientation of the houses to attain comfort inside the dwelling. It is primordial to think about how the sun shines on and in the homes to avoid over-heating phenomena. Therefore, the houses will be slightly titled to not face south and a large amount of sun in summer. Instead, the buildings will face half west and half east. This orientation can be beneficial to gain sun heating when it could be required and it helps to avoid over-heating.

Another element to think about is the access to each house. As mentioned during the analysis, there is a roundabout on the main road that allows a smaller path to come in the direction of the site. This road could be continued further over the site and reach all the houses if it is separated properly. Then there could be walk and bike paths along those roads. The other paths around the plots could be connected to these elements to create cohesion and integrate the project within this neighbourhood.

Finally, there have been some discussions about common areas. As the project tends to focus mainly on the housing proposal, there will not be complete development of those spaces. However, they can be indicated on the site plan. They could be recreational areas with a playground for kids, or a fitness path outside. Another idea for those spaces could be to integrate communal gardens for the people of the community. Then, they could meet there and exchange to create durable relations. This aspect could bring social sustainability with a strong community that grows together and helps each other.

Now that the boundaries have been exposed, it is possible to explore some drawings to propose a concept. As circulation is the key to integrate the project on this site, it will be the first element to be developed. Then, to place the houses, there will be a grid with a frame of four-point sixty-four meters that correspond to the architectural frame of the project. The houses will be placed on a grid to allow the possible extension of the project proposal in the future and allow more houses to take place there.

On fig xx, it is possible to see the proposed site design. There will be fourteen houses distributed over three roads. Those paths connect the walk and bike lane across the site to bring a smooth circulation and integrate the site in the context. Overall, the houses have big backyards, and on the eastern part of the site, there are some remaining spaces to establish some communal areas. As the main idea was to develop a project that could evolve in the future, the houses are placed on a grid induced by the architectural frame.

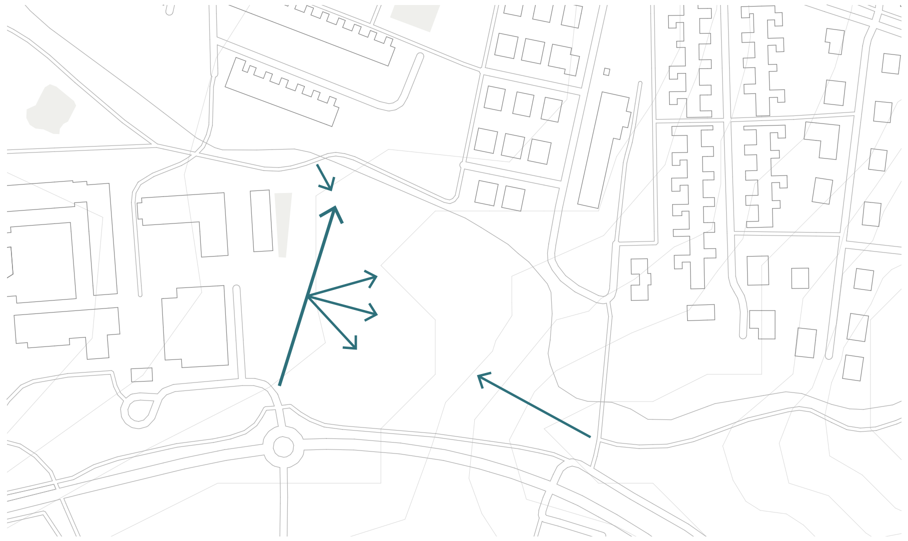


Fig 86. Drawing, Circulation opportunities. ©Personal illustration.

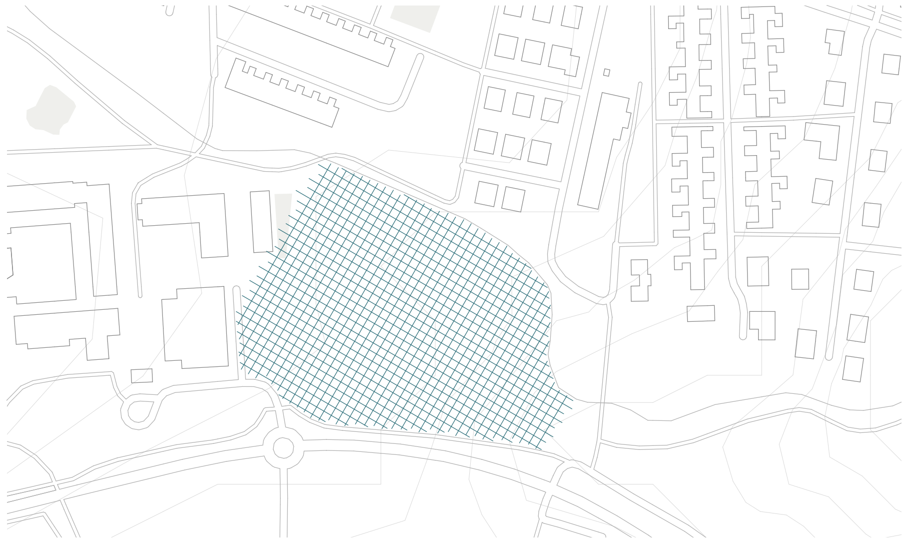


Fig 87. Drawing, Architectural frame over the site. ©Personal illustration.

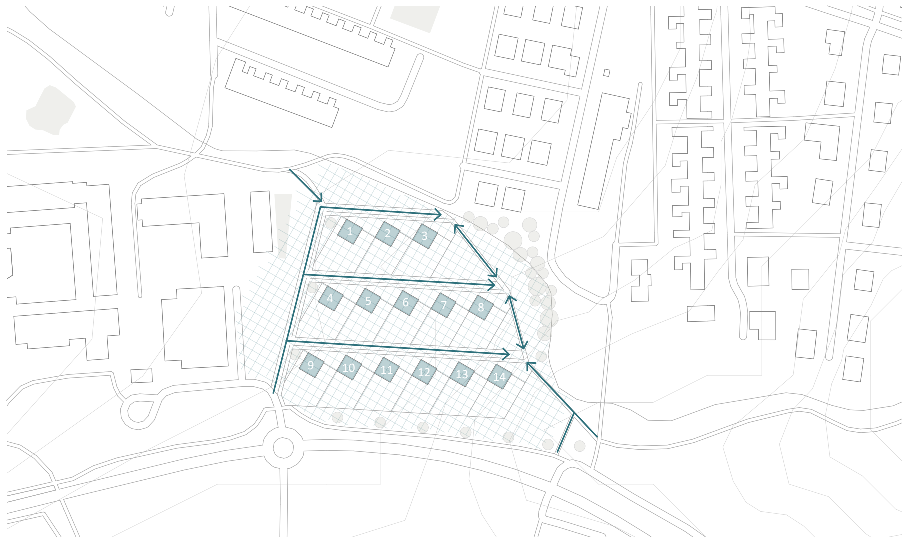


Fig 88. Drawing, Concept proposal for the fourteen houses on site. ©Personal illustration.

Site evolution

Due to the use of a grid that respects the architectural frame, it will be possible in the future to make the project denser. For instance, there are now houses placed with a certain distance. This measurement corresponds to a full house. Therefore, in between each dwelling, it will be possible to add another one of them. This will transform the actual project into a terraced house settlement and there will be more houses to live in that will not be too dense as each of them still get a generous backyard.

Fig 89. Drawing, Densification into terraced houses. ©Personal illustration.

This option is one possibility, many of them could be tried on this site or another one. If the context was denser, the proposal could be articulated into an apartment building with common circulation. Those options have been explained in the building layout proposal and the catalogue. Here are some possibilities with denser buildings if the context was more urban. The proposal on the left represents small apartment buildings that work as mini towers with a central circulation inside the modules. The design on the right is also about apartment buildings, this time it is with a linear shape and a passageway to distribute each apartment. For both projects, it could be possible to add levels. However, the possibilities of evolutions when there are other spaces above each other get lower and the project could lose some freedom.

Fig 90. Drawing, Densification into apartment buildings. ©Personal illustration.

Project proposal

In this section, there will be explanations on the actual project proposal with the overall design of the site and a close-up look at one of the houses. This example for the project aims to show how the different elements of the research come together and how they can promote sustainable living over the years.

In this proposition, there are various sizes of houses with six of them of one story and eight of two levels. Some common are present in the eastern part. The circulation is fluid with the three roads that deserve each building and many walk paths. The site plan below shows the arrangement of the diverse elements.

Fig 91. Drawing, Site design - 1:1000. ©Personal illustration.

Now that the site has been set, it is possible to look a bit closer to one of the houses. The selected one can accommodate up to six persons. It takes place over two floors and possesses a nice garden in the back and some parking areas in the front. On the upper floor, there is a terrace accessible from the corridor. As the house is raised on metal profiles, there are stairs and terraces in the front and the back. At the northern part of the dwelling, there is access to the road. A small grass area makes the place more pleasant.

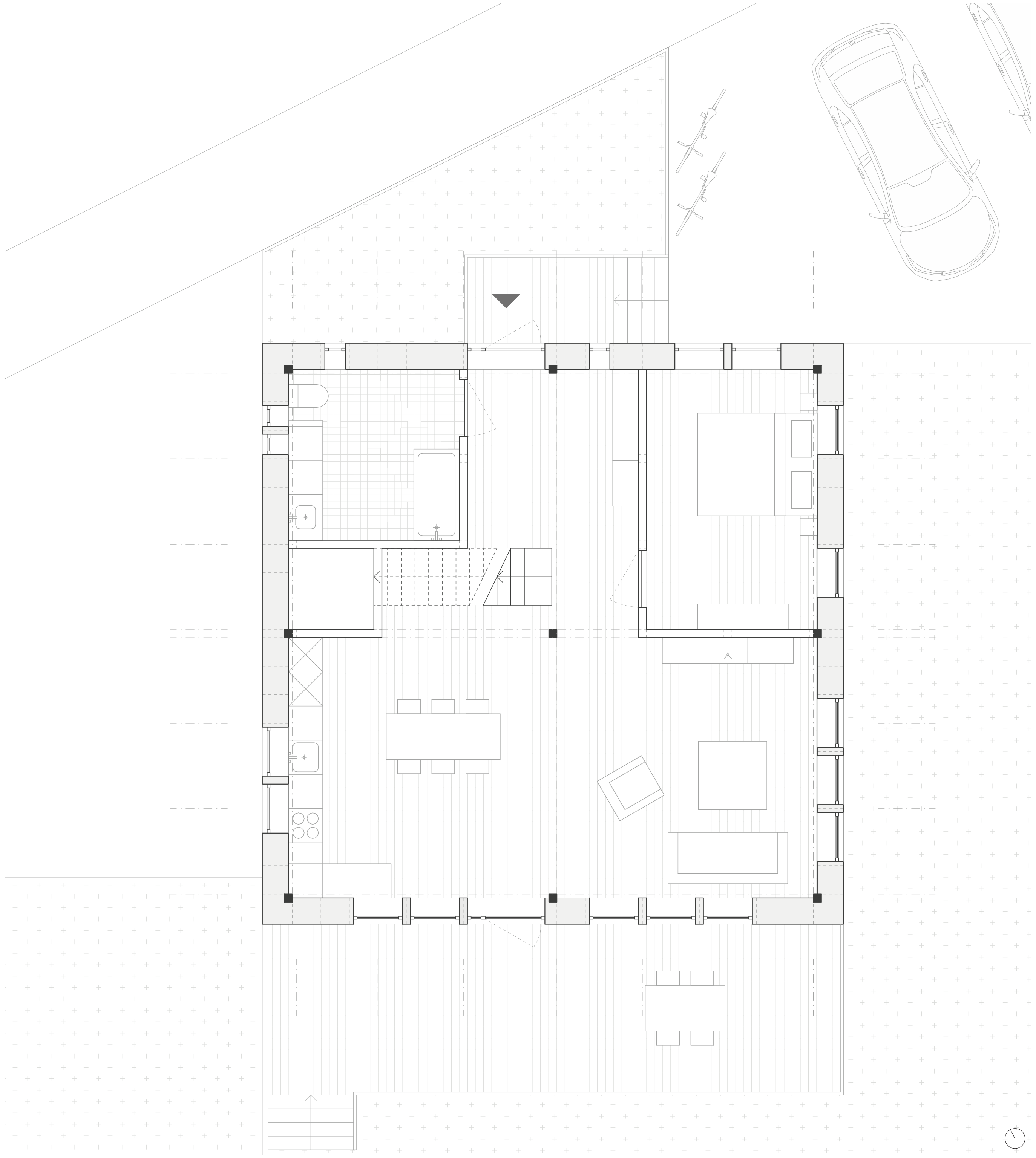


Fig 92. Drawing, Ground floor - Six persons house - 1:100. ©Personal illustration.

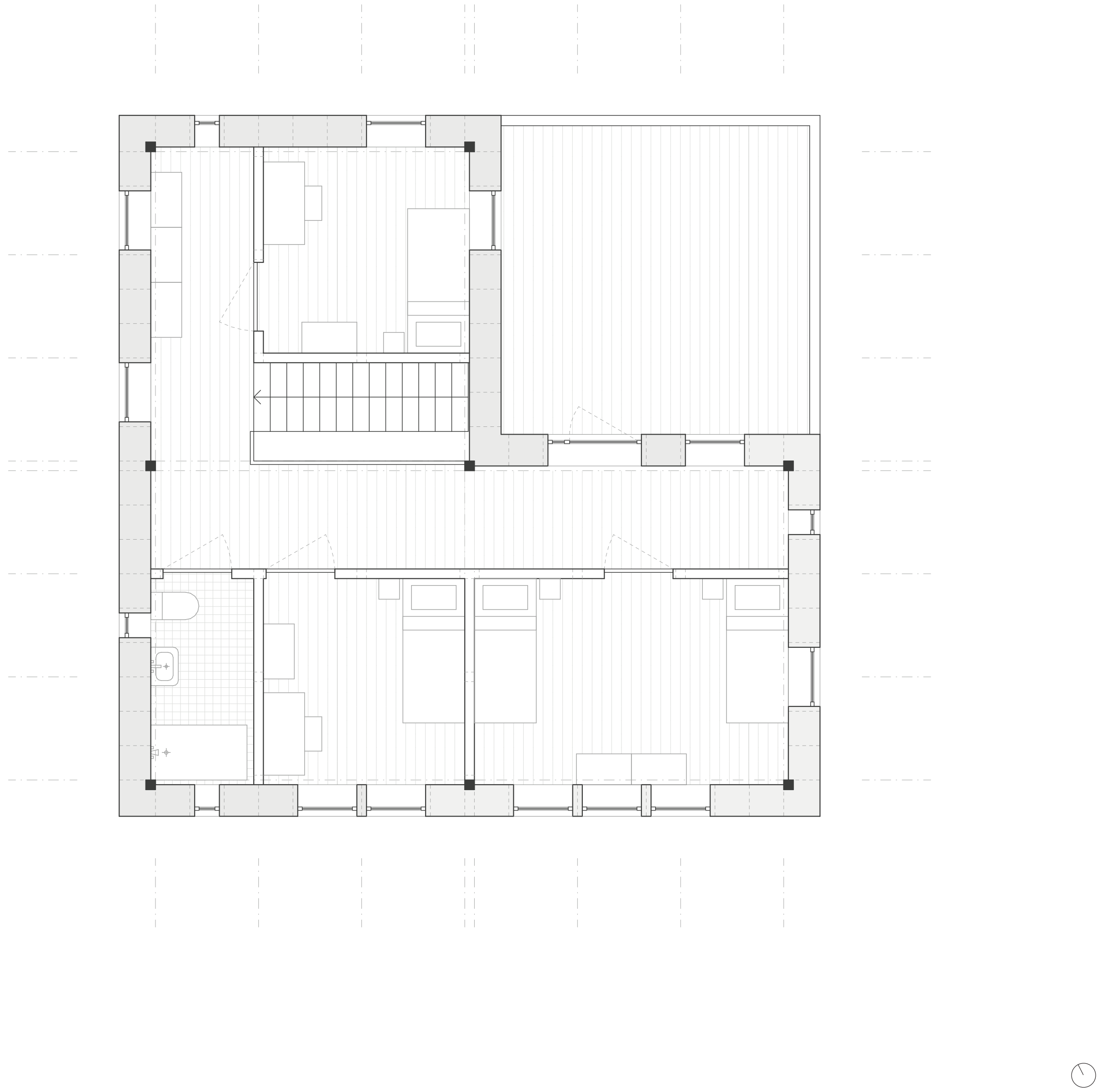


Fig 93. Drawing, First floor - Six persons house - 1:100. ©Personal illustration.

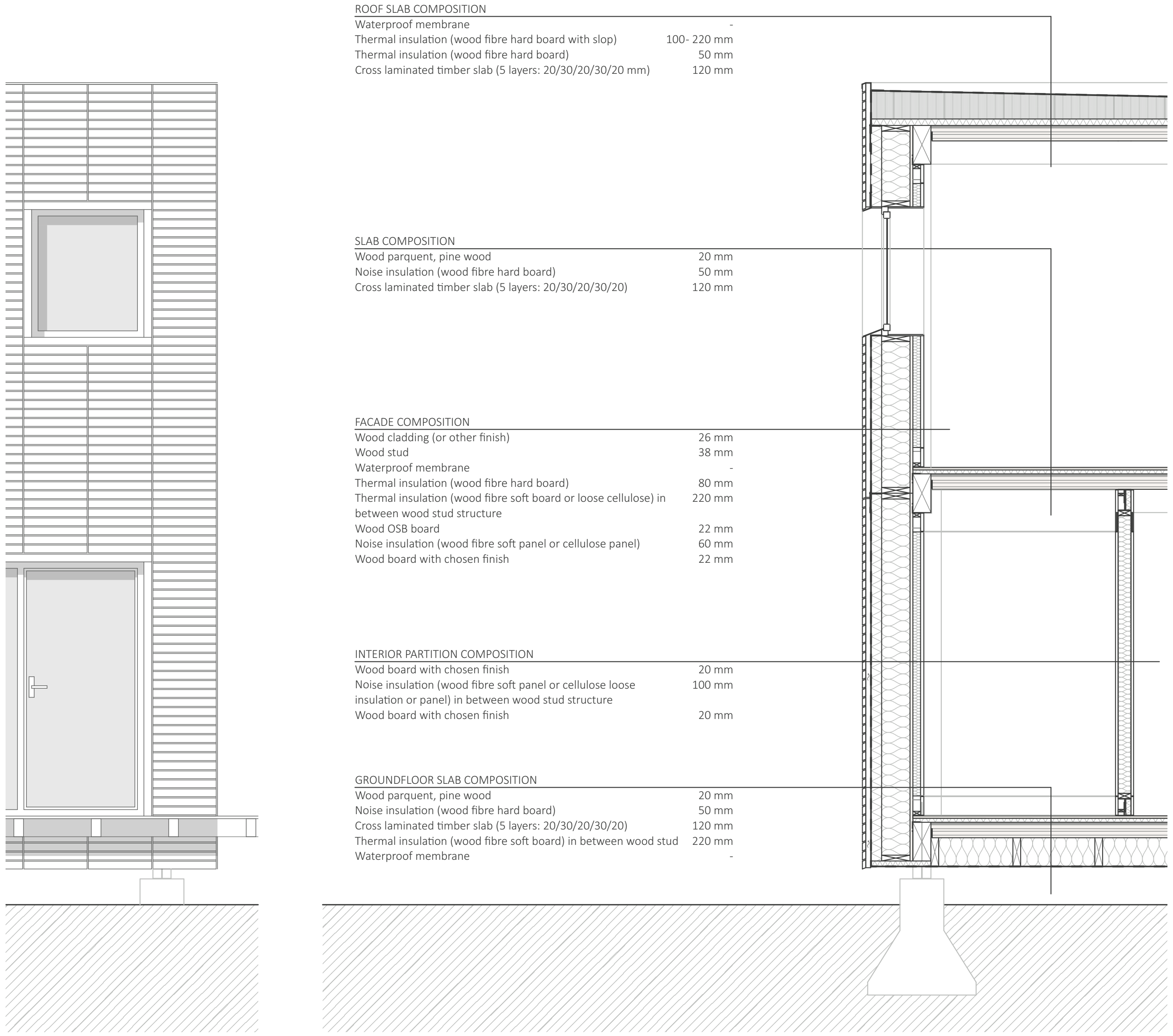


Fig 94. Drawing, Construction section and elevation with composition. ©Personal illustration.

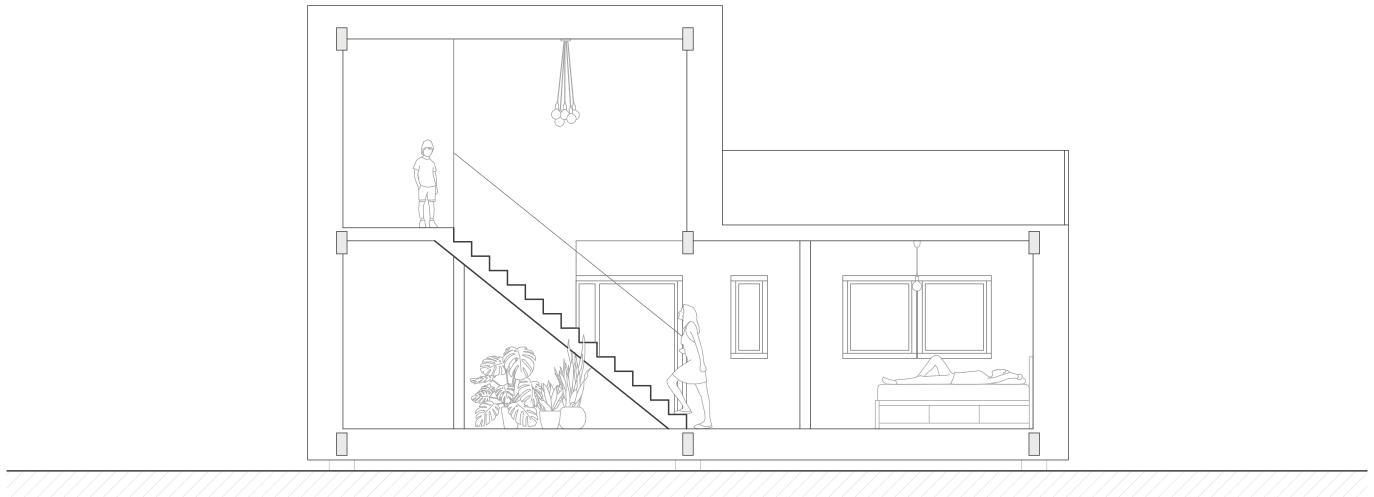


Fig 95. Drawing, Cross-section - Six persons house - 1:100. ©Personal illustration.

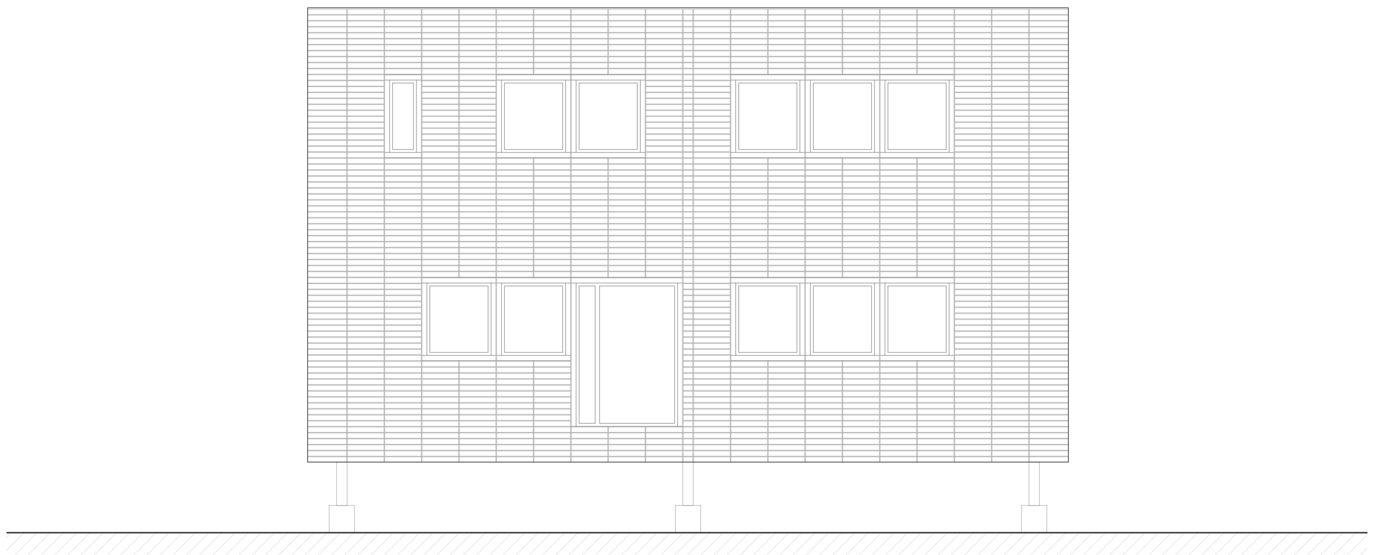


Fig 96. Drawing, Elevation - Six persons house - 1:100. ©Personal illustration.

06 Conclusion

This research was based on the problem of resource availability and waste accumulation deriving from the construction industry. The thesis has aimed to explore the opportunities arising from the concepts of adaptability, design for disassembly, and modularity in housing projects in order to propose building systems and layouts that will be durable and flexible. There are many ways to improve the usage of materials in construction. The system explored in this study is designed to avoid waste as much as possible during the conception of the modules, and once the components are separated, they must find a new purpose instead of becoming waste. Several options have been explored concerning possibilities of repurposing, reusing, recycling, and so on.

The use of certain materials is one way to explore durability, another would be to think about their lifespan in the building. The demolition of buildings in our society usually takes place before the buildings end of life which induces a lot of waste from materials that could still be used. And to replace the building, it is necessary to extract new materials even faster to repeat the process. If materials last longer, it will not be necessary to extract new ones for the project. And while they last, they are obviously not becoming waste. Maintaining a building to make it last longer is more durable and can be easily carried out with the use of modules.

Nevertheless, the building system cannot solve the entire environmental crisis, they try to give solutions for housing evolution in the future. The buildings are designed to answer needs, these are evolving over time, especially in housing where households are constantly evolving. Therefore, the building system has also been designed to progress with the layout. This demarche is aiming to propose a home for life to the users with a project that will adapt to them instead of being a constraint.

The overall project was developed with a layout following the concept of adaptability and a building system that corresponds to the concepts of modularity and design for disassembly. The concepts explored to achieve this thesis help to attain sustainability of resources and waste. In fact, they are allowing flexibility at various levels to pursue the general objective. All research and experimentation during this process have helped to gain knowledge and reflections on how to further develop the design. Many points were challenging such as the technical aspects inside the house. Those elements were solved with simple solutions that engaged more reflections around the building system. Overall, each decision was making the project grow and was opening other questions. For instance, the façade modules were originally planned to be fixed to the beams with interlocking connectors, however, it was not possible to disassemble the modules if there was another one on top, which makes the flexibility weaker. Therefore, there have been more reflections to attain better flexibility with those elements.

Now that the project is completed, unanswered questions remain, and others have arisen during the process. For instance, the building design allows the construction of small buildings, how could it be adapted to larger structures with possible apartment buildings? The structure must be reconsidered; it can impact the entire system and the degree of flexibility that it contains might not be sufficient to adapt it in this case. Following the same kind of reflections, there can be questions about the structural dimensions. The project has focussed on the building system, therefore the layout dimensions have remained in the shape of a square. What could have happened if the building was designed in another shape or even without a fixed shape? One of the main principles of the concept of modularity and adaptability is to follow a structure, but the entire building can be of any shape as long as it stays within this structure, and in this case, how does the system react both inside and outside? There are many possibilities of buildings where the system has not been tested. Could it work for a public building, or is it too simple to respond to other types of programs?

Overall, the process behind this thesis has been enriching. The diverse possibilities have been challenging and have encouraged me to do more research and go further in the design process. Many other aspects could have been explored if the time had allowed it. Nevertheless, the outcome of this thesis is pleasing and would be something to work on again in the future if the opportunity presents itself.

Fig 97. Diagram, Final proposal evolution with construction and users. ©Personal illustration.

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