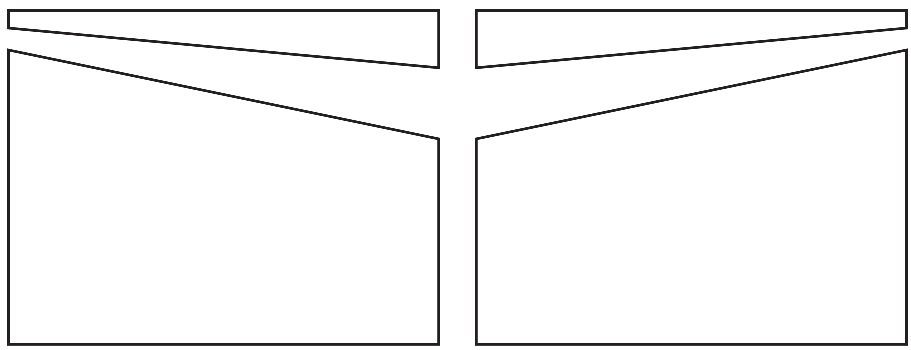

F O L D A B L E   C A N O P Y

P R E F A B   S Y S T E M

KONRAD WOJCIK
MATIJA JURSE

FOLDABLE CANOPY

Subject
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SYNOPSIS

This report is a result of MSc04ARK Spring semester 2015 at Aalborg University. Its main focus is aimed towards solving the common problem of poor quality regarding large percentage of today's prefab architecture. By analysing and rethinking prefabrication concept as an answer for this situation, new ways of defining prefabricated design are to be put under consideration and thereafter examined and tested. The purpose of such action is to find new more flexible modular systems that could assure both: high quality of manufacturing and non-limited creation process.

Prefabrication for last 60 years was a very popular idea that had been implemented many times with different level of success. Starting from prefabricated elements and ending on full buildings assembled in the factory and thereafter transported to its final destination, this way of building was always associated with limitations, repetition and almost container-like-architecture.

This report is investigating different possibilities of pre-assembly that would not affect the creative process, thus would only assure high quality regarding architecture, sustainability and joinery level. By analyzing different solutions that can be already found on the market, modular system is being developed to strive to minimizing the complexity level to minimum while maximizing the application possibilities in the architecture.

The success of the assignment is being tested throughout number of designs of fully functional buildings, made using developed system. This action is a assessment of the effectiveness that is determining elements needed to be redesign or leave behind to make space for new solutions. By repeating this procedure until obtaining satisfactory results, new way of prefabrication is developed that fulfills our goals specified in next chapters.

FOREWORD

This thesis is created by Group 47 in last semester of Architectural Design Master at the Architecture and Design Engineering Program at University of Aalborg. This project is a manifestation of gained knowledge from previous semesters, thus the themes that the project is paying special attention are Sustainable and Tectonic Architecture, accompanying with advanced integrated process methodology.

The theme for this paper can be chosen freely by students. With that in mind it is necessary that the problem is challenging enough for the last work at the Mater program. Hence this paper theme is rethinking of modular prefabrication. Thus it requires all the above stated approaches and also new skills and knowledge for the designing of such architecture.

This thesis is supervised by Michael Lauring, Associate Professor at the Department of Architecture, Design and Media Technology, AAU and technical supervisor Claus Topp, Part-time Lecturer, Department of Civil Engineering, AAU.

READING GUIDE

The report is presenting process of prefabricated system development and its application on different locations around Aarhus. Thus the aims and vision is presented in the beginning to outline the path we took, following by theme analysis to get bit deeper understanding into the problems.

The result of this analyses is short presentation of different system proposal principles, which gets in-depth research in chapter Concept development. This is also a step between sketching and detail phase which ends with Presentation of the finalized system.

The final chapter contains conclusion and reflection upon the thesis and its themes. There is also literature and illustration list as a last but not least part of the project. The literature is referenced according to Harvard method.

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1

PROGRAM

1.1

INTRODUCTION

Nothing in the ecosystem is permanent. Humans and their environment are not an exception. As much as we would like to live in such disillusion, people do not have the power to contradict evolution and adjusting. This is a natural process which strives to achieve perfect solutions by eliminating unnatural behaviors that contradicts good being of the majority. Nothing is permanent and will never be. By understanding and acknowledging this rule of nature we should embrace it and not stand against.

Even though people are aware that everything they do will be changed eventually for something improved, they seem to reject this thought. By looking at cities for instance, or by narrowing the scale to single buildings, the majority of them are created by using permanent methods and materials. We “glue” materials together almost like paper model. They will not have to change, they will not have to adapt- we repeat, knowing that is just a disillusion. A huge waste of materials, energy and time just to build a next “memorial” of humanity.

Unfortunately, as we look on our past, there is only extremely small percentage of buildings that survived this barrier of time and even then, they are usually treated as monuments, a tourist attraction without or with minimized its original function. Therefore, if we could assume that almost nothing is permanent is there a solution that could embrace this change and not fight against it? Is there a simple solution, an idea that could help humanity to overcome this selfish approach?

This report is build on a belief that humanity will eventually swallow its pride and will start creating their environments.

1.1.1

AIMS

We aim to design building principle that can offer flexible creation of space with serially produced modular elements.

We attempt to rethink modular prefabrication to overcome stigmatization of container-like-buildings thus create high quality, unique architecture.

We aim to solve technical as well as sustainable aspects within the module allowing free creation of space defined by users’ needs.

1.1.2

METHODOLOGY

In order to design a prefabricated system that could be flexible with the modules, adjustable, sustainable and additionally would allow to create a high quality architecture, deep analysis is required in many different fields. If fact, to assure fulfilling all these ambitious goals mentioned above one special case is taken into consideration with characteristics what would present most unfavorable conditions. We decided to analyzed our design according to 4 different main categories: environment, function, aesthetics and construction, where all will be analyzed at the same time as integrated design strategy. Main categories are thereafter subdivide into more precise aspects that in our opinion are important to analyze and discuss.

After analyzing both: Environment and Function aspects which are more general part of “analysis and sketching” phase, this report will divide different ideas and discusses them separately through aesthetic and construction stage including their subcategories. In this way every concept will be disused one by one, giving order and reflecting natural way of how each idea was developed. Such approach will also include integrated design thinking where aesthetics, construction and function goes together by informing and affecting each other. System designed in such way should gain from each analysis and by implementing ideas and solutions into one design we hope to achieve prefabrication system that could overcome all difficulties and requirements stated at the end of this phase in Program Summary chapter.

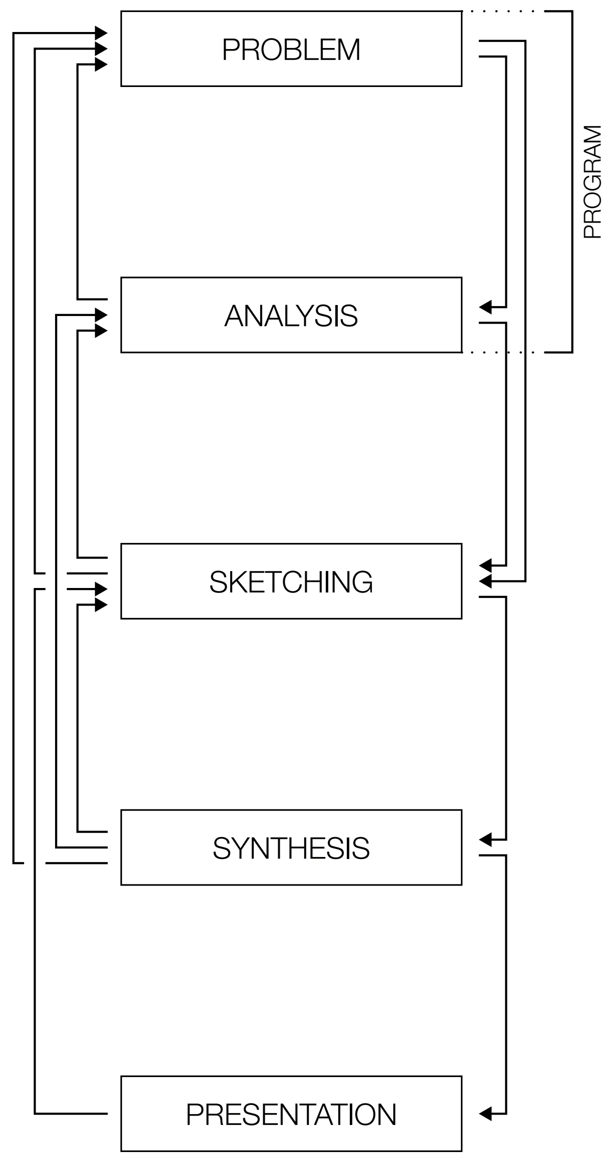
By analyzing single family house, building model that in a lifespan has to adjust to changing conditions, different configurations and designs will be tested within one system. Additionally we decided to test our design in temperate climate of Denmark that requires extra attention for energy saving solutions, thus could easily deal with most of European conditions. Construction wise, different structures and materials will be tested in order to achieve most optimized solutions. Above all we hope, by studying various aesthetics of architecture, to meet the challenge of prefabrication appearance that would contradict stigmatization of container like appearance and open design for new possibilities.

Every aspect of this analysis will look back at program summary defined at the end of this chapter, in order to stay focus and precise regarding our goals. After the analysis phase, designed system will be put under testing which will define if another design loop is necessary or not.

1.1.3

VISION

ARCHITECT AND THE CLIENT CAN FOCUS ON THE DESIGN INSTEAD OF TECHNICAL ASPECTS SINCE THEY ARE ALREADY INTEGRATED IN THE MODULAR SYSTEM



ill. 001
Task flow as a method to achieve vision

1.1.4
MOTIVATION

Growing and transforming modern suburbs

“Cities are the crucible of civilization; urbanization has been expanding at an exponential rate in the last 200 years so that by the second part of this century the planet will be completely dominated by cites.” (Geoffrey West: The surprising math of cities and corporations, TED talk, 2015). According to his research while considering US as an example, in last 200 years number of people living in urbanized environment grew from less than 4% to more than 80% in year 2011. In year 2006, humanity crossed the border of over 50% people concentrating in cities. By analysing years of research this number will grow exponentially and nowadays the predictions are that more than 75% of human population will become urbanized by the end of 2050.

This analysis of urbanization clearly shows that the way how we understand and think about the cities will have to evolve and change in order to adjust to this new situation. By looking at evolution of big metropolises, it can be noticed that cities could be almost considered as a living organisms that grow and expand. They need to transform and change in order to meet the needs of new citizens. Areas once considered as suburban, often have to evolve to the new public centers changing its function and requirements. The way how we now construct and create new buildings today is very permanent and does not leave space for the change. While designing buildings it is hard to predict how evolution mentioned before will undergo, thus the approach taken by urban designers and architects should focus on more flexible solutions.

In this way a standardization of different components across various construction branches is necessary. Demolition as a way to transform cities is highly inefficient regarding time and energy and should be replaced by systems that could adapt to new circumstances will less negative impact. Ideally such system would allow to transform every building to meet the needs of tomorrow with minimal influence on construction, energy and environment.

Client/Quality problem

Second focus of this report is to define new ways of prefabrication to overcome the problem with poor quality of architecture that is being designed and executed under unfavorable conditions caused by many different factors. This problem is an outcome of the difficulty and complexity of the building process where many elements must be executed correctly in order to achieve high quality, sustainable architecture. Simplifying we can divide clients into two categories where end results are completely different.

In the first case, client with optimal deadlines and budget is hiring a highly specialized group of people to design, construct and eventually build his building. He or She is aware of how important is good organization within the project and how miscommunication between groups of people can easily lead to big mistakes that would cause not only financial loss but also regarding time and building efficiency. In this case client cares about the environment and wants to build sustainably using high quality materials even if economically it does not match. Situation described above leads to the creation of high quality architecture often being a milestones for other investors. Unfortunately such idyllic circumstances are rarely a case and very often are impossible due to present economical situation.

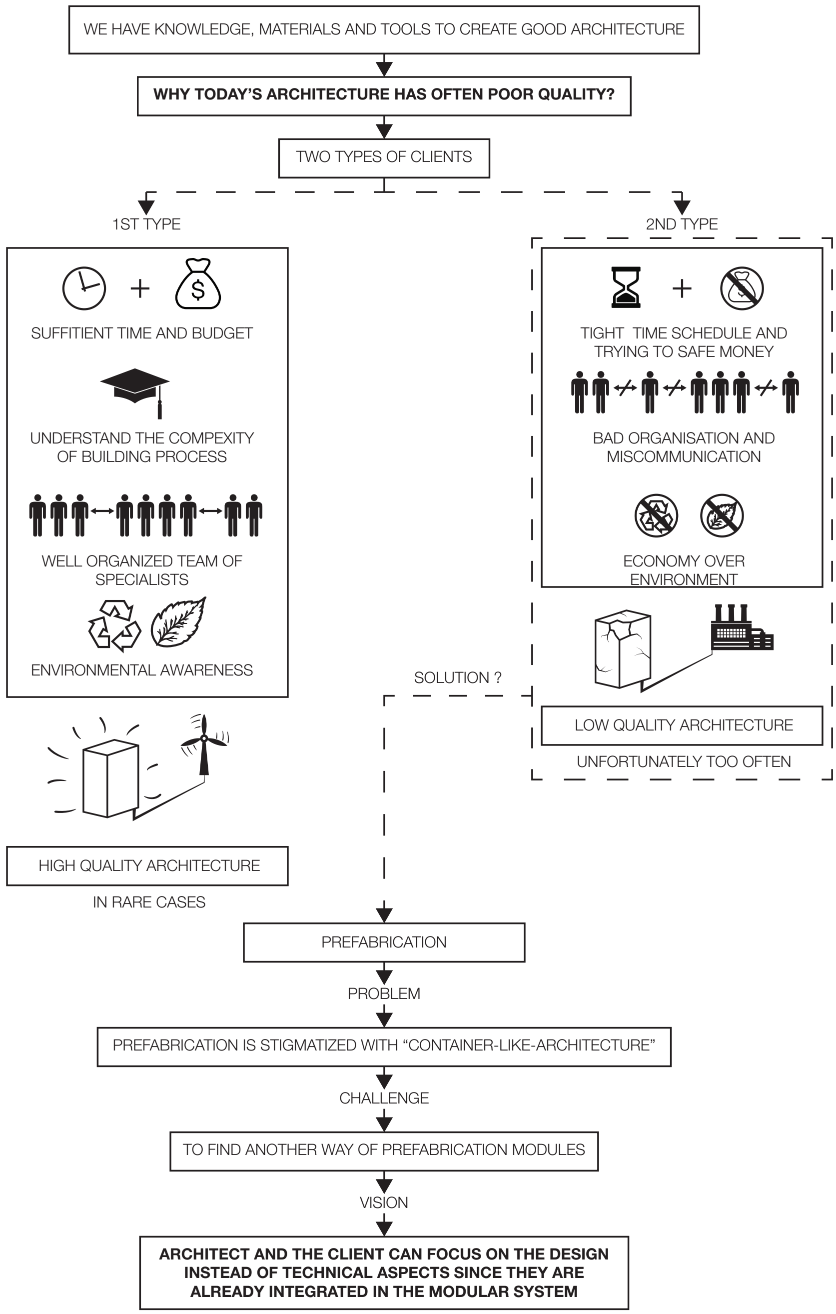
The second client is much more realistic and can be encountered in most of situations with small variations in one way or the other. Tight schedules with very limited budget are almost a certainty. Private clients while seeking savings often turn to many small not necessarily professional companies, being afraid of turning to big company that can offer a Turn-key contract. Instead many different specialists work separately on the project that often leads to miscommunication and mistake. Furthermore, investors rarely can afford to think about the environment minimizing sustainable aspects to the obligatory minimum defined by the legal acts. All these elements, unfortunately lead to inevitable loss of quality, thus producing average architecture. Since this knowledge is known for many decades, prefabrication was invented to overcome inter alia these problems.

As we look on the prefabrication as an ideal solution for the second situation, two main problems instantly emerge. First of all, prefabrication is stigmatized by the container-like look which is discouraging many people from using it in a first place.

Secondly, it is always associated with many kinds of limitations, which for creative people is a unbearable, thus is being automatically rejected. This report is taking these disadvantages, and treats them as a challenge that could be overcome to open new perspectives for the architects and investors. By applying characteristics of prefabrication together with flexible creation of space, new modulars system is being developed as a useful tool for architects, engineers and investors.

Conclusions:

- *Transforming cities requires new approach towards designing that would allow to easily adjust and change already erected buildings.*
- *Poor quality of many buildings is a result many unfavourable factors that could be overcome with help of prefabrication*
- *Prefabrication being stigmatized by container like look and also limitations regarding unit size, is often rejected by architects and designers*
- *In order for prefabrication to be acknowledge by both professionals and laymen it must become more flexible and adjustable*

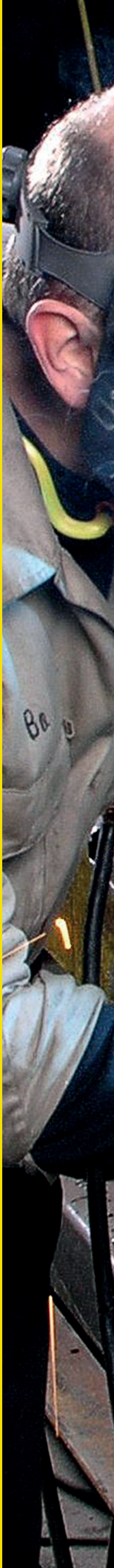


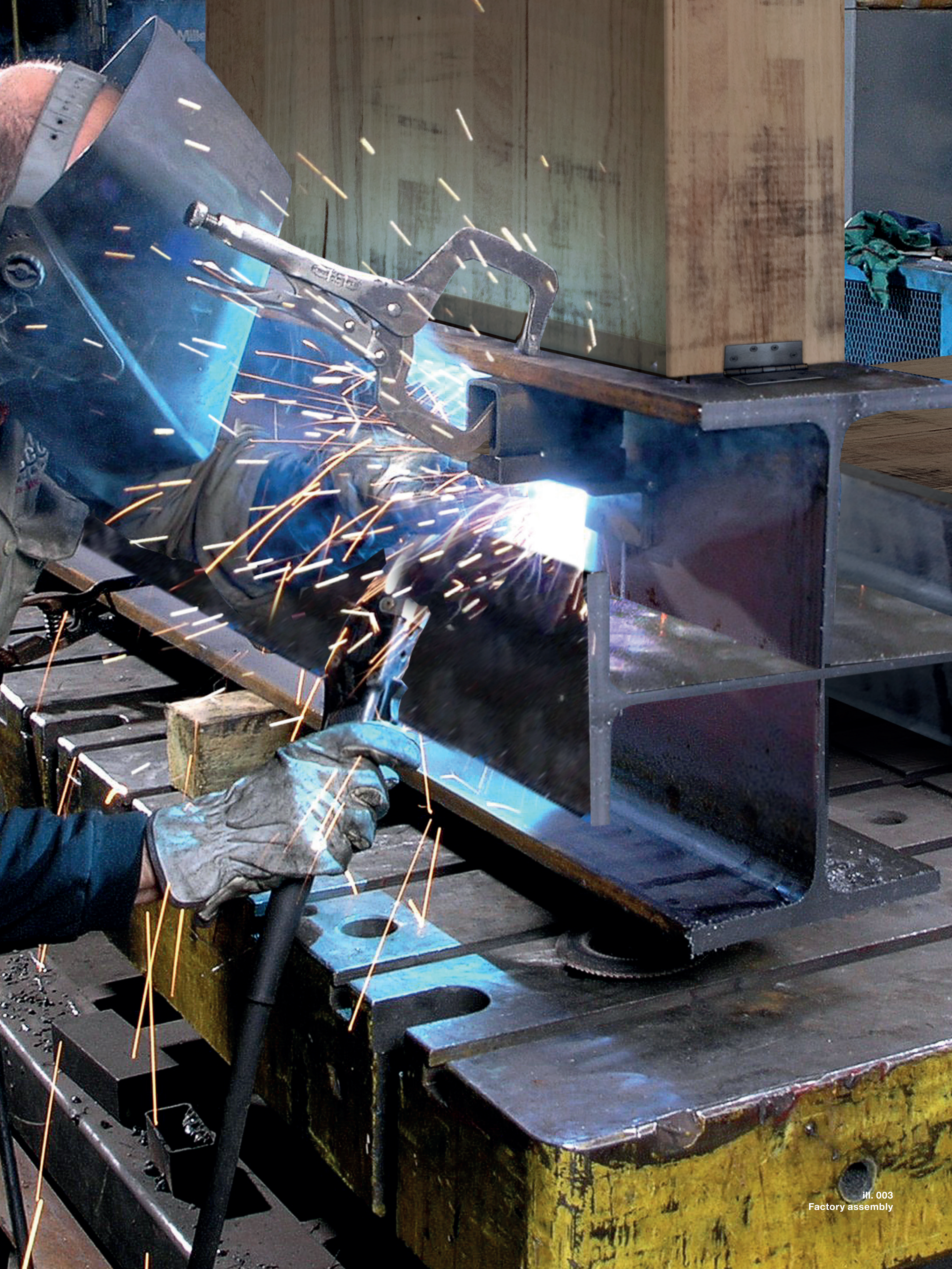
ill. 002
Graphical explanation of reasons why do the prefab building

‘THEME ANALYSIS’

This chapter will focus on prefabrication process as a main theme of this report. First it will discuss shortly the history of prefab together with conclusion and lessons learned from each example. Thereafter, main principles will be analyzed together with fundamentals and elements of prefabrication. This analysis will be made in reference to our aims and vision, and will help us to better understand complexity of this prefabrication process.

1.2

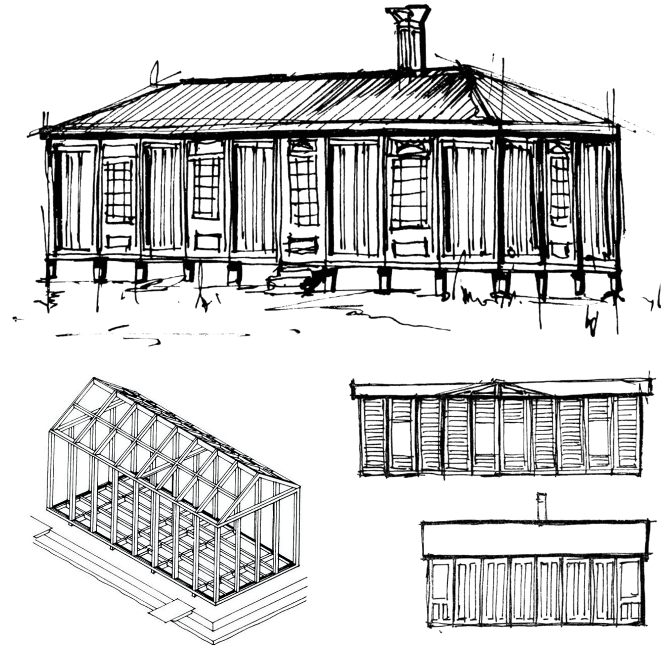




ill. 003
Factory assembly

1.2.1
BACKGROUND

1.2.1.1
SHORT HISTORY OF PREFABRICATION



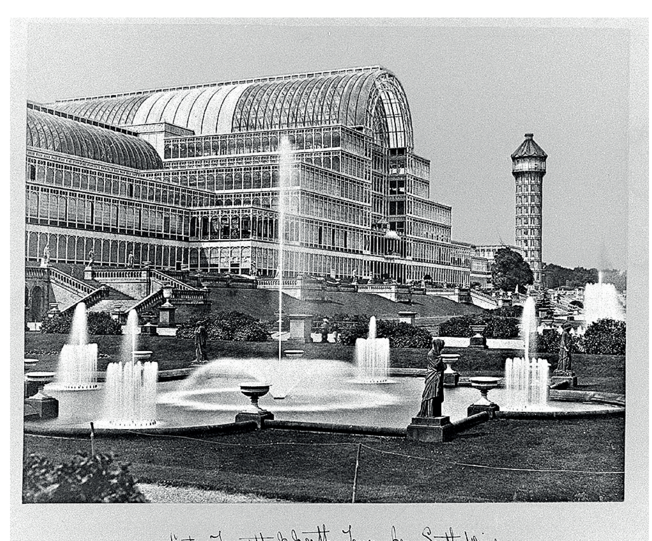
**ill. 004
Manning Portable Colonial Cottage for Emigrants**

Standardization of construction allowed various panelling assuring more personalized building

With aim to design new prefabrication system, it is extremely important to first carefully analyze and also understand the historical background of prefabrication. Defined as “the assembly of buildings or their components at a location other than the building site” (Encyclopædia Britannica, Inc., 2015), great architects such as inter alia Le Corbusier , Mies van der Rohe or Jørn Utzon approached this subject using different strategies and ideas. Their concepts presenting different level of success, each time introduced new ways of thinking and solving technical difficulties. It is important to analyze significant breakthroughs and failures of the past, so that they could be used as a learning tool in order to move forward instead of repeating similar mistakes. This chapter will concentrate on making such analysis basing on two books: “Prefab architecture” by R.E. Smith and “Off-site fabrication: Prefabrication, Pre-assembly and Modularisation” by Alistair G.E. Gibb. Additionally, conclusion will be made regarding this project that would help to successfully finish this ambitious project. Even though beginnings of prefabrication are often mistakenly associated with modernism and the age of industrialization, as a matter of fact, it has appeared in architecture much earlier.

The first attempts of prefabrication can be argued depending on the definition that is considered. One of such examples could be 160 buildings that were designed and build in between AD83 and 86 by the Roman Army in the British Isles. This is one of the first case when advantages of prefabrication allowed for building new villages relatively fast and efficient. (Alistair G.E. Gibb, 1999). Even though it looked much different comparing with nowadays standards, it allowed for creating new camp regardless local materials or specialized tools.

Similar approach can be noticed many centuries later when in 1624 British Colonies started importing pre-assembled timber elements in order to build shed-like buildings on terrains without suitable building materials. With time their system became more sophisticated and while timber frames were always mounted on special previously assembled floor grid, infill components were customize according to the users’ needs. Known as Manning Portable Colonial Cottage for Emigrants, system already show the necessity for flexibility within prefabrication system that could satisfy different users’ and functions’ needs.
When Iron manufacturing became widely applied in building sector, iron prafab era has been initiated. Small elements such as lintels, windows, columns and beams were mass produced in factories for later use on site. This started an idea of standardize iron elements that could be used in order to construct limitless designs. There were many examples following this concept such as bridges at first and thereafter buildings. The most groundbreaking construction that once and for all proved that industrial

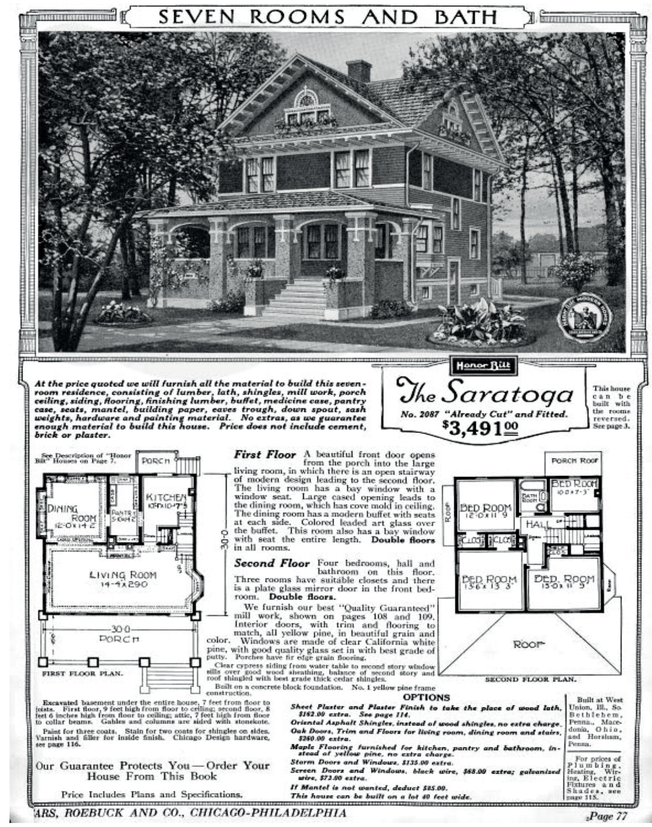


**ill. 005
The Crystal Palace at Sydenham greyscale, London**

approach can be used to achieve outstanding aesthetic qualities was the Crystal Palace, building designed and created for Great Exhibition of 1851 in England. By using standardize elements, engineers were able to design buildings flexibly within short period of time. This example clearly presents the idea where term standardization is not excluding creative thinking but rather works as a new tool for architects.

First attempt to use prefabrication as a way to mass produce and sell houses had place in United States where W.J. and O.E. Sovereign, brothers created a “Kit Homes”. By designing several housing options they offered clients restricted flexibility within their projects. Business model that they created which based on selling pre-designed homes, is also visible in modern prefabrication trends. Restricted flexibility in this case was enough to achieve a huge success on the market proving that people are interested in homes that they can build themselves while having already prepared elements. Their company in the end bankrupt due to both: national crisis in 1920s-30s and unpaid clients’ mortgages. Nevertheless, their business was a milestone in home prefabrication industry showing successors base for this model business. There were many companies that we continuing their idea using more and more advanced methods and materials.

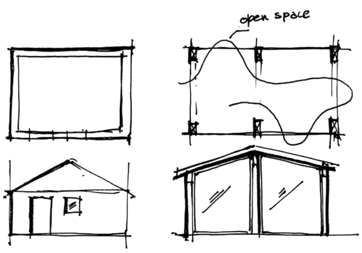
Metal sandwich panels together with flat roof systems allowed companies such as “American Houses” and “General Houses Corporation” to create new designs with modern or even futuristic characteristics. Both these companies were founded by people with architectural and industrial background. Interestingly, Howard T. Fisher founder of “General Houses Corporation“ stated a fresh idea about prefabrication and their new look regarding designing process. While using prefabrication he did not want to copy traditional American housing architecture. On the contrary he said that the origin of prefabrication process should be embraced and not hidden to create new authentic aesthetics in architecture. These words are very relevant while aiming to achieve tectonic values within the prefabrication approach, thus it is important to remember them and try to translate and export this idea to the prefabrication of today. Unfortunately, this approach towards design did not worked for companies mentioned before, forcing them to propose architecture that people were familiar with for last decades.



ill. 006
Saratoga, as seen in the 1922 catalogue

ill. 007
Close-up of the line drawing in the 1922 catalogue

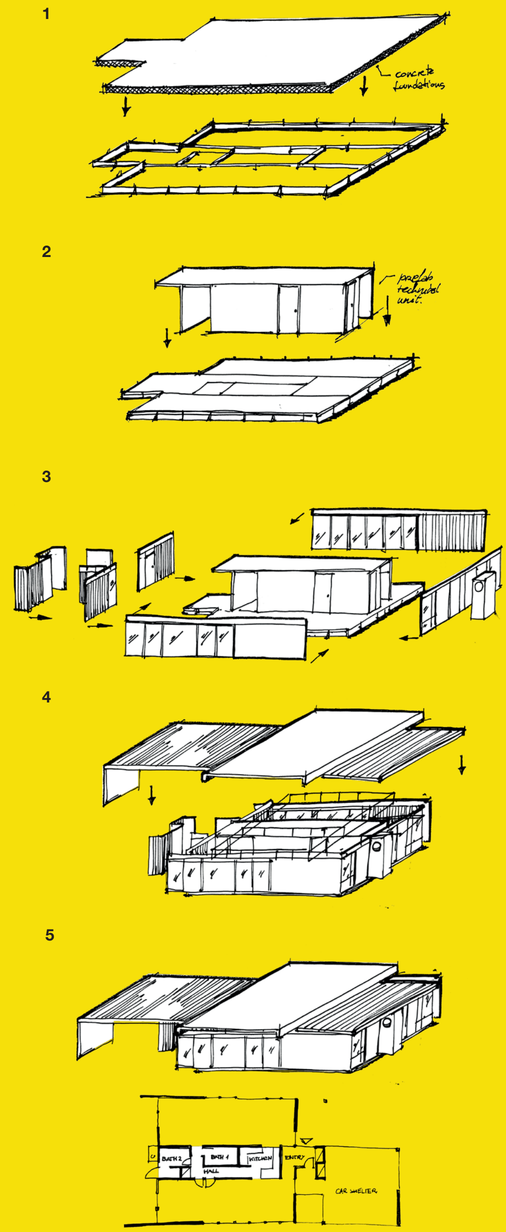
ill. 008
Saratoga in Mukwonago, Wisconsin, (Photo is copyright 2012 Heather Lukaszewski



ill. 009
Traditional housing versus Eichler cesign principle
ill. 010
Eichler Homes designed by Joseph Eichler

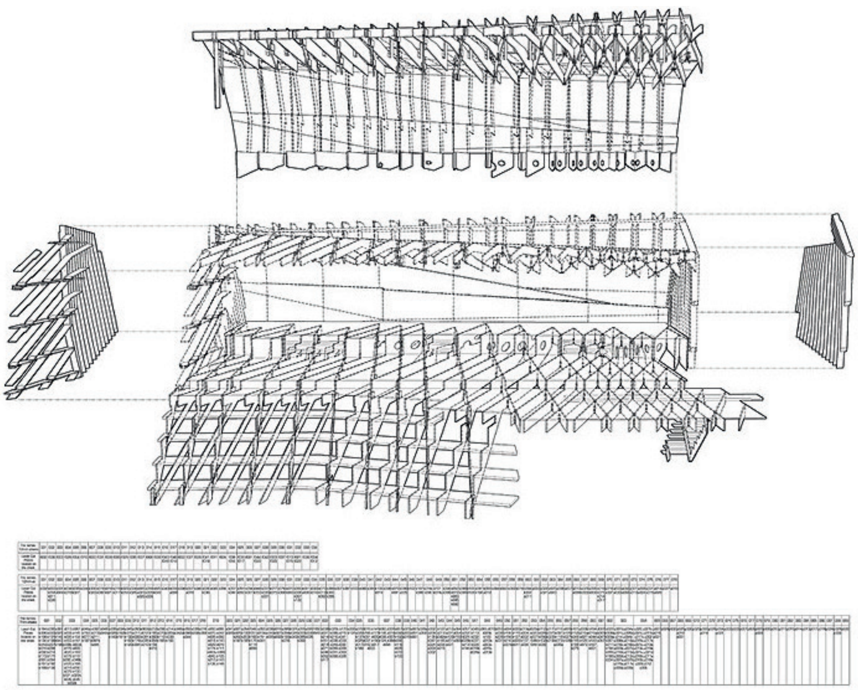
Approaches described before had one common future which was a lack of variety and aesthetic appeal. By opening new company Joseph Eichler who was fascinated with art and beauty proposed new prefabrication system that offered new 'post and beam' design of the modern houses executed on a rigid grid with standardized mechanical and plumbing systems. By carefully studying prefabrication promises, he was able to deliver homes with increased quality and reduced costs. Even though his impact on prefabrication was not very significant, he once and for all proved that prefabrication as a method of building can be as attractive for customers as traditional buildings, but only if cost of such construction is comparable and the quality together with attention to detail is assured.

Joseph Eichler's approach towards prefab architecture inspired many others to follow his passion. One of such people were modernist architects Wexler and Harrison who teamed up with Bernie Perlin, structural engineer, to design simple yet very modern and open house of steel. Their company called "Rheemetal Steel Home System", designed a house that was preassembled in a factory and transported on a site in a package of exterior walls, roofs, fascia, and trim. The process on assembling the house is presented on the right in five steps. (1) First of all concrete work was done on a site together with plumbing and electrical work. (2) Thereafter a technical unit per-assembled in a factory was mounted on foundations. It consisted of kitchen, two bathrooms and circulation system that allowed flexible design around this core. (3) Next stage was mounting wall panels remembering to keep the house as open to nature as possible. Last element was a roof that came in three different options, depending on client's needs. Whole construction together with ground works took up to 30 days, while most time consuming was the interior finishing works (Steel Modern: A History of Steel Houses in Palm Springs, P. McGrew, 2012). This example shows the importance of a technical core that not only provides bathrooms and kitchen but also allows for flexible design around it by providing communication roots through the unit.



ill. 011
Assembly process by "Rheemetal Steel Home System"

ill. 012
Personal sketch of Eichler Homes designed by Joseph Eichler



ill. 013
BURST*008, construction elements prepared for laser cutting

ill. 014
BURST*003, North Haven, Australia

Another trend that had place simultaneously was a mobile and manufactured housing. Designed and build, mobile homes functioned almost like a trailers that were intended to be moved if necessary to the another location. As a matter of fact such relocation very rarely had place and the design together with approach towards such houses started to transform more into more permanent living units that were assembled in a factories and thereafter transported towards its final destination. With time width of the 'unit' changed starting from 2,43 meters in 1954 and grew up to 4,26 meters in 1969. Later on architects started to join units together on the site, creating homes that were 8,54 m wide which is comparable with traditional housing industry. This trend continued till now sharing 4% of housing market in US. Their attractive price together with assured quality and very low risk are attractive for customers who do not expect more from these houses that they can offer.

Precast concrete is a material rarely used while discussing prefabricated homes. This material was first taken into consideration when the idea of reinforcing concrete appeared and successfully proved its potential. Even though there were some attempts to design homes in this way prefab concrete was mainly used to construct bridges and industrial buildings. Nowadays, it is also widely used, however mainly in larger commercial and industrial buildings where durability and long life span is desired.

Nowadays prefabrication is closely linked to digital production where projects using building information model (BIM) can be automatically manufactured using specialized programmable machinery. As easy as it might sound, there are still many problems with establishing fluent transition between the design build on BIM system and the finish building. One of the examples worth mentioning while discussing BIM systems is the BURST*003-8 projects designed by SYSTEMarchitects. Their interesting house was a computer design based on set of formulas, site analysis and client's needs. Thereafter computer splits the design into 1000 plus individual pieces that are cut in a most optimal way from SIP panels and thereafter put together on a site. (PREFAB FRIDAY: BURST*008 at MOMA B. Meinhold, 2008)

As a matter of fact building industry is the slowest to evolve while comparing with other industries. One of the reasons for such behavior could that wide variety of different materials, solution and product is not standardized, thus it requires different companies and specialists to create finished product. In order bring prefabrication to the next level, we must start thinking in a more united way where all components fit together without adjusting and additional corrections.

Conclusions:

- *prefabrication allows for quick assembly of buildings on terrains without necessary materials and tools (Roman Army in the British Isles, Portable Colonial Cottage)*
- *standardization and industrialization does not exclude esthetical values associated with high quality architecture (Crystal Palace at Great Exhibition in England, 1851)*
- *prefabrication is a perfect solution for high housing demand and is welcome by the consumers (W.J. and O.E. Sovereign,"Kit Homes")*
- *achieving tectonic quality by acknowledging the idea of prefabrication process being embraced and not hidden to create new authentic esthetics in architecture. (Howard T. Fisher)*
- *prefabrication can easily compete with traditional building methods when price in comparable and high quality together with care for details is embraced (Joseph Eichler)*
- *technical core should include communication circulation system to assure possibility of flexible design around it (Wexler and Harrison "Rheemetal Steel Home System")*
- *modular architecture that consists of pre assembled units is attractive due to low risks and high quality*
- *precast concrete is used mainly for architecture with expected long lifespan*
- *digital production will eventually automate construction process making it more efficient with high quality value*

1.2.1.2
SHORTCOMINGS

Even though prefabrication evolved greatly from times of British colonization, it is still lacking in various areas. Pointing them out and creating a list of the biggest challenges of present prefabrication is essential to create a good base for designing a new system. Mark Phillipson from BRE Scotland prepared a report called “Defining the Sustainability of Prefabrication and Modular Process in Construction” which became a source information for this chapter. Besides describing Prefab in UK, he is also writing about the study that was made for UK Government to examine potential the barriers of prefabrication use and possible solution to overcome these problems.

Bad reputation

Prefabrication nowadays is being misled by the historical image from last century. Even though the design itself at that time was relatively good, it was the workmanship that caused the biggest problems with buildings at that time. People in the construction industry, having in mind problems from the past are often rejecting this option with concerns that it could repeat. Nowadays this problem can be countered easily by close supervision during the assembly time. Thus, it one of the main issues that must be assured if prefabrication would want to change its image. This problem usually occurs in housing market where people are more close minded comparing with big investments where optimization is the key to successful business.

2. Lifespan

While in non-domestic sector people are less concern about the lifespan of their building, because of changing economy and various renovations, in private housing development this is a key feature that is important for people. Prefabrication from 1970s was publicly perceived by having shorter lifespan comparing with traditional procurement methods. If prefab housing would like to compete with tradition, long lifespan would have to be reassured.

2. Lifespan

Another element that is limiting the prefabrication in private housing sector is that householders prefer traditional brick architecture over other materials. There are currently systems that are prefabricating brick elements that are afterwards transported to the site in order to mimic traditional masonry appearance. Building erected using this method are positively perceived by public opinion and could be and option to overcome this blank in prefabricated housing architecture.

4. Value

Another aspect that influence prefabrication negatively is the perception of lower value comparing with traditional methods. Householders treat their building like an investment and by looking at historical context prefabrication is often less valuable in a long life-span of the building comparing with traditional methods. Non-domestic clients are more open to rationally evaluate the life performance of the building, thus they are more open to include this method into their investment. Prefab housing must be perceived as more permanent to compete with other methods of procurement.

5. Industry

One of the reasons why prefab nowadays is not used regularly is the lack of specialized factories that could handle the manufacturing process. Another problem with prefab in housing is the need of crane to manipulate the units. Some prefab companies are using cranes that are part of the truck, however in this case manipulation of bigger elements is impossible after the truck is gone causing additional difficulties. Finally, unfortunately there is still strong belief that prefab eventually is turning out to be more expensive comparing with traditional methods, even though evidence shows differently.

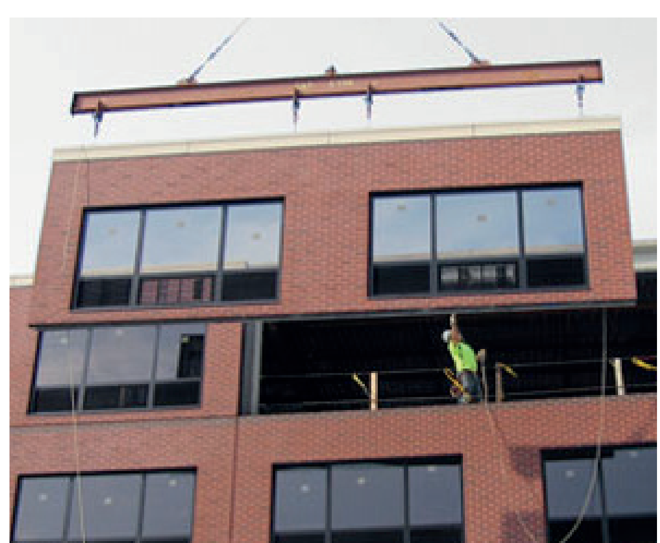
6. Designer awareness

According to the rapport that was made for UK Government about the prefab barriers the last point mentioning the product awareness issue. Designer are still not convinced that using a prefab system would embrace their design, thus that choose not to use it. Additionally, manufacturers while producing innovative systems complain that the community of designers and engineers is very conservative.

Conclusions:

Prefabrication can compete with traditional housing industry if:

- *it will convince public opinion about its high quality*
- *it will assure long life span of the building*
- *it will allow for the traditional appearance of the house*
- *it will present high value of the building*
- *the industry will be able to manufacture essential elements*
- *the designer will want to use this system*



**ill. 015
Engineered Thin-Brick-Systems**

1.2.2
CONTEXT

DENMARK

ill. 016
Map of Denmark showing Aarhus

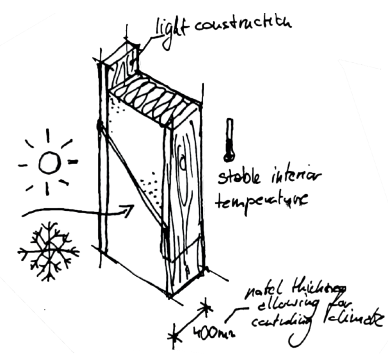
ill. 017
Map of Europe indicating the area (in gray) of temperate climate

When someone decides to challenge one of the themes of architecture, in this case prefabrication, specified localization as such is not most relevant since by definition of designing a system should be applicable in various situations and conditions. However, in order to have the possibility to test designed solution and have precise output data, specifying some sort of geographical localization is necessary. In other words, the analysis of the exact site with unique terrain, sun exposure, communication, noise pollution etc. are pointless regarding design a prefabricated system, nevertheless average climate conditions such as temperature, rain, daylight are extremely important to adjust designed elements to fit sustainably its environment.

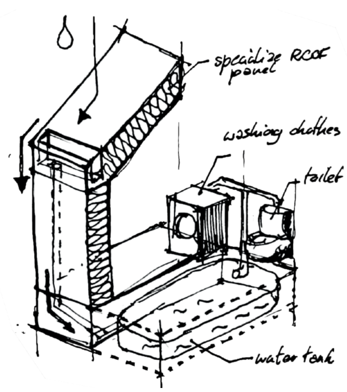
The design of system presented in this report is concentrating on the area of Denmark which with its temperate climate could represent most of the middle and north European countries. It is important to underline that the purpose of this report is to propose a flexible prefabricated system that could adjust and transform to fit different situation. Therefor as a base for our design, suburban areas of Aarhus were chosen.

Aarhus as a second biggest city in Denmark is representing the best potential of growth. Being localized in the middle of peninsula Jutland, having good infrastructure and access to waterfront, it has good perspectives to expand and attract new citizens. Additionally Copenhagen, the capital of Denmark is not centralized and also separated by Lille and Great Belt, is living a space for Aarhus to easily become 2nd biggest economy center in Denmark. At the moment Aarhus is planning to create whole new district for new 15 000 citizens called "Nye". Biggest companies in Denmark were invited to join this enormous venture such as BIG, CEBRA, C.F. Møller, JDS and 6 others to build whole new housing estates according to holistic urban plan prepared for from 2007

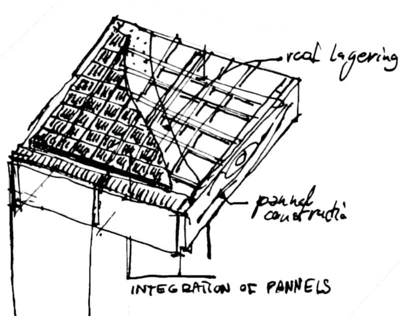
All of the signs show that suburbs of Aarhus, is a perfect candidate to test our design. These areas will expand and transform in future allowing our flexible system to help adjusting to new circumstances. Additionally Aarhus in our case will represent average climate conditions of middle and North European Countries. We are planning to focus on energy saving solutions regarding average conditions typical for that area. While prefabricated system will take care of most sustainable aspects, it will be the design of the building itself created with our system that will correspond to the factors specific for various building sites. To put it in other words, prefabricated system designed in this report will allow for achieving good indoor environment, low energy consumption with flexibility that will allow to design any kind of building that would deal with local factors.



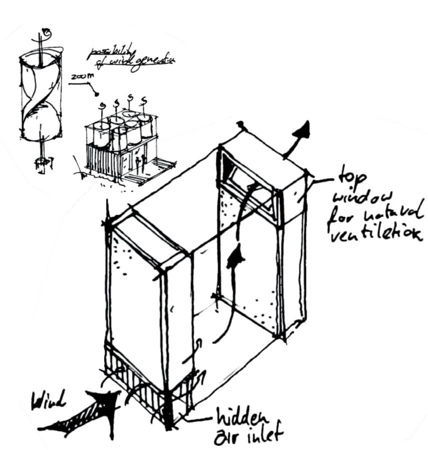
ill. 018
Prefabricated skin must assure stable temperature in warm and cold seasons



ill. 019
Capturing rainwater can be part of prefabricated system



ill. 020
PV as an integrated part of prefab roof panel



ill. 021
a) using wind as a power source,
b) prefab system must allow for natural ventilation

1.2.2.1
CLIMATE

Designing prefabricated system that would be suitable for temperate climate of Denmark, thus climate of most middle European countries requires the analysis of different climate subcategories such as Temperature, Rainfall, Sun, and Wind. Even though we decided on testing our solution in the suburbs of Aarhus, the analysis of each factor will be made in more general approach to meet various situations and conditions.

Temperature

By looking at the average temperature graphs in Denmark, it can be noticed that temperatures vary from 22˚C to -1˚C during the year period. When we analysis such temperatures we must take into consideration that to calculate average results it must consist of different values during the day. These variations are extremely important to take into consideration when trying to assure good indoor climate. Even Though that Denmark's temperatures can vary from -31.2˚C to 36,4˚C to calculate and test our design we will use BSim weather file that for its calculations is using actual weather conditions from last years (worldweatheronline, 2015). Such temperatures, without the doubt will influence the prefabricated element thickness part to assure low heat losses in the cold season and avoid high solar gains in the summer season.

Rainfall

By looking at rainfall in Denmark, it can be noticed that on average 121 days per year it is raining and average rainfall per month is around 50mm (worldweatheronline, 2015). This gives an opportunity to use this water as a sustainable solution. Prefabrication strategies can be use to harvest this water. Integrating such system into the prefab modules of the roof could automatically allow people to use this water for toilet flushing, clothes washing or reducing the need for external water supply like supporting landscape irrigation. In such case there would be no need for designing and adding external water gathering systems since they would be an integrated part of the prefab solution .

Sun

Sun in Denmark is a privilege and it must be treated with special care. With average of 1445 hours per year of sunshine its benefits cannot be compromised by any design and systems that do not allow or limit its potential (worldweatheronline, 2015). Additionally it also creates some difficulties with low almost horizontal angle of sunlight during winter the time challenging any prefabricated system to offer solutions that could overcome this difficulty. That means, special solar shadings should be considered as a part of modular prefabricated element as a passive strategy. Another element that could consider as part of prefabrication is the usage of photovoltaic or solar panels to harness the free power of sun.

Wind

Wind in Denmark is undoubtedly one of the characteristics of this country (average wind velocity of 5,3 m/s) and it distinguish it on the European stage. In can harvest, but it can also cause destruction. This thread must be taken into consideration while designing prefabricated modular architecture where numerous of elements can fall apart when facing strong hurricane. Wind is also a main driving force for natural ventilation and while designing a prefabricated system, it should give the possibility of using this force easily. Interesting possibility would be designing modular units that could harvest the force of the wind and could become a part of prefabricated design as an additional option. This topic is further discussed in the sustainable section of this report.

1.2.2.2
TOPOGRAPHY

While analyzing different type of terrain the discussion usually goes down to foundation technology and other onside work what would allow prefabricated system to be applied. It is rarely a case that the foundation is made using precast solution since for these kind of work it can be easily done on site while prefab units are assembled in the factory in the same time. This allow different subcontractors to work simultaneously, thus it reduces construction time significantly (Smith, 2014).

Designing prefabricated system that aims towards uncompromised flexibility might in some cases affect the modular system itself. In US on terrains with the hillside terrain, special modular system had to be developed in order to adjust to the angle of the slope. While top stories stayed standardize to one solution the ground floor system had to be shortened or lengthened in order to adapt to varying lower floor configurations (Smith, 2014). In such case, prefabrication system that consist of smaller prefab elements, instead of whole units is performing much better since it can adapt to different terrain types within its standardize elements. This is the solution that is more likely to be applied in the prefab system designed in this report.

In Denmark the terrain is relatively flat which could allow for some sort of prefab foundation system. However, if other countries of Northern Europe should be discussed, designed system must be more flexible, leaving space for adjustment and change.

The idea of this report is to design a system that could adapt to different context depending on a need of a user. Nevertheless, at its beginning stages it will probably be used in a suburban surrounding where it should transform and adapt to varying architectural styles of the housing areas and changing needs of the families. In other words, architectural style of suburban areas can vary from more traditional architecture characterized by 45 degrees sloped roofs with porches in front and modern architectural styles assembled with high level of glazing and flat or slightly sloped roof. This is of course just a simplification but it gives the idea of different characters of the spaces and the need for prefabricated system to have the ability of adjusting to various conditions. This is another reason why prefabrication based on smaller flexible elements is better than systems based on whole units, since it is more flexible and gives the space for individual design.

ill. 022
Suburbs of Aargus

ill. 023 Customized prefabrication in concrete

1.2.2.3
LOCAL RESOURCES

When analyzing Danish building industry market is it hard to find collected data that would compare different technologies such as concrete, steel or wood in Denmark. However, without the doubt when we start analyzing various big constructions no matter if it is public sector or housing, the vast amount of concrete use can be notify.

Denmark largest manufacturer of prefab concrete elements, Expan A/S is confirming that is last years the number of buildings in which they participated multiplied. Participating in projects such as Brickholm on Sluseholmen or Kristent kulturcenter in Risskov they proved that concrete can be prefabricated in very flexible way. Poul Kirkegaard, managing director of Expan in article “Customized prefabrication” is explaining how concrete solution developed throughout last decade. Since architectural demands for flexibility and uniqueness rise every year, so does expom developed new prefabrication methods that can adjust to different projects. Extensive use of highly customized solution is nowadays a standard, nonetheless each element is standardize regarding “placing doors, windows, HWS and ventilation. Put simply, we optimise all the building areas where we have influence.” (Kirkegaard, Customized prefabrication).

By analyzing number of certified companies within different fields of civil engineering, it can be noticed that the concrete sector transcend the competition easily. At the moment when Dancert certification for Denmark is taken into consideration there are 9 companies specializing in Structural steel and aluminum structures, 23 companies in Prefabricated Concrete components and 7 companies specializing in prefabricated timber structural elements. Dancert as the independent and competent certification institute connected with the Danish Technological Institute gives a clear image where concrete sector shows very stable situation on the market making it harder for other industries to compete (Dancert A/S, 2015).

Conclusions:

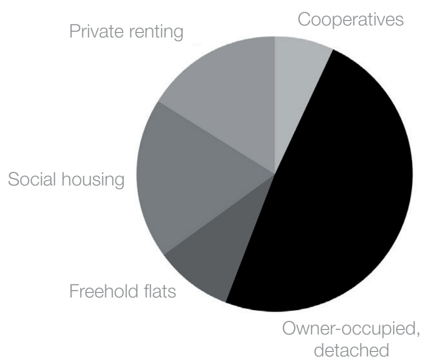
- *Concrete solutions are well trusted on Danish market*
- *Steel and timber constructions are not very popular, however the industry for such solution is together competitive on the market creating a possibility to expand and grow*

1.2.2.4
BUILDING TRADITIONS

“Danes love their homes. Danes talk a lot about their homes. And Danes spend a large proportion of their income on their homes. Consequently Danes have good, large, but also expensive homes. The average housing unit is 109 m2 , and it is occupied by two people.” (Hans Kristensen, Housing in Denmark, 2007) As we can see housing traditions in Denmark are extremely important and good understanding of them is obligatory in order to design a prefab system that would be used for housing purposes.

After 1945

Before World War II Denmark was mainly an agricultural country where over 50% of people lived in rural areas. The end of the war caused rapid expansion of other industries causing people to move nearby cities and build their single-family house on the suburbs. A massive urbanization process started and continued up to 1980. Many housing organizations activated in order to create modern housing estates using concrete as the main material. These movements improved considerably the living standards in Denmark by creating vast number of single family houses and renting units. After 1975 up until



ill. 024
The Danish Housing Market
(Hans Kristensen, Housing in Denmark, 2007, p. 24)

2000 Denmark was intensely improving especially old dwelling,thereby raising the quality of living standards. Nowadays, despite relatively high number of newly build housing units, the number is still very low comparing with those from around 1970.

Another interesting study reveals that on average number of room per dwelling grew from 1 in 1945 up to 5+, which means that nowadays people expect to live rather in a single family house than any other kind of dwelling. Another chart showing Danish housing market seems to confirm this information with almost 50% of people living in detached houses.

Single family houses

First single family houses which are defined by a detach house surrounded by garden, appeared in Denmark in late 19th century. Because of their high price they were only available for local authorities. Other physical and office workers could only dream about such living conditions while renting housing owned by private householders. This small estates of single family houses slowly grew with time and became more and more popular. Nowadays almost 33% of single family houses were built before 1939 showing how popular they became with time (Kristensen, 2007).

After World War II, Danish government started giving large loans with low interest rate for the people so that they could start constructing their own small houses. This was a strategy to overcome housing difficulties in a post war situation. However, the big explosion of housing development had place in 60s and 70s when because of higher incomes and inflation together with negative real interest rate, allowed average people to build their own house. During these years, the number of new houses each year grew up to 40000 a year. This was a huge success comparing with the worst year in Danish history in 1993 where only 1300 houses were build (Kristensen, 2007).

Nowadays the number steadily grow being at 8000 new houses per year giving around 2,9 million square meter between year 2000 and 2004. It is worth noticing that this numbers do not mean that people are not willing to expand since in the same period of time additional 2,7 million square meter were added to existing houses with renovation and extension building (Kristensen, 2007). This clearly shows the potential of additive architecture where people want to expand their living space without moving out from their homes.

SINGLE-FAMILY HOUSES:
AGE, SIZE AND ARCHITECTURE

- Number of single-family houses: 1100000
- Proportion of all dwellings: 42%
- Single-family houses by year of construction:

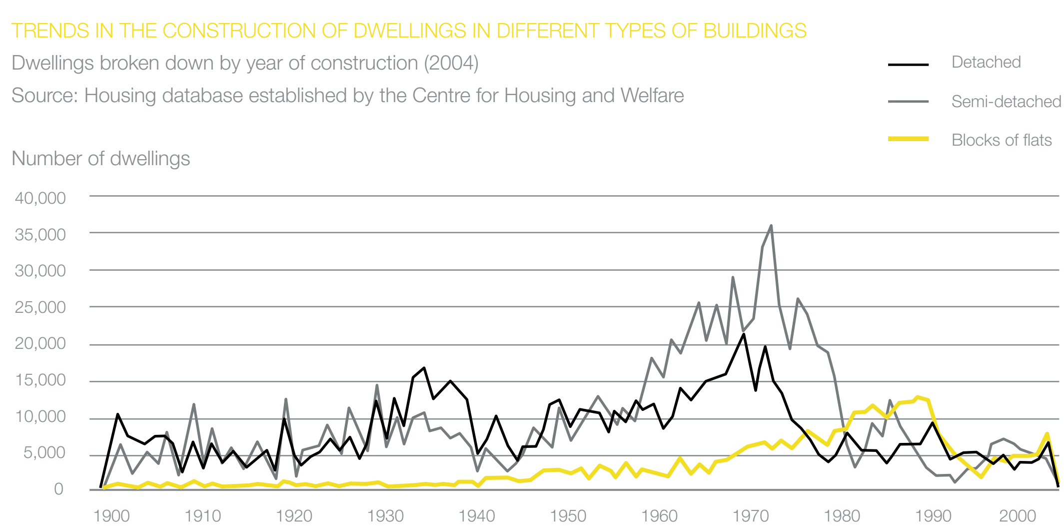
Before 1939	34%
1940 – 1959	13%
1960 – 1979	40%
1980 –	13%

- Average size of single-family

ill. 234
The Danish Housing Market
(Hans Kristensen, Housing in Denmark, 2007, p. 24)

houses 139 m2

From the architectural point of view, few types of single family houses were developed throughout last 100 years such as “the classic villa, the Better Building Practice house, the bungalow, the master builder house and the package-deal house” (Kristensen, 2007). Cities are characterized by their look since usually one or two types of these houses are dominating setting the aesthetic and character of the town



ill. 025
Trends in the construction of dwellings in different types of buildings
(Hans Kristensen, Housing in Denmark, 2007, p. 13)

1.2.3
TECHNICAL ASPECTS

For a complex project Zero energy prefabricated object it is necessary to create overview where technical requirements are gather. This text is also serving as technical guideline for later analysis of different prefab system.

1.2.3.1
TECHNICAL DEMANDS/ ZEB

For the sustainable building it is important that the consumption of the energy as low as possible regardless if it is built onsite or prefabricated. Thus to make a clear goal for the prefabricated system in this assignment, it is necessary to define consumption of energy. Thus to make building competitive with current sustainable buildings appropriate to design a prefab system according to Zero Energy Standard while energy consumption must meet energy regulation of BR-2020 by means of passive strategies which means that energy used for heating, ventilation, domestic hot water and user related appliances does not exceed 20 kWh/ (m2 per year).

Furthermore, it is necessary to define the Zero Energy Standard. Thus we define Zero Energy Building standard for the designed prefab system which fulfills the demands on annual basis while connecting to the grid. Which means that such NET-ZEB building consumes as much energy as it can produces with active energy solutions during the year, while materials' embodied energy, assembly and demolition are not taken into account.

However, for the final results it is necessary that prefabricated system is tested as building. Thus for the sake of testing, the building is placed suburb area of Aarhus where it should fulfill energy demand for heating, domestic hot water, building operation, cooling and user related appliances. This energy demand is covered by the use of integrated active solutions that can be prefabricated together with the system, which means that the most suitable solutions could be photovoltaic while wind mills have unpleasant visual impact and heat pump and thermal solar energy are not economically acceptable due to cheap district heating in Denmark.

Conclusion

Goal is that prefab system is designed in a way that when all the elements or modules are merged together form a building according to Zero Energy standard in various compositions.

For Zero Energy Building it is necessary that building meet energy standard of building regulation 2020

For this project Zero Energy Standard is defined so the building must create as much energy as it is used per year via active solutions

1.2.3.2
INDOOR CLIMATE

It is very important that while creating sustainable building with low energy consumption where envelope is detailed with maximized air tightness and with all active energy producing solution for greater performance, the comfort of users is not set aside. Thus the prefabricated system is designed in a way that it can create building with pleasant indoor environment. However it should be taken into account that even though that the building will be tested in the suburbs of Aarhus the system must be applicable across Northern Europe/ Denmark, thus indoor climate results can vary. Nevertheless the building created with prefabricated system must meet indoor climate demands according different aspects.

Atmospheric comfort restricts the quality of indoor air regarding air pollution with CO2 and OLF . According to acceptable values the mechanical and natural value must be designed. However, at this point the size of test building is not decided; furthermore, the idea of prefabricated system is to be flexible and be able to construct buildings with different shapes and volumes for different users, thus ventilation system must be adoptable to various circumstances. However, as a tool to determine values in the tested object BSim software is used.

Thermal comfort is regulated by BR 2010, where it is saying that building must be designed so the human activities can be done at comfortable and healthy temperature. According to BR 2010 26 °C should not exceed 100 hours, while not more than 25 hours exceed 27 °C. To test building the BE10 software is used, where temperature during the wintertime should not be lower than 21 °C (Bygningsreglement, 2014).

Acoustic aspect of indoor environment is ensuring that designing system will provide that building ensures satisfactory sound conditions for the users. This means that prefabricated envelope and partition wall must cancel exterior noise or noise from the neighboring rooms (BR10, 2010). However, further investigation of acoustics is not conducted due to assumption that prefab system is not able to create so big volumes that long reverberation time can accrue.

Daylight conditions provide that interior has sufficient daylight according to demands of different tasks. This means that daytime space such as living room, kitchen, dining room and working space needs daylight factor of at least 2% . Thus for the test building the daylight analysis are made with Velux Daylight Visualizer software. However, it is expected that prefab system is not able create the same daylight conditions due to different users' wishes regarding windows, hence it is expected that any future building created with prefab system is tested.

1.2.3.2
CERTIFICATION

When designing sustainable building it is appropriate to go extra mile and obtain certificate for it, which ensures the quality and gives building added value. Thus this would be ideally for prefabricated system that can create various types of family houses.

In Europe the two most represented certification systems and assessment methods are BREEAM with origins in United Kingdom and DGNB from Germany. DGNB system is operating for a decade and in 2009 was also appointed as an official Danish system by Green Building Council Denmark. Thus the project would benefit from this system the most.

ill. 026
DGNB Criteria Scheme

Furthermore, DGNB is very flexible and is offering pre-certification that optimizes the project very soon in the process and is assaying six quality aspects, which makes it very holistic and gives opportunity to various projects even in the scale of cityscape. Such precertification can also be updated to a full certificate. The six quality fields are environmental, economical, sociocultural and functional, technical, process and site quality (GBC, 2015):

Environmental quality field covers Life Cycle Assessment (LCA), local environmental Impact, environmental friendly material production, primary energy demand, drinking water demand, wastewater volume and land use.

Economic quality covers building-related lifecycle costs and value retention, suitability for third party use.

Sociocultural and functional quality covers thermal comfort, indoor air quality, acoustic comfort, visual comfort, user influence on building operation, quality of outdoor spaces, safety and security, handicapped accessibility, efficient use of floor area, suitability for conversion, public access, cycling convenience, design and urban planning quality through competition, integration of public art and site features.

Technical quality covers fire prevention, indoor acoustics and sound insulation building envelope quality, backup capacity of technical building systems, ease of cleaning and maintenance, resistance to hail/storms/flooding, ease of dismantling and recycling, pollution control and noise emission control.

Process quality covers comprehensive project definition, integrated planning, comprehensive building design, sustainability aspect in tender phase, documentation for facility management, environmental impact of construction site/construction process, construction quality assurance/quality control measures and systematic commissioning.

Site quality covers site location risks, site location conditions, public image and social conditions, access to transportation, access to specific-use facilities and connection to utilities.

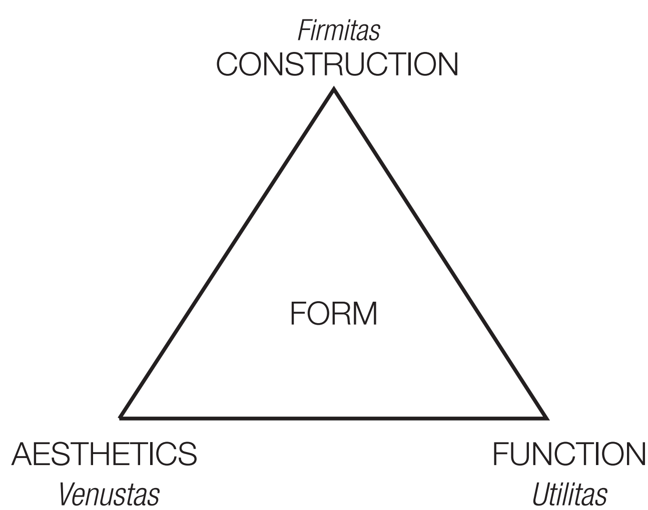
However, even though that prefabricated system can perform well in aspects of safety on building site, performance of building envelope, dismantling and recycling-which are some of our main goals, there are too many variables regarding environment. This derives from the idea that prefabricated system must be able to be applicable in any environment, thus it can be assessed in some fields of certificate. For such examples DGNB is having additional category called DGNB serial certification. It is ideal for prefabricated houses, where buildings have same construction principle but different locations (DGNG. 2015).

1.3 PREFAB FORM

Marcus Vitruvius Polio, an architect and a civil engineer in his treatise about architecture know today as “The ten books on Architecture (De Architecture) formed a Vitruviuan Triad that is still valid today. It formed 3 basic elements necessary to create a good architecture or simplifying a “form”. Architecture would fail if it would neglect one of those elements which are: Firmitas, Utilitas, Venustas that could be translated as Construction, Function and Aesthetics.

In our report we would like to define the theme of this project by analyzing different aspects according to Vitruvian virtues mentioned before. In this way, function characteristics such as: user group, floor areas, floor number, flexibility and democratic design approach will be discussed. Thereafter while analyzing aesthetics we would like to describe current aesthetics of prefab architecture and also discuss what tectonic values could become of prefabrication to embrace the methods and assembly systems used in the project. Last but not least, prefabrication theme will be analyzed from constructional point of view. We would like to analyze details, assembly and disassembly methods and finally possibilities regarding additive architecture.

This chapter is created in order to inform us what are the necessary elements that our system has to cover in order to have a chance of becoming high quality architecture or in other words could fulfill triad demands.



ill. 027
Vitruvian Triad

1.3.1
FUNCTION

1.3.1.1
USERS

Danish people are forced by weather to spent significant amount of time indoor, especially during the winters; therefore they appreciate spacious living room with high quality interior. Thus the average household in Denmark has 109 m2 per 2,1 person. Hence Denmark is a country with highest ratio of square meters per resident. Furthermore, the size of average single family house is 156 m2 and still increasing for six square meters per 10 years where every year there is build around 8000 new single-family house and in addition existing one are extended.

Moreover owning household is deeply rooted in Danish culture, where 63% of population poses own home, which means that detached family house is most common housing type. However, according to statistics, only 0,6 person per household is a child, which means that most common household consists of a middle-age married couple where children moved out (Kristensen, 2007). Also according to Kristensen the prediction is that single-family house will remain most common type of housing in Denmark, since it is a place where people can really enjoy freedom with no constraints.

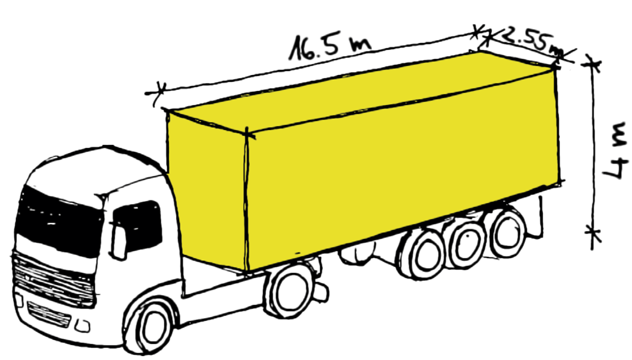
1.3.1.2
FLOOR AREA

After analyzing 56 different projects regarding construction and floor area from the book “Prefabricated houses”, we found out that this prefabricated buildings are designed in various of sizes but in average size of 109,6 m2, with the biggest floor area of 300 m2 in building made out of steel and wooden construction. The analyses are showing that more than half of those buildings are made out of steel construction. Furthermore, the focus is also on modular building, since the modules were more comparable between each other. Thus the relationship investigation between square meters per module and material used for construction is showing that most modules with bigger floor areas are made out of steel or combination of steel and wood or made out of precast concrete. Moreover, the average size of the unit is 38,5 m2 and usually around 3 units are used to create the building, while the biggest module has 93 m2

As seen in the paragraph above there are no restrictions on the size of the prefabricated regarding the technologies, since the building can be made using different systems (components, panels, modules), combination of them and even in a combination with traditional onsite construction. However, to increase the efficiency the parts must be as big as possible, which arise problems with transportation. Thus it is necessary that systems are also designed according the maximum measurements of the truck trailers (ill. 028).

Furthermore, it is possible to notice that the size of modules relate to the flexibilities, which means that big modules can be merged together only in few different compositions and they can quickly start to resemble on stacked shipping containers. However, this does not mean that the examples with big modules does not have well design exterior, interior or plan, but if the same type of module would be used for the other project there is not much possibilities to design different building according to different users’ needs.

Moreover, during the lifetime, people need and afford different amount of space. Therefore the possibility to expend prefab building can be additional value. For example, young person or a couple does not have a need for a bigger house until they have resources to establish family and increase floor area of the house, thus they can start the life with smaller and cheaper house. In that way the prefabricated building must be designed, to allow easy and efficient attachment of new elements. With system that allow extensions the aesthetic is improved, prefabrication allows the same expression of the building and new extensions.



ill. 028
Maximum measurements for road transportation

1.3.1.3

FLOOR NUMBER

In the past, most distinctive prefabricated buildings where similar to trailers or containers, whit not much more than one floor. However, current technology enables to build to impressive heights. Austrian company KLH is capable of creating up to 9 stories so far with wooden prefabricated components only with few weeks of onsite work. Furthermore if the prefabricated components are made out of steel or concrete the heights are even more impressive, not just because of statically reasons, but fire safety. For example Chinese company called Broad Group made 30-story hotel in 15 days (Abc news, 2015). But they used many smaller components to achieve this, thus they had to mount every column separately on the floor. They also made plans for the world highest building with a height of 838 m, but currently they are in process of getting permits from the authorities. However this building is made with modular system that will allow to erect it in 3 months (Huffington post, 2015), in the opposite with the currently highest building, Burj Kalifa, that was build in 5 years. On the other hand, it is much more efficient to build prefabricated tall building than one or two story high ones, especial if the larger part of 30-story hotel has the same floor plan. Furthermore, when building with components, the columns are supporting slab above, and new columns are mounted on this slab, and so on. However, if the building is made out of modules, it is usually that each module has floor, walls or columns and slab, and then on this slab, floor of the higher module is attached. Thus the construction is doubled (ill. 029).

Conclusions:

Conclusion on users

- *During the long history Danes appreciate own space where they enjoy spacious interior of the privately-owned detached house.*

- *Most of the households consist of the couple where child moved out, which means that suddenly the house could be too big for two people, especially when they will get older. Also partly uninhabited house is unnecessary expense because of heating.*

- *The prediction is that single-family house will remain most popular type of housing in Denmark (Kristensen, 2007).*

Conclusion on floor area

- *In modern prefabrication there is no restrictions about size of the building; however, there are restrictions about size of a single module because of the transportation, while building with components or panels make transportation easier and more efficient.*

- *To achieve greater flexibility the building should be designed with many smaller modules instead for example 2 container-like modules.*

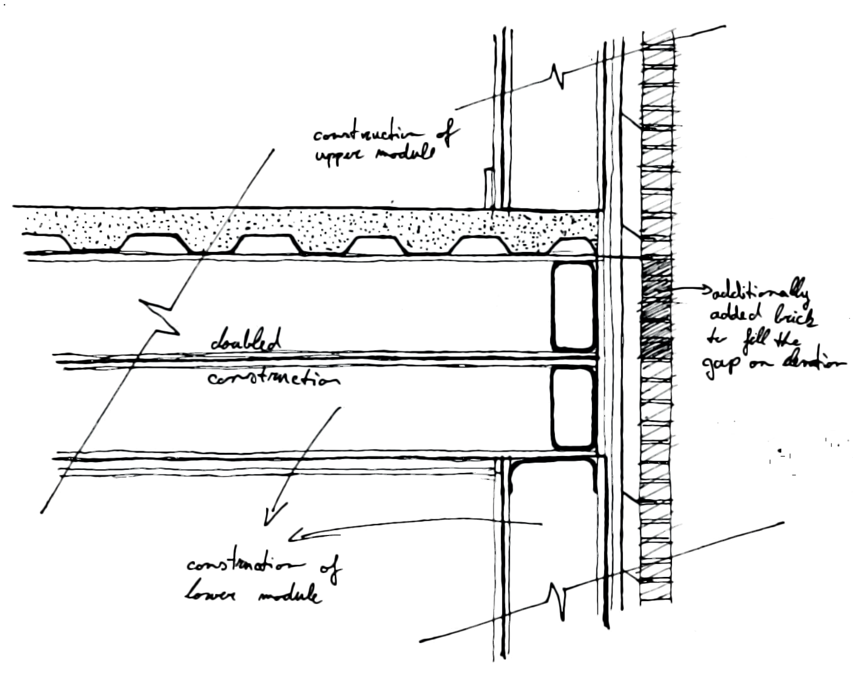
- *Building system should give a possibility to increase floor area with the same system when needed. Thus the esthetic and sustainability factors are increased.*

Conclusion on number of floors

- *Height of the building depends a lot on the material used and fire-safety regulations.*

- *The efficiency of the building erection is related to the principle of the construction, which mean smaller pieces needs more connections to be done on the site. The problem of modular building is that construction is doubled.*

- *We would like to find the balanced way to design a system that will solve the problem of doubled construction, while keeping the amount of elements needed as low as possible.*



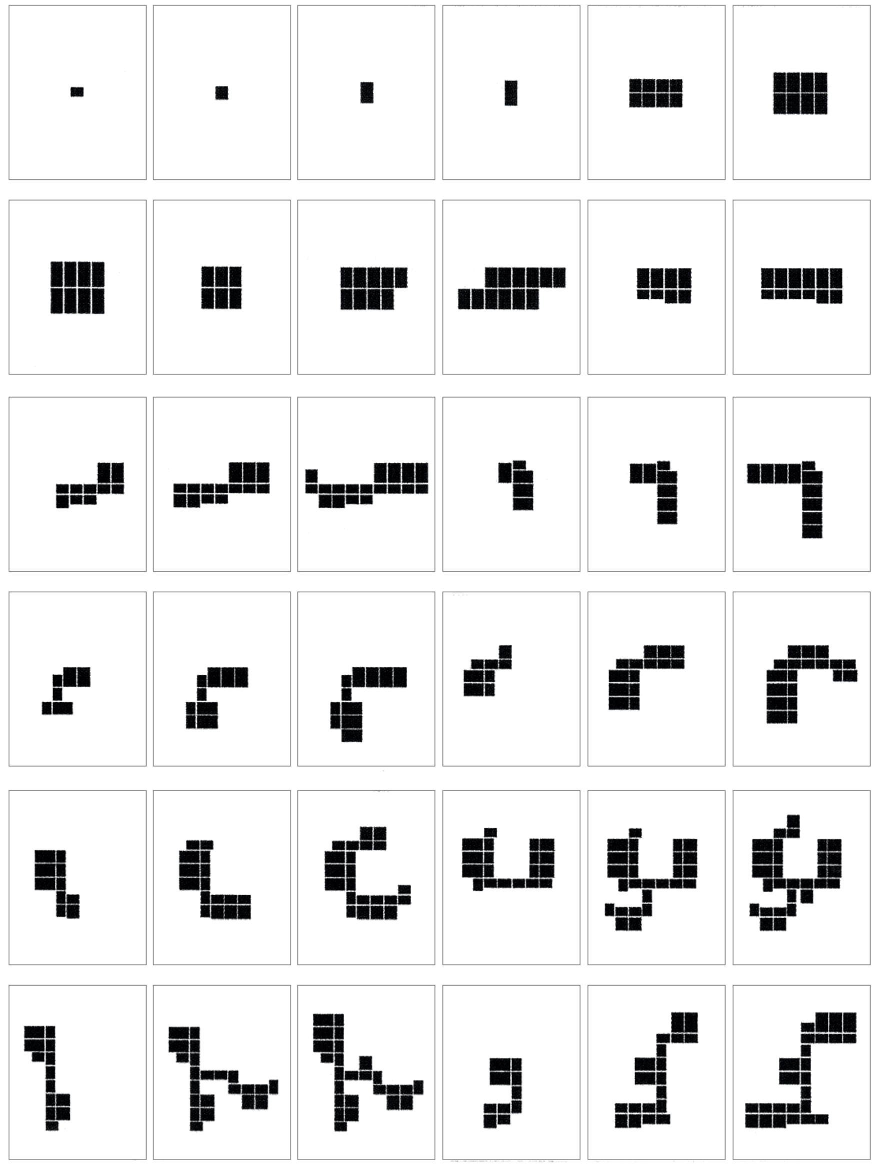
ill. 029
Elements discussed in every concept

1.3.1.4
FLEXIBILITY

As mentioned in chapter 1.3.3 the building can be prefabricated in certain levels of prefabrication. While most efficient are modular elements, they are at the same time least flexible. On the other hand, building made out of prefabricated elements has many small parts, which sometimes resemble on the traditional onsite construction, but at the same time it is also the most flexible way, thus it can adapt to better to different clients and their wishes; thus it is offering more freedom in the design. Moreover, for achieving significant cost benefits it is necessary to repeat production, thus there is not much options with stacking two container-like modules. Hence, the fact that building can be designed according to their needs is not only reason to choose elements over modules, but also the aspect of individuality.

Therefore, it is necessary for successful prefabricated architecture that can offer great flexibility while being efficient both time and money wise. Thus one of the systems that is dealing with the problem of flexibility is Espansiva system by Jørn Utzon. It could be said that this system is combining modular and element or small panel system. Furthermore this system is offering modules in three different sizes, while all of them are compatible between each other. At the same time this modules are fairly small, which means that to create a house of around 50 square meters at least 4 modules are needed. Thus, there are many options for different compositions and greater individuality.

Moreover, one of the ways how to achieve greater flexibility, and that is also one of the aspects of Espansive system, is additive approach, which is also described in chapter 1.3.3.3 Additive architecture. This allows building to expand according to clients needs also during the building's lifetime.



ill. 030
Espansiva system by Jørn Utzon

1.3.1.5
DEMOCRATIC DESIGN APPROACH

In the architectural practice the relation between architect and client can often become complicated and one of the reasons is even thou architect offer acceptable solutions for client needs, client want to be more evolved in the designing process depict a fact that he or she does not have proper knowledge. However, prefabricated architecture can offer pre-designed parts for houses that could easily be chosen by client under supervision of architect, who can consult what parts are needed according to the client's wishes. Thus building can be created in the same way as kitchen.

To achieve such easy design all the aspects should be solved before the designer of the prefabricated system knows clients exact wishes. Thus the ideal solution is that static is solved as module that can be clad with different kind of external panels with or without opening. Furthermore, it is necessary that there is a solution for installations that can be applied in any kind of building composition and that external envelope has certain isolative characteristics to fulfill energy demands. In that way architect and client can solely focus on the design. On the other hand, even though that there were attempts to create such architecture, they were either not able to compete with common onsite constructed housing because of the cost, low flexibility or poor detailing and aesthetic. Thus our goal is to create well designed architecture that will allow client to understand and participate in the designing phase.

1.3.2

AESTHETIC

When prefabrication is discussed, many of the people nowadays will automatically have a similar image of how it looks like and how it could be applied. This general public opinion is even stronger when prefabrication for housing purposes is being analyzed. By looking at both the market and history of prefab single family houses there are two kinds of prefabrication.

First type is mainly associated with container-like architecture which most often is part of some sort of modular system. In this case highly prefabricated modules are assembled in a factory and thereafter transported on site. Because of transportation limits, depending from the country we discuss, we have rather long and narrow units that are then connected to others or stack on each other. The expression of such architecture usually limits to the cladding or the way how each container-like module in positioned regard rest.

Because of such limitations architects often resign from using such system since they feel restricted. Such design could hardly be an expression of individual style and rather works in non-domestic sectors where economy stands over individualistic look. On the other hand, there are examples such as Berkshire House or Dwell House which despite their modular origin, it is hard to distinguish it from building procured in traditional ways. Nonetheless, there are three problems with such buildings. First of all, the amount sitework in such cases is very often much more extensive, almost comparable with traditional methods. Secondly, the uniqueness of each module regarding its size and materials is somehow contrary to the prefabrication ideology where some sort of system makes the elements repetitive and easy to manufacture. This could be on the other hand justified in some random cases in which BIM models with automatized systems can work regardless non repetitive nature of each unit. Lastly, when such architecture is analyzed the question appears “is it tectonic?”. Prefabricated modules that are “hidden” among traditional methods in some ways could be received as “cheating and pretending” as something that this is not.

Another prefabrication method focus on smaller elements or panels that gives the architecture more freedom design wise. This approach is widely used in non-domestic buildings however for single family housing it seems less attractive. There are plenty of reason why such situation has place and most of them are already described in point 1.2.1.2 Shortcamings. When it comes to the design of a home, householders approach this subject very personally. This is the way how they could express themselves or show their status. It is an investment for the whole life. Prefabricated small elements gives the freedom of big flexibility and uniqueness. By looking at the history for instance at Joseph Eichler who sold thousands of prefab houses, he designed a prefab system that gave big freedom of design. Additional frames that were part of the design already gave very interesting expression, making it easy to create interesting, good looking objects. This example shows that good design of construction system is as important as the aesthetics of panels and moreover the construction itself could be a characteristic element of the house. The only problem with prefabricated elements is high complexity of assembly and disassembly almost comparable with traditional method.

Conclusions:

The ideal solution would be to design a system that would integrate simplicity of modular design with flexibility of architecture made of prefab elements. The key elements to successfully design such system would require:

- *constructional modular system that is part of the house expression*
- *smaller elements or panels with easy mounting methods*
- *the balance between uniqueness and repetitiveness*

1.3.2.1

TECTONIC

The definition of tectonic value in architecture is something between the honesty of construction, while use of the materials and good understanding of structure expressed with joinery details and visibility of selected construction parts. The right mixture of these elements creates rare feeling when people can experience different spaces of the building while the harmony and expression is being preserved on equal level.

In prefabricated architecture this expression and harmony can be demonstrated in various ways. Howard T. Fisher founder of “General Houses Corporation“ was describing the prefabricated architecture as it should embrace the process of how it was created in order to achieve authentic aesthetics in architecture. This idea in prefabrication can be done by carefully analyzing joinery between elements, panels and modules. Just like Eichler made the aesthetic value out of wooden repetitive visible beams, this could be translated into another design where construction is equally important as “skin” or shape.

Another example of such approach is represented by Jørn Utzon in his design of Espansiva, where wooden columns in interior are additionally embraced externally by small recesses in between elevation panels.

The idea of making elements visible is however not enough to achieve tectonic values. It must be remembered that detailing journey between elements must behave like an added value and not only present naked construction. Ideally, the construction and paneling system could work together complementing each other. In such way tectonics would evolve from the natural combination of each element and this would represent more than just parts visibility.

ill. 031
Dwell House

ill. 032
Berkshire House

ill. 033
Mountain Retreat

Examples of houses made by Resolution: 4 Architecture

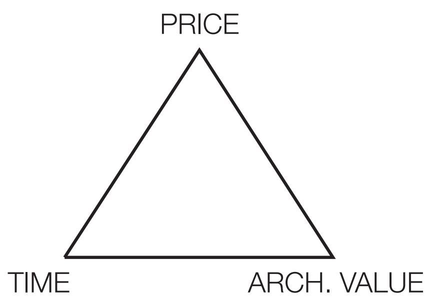
Modular system that looks like modern architecture built on site

1.3.3
CONSTRUCTION

The third part of Vitruvian Triad is dealing with construction and technical performance of architecture. Thus in order to create innovative solution for prefabricated system it is crucial to pay a lot of attention for this aspect as well. Hence this chapter in a guideline for further analysis of different prefab system. Furthermore, while talking about buildings construction it is necessary not to overlook the problem of cold bridges, which is still present in current in prefabricated building, mostly because construction an envelope are merged in one surface (ill. 035). Thus integrated detail solving is vital during the process, also because of our goals which are to create flexible prefabricated system with additive abilities during the buildings lifetime and at the end the possibility of easy and sustainable disassembly. Hence further chapters are looking deeper into current prefabrication principles and elements, while also studying additive and disassembly aspects.

1.3.3.1
BUILDING PROCESS

Process of creating a building, whether it is build on site or it is prefabricated, is always complex task with many different participants as well as different aspects and conditions that has to be taken into account. However, all this factors are usually very various in on site construction, but in prefabrication process they are easier to predict or control. Thus according to R. Smith not all issues are critical for every project, but at the end it should fulfill principles of construction and their effect on productivity (Smith, 2010):



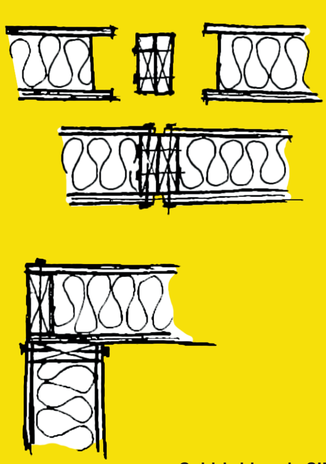
ill. 034
Prefabrication triad

- Cost: capital and operation investment
- Labor: skilled and unskilled human workforce
- Time: Schedule or Duration of the project
- Scope: extent or breadth of the project
- Quality: design and construction excellence
- Risk: exposure to potential financial loss

But to simplify these principles which are depending on each other, could be presented as a triad (ill. 034). However, all this principles are closely connected and change in one can affect others. Hence the balance between them is necessary to achieve well functional prefabrication design that is able to fulfill most of client's needs and at the bottom line his or hers budget. Therefore this project is seeking for hidden benefits and solution because we believe that prefabrication potentials are still not fully exploited. Thus the bases of the principles are described below to gain crucial knowledge and then described in detail during the design process.

Time

It could be said that time is the least abstract of the three factors from the triad. Thus it is not hard to see from the examples (ill. 036) the difference and benefits in favor of prefabricated buildings. This advantage derives from a fact the earth work and preparation of foundations on building site can start and at the same time the rest of the building can be constructed in the factory (Smith, 2010). From the Gant chart it is also visible that in the case of onsite construction the construction phase was executed partly in winter months and spring when the weather is not in favor of site workers, while workers in prefabrication factory has same conditions in any time of the year. Furthermore, with flexible design where standardize modules have integrated solutions for different situations they could be made in advance waiting to be ordered for the new project. In that way also detail design phase could be shortened.



ill. 035
Cold-bridges in SIP system
Wall panels connection detail
Corner wall connection detail

ill. 036
Gantt chart of project duration for two similar projects.
Top one is constructed onsite while the bottom one is showing the duration for prefab

Price

After discussing significant savings of time and with having in mind believe that “time is money” one could consider that prefabricated building would also have noticeable savings. But the practice is not like this, since the price depends beside on time also on the architectural value and its solutions. Furthermore, the aspect of price also consists of expenses for labor/work, facilities, building site and transportation. If this is all summed up, the price is not much different, from the on-site building. For example on-site construction need smaller crane for more but lighter materials, while prefabricated object demand bigger and more expensive crane, but on the other hand it carried out less lifts, since there are less building parts. Furthermore, construction solutions and materials must be more advanced to achieve better architectural value and thus avoid repetition (Smith, 2010).

Form

“Prefabricated architecture requires the creative abilities of architects, engineers, fabricators, and contractors to envision a method to increase both the quality of design and production to the mutual benefit of both” (Smith, 2010). However, the attempts to find the perfect balance started decades ago, and could be said that the final formula for the success of housing prefabrication is still not found. This could be justified through the study cases, where buildings are either with high architectural quality but usually with high price and low rate of prefabrication (see ill. 038) and consequently longer production time, or the building with low price and short production time while without chance for the individuality and consequently also low architectural value. Moreover, the second example is also the main cause for the stigmatization of prefabricated modular buildings as “container-like architecture” (see ill. 037).

On the other hand, in comparison to the on-site construction, prefabricated building has fever construction failures and higher quality of detail execution due to controlled environment and better working conditions inside the factory.

Conclusions of triad:

In the brief presentation of three aspects of prefabrications, it is visible how closely they are all related and that even smallest modification in one can completely change the final result. However, for the propose of this thesis the main focus will be on solving architectural value, since one of the problems that prefabrication buildings have is the leak of interest because of the bad reputation. Furthermore, with holistic approach of integrated design the goal is that the increased value would also be in favor of either price, time or both principles.

ill. 037
Two modules stacked together, by Olgga Architects

ill. 038
House of steel and wood by Ecosistema Urbano as an example of prefab architecture according to client’s needs

1.3.3.2
PREFAB PRINCIPLE

Elements

Prefabricated elements are designed in various forms depending on their size. For the differentiation of systems there are general names according to the level of prefabrication of each element. However, there are no standard names, but according to R. Smith the elements are classified in components, panels and modules (ill. 139-141). The level of prefabrication determines the amount of site works. Thus smaller elements such as components need more finalizing in comparison to fully finalized modules where earthwork is almost only onsite task.

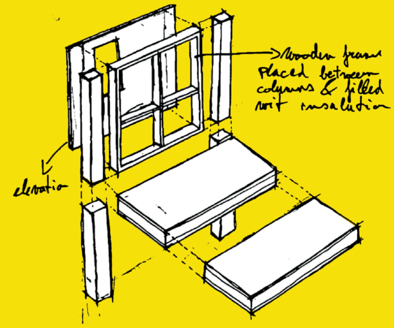
Components allow high level of flexibility in the design and handling them on the site. However, because of the high quantity of different components needed for the erection of the building the confusion can occur in the designing phase as well as on the site. Furthermore, more parts mean more joints and details that take time and make more possibilities for the mistakes. Basically such building is build with prefabricated columns and construction like this needs many different parts (ill. 139). One of the component systems that are kind of a hybrid between components and panels is MHM or massive holz mauer (eng. massive wooden wall). With this system massive wooden panels factory can produce elements that does not need column structure, however, it is still missing other building elements such as insulation or windows for the external walls

Panels can be designed as construction, non-load bearing elements or combined in two dimensional products. Such differentiation appears because each panel is used for the specific purpose such as external wall, partition wall, floor, roof… Panels can also have integrated wiring and cable utilities that reduced time for installing them on site. Furthermore this means that later insulation cannot be sacrificed for the sake of installed cables. One of such panel systems that are very common in prefabrication industry is Light panel system, where it is produced from wooden or light metal frames either with or without insulation and membranes depending on the purpose.
One of the panels systems that was also used by Frank Lloyd Wright is Structural Insulated Panel or SIP. This system is made as a sandwich panel with two OSB board in several thicknesses variations and EPS PUR insulation in between. OSB boards could also be replaced with fiber cement, metal or gypsum boards. This system proves to be stronger, more fire resistant and with better insulation properties.

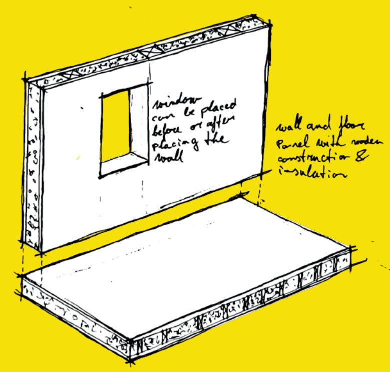
Furthermore, one of the panel systems that is very common in high rise buildings is curtain wall or glass facade. However these are usually non-load bearing and made out of glass and metal. Thus this system is not relevant for our project since they are domain of the office and high-rise buildings. On the other hand, most prefabricated panels come to the site without finalized facade therefore Cladding system is necessary to provide necessary protection from harsh weather and surrounding to the interior and construction. However, it is important that like all prefab elements it is easy and efficient to install and that it is installed in a way that does not damages inner layers for example vapor barrier membranes or insulation

Modules have the highest prefabrication level from all described systems. Hence they are most time-efficient. However, the name module does not described standardize unit in building sector, but it is representing a unit designed according each companies design, that is most suitable for their technologies. However, the larger the module is the higher level of finishing is possible to achieve. On the other hand, smaller modules offer more flexibility and customization of the final form of the building. Furthermore, size of the module is not based only on designing decisions but it is also restricted by the means of transportation. The material for the module construction depends on the purpose of it. They can be made out of precast reinforced concrete with great durability, but they are much heavier then framed constructions made out of steel or wood. However for the residential architecture the last one is more common with the ability to build up to three stories within a reasonable economical frame, while the metal frame construction is used for commercial buildings, since it is possible to build higher building with better performance.

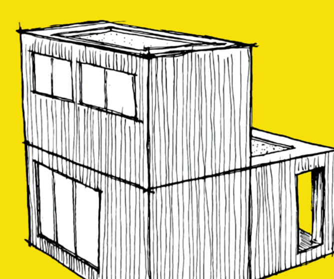
Module element can be finalized to high level thus it can includes beside the construction of floor, roof and walls, complete insulation with exterior and interior finishes, windows, doors and installations. However, to ensure that elements are properly protected during transportation and installation extra material must be used for wrapping and additional support.



ill. 039
Component system



ill. 040
Panel system


ill. 041
Modular system

Furthermore in prefabricated industry it is very common bathroom module. Such module cannot be used only in prefab buildings but also in onsite constructed ones in order to save time. However, as in most of modular industry, the uniqueness is truncated, unless it is ordered bathroom; but in this case the production is not efficient any more.

Conclusions:

- *Prefabricated elements allow easy and fast assembly on site while having high architectural value and ability to answer to clients' needs. Furthermore because elements are made in controlled conditions construction failures reduced.*

- *Most flexible is component system but on the other hand it requires vast amount of different elements; which also means that more connections must be done on the site and thus the construction time is longer. However, modular system, as a system with biggest elements, provides fast assembly on site, but it is not flexible toward clients' needs. Therefore, for the successful project it is necessary to find right ratio between flexibility and efficiency.*

- *For greater flexibility building system should be designed to allow 1 or 2 stories with different type of roofs, while keeping the amount of unique elements as low as possible.*

- *The goal of the assignment is to find a solution that will provide additivity, thus the construction should allow connecting new elements to the existing construction.*

- *Elements and the connections between them should be designed in a way that cold bridge problems are solved.*

- *Last but not least, the system in this assignment must reach zero-energy standard, while the goal is to use high embodied materials for permanent construction and low embodied energy materials for temporary elements.*

ill. 042
Construction of multi-story modular building

ill. 043
Prefab building made in elements system

1.3.3.3
ADDITIVE ARCHITECTURE

“A consist exploration of industrially produced building elements is only achieved when these elements can be added to buildings without the components in any way needing to be cut or adapted” (Utzon, 2009).

The words “additive architecture” Jørn Utzon wrote on the wall of his Sydney-based office while working on project of Opera house. This principle was later used also in Farum town center, Jeddah stadium, additive furniture and more. But one project that this assignment can relate is Espansiva building system with modules in three different sizes and great flexibility, where it is possible to clad building in different facade materials. Same also goes for roof materials and for different door and window components. Thus all modules can be combined together and form a house with possibility to add new modules. The possibility of adding modules is due to external wall design, where prefabricated wall panels are mounted to the construction with French screws that allow panels to be easily removed later (Utzon, 2009).

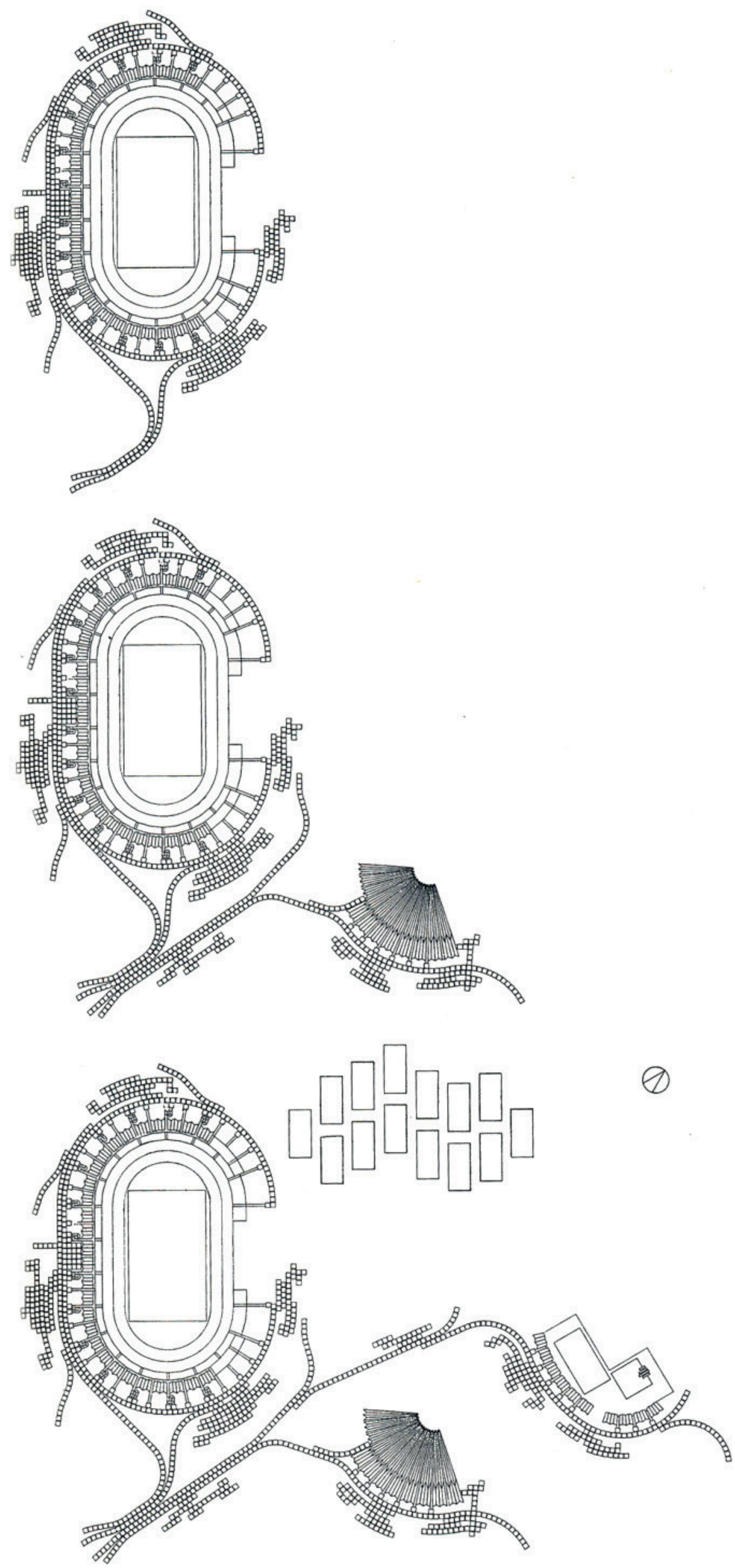
Thus it is possible to see that in order to ensure additive possibility it is necessary that the way how elements are put together is not permanent, which ensure that elements are not damaged by adhesives. Hence integrated design is necessary, where details of joining different elements in different combinations are solved. However, one of the elements that were not solved during the design of Espansiva were installations, which are hard to predict since the use of modules are not predefined. Hence additive aspect of our assignment seeks to integrate installations in best possible way.

Conclusions:

Additive architecture is driving force of flexible prefabricated design, where building easily adopted according to clients needs

Key to efficient additive architecture is that building components can be connected easily with other components during the building construction as well as if additionally added

Because installations should be designed according to the purpose of modules it is hard to predict their position; however, to achieve the quality of final result it is necessity



ill. 044
Jeddach Stadium,
Saudi Arabia, 1967

1.3.3.4
DISASSEMBLY

Every object has certain life span, which in architecture usually ends with demolition. Moreover, waste material, either only wood or material with high embodied energy turned out to be with low value, because they are too hard to separate from other material. Thus everything ends up on landfills. Hence demolition should be replaced with less destructible and violent solution-disassembly.

Disassembly is crucial part of additive as well as sustainable aspect; hence it is one of the goals of this assignment. However, disassembly costs more and last longer. On the other hand, this problem could be solved with efficient deconstruction. But to achieve this, disassembly must start in the designing phase with assessment of construction methods and materials (Architectural Record, 2015).

Thus with clever design it is possible to shorten disassembly time and even earn money, since the waste material can become raw material. Furthermore, if building components are designed for the reuse, the material does not even have to be recycled. Thus disassembly should be executed with same process and tools as construction but in reverse order, which means that elements and materials should not be bind together permanently with adhesive medium but it should be executed with appropriate mechanical process that can be reversed, like using screws instead of nails or glue. This means that details should be carefully carried out to create strong but not permanent connection.

Conclusions:

Disassembly is necessary for sustainable project with additive aspect.

Key to successful disassembly is that it starts in project's designing phase and then it is carefully solved in the same way as assembly, which should gives the advantage to prefabricated buildings.

ill. 045
Destruction of
outdated building

1.4 PROGRAM SUMMARY

By specifying and gathering all our thoughts regarding aims, vision and motivation, this chapter is created in order to gather everything which is relevant regarding programming phase. Instead of trying to design prefabricated system that could be used to cover different types of buildings, we decided to focus on a single family house. We divided our program into 5 categories:

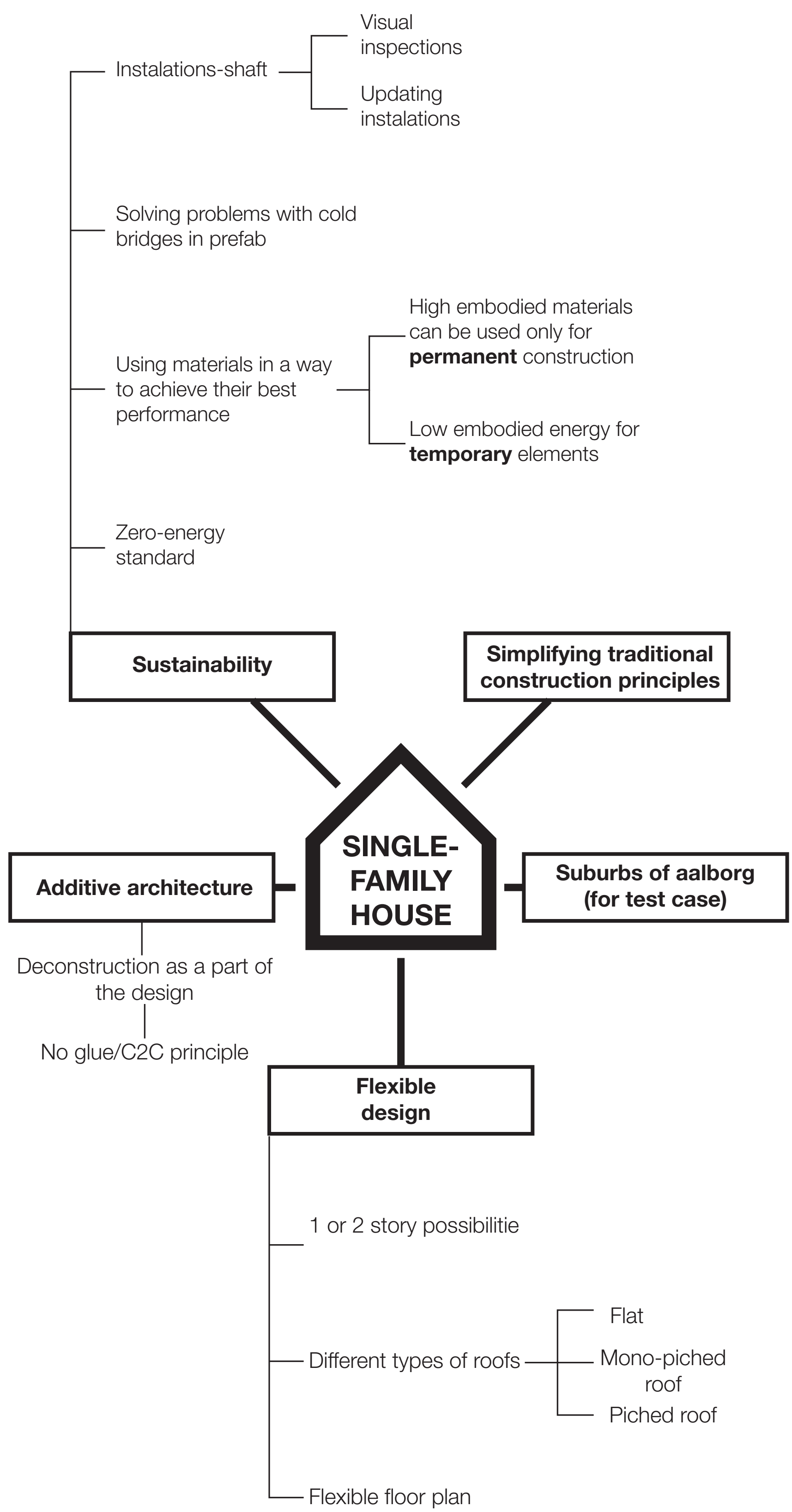
How it should look like?
Our design should give you flexible process of creation while working with various plans, roofing and up to two stories height.

How it should behave?
There should be an easy way to expand and modernize parts of our design, thus deconstruction should be a part of the design. Additionally as a cradle to cradle strategy we want to avoid glue, to assure not destructive deconstruction and high level of recycling.

What is the sustainability strategy?
This important topic is subdivided into few subcategories. First of all, we would like to achieve a zero energy standard as a way of how to assure high performance of our design. Secondly, we aim to use materials in a most efficient way. Finally, as an integrated design process we want to incorporate all technical installations within the design to assure their easy control procedures and modernization.

How it could be better than traditional building?
We will strive to simplify traditional building methods as a strategy to minimize mistakes caused by miscommunication and bad cooperation between many parties involved into the building process.

How it will be tested?
The design will be tested by designing a single family house in Denmark that will expand and adapt during its life time cycle.



ill. 046
Program summary graph

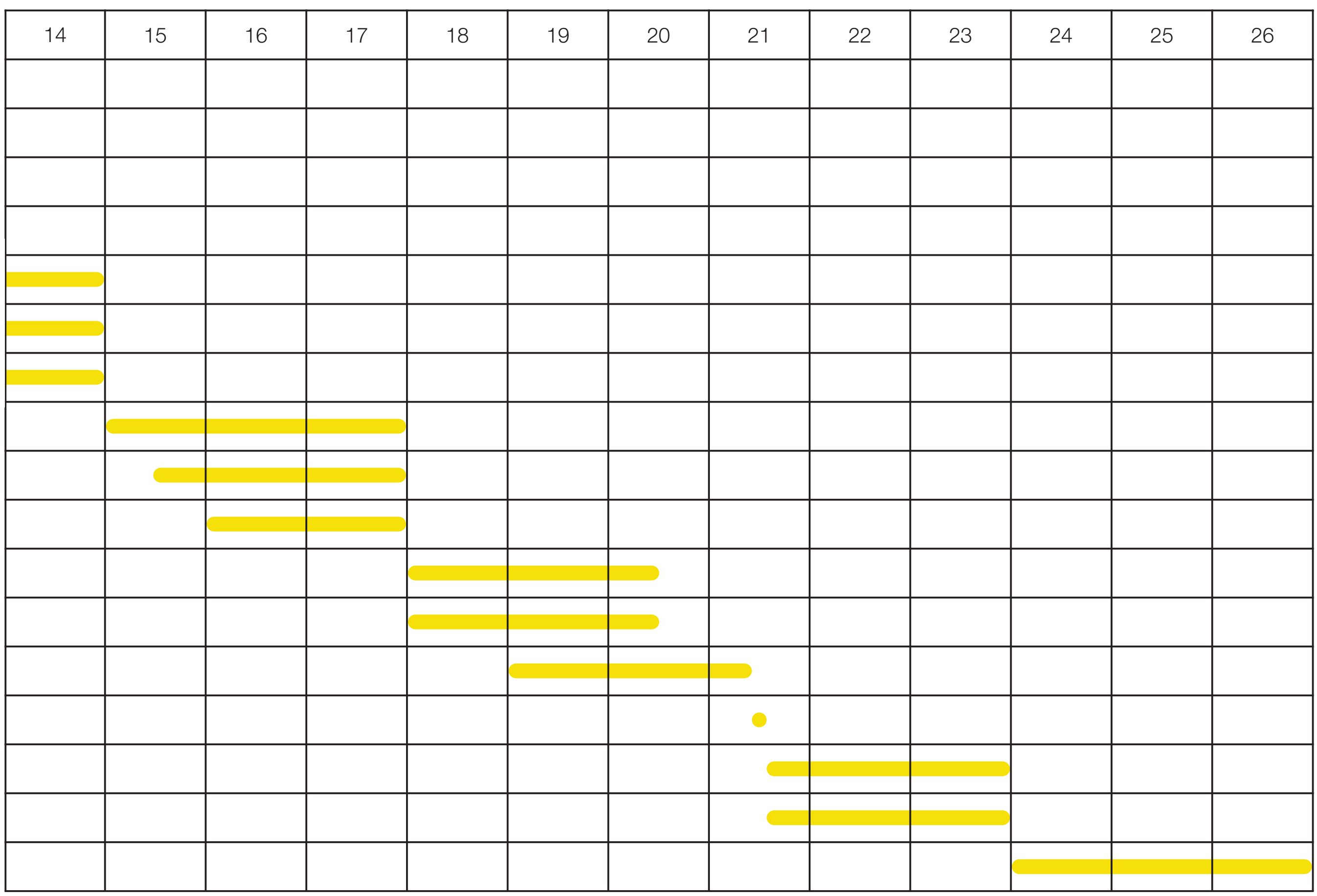
“PREFABRICATION IS NOT NEW BUT IT IS AN IDEA WORTH EXAMINING TO CREATE AN EFFICIENT BUILDING IN MORE EFFICIENT TIMELINES, WITH FEWER MATERIALS AND A LOWER COST.”

KEVIN BRASS

1.4.1

TIMETABLE

	Week	6	7	8	9	10	11	12	13 MIDTERM
PROGRAM	Problem								
	Analysis								
SKETCHING	Exploring different concepts								
	Selecting most promising concept								
	Concept development								
	Concept testing								
	Detail design								
SYNTHESIS	Design of single-family house in different stages								
	Single-family house testing								
	Detail design								
PRESENTATION	Cad drawings								
	Rendering								
	Finalizing report								
	Report printing								
	Physical models								
	Posters								
	Examination period								



ill. 047
Timetable

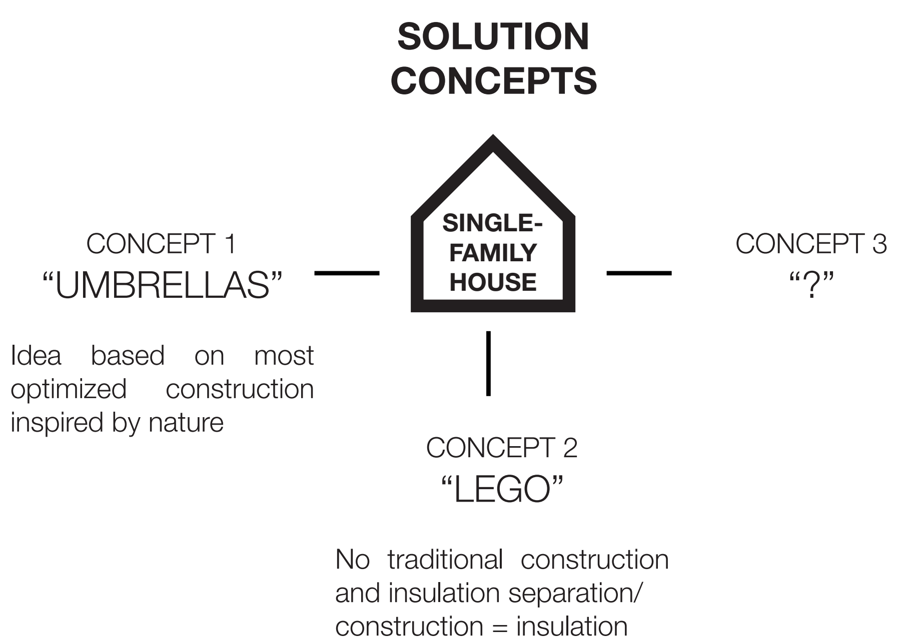
1.4.2

CONCEPT

Number of concepts is the outcome of different core features that were taken as the fundamentals for idea development.

In this way first concept, “UMBRELLAS”, derives from the idea of using materials only according to their main purpose in order to optimize their usage. Being inspired directly by the nature, we want to challenge frequently reoccurring problem in modular prefab architecture of double construction, and analyze natural solution to deal with such problem.

The second concept, “LEGO”, is based on avoiding another problem associated with prefabrication which are cold bridges and element compatibility. By merging materials that are responsible for construction with materials insulating the building we would like to eliminate both cold bridges and high-energy embodied materials such as concrete, steel or brick. At this stage this is just a basis for this concept will be developed in next chapters.



ill. 048
Different concepts that are discussed in this chapter

1.4.3

CONCEPT
CASE STUDIES

1.3.3.2

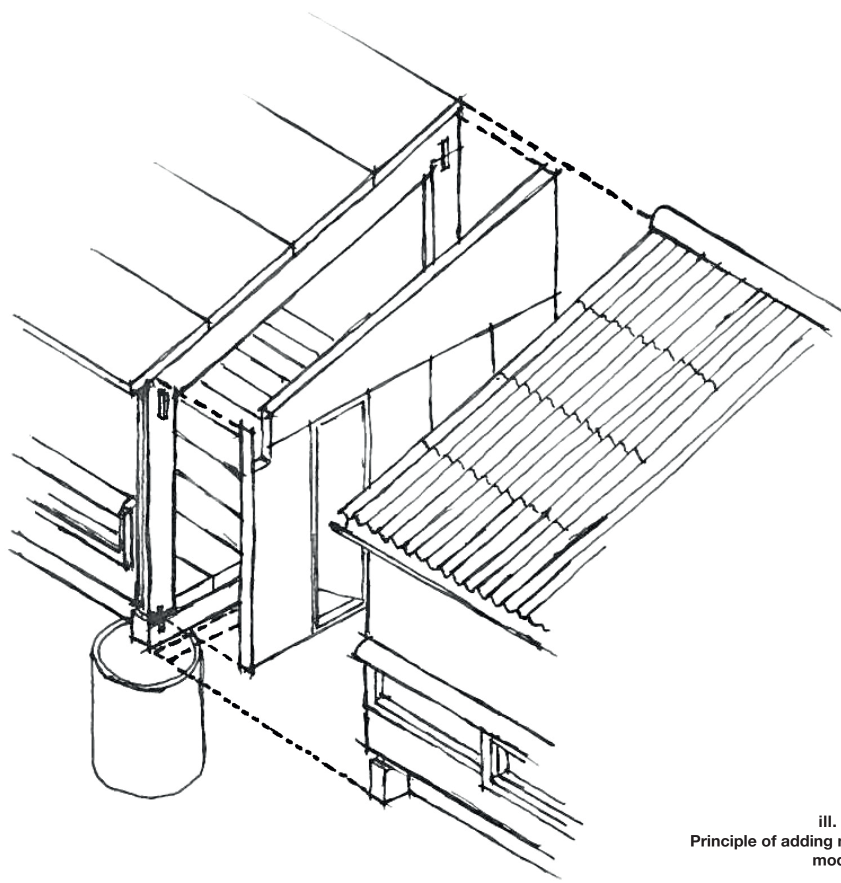
ESPANSIVA

Jørn Utzon, father of Additive architecture, designed Espansiva building system in 1969, which can create highly adjustable living units for different users or even school or motel, as long as it is one floor. This system is a result of years of family-house studies. They showed that the most suitable house that can offer the most while being as simple, is made out of posts or columns placed on floor surface and covered with roof. Such column house can be divided in modules with a size corresponding to the function of it. In that way, functional house can be designed with only three modules in different ways, since modules are connectable between each other, despite different sizes.

Buildings structure consists of four columns, which are placed on concrete beams in each corner of the module. These two beams are placed on the foundations, which are simple concrete pipes with additionally filled concrete. Furthermore, floor made out of different layers, including insulation, is placed on concrete beams as well. Under the ceiling columns are connected between each other with four beams. Columns and beams are made out of laminated wood; however, despite good performance of the material, joints between them cannot resist moments, thus triangular elements are added. The roof that is placed on the construction has 17° angle, which allows the use of different roofing materials.

On the pavilion-like structure that is covered only by roof, one can attach from the side extra module or cover it by different pre-designed external wall panels that can be made as a full wall, or with opening such as doors or different kind of windows. This wall panels are simply mounted to the construction with screws, which also allows easy removal later (Utzon, 2009). However, this simplicity has also downsides, which are cold bridges on places where wooden construction remains uncovered and where the inner layers of panels are extending to the outside.

Furthermore, the additive principle allows different possibilities of buildings by placing modules in various combinations. It also allows to add modules if it is needed later, thus it has great aesthetic value since additional part of the building can be created with the same expression. Moreover, dilatations between modules have great tectonic values, since the principle is shoving honesty of craftsmanship and how. However, on the place where two modules are connected, there is still a gap between constructions; therefore it needs additional element to close dilatation, which is creating the cold bridge.



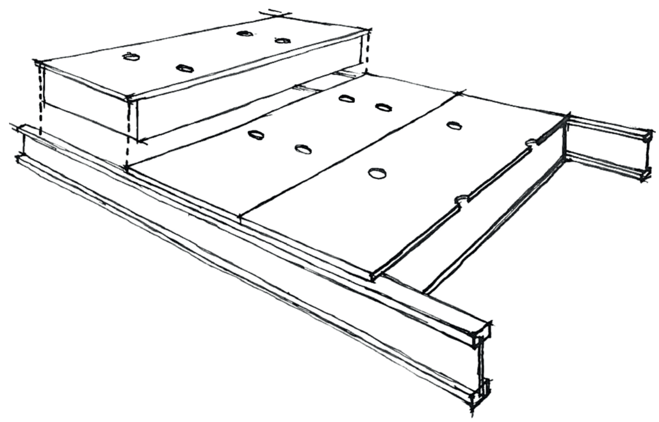
ill. 049
Principle of adding new module

1.3.3.2
FACIT HOMES

Facit Homes is architectural and design company from United Kingdom that developed unique approach toward prefabrication of housing. They tested their first prototype building in 2011 not far from London and until now they expended the production also in Denmark with their partnering office Een Til Een based in Copenhagen (Facit Homes, 2015).

Their innovative approach is bringing prefabrication previously bound to factory on the building side, which is possible because of the way how the building is constructed. Since the walls are made out of plywood boxes, their biggest and also only machine needed is computer operating milling machine (CNC wood router) that is transported on side inside shipping container and which also works as a working station. Thus predesigned elements can be produced on side and taken almost straight from the manufacturing process on the exact place on the building site by two men. However, wall elements have to be put together as a box before the installation because CNC device can work only with boards. When the building is watertight these boxes are filled with specially treated recycled news paper that works as insulation and holes where insulation was purred in are closed with plywood leads.

However, before building is enveloped with watertight membrane, wooden boxes are waiting on the building side under the harsh weather, which lowers the quality of the wood; furthermore, it may take quite some time between installation of first and last box (Facit Homes, 2015). Thus, even though that the transportation from the process to the site is more efficient than the conventional factory process, they don't have the opportunity to store elements until they can use them.



ill. 050
Principle of how floor is constructed with boards and wooden construction

ill. 051
Process of stacking boxes together to create wall

ill. 052
Elements waiting to be installed

1.3.3.2

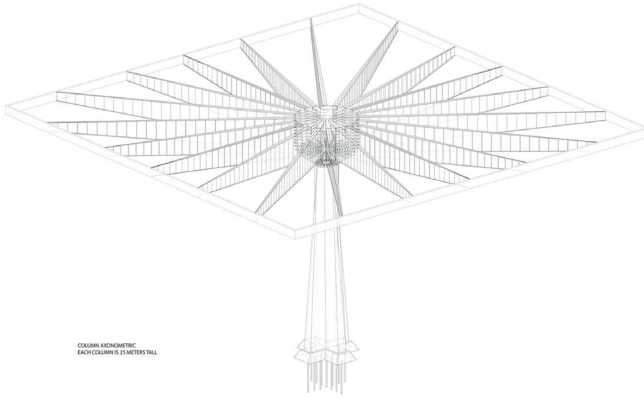
PALAZZO DEL LAVORO

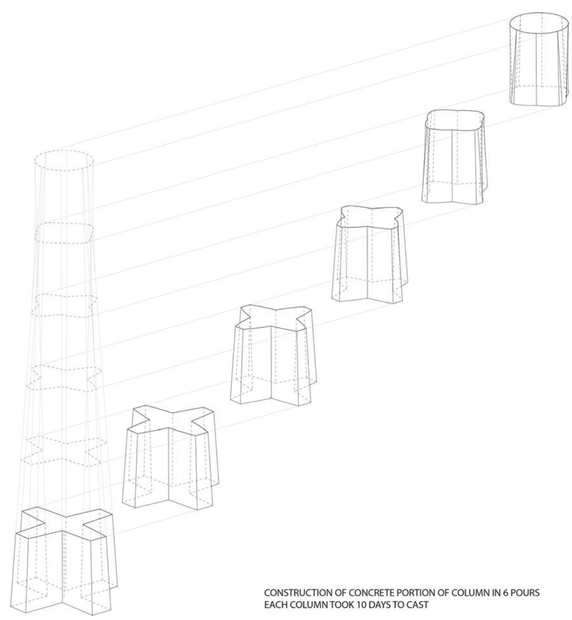
We were especially interested in this building because of its tectonic values were exposed construction is creating strong aesthetic expression. Palazzo del Lavoro was designed and built by Pier Luigi Nervi and his son Antonio specially for Turin exhibition in 1961. This project was a result of a competition that had place in 1959 for a exhibition space for “Italia’ 61”. Interestingly this rather spacious building of 8000 square meters was erected in relatively short period of time, less than eighteen months.

This successful construction time was possible thanks to smart design where sixteen structurally independent steel roof compartments were supported on 20 meters high columns. Construction together was 25 meter height. Very interesting part was the column planar section itself which was changing fluently from cross shape at the bottom to circular shape at the top. This change of the shape illustrates perfectly construction-purpose wise design where cross-shape section at the bottom helps with stability of construction while circular shape at the top works good with transferring the roof loads (Palazzo del Lavoro, 2015).

Another element that caught our attention was the skylight detail between the main elements that emphasize the constructional grid of the space. Additionally it gave lightness to the very massive and heavy construction to working as contrast between mass and light.

To summarize Palazzo del Lavoro is a great example were repetitive, industrial design works very good with creating interesting spaces and look. This could be used in our case where prefabricated umbrella like construction would be used to shape different spaces.





ill. 053
Construction of umbrella-like structure

ill. 054
Scheme showing how section of column is gradually changing

ill. 055
Interior of Palazzo del Lavoro

'SKETCHING PHASE'

In this chapter different concepts will be grouped and discussed separately in order to reproduce natural progress of how ideas were developed. Function, aesthetics and construction will be taken into consideration almost simultaneously to achieve integrated design process where all aspects are informing each other at all time. Each concept will be discussed by function, aesthetic and construction subcategories that are described in our programming phase. By sketching and developing our concepts we intend to design a system that would fulfill all of the aims stated in the program summary chapter. Each idea will be challenged separately. The outcome of this chapter is to indicate best possible solution regarding creation of flexible prefab system for single family housing that will reach zero energy standard. Goals such as simplification of traditional building methods, sustainable use of materials, cold-bridge-less prefab construction and additive architecture with C2C principles, will be the subject of each idea and concept thereafter analyzed.

2

ill. 056
Panel system

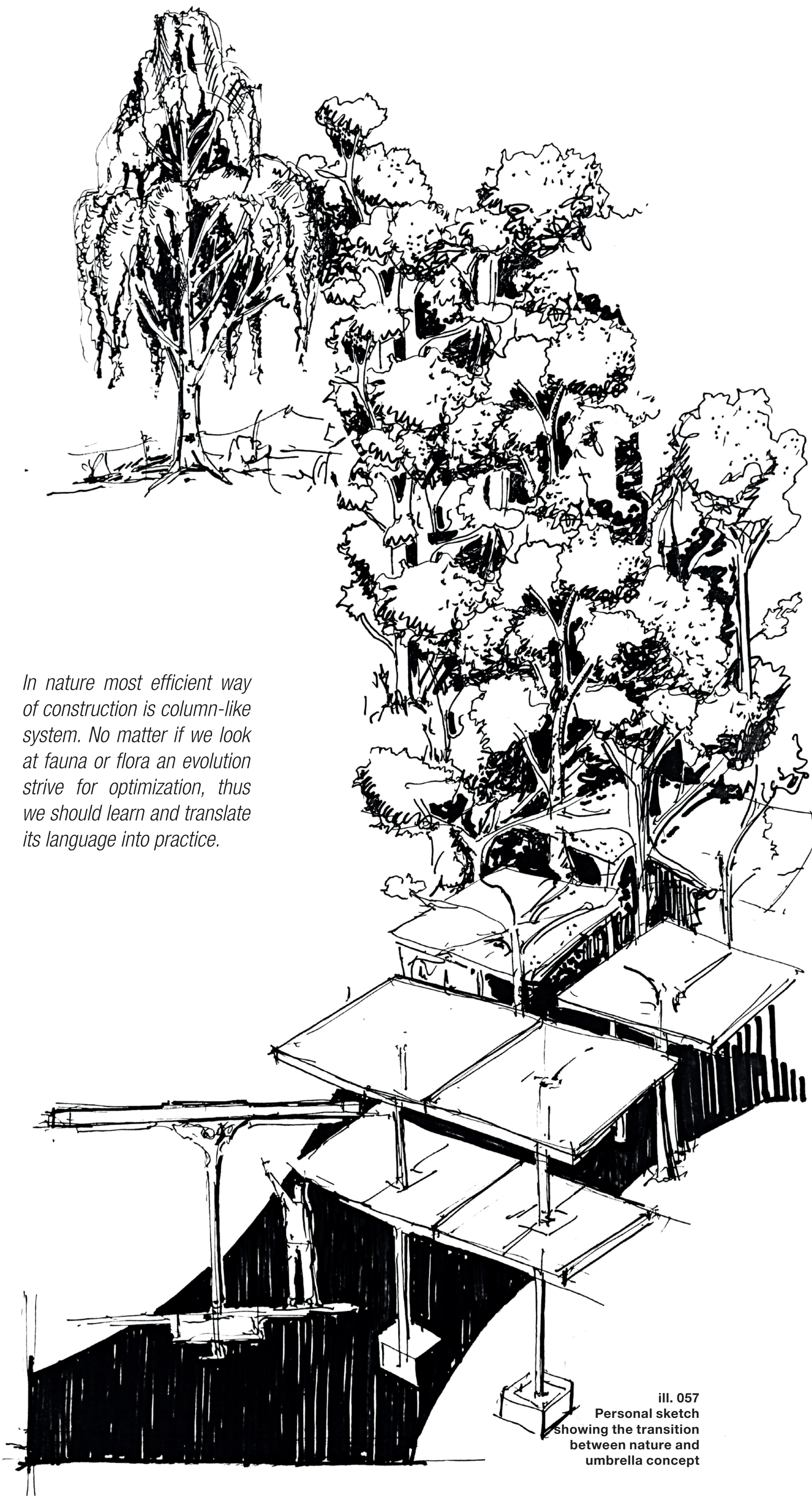
2.1
UMBRELLA CONCEPT

The idea of umbrella-like structures came from a natural process of the analysis and observation. In nature, environment created purely by means of optimization and most efficient solutions, it can be noticed that constructions such as walls are barely if non-existing for load bearing purposes. If we take any mammal for instance and start analyzing how it works from constructional point of view, it can be observed that they usually have a skeleton, relatively thin but strong construction that is later covered with organs and skin. In this way bones are responsible for carrying the loads while rest of organs can focus on their task necessary for whole organism to function. In such case each organ, if it is bone or skin, is constructed in a specialized way to fulfill only its function in a best way possible.

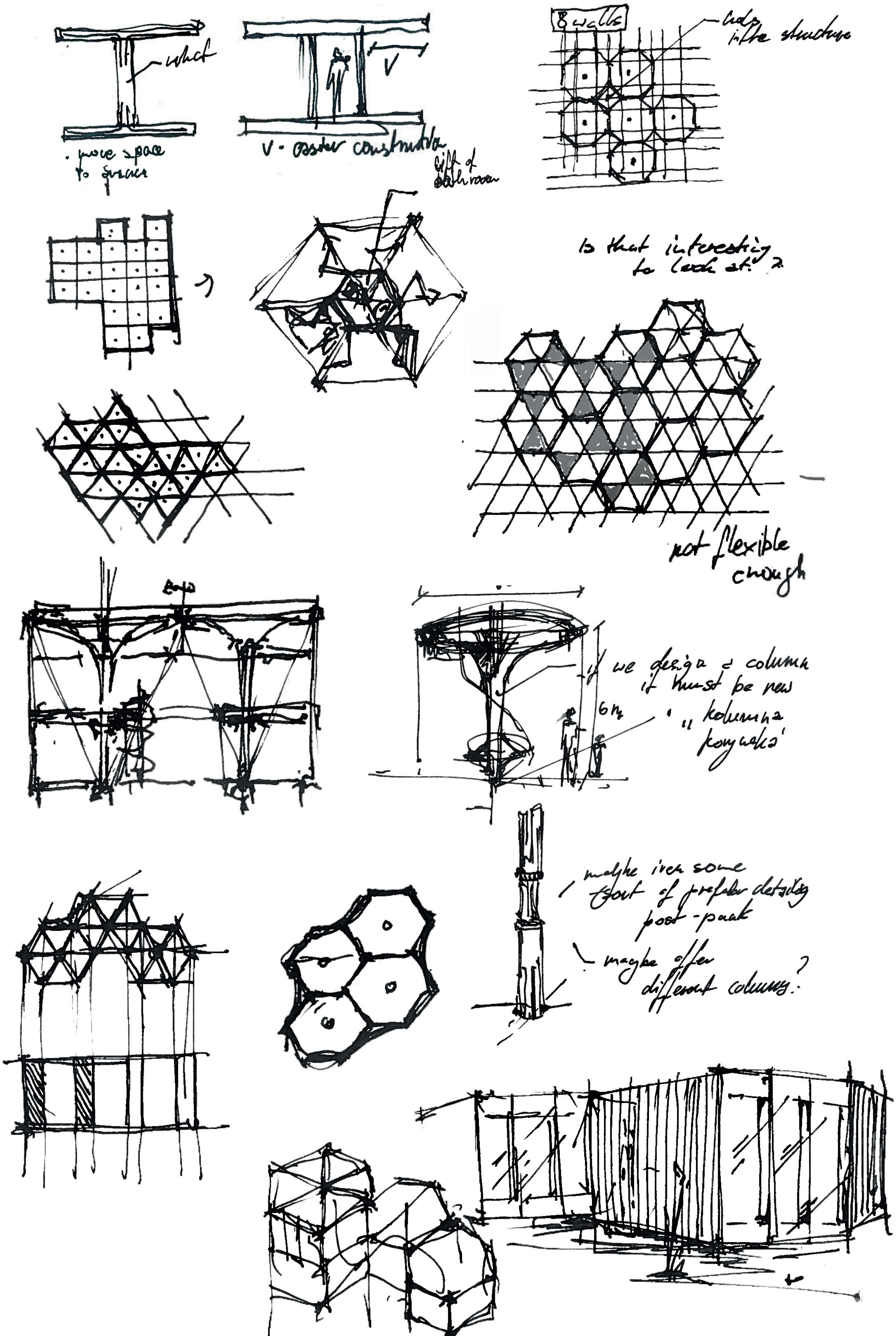
Furthermore, if we will move on to flora and take trees for instance, situation looks similar. Trees have basically trunks, long and relatively thin constructions for transporting and load bearing purposes and then, they have branches that spread out at some height to expand the absorbing surface of leaves, yet another element created purely for its purpose.

When we tried to translate this idea into more practical language of architecture, we can continue this concept by subdividing house construction into elements created and designed entirely for its purpose. If we look at typical house construction it seems like an unnecessary waste of material to use high energy embodied materials such as concrete, steel or brick for walls on every side of a house. Main function of external walls is rather to create a good climate barrier then to assure a load bearing solution. Thus, to use these materials more rationally and intelligently, it is more obvious to create a column or set of columns that would support roof construction. In this way walls could be build out of materials focused on creating good climate barrier and visibility such as insulation and glazing. This is the first reason how umbrella-like structures was created.

In nature most efficient way of construction is column-like system. No matter if we look at fauna or flora an evolution strive for optimization, thus we should learn and translate its language into practice.



ill. 057
Personal sketch showing the transition between nature and umbrella concept



ill. 058
Sketching studies

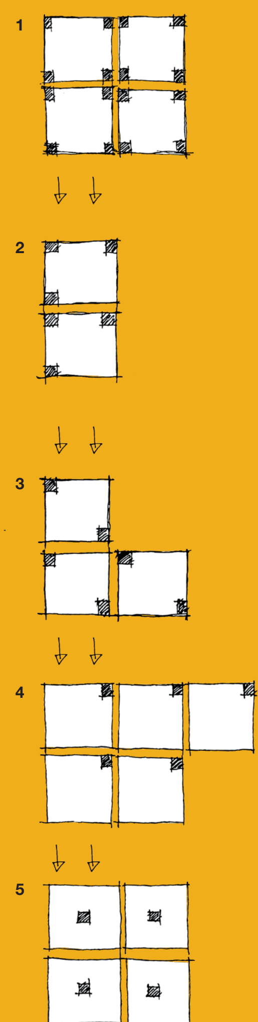
2.1.1
IDEAS/ CONSTRUCTION/ MATERIALS

During the history of Danish prefabricated housing there were many good attempts. One of such is also Jorn Utzon's Espansiva, which was also one of the inspirations for this modular building. Furthermore, Utzon pursued the idea to create large number of different possibilities for housing. Thus his studies showed that the house designed on the basis of posts or columns, in which the roof and floor were firm surface and non-bearing external envelope and partition walls as flexible elements, are the most suitable solutions. His answer to this was the pavilion like module with floor, single pitched roof and four columns that allow free choice of envelope material and openings (Utzon, 2009).

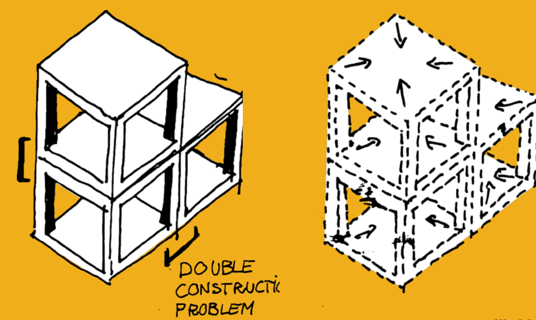
Furthermore, such principle can be classified as element and modular principle. Thus it also has a similar problem with doubled construction as common modular buildings when merging two or more modules together (ill. 059).

However, through sketching process different variations of column placing were tested in the attempt to minimize chances for doubled constriction where first sketch (1) is representing Espansiva's principle (ill. 059). The first step (2) was to remove one column, which shows one corner without doubled construction. However, if one more column is removed, in a way that there are left only opposite columns, modules can be merged together in a row without doubled construction, but in the cluster composition the problem occurs again. However, with only one column (4) the possibility of double construction is completely removed, with a premise of correct orientation of modules. Furthermore, such structure does not look stable because of the moments that would occur in it. But if the column is moved in the center of the module (5) it supports upper plate in the center of the gravity. Furthermore, modules orientation is not important in such composition.

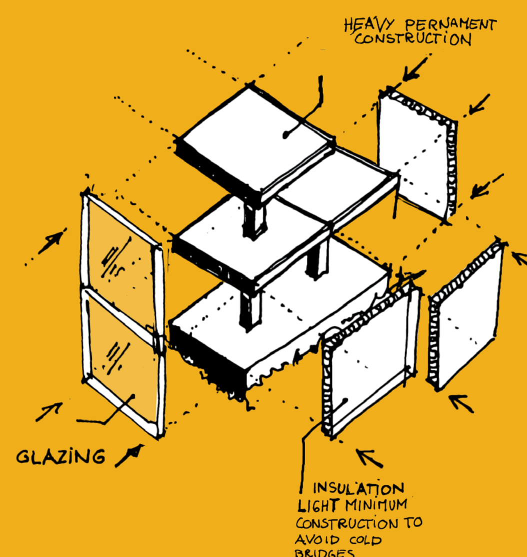
With this solution the amount of construction elements is reduced and consequently also the amount of used material. However, the assumption is that reduced elements and material are not reduced in the same ratio, which means that material will not be reduced as much as amount of elements, since one column must be more robust than system of more columns. On the other hand, one of the goals is to create permanent construction from high embodied materials and temporary elements from low embodied materials, and in such module this elements are completely separated, in the opposite of current building techniques where envelope is attached on the construction or between.



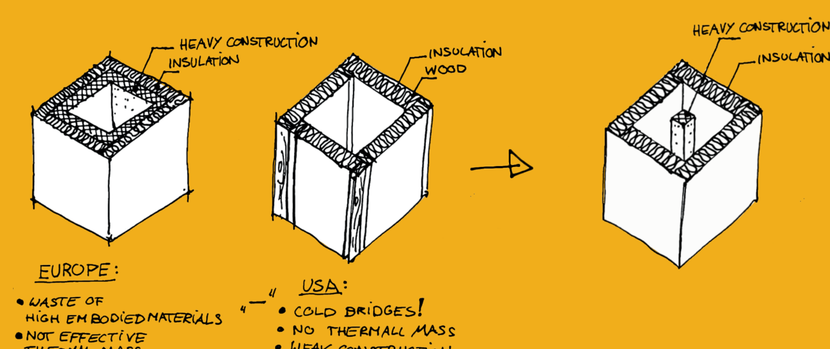
ill. 059
Thinking process of solving double construction problem



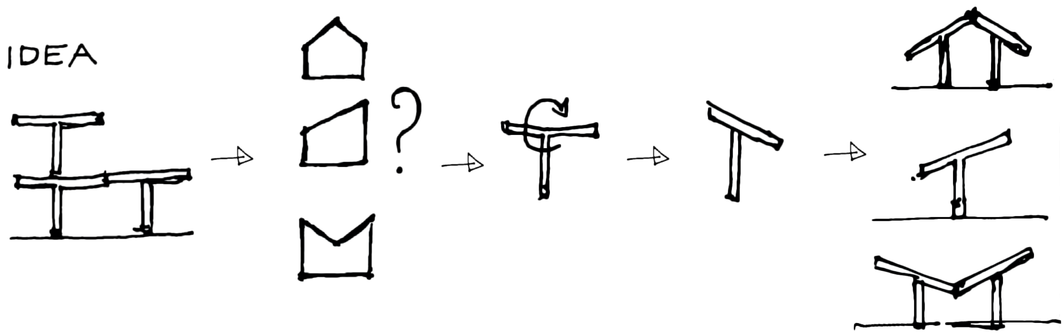
ill. 060
Double construction problem and simple solution



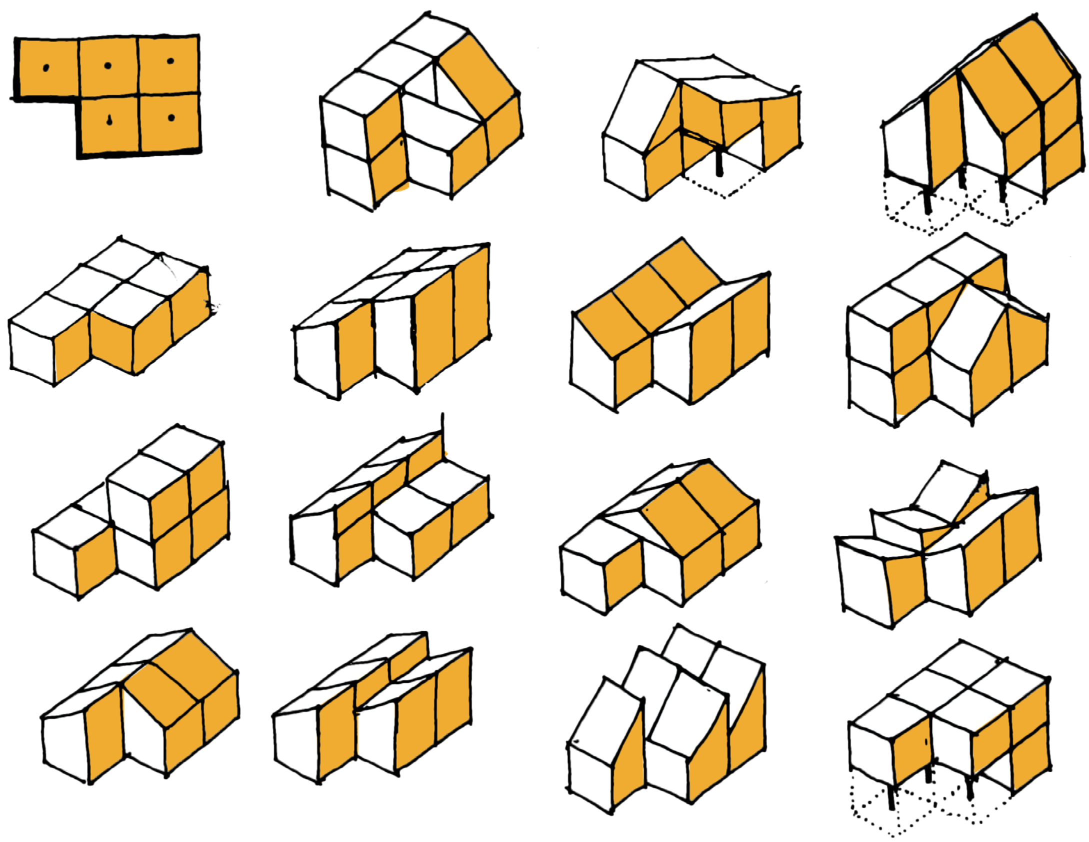
ill. 061
Step 5/ assembly principle



ill. 062
Most common approach to design in Europe, USA and its combination as a solution



ill. 063
Idea of achieving flexibility within the concept



ill. 064
Quick example of various solutions solved using 5 units and the same plan

2.1.2

FLEXIBLE DESIGN

As mentioned in previous chapters, modular prefab architecture must achieve great flexibility to be able to compete with onside constructed building, while remaining standardized. Thus, building must be able to create various of forms to fulfill clients wishes. The idea that was presented in previous page is showing how the simple column and plate above it can create inhabitable space and how can more of such elements be combined if needed. Thus they can be placed next to each other or stack above to create multi story building.

Furthermore, flat roof is not always what clients want, what is allowed according the local rules or appropriate for some weather conditions. Hence, the umbrella-like structure should offer sloped surface which vastly increases the number of compositions that can be achieved while keeping the amount of different elements fairly low.

However, while introducing new form it is necessary that all modules are compatible. Thus it is necessary that modules are designed in right ratios and that the envelope does not need too many modifications.

2.2

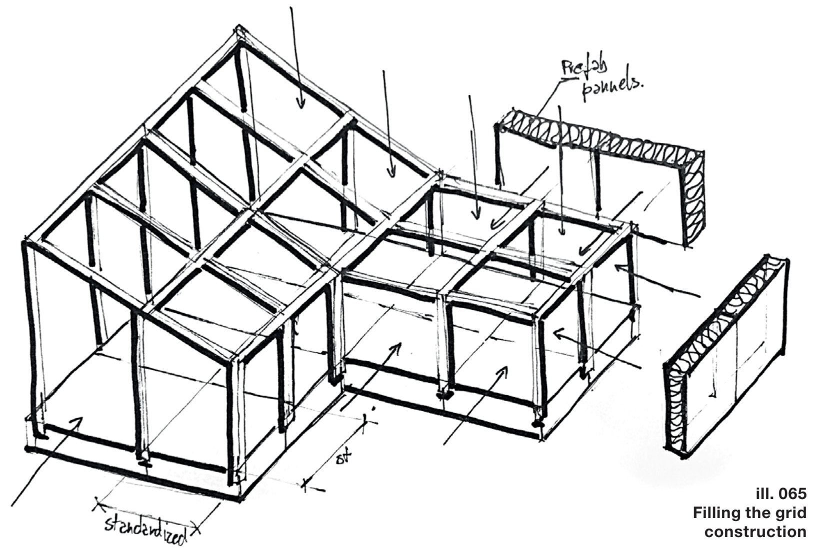
LEGO CONCEPT

Currently, the statistics shows that there are around 86 LEGO bricks per every person on the Earth (The Guardian, 2015). However, even though that not every person was in contact the number of LEGO enthusiasts is still high, not only among children but also as Adult fan of LEGO. One of the many reasons, for such a great success of it is, that it allows unleashing the imagination in great freedom of design despite the rigid form of a single element. Furthermore, such freedom is achieved with carefully designed modular elements that can fit together in various ways. Hence, the idea of this concept was to translate features of the LEGO elements and principles into the building prefabrication process.

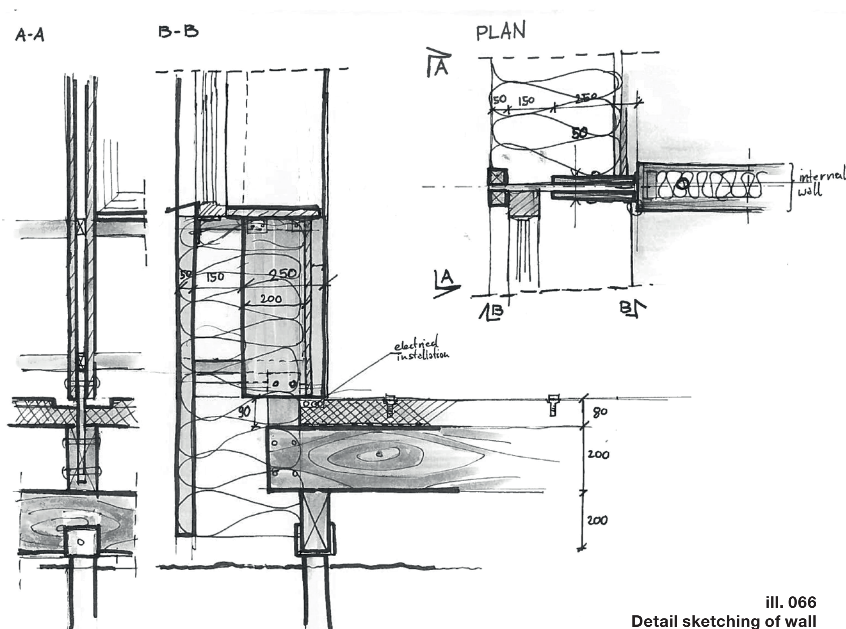
However, the principle of putting LEGO bricks together is similar to conventional brick building with clay bricks, where mortal is used in the opposite with LEGO bricks which are bonded together with system of studs. On the other hand traditional brick building demands vast amount of elements (clay bricks) which after all needs insulation. Thus, the idea of this concept was to create envelope elements that are big enough to speed up the building process, while it is smaller than common prefab panel systems which can gives us greater flexibility.

Furthermore, to provide the necessary structural stability of the wall and roof construction, the grid structure is proposed. Thus brick-like envelope could infill such grid. This means that each brick-element could have different function (I.e. isolative envelope brick and brick as a window or door), while ensuring that all parts fit together.

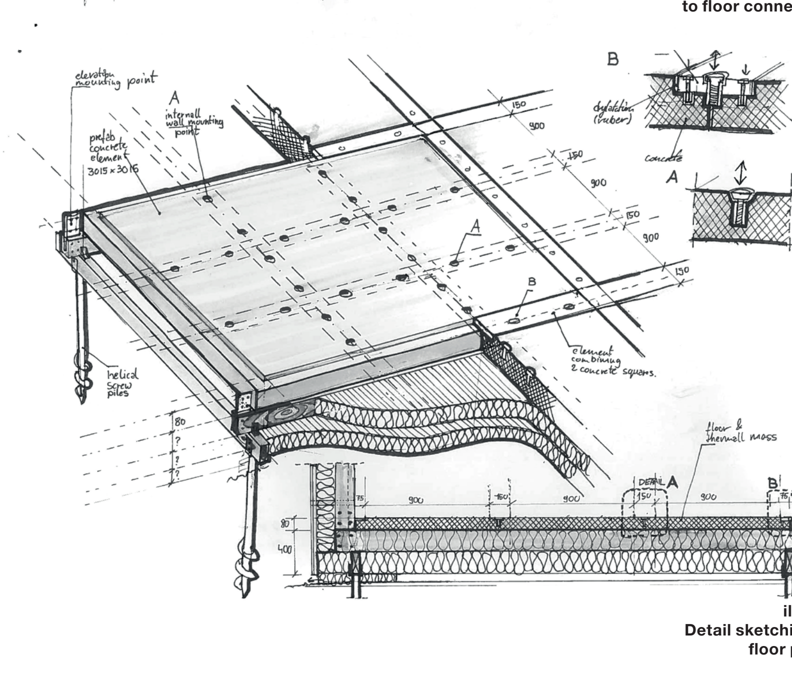
Furthermore, with such design also interior furniture could be designed respectively to the grid. This allows greater compatibility of elements, while the grid is providing readable and easy to imagine interface to the client, which is consistent with the goal of democratic design that allows greater involvement of the client in the building design process.



ill. 065
Filling the grid construction



ill. 066
Detail sketching of wall to floor connection



ill. 067
Detail sketching of floor panel

2.3

CONCEPT OUTCOME

By Following the idea of creating most efficient and flexible prefabricated system for single family housing, one concept had to be chosen in order to be developed in detail. Factors such as sustainability, ease of construction, flexibility and innovation were discussed as the way to select the best and most promising solution. Additionally all elements listed in the summary of programming phase where evaluated as the self checking procedure for this project.

While 2nd concept that based on designing houses thanks to standardized spatial grid of elements seemed rather safe and rational it became its downside when all aspects were taken into consideration. The number of various elements and problems with additive aspects acted discouraging especially with comparison to 1st concept. The rationality of this LEGO approach did not left a lot of space for innovation and experimentation which are inseparable part of development and improvement. The decision was made to follow less obvious choice that without a doubt (succeed or not) would allow for self-education and interesting experience for future which regarding education is the ultimate goal.

First concept the “Umbrella” represents new approach especially for housing industry. Thanks to its skeleton construction it worked well with sustainable aspects of minimizing the use of the high-energy embodied materials. The umbrella construction allowed also to maximize the insulation of an envelope and what is also very relevant it behaved perfectly with additive aspect of our system. External walls that were free of any load bearing structures allowed for free manipulation, different flexible designs and easy dismounting process in case of renovation or expansion. Even though, such system had many obvious advantages, at the first glimpse it was rising many concerns that needed to be addressed in next stage as soon as possible.

Starting from function, the ability of creating comfortable living space with columns located in the middle of each unit, raised instant worries regarding such possibility. Studies of minimal dimensions of one unit had to be done together with variations of multiple units in different configurations. If such studies would present satisfactory results next aspect was to test the umbrella construction and different material combinations in order to achieve most satisfactory results. Next concern would be to investigate the envelope construction that thanks to non-loadbearing aspects was allowing for innovative construction, avoiding cold bridges and additionally assuring easy additive and flexible aspect. An important part that had to be done after succeeding with previous steps, would be to make calculation regarding the energy use, indoor climate and daylight

All these elements are part of next chapter where they are discussed and analyzed in depth one by one. This is an important part of the report that is revealing the process behind creation of this project. Even though steps are presented by category, the process itself was much more chaotic and often many aspect had to be addressed at the same time to solve some problems. Each element was affecting the rest of the project naturally causing designing loops until achieving satisfactory results.

'CONCEPT DEVELOPMENT'

This chapter is continuation of the conclusion of previous one. Thus the Umbrella concept is further investigated. However, best features of the other concept are taken into account to create symbiosis with best possible outcome. Therefore, to achieve well performing prefabricated system, it is necessary to go into details of the structure and envelope, while taking into account the performance of the building regarding internal atmospheric comfort and energy consumption. Thus the beginning will continue as a sketching design which will transform into detail drawings and various analyses regarding different aspects. Even though subchapters are in certain order most of tasks are executed simultaneously as a principle of integrated design process which is resulting in homogeneous design.

3

ill. 068
Panel system

3.1 FLOOR PLAN DESIGN

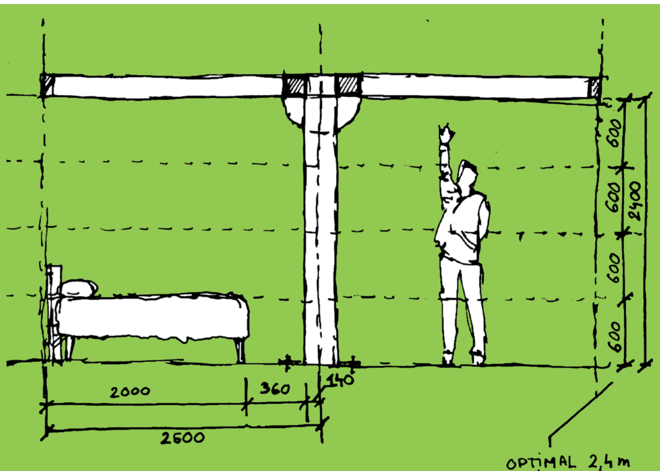
3.1.1
DIMENSIONING

Floor plan dimensioning of prefabricated building requires great amount of time in a designing phase, since beside needed functionality it is also necessary that building is compact enough for transportation. Furthermore, because of our aims floor plan of a module must allow merging of multiple modules and fulfilling needs of different clients. Thus following subchapters are the result of integrated process with many design loops and even though those different aspects are separated they were taken into account at the same time. Furthermore, plan design was also affected by further chapters about construction and various indoor climate analyses. However, we are trying to keep chronological order inside of each subchapter.

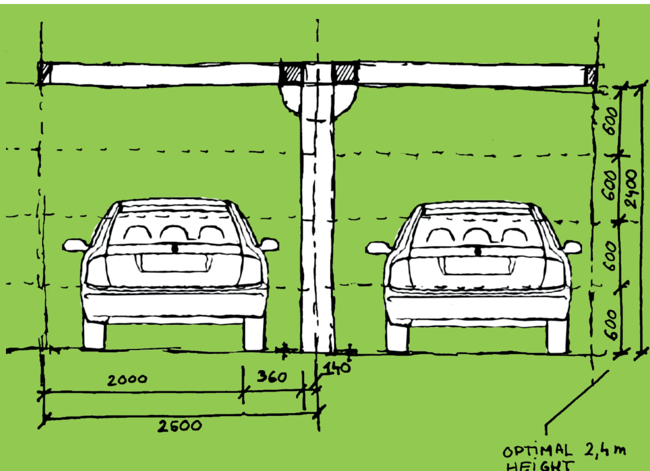
Flexible architecture is demanding great amount of time to create well dimensioned and functional space. Therefore, dimensioning is part of this design from the beginning and is evolving through the process according to different factors; thus, integrated design process is necessary to achieve the best possible outcome, which is most suitable size of the module for clients and their needs. Hence it is hard to draw a line between dimensioning and floor plan design because they are affecting each other; however, at the end the result must be working floor plan.

Thus, to create well dimensioned module, we made analyses of compact floor plans, dimensions of architectural elements, dimensions of people and rooms that they are using. But it is necessary to keep in mind that, to achieve flexibility and to avoid container like expression where 2 modules are put together, we must try to create smaller modules than they are usually produced. Whit this principle more modules must be put together to ensure functional house and in that way there are various possibilities of combining them.

Hence, the initial proposal is showing umbrella design that has footprint of a square, where sides are long 5m and with ceiling height of around 2,4 m. In the umbrella like structure, such dimensions give us around 2,5 m between central column and the edge and this allows



ill. 069
Dimensioning the construction according to the human scale

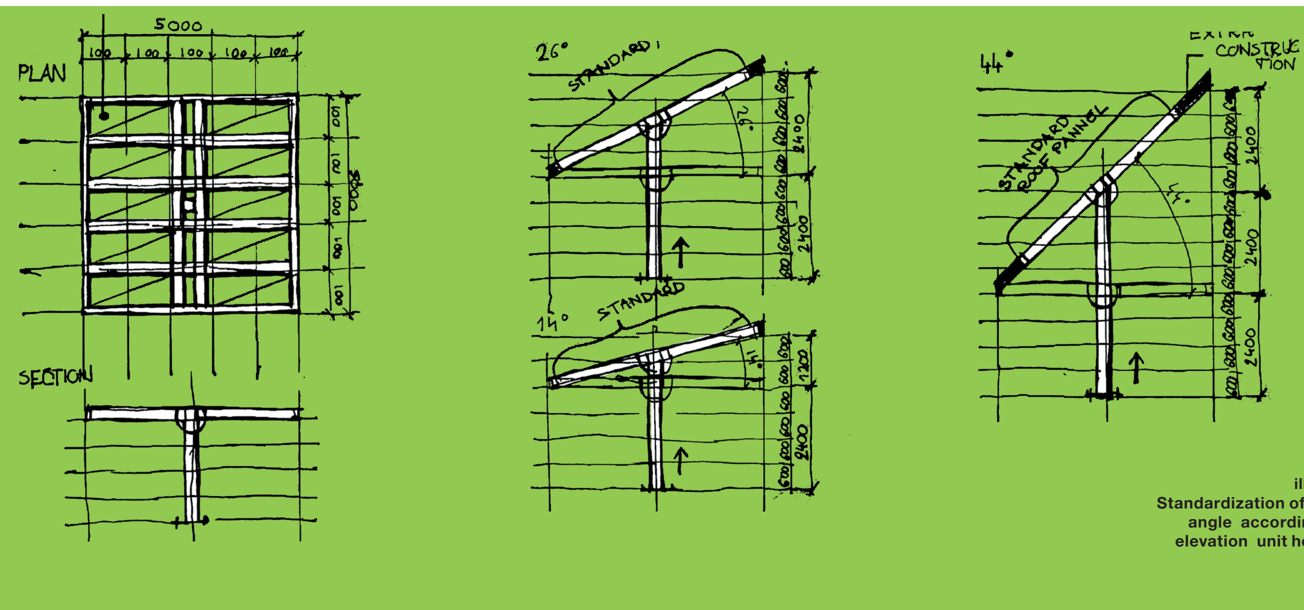


ill. 070
Necessary dimensions for the garage

inhabitable space where biggest furniture can fit in as well as car (ill. 069 and 070). However, it is not always creating most comfortable space; also standardized furniture such as kitchen counter with 60cm by 60cm is not compatible with such dimensions.

Further analyses are showing that square footprint with 6m long sides give us comfortable space even with double bed. Furthermore, such footprint can be divided on 4 smaller squares with 3m long sides, which gives us small and compact rooms, and it allows us to create a grid whit column on intersection of axis, in the opposite with previous dimensioning where column would not be on axis in case 1meter grid lines would be equally distributed. In that way we determine that the smallest size of the footprint can be 6 meters by 6 meters, but final dimension will be explained in the chapter dedicated for grid.

Beside footprint size of the module, height is also important factor in prefabrication as well as the angle of the roof. As already mentioned first proposal was with common height of 2,4 meters and having 3 different inclinations of the roof. First one is a flat roof, then roof with 14 degree angle, which is equivalent of half of the regular facade; then roof with 24 degrees, which create elevation that has double height facade, and finally roof with 44 degrees that creates three story high elevation (ill. 071). Such roof inclinations allow connection of modules of different floor height. However, this increase number of unique parts that have to be prefabricated; therefore, we decided only for the flat roof, and the 24 degree roof, since this allow connecting module with slope with common modules stack as a 2 story module.



ill. 071
Standardization of roof angle according to elevation unit height

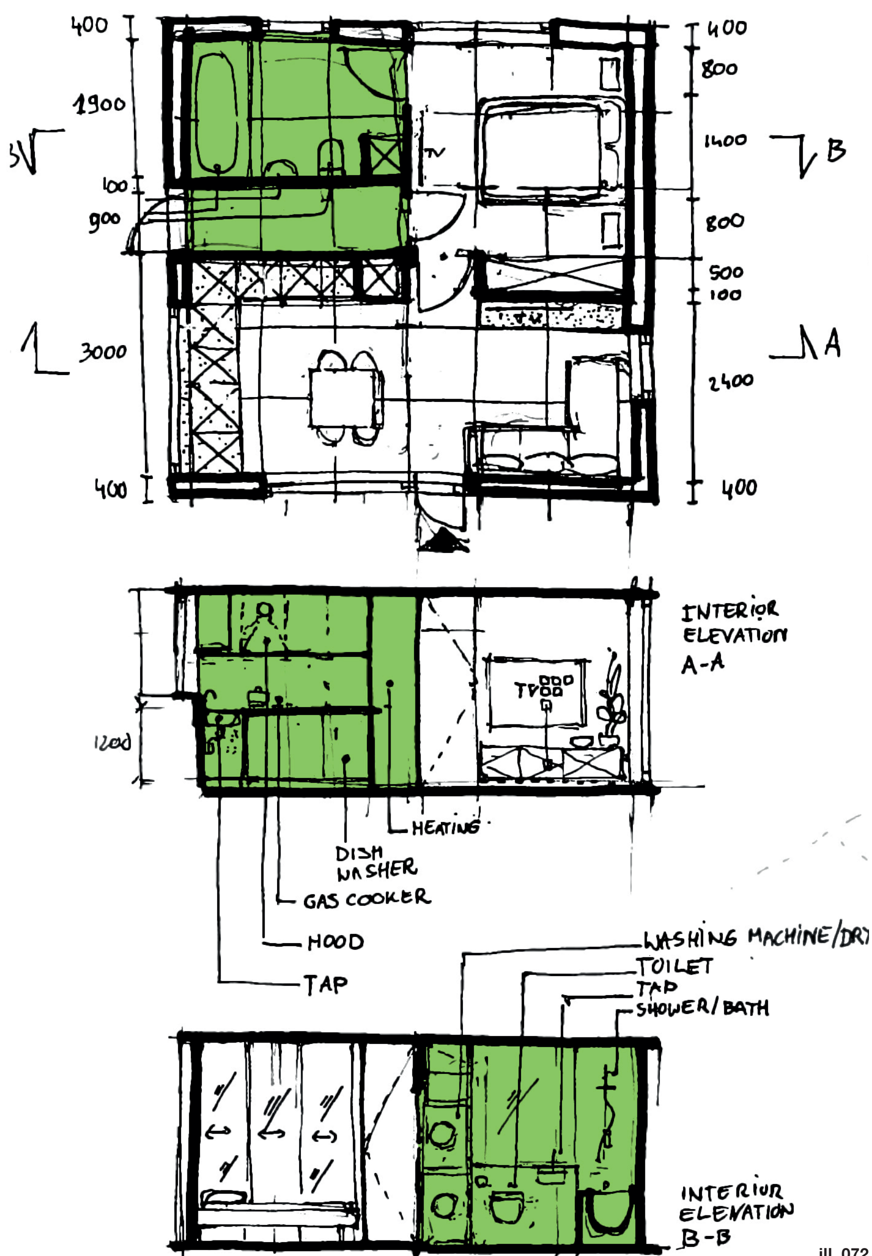
3.1.2

TECHNICAL UNIT

One of the key factors in floor plan design is integration of necessary utilities into prefabricated module. Also here the important role belongs to flexibility, functionality and simplicity according to prefabrication and installation process. Most common practice in prefabrication is to create a bathroom module with complete installations and interior. Such module is than connected to the installation shaft on site, which can be also shared with kitchen installations.

Thus to create technical unit that would fulfill the demands, we set goals for how to design technical module and what it should include. Among bathroom and its installations it should have installation shaft that has prepared outlets on the wall where you can connect all kitchen utilities. Moreover, building should be able to evolve with its users; therefore, shaft must allow easy replacement or improvement of utilities. Furthermore, technical unit must offer space for active strategies such as heat exchanger, power converters for photovoltaic panels and hot water storage tank in case of geo- or solar-thermal energy collection. Thus the result is technical room merged with functions of shaft, where all installations are easy to replace. Moreover it is accessible from the inside of house as well as from the outside.

Thus the technical unit consists of bathroom and technical room. The size of this room was initially 3 meters by 3 meters as according to one quarter of the prefabricated umbrella unit as it was mentioned in previous subchapter. But during the process the size of unit changed to 2,985 by 2,985 meters, while still occupying one quarter of umbrella unit.



ill. 072
Proposal for the technical unit with integrated bathroom

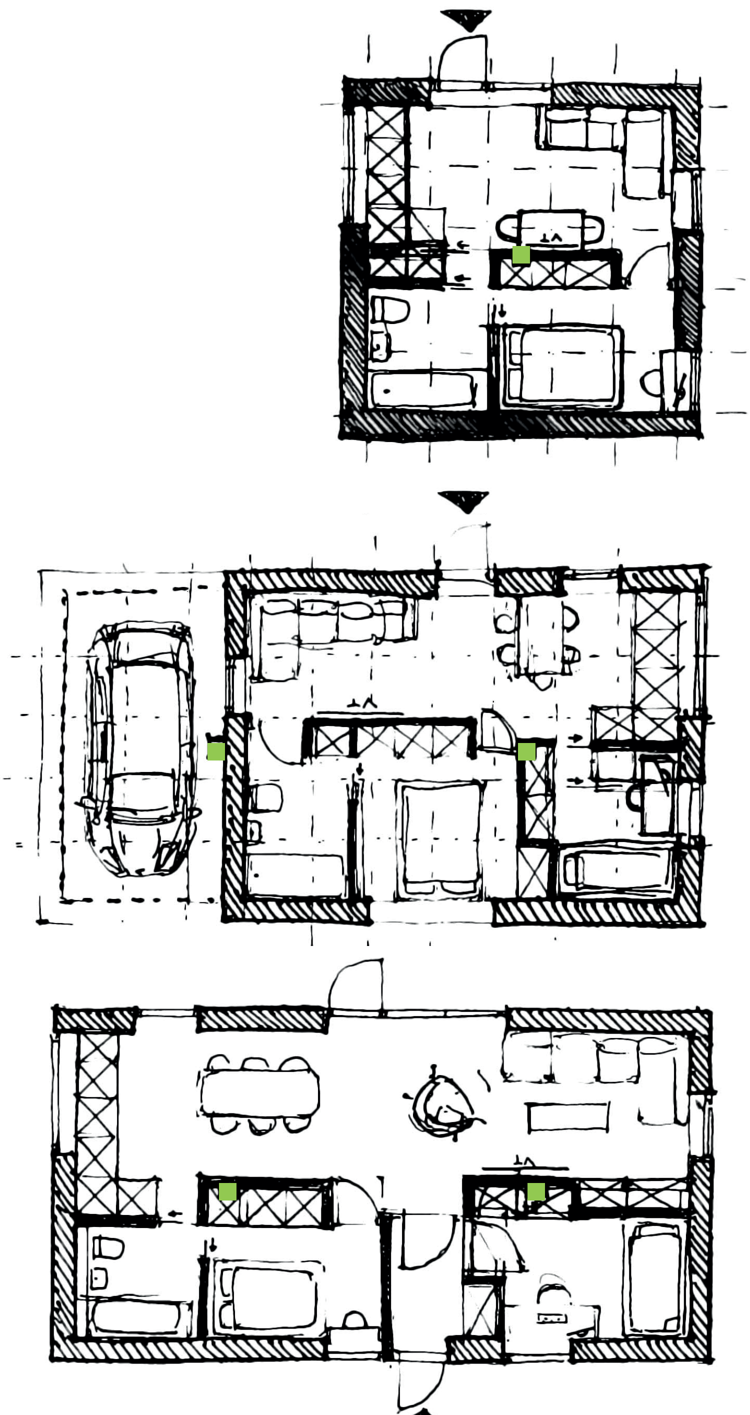
3.1.3

FLOOR PLAN POSSIBILITIES

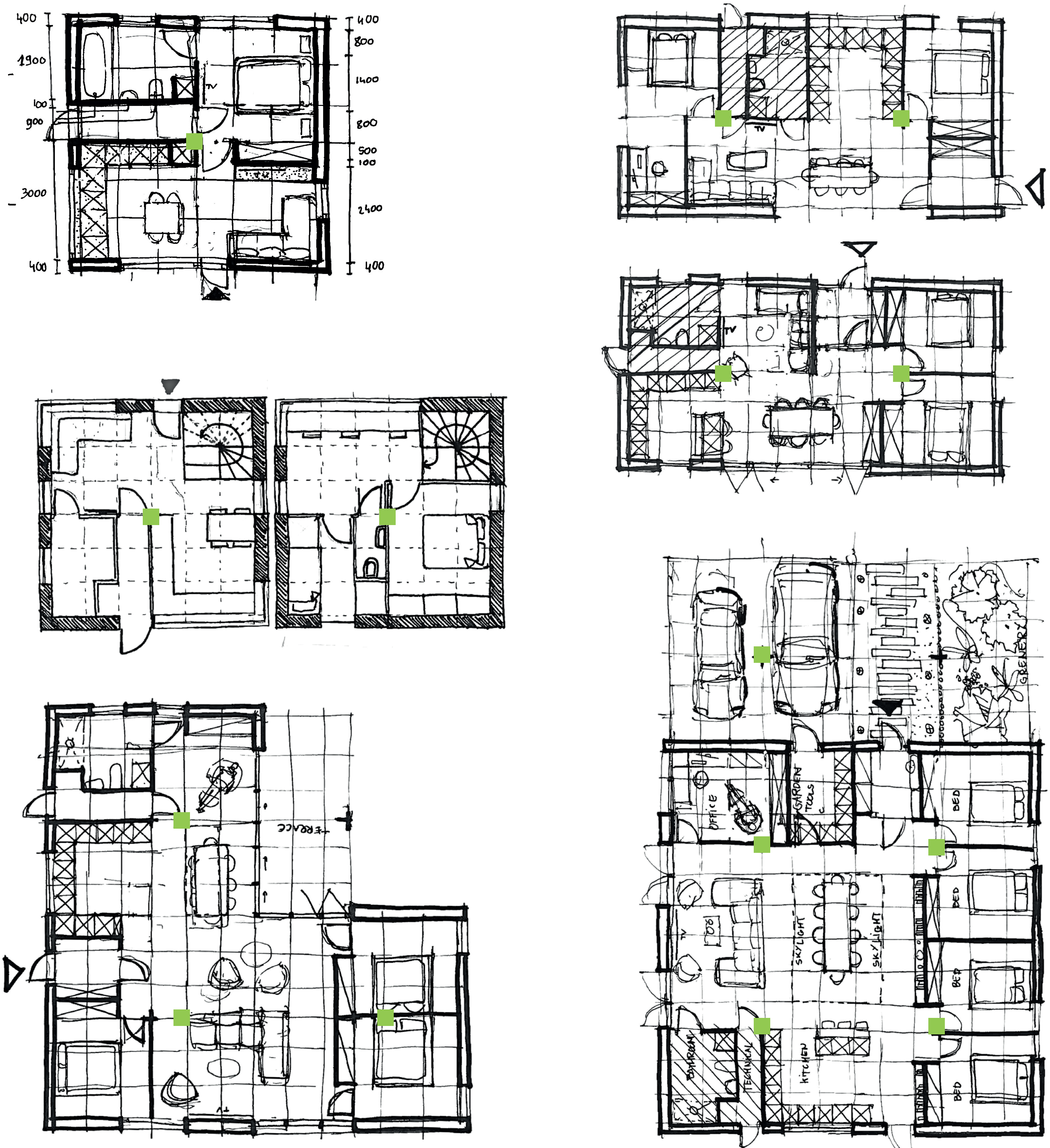
Along the way of concept and plan developing we made tests every time we introduced new feature to our prefabrication system. The purpose of these tests is to see the way of how modules can be combined and how arrangement and zoning of the indoor space can or cannot be achieved.

One of the crucial influences on the plan is dimensioning process, which is described in chapter 3.1.1. Thus every change in building element's dimension must be checked in the floor plan since even a small change of the column dimension can affect whole prefabrication system. However, not always we need the whole building plan to see if new feature is working. Thus first testing plans are designed for the umbrella structure with measurement of 5 meters by 5 meters (ill. 073). There are three plans made out of one and two units and the third example where half a unit is dedicated as covered car port, thus leaving one and a half unit for the interior. These tests are conducted in order to see if module can create compact floor plan for example for a young couple or a small family. However, the results are showing that one unit that can be used by a couple is too condensed and thus creating tight passages. On the other hand, two-unit floor plan is more spacious, but because of construction in the middle the passages between bed and wall are still tight.

As seen in the chapter "Dimensioning" the next stage in the size of the module is module with six by six meters edges which also includes technical unit. Floor plan sketches are presenting combinations for one unit, two and two units stack on each other, three and four units. In the opposite with previous floor

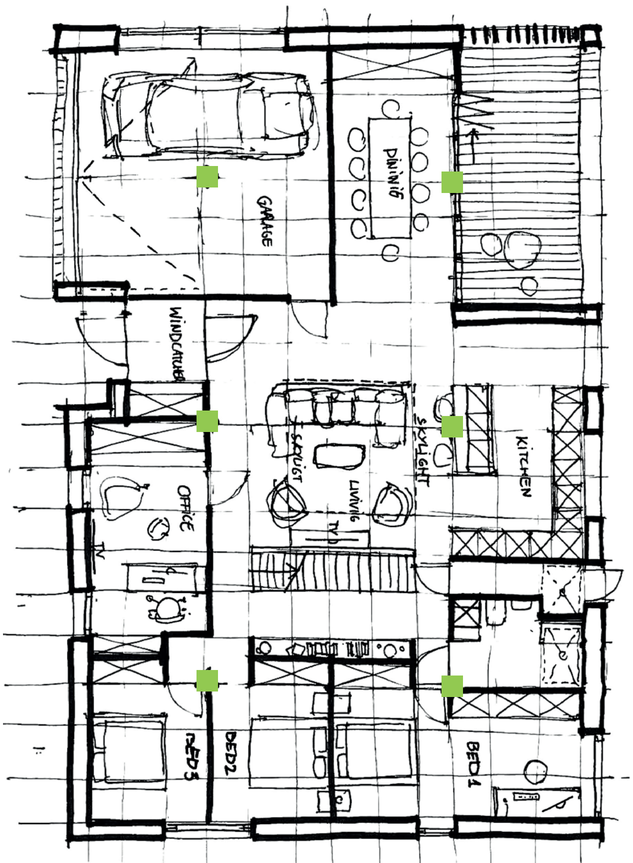


ill. 073
Floor plans with one, one and a half and two units (green squares are indicating columns)

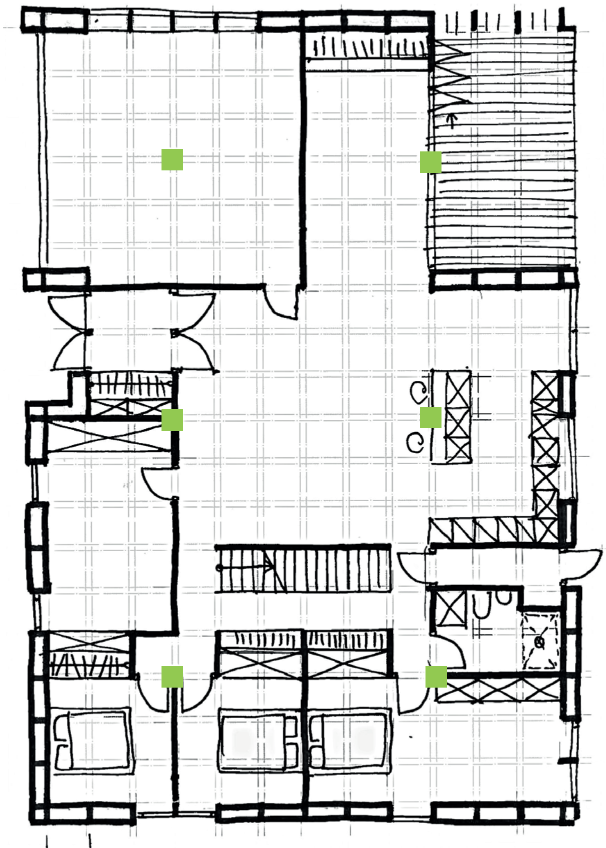


ill. 074
Plans designed whit 6 by 6 meter units (green squares are indicating columns)

plans, these ones are more spacious while remaining compact. Furthermore the passages around beds are sufficient and there is enough space to use doors suitable for wheelchair. Moreover, they are easier to design different proposals for same size floor plans. However, since the unit is bigger it must be verified that also compositions of more umbrella modules can function together. Also to see if prefab system can compete with buildings made on site, we try to use examples of existing plans and to recreate them with our proposed system. Thus illustration 075 is showing floor plan made out of prefab system, but it is similar to the existing building designed by ZAG Architects. Nevertheless, it is possible to notice that there is the area of the house with deep space, which can result in insufficient daylight, but this could also be solved with additional skylights.



ill. 075
Floor plan of the existing building designed using umbrella modules



ill. 076
Floor plan of the existing building with updated grid

Furthermore, with grid optimization process the dimensions of the module slightly changed. However, the result of gird development allows creating floor plans faster, thus testing of building layouts is even more efficient. Moreover, because of minimal changes, it is possible to create same floor plans as before.

On the other hand, we are not working in two dimensional medium, but rather in three dimensional space. Thus it is not hard to realize, that even though that plans are functional, they are not corresponding to the construction (chapter 3.2 Construction). Furthermore, the idea of 21st century prefabrication also needs the 21st century lifestyle. This means that fast, dynamic and ever-changing life needs dynamic living unit, which can be partly achieved with additive design, but floor plan is still limited with rigid "semi-movable" partition walls.

Thus our final result of floor plain design is made with flexible open space, that can adjust accordion to client needs in different stages of life. Hence, the prefabrication system has only two permanent elements that cannot be rearranged since the rearrangement would require too much effort to be efficient. These are the columns of the umbrella-construction modules and technical unit, while the rest of the floor plan is formed with movable furniture that can separate different space in order to create private rooms.

Furthermore, such furniture creates wall-like barriers; however, it is not completely closing space up the ceiling. This gives possibility to embrace the umbrella construction is exposed and not blocked by the wall,

Furthermore, if the traditional wall concept is not used, there is also no need to be limited by ceiling - meaning that umbrella module can create a volume, which can be used in different ways. For example, if the part of the building has enough height because of the sloped roof, the space can be inhabited in two stories which could be achieved with box-like movable furniture that has the access to the top. Furthermore, the same principle has the technical unit, since the new proposal includes stairs, so it can be inhabited in a second floor.

Thus, we believe that such approach toward the arrangement of the living space can fulfill needs of different client types. Furthermore, the fact that the modification of space during the lifetime allows us to reuse elements in different arrangements, it is complementing the sustainable aspect of the project.

3.1.4
GRID DEVELOPMENT

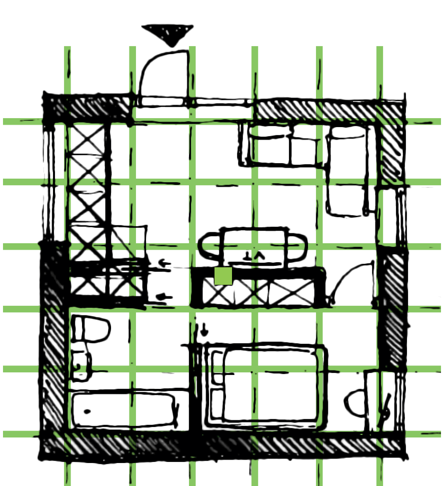
In order to create designing and production process more efficient it is necessary to optimize and standardize building elements. Thus, it is possible to notice in sketches of previous chapters that floor plans are drawn on grid, which is one step closer to standardization. The initially proposal for grid is based on the fact, that building elements must be prefabricated in factory, where their production must be fast and efficient in order to create fast assembly on the building side. To achieve high productivity, the number of unique elements should not be too high and even despite unique elements their size should be the same (i.e. external wall panel with and without window in the same size). Furthermore, even if unique elements are in different size they should be able to be assembled in various combinations and one of the answers to this problem is grid.

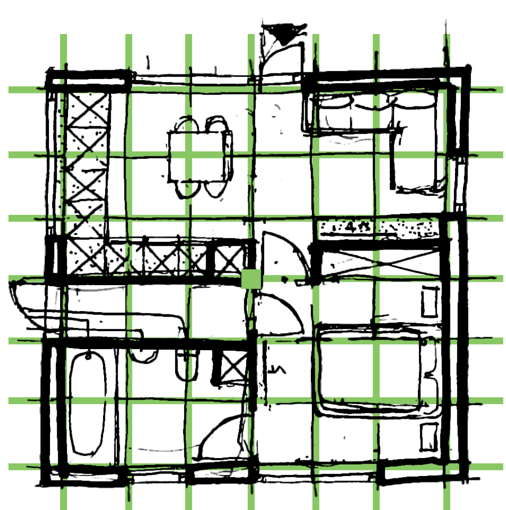
Furthermore, grid could help client as well, since with grid it is easier to have feeling for scale of building plan. Moreover, with the idea of democratic design where client can actively participate in the design process building system must be simple and understandable, similar to the current practice of client combining kitchen elements.

Thus, grid is developed together with prefabricated module. This process could also be seen in chapter "Floor plan possibilities", where initial module has gird lines every 1000 mm, while the module size is 5 by 5 meters. In this case construction is not quite related to the grid, since umbrella's column is placed between grid lines. Furthermore, with even number of axes is impossible to divide module interior into two or four equally big spaces while having even number of spaces between axes in each part.

Thus examples from previous chapter are showing prefab module that has seven grid axis in two directions with 1000 mm spacing, which means the module size is 6 by 6 meters. This allows that central column is on the intersection of two lines, thus any internal partition wall placed on the axis meets construction.

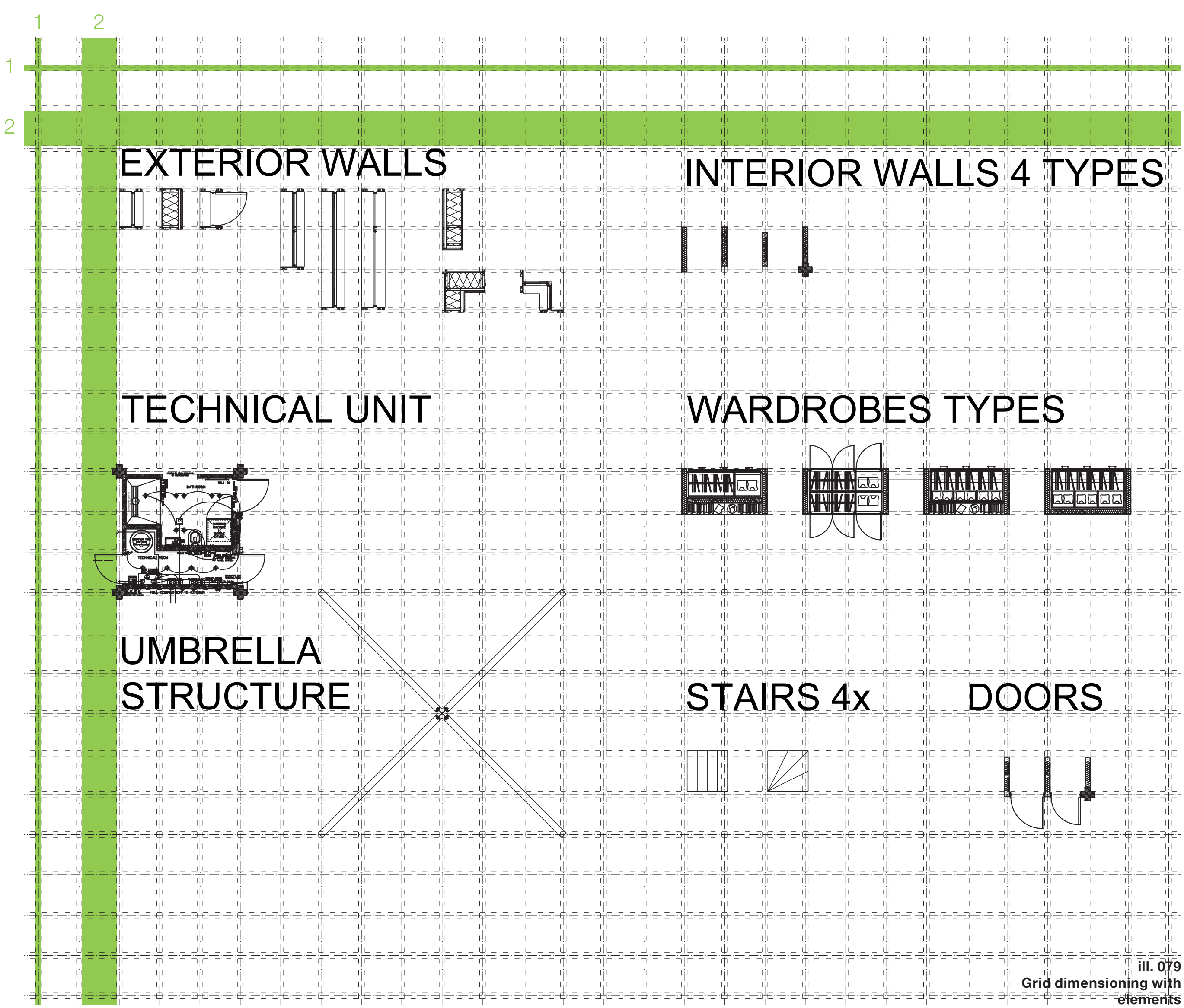
However, if the axes are defining size of the window (i.e. where window is between two grid lines) and if axes are defining the position of the internal wall the overlapping can occur. Thus, optimized grid is proposed, where grid has two different intervals of line spaces. This means that lines are 150 mm (ill. 079 1) and 900 mm (ill. 079 2) apart. 150 mm is due to thickness of internal wall, while 900 mm is due to studies of building elements dimensions and compatibilities such as doors, windows, stairs, wardrobes and kitchen counters. With such grid, the designing process is fast and also more suitable for client, since position for placement of internal walls and other elements is clearly





ill. 077
Leftmost-floor plan with 5 unit grid module
ill. 078
Left-Module designed with 6 by 6 unit grid

defined. Moreover, due to prefabrication process all elements are predefined, thus with element library (ill. 079) they can just be picked from the database and placed on the grid. However, during the design process we abandoned the idea of traditional internal walls as a tool to create space and instead of this we are proposing movable furniture that can be freely arranged. Thus there is no need for the grid, but because grid is good indicator of the necessary dimensions, we are keeping it in order to achieve compatibility between different building elements and also furniture.



ill. 079
Grid dimensioning with elements

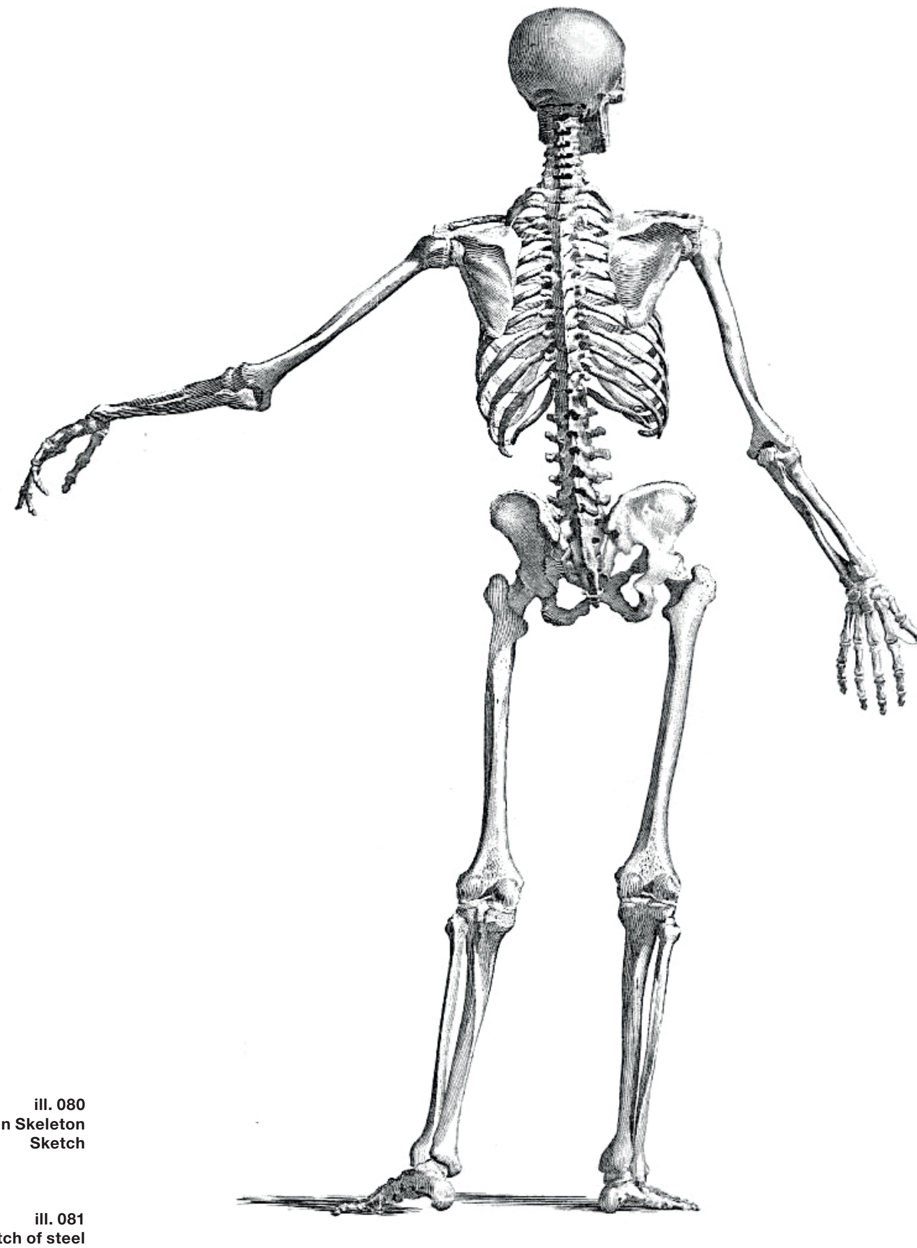
3.2
CONSTRUCTION

3.2.1
STEEL AS INITIAL PROPOSAL

As mentioned before the idea behind creating construction for prefabricated system origins from very fundamental characteristics of nature which can be noticed in every living organism - the efficiency of material use. By taking human body as an example and by analysing its load bearing construction, it becomes visible that the skeleton is relatively light comparing with total body mass. Strong and long structure of bones positioned usually in the middle of the limbs, creates an efficient construction that transfers weight through our bodies. It is our belief that these qualities not only can be translated into architectural language but can also assure sustainable thinking throughout the design process.

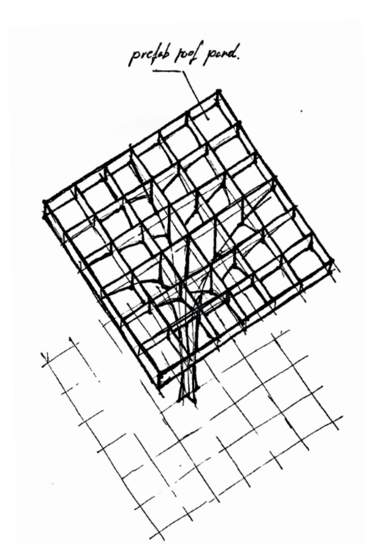
The translation of a skeleton as the load bearing construction can be interpreted in more technical manner as the column-slab structure where vertical elements are minimized to points plan-wise that are horizontally connected by net of beams. Such construction typically observed in modern office buildings, is rarely a case when it comes to single family industry. By moving this trend into smaller buildings we aim to eliminate high energy embodied materials for load bearing purposes on the external and internal walls to exchange them with materials designed especially for this purpose. The main goal of a building's envelope is to ensure good thermal control and to provide good daylight conditions. Typical external barrier largely consists of materials such as brick or concrete, that do not provide qualities mentioned before. Therefore naturally they should be replaced by more adequate materials such as just insulation to minimize energy losses and glazing to achieve good daylight conditions. Umbrella like structure freed envelope from load bearing purposes allowing uncompromised envelope design. However such construction caused series of other problems which had to be addressed and solved before going further into the design.

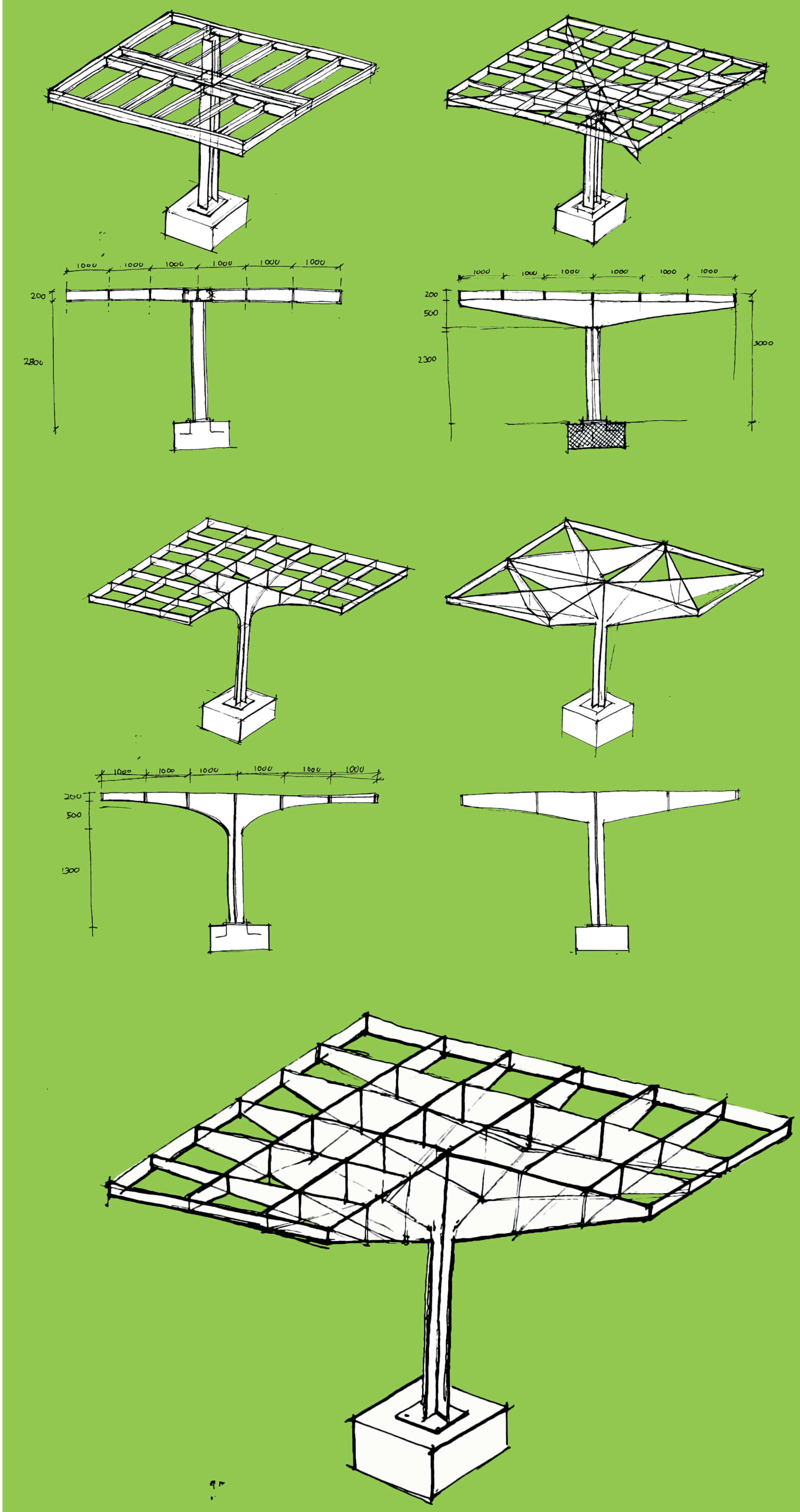
Our first attempt to design the umbrella construction evolved from the concept that based on simple construction made out of steel industrial profiles. This time



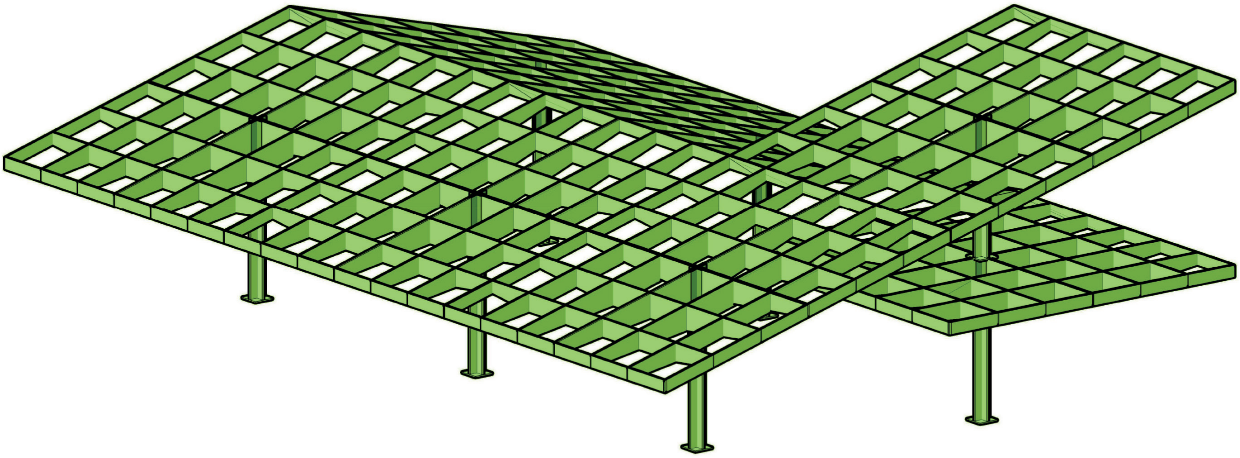
ill. 080
Human Skeleton Sketch

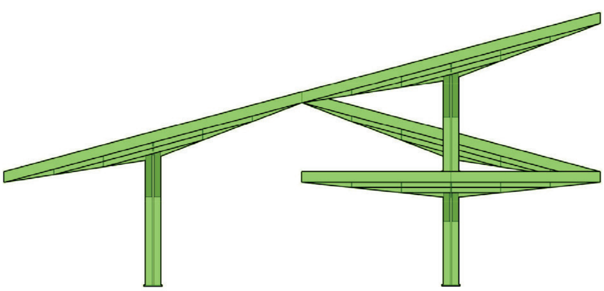
ill. 081
Sketch of steel construction





ill. 082
Steel umbrella
evolution





ill. 083
Autocad Model of standardized umbrellas creating test house

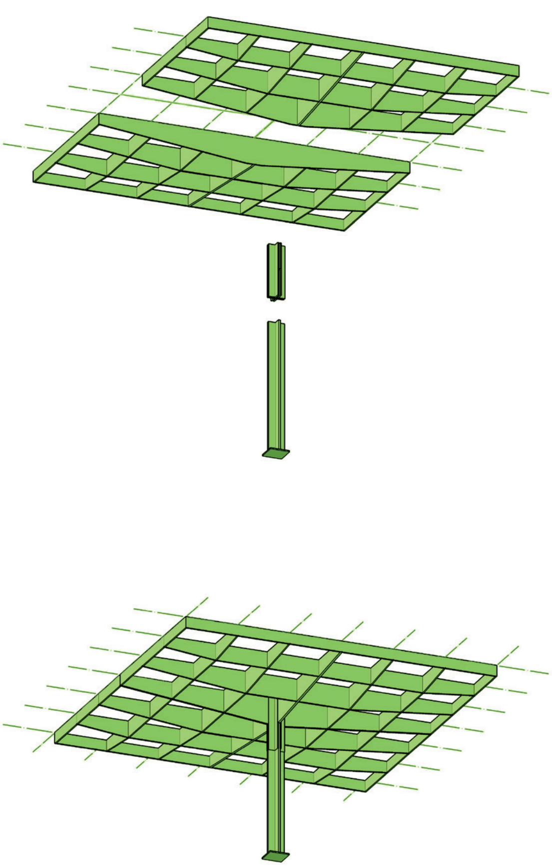
being inspired by proposal for Courtyard Roof in Warsaw Museum made by “2pm architects”, we created elegant and relatively thin steel sheets structure that connected into a spatial grid created strong construction. Having a technical data about dimensioning and materials that were used to design previously mentioned project it was possible to create first initial design.

This construction based on using 32mm thick steel sheets of for main grid cross including the column. The rest of supporting elements were intended to be made out of 15 mm steel plates to reduce the weight and use of this high energy embodied material. Such combination would hopefully create stable and clean looking three dimensional sculpture working as a load-bearing spine of each unit. To achieve different structural combination we created several different proposals to finally ended up with umbrella like structure that would be created on a simple grid and additionally would avoid curves to better fit different house options.

By going further into detail of the design, Autocad model was created thus helping with better understanding of the complexity that goes behind relatively simple solution. Umbrella was at this stage divided into 4 elements that would be thereafter assembled on the site. By investigating this solution, unfortunately several problems occurred that pushed us to search for new ideas.

Problems with steel construction:

- *price of steel*
- *weight of umbrella*
- *difficulty of welding plates together to achieve “clean look”*
- *complexity and difficulties with assembly.*



ill. 084
Steel umbrella construction concept

3.2.2

CONCRETE STRUCTURE

After making the mistake of choosing very expensive material such as steel that is hard to manufacture and join, further investigation about Danish market was made. Concrete industry quickly became an obvious direction to undertake. Not only Danish market regarding this material is well developed but also its physical properties allowed to design interesting prefabricated solutions.

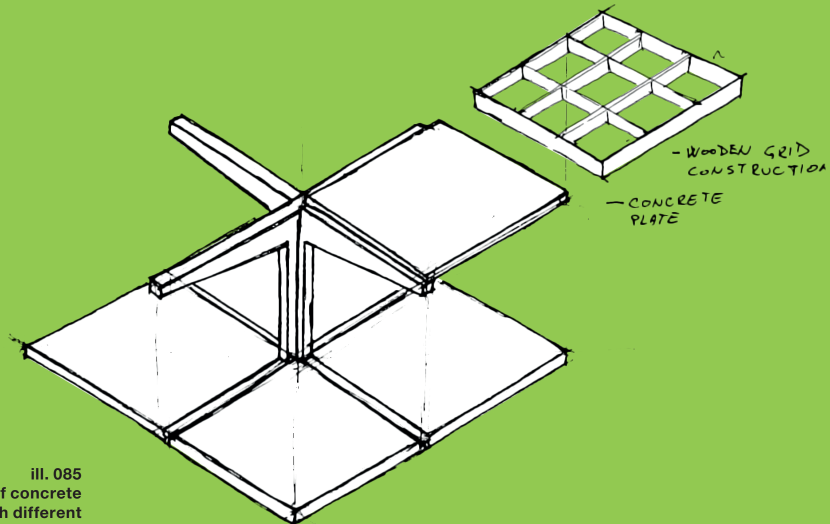
The main idea was to design cross shape construction that would be assembled on site out of two parts intersecting with each other. Such system would allow for easy transportation together with achieving big spans after the mounting process. By choosing concrete good results regarding deflection were expected but their precise analysis was left for next stages. Additionally, by analyzing the properties and possibilities with concrete manufacturing, using prestressing methods was part of the strategy to overcome significant bending moments.

To stiffen the umbrella construction, it was thereafter covered with 4 prefabricated concrete slabs (3000/3000/80mm) that would be joined together to create one solid surface. These prefabricated concrete tiles would be equipped with special inputs reflecting the layout of interior walls that would help with their quick assembly time.

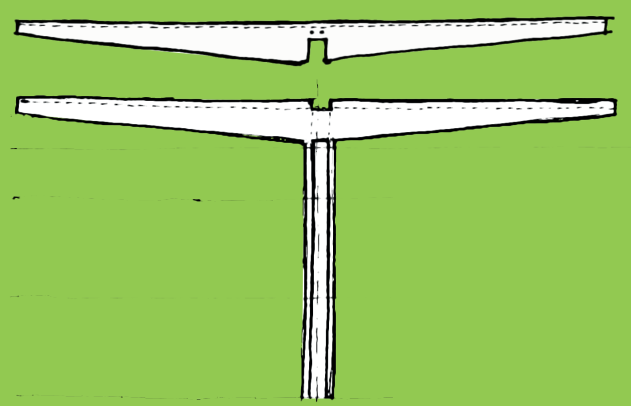
3.2.2.1

DETAILS

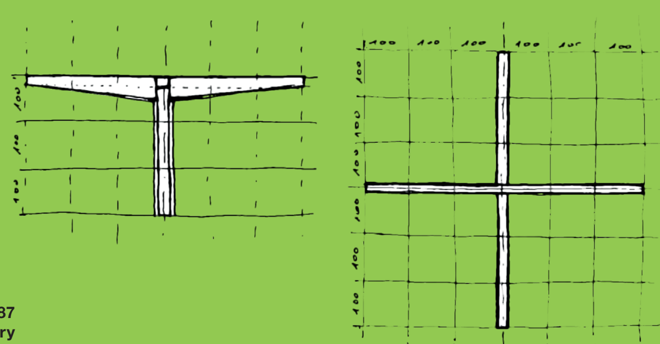
In order to test if such construction could be successfully created in real circumstances, a deep analysis was made regarding prefabrication of concrete elements and their joinery.



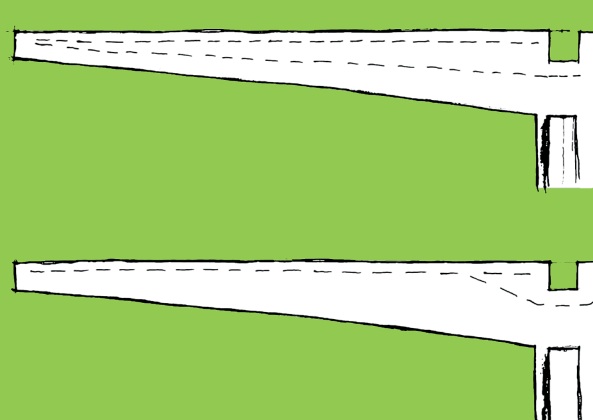
ill. 085
Idea of concrete umbrella with different slab/ roof panels



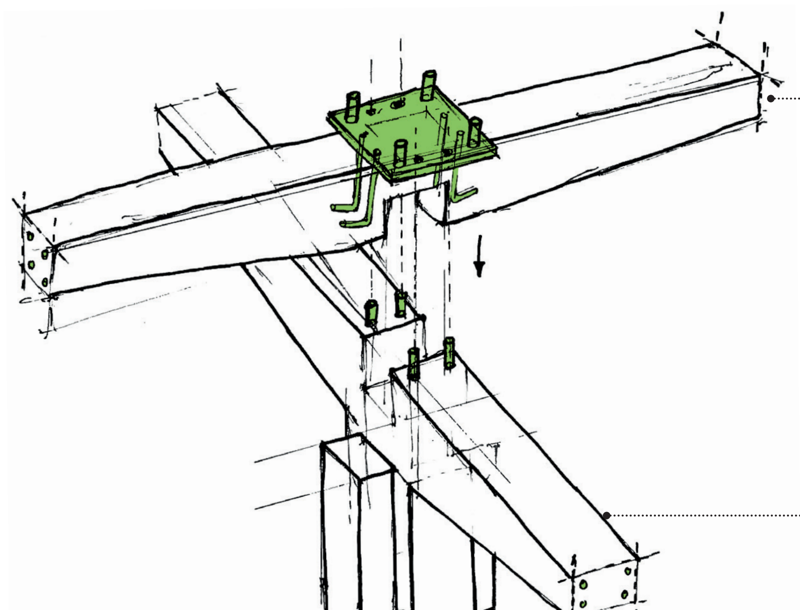
ill. 086
Concrete elements before assembly



ill. 087
Preliminary dimensioning

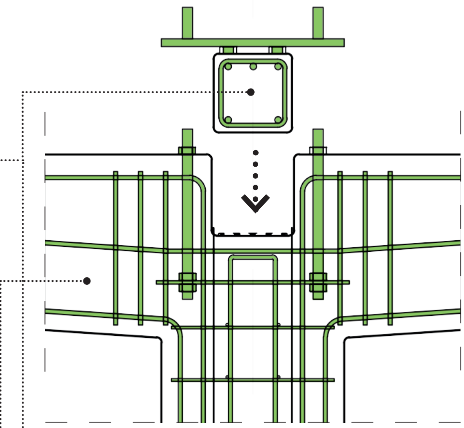


ill. 088
Idea of how to solve reinforcement of concrete elements

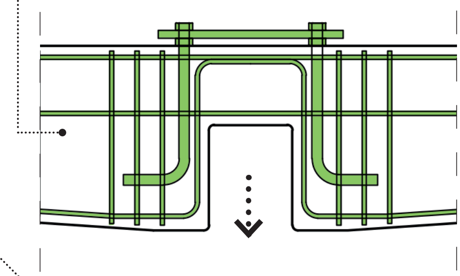


ill. 089
Concept sketch/ Connecting prefab concrete elements

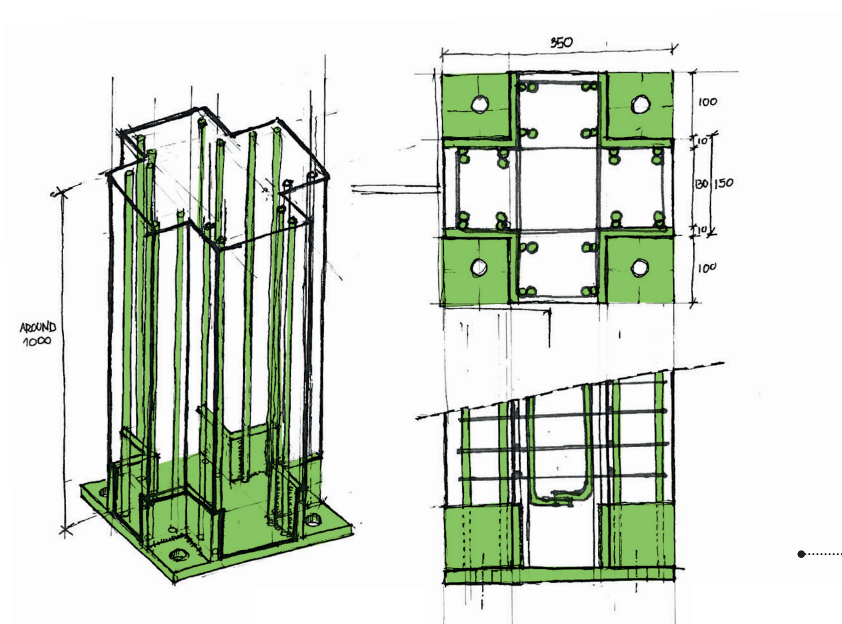
Detail 1



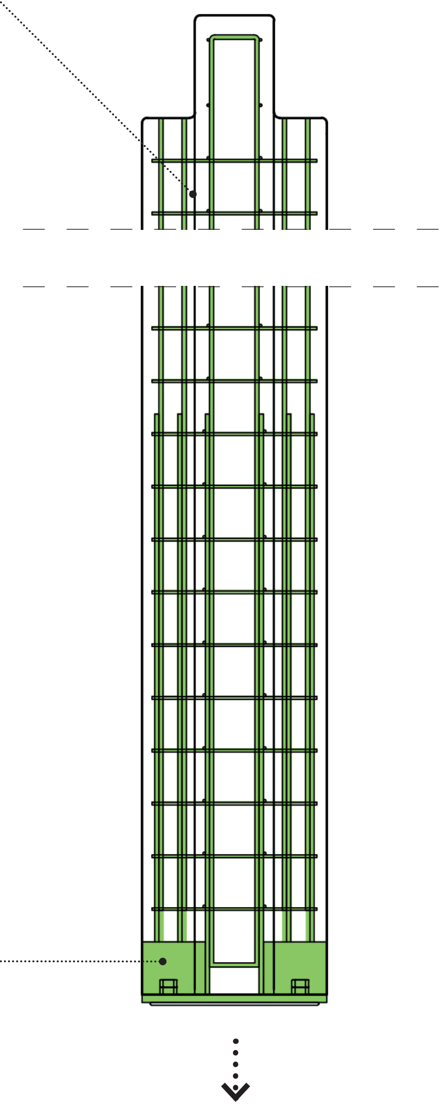
Detail 2



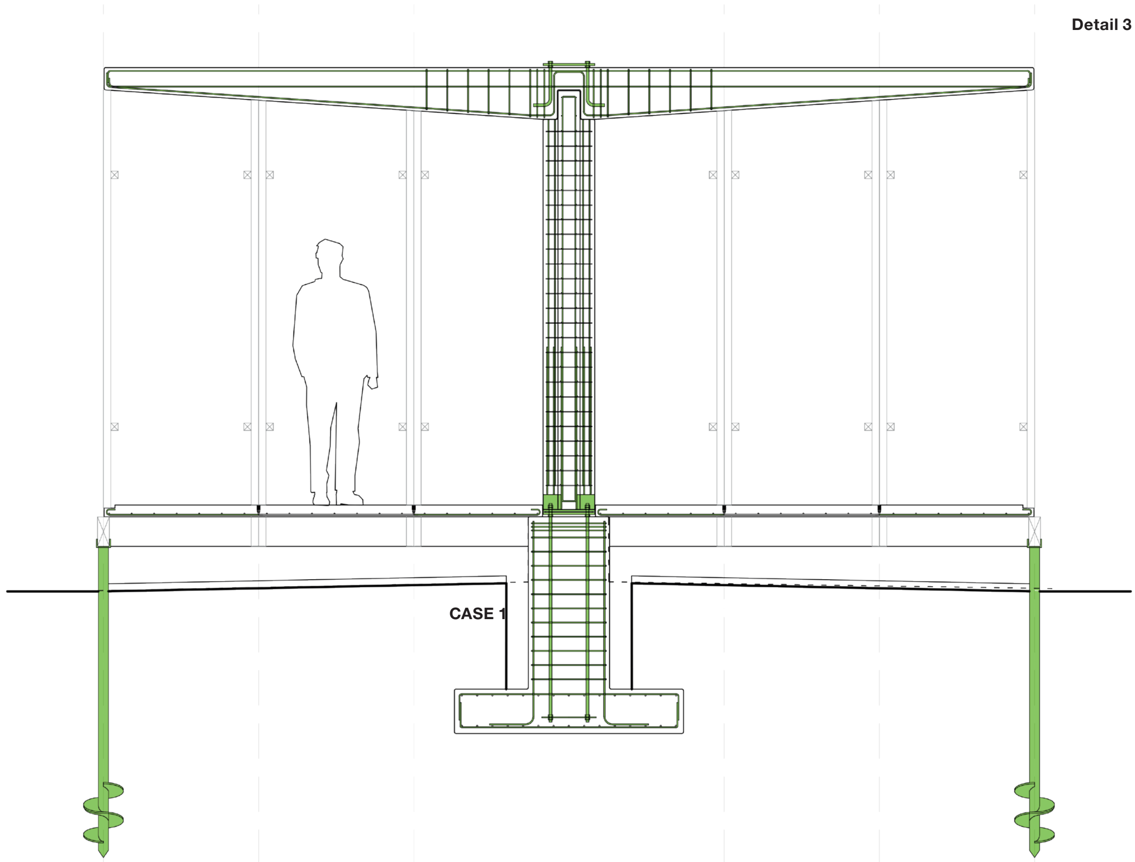
The focus was on two joints: column-foundation and column-beam connections. The inspiration for designing foundation and column joinery came from looking at monopoles foundation design by DaVinci Engineering Inc. and also by studying Columns to foundation shoe connection described in "Guide to good practice "Structural connections for precast concrete buildings". Having this knowledge allowed to proposed the design of the intersection where creating a stiff connection was extremely important. Additionally, the problem of narrowing the concrete element at point exposed for extreme bending moments was solved by either creating specially pre-stressed element or joining both elements with one thick steel plate. Next step after checking buildability of such construction, Autodesk Robot Structural Analysis program was used to define best possible layout of beam slab structure.



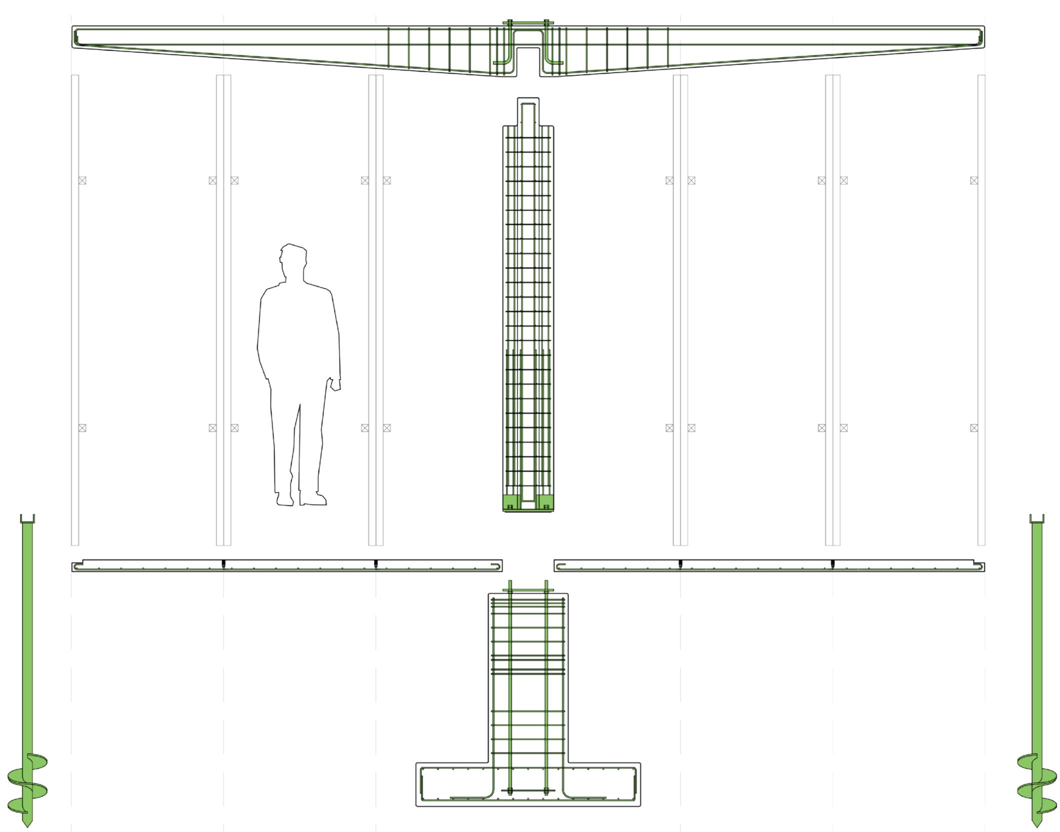
ill. 090
Concept sketch/ Connecting prefab column & foundations



Detail 3



Detail 4



ill. 091
Technical Drawing
(on the left)
Connecting concrete
reinforced elements

ill. 092
Technical Drawing
(on the right)
Construction elements
of single unit

3.2.2.2

ROBOT ANALYSIS

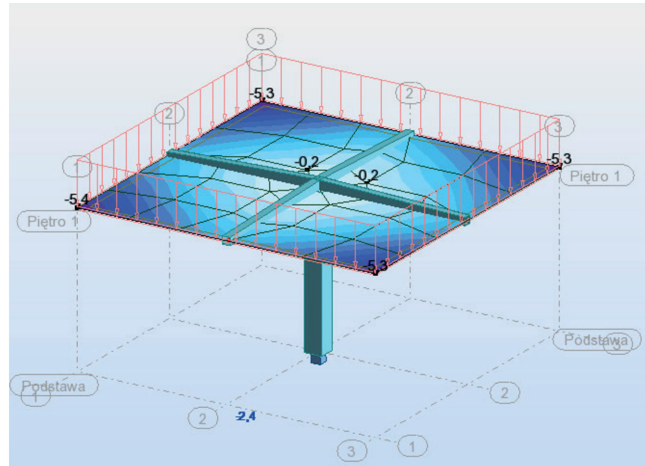
Three different cases were analyzed focusing on different umbrella beam layouts. In first case (1) simple cross structure in the middle was tested with concrete slab on the top. Simple load of 4kN/m2 was used and assigned to the surface of slab. The main goal at the beginning phase of testing was not to define the accurate deflections but rather to understand how different umbrella constructions behaves in comparison with each other and how much material is being use.

By looking at the outcomes of this analysis the choice of which path to follow was rather straight forward. By comparing case 1 scenario and treating it as our base results, case number 2 resulted with 56% improved deflections while 38% increased material use and case 3 resulted with 69% improved deflections while 138% increased material use. When these results will be recalculated into the overall performance of material use case 2 is characterized by 1,11 and case 3 by 0,71 efficiency comparing with case 1.

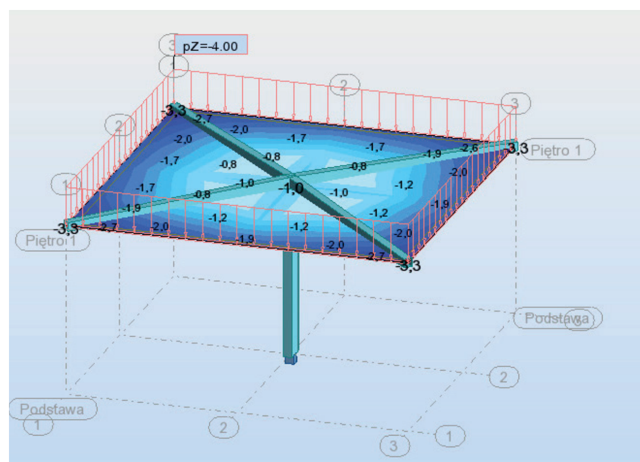
Case	Max deflection (mm)	Material use (%)	Performance
1	61	100	1
2	28	138	1,11
3	19	238	0,71

Another test made during this stage was the integration of technical unit as the additional support. Adding extra three columns (case 4) and only one column (Case 5) resulted better performance on the 3 corners of the construction, however, unexpectedly much worse outcome was observed on the opposite corner were deflection grew almost double. Such behavior of construction was probably caused by stiffening only part of the construction that previously worked in favor of overall balance. Last tests were made with two umbrellas connected in structural system. As expected, their behavior was better than single unit since stability was increased. Knowing that performance of each solution was within the EU norms we decided to make model workshops in order to assess the aesthetic side of the project

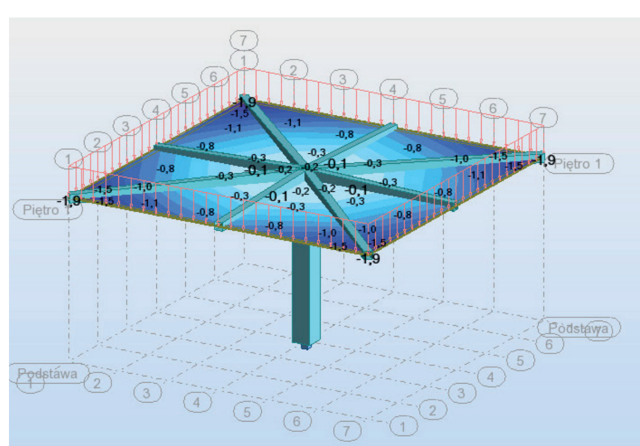
CASE 1



CASE 2

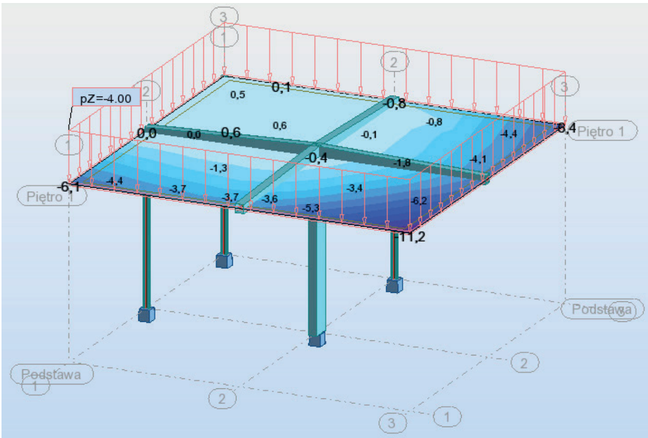


CASE 3

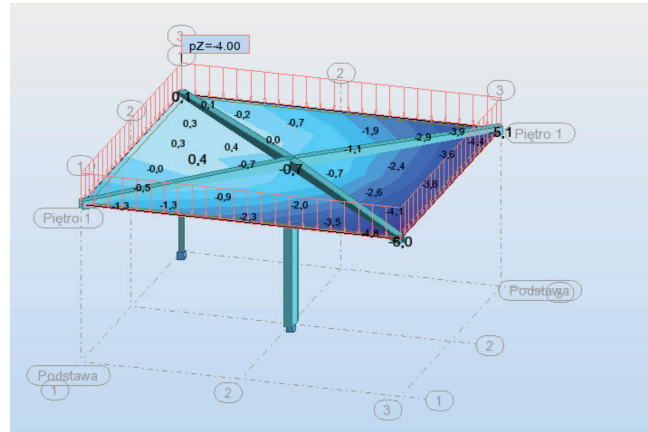


ill. 093
Technical Analysis/ Robot calculations for different cases

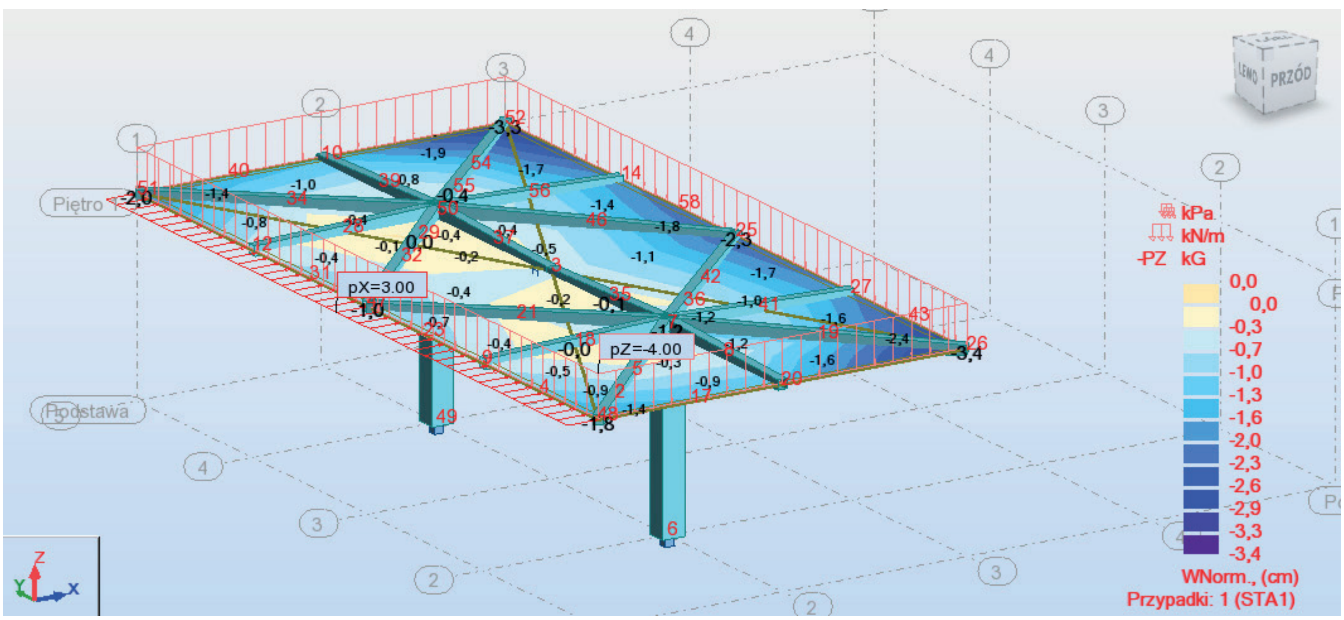
CASE 4a
technical unit as support

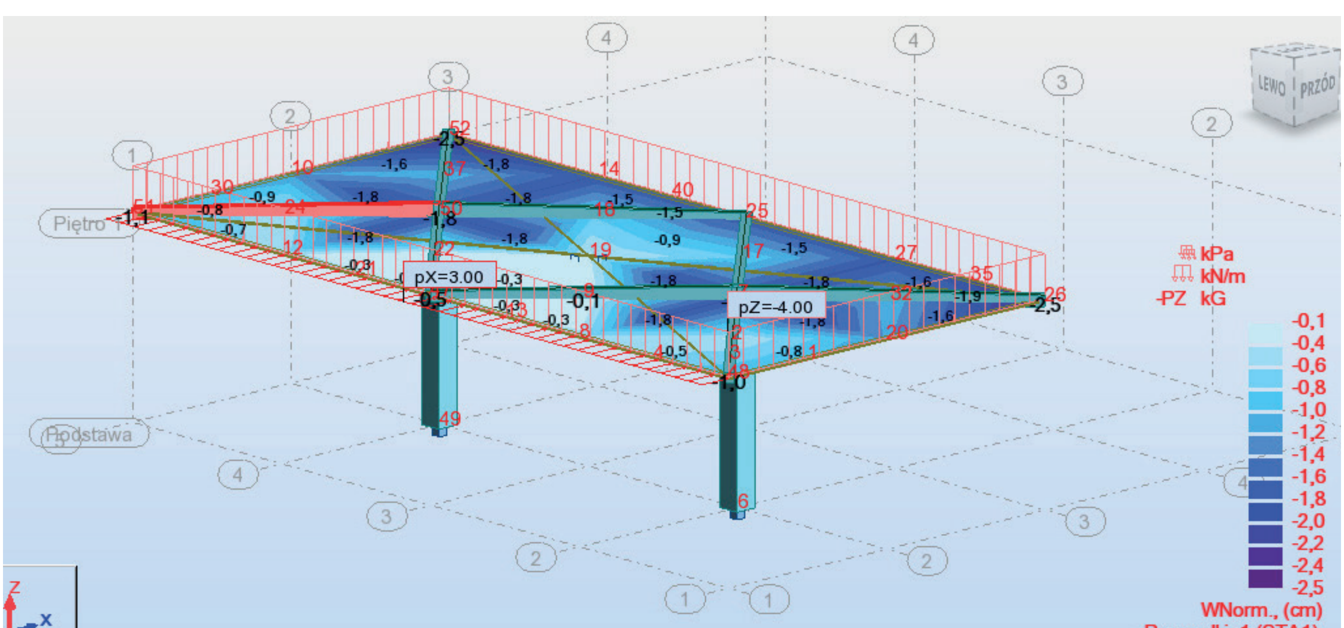


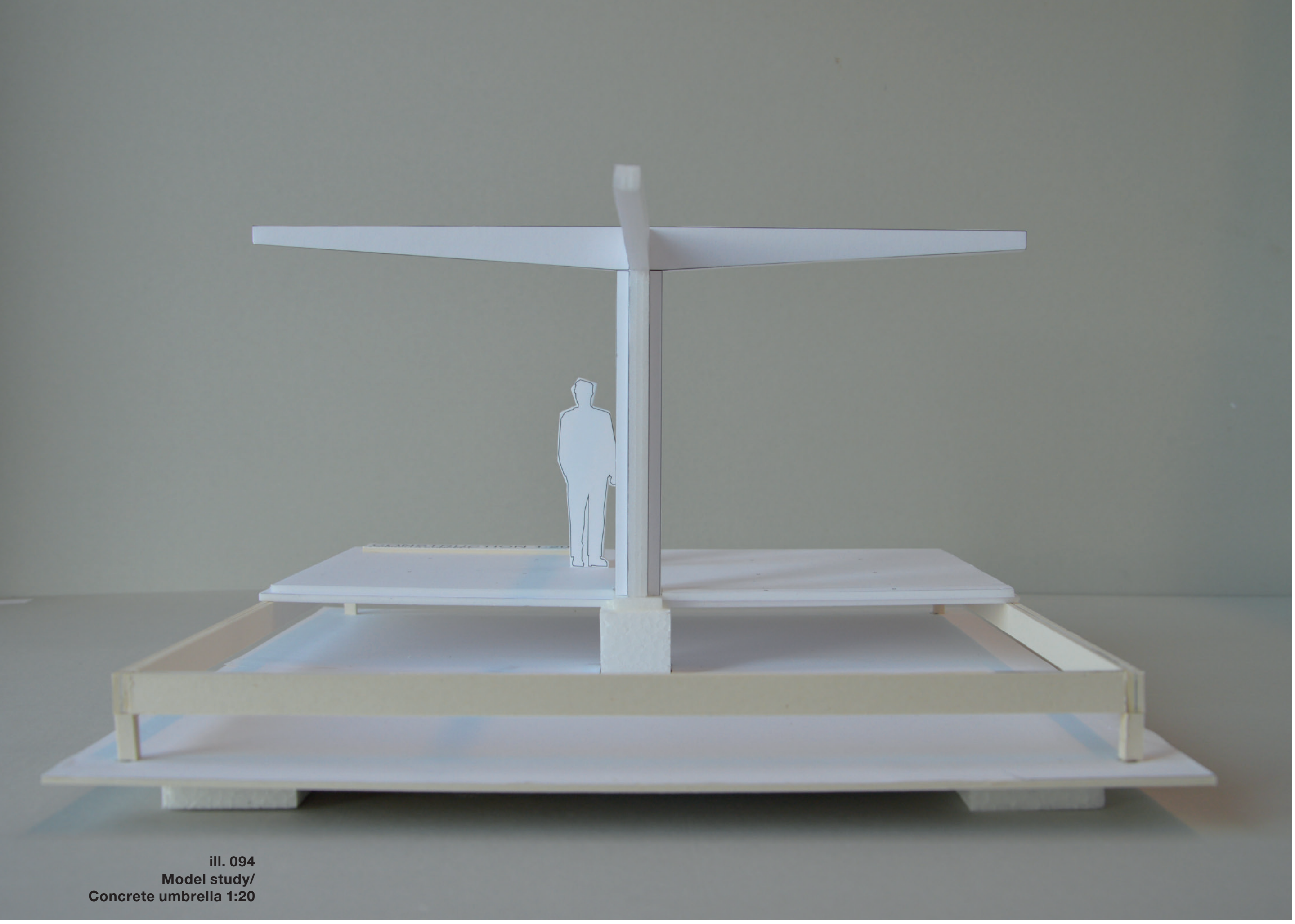
CASE 4b
technical unit as support



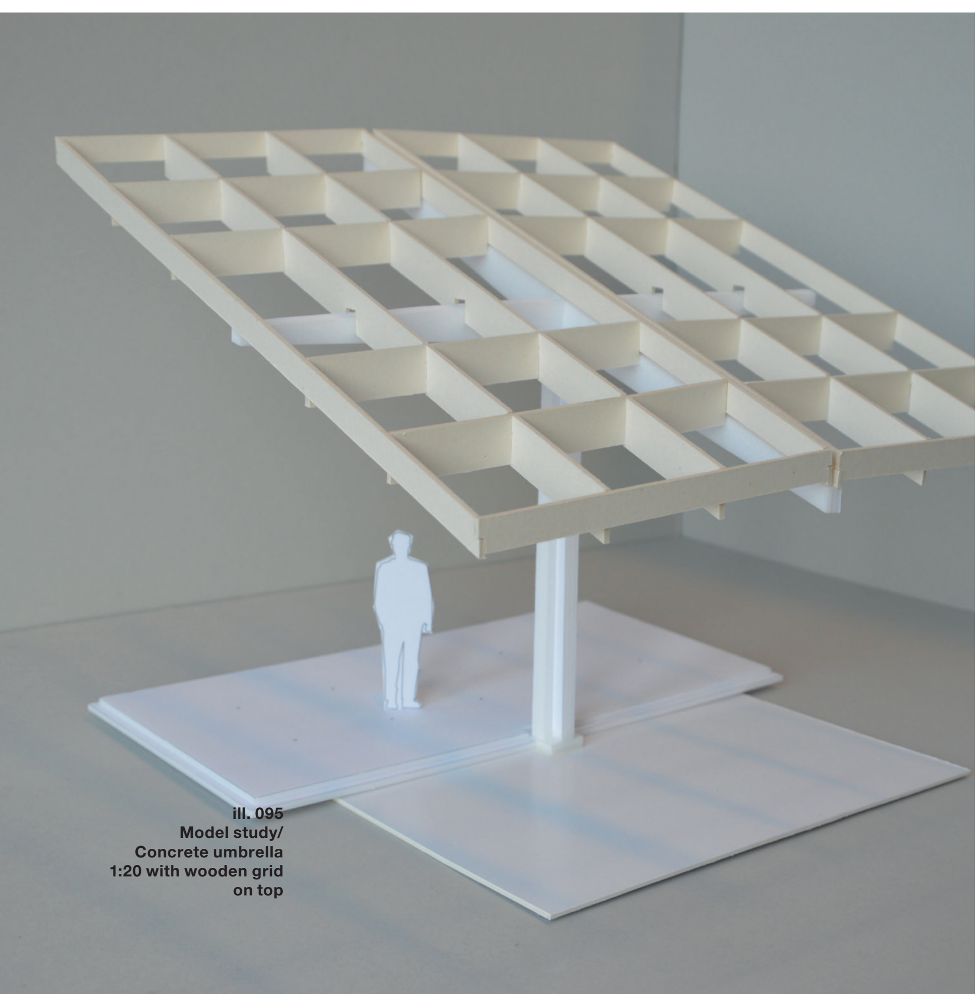
CASE 5 & 6







ill. 094
Model study/
Concrete umbrella 1:20



ill. 095
Model study/
Concrete umbrella
1:20 with wooden grid
on top

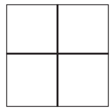
3.2.2.3
PHYSICAL MODEL STUDIES

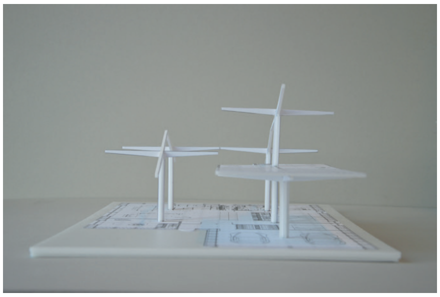
The goal of making construction models studies was to better understand the spatial quality of each solution. Two scales were used 1:20 and 1:50 for different purposes. Detail model (on the left) was done in order to experience proportions and aesthetic values of different elements. On the right 3 different models were made of the same test house with different umbrella constructions. This allowed us to notice stability issues and overall appearance of five units put together. At this moment if technical issues would not interrupt, the decision was made to follow simple cross-construction from corners of each unit since the stability, simplicity and expression worked perfectly with our concept.

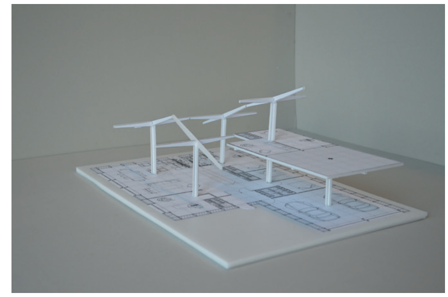
Even though concrete worked well with our project we decided to go even further and investigate more sustainable solutions such as wood.

CASE 1

ubmrella beam connections: **4**
deflection: **61 mm**
material use: **100%**
performance: **1**

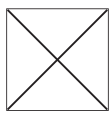




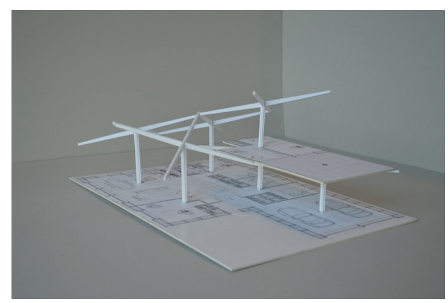


CASE 2

ubmrella beam connections: **14**
deflection: **28 mm**
material use: **138%**
performance: **1,11**

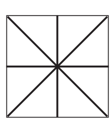


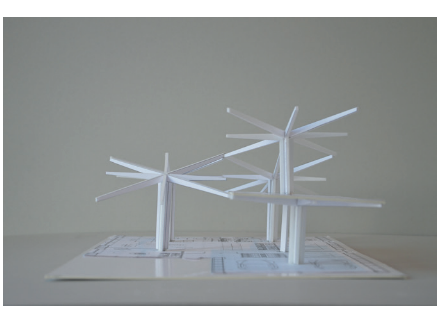


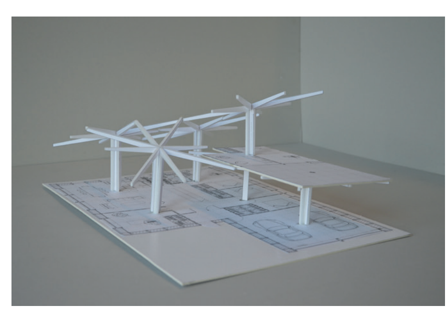


CASE 3

ubmrella beam connections: **17**
deflection: **17 mm**
material use: **238%**
performance: **0,71**







ill. 096
Model Studies/
Comparing different
structures

3.2.3

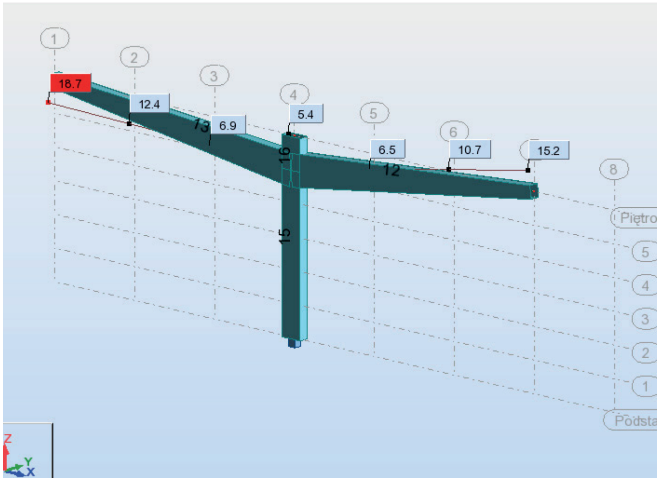
WOODEN STRUCTURE

In order to design construction that would answer 21st century need of sustainable solutions, decision to redesign umbrella construction using timber was made. This time the design process started from Autodesk Robot Structural Analysis Program since the biggest concerns were regarding deflections and big moments in joinery. All calculations were simplified to 2 dimensional structure with linear load recalculated from 4kN/m2 according to European Norm , self weight and average wind load of 1 kN/m2. Thereafter, the worst case scenario was taken into consideration with just a half of umbrella fully occupied by people and additionally windload that increased extremal moments in column beam joint.

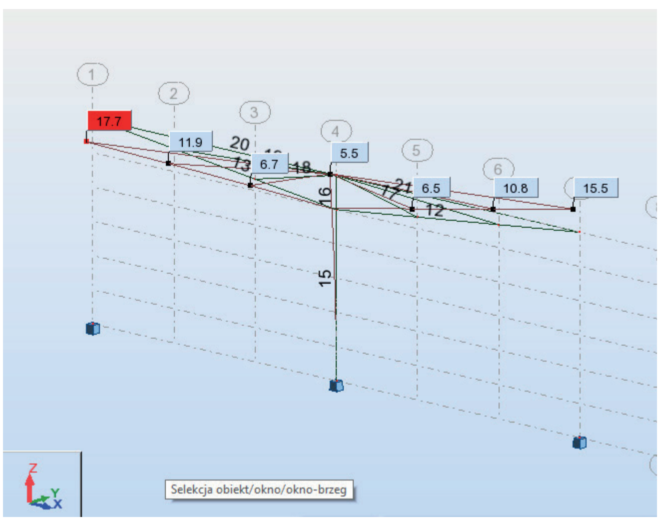
As our first initial test showed the biggest deflection appeared at the end of the occupied half of umbrella and surprisingly very similar deflection was observed on the other end of construction but with counter vector. To minimize this movement the decision was made to mount the ends of umbrellas with steel wires that should significantly improve the balance of whole construction. This change reduced the deflection on non-occupied half to almost a zero and the other half experienced 150% reduce of deflections. Even though improvement was significant and also in next tests umbrellas wings were prestressed with steel wire that worked well against tension forces, the deflection still exceeded the allowed value. The reason for such behavior was caused by relatively long arms of the umbrella which moved a lot together with deflection of main column. In this way movement of the top part of column (around 20 mm) meant big deflections of wings. At this point the measurement of bending moments were made in the whole construction and the biggest moment was observed at the joint of wing and column which is expected when we analyze how such construction should work.

Moment in the column always stayed at similar level of around 150 kNm and was the main reason of big deflection in the center of the structure. To overcome this obstacle the decision was made to propose different material combination where timber will still play big role in construction however it will be supported by some other material regarding the column.

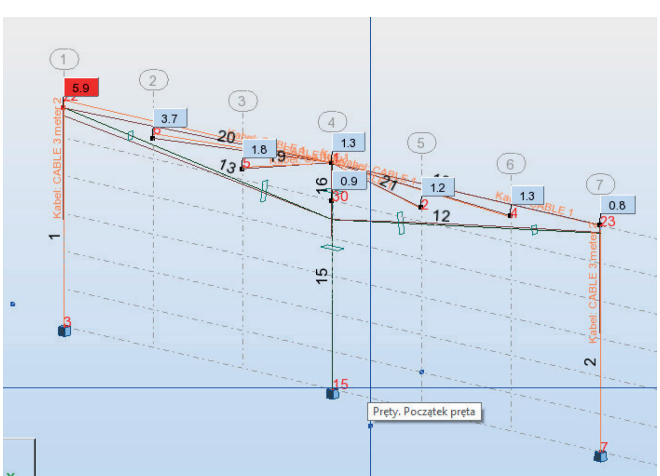
By analyzing moments and how it



ill. 097
Robot calculations/ Wooden construction no cables



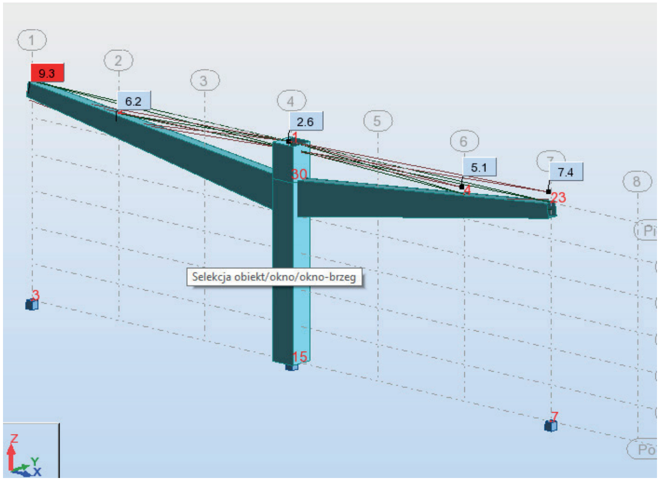
ill. 098
Robot calculations/ Wooden construction cables stiffening top construction causing worse deflection

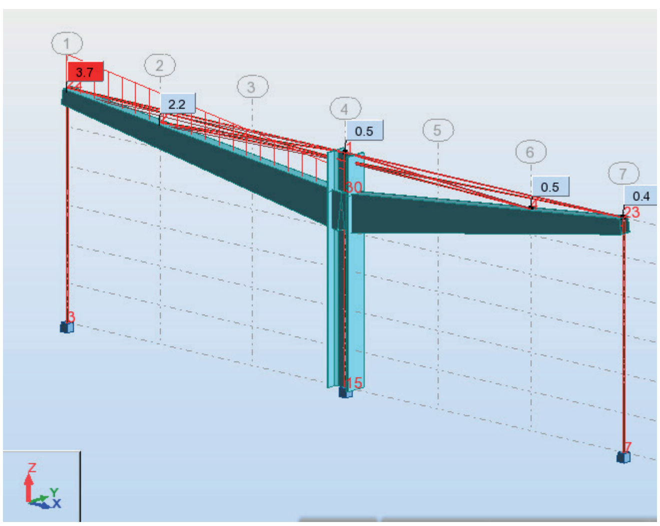


ill. 099
Robot calculations/ Wooden construction stabilized with cables

3.2.4

MATERIAL COMBINATION



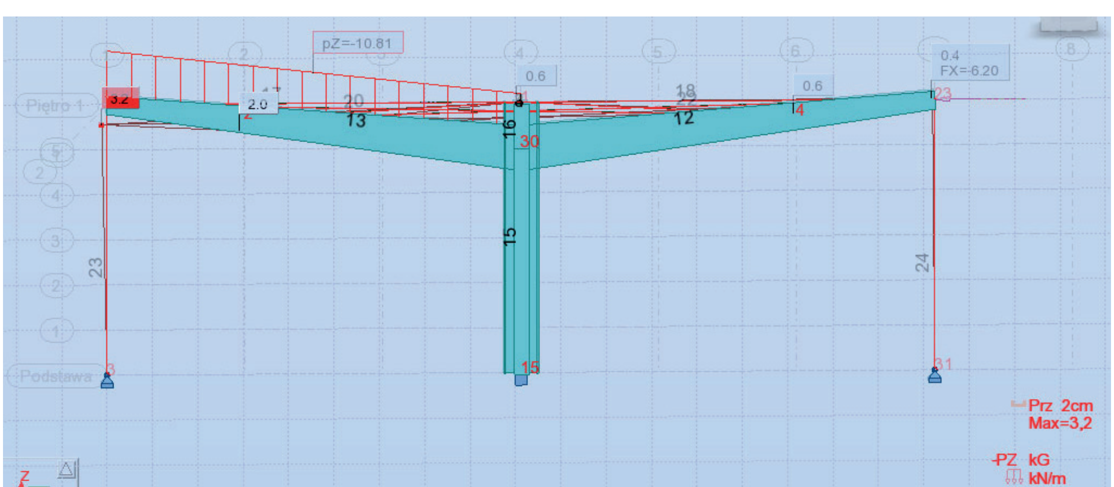


ill. 100
Robot calculations/ Concrete column & wooden beams

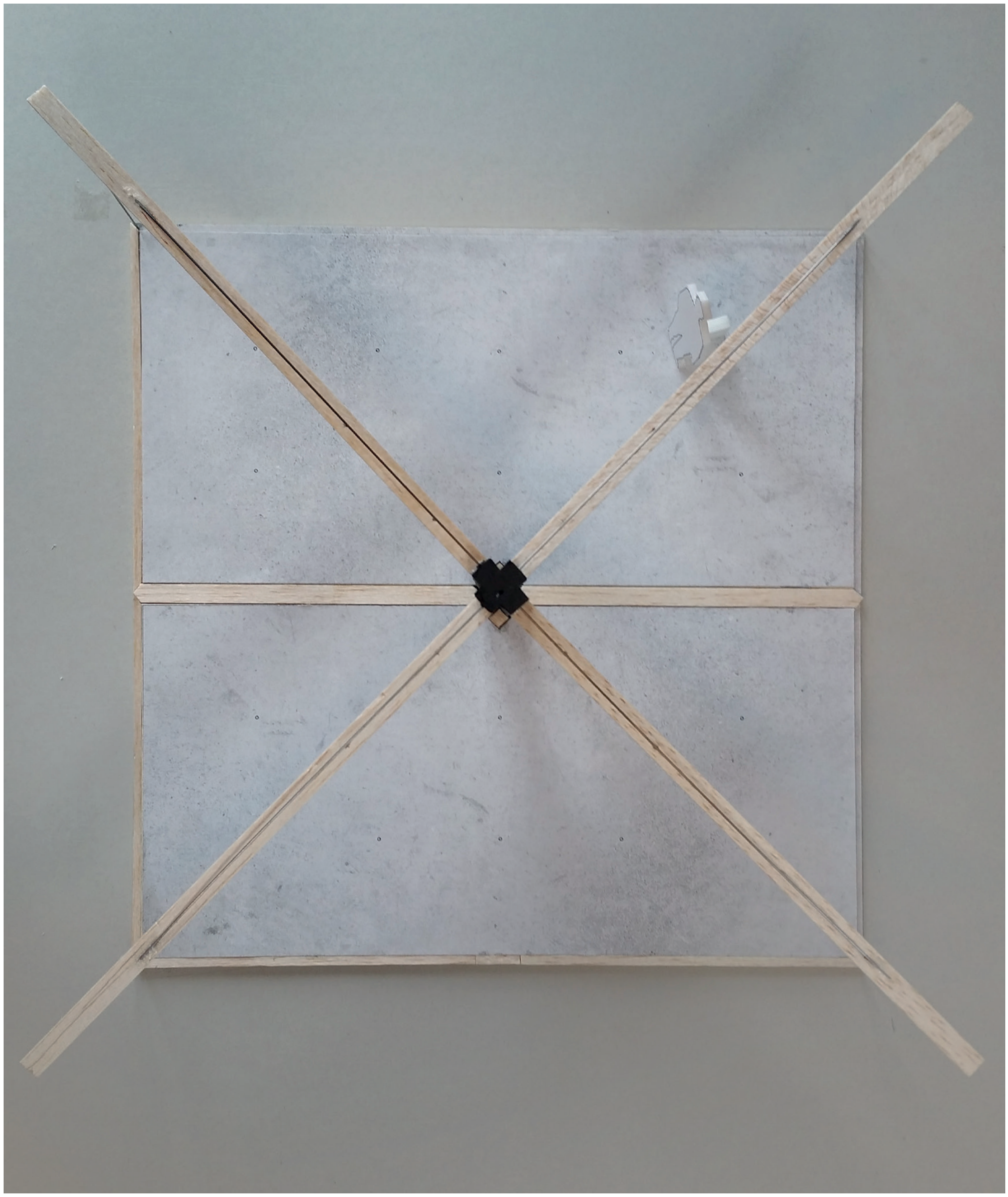
ill. 101
Robot calculations/ Steel column & wooden beams

affected construction, different materials of column were tested such as concrete that from aesthetic point would work perfectly with concrete flooring. First test were very promising since deflection of the column was reduced significantly. However, it turned out that the amount of reinforcement that would have to be implemented to work against moments would be extremely high and in this way it would be dishonest regarding our intentions for efficient use of materials. Since concrete is good to transfer compression loads and in contrary big moments in column caused tension, next step was to test out steel and wood combination. Steel column (initially HEB 340 then 2x IPE) behaved even better than concrete and by checking and comparing costs of each solution we were satisfied also with this economical aspect. Next step was to assure buildability of wooden wings and designing connection that would be able to transfer big moments of this construction.

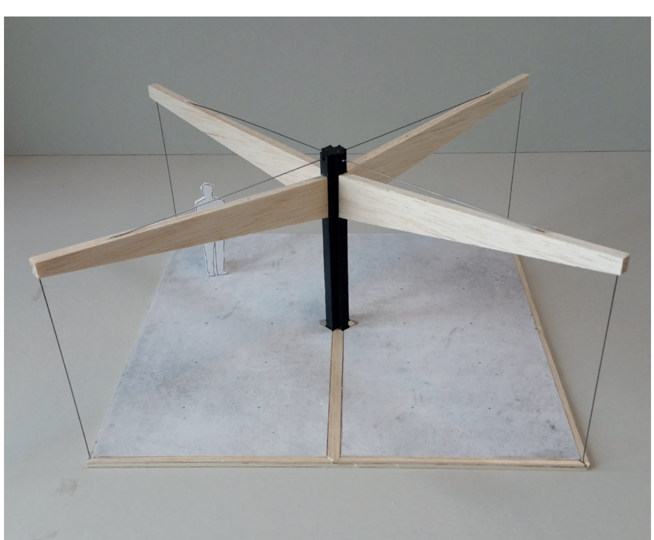
By studying most recent solutions within timber constructions, the best revolutionary joints were used for connecting wood beams with steel column using 8 HSK Pipe connectors for moments in wood with M16 or M22 screws. Additionally to assure best performance of wood it was additionally reinforced with special fastening system that helped with lateral tensile forces. Beam were also prestressed with steel cables and additionally stabilized on the sides with cables that were only working in favor when the construction was bending in opposite direction otherwise they stayed neutral.



ill. 102
Robot calculations/ Steel column & wooden beams



ill. 103
Model study/
Material Combination
1:20

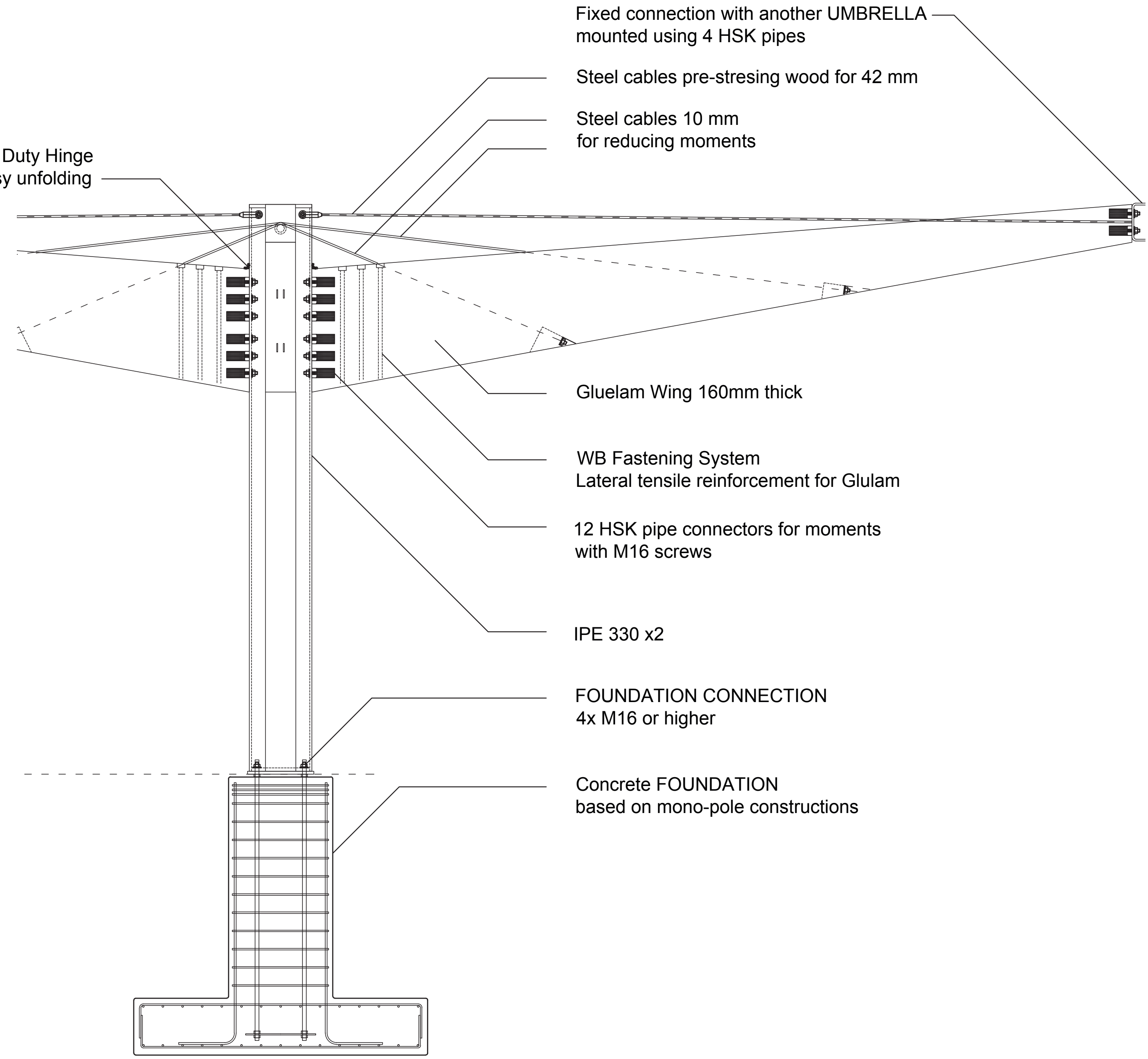


ill. 104
Model study/
Material Combination
1:20

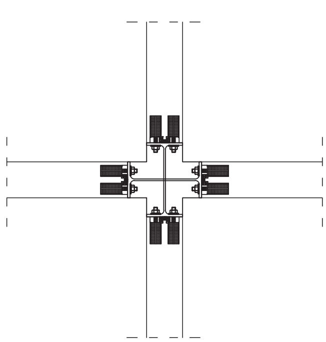
3.2.4.1

PHYSICAL MODEL STUDY

Being satisfied with materials and their combination another model was done to experience the materiality of the construction (scale 1:20) and combination of concrete flooring, black galvanized steel column and wooded massive glulam beams that were prestressed and stabilized with steel wires.



COLUMN
PLAN



ill. 105
Construction study

3.2.5
FOUNDATIONS

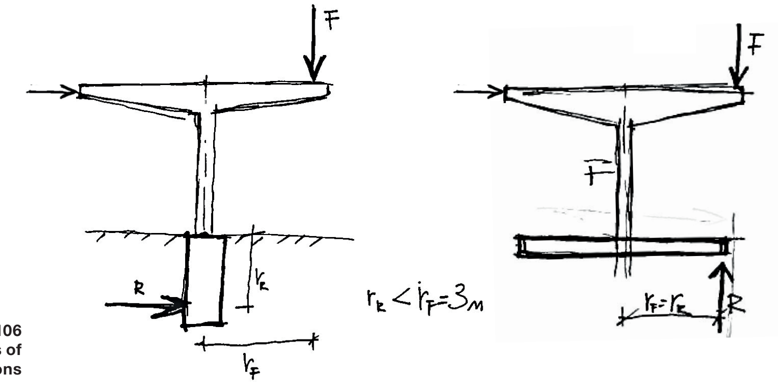
Subject of foundation system for umbrella-like structure was raised very early in the process of designing this prefabricated system. The reasons for this were inter alia:

- creating a monopole construction where problems of deflection and bending moments are much more difficult to solve with comparison of traditional structures
- attempt to design system that could be use in every season including winter that is uncommon for most nowadays architecture
- designing a system that would require minimum work onsite, allow quick assembly and would work good with the additive aspect.
- designing a system that would minimize the use of high energy embodied materials and would allow for C2C strategy of reusing applied materials.

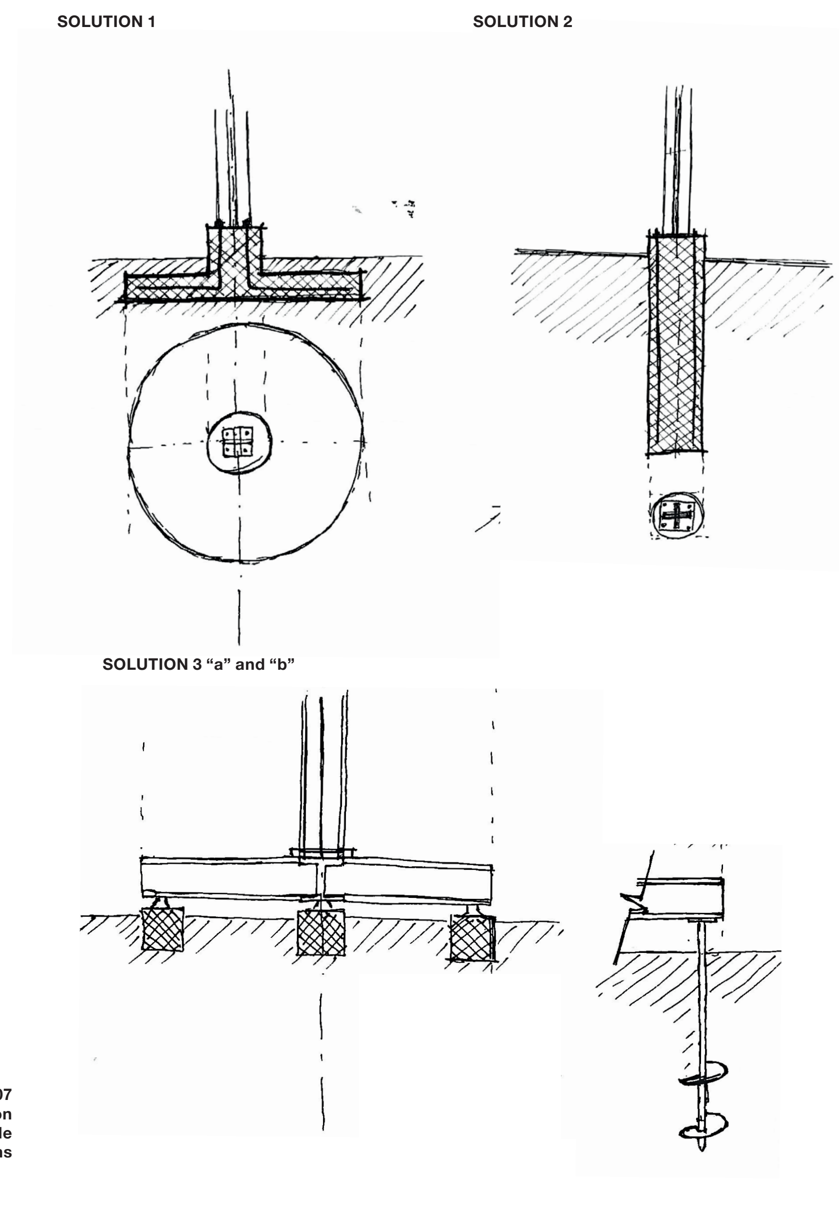
The process started from analyzing forces that could affect our construction that are described in-depth in chapter 3.2.2.2, Robot Analysis. The most unfavorable case where force is pushing only on one side of umbrella and additionally wind is strengthening the bending moment in column must be transfer by the ground by some sort of foundations. By looking at monopole constructions such Wind turbines, monopole Billboard constructions, special parking covering system and other, it was possible to distinguish different approaches to this similar topic.

Three different foundations were investigated

- (1) special reinforced concrete disc that being buried under the ground, was helping to stabilize construction. Such foundations are most common for wind turbines and monopole adverts construction. The radius of disc is working like a frame construction where column and foundation are connected with fixed joint round shape of disc is working equally well regardless the direction of forces affecting the construction
- (2) second type is less popular within monopole constructions and is used in cases where forces affecting the construction are lesser than in case “1”. Such foundations are sometimes used on parking lots because of its easy execution and



ill. 106
Simple analysis of forces and reactions



ill. 107
Different foundation types for monopole constructions

quick implementation. The depth of the foundations increase its performance since both: the traction between ground and concrete, and also "arm" which must transfer the bending moments is working in favor of whole construction.

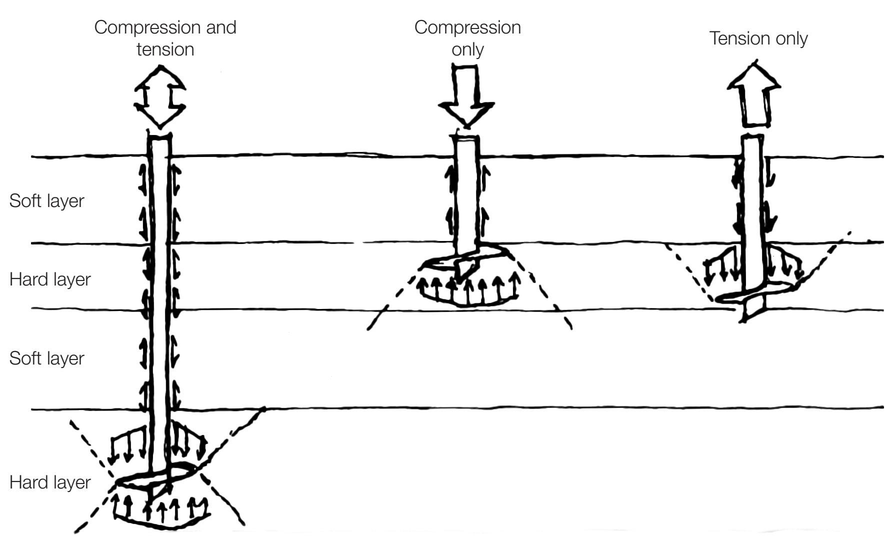
- (3) third type of foundations can be found in many examples mainly with steel column as the main support. Such foundations allow for multiple mounting points that increase the stability of construction. Additionally we can use either concrete blocks or helical screw piles which have an unusual ability of flexible applying time. That means they can be used both in summertime and winter time. Furthermore after demolishing these foundations can be unscrewed in order to be reused or 100% recycled.

By analyzing and consulting different solutions we decided to propose 2 different solutions "1" and "2b". Depending on the ground conditions different foundations will be used. First solution is design on the basis of foundations designed to fit 30m high billboard advertisement made in concrete. Dimensions and reinforcement were appropriately changed to meet the requirements of our construction. In similar way steel foundations were proposed and designed giving us the choice between these two solutions.

When floor-plan, construction and foundations were designed, the next step that worked in loops within previous elements was the envelope of this prefabricated system.

ill. 108
Process of installing screw pile foundations

ill. 109
Principle of helical screw pile dimensioning



3.3 ENVELOPE

3.3.1

THE IDEA

Thanks to unique umbrella construction, the envelope of our building was planned to be designed fitting exactly its purpose. Just like in nature, skin was developed as the outer barrier to ensure safety from external factors and keeping constant internal conditions, these abilities could be mimicked and transformed into architectural language. Thin and elastic human skin is the perfect external barrier for human bodies, however the question is what should be expected from perfect building envelope?

Nowadays, due to increasing energy consumption demands, the envelope of the building became thick and massive. While in bigger commercial objects this aspect is not that visible because of its scale, single family housing is being overwhelmed by this aspect. Not only it is causing very deep window openings that are limiting daylight factor but also it is physically taking usable space from the house by only increasing gross area of the object. This however can be significantly improved if loadbearing layer will be removed from its components.

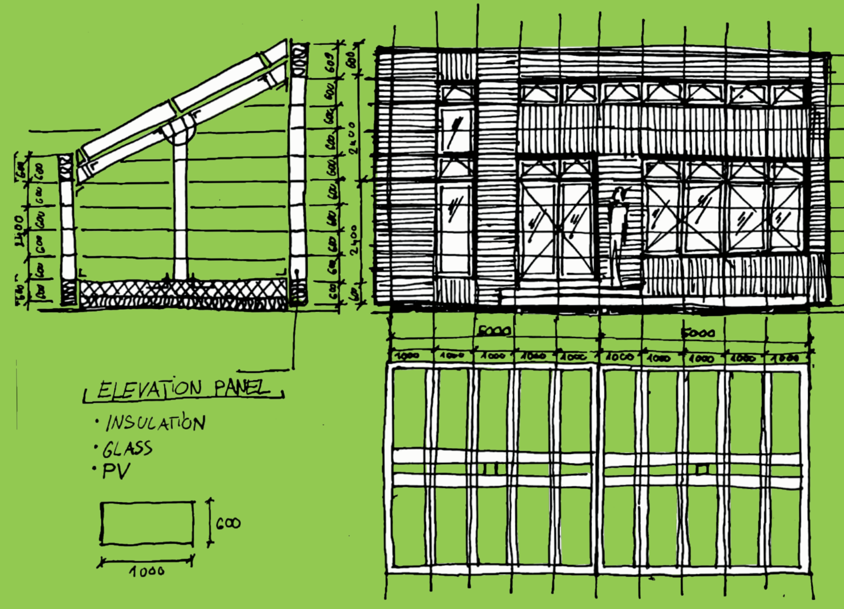
This is especially visible in European houses where heavy and high-energy embodied materials take around 250 mm of envelope space excluding cases with brick as the external elevation finish. Together with 300-400mm of insulation that is necessary to reach U-values under 0,1 W/m2K, total width of wall can reach up to 750 mm or more if we consider more demanding elevation systems. In our prefabrication system, different approach will be presented to overcome issues mentioned before.

ill. 110
Michelangelo anatomy sketch

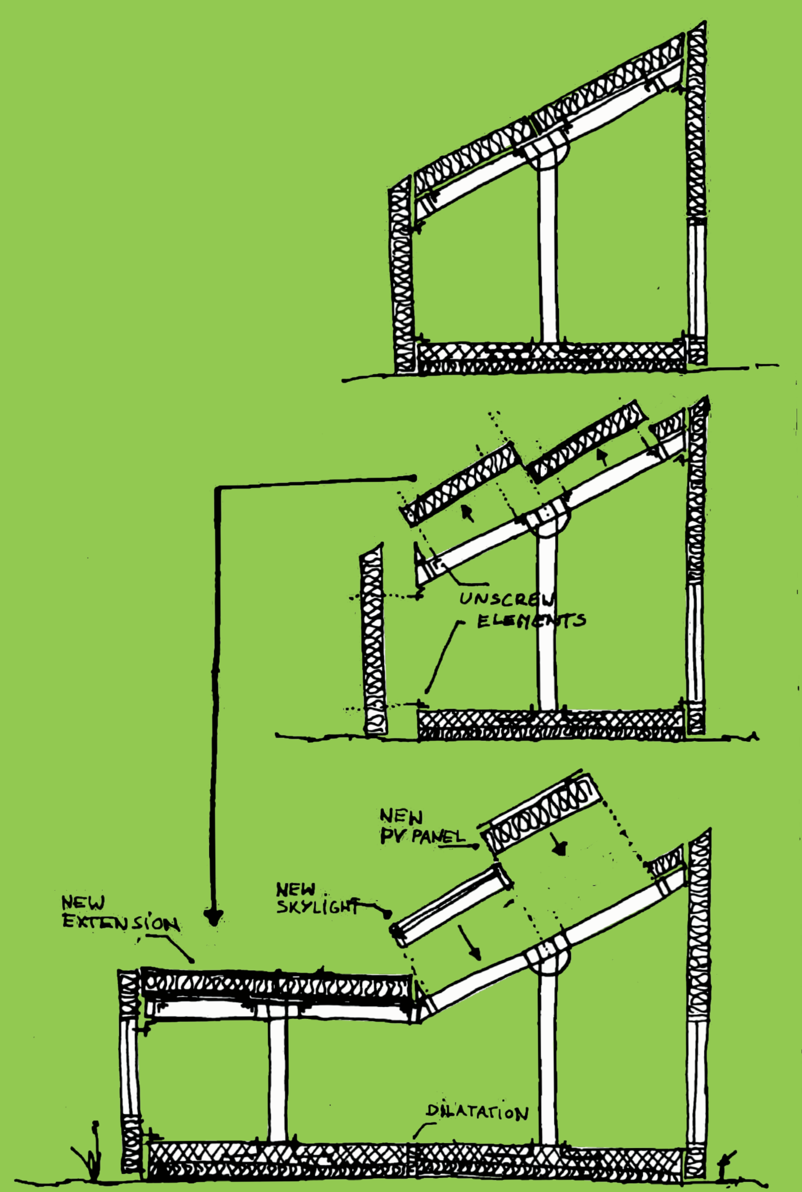
Special wooden skeleton with insulation taking most of wall structure will be used to prefabricate standardized panels. Transported on the site, panels will be thereafter quickly assembled to create close and strong envelope, helping only with shear forces. In case of renovation or expansion, panels should have the ability of quick dismounting without affecting the whole construction. Having such goals next important aspect was how to include the client into the design process.

Special simplified elevation grid was developed continuing floor grid as width of panels and vertically divided into smaller 500 mm parts. Such parts stack on each other could then form one panel might easily be designed by the client. In other words, when plan of the house is developed, each elevation can be represented by special grid where by choosing each "tile" to become a wall (with various elevation materials) or window, different outcomes are being achieved. Having such principle we moved to testing different possible expressions that would be possible with this idea

1.

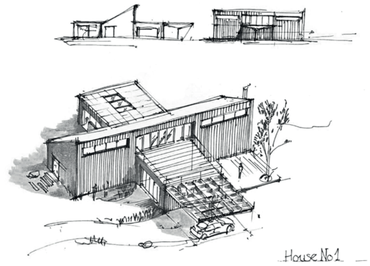


2.

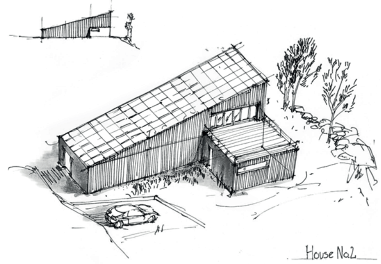


ill. 111
1) Initial idea of envelope design

2) Modernization process



House No.1



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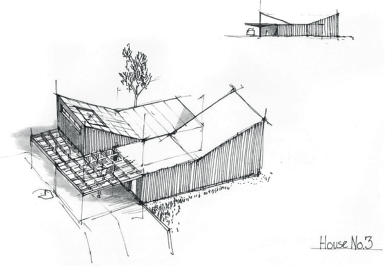

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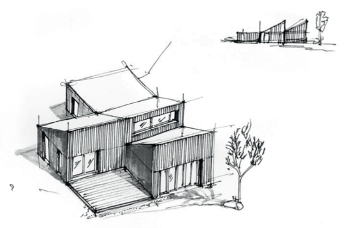
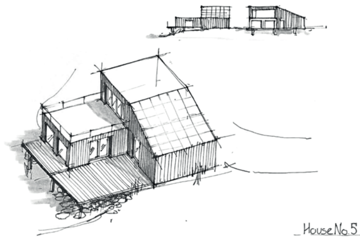
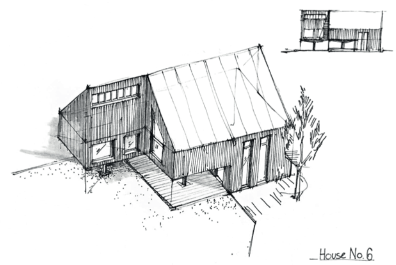


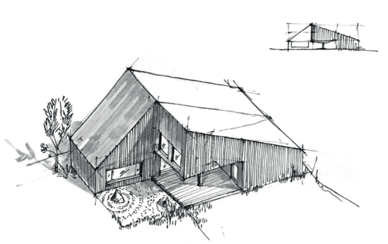
House No.4



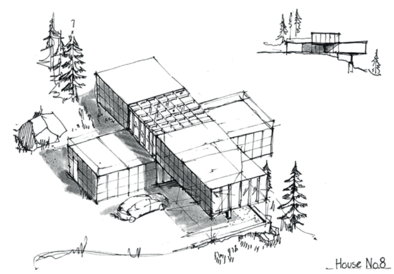
House No.5



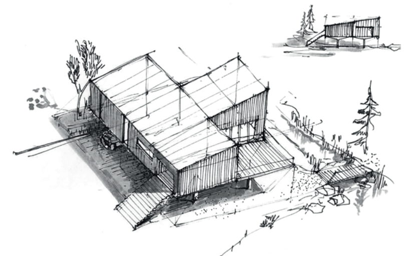
House No.6



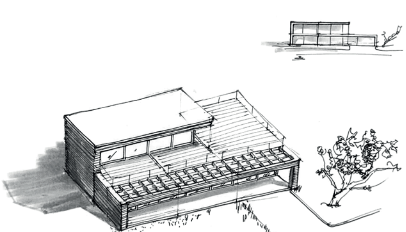
House No.7



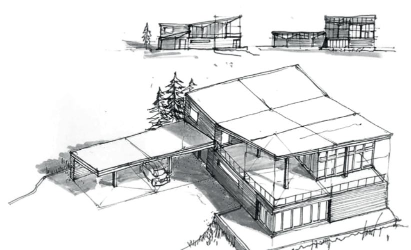
House No.8



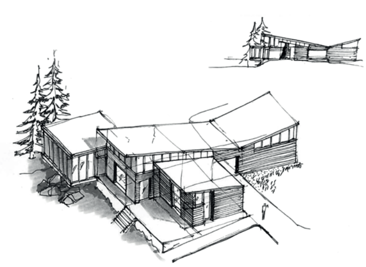
House No.9



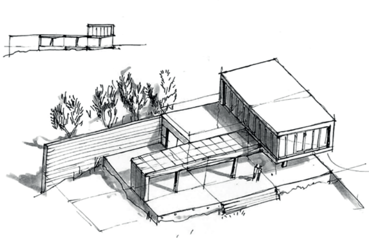
House No.10
inspired by D. Sauer House



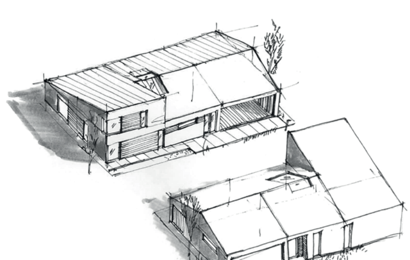
House No.11
inspired by Boora Architects House



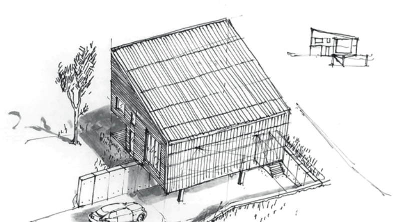
House No.12
inspired by house R.M.Coin



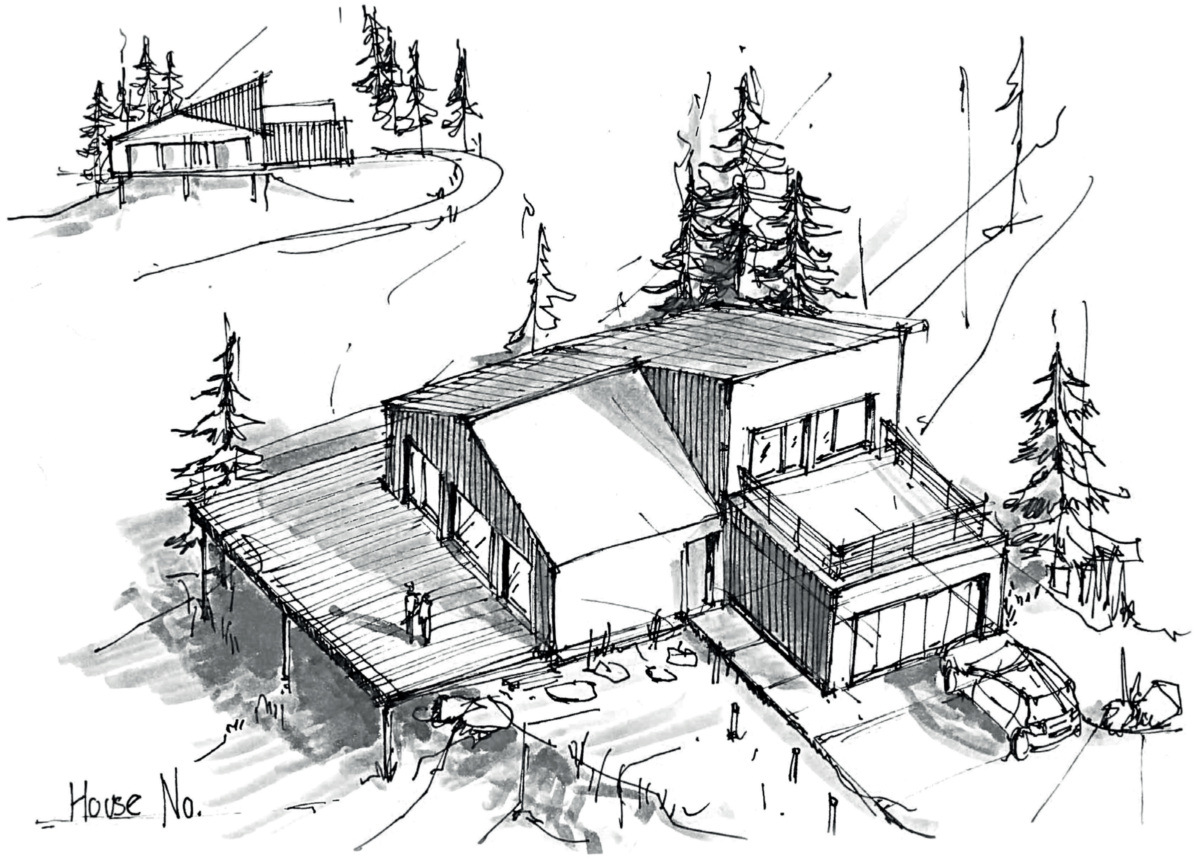
House 13



House No.14



House 15
inspired.

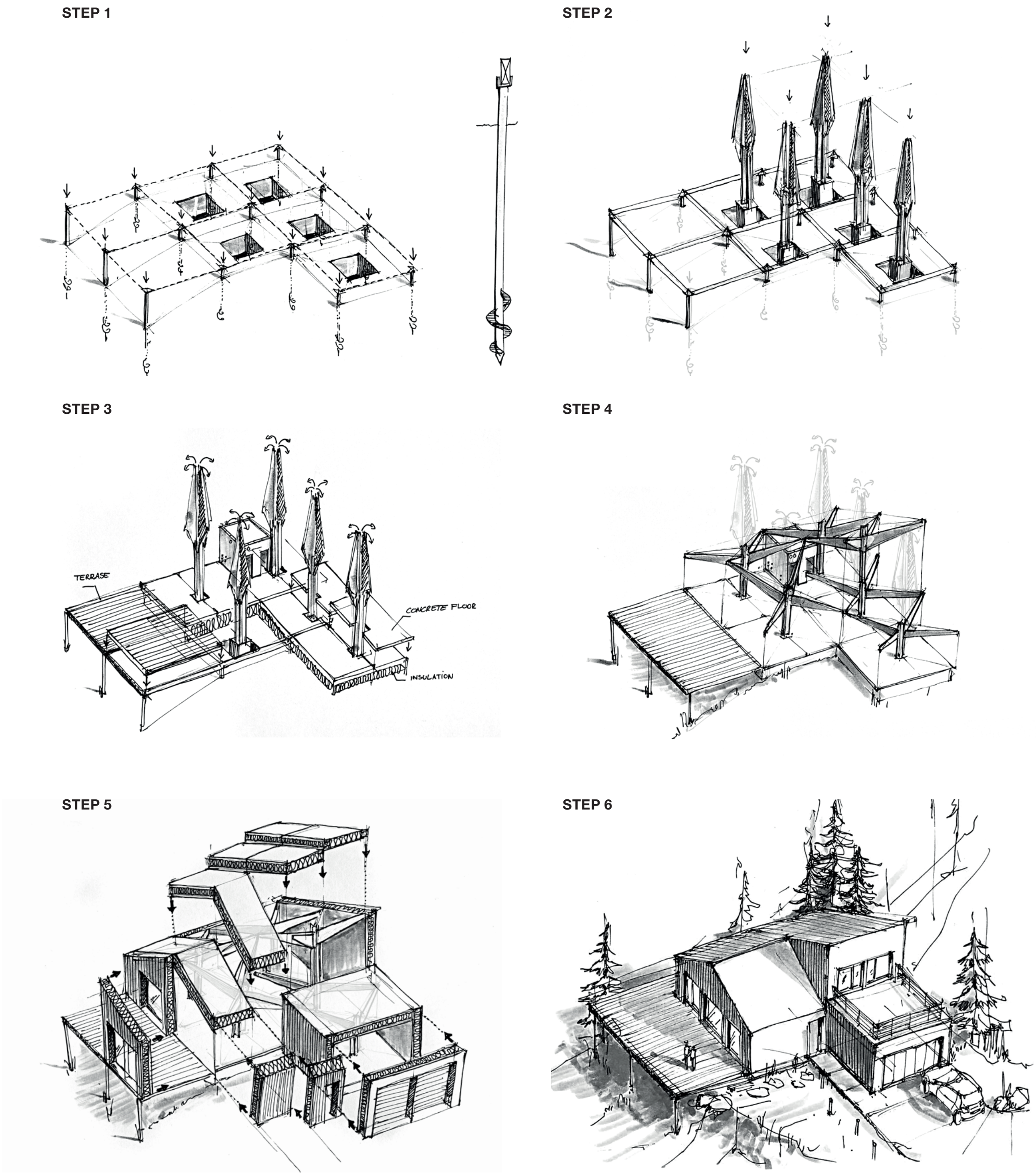


ill. 112
Variations of concept houses

3.3.2
FIRST CONCEPTS

Different sketches visible on the previous page are representing the studies of various houses that could be potentially possible to create with our prefabricated system. Having the goal of creating construction that would allow to flexibly design most of nowadays single family housing, at the beginning stages, designs were trying to hide its unique construction which changed in further development of the project. Nonetheless, to test and solve different elements of our prefabricated system the decision was made to design simple "test house" visible at the top.

The idea behind this house was to create something relatively simple that would at the same time enforce solving many technical aspects and details. These technical aspects were extremely important for successful completion of this project and they had to be addressed as fast as the main idea shaped in order to realistically evaluate the advantages and drawback of each decision. Elements such as foundation, transportation, mounting, joinery and finishing works where the subject of further analysis and they are all based on the "test house".



ill. 113
Step by step process

3.3.2.1
STEP BY STEP PROCESS

One of the main advantages of prefabricated building over on-site construction is the erection time and ease of putting building elements together. Hence, each element must be carefully designed and thought through, especially the joinery that should not require any modification on site. Thus, we proposed elements that could construct building in 6 steps:

STEP 1: Foundations using helical screw piles are prepared on previously arranged positions. Because of piles properties excavation is not needed, which means that building can be constructed during winter.

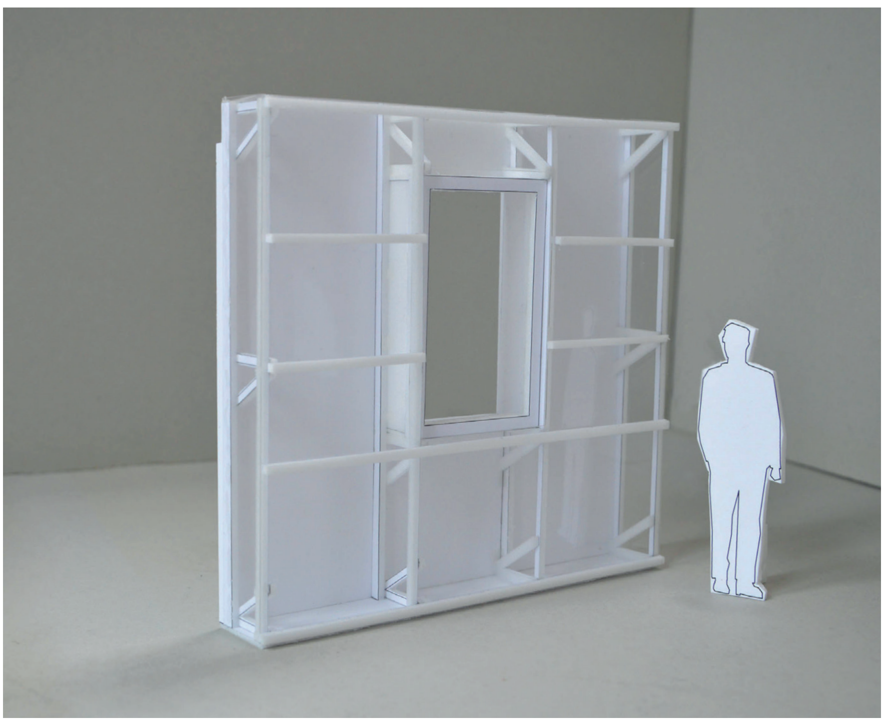
STEP 2: Prefabricated umbrella constructions are placed on site. Initially wooden beams are attached to the column with hinges but they are folded during transportation.

STEP 3: After umbrella construction is on the right position, prefabricated floor with necessary insulation can be installed. At this time also technical unit with bathroom is placed on its position.

STEP 4: In this stage, beams can be unfolded and secured whit bolts to the column. Furthermore, ends of beams are connected to the top of the column and to the ground using steel wires for additional stability and robustness of the construction. At this point beams are also connected with neighboring beams, if there is more than one umbrella construction.

STEP 5: When the construction of the building is done, it can be enveloped with standardized envelope elements. Because these elements do not have significant statical function in the building they can be installed as easy as they can also be removed or replaced.

STEP 6: When building is protected against external conditions, interior work can continue.



3.3.2

ENVELOPE

As mentioned in previous chapters the idea of umbrella prefabricated system is to differentiate construction and envelope. This allows to implement additive system that cannot interrupt the construction when removing envelope and adding new elements. Therefore walls do not need load bearing characteristic; however, it must support itself and attached elements such as windows. It must also withstand external forces such as wind load. Therefore, it needs own supporting construction but it can be minimized which reduced problem of cold bridges.

Similar example of wall construction can be seen in illustration 114, where skeleton-like wooden construction is filled with straw. However this wall is of great significance to the building statics, thus it is not appropriate for additive architecture. Furthermore straw has density of around 100 kg/m^3 (Ecococon, 2015) while glass mineral wool can be as low as 11 kg/m^3 (Knaufinsulation, 2015) which means lighter panel. Also straw demands special care with fire protection. Thus we proposing modified wall and roof panels based on straw walls but using mineral wool (ill. 115)

Important factor in the envelope design is also U-value demand and transmission losses through building envelope (excluding windows and doors) according to Building Regulations. Thus the design of envelope is following technical demand as well as functionality and aesthetics.

Building elements	**U-value [W/m^{2}K]**
External walls and basement walls in contact with the soil.	0,15
Ground slab, basement floors in contact with the soil and suspended upper floors above open air or ventilated crawl space.	0,10
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining roof.	0,10
Windows, including glass walls, external doors and hatches to the outside or to rooms/spaces that are unheated or heated to a temperature more than 5 K bellow the temperature in the room/space connected	1,40
Rooflights and skylight domes.	1,70

Building types according to number of floors	**Transmission loss [W/m^2]**
1 level building	3,7
2 level building	4,7
Building with 3 or more levels	5,7

ill. 114
Upper left -example of wall element made out of straw and wood
ill. 115
Middle-physical model of wall construction
ill. 116
Bottom-Tables of U-values and transmission losses

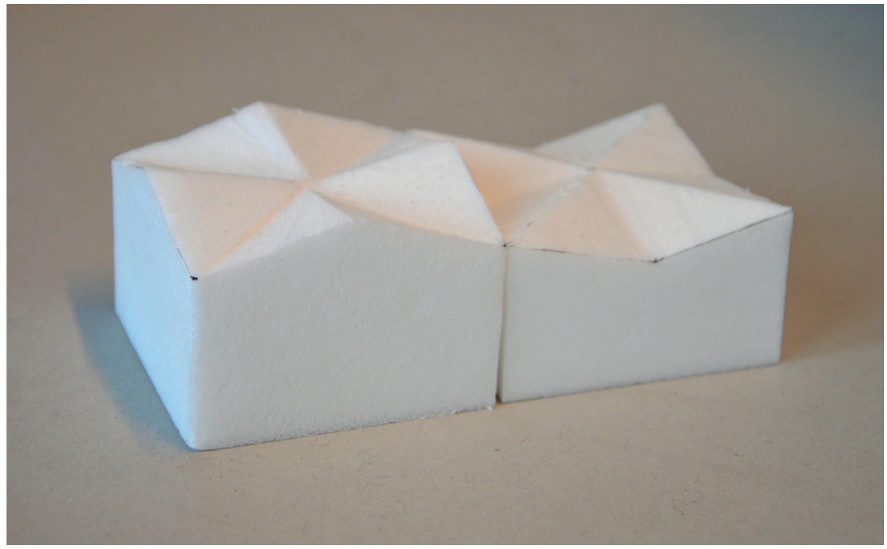
3.3.4
ROOF

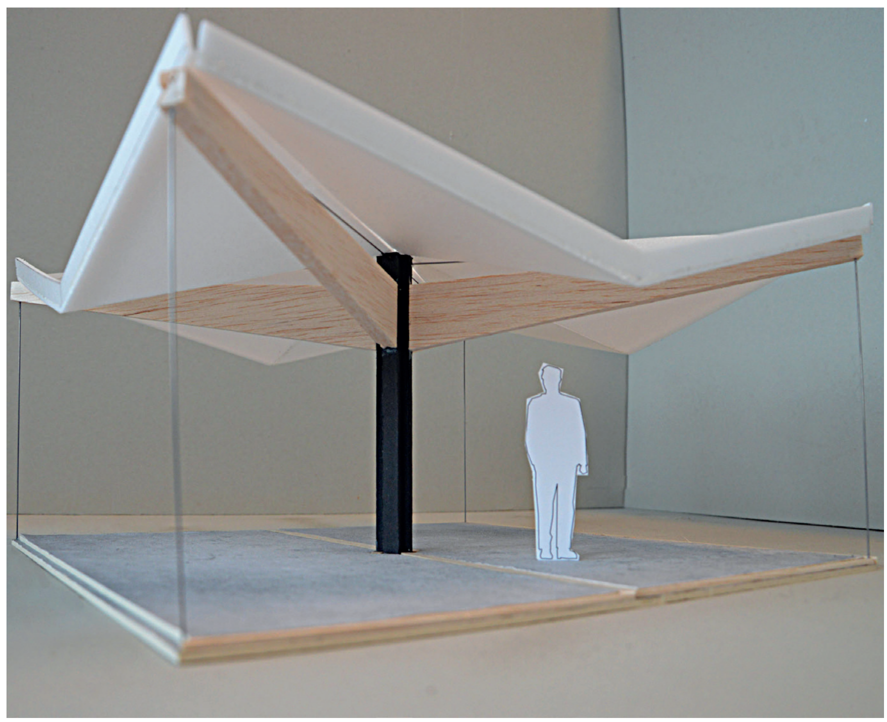
When trying to achieve prefabricated architecture with high level of flexibility and additive aspect, even elements that are usually easy to solve with straightforward solutions, requires special attention. One of such is also roof element.

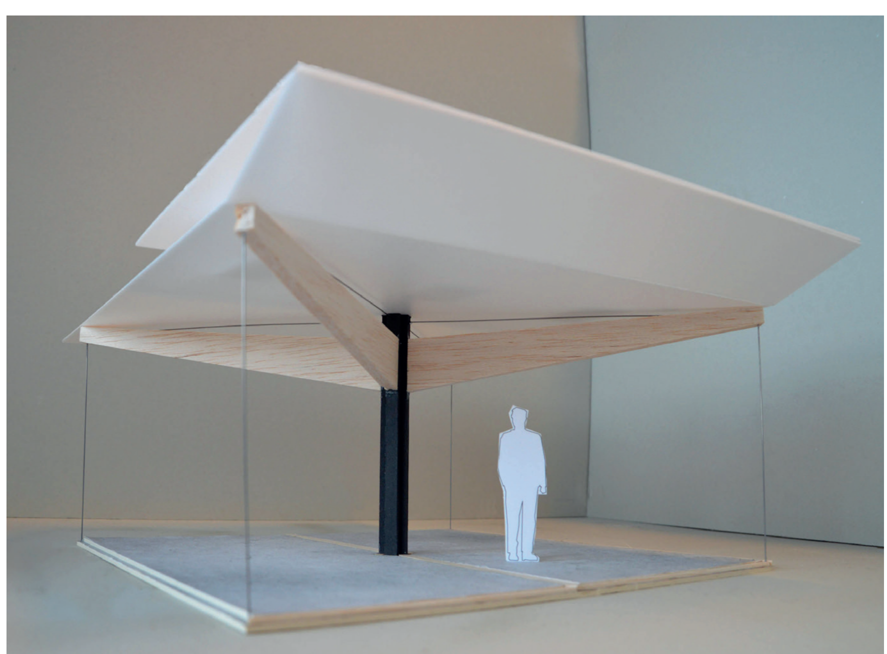
However, the specific umbrella shape could offer interesting variations (ill. 117), but we found it problematic when it comes to combining more than one module since it brings the issue of removing water from the roof. It is also not embracing the umbrella structure rather it is overshadowing it.

Thus we focused on more simple forms, which allow creating traditional saddle roofs as well as single sloped and flat ones. The result of such roof is that construction is embraced as only element under the ceiling, hence there is no battle for attention, which gives more calm but elegant expression. On the other hand, even though analysis of indoor climate showed benefits of overhangs with reduced overheating, this brings new problems.

When it comes to adding new module to the existing building, it can occur that existing eave is in the way of new module. Hence, such roof requires removable eave to fulfill the additive aspect. The solution to this is presented in chapter 4.1.







ill. 117
1:100 model of combining module
ill. 118
1:50 model study of roof expression regarding interior and exterior
ill. 119
1:50 model study of roof with eave

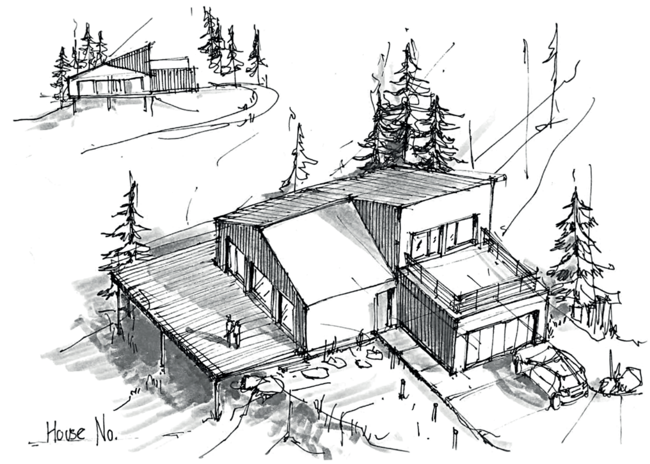
3.3.5
ELEVATION

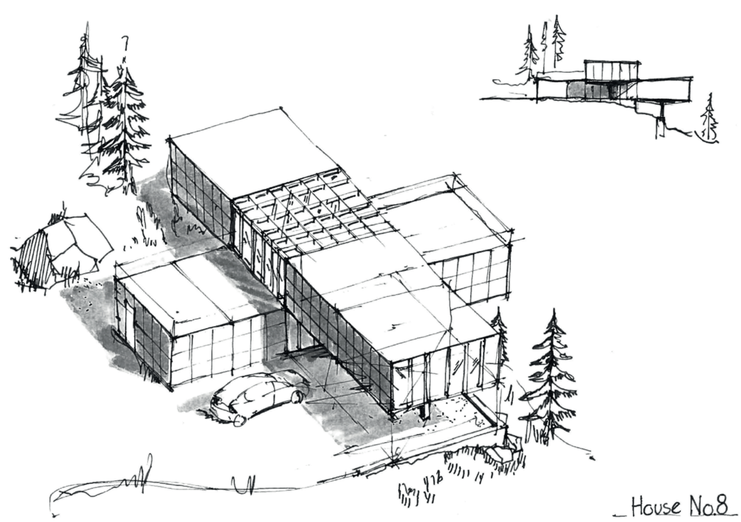
STEP 1

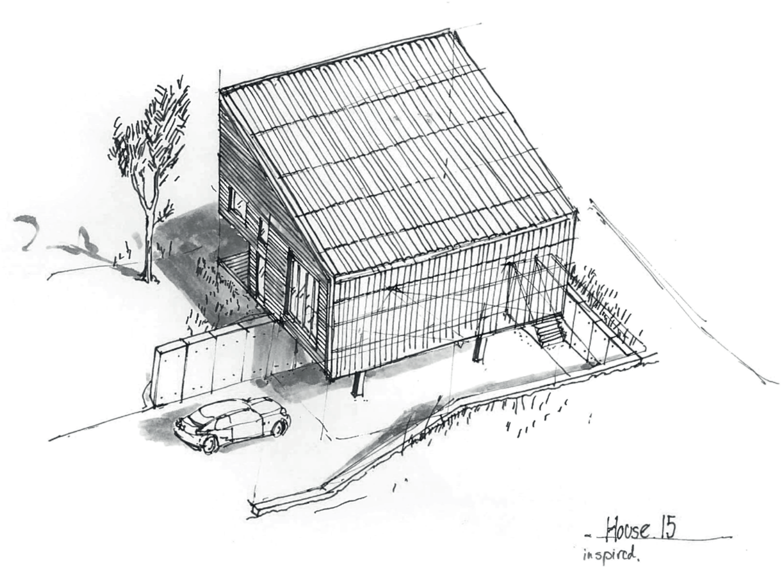
VARIOUS ELEVATION SYSTEMS

The design of external envelope for prefabricated system should most of all allow for easy assembling and disassembling methods. As important as it is, the visual aspects and expression is equally relevant when specific prefabricated approach is being discussed. The appearance of external envelope should embrace its origin and reveal the assembling methods to ensure that it is an integral part of the tectonics. Especially this aspect was the main reason for pushing the elevation expression towards different directions as presented on next 3 pages in order to find the most optimal solution.

At the very beginning the main focus of the elevation was to ensure maximum flexibility. The client was the one deciding what sort of elevation he or she wants, therefore in our sketches we focused more on the form of the house rather than the actual materials and their layout. Sketches of elevations were done to express both the modular specification and specific character of the individual house. However, as design and construction became more specified during the process, the decision was made to reimagine the envelope into something that would fully express internal, unique structure. This is how elevations described as “stage 2” were designed.



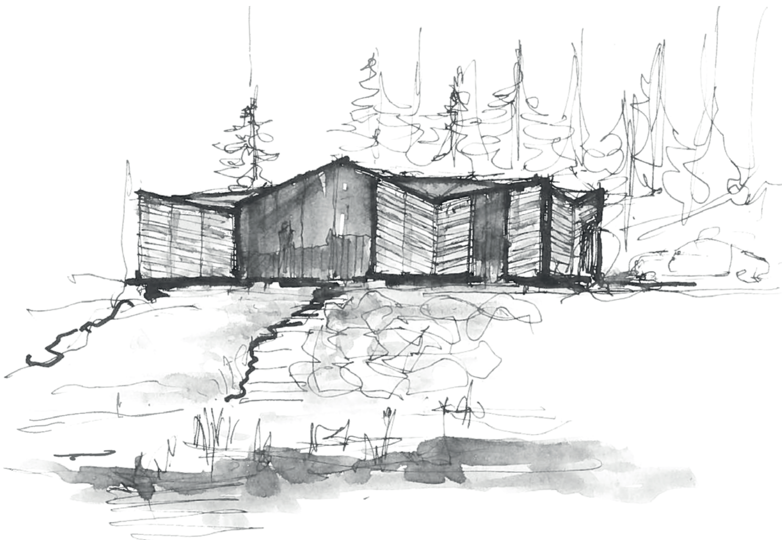




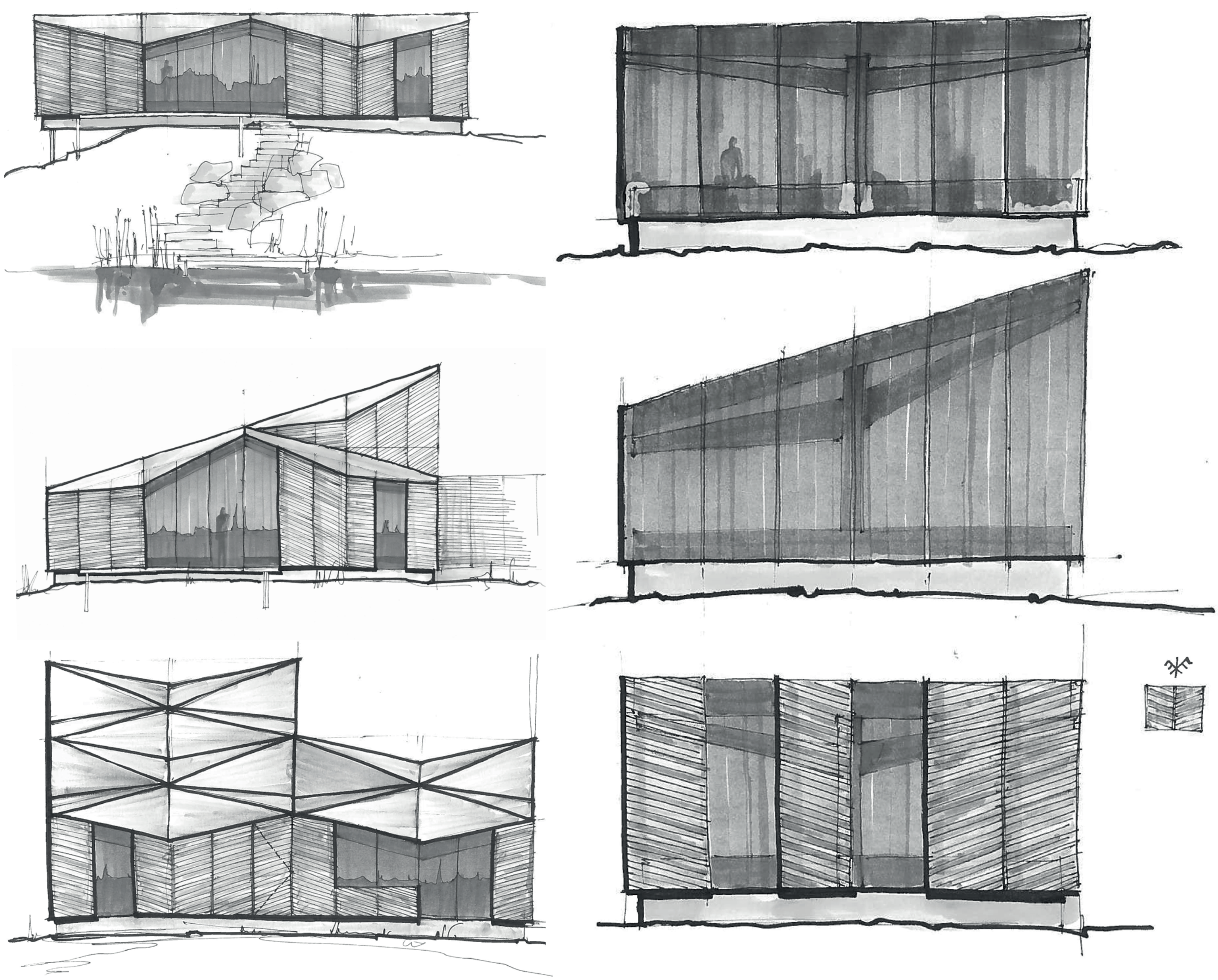
ill. 120
Elevation study stage 1

STEP 2

UNIQUE ELEVATION REVEALING INSIDE CONSTRUCTION



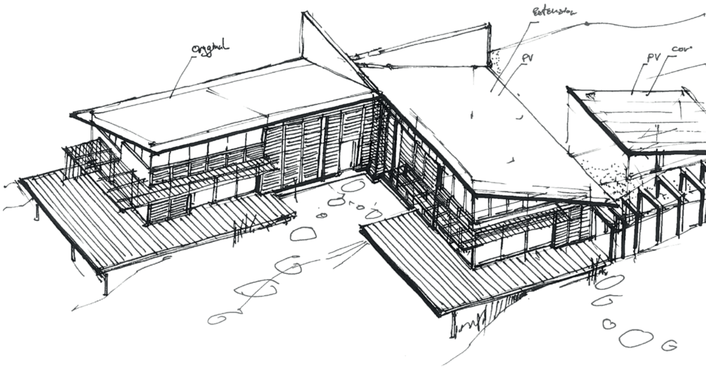
Both: the shape and detailing of the wood paneling was mimicking the interior of the house. Tilted elevation wooden planks were flowing together with repetitive shape of the umbrellas. Additionally, the cross plan of our umbrellas allowed for unique roof shape construction that was either raised at the end and or lowered. Raising was opening the space, creating a direction inside, on the other hand lowering allowed getting down to human scale and better experience of its form. Even though the expression of this idea was something that attracted us at the beginning, it was also a main reason for abandoning it at the end. The decision was made to look for something more quiet that would leave the space to the unique construction inside.



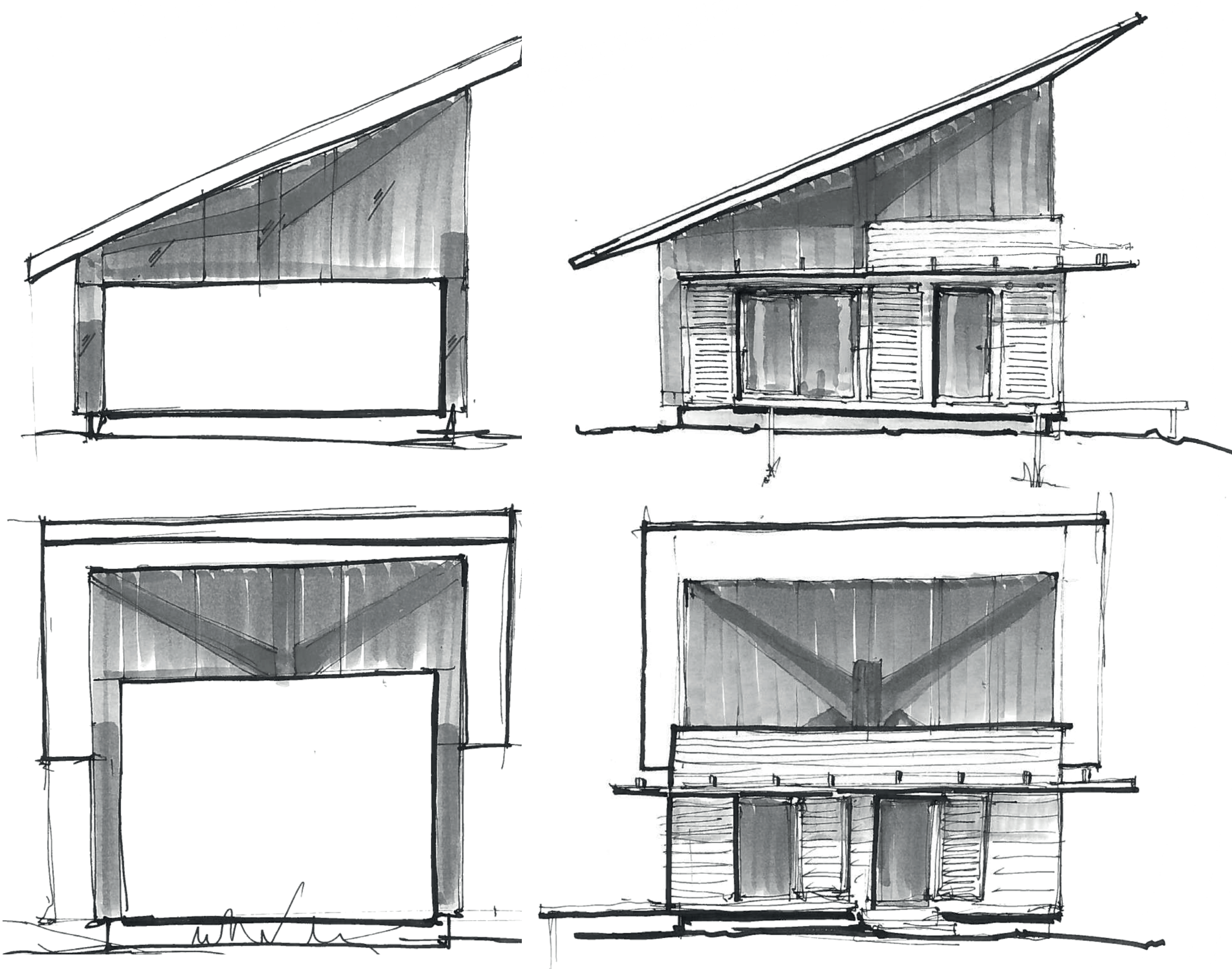
ill. 121
Elevation study stage 2

STEP 3

SIMPLE, HUMBLE ELEVATION SENSITIVELY REVEALING CONSTRUCTION



At this stage, design of the elevation was aiming towards creating a perfect background for the unique umbrella construction. It should not attract attention but rather melt within surrounding neighborhood to better coexist with local architecture. Furthermore, the intention was to use glazing in a way to gently expose load bearing properties of internal structure, thereby raising its tectonic awareness. As the result, single tilted roof was proposed with glazing gap underneath. Elevation was build up by simple horizontal wooden planks which were divided by vertical shadow gaps every meter to reveal its prefabricated nature. Composition of these elements was supported by passive energy saving solutions such as shading or shutters to complete final appearance add functionality into the design.



ill. 122
Elevation study stage 3

‘PRESENTATION’

This chapter is summing up gathered knowledge about theme research and concept development of prefabricated umbrella structure. To proof the system flexibility, seven different houses were created according to various scenarios. One of our main aims is to exploit the additive approach; thus, the last example is presented as growing architecture that adopts to the need of a family members through their lifetime.

Even though some of the analysis that follow building presentations are part of concept development, they are presented together with final architectural outcome to ensure better overview.

4

ill. 123
Panel system

4.1 PREFAB SYSTEM

This chapter is revealing the product of our designing process that you could go through in previous pages. In the opposite with the assignments where final result is the building, this time as a main product we are presenting system to create buildings. However, there are also presented buildings that serve as a demonstration of prefab system and its functionality in following chapters 4.3 and further. These examples are showing various ways of how applicable such system can be.

Implementation of principles such as flexible design, additive aspect and energy efficiency creates complex detailing. However, similarly as technological devices such as smart phones, that contain highly sophisticated and complicated solutions on the inside, they are still offering simple handling for users. In that fashion, the prefab system is composed from pieces that are understandable for client and easy to install for workers on the building site, while the tricky and delicate process of creating modules is executed in the controlled environment of factory.

The unit of prefab system is made in two different variations regarding roof type (flat or inclined roof), while every unit has the same floor area of 39,7m^2. Depending on number of users and demand of space, multiple units can be merged together; however, only one unit is enough for fully functional house. Despite the fact that external unit measurements of a plan are 7,35 by 7,35 meters, it is possible to transport it from the factory to the site since it is made out of envelope and construction elements that does not occupy much space during transportation. On the other hand, elements are designed to be as big as possible, which ensures fast assembly, while keeping size of one module unit small enough to provide flexibility. Thus external wall pieces are 1,05 m wide while the height is adjustable with increment of 0,5 m starting from 2,5 m. Roof and floor panels has triangular shape and are approximately 6,3 m long and 3 m wide. The construction is using the principle presented in chapter 3.3.2.1, thus when deployed, width and length are slightly smaller than floor and roof, while the hight is adjustable in the same way as wall panels. Yet the space that is occupied by construction during transportation is comparable with a volume of a tree trunk.

All prefab elements are merged together with carefully designed joints. This connections enable fast and easy construction as well deconstruction. Joints of every element are accessed from the inside and are visible, thus they are not just functional but they have also aesthetic value.

As mentioned in previous chapters, prefab system is based on umbrella construction, thus with open floor plan we are embracing its tectonics. To achieve this it is necessary to design movable furniture that can create space and replace conventional partition walls. At the same time this allows us to fulfill the goal of creating the architecture that is suitable for fast and ever changing lifestyle for clients with different profiles.

Prefabricated triangular roof panel
Detail, page 94

Roof panel blow-up

Removable eave
Detail, page 94

Umbrella construction
Detail, page 93

Prefabricated wall panel
Detail, page 94

Joint between two wall panels
Detail, page 96

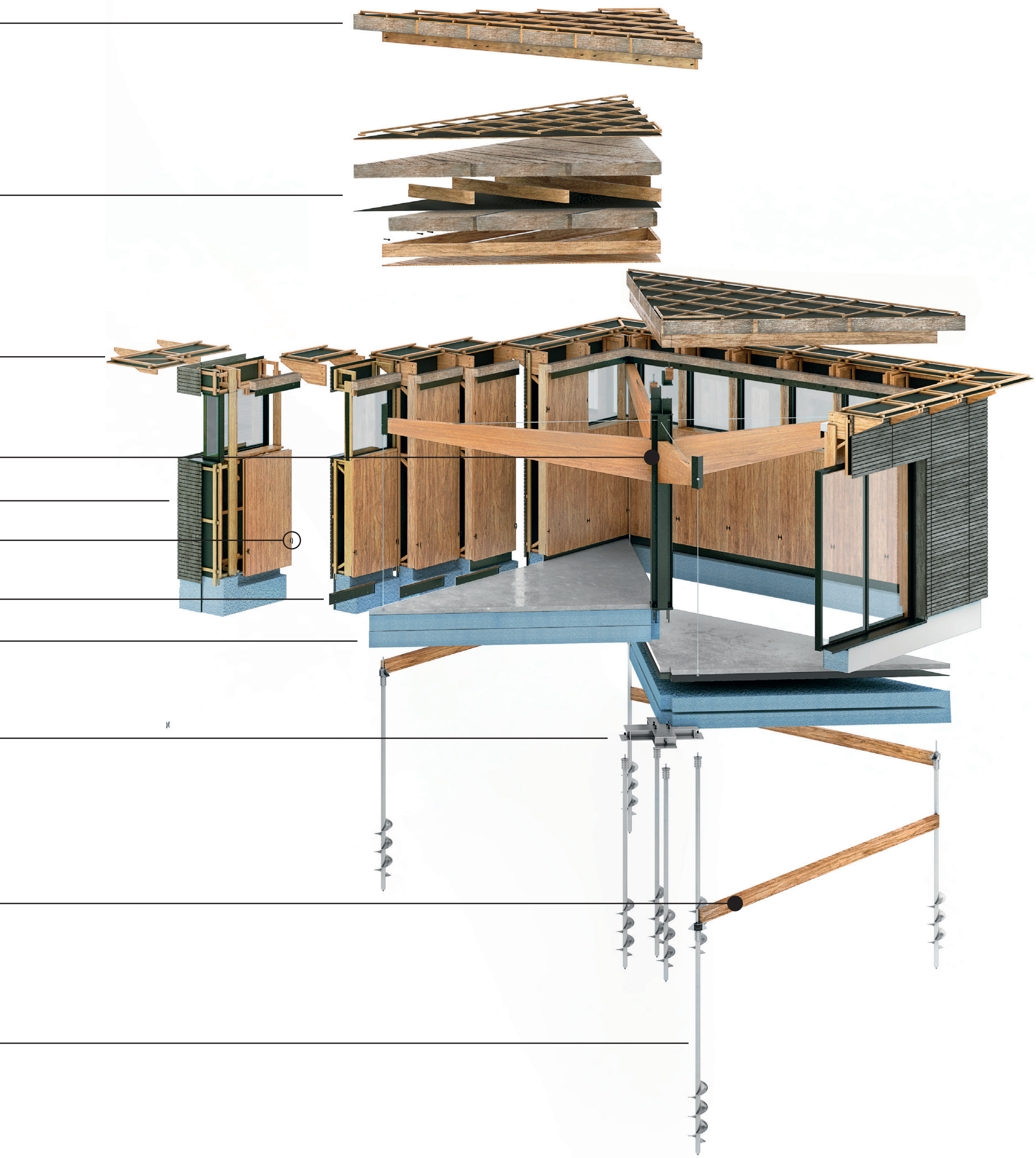
Steel connector between wall and floor
Detail, page 96

Prefabricated concrete floor with insulation
Detail, page 94

Steel connector between foundations and umbrella construction
Detail, page 92

Wooden beams as support for floor
Detail, page 94

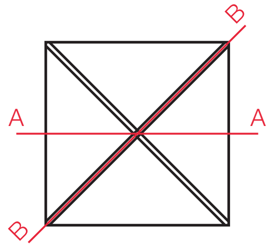
Helical screw piles as foundations
Detail, page 92



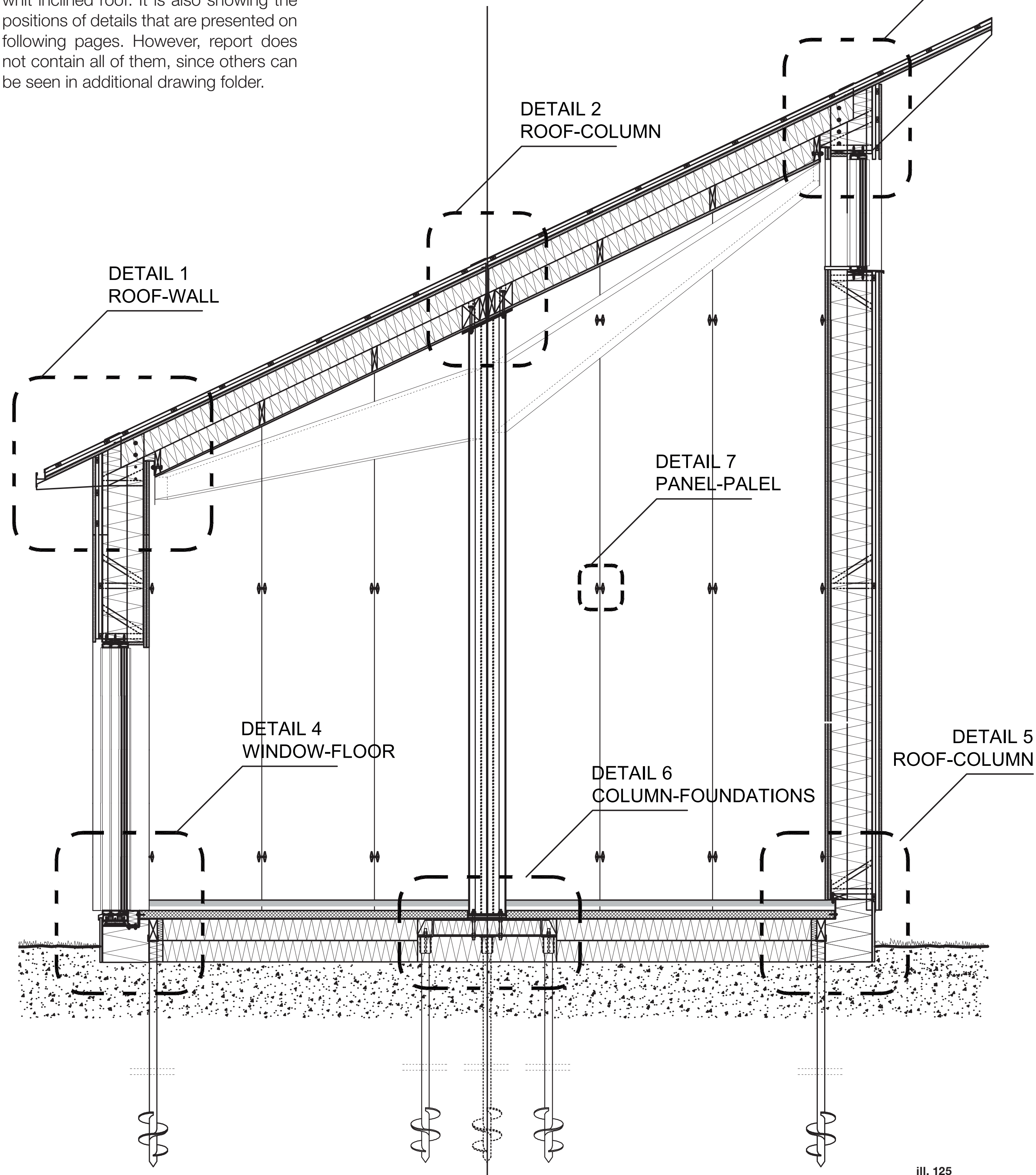
ill. 124
Blow-up of prefabricated unit

4.1.1

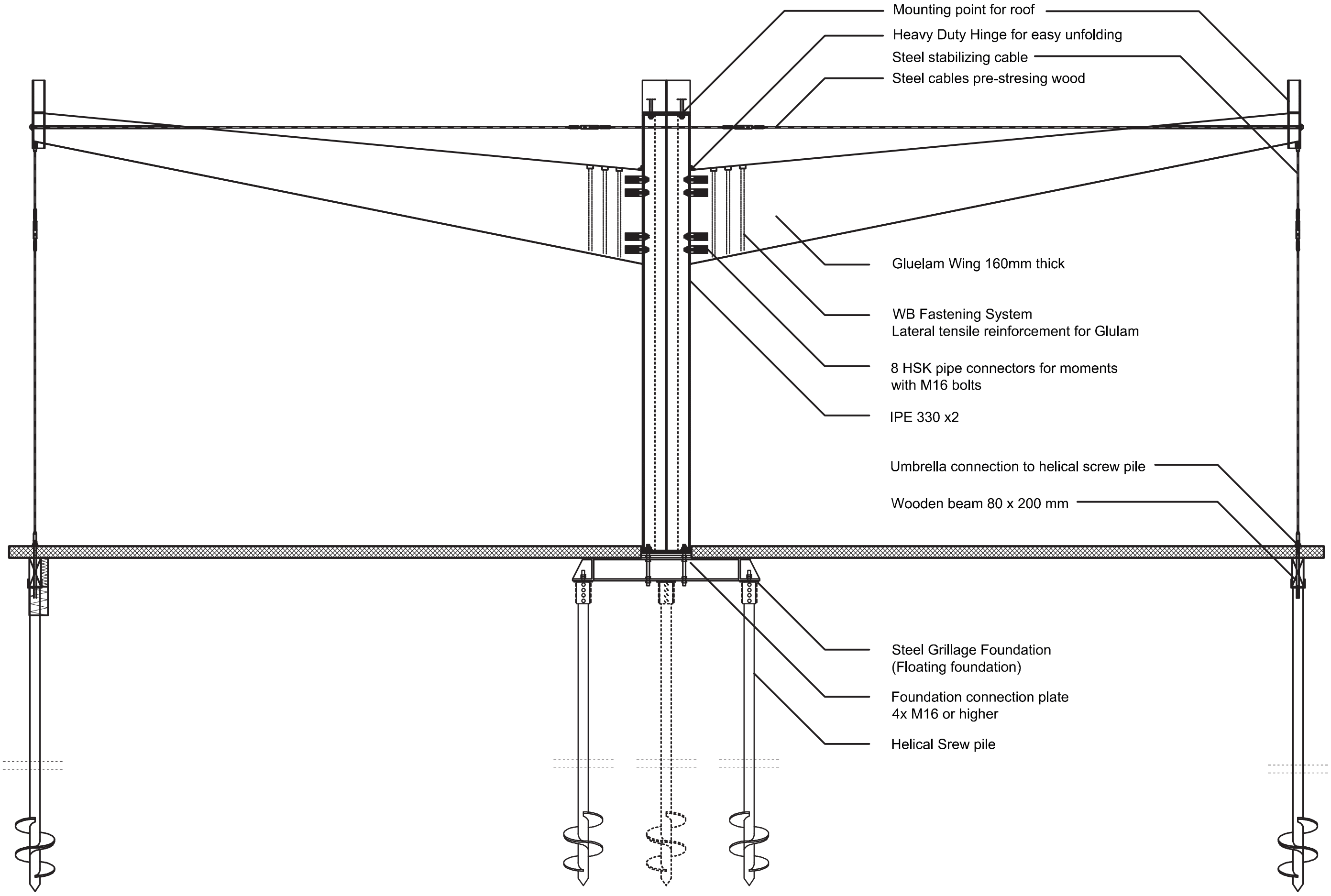
DETAIL SECTION A-A



In the opposite with illustration 124 the section in this chapter is presenting unit whit inclined roof. It is also showing the positions of details that are presented on following pages. However, report does not contain all of them, since others can be seen in additional drawing folder.



ill. 125
Detail section A-A 1:50



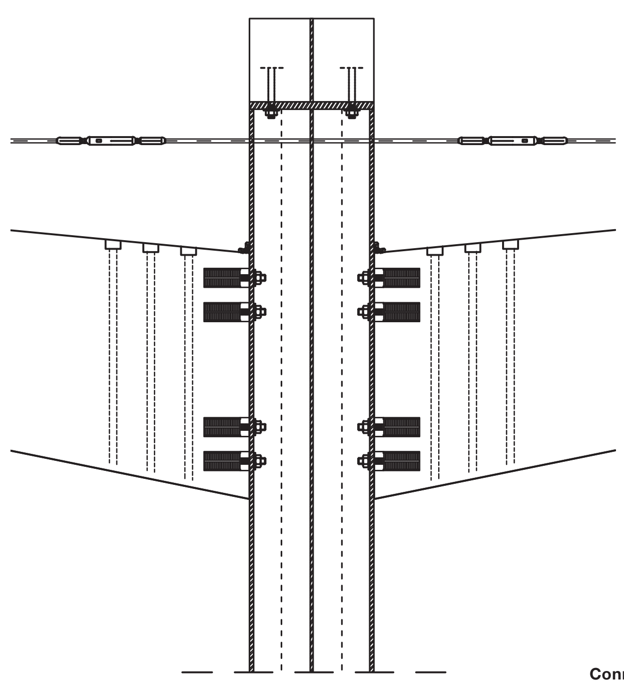
ill. 126
Construction section B-B
1:50

4.1.2

UMBRELLA CONSTRUCTION

This drawings are explaining principles and materiality of umbrella-like load bearing construction. Using computer software, this was most suitable solution to ensure statical stability and robustness while using as much wood as possible. Prefab system can offer different kind of foundation based on soil analysis and time of building.

As mentioned before, steel column and wooden beams come to the building site as one element. They are connected together with hinges and then secured on sides with bolts. Also to minimize deflections, steel wires are used to connect end of beams to the column and to the ground. Render of this detail can be seen on page 129.



ill. 127
Connection between column and wooden beams 1:20

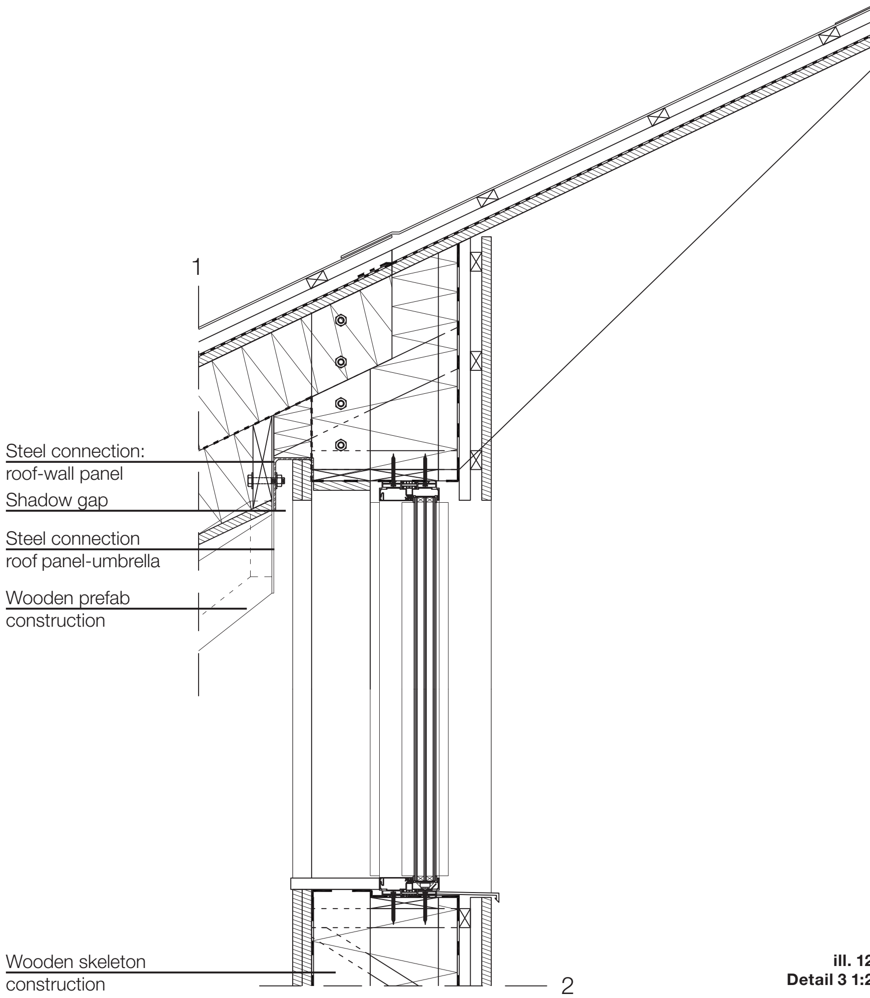
4.1.3

DETAIL 3

Detail 3 is presenting a meeting point of 4 elements as it is also presented in the blow-up on the following page: wooden beam of umbrella construction, wall panel (in this case with window under the roof), roof panel and eave.

1 Aluminum standing seam roof
Battens/ventilated cavity - 30 mm
Battens/ventilated cavity - 30 mm
Waterproof membrane/
nail sealing tape
Oriented-standard board - 25 mm
Thermal insulation/
wooden beam -200mm
Vapor barrier
Thermal insulation/
wooden beam - 200mm
Plywood - 25 mm
Umbrella construction

2 Wooden plank facade - horizontal
Battens/ventilated cavity - 30 mm
Battens/ventilated cavity - 30 mm
Waterproof membrane/
nail sealing tape
Thermal insulation with wooden skeleton construction - 400mm
Plywood - 25 mm
Plywood - 25 mm



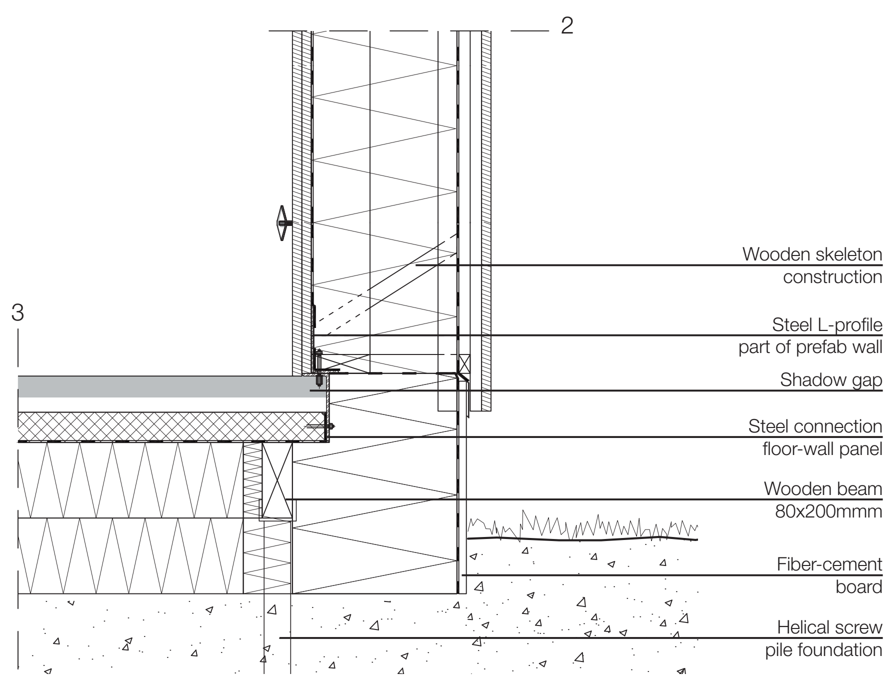
ill. 128
Detail 3 1:20

4.1.4

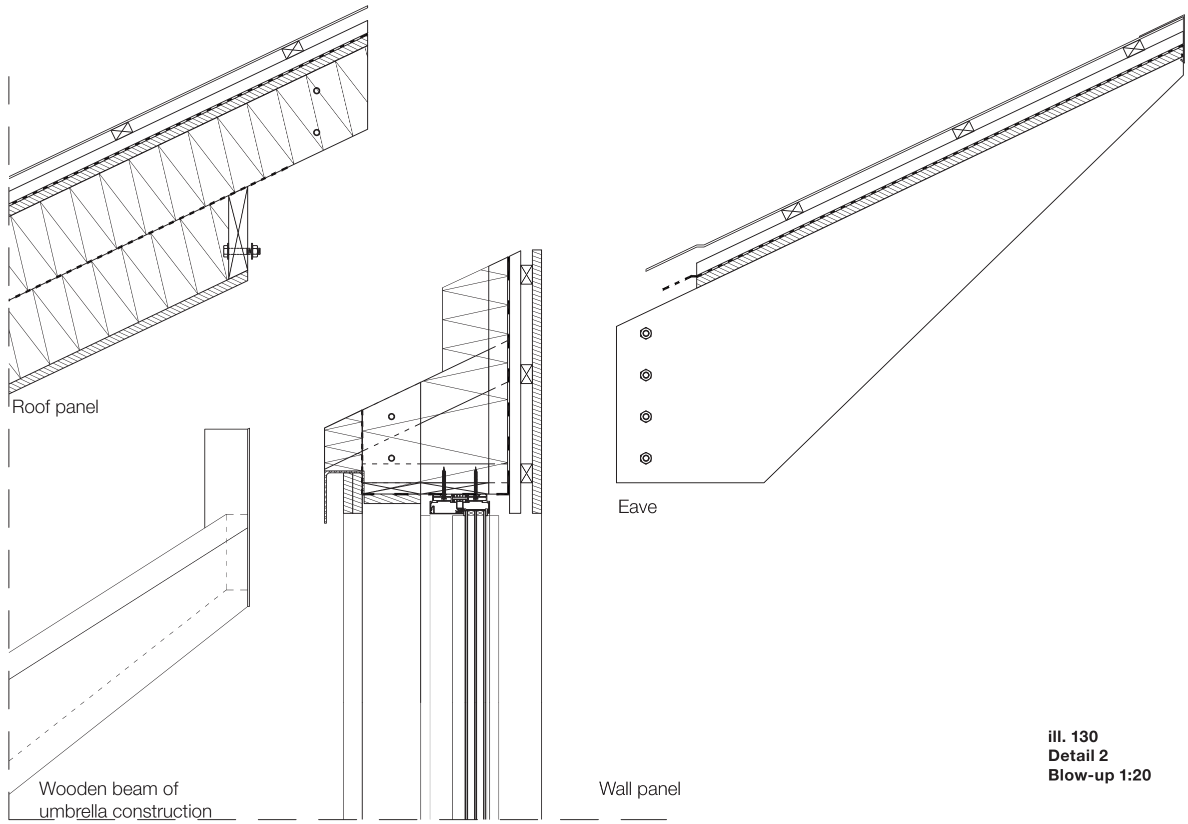
DETAIL 5

Detail 3 is presenting a meeting point of 3 elements as it is also presented in the blow-up on the following page: wall panel as seen in detail 3, prefabricated floor element and helical screw pile foundations.

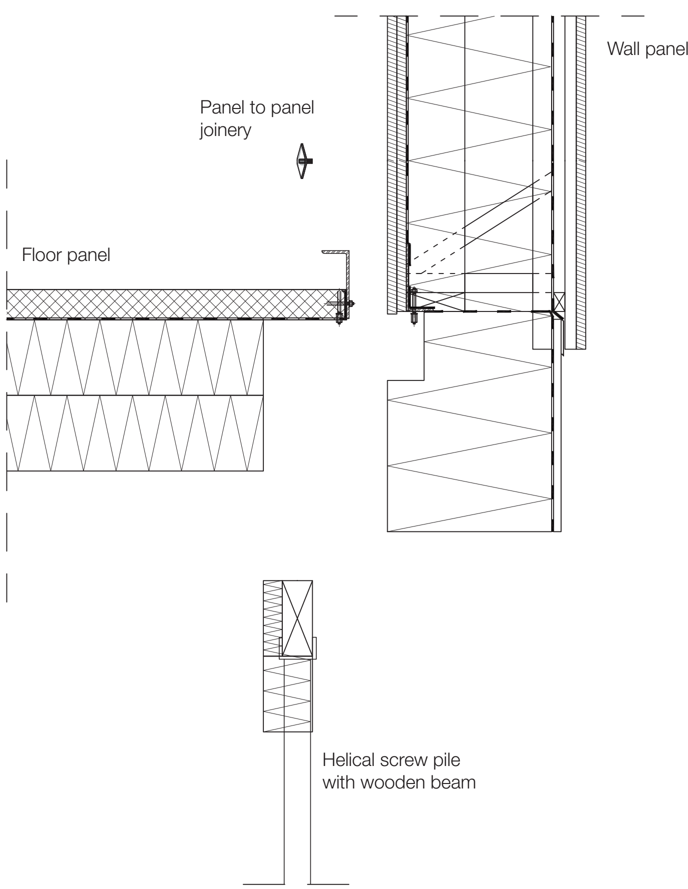
3 Concrete slab - 100 mm
Waterproof membrane
Thermal insulation /
wooden beam - 2x200mm
Plywood - 25 mm



ill. 129
Detail 5 1:20



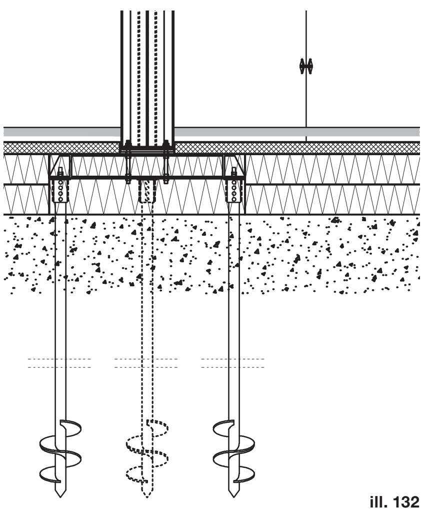
ill. 130
Detail 2
Blow-up 1:20



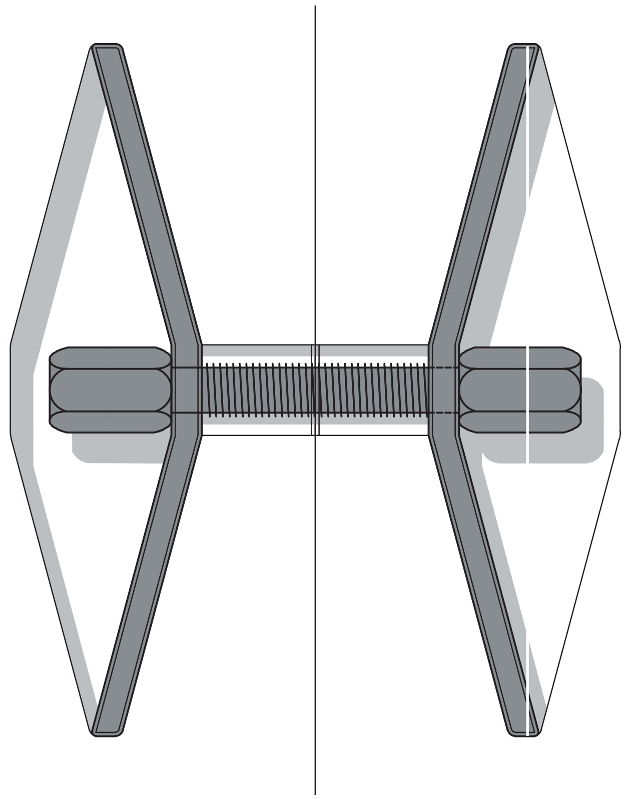
ill. 131
Detail 5
Blow-up 1:20

4.1.5
DETAIL 7

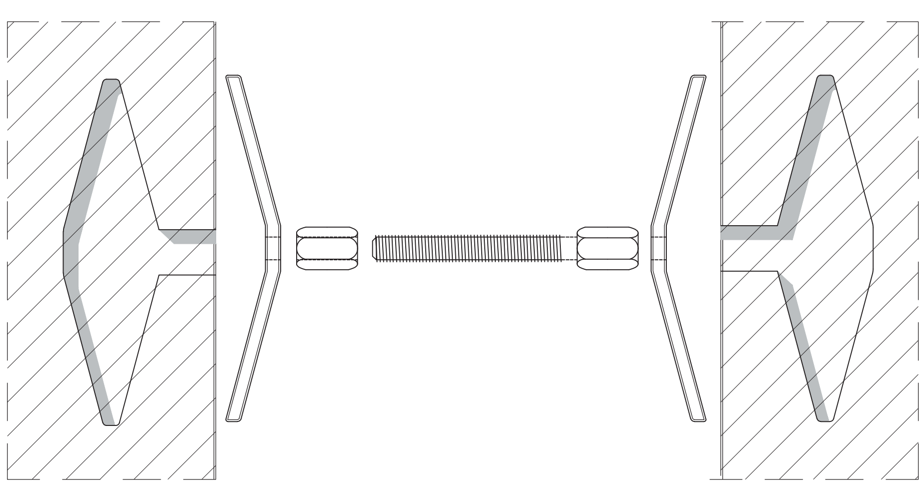
In order to embrace tectonics of prefabrication, wall surface is clearly showing borders between panels. To connect neighboring panels we are using visible joint that reveal honesty of system while creating joinery that is easy to access during assembly as well as disassembly. The connection is made with milled holes in internal surface of two panels, which have inserted two steel washers and a bold which pulls everything together.



ill. 132
Panel to panel connection 1:50



ill. 133
Panel to panel connection 1:1

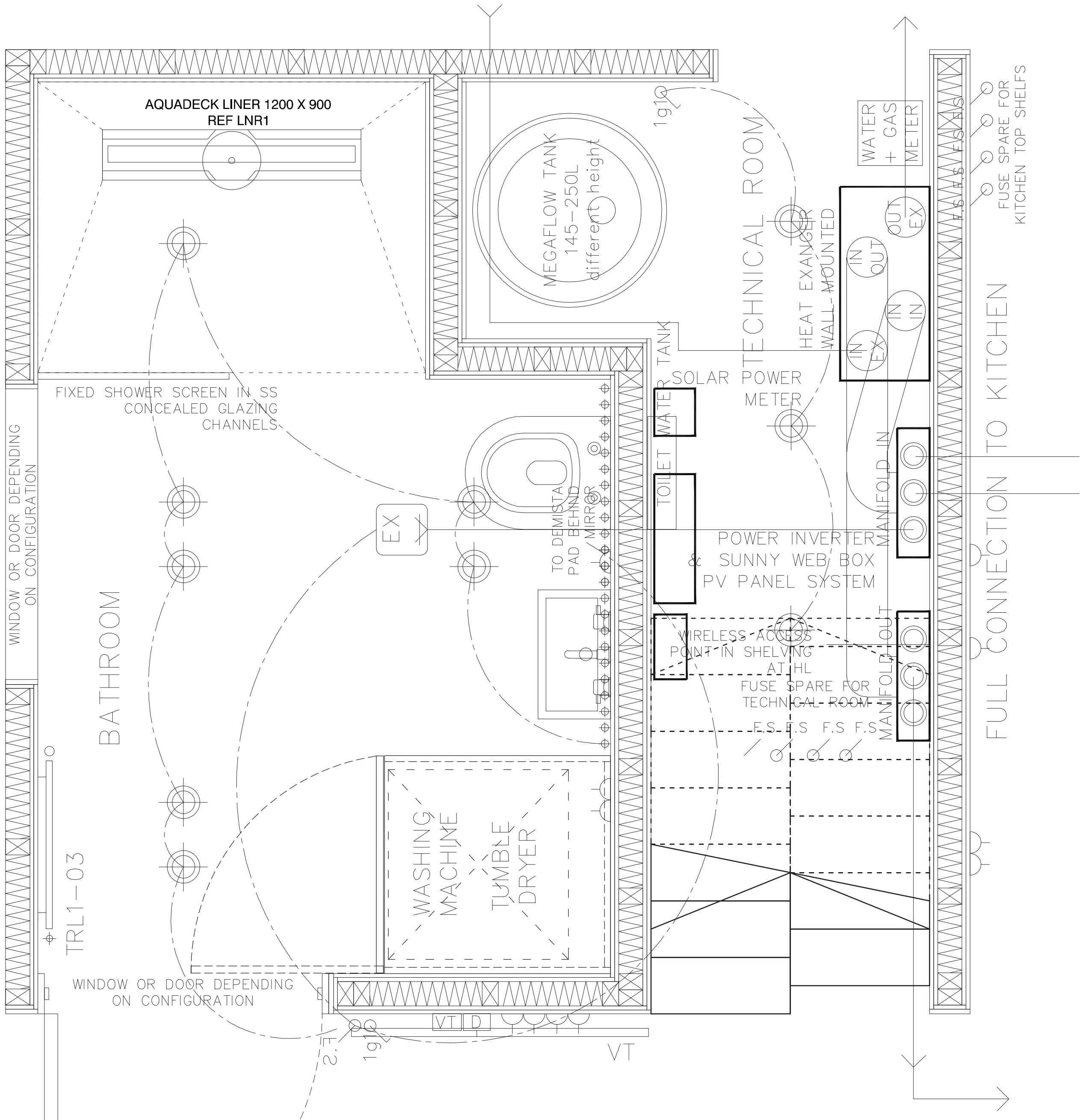


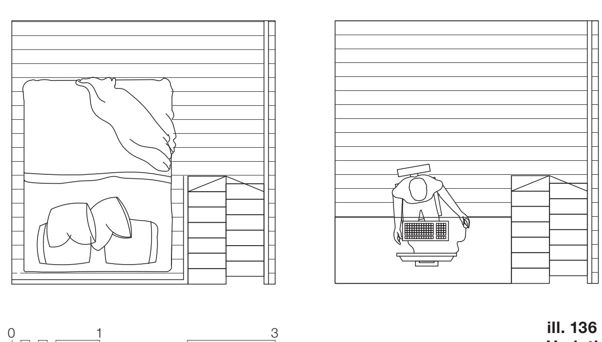
ill. 134
Blow-up of panel to panel connection 1:20

TECHNICAL UNIT

This drawing of technical unit is final modification of sketches seen in chapter 3.1.2. This module has the access to technical room only from the outside, thus giving a space to create alternating tread stairs. It has also possibility to accommodate storage tank in case when client wants thermal solar collectors.

ill. 135
Technical unit 1:20





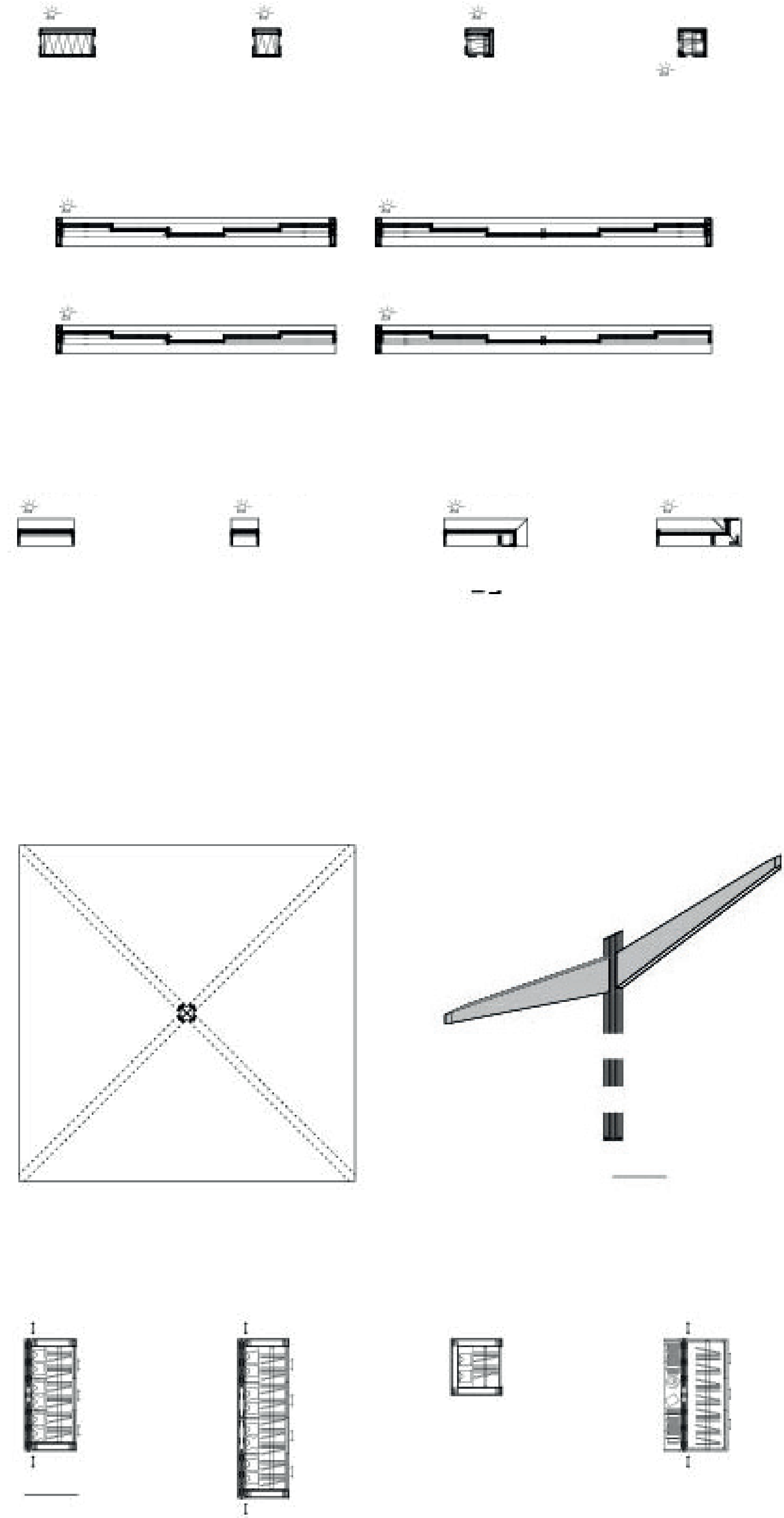
ill. 136
Variations for top of the technical room

4.2 DEMOCRATIC DESIGN

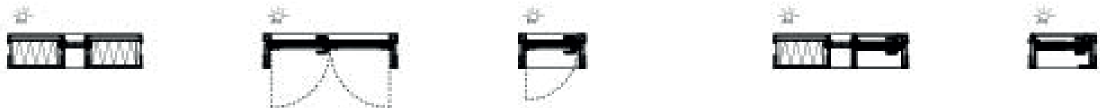
4.2.1
ELEMENT LIBRARY

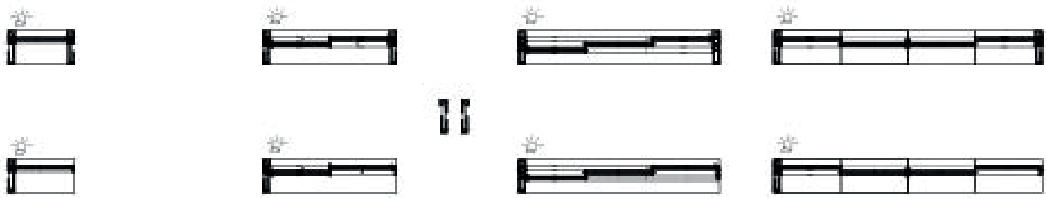
Prefabricated design requires pre-designed elements to fulfill certain demands. Thus it is necessary to predict various situations and find a solution that can solve multiple problems. However, when facing demand of increased flexibility, it is also important to reach compatibility between different elements which can be connected between each other in different ways. Thus elements are designed with iterative process of integrated design which ensure flexibility with as few building elements as possible that could consequently lower the cost of production.

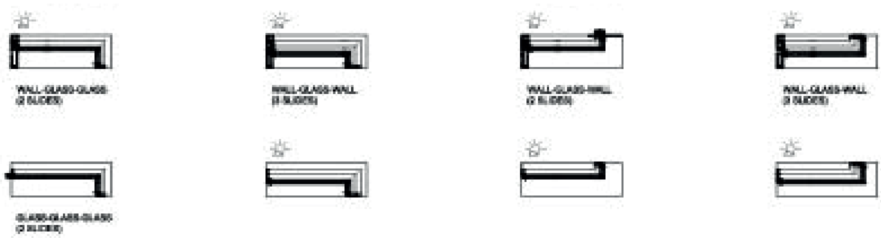
With such library not only we get good overview of elements, but it also creates a database that can be used for fast house designing and allowing client to put functional elements together in certain ways. This enables the democratic design where client is part of the designing process, which resembles of current practice in kitchen design, where client can create basic outline on her or his own under supervision of the expert.

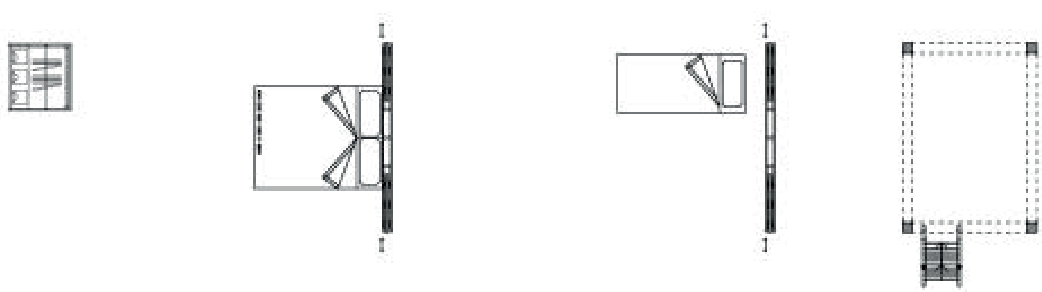


ill. 137
Library of elements for plan drawings






WALL-GLASS-GLASS
(2 SLIDES)
WALL-GLASS-WALL
(3 SLIDES)
WALL-GLASS-WALL
(2 SLIDES)
WALL-GLASS-WALL
(3 SLIDES)
GLASS-GLASS-GLASS
(2 SLIDES)



4.2.2

DEMOCRATIC DESIGN AND PROCESS

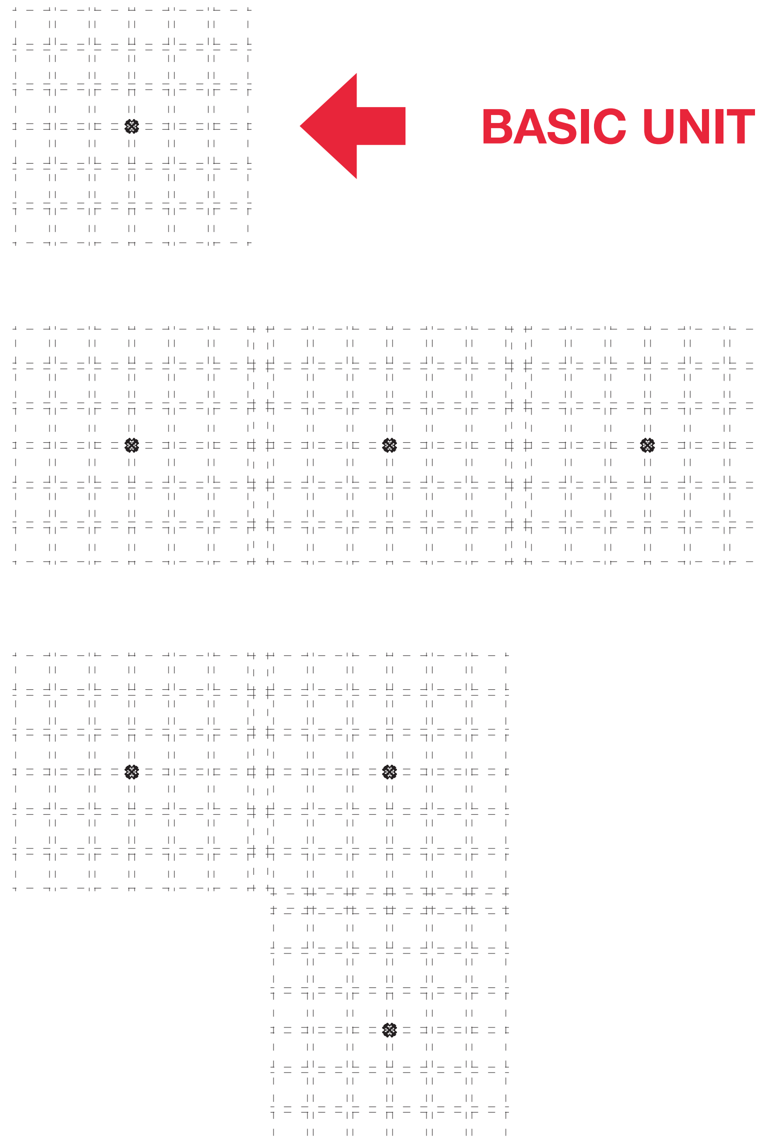
With established database as seen in previous chapter, the building can be quickly designed using prefabricated elements from it. First such element to be used is indicating the construction and module's footprint. Thus at this stage number of units and their composition can be arranged.

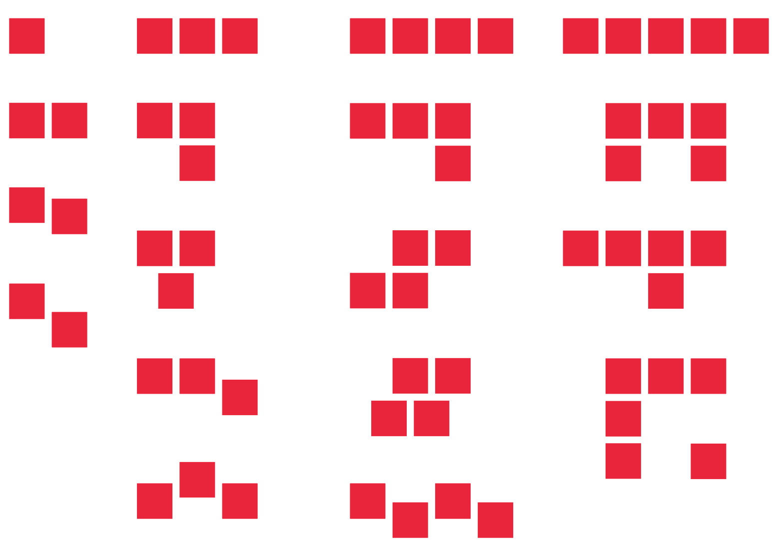
In next step, elements are used to create floor plan. These elements are presenting walls and furniture in a plan view. Wall and some of the furniture are made in respect to the grid and module footprint, which allows that elements always fit together. However, this step can be executed together with the envelope design, thus having the overview on the building design. And in the same way as floor plan elements, also this ones are designed in certain raster. They are keeping the same width, while the hight of elevation grid has the increment of 500 mm. Hence umbrella module is allowing hight variations.

However, this approach would required additional software development in order to create easy interface for clients.

1.3.3.2

NUMBER OF UNITS AND THE ARRANGEMENT

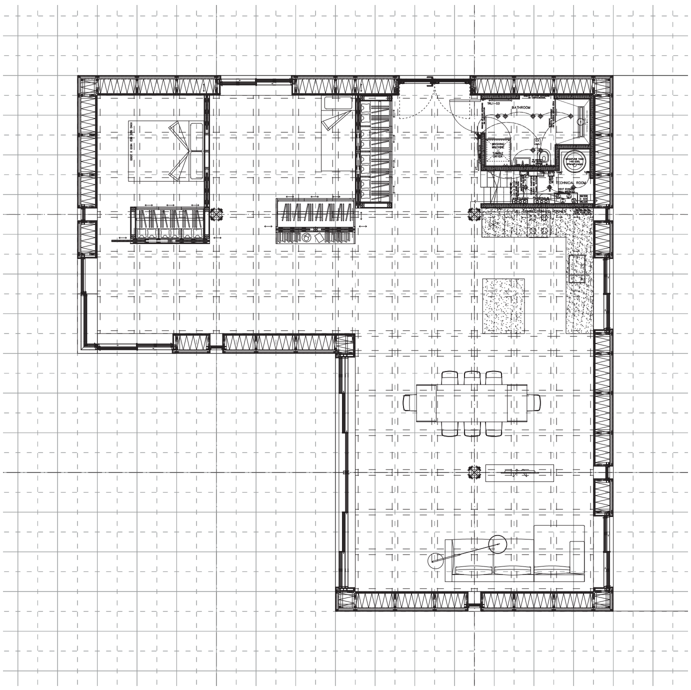




ill. 138
Floor plan possibilities according to number of units

1.3.3.2

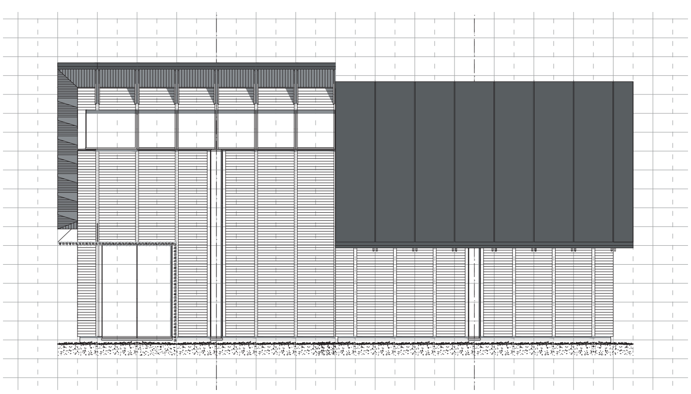
FLOOR PLAN DESIGN



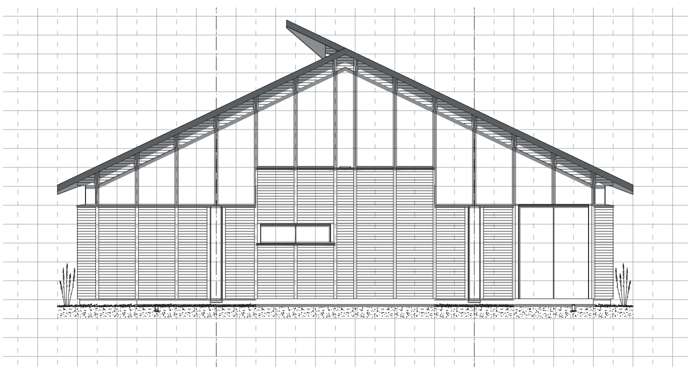
PLAN ELEMENT LIBRARY

1.3.3.2

ELEVATION DESIGN



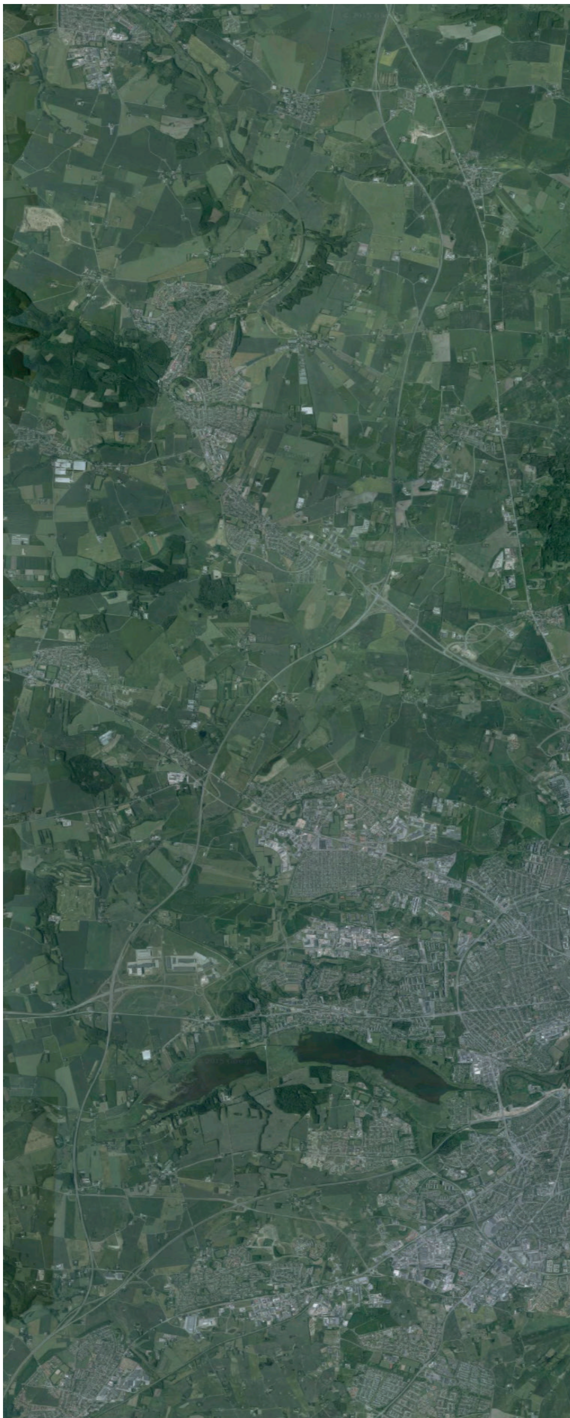
ELEVATION ELEMENT LIBRARY



4.3 FLEXIBLE SYSTEM

In order to ensure the flexibility of proposed prefabricated system, we are creating 7 buildings with different locations around Aarhus bay. 6 of them are presented in this chapter and the 7th building is presented in chapter 4.3 Additive system. These buildings are designed with same elements, as seen in the previous chapter.

Despite same building system, buildings are made for different scenarios according to the number of units, number and type of users and orientation of the view and entrance presented in the table below. Beside prefab system, the constant parameter is that each building has part or the roof oriented in the way that slope is facing south in order to ensure appropriate location for solar panels.



ill. 139
Map of Aarhus with locations of house examples
ill. 140
Table with designing parameter

House number	Number of prefab units	Users profile	View orientation	Entrance orientation
House No. 1	1	Single young person	Toward North	Toward East
House No. 2	6	Couple with 2 children, wealthier	Toward East	Toward North
House No. 3	4	Couple with 4 children	Toward East	Toward Northeast
House No. 4	5	Couple with 2 children, wealthier	Toward Southwest	Toward West
House No. 5	2	Senior couple	Toward South	Toward North
House No. 6	2	Couple with 1 child	Toward West	Toward East
House No. 7	Varying	Varying	Toward West	Toward East

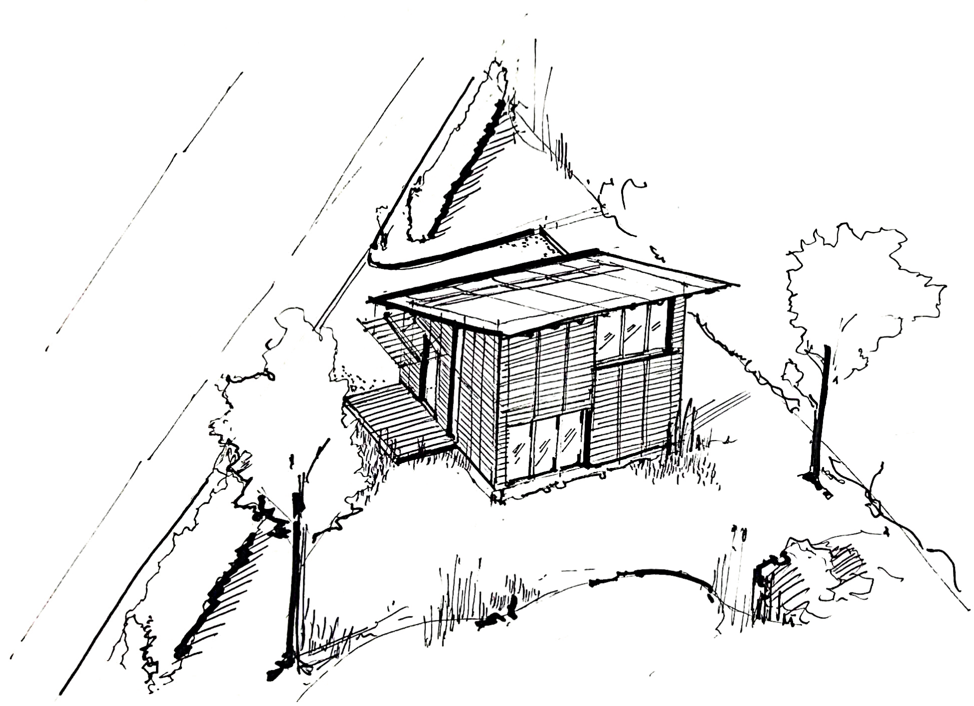

1
2
3
4
5
6
7
AARHUS
BAY

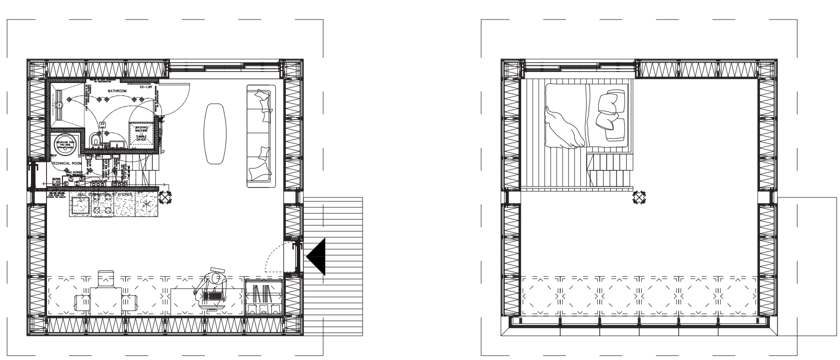
4.3.1

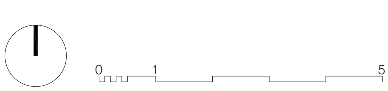
EXAMPLE 1

First example house is situated on the edge of Aarhus suburbs designed for a young single person. Condensed floor plan allows to fit necessary functions into 40 m^2 including working space, spacious living room and double bed above the technical unit.

Building is opened towards the view on the northern side with windows in living room and sleeping area. Single-sloped roof is facing south, which gives appropriate surface for solar panels. Also at the bottom of the roof there is row of skylights to benefit from passive solar heating.





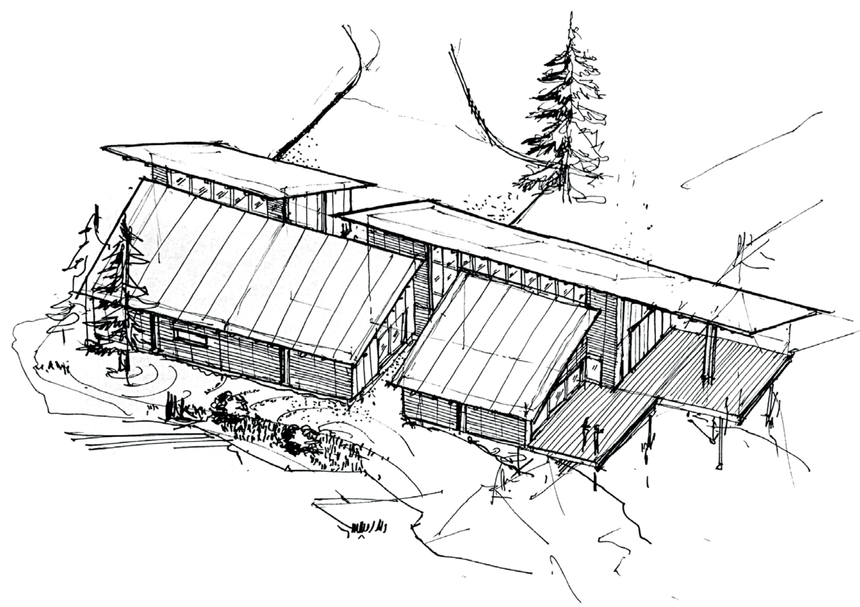


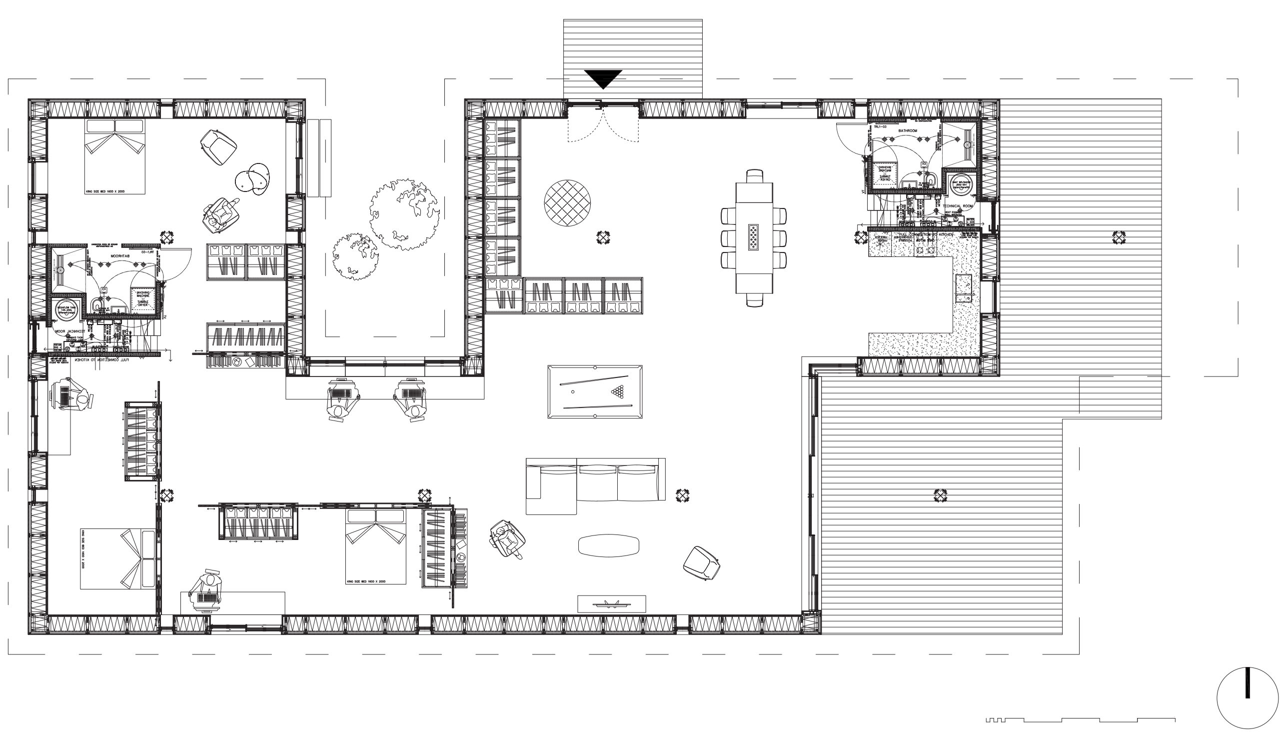
4.3.2

EXAMPLE 2

The scenario situation for the example house number 2 composes with family of two adults and two children that can afford bigger house and the building site that has view over the Aarhus Bay in eastern direction. House is designed from 6 prefab units which gives approximate size of 240 m^2

House is divided on two areas where living space with the terrace are in the eastern and sleeping area in the western part. Working space and master bedroom are opened toward the small atrium on the northern side of the house. Moreover, master bedroom has own bathroom, walk in closet and the access on the top of the technical unit with cabinet.



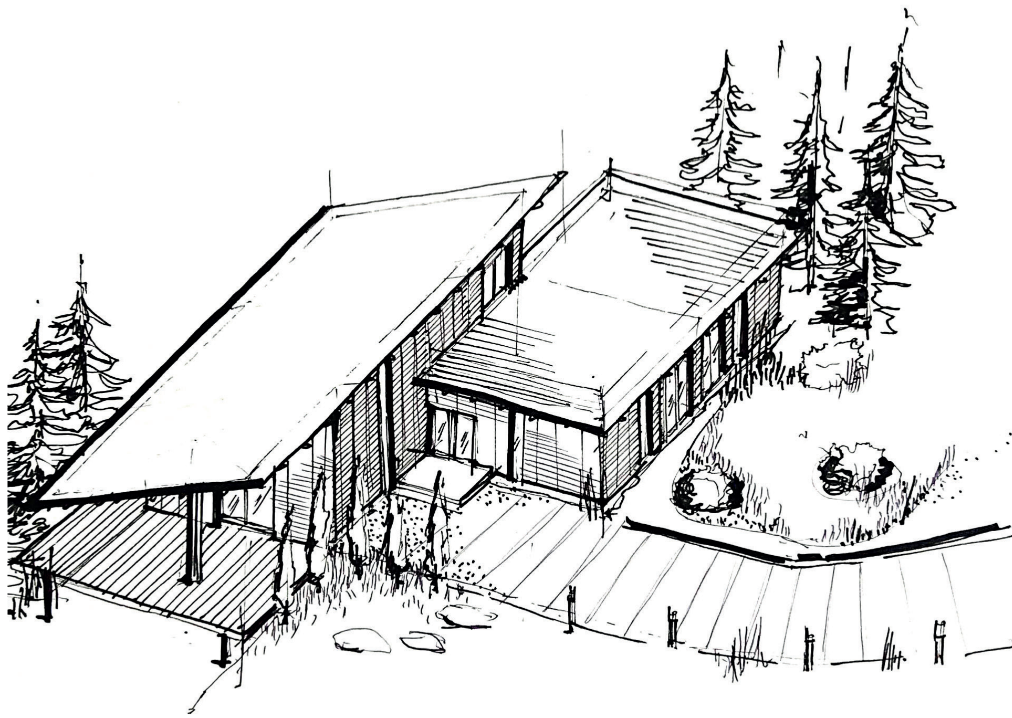


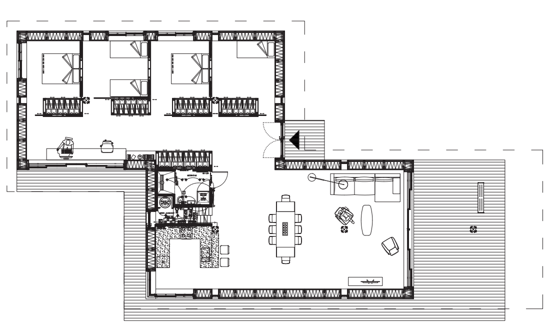
4.3.3
EXAMPLE 3

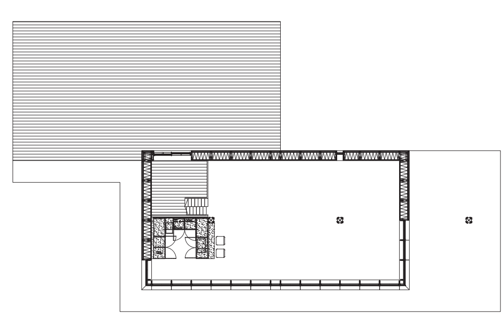
Third example is simulating the family with 2 adults and 4 children, while the house has the size of 4 units, around 160 m^2 . This means a bit higher density of 1,5 people per unit compared to the previous examples.

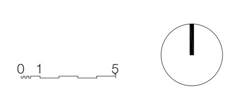
Daytime area is opened toward the view on the east, while it is situated in the southern part of the house. Bedrooms have openings toward the north, except of master bedroom. The private area also includes long table as a part of the working area, which is opened towards the south on the small courtyard.

Southern units has sloped roof facing south, while northern units have the roof terrace. It can be accessed from the technical unit.







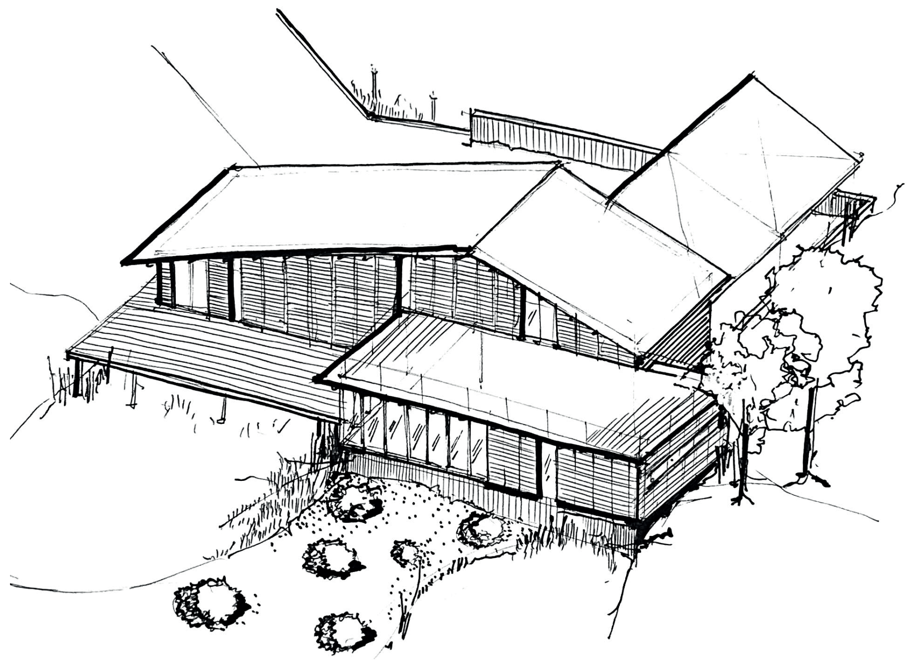


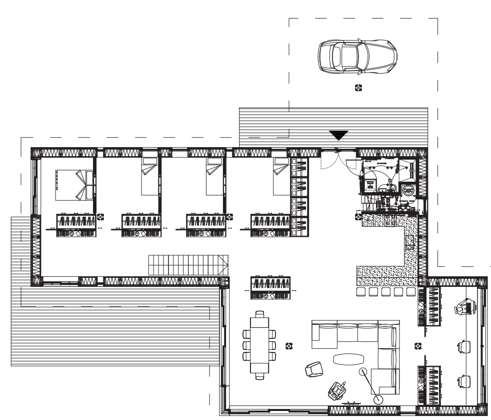
4.3.4

EXAMPLE 4

User group of House 4 is the same as in the example 2. However house has view oriented towards southwest. Also it is one unit smaller with a bit less than 200 m² but it is using one umbrella unit as carport.

The entrance is on the northern side connected to the kitchen. The southern part of the house includes living room and working area. The latter is separated with movable furniture and sliding doors. Quiet area is located in the western part with daylight coming through the opening on the north and the strip of glazing under the roof. The terrace in the southwestern part of the house is connected with both daytime and nighttime area.



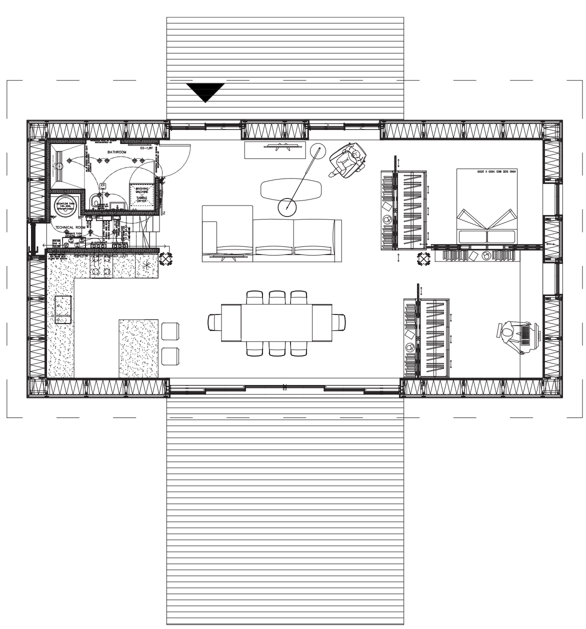


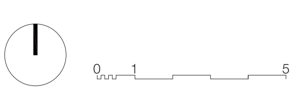
4.3.5

EXAMPLE 5

Example house number 5 is situated on the outskirts of small town Rønde, not far from Aarhus. It is designed for senior couple.

House consists of two units with area of 80 m². The access to the house if from the north while garden is on the southern side. To connect house with the garden there is also a terrace, which allows kitchen and dining area to extend into the nature. The eastern part is divided into the bedroom and office but movable furniture allow to create one big room or even connect this two rooms with daytime area to create one bigger open space.



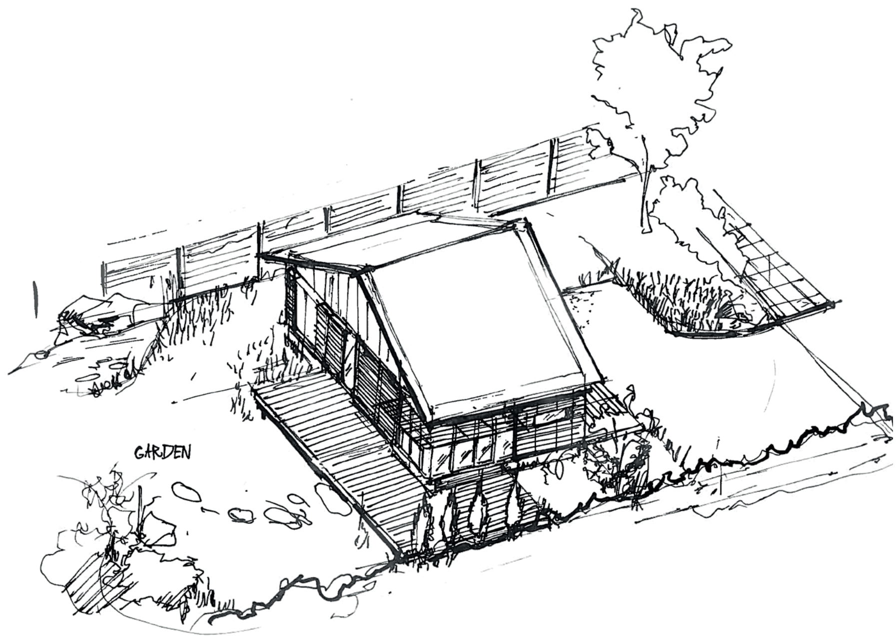


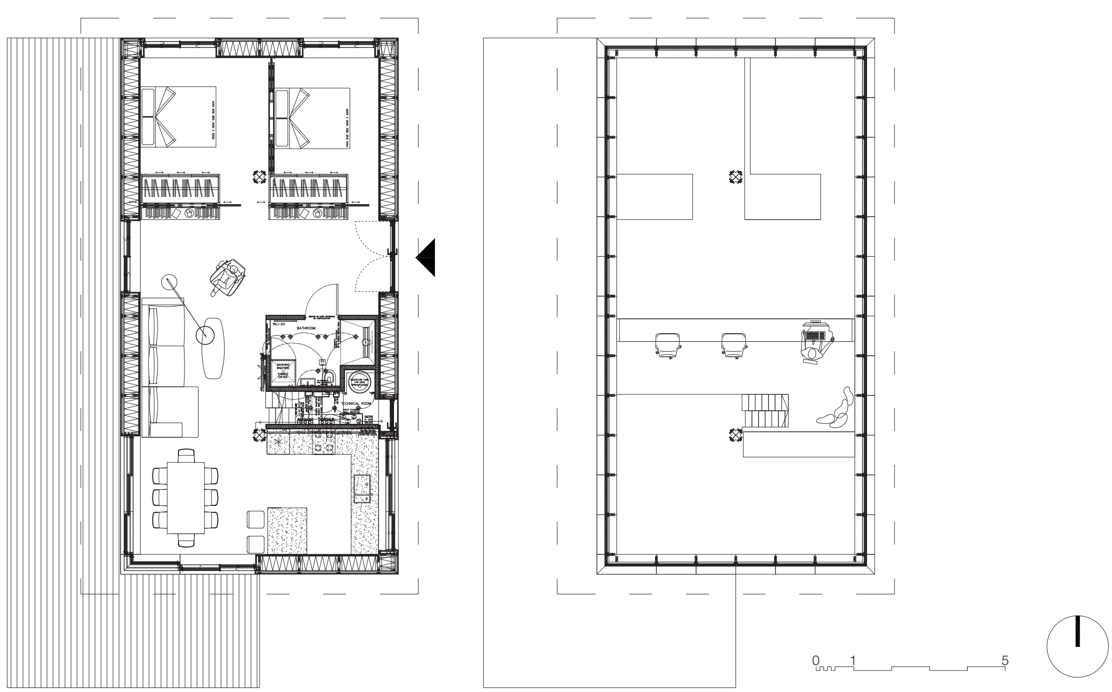
4.3.6

EXAMPLE 6

Same as House 5 also this example is designed using 2 units. But it is comparable with example number 3 regarding floor area per person, since the user is a family of two adults with a child.

House is situated in rural area on the eastern side of Aarhus Bay, hence it has nice view toward the sea on the west. The exterior is designed with more traditional saddle roof, where one surface is facing south, thus it is suitable for solar panels. Interior includes two bedrooms in the northern part and daytime area that is opened to the west. There is also the access on top of the technical unit with a working space. Working space is extended with the use of inhabitable furniture which can create additional floor in a double height space.





4.4 ADDITIVE SYSTEM
EXAMPLE 7

First six examples are demonstrating the flexibility of the prefab system with different floor plan arrangement. The example house is also showing the 7th and last version of house presented in this report. However, this case consist of three different stages showing the additive potential of the system.

Thus following chapters are presenting house through the life of their users. Since some personal decisions have a life changing effects we believe that the house should be able to adapt to such situations. Hence the stages are designed according to the scenario, where a couple buy plot on the cost of Knebel, a small community close to Aarhus. While one person is driving every day to work the other is working from home. Furthermore, initial financial situation is not allowing to buy more than 80 m^2 house.

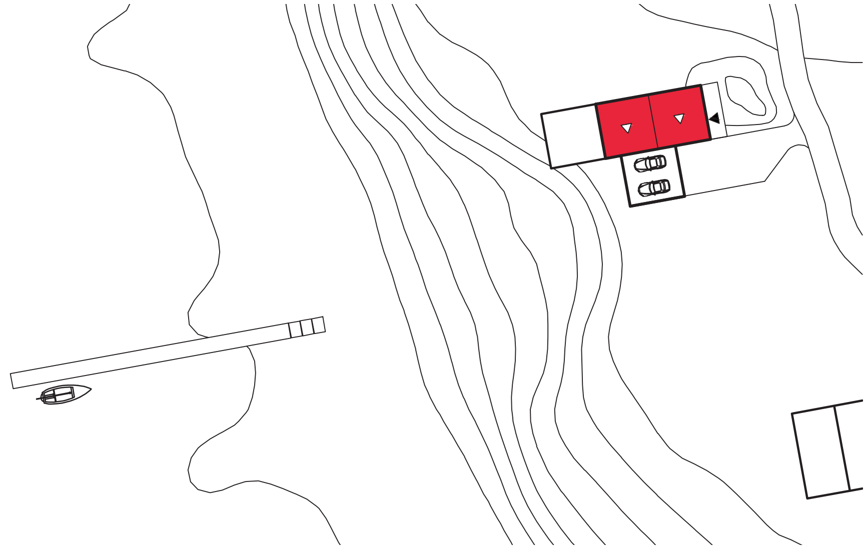
Second stage is presenting the growth of the family with 2 kids. Furthermore, the partner who works from home is expending the company thus there is a need for additional working space.

Last stage is showing the house when kids moved away, but are still returning for short stays. Furthermore, to expand a company it is necessary to move it to the city, thus the space previously used as office should get new function. Furthermore, there a wish of winter garden to enjoy winter view over the bay while sheltered from the wind and having a possibility to store the plants inside during this time.

ill. 141
Map with location of example house 7

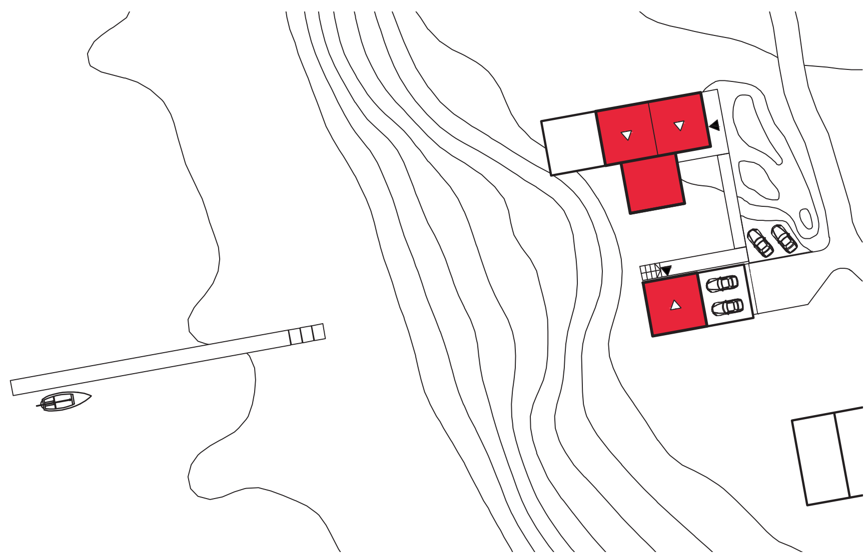
STAGE 1

As mentioned, in first stage couple gets settled on the shore of Kneble. Using two units as house, one unit as a carport and one as the terrace cover.



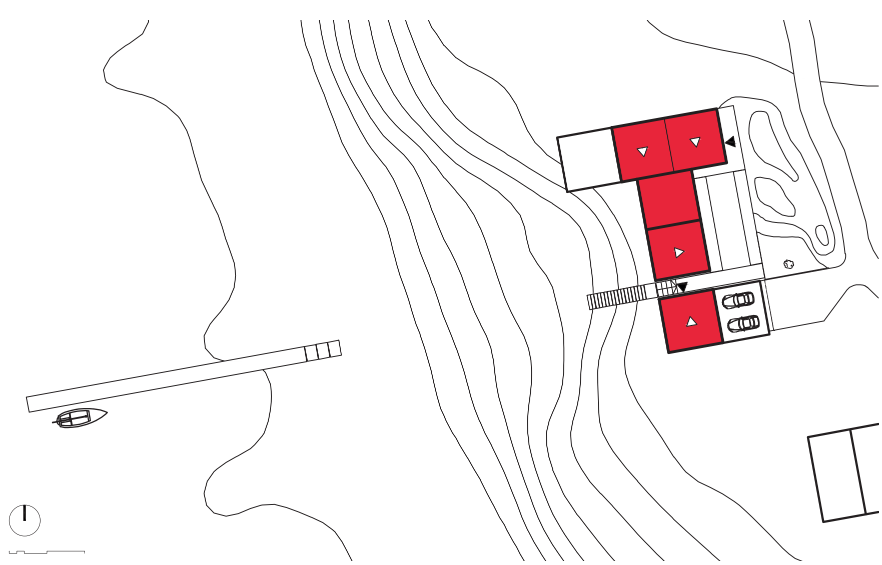
STAGE 2

At this stage family starts expanding; therefore previously used unit as a carport is now converted into a part of house. However, on the southern side of the plot new unit is added as the office with additional carport on the east.

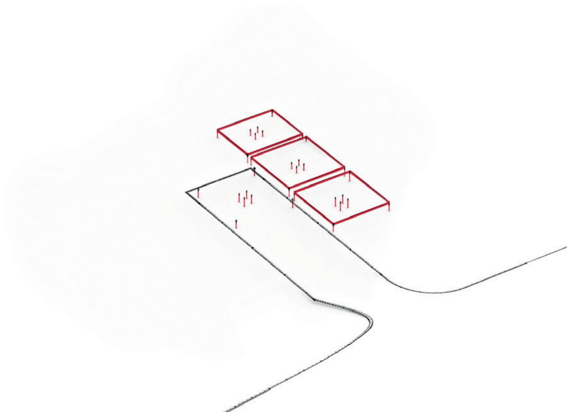


STAGE 3

In the final stage, the additional unit attached to the house is presenting the winter garden. In the meantime the unit that was used as the office is converted into the guest house.

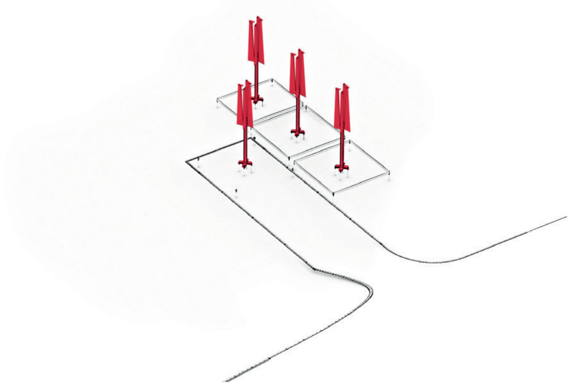


EVOLUTION PROCESS



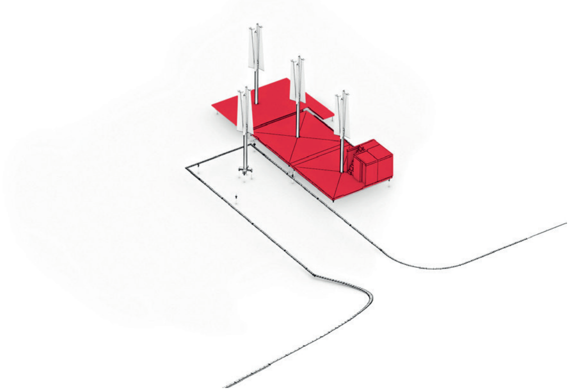
STEP 1

SITE PREPARATION (HELICAL SCREW PILES)



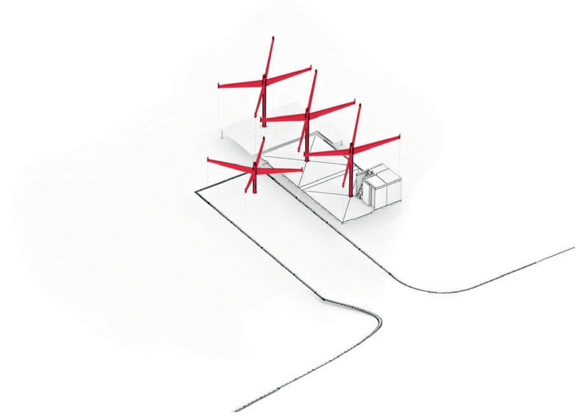
STEP 2

UMBRELLA POSITIONING



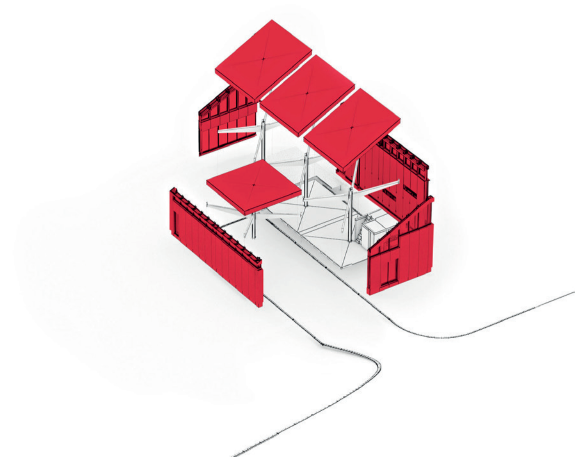
STEP 3

FLOOR PANELS + TECHNICAL UNIT



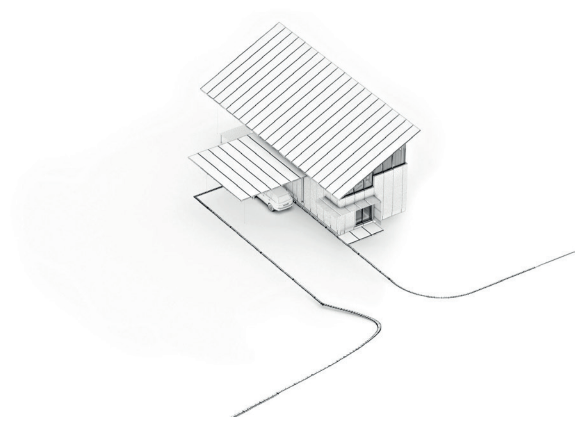
STEP 4

UMBRELLAS UNFOLDING AND PRE-STRESSING



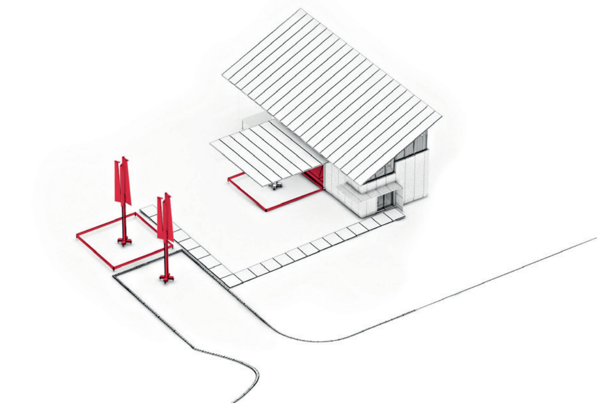
STEP 5

WALL AND ROOF PANELS



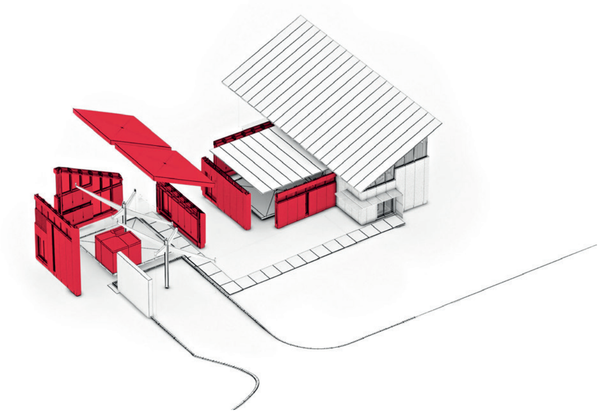
STEP 6

HOUSE STAGE 01 READY

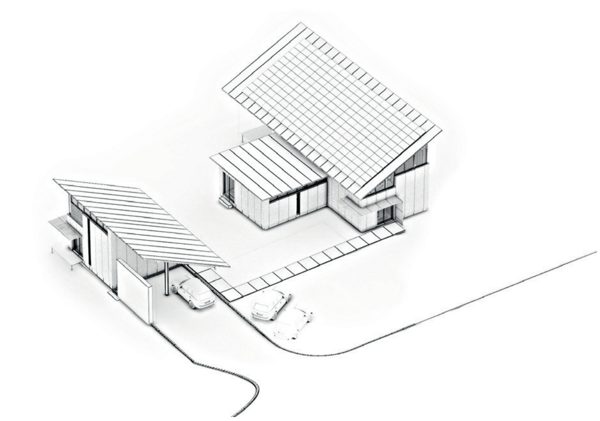


STEP 7

PARTIAL DECONSTRUCTION + 2 UMBRELLAS POSITIONING

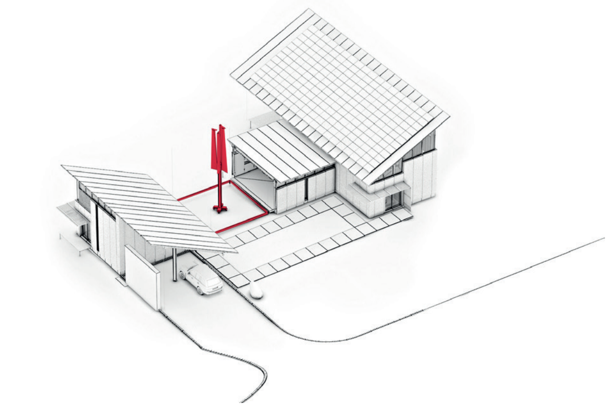


STEP 8
FLOOR, WALLS AND ROOF PANELS



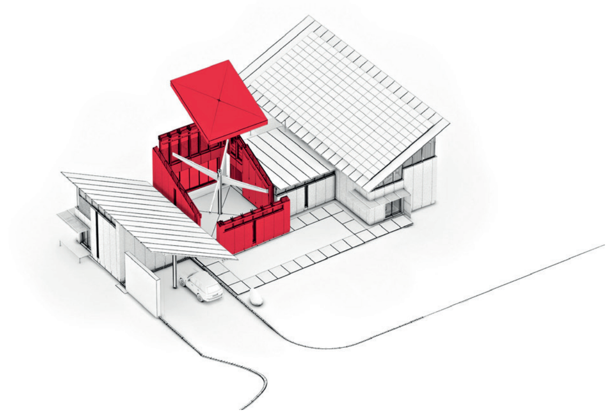
STEP 9

HOUSE STAGE 02 READY

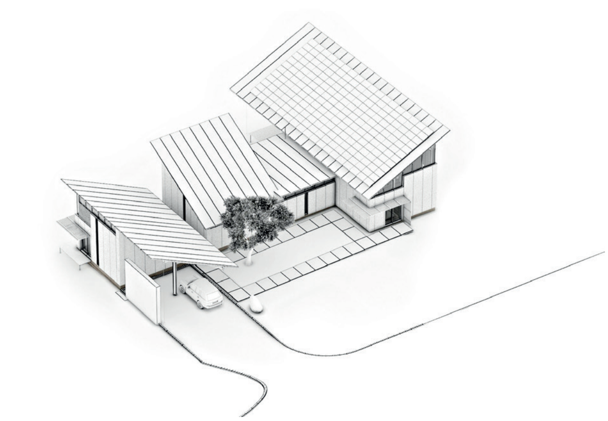


STEP 10

LAST UMBRELLA POSITIONING



STEP 11
FLOOR, WALLS AND ROOF PANELS



STEP 12

HOUSE STAGE 03 READY

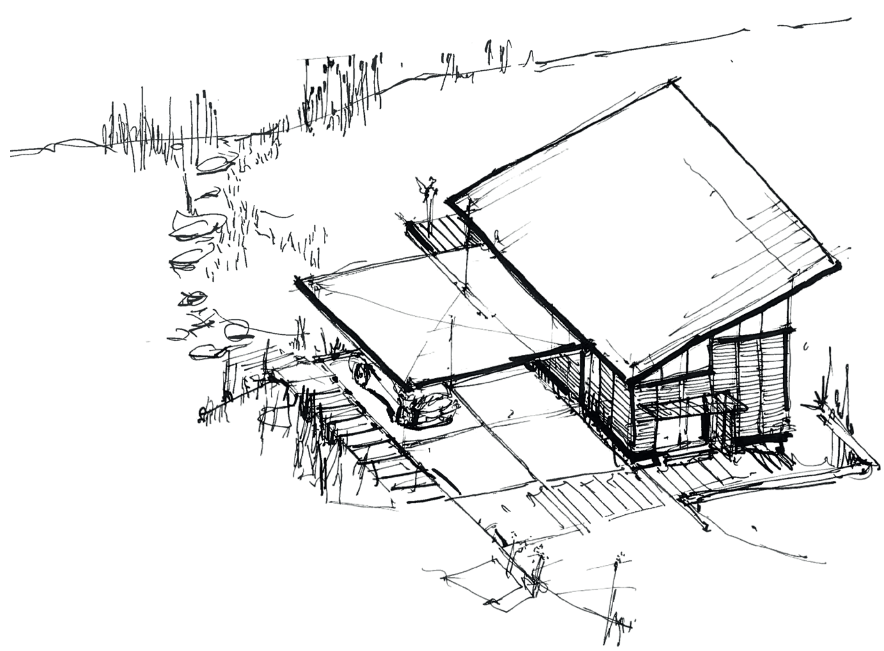
4.4.2

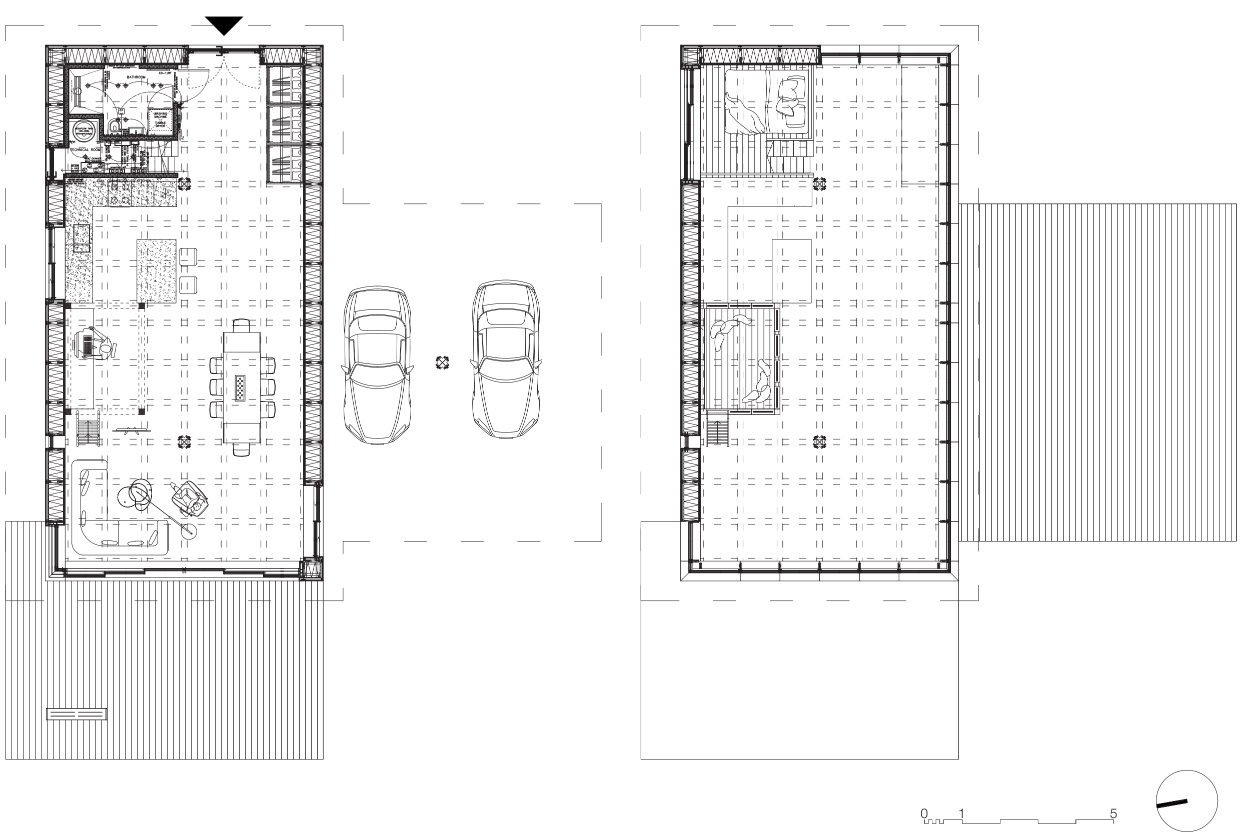
STAGE 1

Family's first house on the shore of Knebel consists of two units, with additional carport. First Idea was to keep the terrace uncovered and buy additional umbrella construction later, but further investigation showed that it is needed due to overheating.

The access is on the east, where is also the road, thus this part is more enclosed, while the western facade is opening toward the sea. Hence the interior is arranged in respect to the surrounding. The entrance door is in the south-east corner and since there is open plan the view immediately opens through the house into the bay.

Technical unit is on north-east with sleeping area above. Kitchen is following these spaces together with dining area and box-like furniture where working area is arranged. The box has the access on the top with cozy nook which can also be additional working space. On the west end of the house there is living space where you can catch last sunlight after a long day.



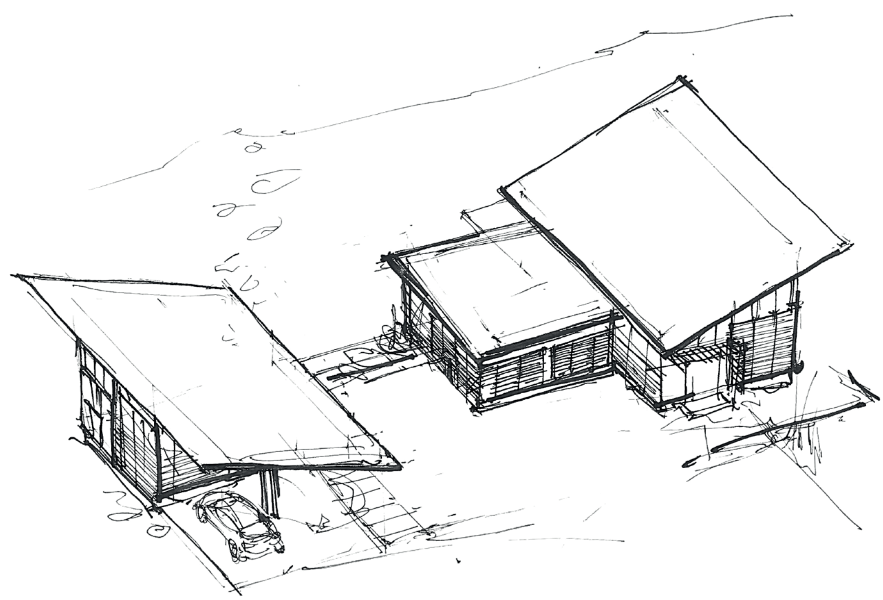


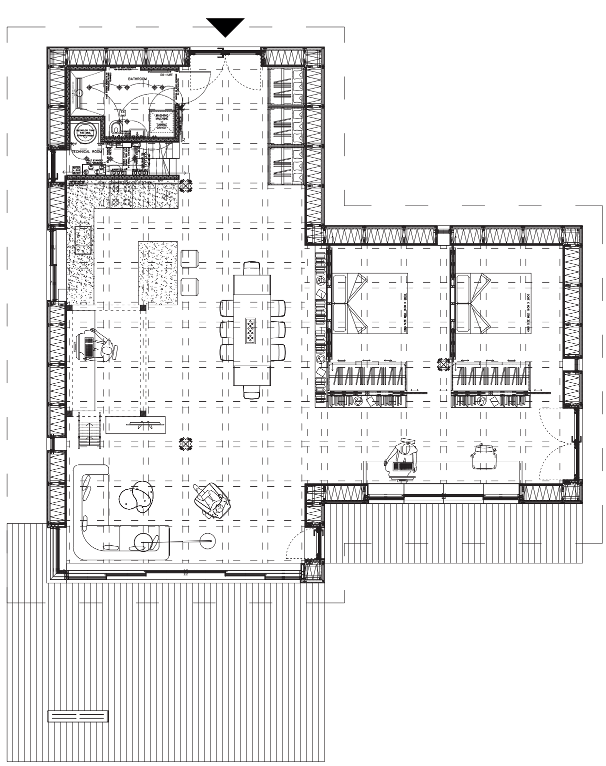
4.4.3

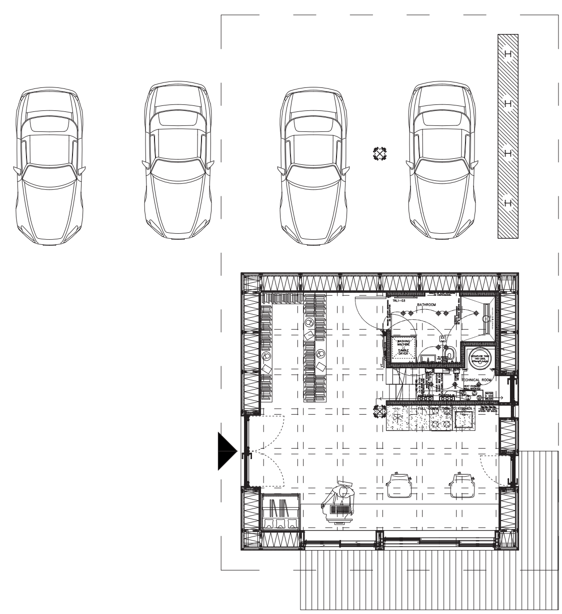
STAGE 2

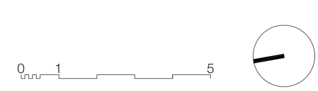
In this stage previously arranged spaces have only minor changes, while carport is transformed into additional bedrooms and working area for kids. This is possible due to the system that has compatibility between structure and different envelope elements. Furthermore, the panels that were next to carport could be reused to close new space.

To replace old carport, one is build next to newly erected office-house, located southern from the main house. Office unit is accommodating 3 working stations on the ground floor, with additional tea-kitchen and small library. There is also technical unit with utilities, and additional working space for the owner at the top.









4.4.4

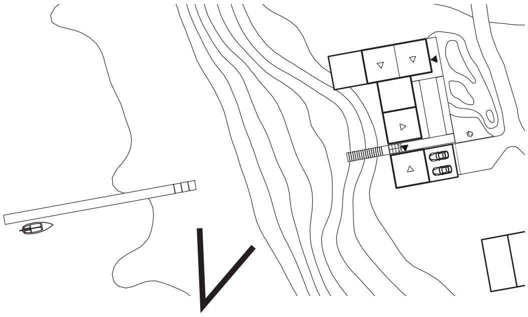
STAGE 3

The last modification includes additional unit used as the winter garden. To accommodate different activities in spring and autumn months. It also contains stairs to the roof terrace of a unit that was added in second stage. Modified box furniture in living space is now transformed and connected with technical unit to create a hobby space at the top and extend the kitchen underneath.

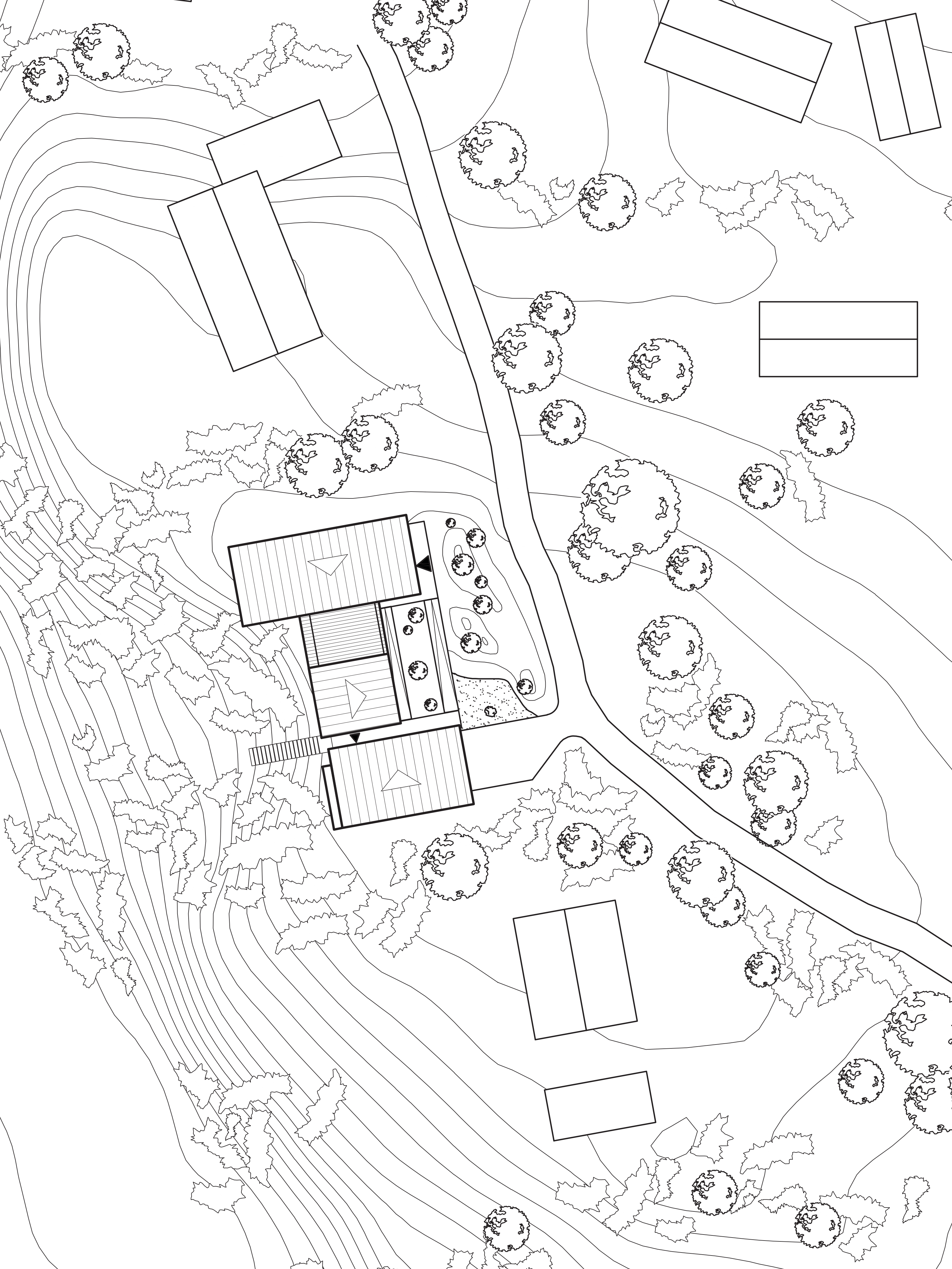
Due to relocation of the office, this unit is now fully functional guest house. It has tea-kitchen and space above technical unite is converted into the sleeping area.

Furthermore, the landscape arrangement has its final form. There is a narrow passage between both houses that reveals the view when walking from the parking are into the main or guest house.

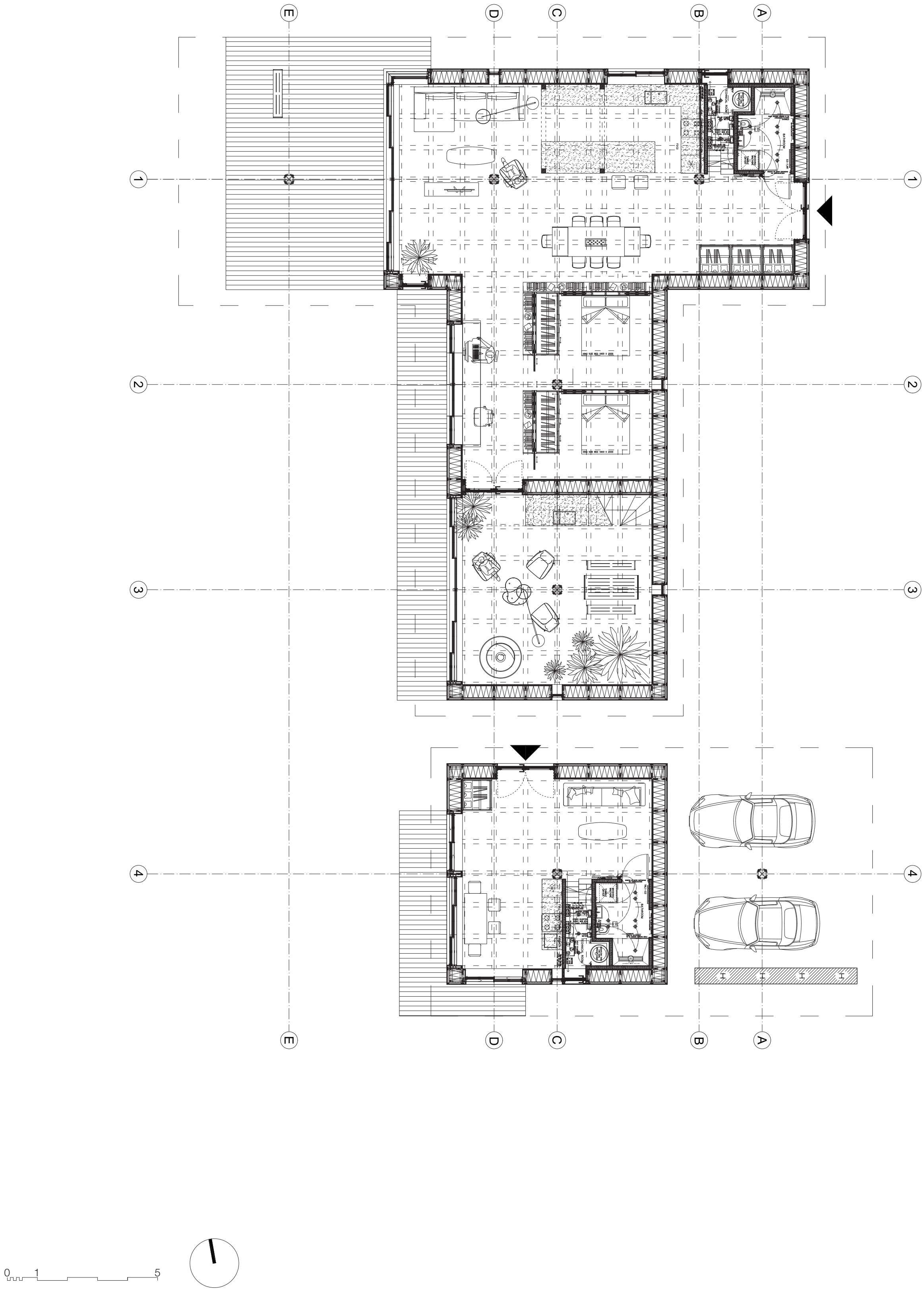
ill. 142
Exterior visualization from Southwest



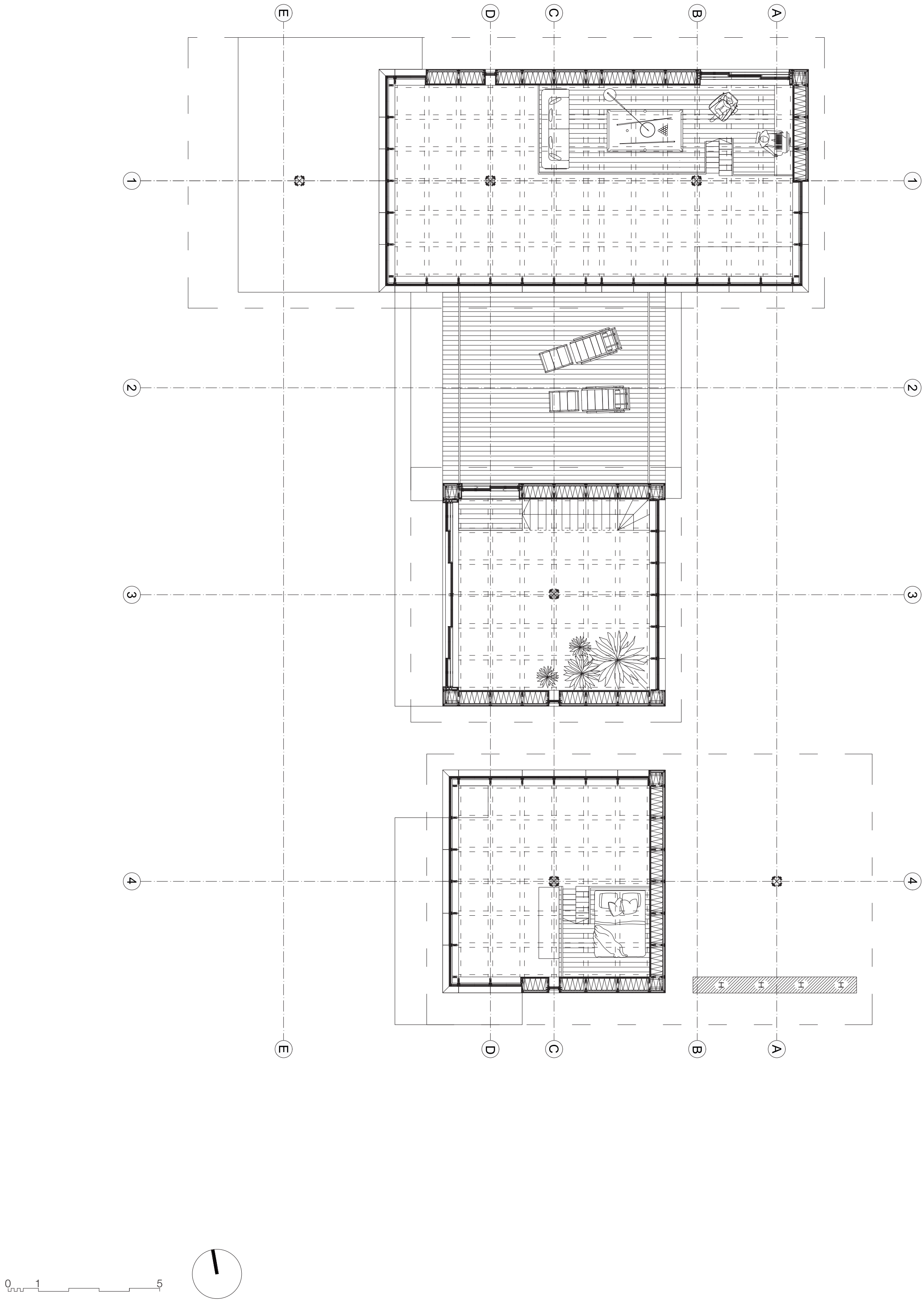
MASTER PLAN 1:500



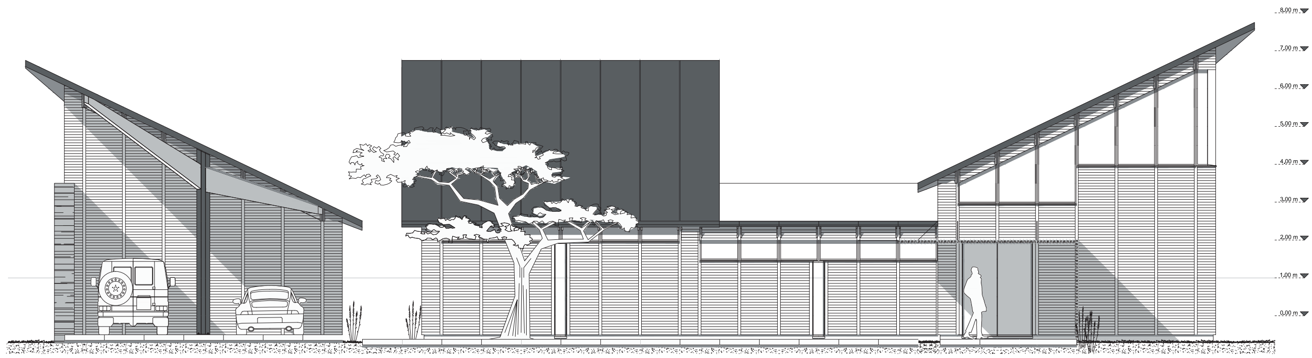
GROUND FLOOR PLAN 1:200



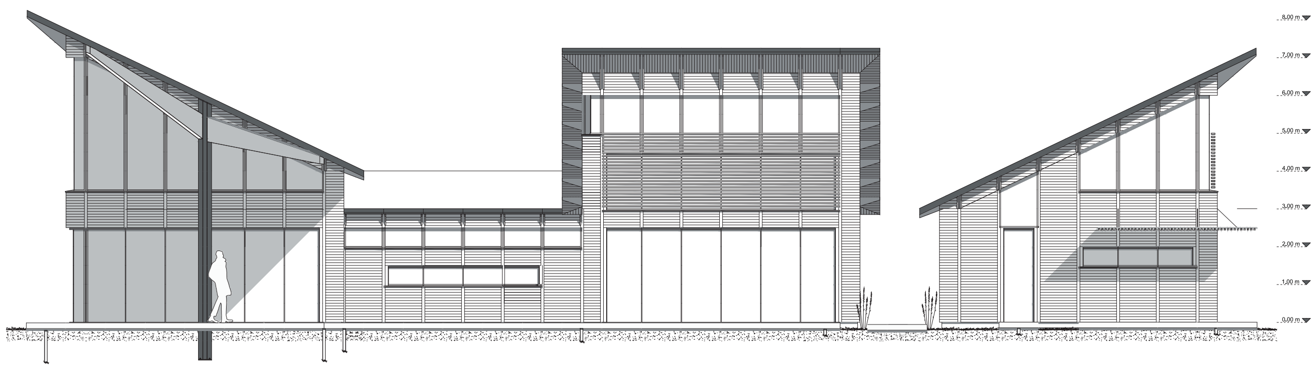
SECOND FLOOR PLAN 1:200



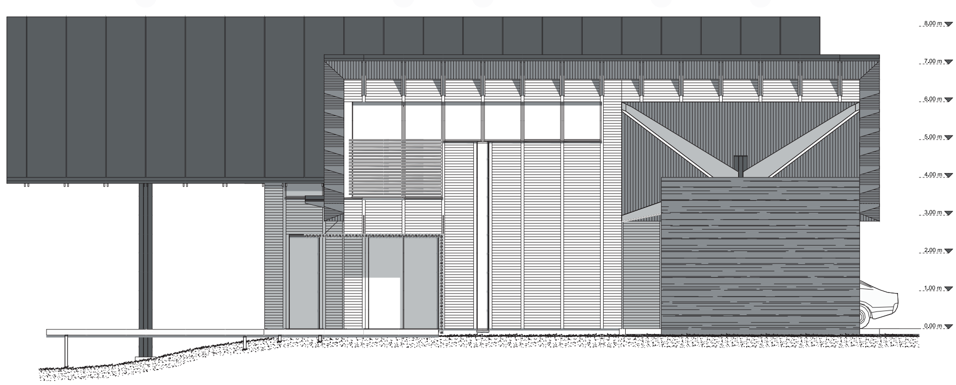
EASTERN ELEVATION 1:200



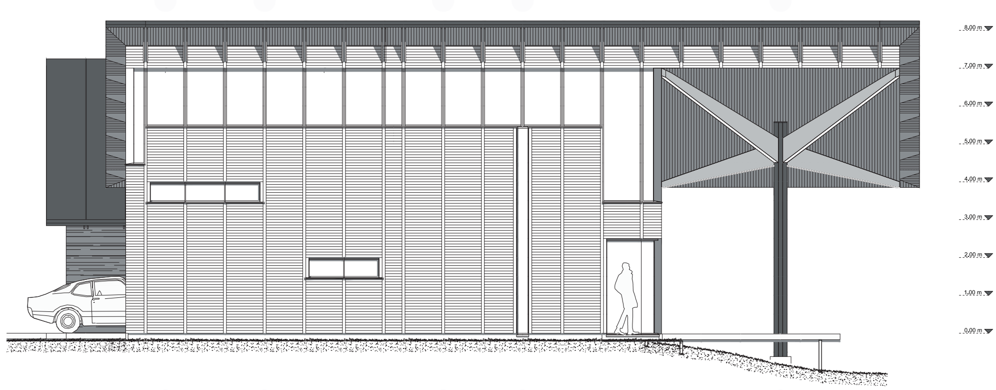
WESTERN ELEVATION 1:200



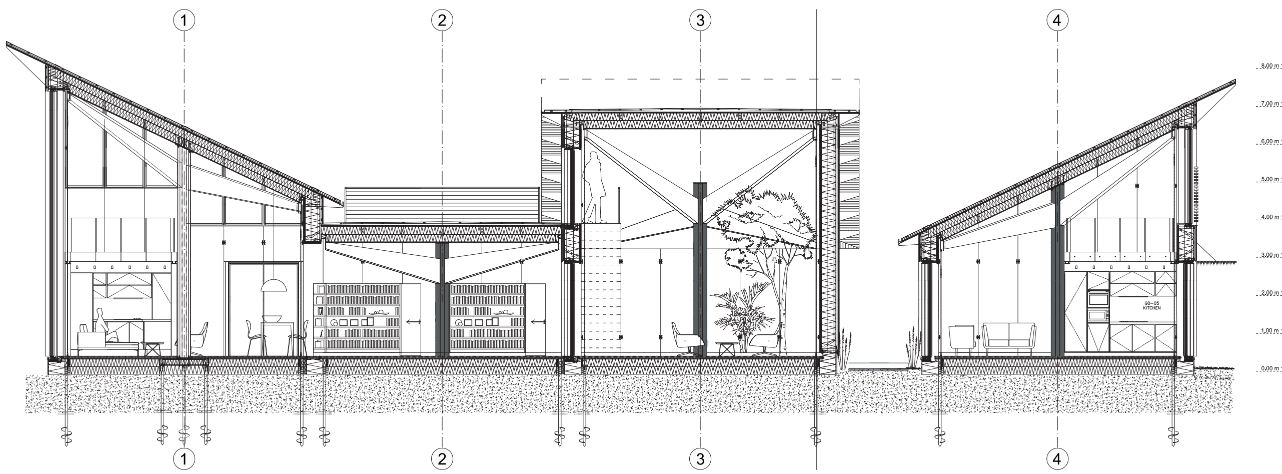
SOUTHERN ELEVATION 1:200



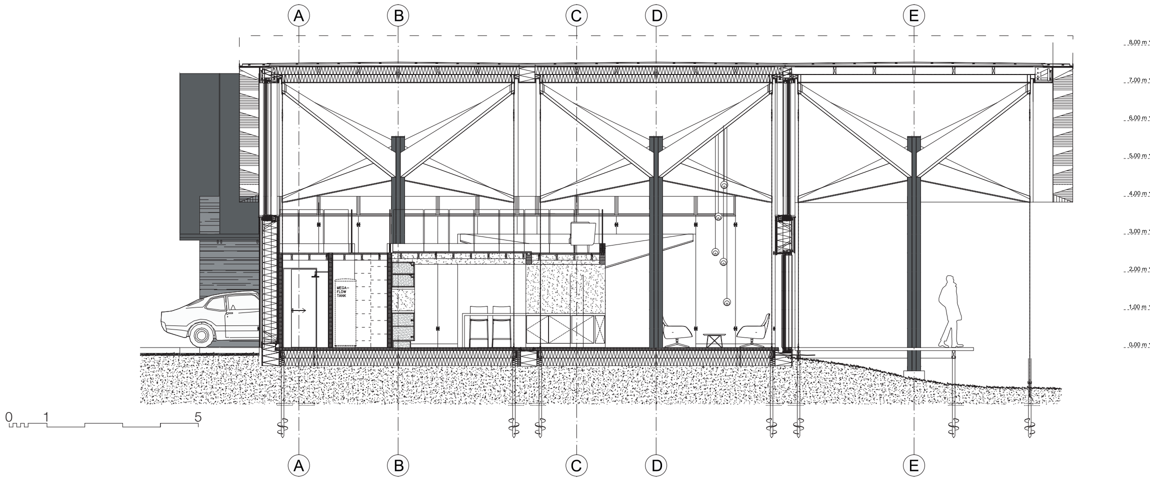
NORTHERN ELEVATION 1:200



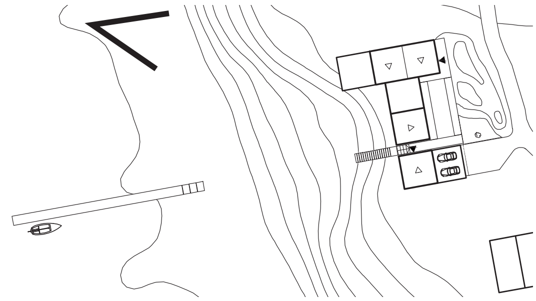
SECTION A-A 1:200

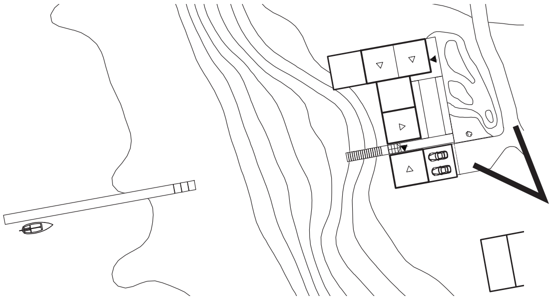


SECTION B-B 1:200



ill. 143
Exterior visualization
from Northwest





ill. 144
Exterior visualization from Southeast

ill. 145
Interior visualization
from daytime space

ill. 146
Wall detail visualization
showing connections

4.5 ANALYSES

The analysis are conducted to determine energy performance, indoor climate and daylight conditions of buildings designed with proposed prefab system. However, different kinds of analyses are not made for the same examples. Thus, the decision of which example is the most suitable for testing is according on predictions of which example can offer most relevant results.

Hence, daylight analyses are made for the final stage of house 7, where different variables such as shading and amount of windows are used. For calculating the energy demands with Be10, tests are made on all 3 stages of house 7, which allows to see the effect of additive principle on the energy performance. Last but not least, to test indoor climate precisely we are using BSim. These evaluations are also made for the final stage of house 3 since, this allows to test building designed with 4 units and 1 unit guest house.

4.5.1

DAYLIGHT

Daylight have significant role for the perception of space and architecture. Thus also for this project we are conducting daylight analyses of different variations of building, where results are determining the adequacy of bringing natural light into rooms. According to Building regulations 2010 the necessary factor should not exceed 2%, but according to improved standards for 2020 the minimum is 3% of the daylight. Furthermore, these analyses are not taking into account direct sunlight rather it is calculating diffused light of the environment. Velux Daylight Visualizer is used to perform these tests, which are executed on the final stage of Example House number 7. This testing object is chosen based on the fact that the sufficiency of the daylight can be proven for one unit guest house as well as for the composition of 4 unit house.

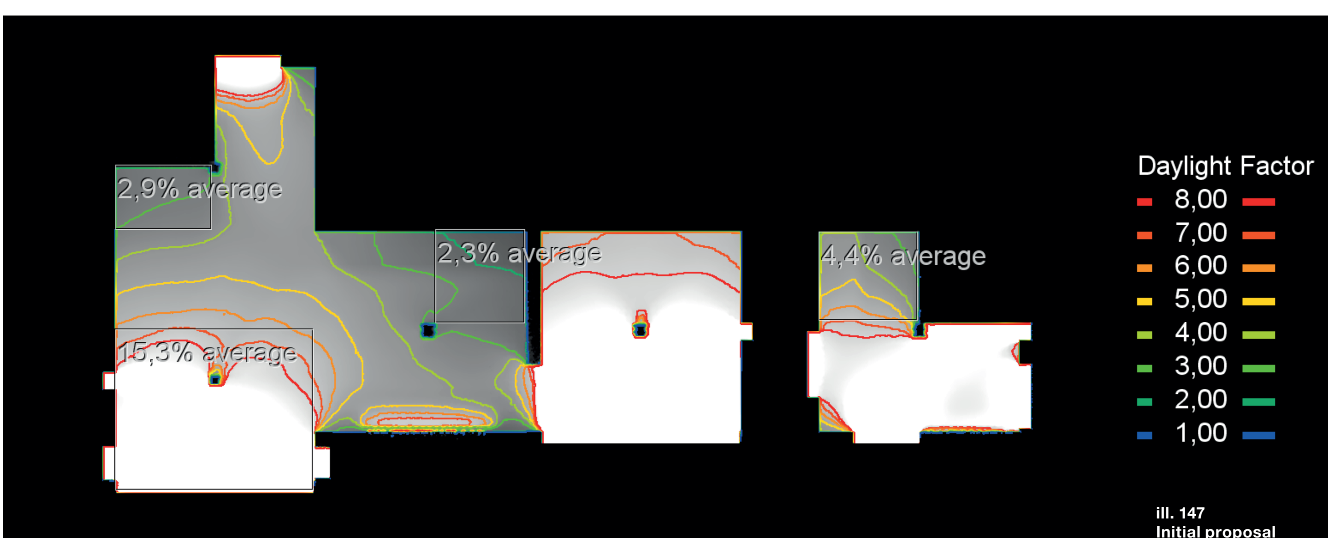
As seen on illustrations on this and next page. The differences of results are usually not major except in the living room and winter garden. However, it is necessary to know the variables and their effect for other buildings made with the same prefab system.

Thus, the results below are showing the daylight factor for the building without eaves, since building without eaves is more suitable for additive design. This also makes good daylight since even darkest corners are fulfilling the demand of BR2010. However according to energy efficacy the eaves or overhangs are needed to prevent overheating. Thus the examples on the next page have overhangs.

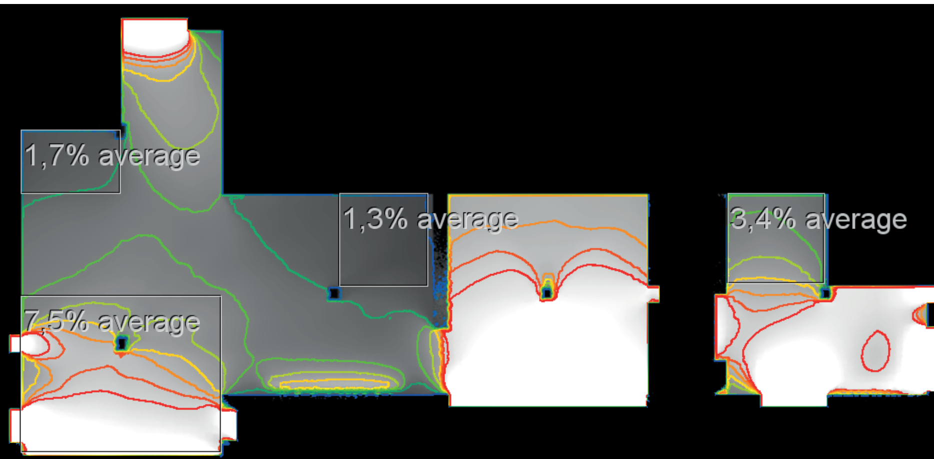
Windows of last 4 examples have the overhangs 50 or 100 cm long, except in living room (area with big window and DF 7,5 %). For shading of this space extra umbrella as extended roof is used for the significant reduction of overheating in daytime space. However, guest house is still facing with extensive overheating thus in the third example southern windows in the guest house and half of the western window in the winter garden are covered with horizontal lamellae.

In second and third example it is possible to see that kitchen area has DF of only 1,7 %. Hence, extra window is added there and also one in the area proposed for bedrooms and winter garden. With this action there is small improvement in bedrooms but significant one in kitchen area, which is because of working surfaces also the most crucial one. However, upon realization that also movable furniture block the light the final analysis is made with furniture that separates bedrooms. Thus last example is revealing that right bedroom has DF 1,2% and the left one only 0,8%, which is not enough. This could be solved with extra window; however, such action would affect the composition of the facade. Other solution could be to redesign vertical window in a way that it is composed of two vertical parts and partition wall would fit in between. In that way factor could be increased in left bedroom while elevation would not changed significantly.

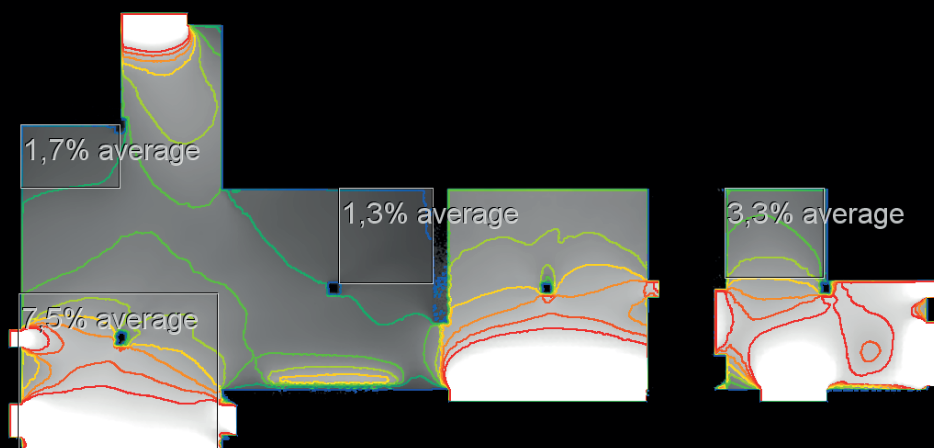
Even though the results are not entirely fulfilling Building regulations, we are able to equally distribute the daylight with designed prefab system. However, for the future projects it is necessary to predict and take into account also movable furniture from the beginning.



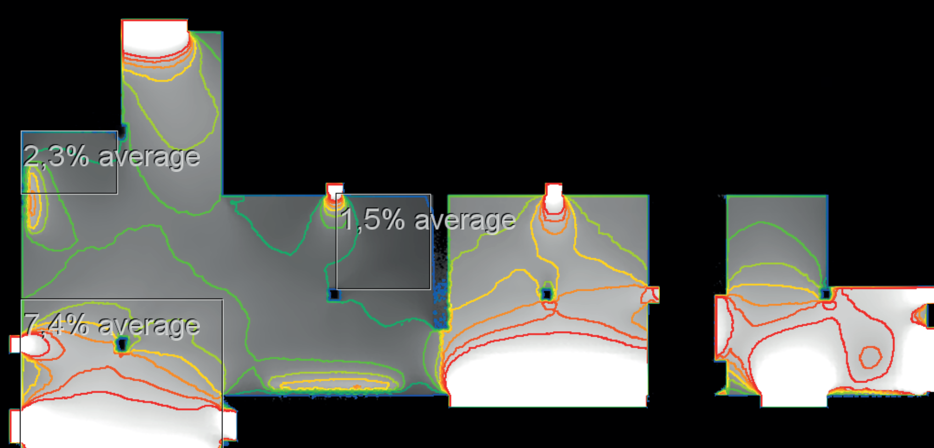
ill. 147
Initial proposal



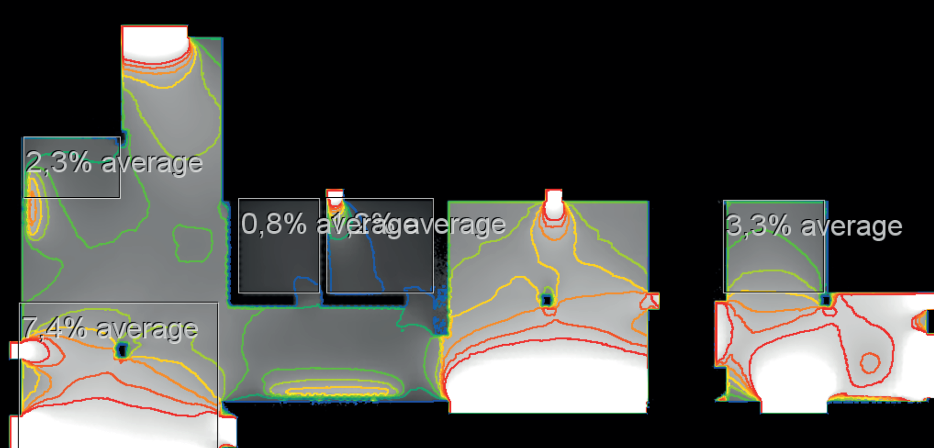
ill. 148
Optimization 1
additional overhangs



ill. 149
Optimization 2
additional lamellae



ill. 150
Optimization 3
additional windows



ill. 151
Final analysis with
furniture

4.5.2

BE10 ANALYSES

Goal of Denmark is to reduce energy demand with a help of Building Regulation 2020. Using such energy class should allow reduction of energy consumption for 75% in new buildings. These regulations are well rounded, thus the reduction of energy does not decrease the quality of indoor climate. Additionally, energy consumption for heat, ventilation, cooling and domestic hot water should not be over 20 kWh/m^2 per year, while the transmission losses for one story building are limited to maximum of 3,7 W/m^2. Also of a great importance for Be10 analyses is the air permeability, which should be lower than 0,15 l/s per square meter (Activehouse, 2015).

Software Be10 is used for verification of energy frame for buildings designed with prefab system. With this computer program we are testing all three stages of building example 7. The initial goal was to test the final stage; however, BSim analyses showed that additional tests are needed. Thus, not only last stage is verified using Be10, but also first two.

The analyses are presented in chronological order of conducted tests and not of building stages; therefore it is starting with stage 3 analysis, following with stage 1 and 2. Even though, the stage 3 consists of a main building and guest house, both objects are analyzed together. However, the additional and final test is performed only for guest house in order to confirm findings.

4.5.2.1

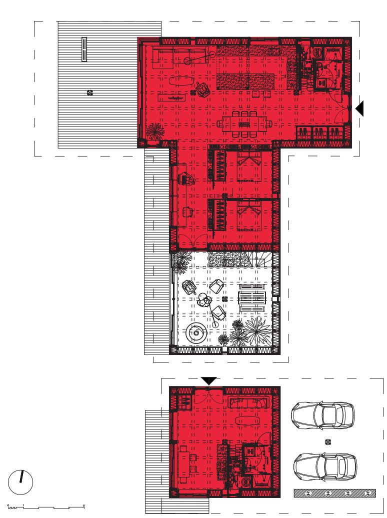
STAGE 3 ANALYSIS

As mentioned in chapter introduction, the analysis started with last stage, primarily because it includes various solutions and both buildings.

Key numbers in the graph below are shoving that the building is fulfilling BR2020. The assumption after this test was that stage 1 and 2 should have better results because of more compact shape (favorable ratio between volume and envelope). Furthermore, winter garden is not part of heated floor area.

However, latter results convinced us to conduct analysis separately for a guest house.

Total energy requirement	**Energy frame Buildings 2020**
17,7 kWh/m^{2}year	20,0 kWh/m^{2}year
Transmission losses	**Transmission losses Buildings 2020**
1,9 W/m^2	3,7 W/m^2



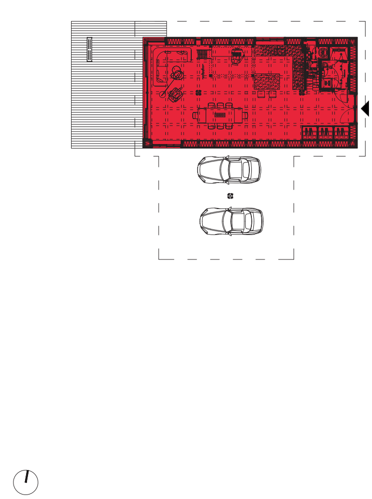
4.5.2.2

STAGE 1 ANALYSIS

Even though that the building has better volume to surface ration than house in stage 3, it is not fulfilling BR2020 demand.

However the assumption is that with removing modules we are reducing amount of windows that are facing east, west and south, while the amount of windows toward north is remaining the same. Which in numbers means that stage 1 has 58% less south, east and west windows than house in stage 3. Thus has less potential for solar heat gains. Also initial idea was to create building without roof above terrace like in stage 2, but because of the size, it has big influence on overheating.

Total energy requirement	**Energy frame Buildings 2020**
23,9 kWh/m^{2}year	20,0 kWh/m^{2}year
Transmission losses	**Transmission losses Buildings 2020**
2,0 W/m^2	3,7 W/m^2



4.5.2.3

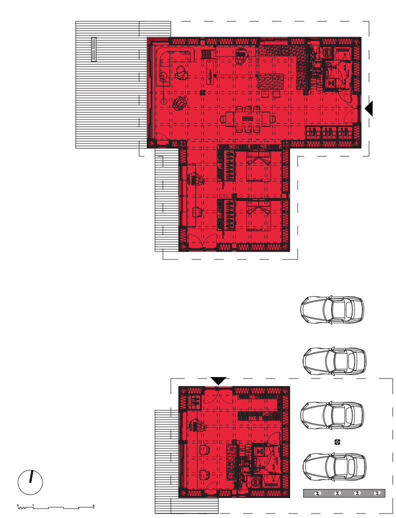
STAGE 2 ANALYSIS

The graph below is showing that energy consumption is much closer to results for stage 3 than stage 1. This means that either guest house or additional unit in main house has big influence on building's energy frame.

Knowing that guest house has the majority of the southern windows, this leads us to conduct additional analysis solely for guest house.

Furthermore, it is possible to notice that green house has minimum impact on the heat gain on the main building, in the opposite with the expectations.

Total energy requirement	**Energy frame Buildings 2020**
18 kWh/m^{2}year	20,0 kWh/m^{2}year
Transmission losses	**Transmission losses Buildings 2020**
1,9 W/m^2	3,7 W/m^2



4.5.2.4
GUEST HOUSE

Additional analysis shows that significant improvement in energy demand between stage 1 and 2 is caused by guest house. Better ratio between guest house's southern windows and other opening contribute to such outcome.

Furthermore, the results can be verified, where average of energy used in a year between guest house and stage 1 should be similar to stage 2.

Guest house:

$$54\ m^2 \cdot 14.2\ kWh/m^2year = \\ =766,8\ kWh/year$$

Stage 1:

$$104,2\ m^2 \cdot 23,9\ kWh/m^2year = \\ =2490,38\ kWh/year$$

Average:
The sum of floor area:

$$54 + 104,2 = 158,5\ m^2$$

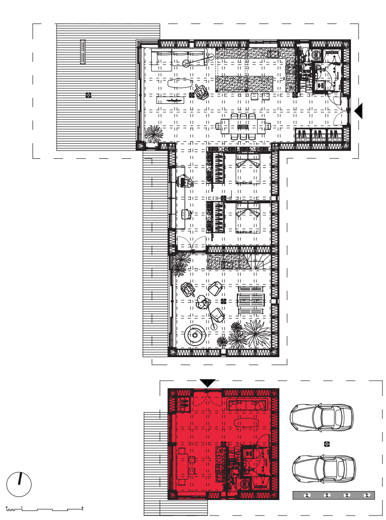
The sum of used energy area:

$$766,8 + 2490,38 = 3257,18\ kWh/year$$

$$3257,18\ kWh/year\ /\ 158,5\ m^2= \\ =20,5\ kWh/m^2year$$

However, there is a difference between the average and stage 2 since stage 2 has one more unit in main house. Nonetheless, this calculation is demonstrating the influence of 1 unit guest house to the rest of the building complex.

Total energy requirement	**Energy frame Buildings 2020**
14.2 kWh/m²year	20,0 kWh/m²year
Transmission losses	**Transmission losses Buildings 2020**
2,0 W/m²	3,7 W/m²



4.5.2.5
ENERGY PRODUCTION

In order to create Zero Energy Building, it is necessary that building energy consumption is reduced to fulfill BR2020. After this condition is accomplished, building uses active solutions for energy production. Energy production technology such as heat pumps and solar thermal collectors are producing heat. However, district heating is widespread in Denmark, thus for most buildings the production of electricity with photovoltaic panels would be most suitable solution.

Building's energy consumption that solar photovoltaic panels should cover in order for building to become zero energy building:

Heat demand: 13,4 kWh/m² year
Primary energy factor: 0,6

Total el. consumption: 33,1 kWh/m² year
Primary energy factor: 1,8

Heated floor area: 204,5 m²

$$33,1 \cdot 1,8 + 13,4 \cdot 0,6 \\ = 67,62\ kWh/m^2\ year$$

$$67,62\ /\ 1,8 = 37,57\ kWh/m^2\ year$$

$$37,57 \cdot 204,5 = 7683,07\ kWh/year$$

The energy production is calculated with a help of calculation spreadsheet "Skema til overslagsberegning af nettilsluttede solcelleanlæg i Danmark". Panels used for production of energy are made by s Sunpowe. Panel X21-345 is monocrystalline with high efficient of 21,5 % (Sunpower, 2015).

A (area for panels) :60 m² (roof of 1 prefab module)
B (module efficiency): 0,215

$$C = A \cdot B =60 \cdot 0,215 = 12,9$$

D (system factor): free standing=0,85
E (solar radiation): South orientation, 20°inclination = 1124 kWh/ m²

The amount of energy that one prefab module with photo voltaic panels can produce:

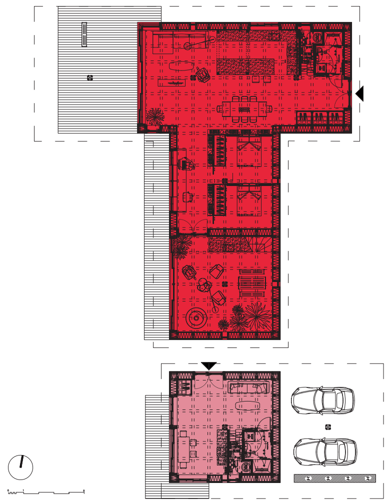
$$C \cdot D \cdot E = 12,9 \cdot 0,85 \cdot 1124 =$$

$$= 12324,66\ kWh$$

Which means that is more than enough to cover roof of only one module to fulfill all energy demands.

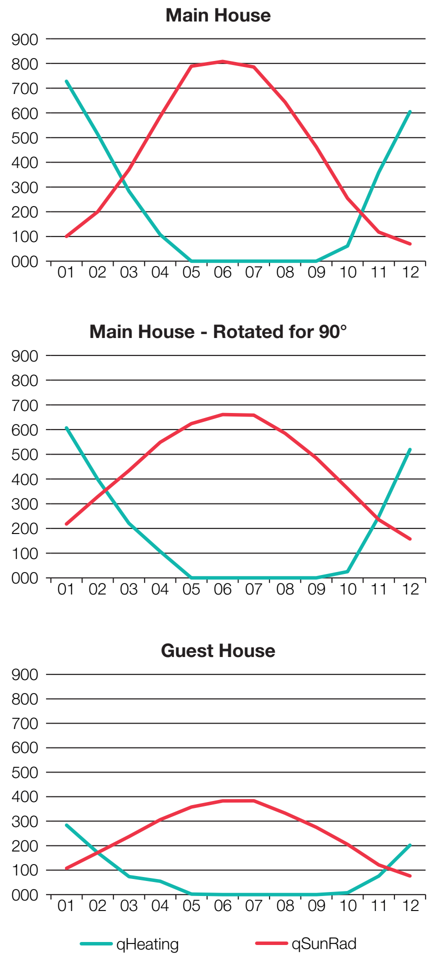
BSIM ANALYSES

During the detail design phase, BSim software has been used in order to optimize atmospheric and thermal comfort of a main and guest house in stage 3. Same optimization principles are also used in previously seen chapter Be10 analyses. In the opposite with



Be10 analyses, BSim results are made for the main and guest house separately. Number for qHeating in table below is a sum of qHeating for main house from illustration 155 and guest house qHeating for example 5 in illustration 157.

	qHeating	Area	Heat demand
	kW/year	m²	kW/ m² y
BSim	3527,49	204,5	17,25
Be10	-	-	13,4

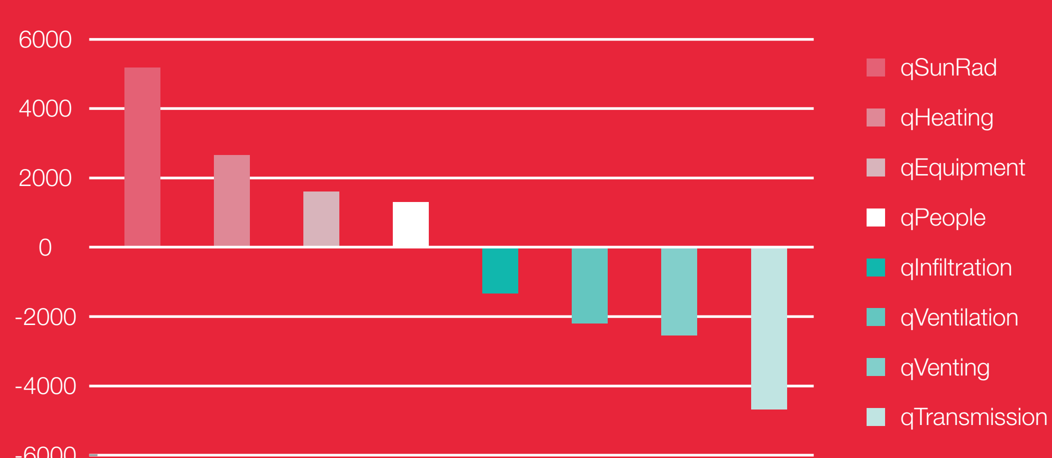


ill. 152
Above -graphs comparing heat demand and solar gains
ill. 153
Upper left -plan presenting different areas of analysing
ill. 154
Left -comparison of heat demand from Be10 and BSim
ill. 155
Below - essential BSim results for main house

Even though that graph 155 an 157 are showing good results, the data is revealing that heat demand per square meter in a main house is higher compared to the guest house. However, it is showing consistency with the same problem as in Be10 analyses. Hence, for the further investigation graphs in illustration 152 are made based on collected data from BSim. They are comparing heat demand and solar heat gains for main house, main house where western facade is rotated toward south (for 90°) and guest house.

Comparison in first graph is conducted for main house, with a orientation as it is designed. The experiment that followed this one chronologically is made for guest house. Even though that heat gains and demand are smaller, it is possible to notice the ration between both.

For example comparison of January shows that gains in main house are only 14 % of heat demand, while in guest house they are 38% of heat demand. Thus knowing the difference in glazing amount and orientation from Be10 analysis, the difference indicates better orientation. Therefore, the additional test is made where western facade with majority of glazing is facing toward south. Thus this improves heat gains for January from 14 % to 36% of heat demand. Furthermore, heat gains in summertime are lowered.



In the opposite with main building, where there is not enough solar gains, guest house was facing problems with overheating. Therefore, different passive strategies were applied during the process of improving the indoor climate. According to By og Byg Anvisning 202, 26°C can be exceeded in not more than 100 hours, while 27°C in not more than 25 hours. However, the example number 1 in illustration 157 is showing high amount of hours with excessive temperature. Thus, we tried to improve indoor climate, while keeping heat demand as low as possible:

STEP 2 - in this step additional shading is added as overhang above lower windows on southern and western facade.

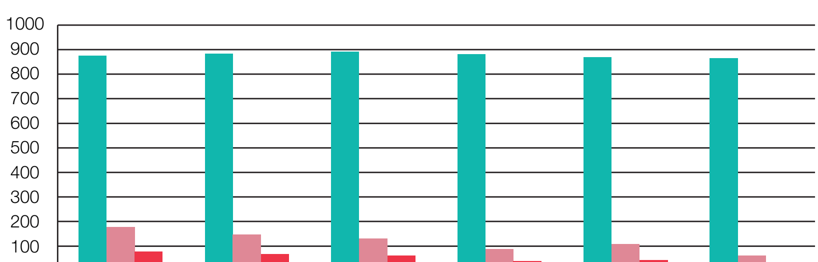
STEP 3 - lamellae are added in front of one higher window on southern facade.

STEP 4 - with removing part of the window in this step we are reducing hours above 26 °C for 33 %.

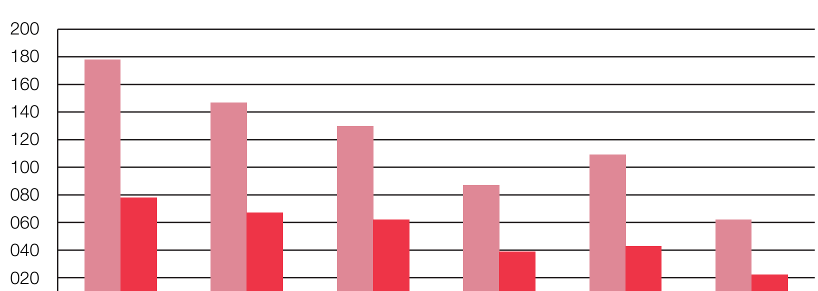
ill. 156
Removed windows on western facade

STEP 5 - high heating demand appeared in April in step 4 due to reduced solar gains, however there was still possibility to adjust natural ventilation. Thus step 5 present the effect on adjusted ventilation. However, this step needs more fine tuned ventilation, since April's overheating appears only at very limited hours of certain days.

STEP 6 - this step is presenting additional elimination of western widow. However, with such act the building would lose the expression and the lightness that this window is giving to building. Hence we made one step back,



	1	2	3	4	5	6
qHeating	875,92	883,64	892,1	881,19	869,84	866,01
Hours > 26	178	147	130	87	109	62
Hours > 27	78	67	62	39	43	22



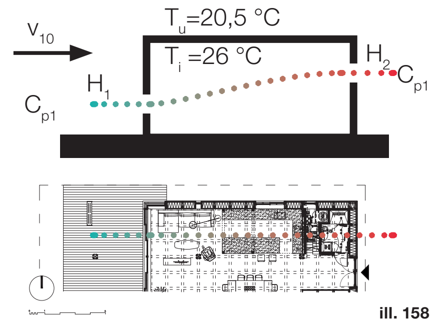
	1	2	3	4	5	6
Hours > 26	178	147	130	87	109	62
Hours > 27	78	67	62	39	43	22

ill. 157
Graph above presenting relation between overheating and heat demand. Lower graph is presenting only hours of overheating

4.5.3.1

NATURAL VENTILATION

Following calculations are made to ensure the possibility of natural ventilation during the summer, thus the result is needed surface of the opening. They are based on the example from SBI 202 on page 112. The analysis are made for daytime space with opening of the same size for average wind and situation without wind.



ill. 158
Scheme of natural ventilation

Wind speed 9 m above sea level:

$$v_9 = v_{10} \cdot k \cdot h^{\alpha} =$$
$$= 4 \text{ m/s} \cdot 0{,}35 \cdot 9^{\,0{,}25} =$$
$$= 3{,}15 \text{ m/s}$$

Desired flow rate [q_v]:

basic air exchange = 3 h^{-1}
buildings volume = 426,9 m^3

$$q_v = 3\ h^{-1} \cdot 426{,}9\ m^3 =$$
$$= 1280{,}7\ m^3/h = 0{,}35\ m^3/s$$

Pressure difference when with two same sized openings:

$$\Delta p_1 = \Delta p_2 = ½(½ \cdot \rho \cdot (C_{p1} - C_{p2}) \cdot v_9 +$$
$$+ 1{,}25 \cdot 9{,}81 \cdot (H_2 - H_1) \cdot (\Delta T/T_i) =$$
$$= 2{,}9633 \text{ Pa}$$

Necessary area of the opening for natural ventilation:

$$A_{nødr,1} = A_{nødr,2} =$$
$$= q_v / (C_{d,i} \cdot ((2 \cdot \Delta p) / \rho)^{½} =$$
$$\underline{= 0{,}23\ m^2}$$

Opening for worst case scenario with no wind. Thus ventilation is caused only by thermal buoyancy:

$$\Delta p_1 = \Delta p_2 = \rho \cdot g \cdot (H_2 - H_1) \cdot (\Delta T/T_i) =$$
$$= 0{,}4511 \text{ Pa}$$

Necessary area of the opening for natural ventilation:

$$A_{nødr,1} = A_{nødr,2} =$$
$$= q_v / (C_{d,i} \cdot ((2 \cdot \Delta p) / \rho)^{½} =$$
$$\underline{= 0{,}59\ m^2}$$

‘FINAL CONSIDERATIONS’

The summary of this report will present our thoughts, reflections and personal critics towards this project and its theme. It is extremely important to finalize every working process with valuable summary thanks to which we can learn and grow as a person and professional. Furthermore, it should help us developing every next project with necessary caution and precision that comes from experience and avoidance of mistakes from the past. This chapter will be divided into two parts: reflection and conclusion, where discussed separately will elaborate on our thoughts about this project as well as general idea of prefabrication.

5

ill. 159
Panel system

5.1 CONCLUSION

During the design of sustainable prefabricated system we encountered many different challenges, due to aims for which we believe can give to prefab building an added value and the advantage over common onsite building approach. Thus following iterative approach of integrated design process we tried create flexible and unique prefabricated architecture that could move away from stigma of container-like-building while allowing architect and client to merge forces and ideas during cooperative design.

However, with integrated design approach every new idea or proposal for prefabrication should be rethought in a process of design, assembly in factory, assembly on the site and disassembly at the end of building's life. Thus each stage that is unsuccessful closes the loop and starts the process from the point where system was still functional. Moreover, with enhanced flexible, sustainable and additive aspect we are adding three more criteria into development of prefab system that must be fulfilled in order to meet our aims and vision. However our belief is that current principles of construction are limiting our goals, thus we are moving away from traditional approach of prefab and exploring the application of umbrella construction. Even though that such system is not common in private housing, this architectural principle is often seen in office and exhibition buildings since it has minimal limitations on their floor plan arrangement. With such building and use of movable furniture client can really create the space that meets his or her needs at any time.

We believe that such premise is valid and it is worth exploring, but it is important not to limit ourself with current form of prefab buildings. However, even with a longer period dedicated to design of new principle it is necessary to acquire the team of people due to complexity of the project. Furthermore, the knowledge should not be limited only on architectural, civil engineering and management trades but it should also include computer science and robotics to introduce new approaches and perspectives. It should also include advanced material knowledge which is crucial for both construction as well as envelope. Hence, even though prefabrication is often discriminated in architectural world, many well know architect that have ability to dedicate resources in a prefab developing tries to reach for the Holy Grail of well designed flexible architecture.

Despite limitations, the result of this project is fulfilling goals. Umbrella system with foldable construction is allowing easy and efficient transportation and installation. While it is compact when folded, it is creating module big enough for a living unit when unfolded. Also with the studies of the size we were able to create module that makes suitable interior for different amount of users while it is small enough to combine multiple number of units which gives the diversity. Furthermore, the umbrella system is separating envelope and construction, thus giving the possibility of freely rearranging the facade without interfering the construction which is also of a great importance when it comes to additive architecture. The separation of structural element and facade layer creates a column in the middle of module which is embracing the structure and tectonic while expressing the primal instinct of finding a shelter under the tree. On the other hand, in some occasions such placement of column could be a double-sided sword. While allowing flexible floor plan and even expansion, it brings additional element that must be taken into account in interior arrangement. Yet, from sustainable point of view, such design is reaching high level of disassembly, thus allowing separation of the material, recycling and reuse. Furthermore, with flexible envelope and adjustment of it, passive strategies can be easy to apply. Thus low energy consumption and good indoor climate can be reached for each individual project.

All in all, the outcome of this project is a system that is able to crate living units of various sizes, while embracing architectonic of structure in respect to the environment. But for truly advanced prefabrication the primary condition is advanced technology.

5.2 REFLECTION

Prefabrication in last few years became a topic number one for many architects, engineers and businessmen. It is visible everywhere: in magazines, books and all other types of media. Everyday we are bombarded with headlines: prefabricated this, prefabricated that... When this project was started, we were aware that there is a demand and space for improvement in prefabrication, however our predictions were not even close to what we experienced. Searching through ideas, concepts and ready solutions that are available on the market today, two different approaches could have been easily distinguished. On one hand we have flexible solutions which complexity level of construction on site is similar or higher compared to common building systems. On the other hand there were highly prefabricated module-like architecture that allowed for minimal flexibility and change. The gap in the market for something that would found its place in the middle of these two extremes seemed to be almost empty thus our project was aiming to fill this void.

The initial idea seemed simple and elegant: to create a set of limited components that put together in different variations, would allow for almost infinite number of combinations and outcomes. Being surprised that nobody before us have succeeded in creating such lego-like system, full of optimism, we started filling out blank pages with sketches of possible solutions. As simple and clean as it seemed at the beginning, the more detail was introduced to the concept, the more complex whole system became. Trying to design innovate cold bridgeless construction system, components became more complex in the process, lost their elegant nature.

Looking back at the project and analyzing where some elements could be improved or designed differently, there is really not that much space where the system itself could be adjusted. As we believe, it is not as much fault of the design as it is of the whole low-tech/ common approach that was chosen almost automatically as something that we know and had experience with. In other words, to revolutionized prefabrication in architecture, new way of manufacturing, developing materials and assembly should be introduced.

Nowadays when highly prefabricated units are being discussed, in almost all cases we are dealing with common building techniques. They are moved into factory and thanks to optimizations and standardization can be executed faster and more efficiently. Nevertheless, these are still traditional methods that are inevitably linked with limitations exactly like our system. The level of complexity when we push such system to be more flexible, thus should consist of smaller components, is rising significantly. These are the reasons why in order to achieve true 21st century prefabrication in architecture, we should look rather into high-tech approach and solutions that are pushing technology as we know it today.

Such approach is unfortunately impossible to achieve by a small group of people specialized in one field of knowledge and rather should be approached by a group of specialists with different backgrounds that together have the ability overcome traditional way of thinking. Prefabrication itself exceeds beyond knowledge of even most experienced architects which are mainly responsible for design and visual aspects. To achieve a modular system that would combine aesthetic values with technical and economical ones, different specializations are required. This is undoubtedly one of the reasons why such system is still unavailable on the market. Civil engineering sector seems to develop slower than any other even though separately, building materials such as windows/ elevations or technical machinery becomes more advanced every year. It looks like there is a missing link that would integrate all of these components into one efficient and organized system.

Single cases of such movement can be already noticed on today's market, nonetheless they are still imperfect regarding one or the other aspect like energy frame or democratic design strategies. The use of "3d printing" in different materials or advanced methods of CNC produced components are already available to purchase. However, these technologies are only the beginning, an introduction to revolution of truly unlimited and widely available design system. Most of the problems that are affecting slow development in this field are caused by combination of rising energy consumption requirements and absence of new type of material that would limit the complexity of every construction.

When simple wall construction is being analyzed this problem starts to be clearly visible. Complex wall technology not only is causing problems regarding its thickness but also is affecting complicated joinery issues that are allowing multiple mistakes and shortcomings. Prefabricated system that is based on common building methods is struggling when different components or modules are put together to ensure tight connections and easy assembling methods. When such system is aiming towards flexibility, thus is consisting of bigger number of components this problem rises significantly. In order to counteract such situations and think of designing truly innovative prefabrication system, new type of material must be created that would combine loadbearing properties, low heat transfer coefficient, water tight properties and ideally environmentally friendly origin. Of course such material would revolutionized both traditional building industry and prefabrication. It would allow for almost unlimited creation of spaces where cold-bridge term would become nothing more than a problem of the past. However as long as such material does not exist, at least for now, prefabrication still remains challenging and not truly solved.

Summing up project that is developed in this report is very close to its full potential, however basic objectives of technology that is being used are the main reason for some limitations and difficulties. In order to move the project into next century, collaboration with different specialist is necessary to simplify and further optimized specific solutions. In general prefabrication is undoubtedly something worth investigating since it could make the design more democratic thus it would allow client to be a bigger part of the process. Development of designing and creating buildings is facing new era where full prefabrication will become an integrated part of the process, facilitating clients to participate in a simplified creation process.

“TO BUILD MEANS TO ADVANCE THIS PROCESS, TO INVESTIGATE, AND TO MAKE. THE DEVELOPMENT OF BUILDINGS BEGAN OVER TEN THOUSAND YEARS AGO AND HAS REACHED AN EXTREMELY HIGH LEVEL, BUT IS IN NO WAY A CLOSED PROCESS. THERE ARE STILL AN INFINITE NUMBER OF OPEN POSSIBILITIES, INFINITE DISCOVERIES TO MAKE.”

OTTO FREI

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