Modular Healthcare

-TEMPORARY HEALTHCARE FACILITIES IN WOOD

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Modular Healthcare
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Thank you to

my tutor Lin
and my friends & family

The Author

I am an architecture student at Chalmers University, studying the master program “Architecture and Planning Beyond Sustainability,” and hold a BA. Degree of fine arts in architecture from Umeå University of Architecture.

During my education, I have focused on sustainability; working with circular design is a personal interest. What also drives me is to work with innovative ideas that strive to make a change.

This thesis will be a way for me to expand my knowledge areas and learn more about how sustainable systems can be applied in healthcare architecture. I do not come from a background in healthcare architecture; however, I have studied innovation projects in healthcare and the diffusion of innovations within the sector during a transdisciplinary course.

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Ms. Project Managment in Construction and Design Projects, Chalmers

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Abstract

The thesis explores the use of wooden room modules for temporary healthcare facilities. Today, temporary healthcare facilities have a broad usage area; the typology is used when expanding hospitals, creating temporary wards, and forming self-standing hospitals. In the future, the use of temporary healthcare facilities will also increase due to impending pandemics and natural disasters and renovations and upgrades of hospitals. This thesis aims to contribute to developing the building typology of temporary buildings for the healthcare sector.

The thesis investigates how room modules can be built to fit the needs of general wards and how they can be combined to create spaces that fulfill the healthcare sector’s needs. The thesis also investigates how modules can be designed for disassembly. with a circular approach to them and

This thesis uses a qualitative approach in a comprehensive literature review investigating four subjects 1. temporary buildings 2. modular building systems 3. Sustainable buildings 4. Healthcare architecture. The study leads to a design exploration where the findings are tested in a concept development and design proposal.

The result of the project is a proposal for prefabricated room modules with a Cross-Laminated Timber (CLT) structure as a building system for temporary healthcare facilities. It proposes versatile room modules that come in three sizes to fit the needs of different projects. The room modules can either be used as they are or complement each other to form larger spaces. The building system is designed to be reusable and disassemblable, and a circular strategy is made for it. Finally, a design proposal is made that suggests how different room modules can be combined to create a temporary two-level ward unit for a hospital.

Keywords : Temporary healthcare facilities, design for disassembly, Timber structure, modular building, prefab,

Content

Content

1.Introduction

Purpose

Research question

- How can standardized room modules for temporary healthcare facilities be built to promote circularity and disassembly?

-How can wards and clinics be formed using room modules?

Aim

The thesis aim is to propose wooden modules as a building system for temporary healthcare facilities. The room modules will together be able to form different healthcare facilities depending on the client's needs. Because it is a temporary building typology, the thesis aims to propose a circular system that enables the modules and material from them to be reused.

The scope of this project is to explore modular systems for healthcare buildings. The thesis will investigate the possibilities and limitations of modules for temporary facilities, both on a broad scale and a detailed scale. Danderyd Sjukhus is picked as a site to contextualize a design proposal. The thesis has focused on spaces for general inpatient wards and outpatient clinics.

delimitations

The project has not investigated further the possibility of having heavy equipment like MR scans and X-ray machines. Operation theaters and ICU rooms are also delimited from the project.

The thesis does not address HVAC systems or other technical aspects.

The proposal limits itself to sizes that are transportable by truck, based on Swedish regulations.

Method

Four main topics were used as guiding principles throughout the thesis 1. temporary buildings 2. modular building systems 3. Sustainable building 4. Healthcare Architecture. The thesis used "Research for Design" and qualitative research methods to investigate the topics.

Methods used:

- Literature studies
-interviews
-case studies
-site visits and observations
-spatial explorations

Literature study:

The literature study gave a picture of the existing situation, investigated what the research tells today and what had been done in the field already. The main focus was the Swedish industry and sector but also addressed the broader perspective. There are four main areas that the literature study focused on: the Healthcare sector, sustainability, prefabricated modules, and wooden elements.

Scientific articles and reports were used in the literature study. A critical selection of the sources was made based on relevancy and date.

Chalmers library website and google scholar were used as tools to find the sources.

Case studies:

Case studies were explored to investigate similar projects and what has been created up to today regarding modular buildings and temporary building structures in healthcare-related projects.

Interviews:

Conversations and informal interviews were conducted with construction and material companies.

A semi-structured interview was conducted with a researcher at Chalmers to get a better understanding of DfD and the use of modules in practice. The interview was semi-structured to have the possibility to deviate from the prepared questions.

Site visits and observations:

Site visits were done to explore different hospital sites and explore possibilities for hospitals to expand.

A more in-depth site visit was done at Nya Karolinska Sjukhuset in Solna, Stockholm. It gave an overall understanding of the flows and setup of hospitals.

Spatial Exploration:

Sketching, 3D modeling, and a series of spatial iterations were used for spatial exploration. The spatial exploration tested the findings from the research in a design proposal.

Tools used:

Paper and pen, Archicad 24, Adobe Illustrator 2021.

Reading Instructions

Background

Concept

Design intervention

Discussion

This paper consists of four main parts, theory, concept design proposal, and discussion.

Background

This part gives an understanding of the previous research within the field today; it covers the different areas that the thesis reflects upon.

Concept

The concept is the first part of the idea development and lays the ground for how the thesis questions can be answered. It explains the main ideas from the theories that the design proposal will develop further in detail.

Design Proposal

The proposal shows the results of the concept development and the theoretical part by implementing the ideas and theories into an actual architectural project.

Discussion

Reflections on the results are gathered here

2. Background

To be able to give a holistic understanding of the project, this chapter covers a broad spectrum of research. Data from the fields of healthcare architecture, Sustainable building, Timber buildings, and Prefabricated Building technology has been studied in the background chapter and set the ground for the thesis.

Problem Formulation

Trends and challenges

The healthcare sector will face large challenges The healthcare sector will face extensive challenges shortly, and several upcoming trends will impact the sector, how it operates, and its facilities. At the same time, society is also requiring high-quality healthcare and increasing its demands on the sector. (PTS,2019)

Below three trends and challenges of the healthcare sector are listed, these will. The facilities and their architecture will play a role in how the sector tackles these trends and challenges and at what level the sector can keep up with its challenges.

1. TEchnology and equipment

PTS (2019) mentions that Medtech and medical treatments are developing fast, affecting the entire healthcare sector.

It is not easy to know what treatments and equipment will be used in the future, but it is important that the facilities support the new equipment. (PTS,2019)

2. Population increase

Another megatrend seen is the change in the population and diseases. The population keeps growing, and people are getting older. This leads to increased pressure on the healthcare sector (as more people are getting sick) and the up-coming of new diseases, bacteria resistance, and patients getting multi-diseases.(Fröst & Hammarling ,2017).

3. Climate Change

Climate change is a challenge facing the entire world, and the healthcare sector will need to address and build resilient facilities with low environmental impact (PTS,2019). At the same time, it will be essential for the healthcare sector to be able to handle challenges like an increased amount of natural disasters and the sudden need for healthcare that it leads to (Bitterman & Zimmer, 2017).

Climate Change and a population increase will lead to disasters like pandemics, natural disasters, and human-made disasters to increase (Bitterman & Zimmer, 2017). It becomes crucial that healthcare is equipped to face these challenges.

4. Cost efficiency

PTS states that money within the public sector can become tight in the future, and the care sector will need to become more cost-efficient. Buildings that enable less staff to work will be necessary (PTS,2019).

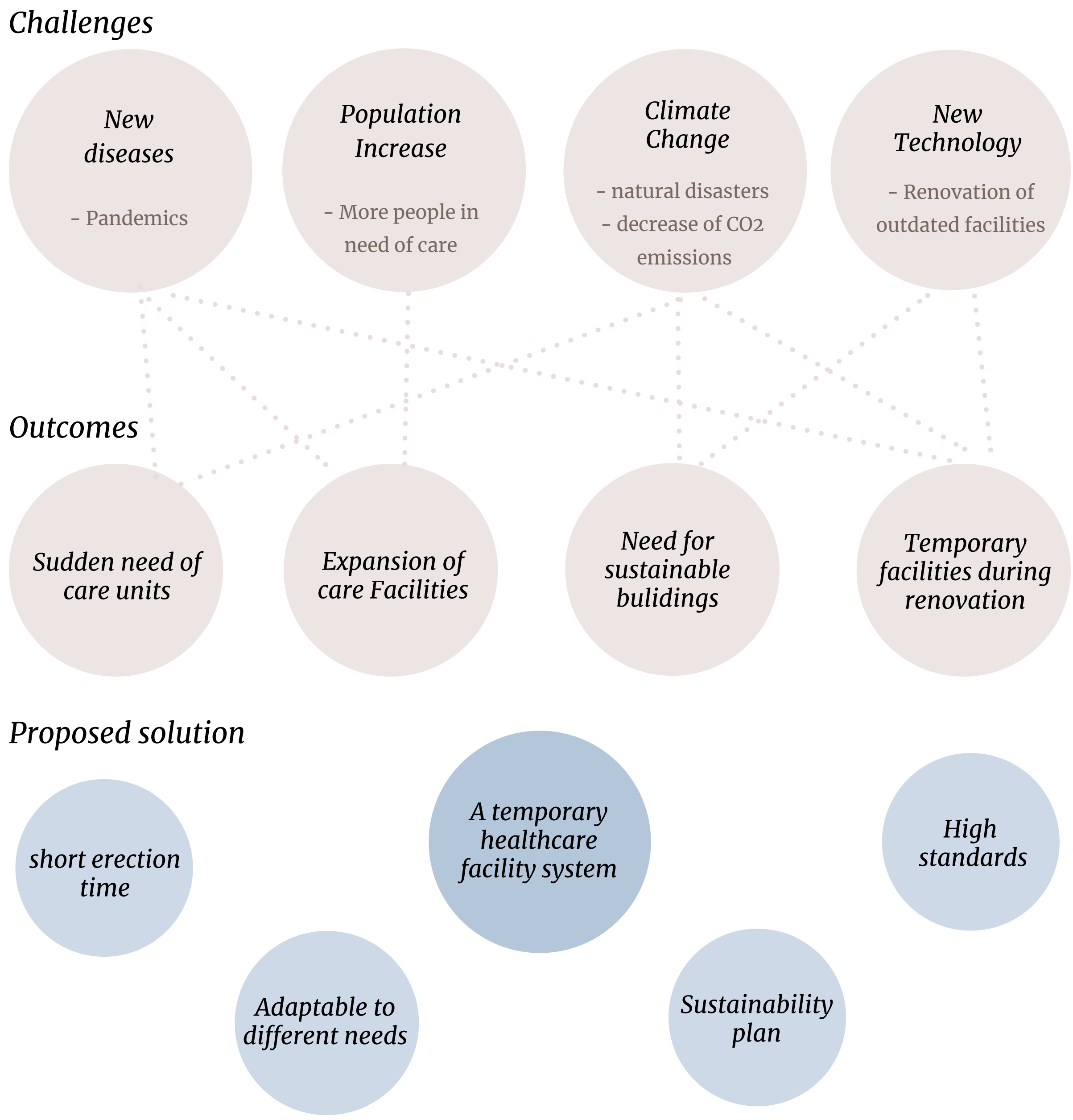


Illustration of the problem formulation

The thesis derivates from the trends and challenges mentioned above. It can be concluded that there will be an increased need for facilities within the care sector. Facilities that can handle the challenges and facilities that are easy to expand and fast to erect in crisis. Also, while old facilities are being renovated the functions need to be moved to temporary buildings. Offering the same care quality, security and comfort as the standard ones. A recurring need for temporary healthcare facilities becomes evident.

Building for the future

According to Fröst & Hammarling (2017), healthcare is constantly changing. Due to unknown struggles of the future and upcoming new technology, the spaces we build can not be based on known solutions and patterns.
There is a need to build to address tomorrow's challenges and fulfill the needs of today (Fröst & Hammarling,2017).

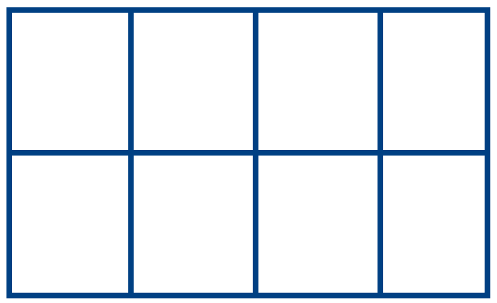
When speaking about future healthcare facilities, flexible and adaptable solutions are recurring keywords. Together with terms like resilience and elasticity, it is covered under the topic Future-proofing. Future-proofing refers to strategies that are supposed to prepare our healthcare facilities for the changes that can take place in the future. The idea derives from the belief that hospitals should change depending on the demographic of the population and changes in the clinical practice. (Carthey et al. 2011)

Below, some strategies for future-proofing when working with a room module system are listed:

Universal Design/ Generallity

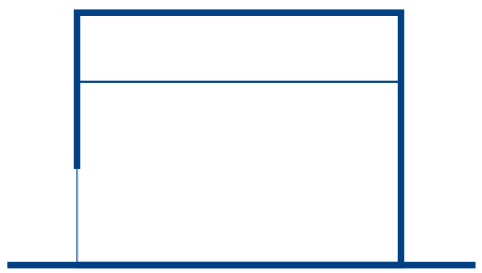
The concept of universality, also known as generality, is according to Pati. et al. (2008) a strategy to increase flexibility in healthcare buildings. It is explained to be an example of adaptable design (Pati. et al., 2008). Building with generality in mind is a way to build to cover the requirements of different functions. The rooms are suited with equipment and requirements for several types of practices. (Pati. et al. 2008). Technical installations and the load-bearing properties of the spaces has to therefore fit the upcoming functions as well (Karlsson, 2019).

Karlsson (2019) also describes a general floorplan as a floorplan where different functions can be moved or replaced with other functions with small or no changes to the floor plan.



Intersitial floors

Working with interstitial floors on each floor plan allows the installations to go through the ceiling instead of the walls and thereby makes it possible to upgrade technology and electrical elements in the facility. Therefore, it is also beneficial to have some extra space to fit future installations. (Kjisik, 2009)



Evidence Based Design

Evidence based design has shown that healthcare architecture has several benefits like a higher patient safety and higher well being for the people in the building. (PTS, Chalmers & Göteborgs Universitet, 2016)

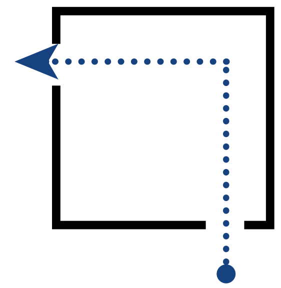
Research shows that different factors in our care environments can have an impact on our wellbeing and health. It can for example lead to feeling calm, less stressed and even decrease the time spent in the care facility. Attractive and especially pleasing environments have also been shown to have an impact on the patients' overall experience of the care visit (Fröst & Hammarling,2017).

Daylight and view

Windows and sufficient daylight have shown to be beneficial for both patients and staff members. It can lead to decreased depression, a lower pain level, and also better sleep. When it comes to the staff it leads to a lower stress level. (Fröst & Hammarling,2017).

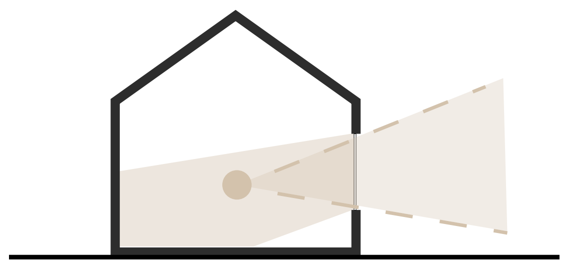
Orientation

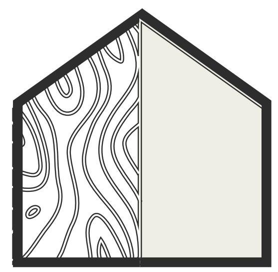
The buildings need to be easy to orientate in to give the patient a feeling of comfort and safety. Having windows in the hallways makes it easier for the patients to orientate in the ward areas. Color coding the hallways and marking entrances and different rooms by color also helps to orientate. (Fröst & Hammarling,2017).



Materiality

The Material choices can also lead to a feeling of calmness and safety. color pallets and martial combinations have shown to impact the patient. Wood in particular has shown to have a positive impact on the patients' health (Fröst & Hammarling,2017).





Wards & Clinics

Hospitals offer two types of care, Inpatient and outpatient care. Inpatient wards are where the patient stays overnight or during an extended period. An outpatient clinic refers to departments for patients who visit the hospital but are not staying the night.

Often outpatient clinics and inpatient wards for the same specialty are placed close to each other (PTS, Chalmers & Göteborgs Universitet, 2016).

Outpatient Clinic

The outpatient clinic consists of spaces like waiting rooms, receptions, expeditions, examination rooms, treatment rooms, clinic rooms, and administrative spaces. Depending on the type of specialty located in the facility, other rooms might be needed as well. The administrative spaces in an outpatient clinic can either be located in the same room as the treatment room (called a Clinic room) or separated from the patient room. (PTS, Chalmers & Göteborgs Universitet, 2016).

PTS & Chalmers (2019) state that the single patient room can be transformed and used as an examination room or a treatment room.

Inpatient Ward

According to Den Goda Vårdavdelningen (PTS & Chalmers, 2019), an inpatient ward consists of several units; each unit consists of 5-8 patient rooms depending on what type of ward it is and what type of care is located there.

Besides the patient rooms, the units consist of what they call support units. These units are meant to offer space for both patients and staff. It can be day rooms for patients, group rooms for the staff and the patient to discuss in private, or workstations for the staff to do their daily tasks (PTS & Chalmers, 2019). Schmitt and Strid (2017) mention that the workstations' placement has to consider the shift in the amount of staff working during night time compared to the day (Schmitt & Strid, 2017).

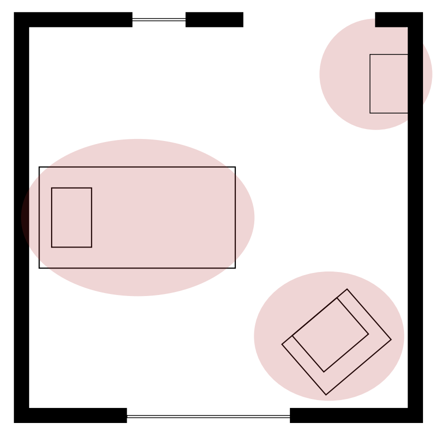
There are also supporting functions like storage, recycling room, and kitchen that are not used as often and therefore do not need to relate to the units directly. These spaces can also be shared with the other units in the ward.

Schmitt & Strid (2017) also explain that the layout for the ward can either be with one corridor or a double corridor, each coming with its pros and cons.

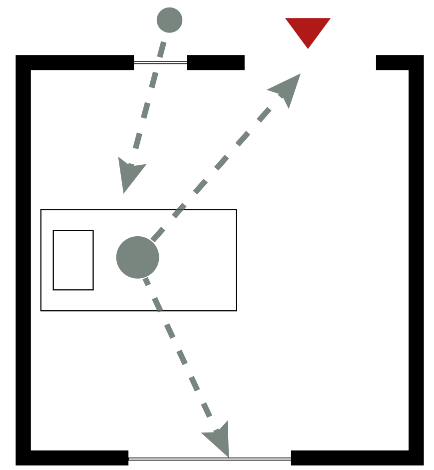
Singel Patient rooms

Patient rooms have gone from being group rooms to single-patient rooms with private bathrooms. Single patient rooms offer the patient more privacy and comfort. Private bathrooms have led to a decrease in falling accidents. The patient rooms should offer space for the patients, staff, and visitors to stay in the room altogether.

The room should have a layout that enables the patient to see the room entrance; this is supposed to give a feeling of safety because the patient can see who is entering. At the same time, the staff also need an overview of the room without getting far into the room or having to enter it. (Fröst & Hammarling,2017). (Fröst & Hammarling,2017).



Space for patient, staff and visitor.



Visual connection in room.

Hygiene classes

To decrease the spread of infections in the facilities, the staff have routines to follow, and the facilities have to follow certain hygiene classes. These hygiene classes are applied to all zones used by staff or patients, and the classes go from 0-3. Zero is for areas where no patients or staff are and three for sterile rooms, operation theatres, and similar spaces. Common areas like lifts, waiting rooms and day rooms are often hygiene class 1, and rooms like patient rooms, WC, disinfection rooms are hygiene class 2.

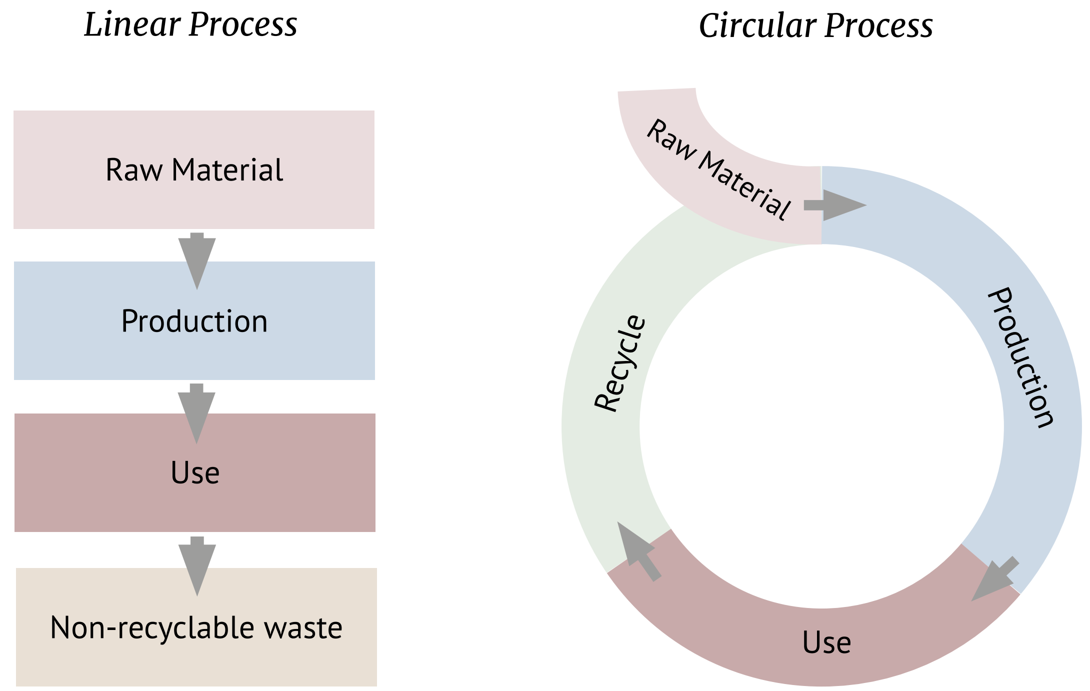
These classes affect, amongst other things, the material choices on flooring and walls. The flooring has to be durable and able to handle disinfectants and rough cleaning. It has to be joint free or with welded joints. The floor must also be visibly clean. The walls also have to be able to handle disinfectants and be free from cracks. (Dahlberg A.,2016)

Rooms Types

Some of the primary room types within inpatient wards and outpatient clinics are reviewed to understand each room's needs. The findings are listed in a table below, and the list is based on several floor plan studies from different hospitals and concepts Reports, both from Program För Teknisk Standard (PTS) and Locum.

Room Type	*Room Size*	*Hygiene class*	*Special Requirments*
patient room	min= 16 m^2	2	» one patient room
Treatment	18-30 m^2	2	–
Examination	18-30 m^2	2	–
ICU patient room	≈30 m^2	3	» High tech. capaCity » Air locks » connection to work station » High Hygien
Emergency	≈40 m^2	2	–
Operation Theather	≈60 m^2	3	» vibration sensitive » Air locks » sterile zones+ High Hygien » Radiation protection
staff areas	40 m^2	1	–
Hallways	–	1	
desinfection room	12 m^2	2	
Cleaning & Recycling Room	9 m^2	0	
Medecine Room	12 m^2/26 m^2	2	» Daylight sensitive medicine
Pentry	40 m^2	1	

Sustainability



Adapted illustration. Illustrating a simplified version of linear and circular processes

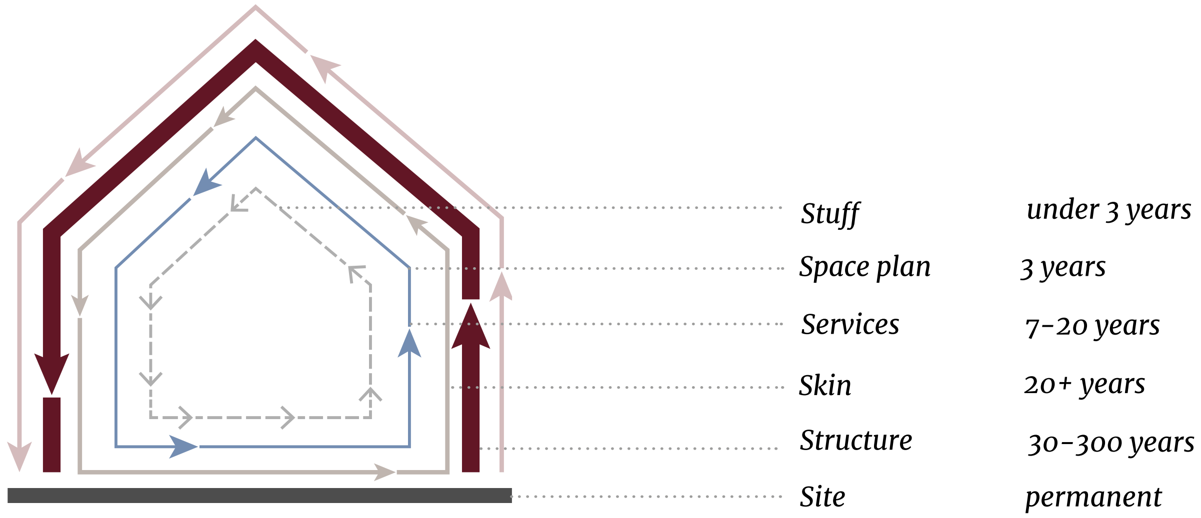
Circular Thinking

Carruth et al. (2019) states that Sweden's building and housing industry stands for about 21% of the national CO2 emissions. For the industry to face the challenges of climate change and decrease its emissions, it has to decrease its use of primary and non-renewable materials (Carruth et al.,2019). When going from a linear approach to a circular one, the hope is to reduce the environmental footprint of the built environment (Lemmens & Luebkeman, 2016). A Circular approach can also lead to lower prices and less delay in production.

As an architect, circularity can be applied in work by designing for re-use, using modular systems, and applying BIM. From the industry side, it is necessary to create systems and processes that enable circular processes.

Lemmens and Luebkeman (2016) explain that Modularity and adaptability are two critical components when striving for a circular built environment. Creating reusable and flexible pieces for the buildings can be used for other purposes and create new buildings later on. Lemmens and Luebkeman (2016) also state that prefabrication is an important aspect to enable circular processes. The off-site production leads to less waste on-site and lowers material use (Lemmens & Luebkeman, 2016). Carruth et al. (2019) explain that circular architecture is striving for dynamic buildings and buildings that can adapt to the needs of that time.

Sustainability



Adapted illustration. Shearing layers (Brand, 1997)

Design for Disassembly (Dfd)

An essential part when creating circular processes will be to re-use and recycle materials and components. Designing for Dissasembly is a strategy that ensures that the materials used in projects are able to be dissasembled and reused. DfD is also beneficial if parts of the building have to be repaired or upgraded. DfD enables that specific elements in a building can be removed and replaced without impacting the entire building.

According to Guy and Ciarimboli (2005)it is crucial to design for disassembly (DfD) in the early stages of the project for it to be. Some of the factors for enabling DfD are:

Design Factors that enableDfD:
- Modular design strategies
- Standardized grids
-Layering approaches

Human Factors that enable DfD:
- Communication
-Team training

Building Factors
- Avoiding toxic materials
- Using Mechanical Fasteners
- Using Durable and High-quality Materials.
(Akinade et al., 2017)

Shearing Layers

The concept of shearing layers first came from Frank Duffy and was later developed by Stewart Brand. It is based on the idea that buildings consist of 6 layers with different time frames. (Brand, 1997). Working with layers in buildings is crucial to enable DfD. Keeping the layers separated from each other will allow easy disassembly of specific layers without interfering with other layers. Each layer has its lifetime, which means that a layer can be upgraded when its lifetime is over while another keeps working.

Timber

Timber is a material that works well for circular design, modular building systems and is highly advocated for its environmental qualities.

It is a material with low CO_2 emission, renewable material, and has CO_2 storing properties. In Sweden, there is also no shortage of the material. (Gustafsson, et al., 2019)

Nationally (in Sweden), there has been an increase in the use of wood when producing apartment buildings. It has gone from being used 0% to 15% in newly built apartment projects during the last ten years. However, this increase in timber construction has not yet taken place in the public sector. In hospitals, the most common construction material is concrete, followed by steel (Gustafsson et al., 2019).

The most significant difference between wood buildings and concrete ones is the dimensions used and the height difference. Wood beams need to be thicker to fulfill the same criteria as concrete beams (Gustafsson et al., 2019).

Sound and Vibration

One of the more immense challenges with wooden structures is sound and vibrations. Healthcare facilities also have specific standards for sound and vibration that have to be reached (Gustafsson, et. al, 2019). In hospitals, there is vibration-sensitive equipment. Gustafsson(2019) states that adding secondary flooring (övergolv) and suspended ceiling helps to reduce sound and vibration transmission, but also double walls and covering gypsum boards help to face these issues.

Fire Safety

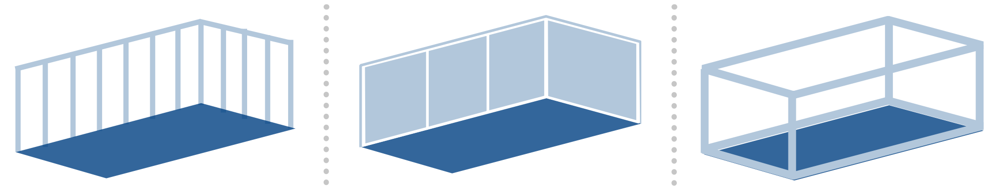
Fire safety is another concern in wooden buildings. Fire issues can be faced through several strategies; if the wood is visible, a fire retardant layer can be added, otherwise covering the wood with gypsum boards also increases fire safety. A double wall system or adding sprinkler systems are other alternatives to tackle the challenge.

Timber Structures

The illustration on the next page show three commonly used techniques when building in wood: stud frame structure, Cross Laminated Timber (CLT) structure, and Glulam. Post-beam structure.

According to Gustafsson et. al. (2019), CLT and Post-beam structures are applicable when building hospitals. A post beam structure offers high flexibility to the building. CLT offers stability to the building. Interview 1 (2020) states that light frame structures like Stud frame are easy to build with but do not offer the same flexibility or disassembly possibility as more massive structures like CLT.

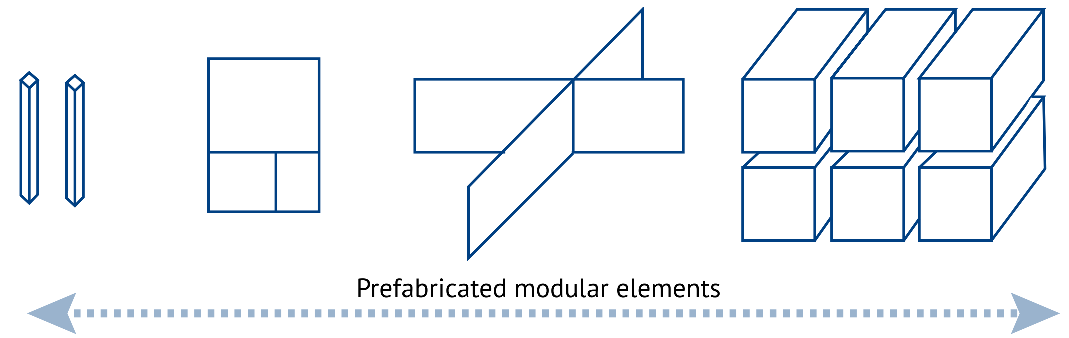
Timber Structures



Structure	*Stud frame*	*CLT*	*Post-beam*
Flexibility	Low	Medium	High
Number of materials	5	3	5
Prefab. level	Module	Module	Elements
Disassembly	Difficult	Easy	Easy
Initial Cost	Low	High	Medium

*Numbers from Bergås, Lundgren (2020), interview material, and a conclusion from the literature review. The diagram is to give an overall idea of the structure types, and the comparison is relative.

Prefabrication



Adapted illustration by Smith & Timberlake (2010)

"Modular mass timber is one of key construction methods in making timber as structural material more affordable and competitive, and enabling wider application of it within building sector in general."

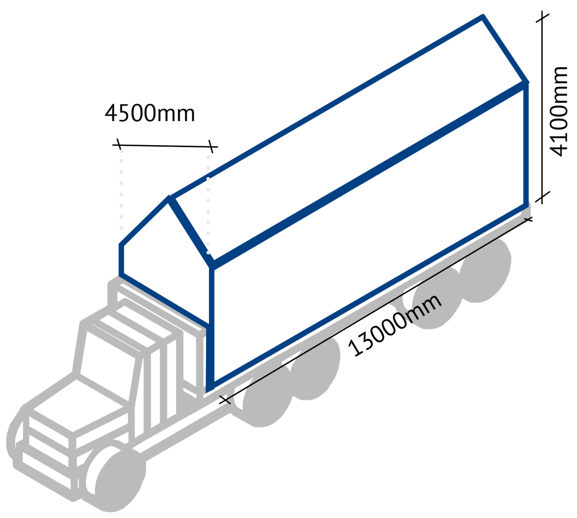
-Toni Yli Suvanto, Architect

The concept of modular building construction and prefabrication is about construction processes where the buildings or building elements are manufactured in a factory instead of in situ construction as traditional methods. The modules are shipped to the site where they are erected. Prefabricating modules in a factory lead to an increase in the project's quality, productivity, and workers' safety increases. (Gonzalez, 2020)

Smith & Timberlake (2010) point out that a module either can be a wall panel or building element constructed off-site and shipped to be put together on-site or an entire modular building made off-site (as seen in the illustration above). Depending on the type of element that is manufactured, the level of prefabrication increases/decreases. The level of prefabrication can be anything between 60% (for a wall panel) to 95% (for a finished room module) (Smith & Timberlake, 2010).

Smith & Timberlake (2010) also state that a prefabricated project can have a higher initial investment cost, but it is lower and offers higher values in the long run when looking at the life cycle costs.

Transportation size



Modules in Healthcare

ADVANTAGES WITH PREFAB IN THE HEALTHCARE SECTOR:

1. *Less disturbance for the hospital and its staff. Moving the work outside of the hospital decreases the site impact.*
2. *Safety of the construction workers will increase; there will be optimal conditions for the workers in the manufacturing fabrics.*
3. *Leftover material from the project will be re-used in other projects directly.*
4. *Reduces labor and time of the project, increases productivity. It allows several parts to be done simultaneously instead of in sequence.*
5. *Manufacturing in a fabric increases the quality of the work.*

Joan et al. (2018) state that prefab is not used in healthcare as much as it could be. Some reasons are because it could be an unknown topic and a lack of experience in the topic. Smith & Timberlake (2010) explain that the concept has not spread in general because there is a lack of knowledge from the clients and construction side. Information about the benefits and the increased values is lacking.

Prefab and Module healthcare facilities are today commonly used when building temporary hospitals in disaster or rescue zones. In situations where there are no permanent hospitals or hospitals are overcrowded, temporary and mobile healthcare facilities are brought to cover the need. Often modular ones that are efficiently erected and ready for use. (Verderber,2017)

During the COVID-19 pandemic, these portable and modular healthcare facilities have been set up to ease the pressure off the overcrowded primary hospitals. According to Wee et al. (2020), using prefabrication and module systems, it has been possible to set up healthcare facilities in a rapid phase during the pandemic to help ordinary health care.

Portable healthcare units

-CASE STUDIES

Portable healthcare facilities come in several different shapes and sizes. They come as permanent and temporary facilities. Permanent often aims toward healthcare facilities that are mobile and self-powered. Ie. Hospital ships, hospital airplanes, or trucks. These are great for places where one can not assemble a hospital or do not have access to electricity.

On the other hand, temporary ones are hospitals that are transported to the site and then erected. These case studies are focusing on the latter type. (Bitterman & Zimmer, 2017).

Temporary healthcare units come in two main sorts, soft and hard:

Soft units

Soft units are often used by NGOs like UNICEF and Red cross but also by countries. They come with a soft shell and a rigid structure or a soft inflatable structure (Bitterman & Zimmer, 2017). Similar to larger tents.

Hard Units

These can be organized in several different configurations to offer the spatial needs that are required. They often come as flat packs with prefabricated elements to construct on-site or as ready-to-use containers or modules (Bitterman & Zimmer, 2017).

SWEDISH MODULES

Site:
- Söder sjukhuset, Stockholm

Facility type:
- Hospital modules: inpatient ward, operation theatre

Characteristics:
- Hard units
- ready-to-use modules
- Steel construction

Module size

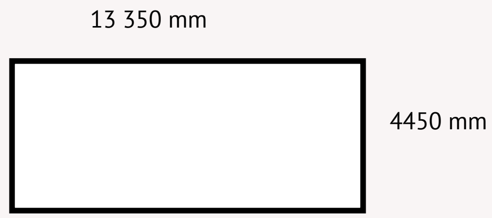


Image 1. Inside of operation theatre

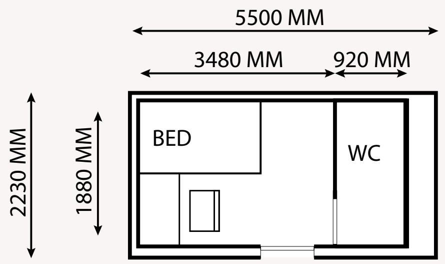
Image 2. ward facade

COVID-19 WARD IN SINGAPORE WARD@BOWYER

Facility:
- Isolation ward for COVID-19 patients

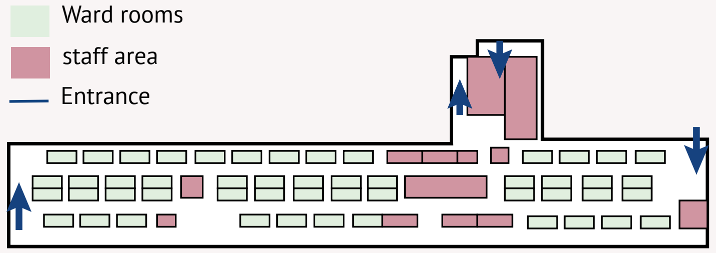
construction period:
- 50 days

site:
- Singapore General Hospital,
- Parking lot



Ward room: adapted illustration Wee et al. (2020)

Characteristic:
-Both hard and soft units.



overall plan drawing of the ward: adapted illustration Wee et. al. (2020)

A scalable modular design has been used in Singapore to meet the demand for healthcare during the COVID-19 pandemic. Prefabricated containers were brought to the site and used as single-patient rooms. Together they formed an isolation ward. If modifications had to be done to the containers, it was done off-site and then brought to the site. Because it used prefabricated modules, the construction was done rapidly, it took 50 days, and 100 workers were involved. The modules were placed on a reinforced base, and a similar tent fabric was used as a roof to cover the modules. This created a sheltered space between the single-patient rooms, similar to hallways (Wee et. al. (2020).


Image 3. inside of ward@bowyer


Image 4. inside of ward room

Interview

The interviewee is a researcher in Timber Structures with a background in engineering and knowledge in adaptable buildings and adaptable design using timber. In the interview, topics like adaptability, modules, and material choices were discussed.

Adaptability

The interviewee explained that when using conventional building structures that are not adaptable, it can be hard to repair specific parts of a structure when damaged or replace it when it needs to be upgraded. With a flexible structure, on the other hand, it will be possible to remove elements and exchange them easier.

The interview mentioned that the connections between different elements become important in adaptable structures; they need to enable disconnection and disassembly. There is also a need for more standardized elements in the buildings; if all buildings are individualized, it will be hard to implement an adaptable system. Adaptability should also be considered early in the planning phase, considering floor area and ceiling heights to create more standardized options. If the purpose of the building changes, the building or elements from it can still be used this way.

When asked if adaptability affects the quality or comfort of the building, the interviewee explains that the aim should be to have no negative impact on the construction or comfort. It is also explained that the quality does not necessarily decrease; choosing adaptable systems can also increase it.

Material

The type of timber structure used is dependent on the type of project. For adaptable projects, there is a need for more solid ways to construct. Column and beam structures offer a flexible solution and another solution is CLT panels. Massive elements are more beneficial compared to light-frame structures. Light frame structures can be efficient to build with but is not as flexible and is hard to disassemble and re-use. re-use.

Modules

Using modules and temporary constructions the interviewee states that it has the potential to offer the possibility to move around the modules and relocate them where they are needed, it also helps organizations to expand their facilities depending on the demand at the time. Some examples where this is used today in Europe are for school classrooms, hospitals, and elderly care. Depending on the demand of that year, or the size of the class modules are removed or added. Working with modular systems can also help decrease vibrations because of the double walls created by two modules next to each other.

Conclusion

From the literature study, it can be concluded that prefab increases production efficiency, and working with a standardized modular system enables disassembly and circular processes. Even if the initial cost can be high, it often pays off in the long run.

The case studies show that room modules for the healthcare can be made in different sizes and materials. Either elements of the facility are modular, or the facility is made out of room modules.

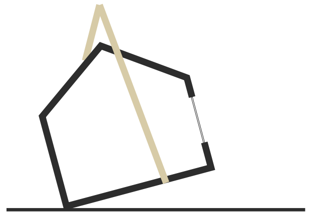
In both the literature study and the interview, timber stands out for its properties. It is a material that is easy to work with within prefab manufacturing and a lightweight material that makes transportation easy. Using a massive timber structure offers the project flexibility and makes it easier to disassemble. From a sustainable perspective, timber is a CO_2 storing material and a renewable and local material. When working in timber, it is crucial to be aware of the material's fire, sound, and vibration challenges.

Lastly from the literature study it was understood that applying future-proofing strategies and working with evidence-based design to create calming and stress-free environments will improve the spatial qualities.

3.Concept

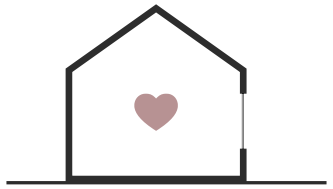
The main idea behind the concept of the proposal derives from what was found in the previous chapter. The concept chapter explains the basis for the proposed solution and its usage areas.

Design Strategies



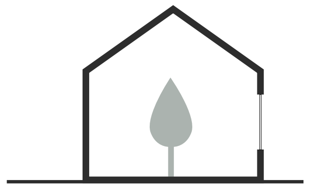
Movable modules

To create a fast way of assembling the buildings and bringing down production prices, prefabricated modules are used.



Feels like home

By working with health-promoting materials, social spaces, the aim is to create an atmosphere that is calm and nurturing.

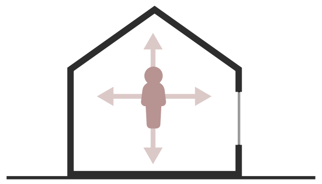


Wood as main material

Wood will be used for the structure because of its sustainable properties

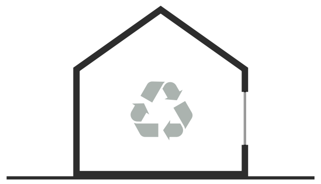
Site and Surrounding

The building follows the existing flows on the site and aims to intervene as little as possible with existing flows.



Person Centered Care

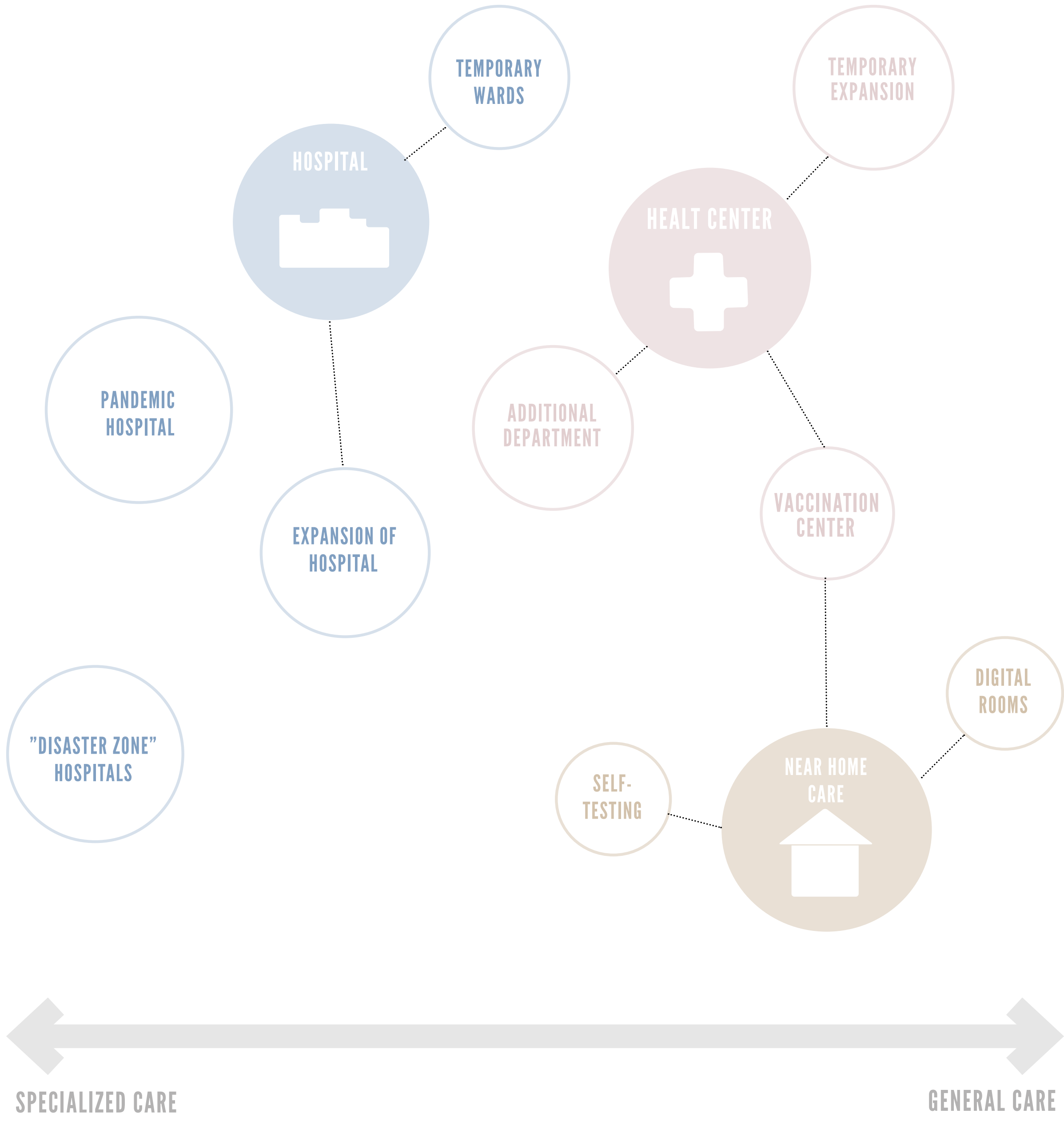
It creates a space that offers good conditions to both the care givers and the patients. Good daylight and easy orientation are two aspects taken under consideration for this.



Closing the loop

Having a building technique that promotes re-use and easy disassembly for upcycling/recycle. This leads to a limitation of pure waste.

Usage Areas



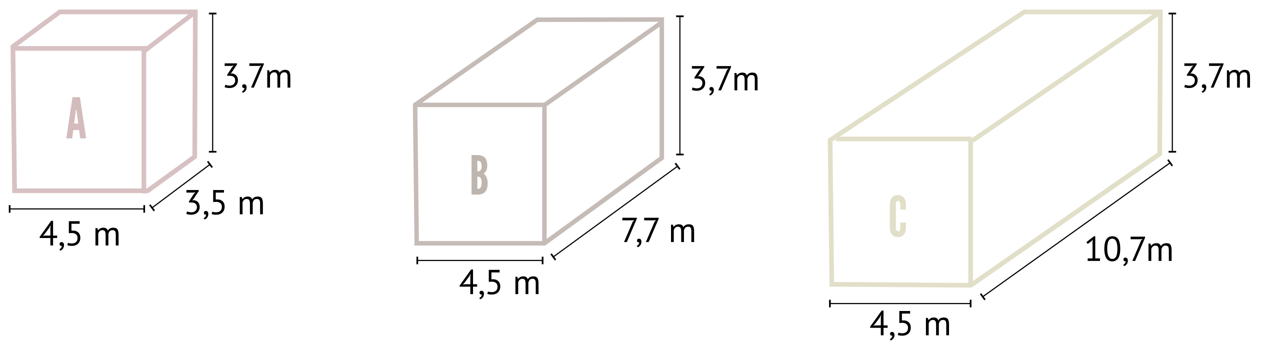
The diagram above shows how the modules are related to the existing healthcare structure. As seen in the diagram, the modules can be used for general care and specialized care.

The concept is applicable in several different healthcare areas, and by creating adaptable modules, the usage area of the modules can expand in the future.

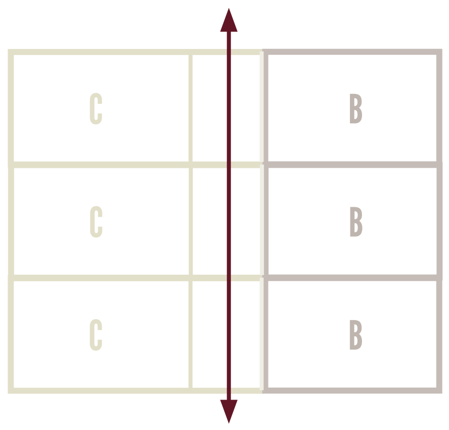
4. The Module

In this chapter the modules and the building system are explored further. It contains the circular approach, assembly and disassembly strategy and typical room layouts.

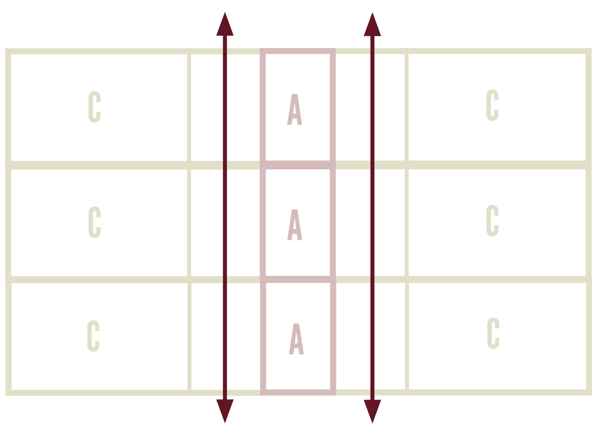
Set-up



One Corridor



Double Corridor



Set-up

To be able to create both single corridor and double corridor buildings the building system consists of three module types in different sizes, A,B and C. The sizes of the modules are decided upon based on transportation limits and room sizes. When investigating the sizes, it was important that the modules where in a universal size.

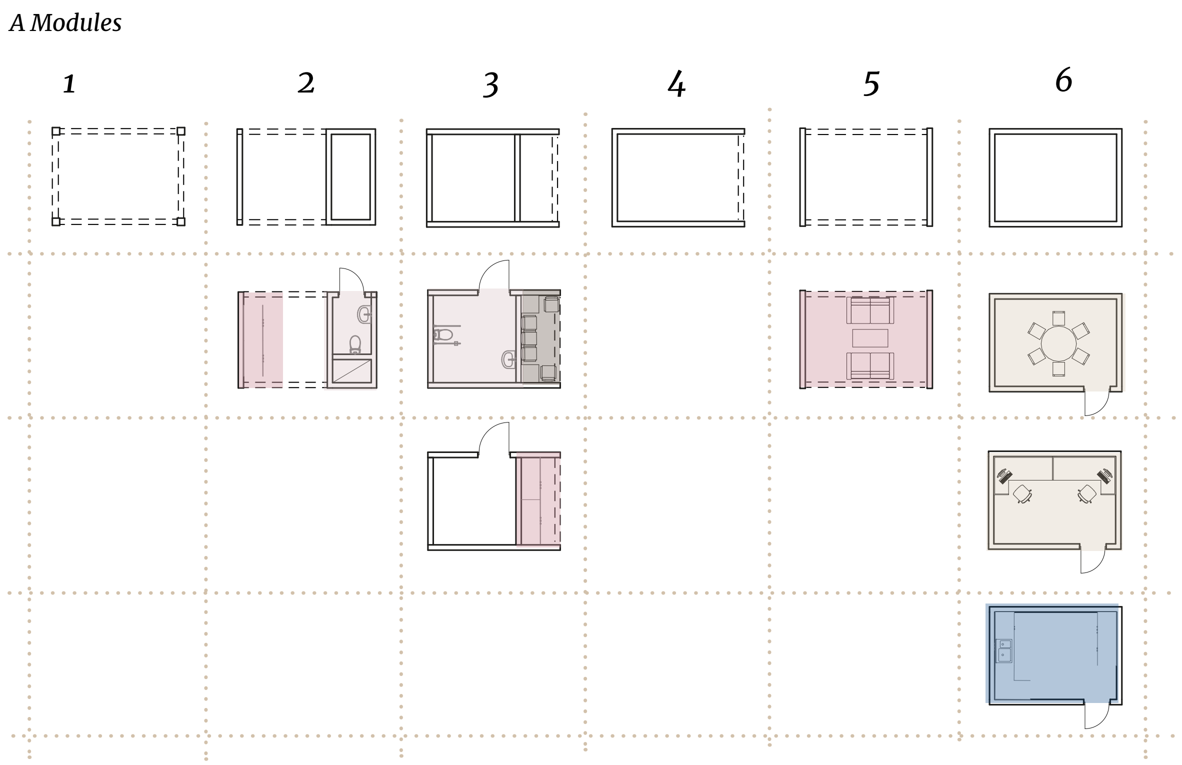
Module B is based on a size that fit examination/ clinic rooms and patient rooms firstly but also waiting room, reception and workstation. Module B is set to a size that fits, group rooms, storages, and other supportive functions. Lastly, Module C is an extension of module B.

This extension has been done to form corridors. If a function need more space two modules can be put together to or more modules can be put together to form a larger space and if smaller spaces are needed partition walls are set up.

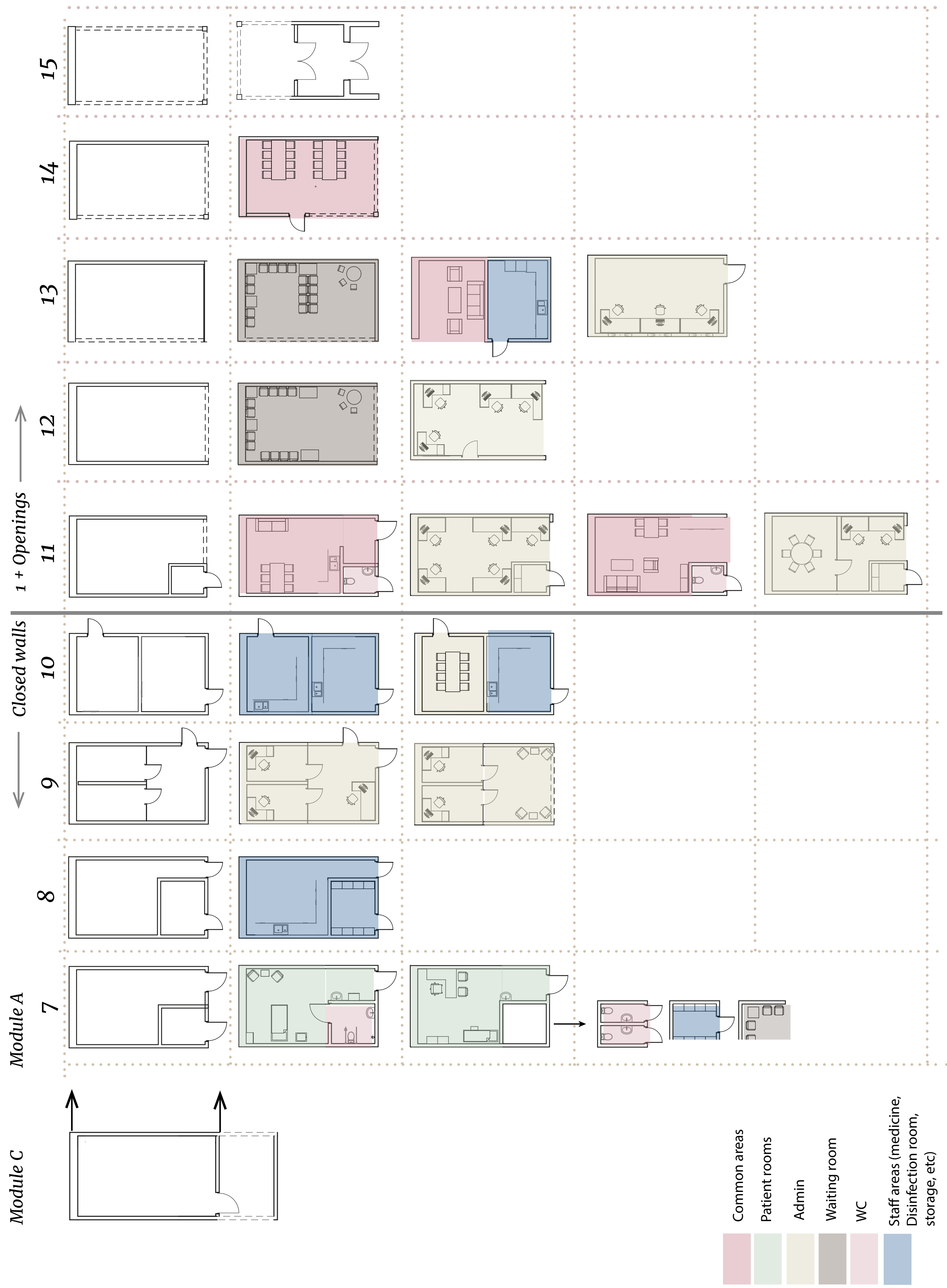
Stairs and lifts have their own structure and module, with standardized measurements and safety requirements.

Module Layouts

The diagrams on the upcoming pages show different iterations of the modules. Module C has the same possibilities as module B, only with an extended piece that is used as the hallway. Therefore the diagrams show module A and B only but with an understanding that module B represents room types that can be created with module C as well.



Common areas
Patient rooms
Admin
Waiting room
WC
Staff areas (medicine, Disinfection room, storage, etc)



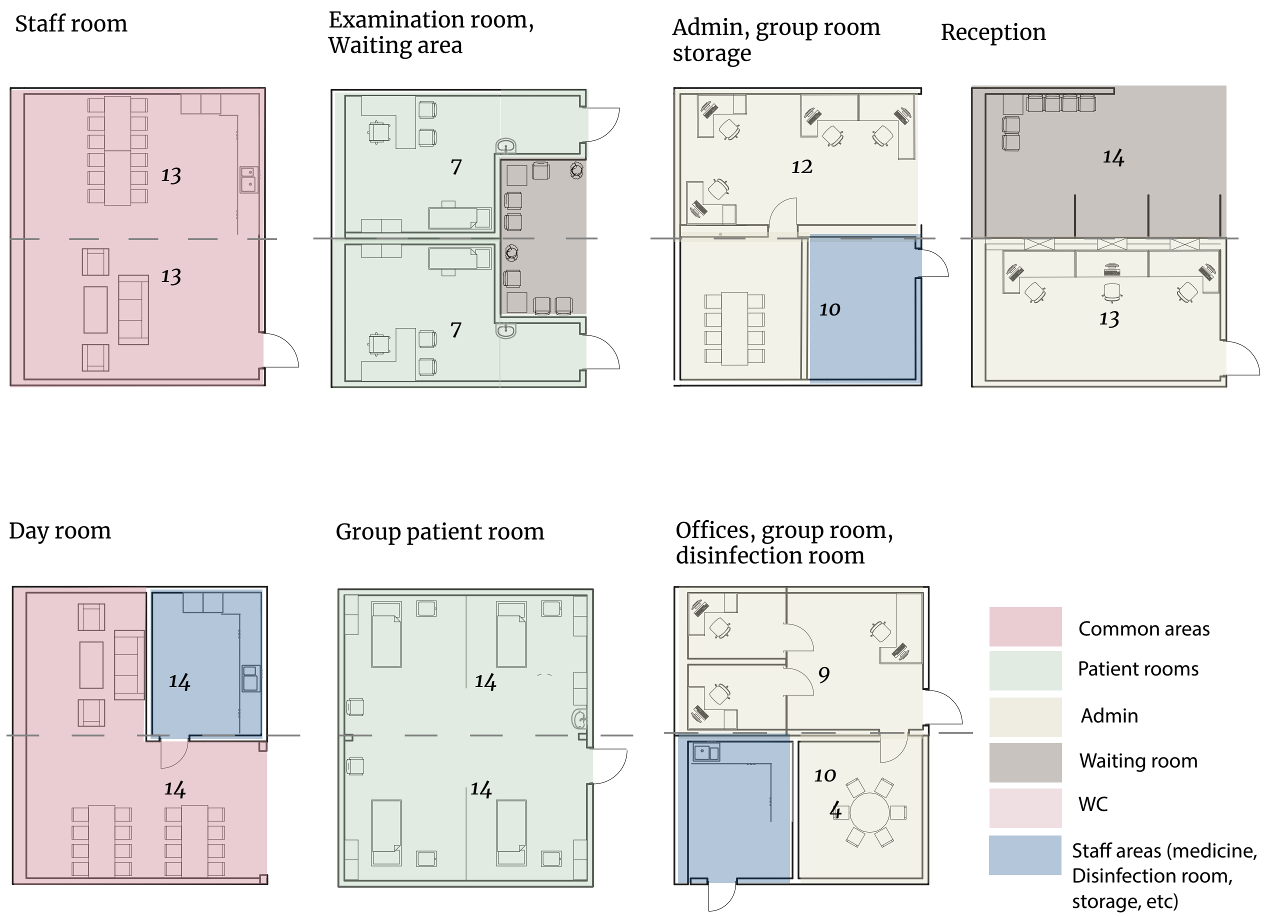


Diagram. Different ways of combining modules of kind B or C

Modules with open sides can be combined to form larger spaces. Some examples of rooms can be found in the diagram above.

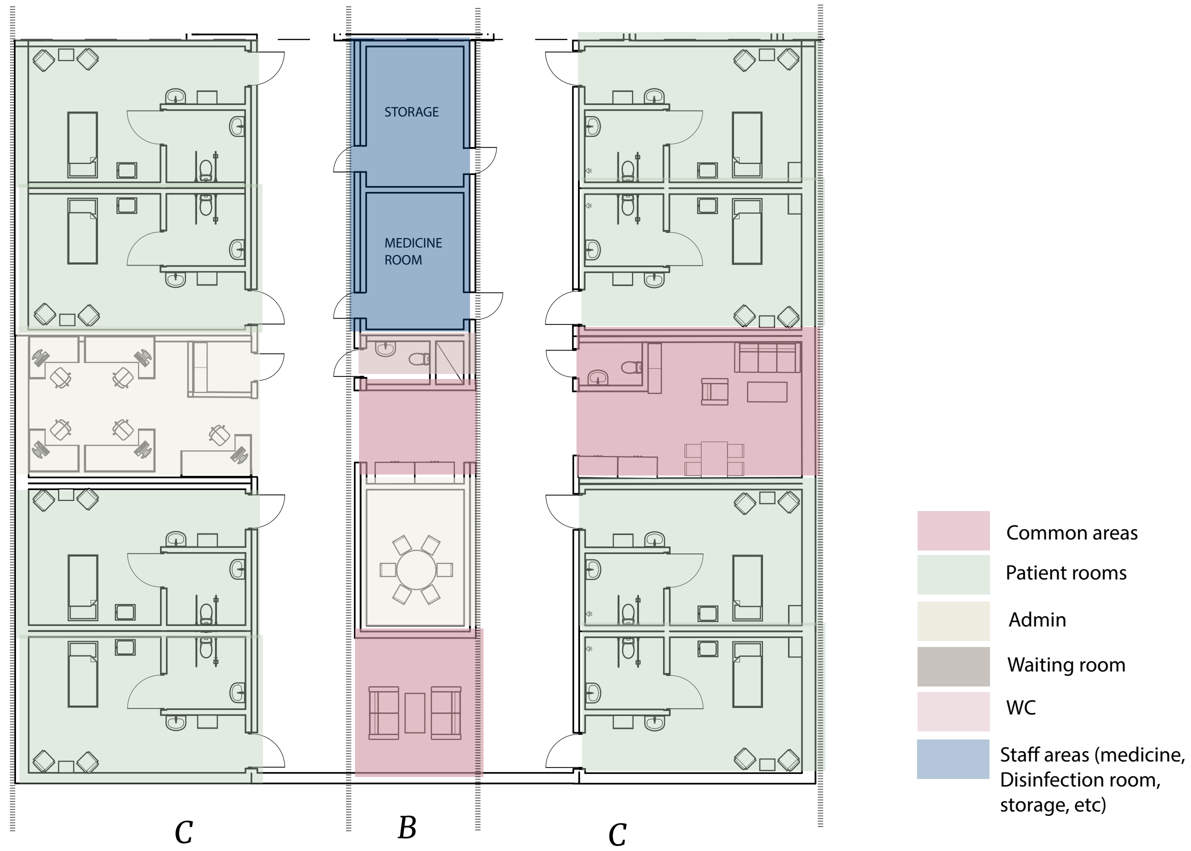
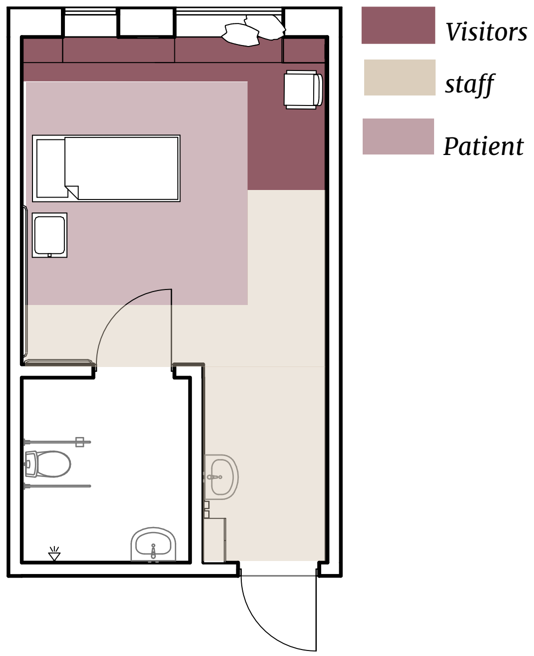


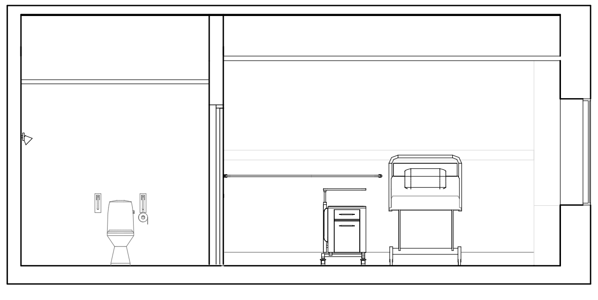
Diagram. An example of a double corridor ward floor plan.

The diagram above shows what a combination of module C and b can look like. It is illustrating a double corridor ward.

Ward room



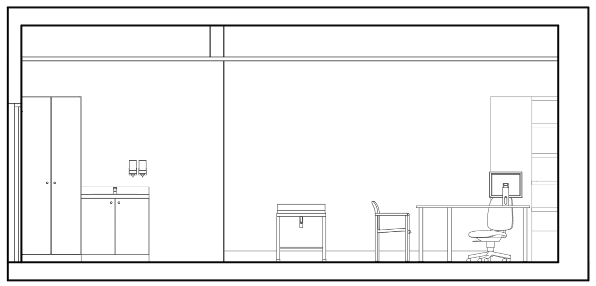
Plan 1:100



Section 1:100

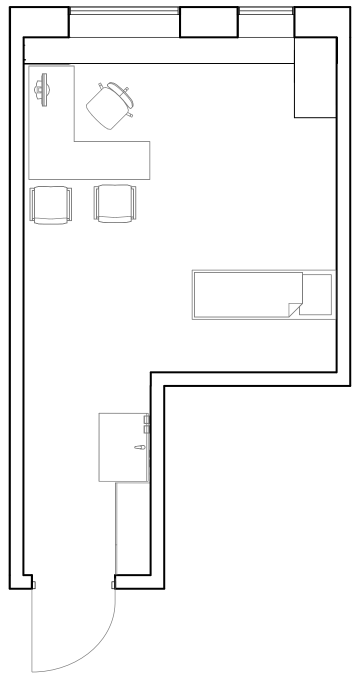
The inpatient room is formed to have space for patient, staff and visitors. The smaller window next to the patient bed offers privacy to the patient, while the larger window further away from the patient lets in daylight. There is also space for patients private belongings.

Clinic room



Section 1:100

The clinic room is used for both examination, conversation, and expedition.



Plan 1:100

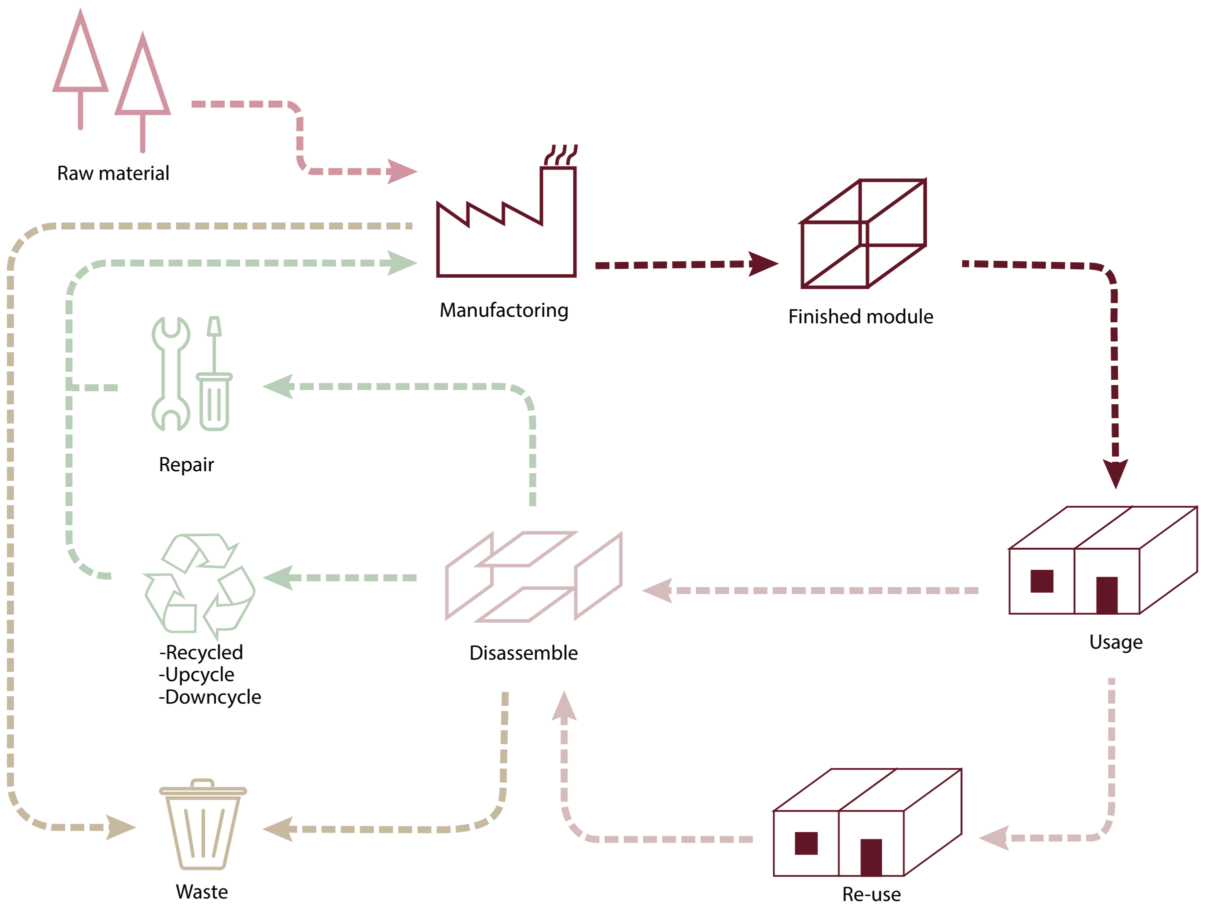
Sustainability

The aim has been to create a proposal that makes it easy for actors to choose a circular process.

Prefabricated modules in CLT offer standardized module elements that facilitate the circular approach and DfD. However, since healthcare facilities have specific hygiene classes that have to be followed, it limits the material choices and joint possibilities. Visible connections on the walls and the flooring or materials like plywood panels and wooden flooring that have good properties for circularity and are easy to disassemble can only be used to a limited degree. These aspects make the DfD process different and more complex compared to other traditional DfD projects. Nevertheless, disassembly methods and re-use of the materials are applied to the degree that is possible.

The modules are produced using raw wood for the structure. This way, the building elements produced can be optimized for disassembly, creating a longer-lasting circular process.

The Circular Approach



Re-use

After a module has served its purpose in one project, it can be de-attached from its surroundings and with little or no interference, a module can be moved from one project to another where it is used again.

Disassemble

The module can be disassembled for several different reasons. When the module has served its purpose and has to change function/layout to keep operating, it can be disassembled. A module can also be disassembled when a building element within it or a layer of the module has reached its end of a lifetime. The element is then disassembled and either recycled or downcycled. Being able to detach and upgrade pieces of the module expands the lifetime of the overall module.

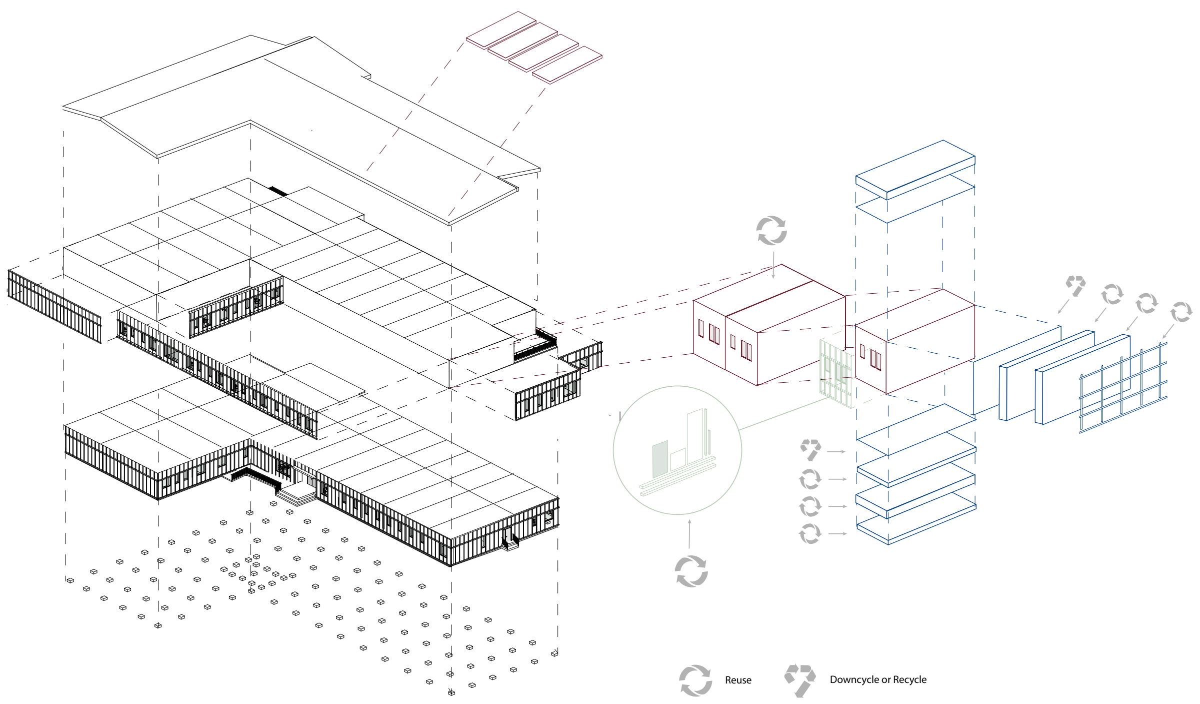
Recycle // Downcycle

When elements do not serve as their first purpose or can not be disassembled without being broken, they are recycled or downcycled.

Design for disassembly

A modular system is beneficial for applying DfD, each module can be disassembled from the others and re-assembled to new ones on another site.

However, as previously mentioned, there are limiting factors when designing for disassembly and re-use of a healthcare facility. The limiting factors play a role when the module itself is disassembled to its elements. The difficulties lie in the layer that Brand (1997) refers to as “Space and Plan” in the Shearing Layers diagram. More specifically, the inner layer of the walls and the slabs, the cladding, and the flooring. Due to the hygiene class requirements, the walls should be covered in gypsum boards without any visible edges, meaning that any visible joints of the gypsum boards, like screws, have to be covered up. There is a similar situation for the flooring. Due to the hygiene classes, the material for the flooring will be linoleum, and the edges are welded, making disassembly for re-use impossible. In the diagram, it is shown what will be recycled or downcycled and what can be reused after disassembly.



The Illustration shows the disassembly plan of a building.

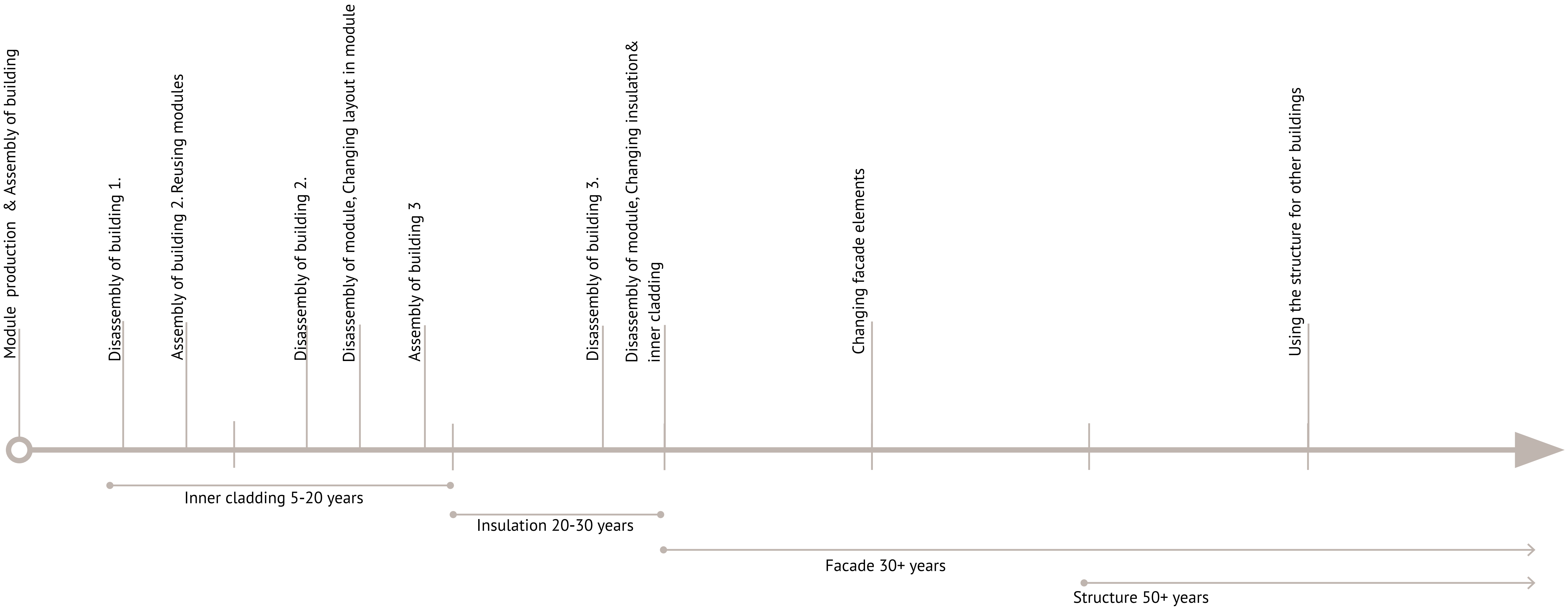
Material bank

Creating an Inventory list is a key aspect when creating a circular system. Therefore, a material bank has been created to list the different elements used in a standard module. This inventory list makes it possible to re-use and repair modules and single elements in the modules. If the modules are not used in the future, or there are some leftover elements from the modules, the material bank simplifies the use of the elements in other projects.

Elements	Properties	Material	Circular approach*
External wall	» Wind/ water protection » Insulating » Load bearing » Fire resistance	» CLT 5-layers » Cellulose insulation panels » Gypsum boards » Wooden facade	» Disassemblable
Facade	» Weather protection	» Prefabricated wooden panels	» Re-use
Windows	» Daylight and view	» 3 plane windows	» Re-use
Inner wall	» Load bearing » Sound regulating	» CLT 3-layers » Cellulose insulations panels » Gypsum board	» Re-usable » Disassemblable
CLT Panels (slab & wall)	» Load bearing » CO2 storing	» CLT	» Re-use
Interior wall cladding	» Fire safety » Hygien » Sound/ vibration Absorption	» gypsum board » paint	» Downcycle
Slab	» Fire protection » Sound/ vibration Absorption » Load bearing	» CLT 5-layer board	» Re-use
Flooring	» aesthetics » hygien	» Linolium flooring	» Downcycle
Flooring	» aesthetics » stirdy	» Terrazzo tiles » Lime mortar	» Re-use
suspended ceiling	» Sound/ vibration Absorption	» gypsum	» Re-use
Insulation	» insulating	» Cellulose » wood fibre	» Re-use » Recycle

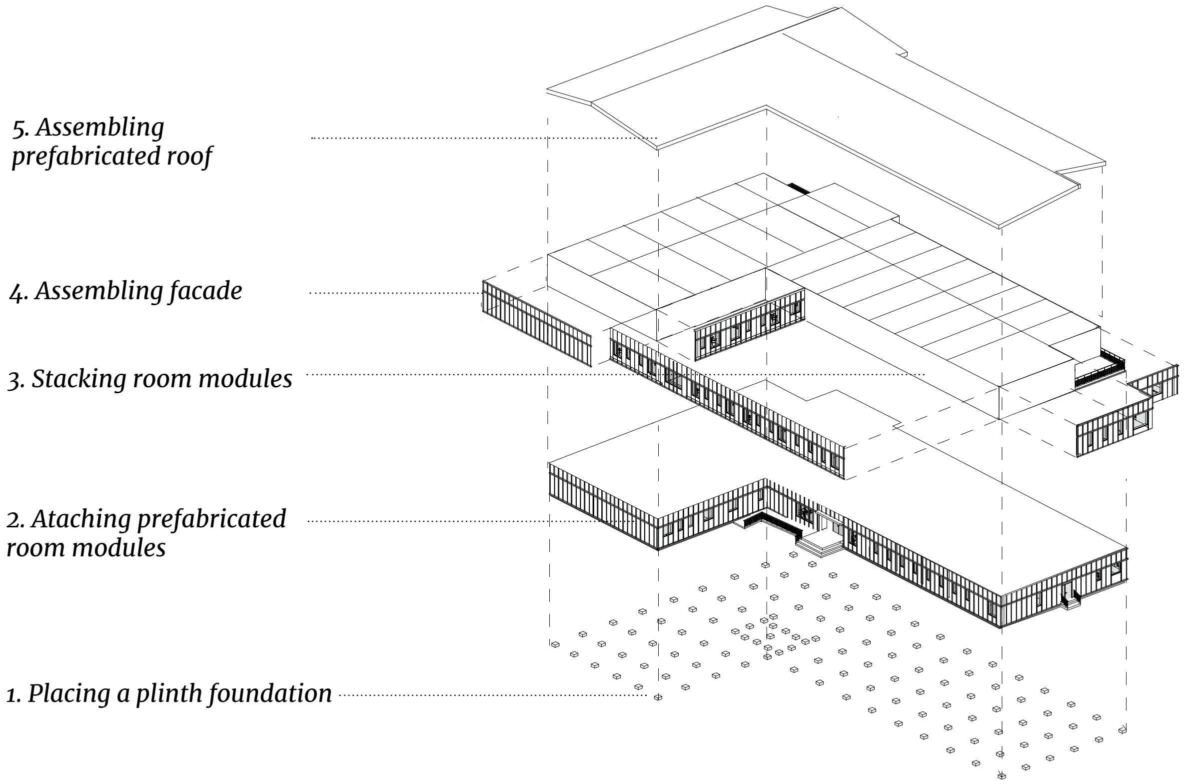
**recycle, downcycle, disposal, reuse*

Life cycle



The illustration shows what a possible lifecycle of the modules and materials can look like.

Assembly

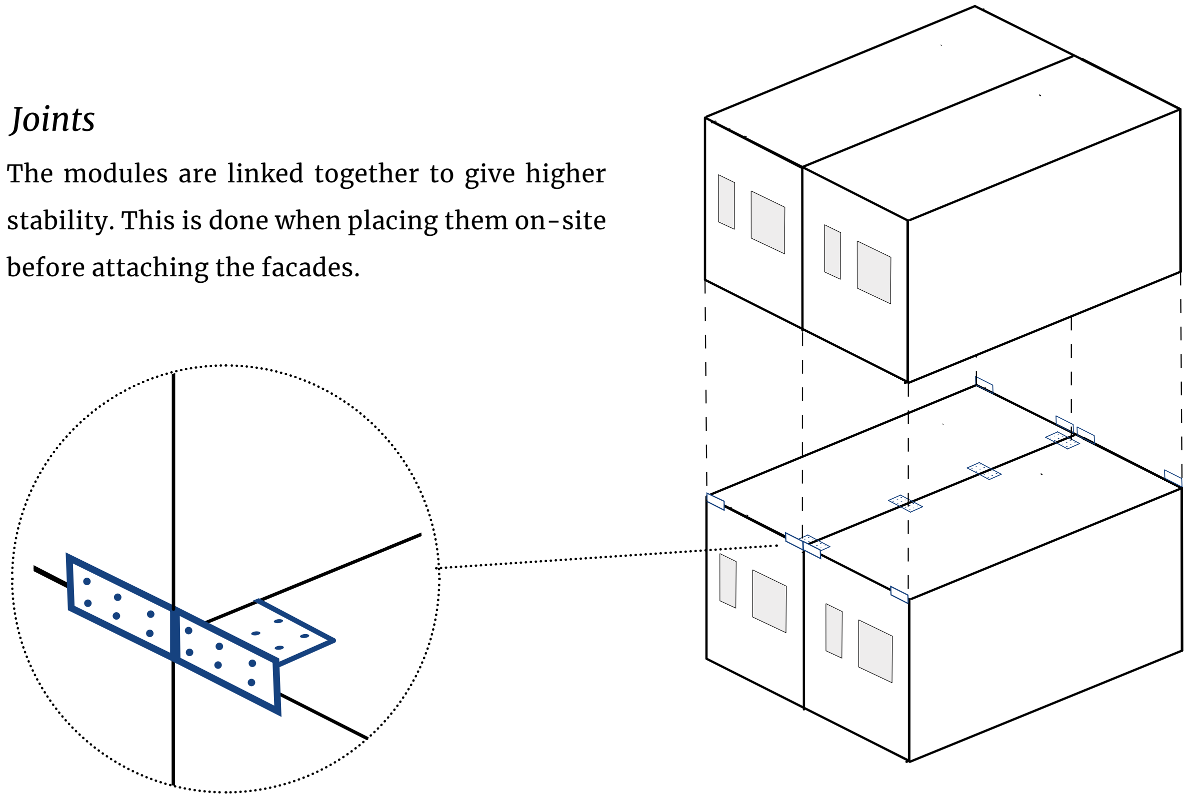


When module types and functions are decided upon, the modules are brought to the site and assembled. First, the entry-level is assembled to a plinth foundation, and then a second level can be assembled. Facades are attached on-site to the modules to hide the gaps between the modules and give a finished look. Lastly, the roof is assembled.

Assembly

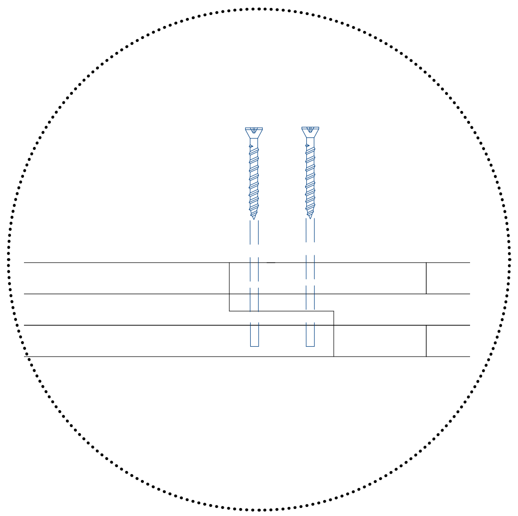
Joints

The modules are linked together to give higher stability. This is done when placing them on-site before attaching the facades.

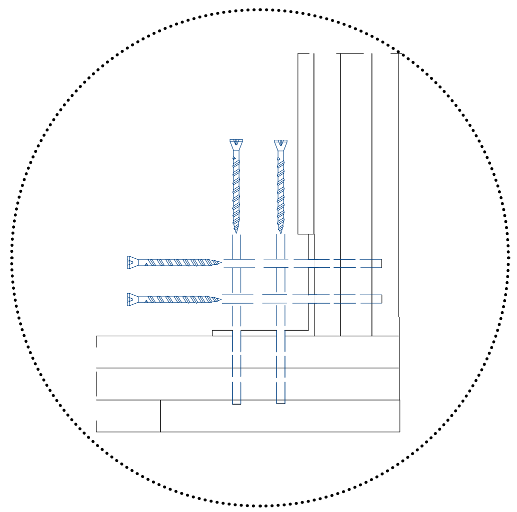


Mechanical Connectors

The module elements are as far as possible connected with mechanical connectors, screws and bolts. This is to enable disassembly at a later stage.

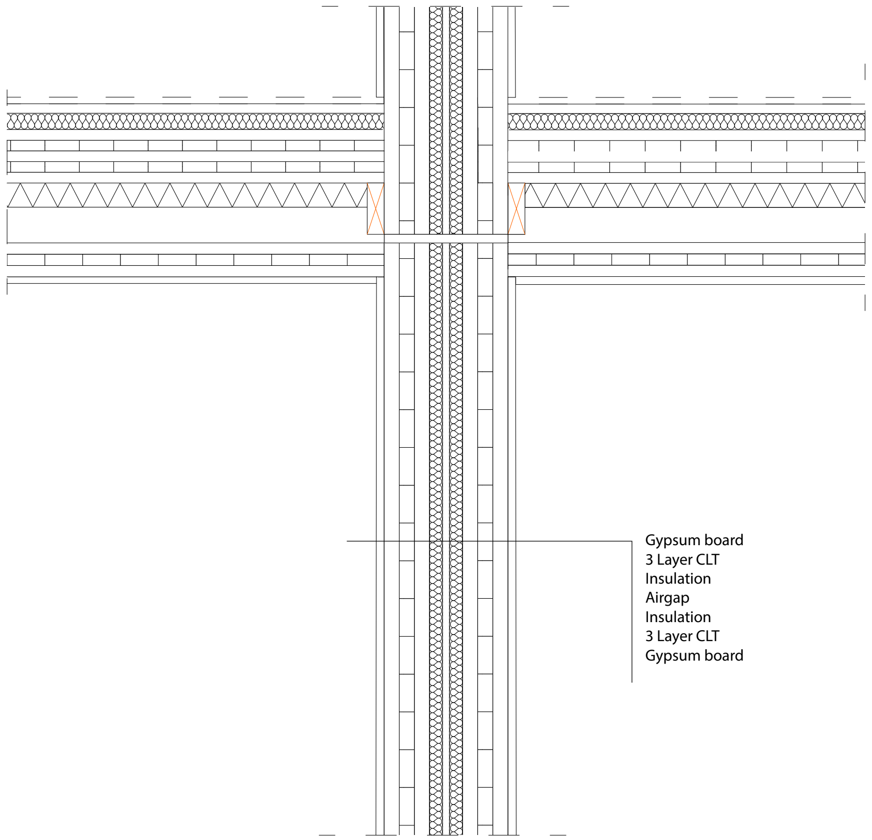


CLT panel connection



CLT panel Wall-Slab connection

Details

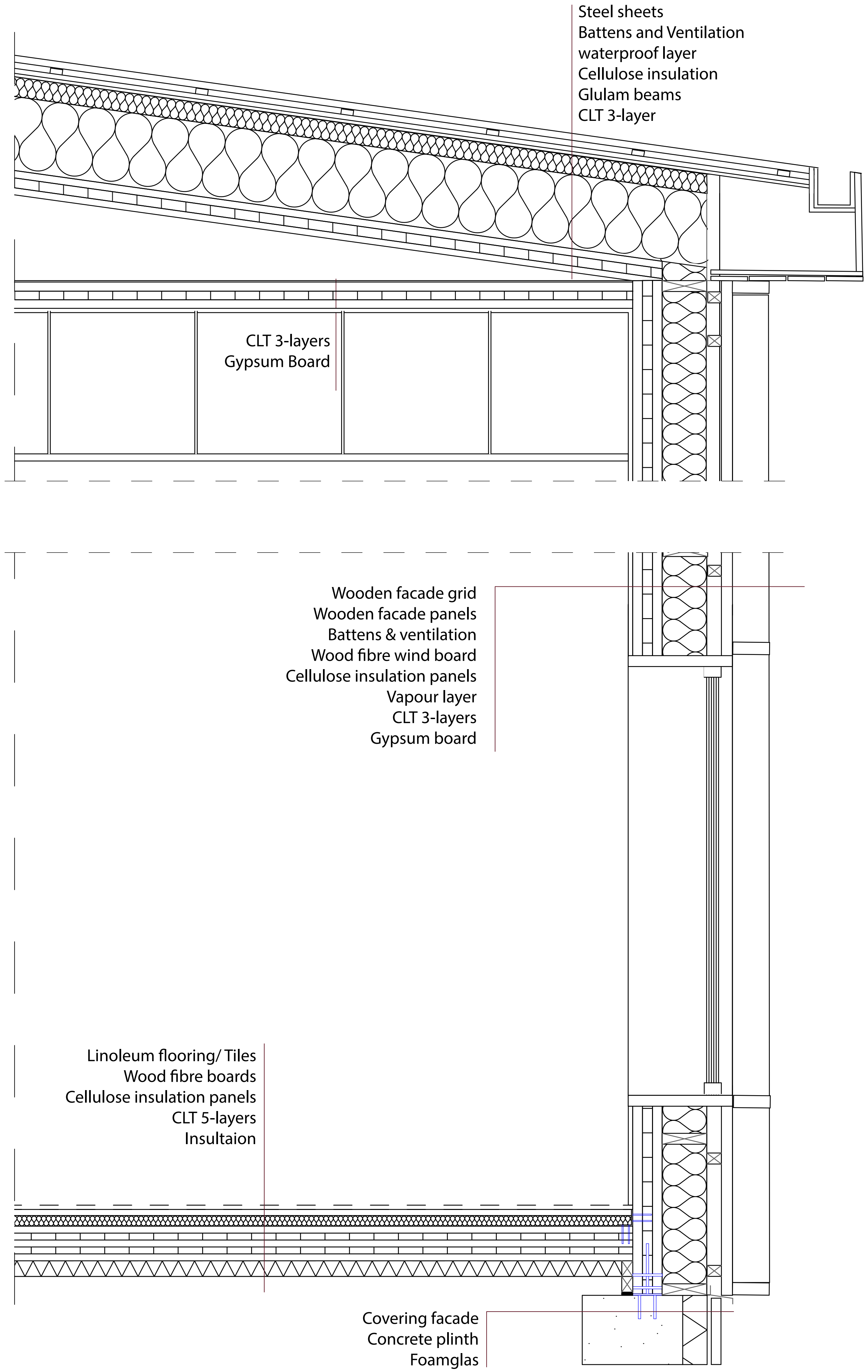


Detail section, interior walls. 1:50

Challenges

In wooden buildings, fire and sound issues have to be addressed. For fire security, the timber structure is protected with gypsum boards that are fire regulating. Gypsum boards also help with acoustics.

For acoustics, a suspended ceiling will also be added to improve it. When the modules are connected to each other double walls are formed, these also decrease sound and vibration transmission.

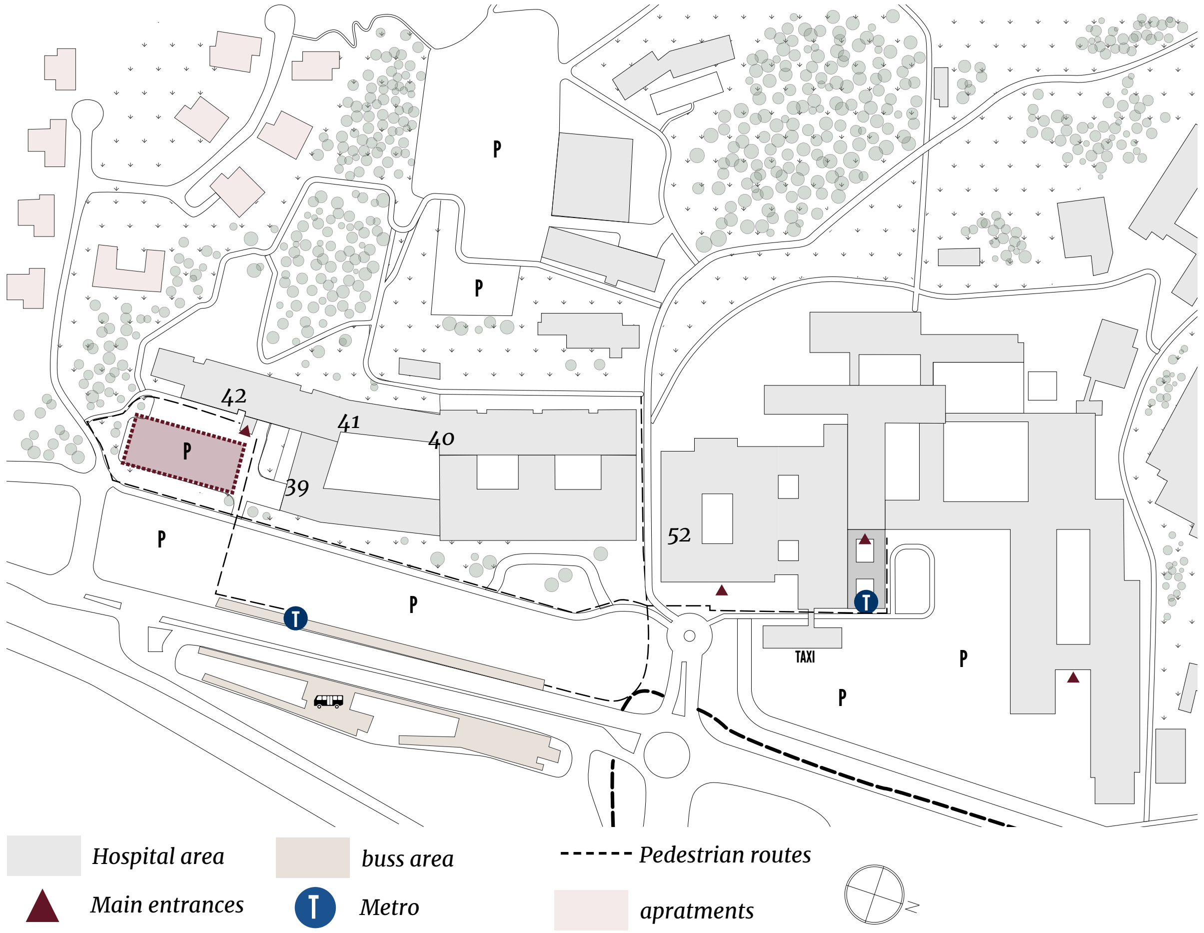


Structural section 1:50

5.Design Proposal

To test the concept, a design proposal has been made. The proposal is a hypothetical one, only with the purpose to try the principles from the previous chapter.

Danderyd Sjukhus



Site

Danderyd Sjukhus is one of the main hospitals in Region Stockholm. The site is chosen to show an example of how to create a temporary ward and clinic unit for a hospital.

Today, construction is going on at the hospital; building 52 is, i.e. newly built, and another building is being built right next to it.

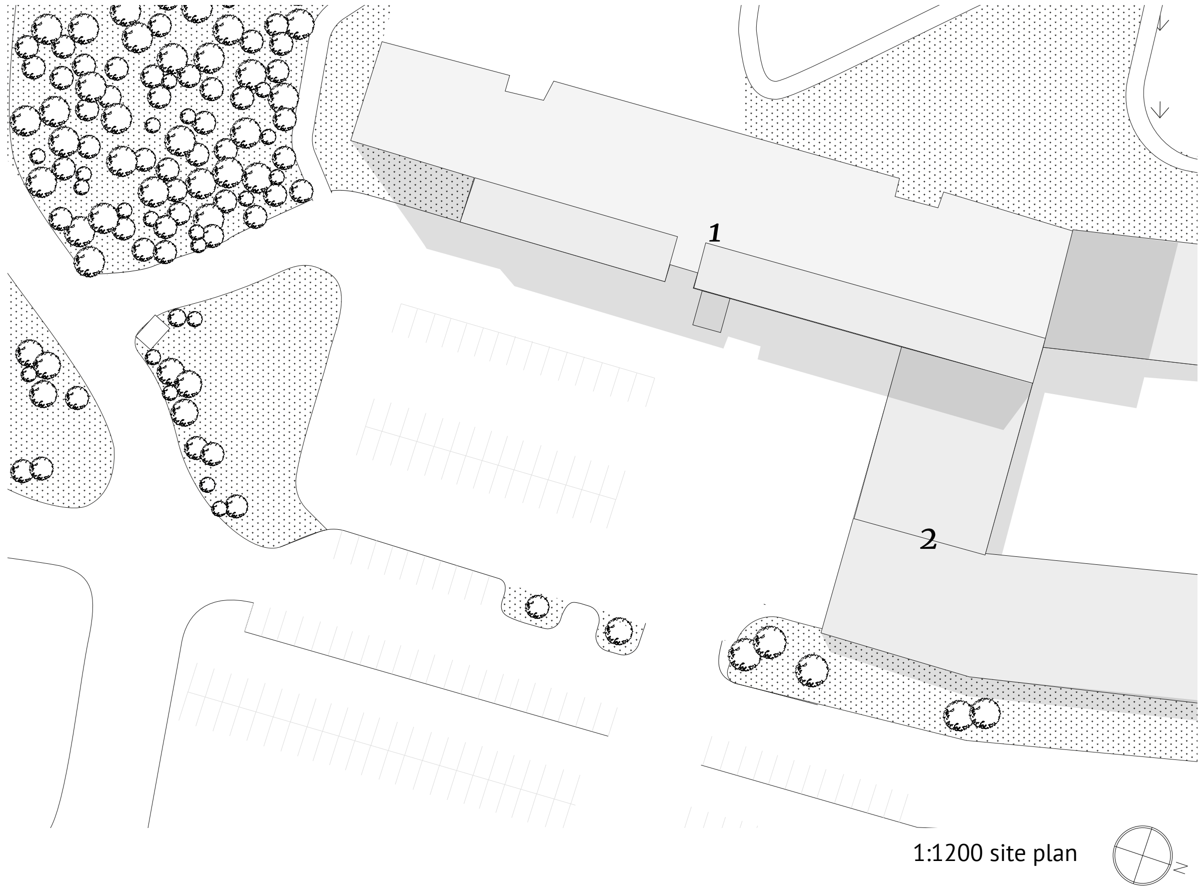
Transport

The site is located close to both a buss central and a metro station. there is also a large patient parking in front of the hospital area.

Use

Building 42 is used for geriatrics today. The proposal is hypothetical and a reason for why this could have been needed in reality could be for renovation purposes of the permanent building for example.

Current situation



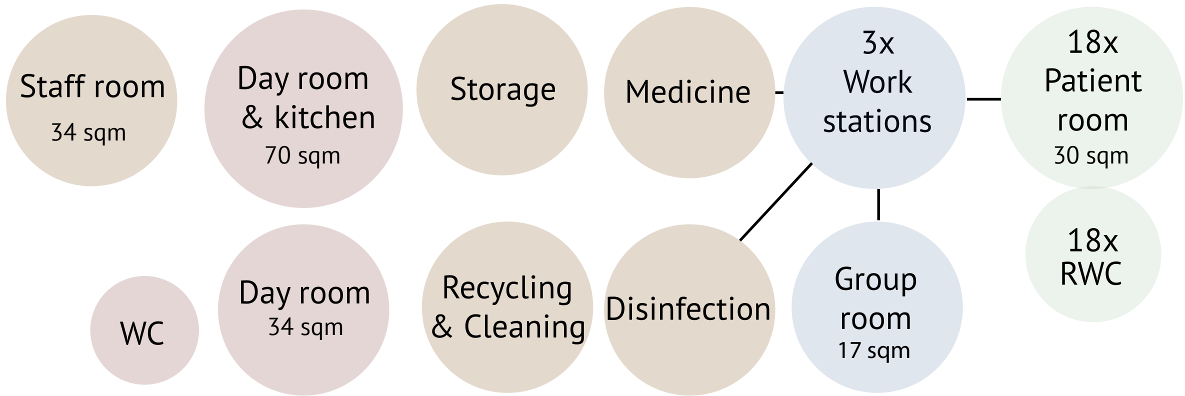
1

2

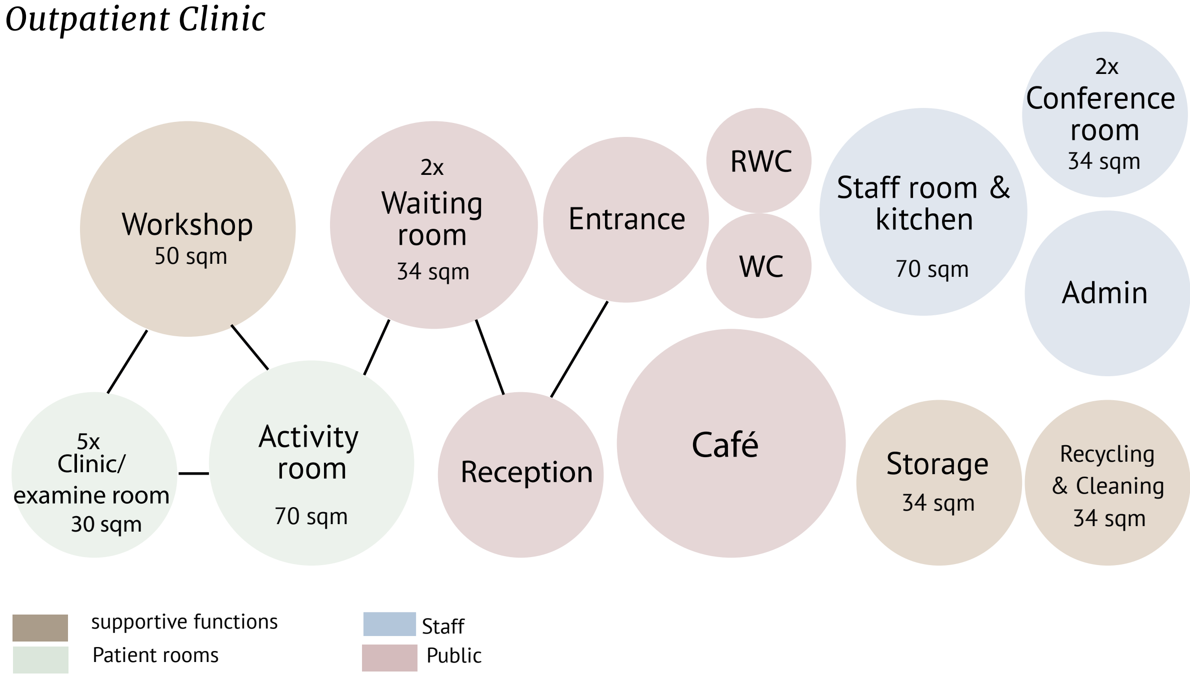
The plot chosen for this temporary unit is a parking lot in front of building 42.

Program

Inpatient ward

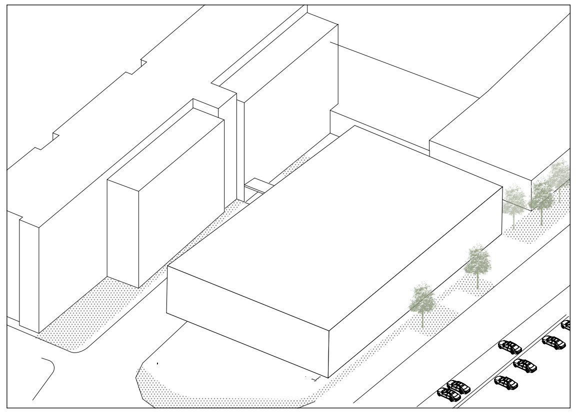


Outpatient Clinic

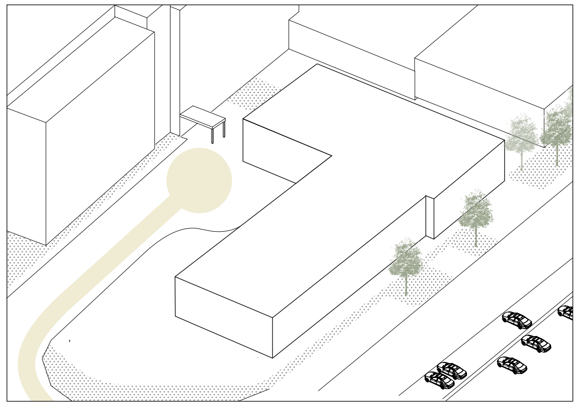


The program is based on building 42; it replicates the main program of the first-floor plan of the building. Building 42 is the geriatrics department, and the floor plan consists of both a general ward and an outpatient clinic with a specialty in orthopaedics.

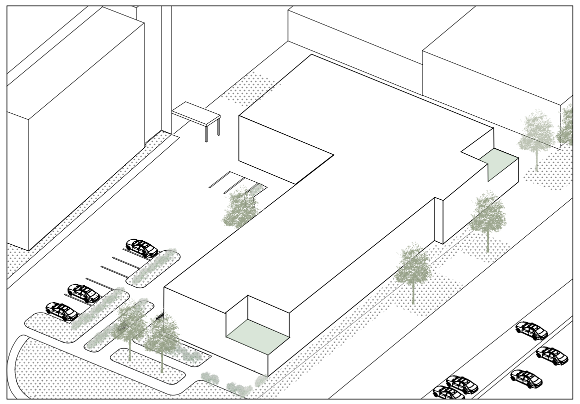
Shaping the building



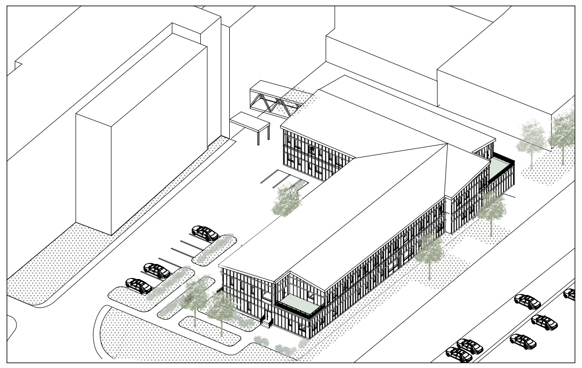
It starts with the maximum volume that fits on site.



The building gets an L-shape to open up for car access to the front of the permanent building and the temporary new one.



Balconies are added to the building and a green outdoor environment is created to bring nature close to the patients.

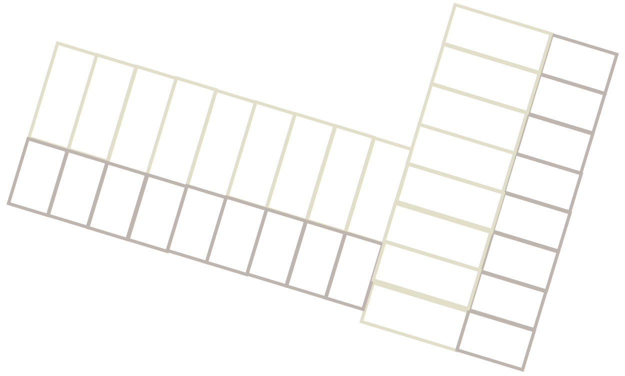


Windows are placed to let in daylight and give a connection to the outside. The facade grid follows the window shapes. The building is connected to the main building (42) through a bridge.

Entry Floor

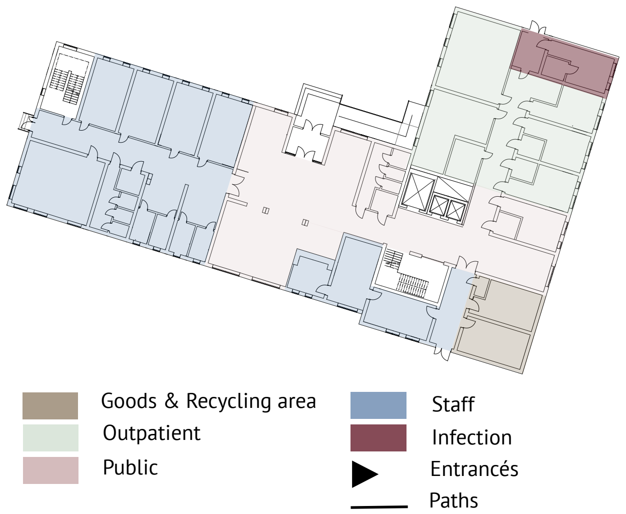
Module Grid

This building is made out of module shape B and C.



Program

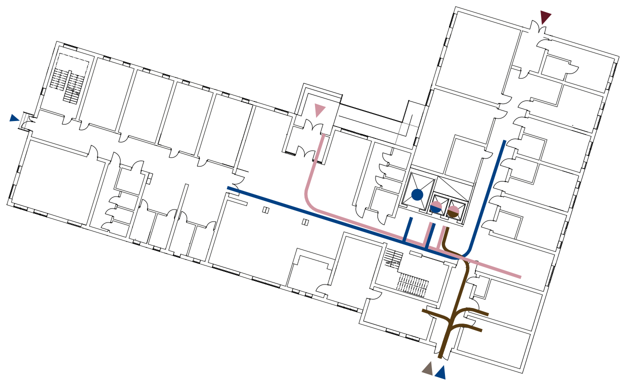
On the entrance floor, the outpatient clinic, administrative spaces and staff rooms are located. There is also a small cafe for patients and visitors.



Flows

An L shaped corridor leads the users through the building, connecting all the programs.

The staff areas are separated from the patient areas to keep the flows separated.



1. Cleaning & Recycle
2. Storage
3. Technical Room
4. Workshop
5. Activity room
6. Cafe kitchen
7. Reception
8. Admin
9.staff room
10. parking space

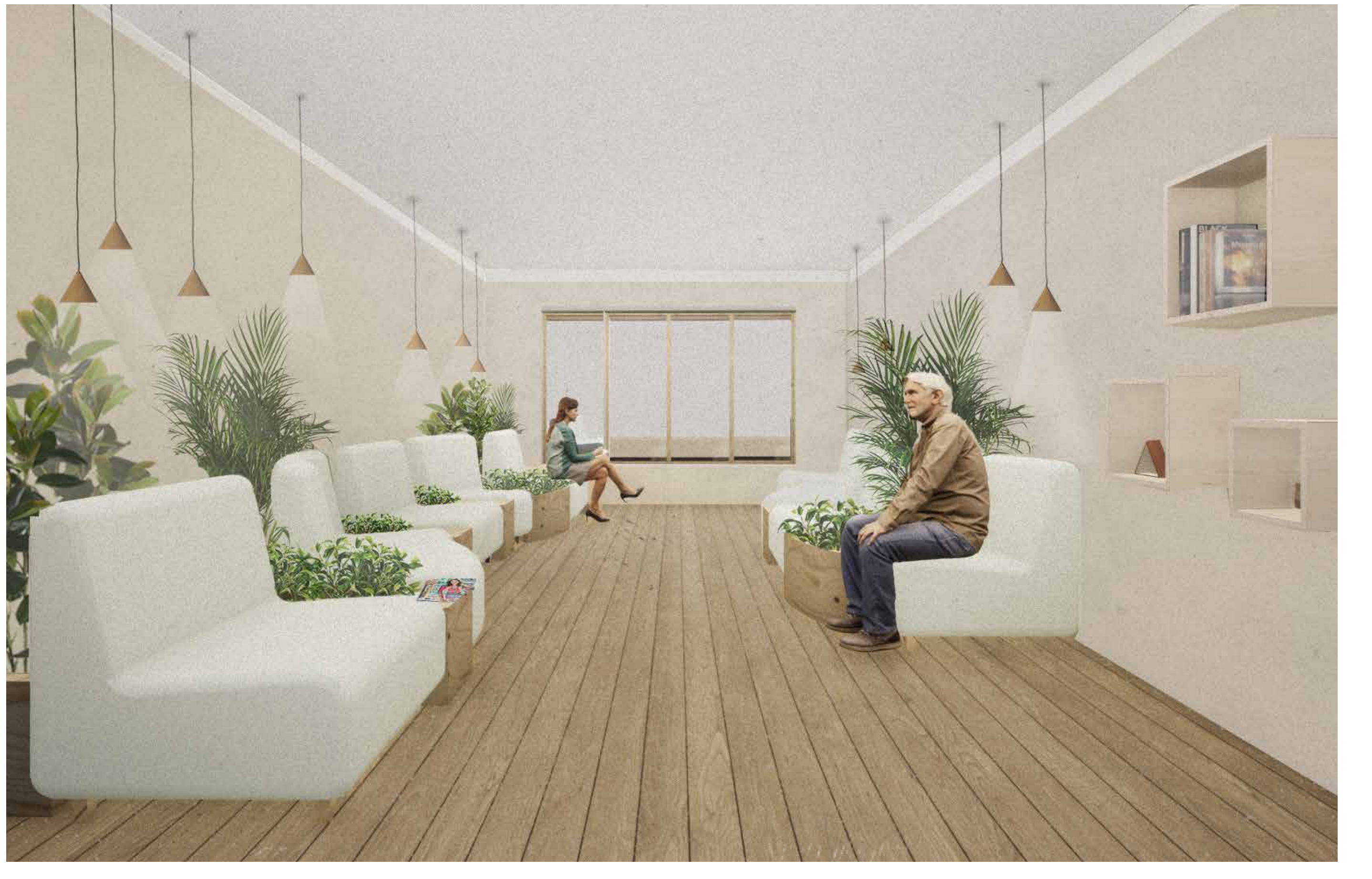
floor 0. 1:400

Reception

The reception is located right next to the spacious entrance area, in-between the outpatient clinic and the staff area. Signs are set up to increase the orientability in the building. Wood finishes are an ongoing team in the common areas.

Because of a lot of movement in this area, durable material is chosen for the flooring, terrazzo tiles.

Waiting Room



Warm and light colours are used together with a lot of greenery and wood to create a calm and welcoming feeling in the waiting room. The flooring is in a wooden texture for the same reason.

The waiting rooms have large windows to bring in as much daylight as possible and give the patients a connection to the outside.

Upper Floor

Program

The inpatient ward is located on the second floor. In the corner of the ”L-shape, the main stairs and elevators are located together with other less shared supportive functions.

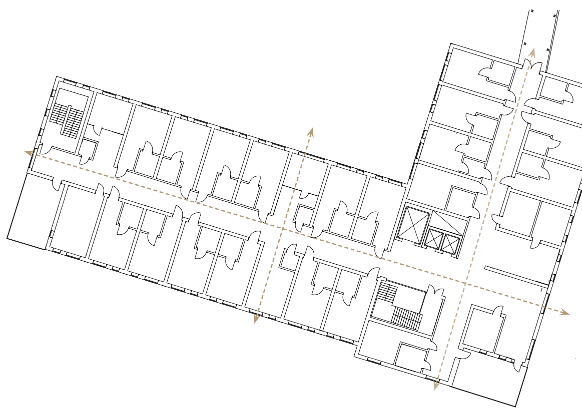
The workstations are decentralized to have them closer to the patients. A bigger workstation is placed next to the shared supportive functions and is used during night shifts.

Two balconies are also located on this floor level to bring nature closer to the patients.

Sightlines

The sightline increases the orientability in the building for both staff and patients. All corridors end with a large window or a glass door for this reason.

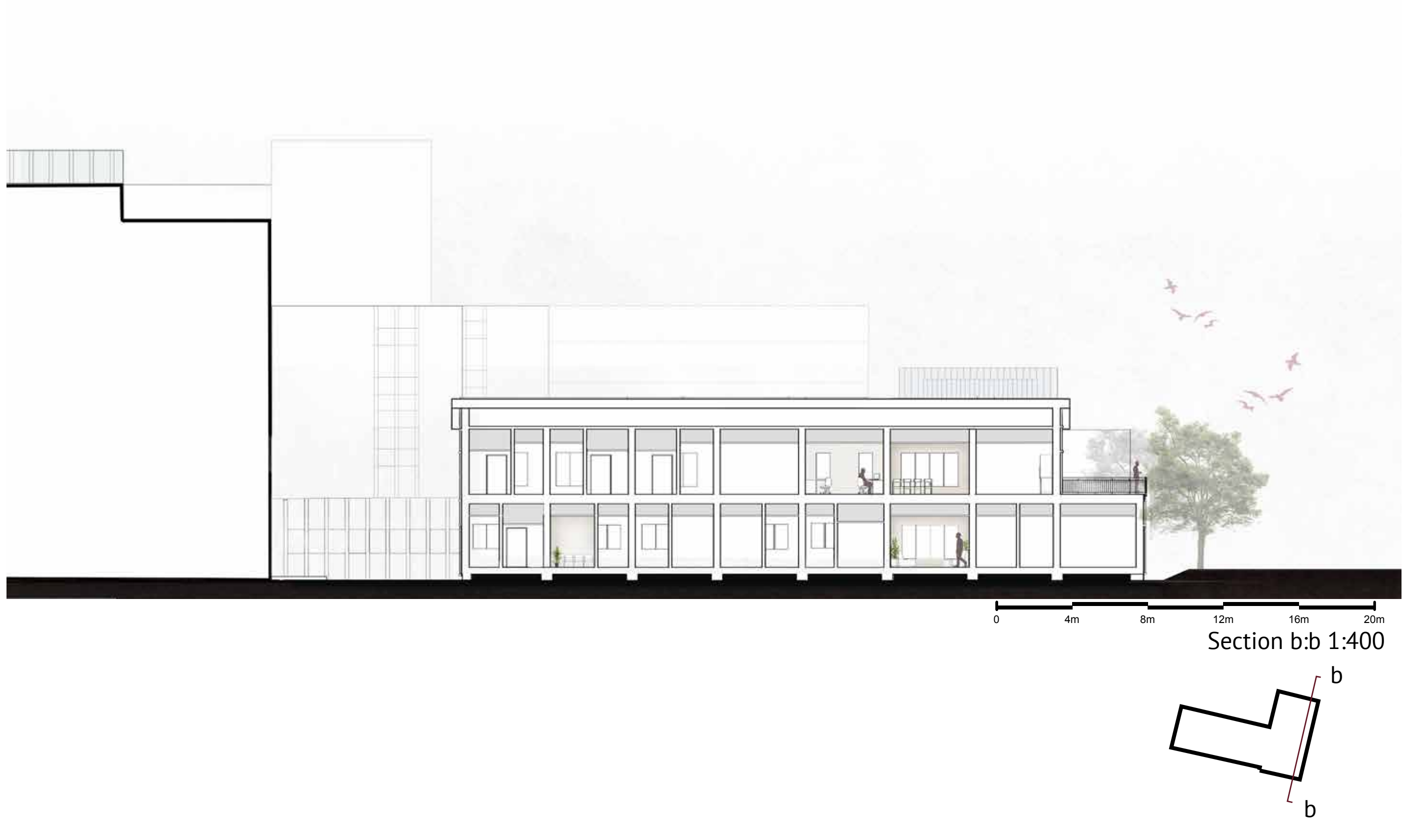
To break up the long corridor going from north to south, a sightline goes through the workstation to the dayroom as well



1. Cleaning & Recycle
2. Storage
3. Technical Room
4. Medicine storage
5. Conference room
6. Group room
7. Day room
8. Canteen
9. Disinfection
10. Balcony
11. staff room
12. work station

Floor 1. 1:400

Sections



Facade

Wooden Facade

The facade is in Thermowood, with prefabricated panel elements that are assembled on-site. Thermowood is a nontoxic and durable material choice that stands against decay.

The choice of having the facades in wood is based on three aspects:

1. To reflect the structural material and promote wooden structures.

2. The environmental benefits of using wood compared to other materials and its CO2 storing properties.

3. To give a feeling of safety and calmness to the visitors.

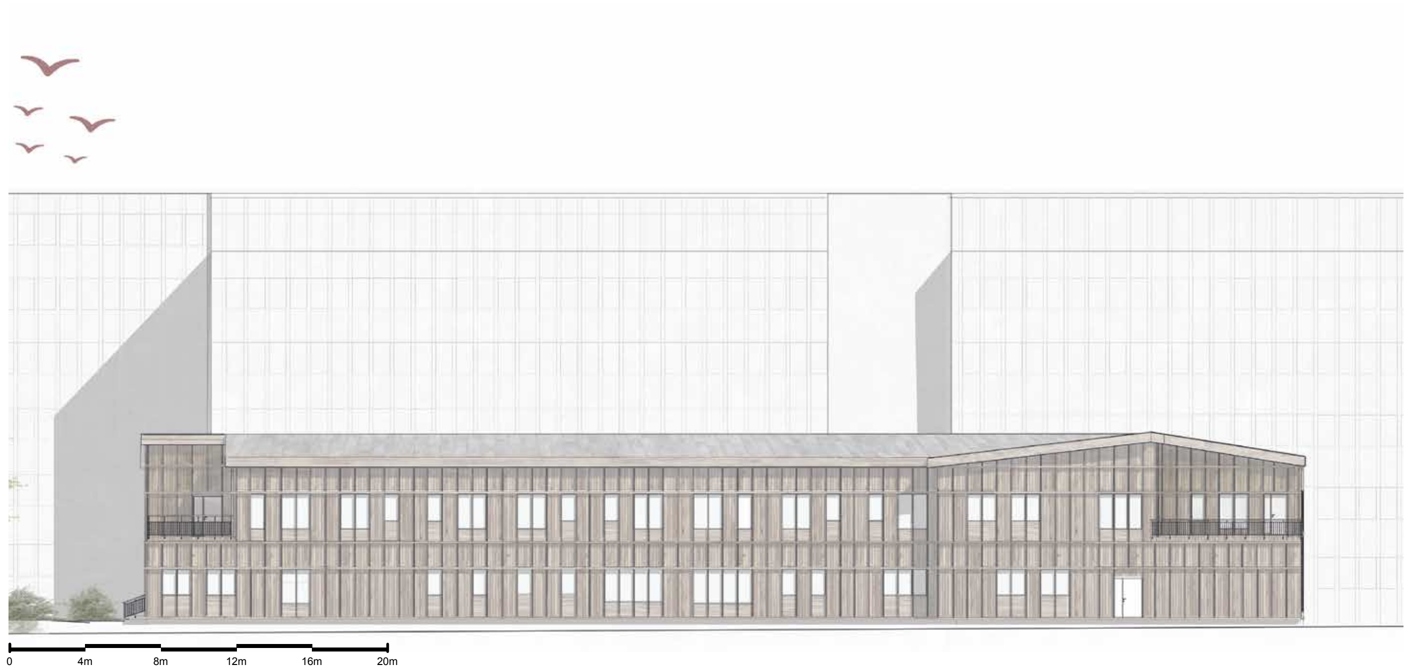
Facade grid

The grid of the facade follows the window sizes.

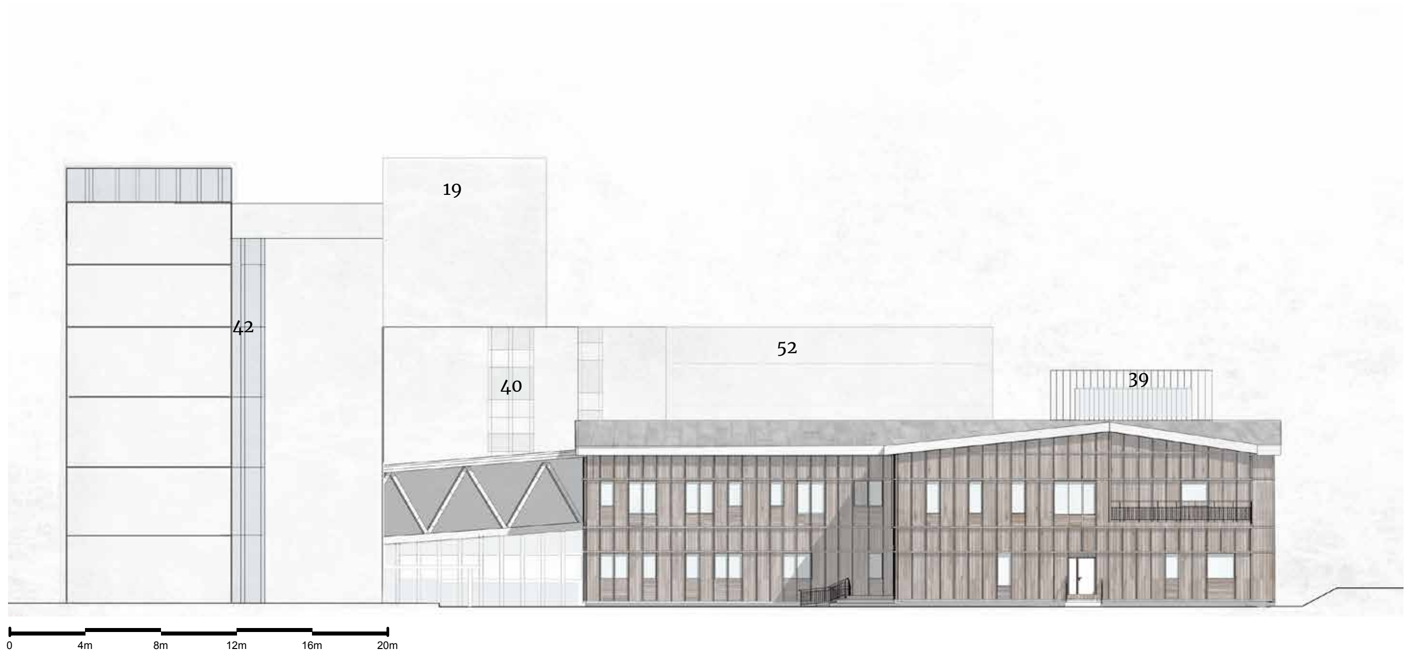
Gavel roof

The roof has a slight pitch to it to lead away water and give a feeling of homeliness to the patients.

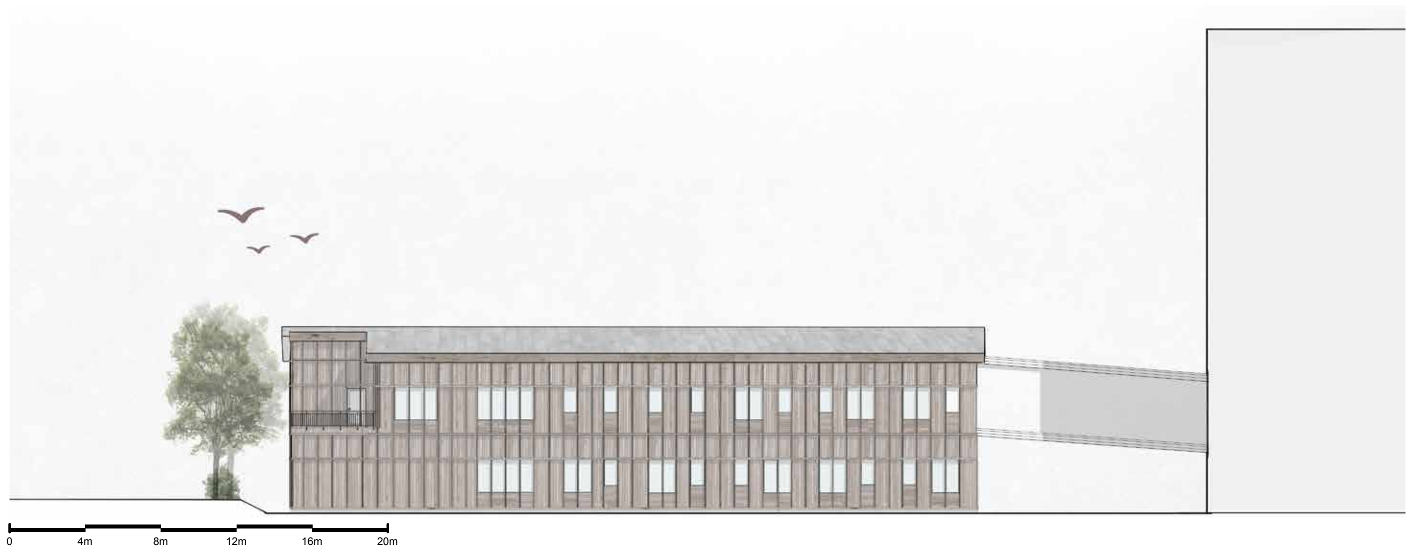
Facade



East elevation 1:400



South elevation 1:400



North elevation 1:400

West elevation 1:400

6.Discussion

The discussion chapter is a reflection over the results and how the project can develop further in the future.

Discussion

The thesis proposes a strategy for building temporary healthcare facilities in wood using prefabricated modules.

The modules have been tried out for a clinic, an inpatient ward, and administrative rooms. The modules also prove to work for more site-specific needs like forming a large entrance area, cafe or activity rooms.

The modules are built in layers to ease disassembly, and a circular strategy is made to have a future plan for the modules.

Wood has been used as the main material throughout the project because of its properties of being a sustainable material and also because of its healing factors. Making the facades in wood gives a feeling of safety and also mirrors the structural material, to spread awareness to by passers about the building.

What does the research contribute to?
From the case studies, there is an understanding that this building typology is already well established and frequently used. Modularity is nothing new in architecture or the construction industry but has a lot of potentials to investigate further.

The thesis proposes a further development and refinement of the building typology. What differentiates this project from the existing stock is its sustainability strategy.

When working with temporary facilities, the relocation of the care can be a stress factor for both patients and staff. Therefore it becomes essential to offer a calm and safe environment for the users of the new building. However, when looking at the case studies, these temporary module facilities often do not meet these requirements and only serve one purpose: filling in for the specific need.

This proposal aims to have the same standards and follow the same design principles as a permanent building. Both the exterior and interior spaces are created to serve the patients' and staff's wellbeing.

Some examples of how it is applied are:
- using large windows for sufficient daylight and a view to the outside.
- Using wood on interior details, calming colours and greeneries.
- bringing nature close to the patients.
- Single patient rooms with sufficient space for staff, visitors, and patients, with wooden detailing on the interior.

Modules and standardisation, what are the benefits?
As mentioned in chapter 2.x modules decrease the construction price and the assembly time. For the architect, this means that the focus can preferably be on choosing high-quality materials and the design.

Another point is that there is not always time to build from scratch, i.e. during a pandemic or natural disaster, having modules will then speed up the process.

DFD in healthcare facilities
It has been essential to explore the possibilities for disassembly and circularity based on the requirements and the standards we have today on hygiene classes in healthcare facilities. The project has aimed to follow these requirements and see in what ways DfD still can be applicable. It is a valuable tool for the circular process and extremely necessary to form a sustainable sector. The conclusion is that it is still beneficial to have a strong disassembly approach even if all materials cannot be disassembled and reused when disassembling the modules into their materials.

Future research
The next step in the research is to look into other types of facilities that can be formed with these modules and also how unique spaces can be formed with standardised modules.

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Images

[Image 1. Picture ward facade]Retrived: 2021-03-17 *https://www.swedishmodules.com/sv/reference/sodersjukhuset-stockholm/*
[Image 2. inside of operation theathre]Retrived: 2021-03-17 *https://www.swedishmodules.com/sv/reference/sodersjukhuset-stockholm/*

[Image 3. inside of ward@bowyer] Retrived: 2021-03-17 from *https://www.sgh.com.sg/patient-care/visitor-information/ward@bowyer-ward-88*

[Image 4. inside of ward room] Retrived: 2021-03-17 from *https://www.snec.com.sg/news/singapore-health/ward-a-feat-50-beds-in-50-days*

Quote

Toni Yli-Suvanto ,Toni Yli-Suvanto Architects *http://www.toniylisuvanto.com/modular_mass_timber.html* [Retrived: 2021-05-01]