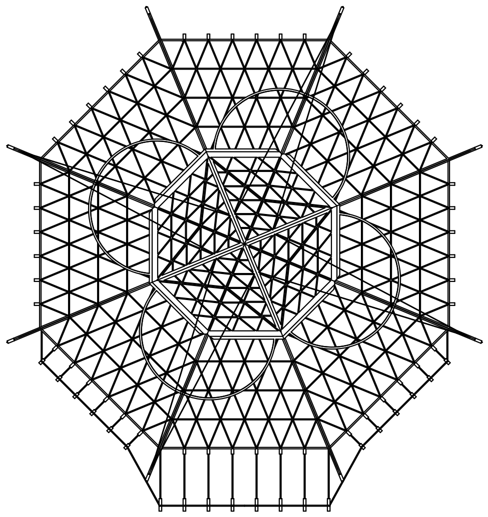

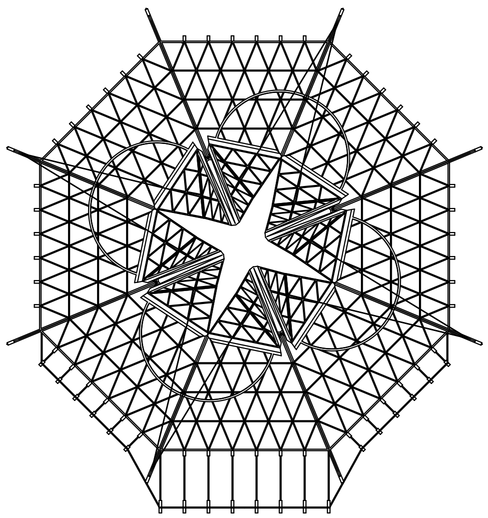

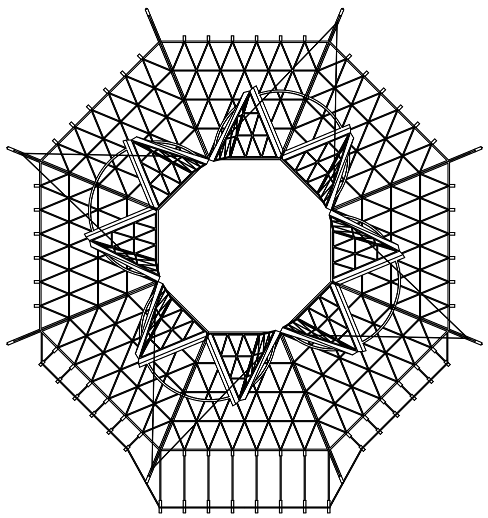

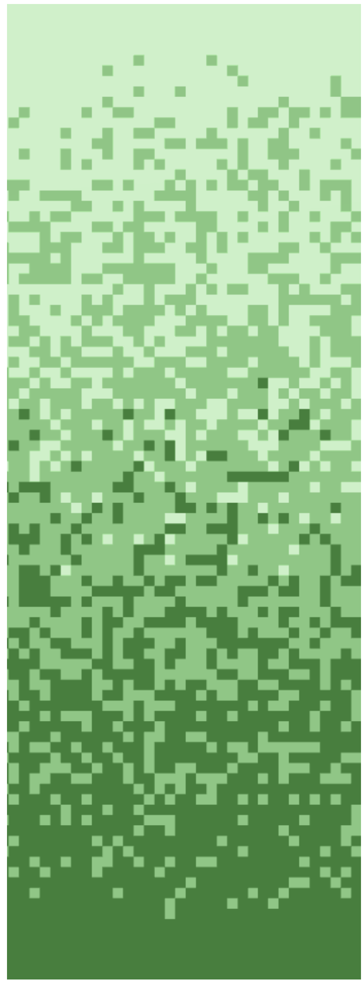

THE WOOD MOVEMENT STADIUM

An exploration of stadium design with wood structure and a retractable roof

ANTON PERSSON

Examiner · Jonas Lundberg
Supervisor · Erica Hörteborn
Architectural Experimentation
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ABOUT THE AUTHOR

Anton Persson has studied at Chalmers School of Architecture both for a bachelor's and master's degree in architecture. During the master's studies he has explored a wide range of subjects including healthcare, housing and public buildings. He is especially interested in public buildings and also find wood to be an interesting material. Moreover, with a personal interest in sports it is not surprising that he choose to explore the possibilities of building a football arena in wood with a retractable roof for his master's thesis.

ABSTRACT

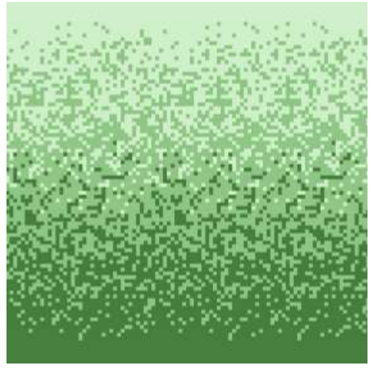
Wood is a building material that for a long time was non-existing in large buildings in Sweden. However, new technology, new fire regulations and a more sustainable mindset has led to an upwards trend in buildings with wood structure for a while. Furthermore, these buildings are getting taller and therefore more complex. This thesis explores the concept of wood in the complex structure in another way which is a multipurpose stadium with a retractable roof.

The final result is a conceptual stadium design proposal for Heden, a large open space in the middle of Gothenburg, Sweden. Although basic considerations have been made for structural dimensions and space for support functions, the resulting proposal is of a conceptual kind and focuses on the architectural expression of the stadium.

The main focus of the thesis is the author's process and method leading up to the design proposal. Nonetheless, reference projects, origami and traditional wood joinery that has inspired the design are presented in the background chapter.

Keywords: stadium, retractable roof, kinetic architecture, wood structures, architectural exploration

CONTENTS



1. INTRODUCTION

1.1. METHOD

There are similarities between design projects and research projects (Hauberg, 2011). Both starts with a question and ends with an answer. The difference is the use of drawings and models instead of papers with words.

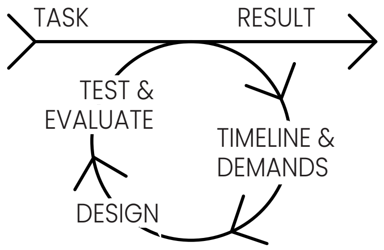


Figure 1. Iterative process diagram.

A design project can use an iterative approach (Sisodiya, 2022). The approach can be described as a circular process where the design object is refined in cycles as seen in Figure 1. It starts with an initial question before entering the circular part of the process. The first step is to determine the timeline and requirements. Secondly, the designing of the product is started. Thirdly, the product is tested and evaluated. Based on the evaluations a new cycle is started with a new timeline and requirements.

This research project has used a "research by design" approach with an iterative process. However, the iterative process was used in a loose format and could been classified as trial and error. During the process multiple ideas was been created and evaluated. Some ideas from the early stage has been reimplemented at a later stage.

This research project also uses literature studies and field studies. The field studies took place in Japan to primarily explore modern Japanese wood architecture but also traditional architecture and modern architecture in general. The litterature studies were made for background information about the main materials used in the project, sustainability in the building industry and the site.

Both digital and physical models has been used in this project. Digitally most of the work has been made in the 3D modelling software Rhino and the plug-in Grasshopper. By making and evaluating physical models a greater understanding was achieved. Moreover, the game engine Unity has been used for physics simulations to transfer the origami-based physical models to a digital format.

1.2. THESIS QUESTION

How can a retractable stadium roof be a design element?

How can traditional wood joinery be used in an architectural design with modern structural engineered wood products?

1.3. DELIMITATIONS

To have a clear focus and work in fields which the author has previous experience in the following delimitations has been made.

The thesis does not included calculations for the structural system. Literature studies have been carried out to create plausible dimensions.

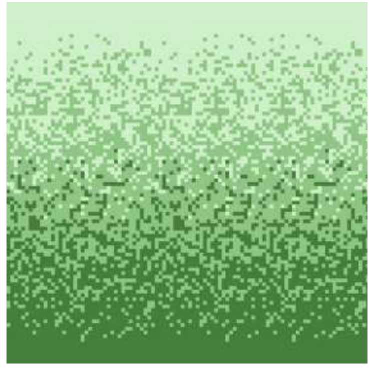
The thesis focuses on the structure and shell of the stadium. The layout and size of the functions of the arena is solely to understand what a reasonable size is for the arena as a whole.

The thesis focuses on wood architecture, traditional and modern, in Sweden and Japan although the author acknowledge that wood architecture heritage exists in other countries as well.

1.4. DEFINITIONS

This project uses parametric design in the sense that parameters are used to create the design. These variables are set by the author and therefore it is not parametric in the sense that external factors, such as sunlight, effects the design.

When describing functions in the floorplans of the proposal the definitions commerce area, hospitality and offices are used. Commerce area is area for sale of various goods such as food and merchandise. Hospitality is space for invited guests such as sponsors. Offices are to be used on match days and is for example used for the surveillance operations of the arena.



2. BACKGROUND

Sustainability in the Building Industry
Wood
Traditional Wood Architecture
ETFE
Kinectic Architecture
Origami
The site Heden
Arena Castling in Gothenburg

2.1. SUSTAINABILITY IN THE BUILDING INDUSTRY

According to Boverket, the Swedish National Board of Housing, Building and Planning, (2024) 22 percent of Sweden's domestic greenhouse gas emissions came from the building industry in 2021. In addition, an unknown amount of emissions are generated outside of Sweden from imported goods that is used in the building industry.

Construction emissions are a global issue and at the same time construction is needed to keep developing urban areas (El-Shorbagy, 2020). Developing is needed as the percentage of the earth's population living in urban settlements is expected to rise from 55 percent in 2018 to 60 percent in 2030.

Wood is known as sustainable material for multiple reasons writes Li et al. (2018). For example, its low energy consumption during its life cycle from production to disposal. It also acts as a carbon storage which has a positive impact on global warming. However, there are regions in the world that does not have an abundance of wood. For these regions, a sustainable import process is important to make wood a sustainable material.

In a survey study conducted by Viholainen et al. (2021) there was both positive and negative responses regarding the wood as a sustainable material. The positive mainly focused on the renewable aspect of wood and some recipients also mentioned that wood is a carbon storage. The Nordic countries Finland, Sweden and Norway stood out from the rest regarding the questions about sourcing the timber. In the Nordic group there was a focus on locally sourced timber which was seen as positive while in the second group there were concerns about the origin of the wood. Respondents mentioned the issue of forestry operations that does not operate in an environmentally friendly way.

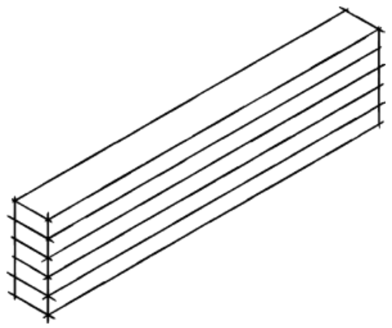


Figure 2. Glue-laminated timber (Glulam)

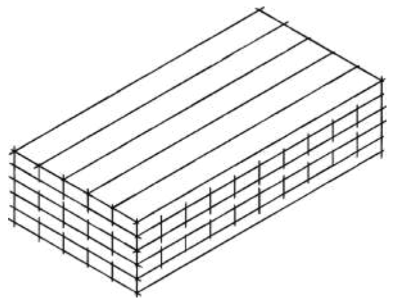


Figure 3. Cross-laminated timber (CLT)

2.2. WOOD

There are multiple reasons as to why wood has been used since primitive times (Zink-Sharp, 2003). For example, it is easy to shape, has good strength for it is mass, is renewable and is fire-resistant in large cross-sections. Most wooden buildings are single-family homes. However, larger buildings are also constructed with wood.

Wood can be divided into two main categories and manufactured in various ways (El-Shorbagy, 2020). The categories are hardwoods and softwoods. Hardwoods are used for buildings and be manufactured in many ways to create various wood products. Two of these are Cross-laminated timber (CLT) and Glue-laminated timber (Glulam) (Kallesoe Machinery A/S, 2024) seen in Figure 2 and 3. Both consist of timber lamellas that are glued together with adhesives. The main difference is that CLT has several layers in a crosswise configuration while Glulam has all lamellas in the same direction. CLT is commonly used for loadbearing walls and floor slabs while Glulam is used for beams and columns. According to El-Shorbagy (2020) the advantage of using engineered timber products is that smaller trees can be used and a larger percentage of the timber stock can be used.

While a majority of people are positive to wood construction, there are also people how are not positive according to a survey carried out by Viholainen et al. (2021). In the survey citizens from Austria, Denmark, Finland, Germany, Norway, Sweden and United Kingdom answered various questions about wood as a construction material. The questions where open-ended and the most mentioned topics by the participants was social aspects and physical aspects while economy was rarely mentioned. In the survey the fire hazard of wood buildings was brought up. Swedish and British respondents were most concerned of fire hazards. However, wood buildings are safer than steel buildings in case of fire according to Seike (1977) as heat does not transfer easily to the core of the wood. Steel on the other hand transfers heat quickly and softens. In Sweden the height of wooden houses was limited to two floors in 1874 after a series of large city fires (Svenskt Trä, n.d.). This restriction was lifted in the 1994 as the new rules was based on function instead of material. Nonetheless, the ban led to a public opinion of wood as an old and fire hazardous material writes Johansson (2013). Since 1994 the knowledge and public opinion has been moving in a positive direction.

Regarding wood from a social viewpoint there were both positive and negative comments (Viholainen et al. (2021). Wood was described as friendly, warm and beautiful. Heritage was mentioned mostly by citizens from Finland and Norway. The negative responses included for example that wood should not be seen everywhere and that its farm-like. There were also comments stating that maintenance is needed for wood to remain beautiful outdoors. A comment that aligned well with this thesis was:

"especially in Finland, the skilled and respectful use of wood material [of the past] should be brought back to construction, and at the same time we should heavily invest in studying new opportunities for wood utilization" (p. 655)

2.3. TRADITIONAL WOOD ARCHITECTURE

In both Sweden and Japan, a lot of old buildings has a wood structure (Seike, 1977; Stockholms läns museum, 2023). One reason for this is the large quantities of wood available in the countries compared to other building materials, for example

bricks. Seike (1977) writes that when working with wood, post and beams are more common than when working with stones or bricks. However, in Sweden log cabins with horizontally stacked wood, known as liggtimmer, was the most common construction method from the Middle Ages to the second half of the 19th century (Stockholms läns museum, 2023). A similar method exists in Japan called azekura (Seike, 1977). Nonetheless, post and beams have also been used in Sweden historically as well as vertically placed planks, known as plankvägg (Svenskt Trä, n.d.).

In general the wood works well in the humid environment of Japan and moreover it can withstand natural events such as earthquakes and typhoons (Seike, 1977). For example, wood buildings are lighter than concrete buildings and have joints that allow some movement which is an advantage during earthquakes.

During the ban of multi-level wood buildings in Sweden there was a loss of knowledge regarding wood among all parties involved in the Swedish building industry (Johansson, 2013). Building standards were based on other materials, for example concrete. Single-family houses was still being built in wood during the ban and 90% of single-family houses in Sweden are made out of wood (Svenskt Trä, n.d.). However, while wood was still used there was a change from focusing on the material's properties and traditional techniques to focusing on industrial production. Currently there is a rise in clients asking for a stronger connection to the heritage although there are also clients asking for a modern expression.

The reality of trees not being infinitely long means the size of a building is limited unless joinery is used. In Japan, joints are divided into two classes, tsugite (splicing joint) and shiguchi (connecting joint) (Seike, 1977). Tsugite are joints for end to end connections while shiguchi joints are used when the connection is made at an angle. Common for both is that the joints should add to the beauty and strength of the structure. The moisture level can be used to create tighter joints. This is done by drying the wood in the construction phase. Then as the wood reaches it natural moisture the wood swells and tightens the joint.

On the other hand, in Sweden farmers often built many smaller houses instead of one large house to avoid having to find and transport large timber logs (Timmerhus, 2021). It was also an advantage when moving as the houses could be disassembled and then reassembled at the new site.

2.4. ETFE

ETFE (Ethylene tetrafluoroethylene) is a fluorine-based plastic that is one of the most used polymers in architecture according to Lynch (2019). The materials received a lot of exposure when it was used in swimming arena for the 2008 Beijing Olympics by PTW architects (Figure 4). Lamnatou et al. (2018) describes the characteristics of ETFE and compare them with the characteristics of glass as both materials can be used as a transparent façade material. EFTE can be treated in various ways to change its transparency. ETFE has a lower weight and is more resilient. The surface has little friction which means debris and dirt does not stick to the surface. Both EFTE and glass is recyclable, however according to Lamnatou et al. EFTE can be recycled at a lower cost.

Figure 4. The ETFE clad facade of Water Cube in Bejing, China (Alerigi, 2008).

The production process involves melting the materials and then extrude them into large sheets (Lamnatou et al., 2018). A temperature of 170°C is needed and there are gaseous byproducts, such as CO_2, SO_x and NO_x. When compared to the environmental impact of glass the environmental impact of EFTE is considered lower. The exemption was the impact on the ozone layer. It is not only because of the production process that EFTE is more environmentally friendly than glass. It is also a lighter material and therefore the support structure can have smaller dimensions which lowers the overall material usage.

2.5. KINECTIC ARCHITECTURE

Movement in architecture often have three states, closed, open and in-between (Schumacher et al., 2010). There is also movement that is continuous, for example sun shading modules following the path of the sun. The movement is usually present in specific parts of the building. However, there are examples of whole buildings moving.

Movement can be done with an essentially linear velocity or acceleration and deceleration writes Schumacher et al. (2010). Using a varying velocity is more natural, for example is this the pattern when a human opens a door. Speed can affect the expression of the movement. Very slow movement is not noticeable to the human eye and very fast movement is difficult to see sharp. Moreover, speed can amplify an already existing expression, for example a slow-moving massive door gives the expression of gravity and safety.

Movement is a possibility to create a feeling of surprise and fascination (Schumacher et al., 2010). For example retractable car roofs. The car should be aesthetically pleasing in both the open and closed state. When using movement in architecture it creates an opportunity to shape the building's identity and for the movement to be more than a functional element of the building.

Kinetic architecture mainly consists of rigid bodies that are connected with joints to allow for movement (Schumacher et al., 2010). The movement can be divided into rotation and translation with three axis each. Each axis is a degree of freedom. For example, both a sliding door and swing door have one degree of freedom each however, the sliding door has a translation movement while the swing door has a rotation movement. A car wheel that can turn has two degrees of freedom and if you examine an aircraft as a whole it has six degrees of freedom.

Figure 5. The retractable roof of Mercedes-Benz Stadium in Atlanta, USA (Byrom, 2023).

Retractable roofs is one type of kinetic architecture writes Schumacher et al., (2010). The most common solution is to retract the roof in a translational movement with one degree of freedom however there are stadiums that use more complex movement. One example is Mercedes-Benz Stadium in Atlanta, USA designed by HOK seen in Figure 5. This American football arena has a retractable roof consisting of 8 modules and although each module only has one degree of freedom the entire system has translational movement in 8 directions since each module move in a specific line.

2.6. ORIGAMI

The word origami is Japanese and a direct translation to English would be fold paper (Robinson, 2023). There is some uncertainty regarding the origin of origami and one theory is the art form developed across the globe in multiple places independently. It is difficult to know how long humans have folded materials as an art form.

Figure 6. Origami.

Nonetheless, the art of origami has spread across the world (Robinson, 2023). One of the first to take origami outside of Japan was a German educator named Friedrich Froebel and the word origami became more common around year 1880. The design school Bauhaus used origami in its education.

Nowadays, origami is a common area of study in engineering with both two-dimensional and three-dimensional applications (Suh et al., 2021). A two-dimensional application in space engineering is using origami patterns for improved packing efficiency. A three-dimensional application example is cylindrical structures that can be stored in a flat configuration and then deployed into a three-dimensional structure.

2.7. THE SITE HEDEN

Heden, officially known as Exercisheden, is a large open area in central Gothenburg, Sweden (Svensson, 2019). Heden is also the name of the district in which the open area is located. The open area is approximately 40 000 square meters and bounded by Södra vägen, Parkgatan, Sten Sturegatan och Engelbrektsgatan. There is a walk and bike path going east to west which splits the site into two parts.

There are buildings on Heden (Svensson, 2019). Towards the north-west corner is Exercishuset that was built in 1867 and is today used for a various sports, for example table tennis. There is a hotel in the east corner. There are also two temporary structures near two of the sides of the hotel. The first is a kindergarten and the second a building mainly for parking however, it also has a café and seating that can be used as bleachers for the football pitches. Houses from an exhibition farm from the Jubilee exhibition of 1923 is still standing in the northern corner. Nowadays one is used by a restaurant and the others are used as dressing rooms for the sport activities on Heden.

Svensson (2019) writes that sport, in particular football, is the main use of Heden today. There are three 11vs11 pitches and two 7vs7 pitches. There are also courts for basketball and beach volleyball. There is a bus terminal in the north-west corner and there are parking lots at various locations on Heden.

Since 2009 the development of Heden has been discussed (Göteborgs Stad, n.d.). However, it was in 2017 that a more detailed investigation was made for a future zoning plan. The work with this plan is at the time of writing paused.

In 2021 the property company Wallenstam together with the architect office Wingårdhs presented a proposal for developing Heden writes Kennedy and Oscarsson (2021). The proposal aims to create a space for interactions and sports. In the corners 40-story apartment buildings are placed. These apartments will cover the cost for the development of the public areas according to the proposal. Hampus Magnusson who was president of the municipality's building committee at the time said that there are many opinions regarding Heden however most of them contain a wish to develop Heden. He also said to the journalists that it is important to make sure Heden continues to be a space for sports and has the capacity to host Gothia Cup and Partille Cup, two large youth tournaments in football respectively handball.

2.8. ARENA CASTLING IN GOTHENBURG

The municipality has identified a need to renew and improve the so called "evenemangsområdet" (the event area) which includes multiple arenas (Figure 7, 8) (Göteborgs Stad, n.d.-b). Although no final decision has been made, demolition of both Valhallabadet and Scandinavium are part of the primary strategy at the time of writing. The idea is to build the replacement for Valhallabadet at the location of Valhalla IP to allow construction of Scandinavium's replacement at Valhallabadet's current location.

The municipality's plan for replacing Valhalla IP is not liked by the main users of the pitch, according to an article by Trollér (2023). The proposal is to replace Valhalla IP with an arena in the city district Kviberg. One of the spokespersons interviewed in the article mention that many female football teams use the pitch and a move outside the city centre could be negative for women's football in Gothenburg. Although the teams effected would prefer to stay at Valhalla IP a move to Heden is the second-best alternative. When asked to describe an arena at Heden they described a small arena, similar in size with Valhalla IP, with a feeling of closeness and artificial grass to handle the high usage. In the interview it is stated that a possible obstacle of an arena on Heden are the strong lights that are needed for professional football matches which could disturb the residents in the apartments close to Heden.

1. Ullevi
Arena for track and field as well as football with capacity for 40 000 spectators during sport events and 75 000 during concerts.

2. Gamla Ullevi
Football arena with capacity for 17 000 spectators.

3. Valhalla IP
Football arena with capacity for 4 000 spectators.

4. Valhallabadet
Aquatic centre with 500 000 visitors each year.

5. Scandinavium
Ice hockey arena with capacity for 12 000 during sport events and 14 000 during concerts.

Figure 7. All numbers are approximate. Source Got Event (n.d.)

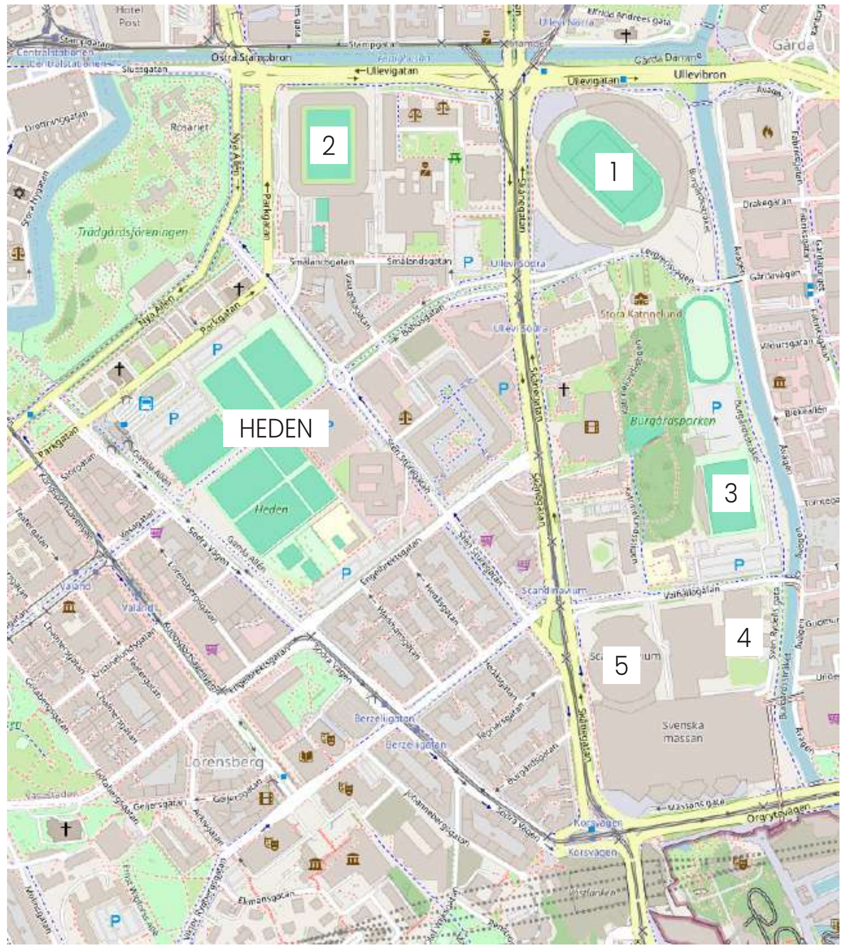
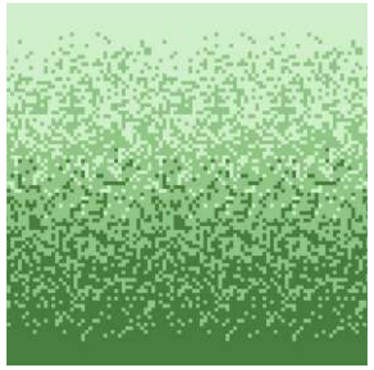


Figure 8. Overview of Heden and evenemangsområdet. (OpenStreetMap Contributors, n.d.)



3. EXPLORATIONS

Retractable Roofs
Japan Journey

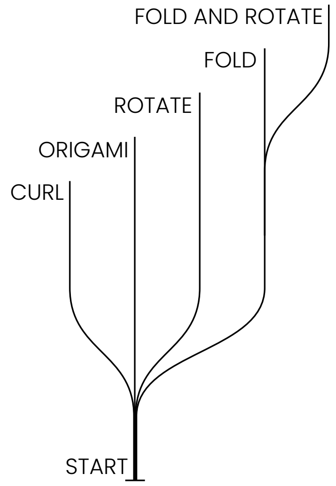


Figure 9. Roof exploration map.

3.1 RETRACTABLE ROOFS

The design process started with the retractable roof. The aim with this approach was to increase the chance that the retractable roof is a well integrated part of the design. Various themes were explored which can be seen in Figure 9. Each theme has one or more explorations. Rhino in combination with Grasshopper was used to create variations on the designs and physical models was used to test most explorations.

There were some general observations from the exploration as a whole. Firstly, sometimes the movement displayed as something it is not, for example a folding motion looked like a rotation. Secondly, a concept could be related to origami both because it was based on a folding pattern but also due to the intriguing way it moved. And lastly, the optimal number of parts varied. For example for the designs in the rotation theme 6 modules was optimal.

CURL

This roof consists of multiple modules along the longer sides and when open creates a rectangular opening. Each module consists of seven rectangles that curl into an octagon shape (Figure 11). It could have been one module on each side or even only one module on one side. The decision to separate into smaller parts was to divide the forces to multiple parts. It also creates the possibility to open up different parts of the roof.

Figure 10. The Rolling Bridge (Pycock, 2013).

This concept was inspired by the Rolling Bridge in London, United Kingdom (Reina, 2004) (Figure 10). The designer Thomas Heatherwick describes his vision for the bridge movement as sensuous and a transformation in entireness. The bridge consists of eight steel modules. Pistons and hinges control the movement. The pistons are powered by hydraulic machinery underground.

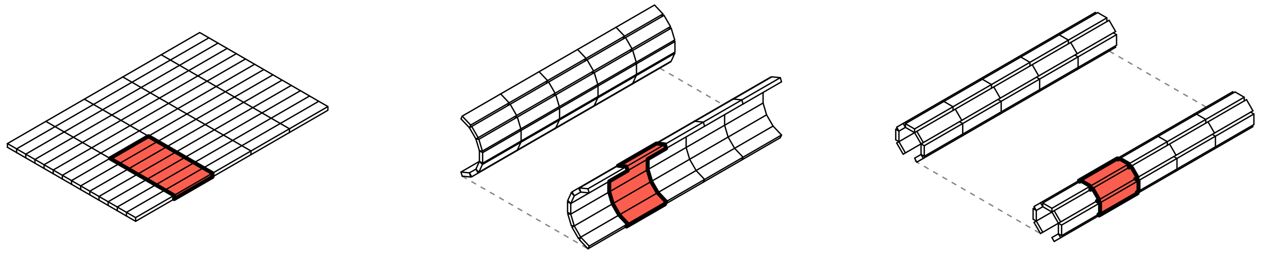


Figure 11. Curl concept in different stages of transformation.

FOLD

These roofs were designed through exploration of folding paper. The modules have two hinges and can create an oval or circular opening. The angle of one of the hinges and the number of modules can be changed. The roofs shown in the diagrams to the left have 10 modules. This creates a rather round shape in the open state and the modules have a resonable size. In the circular shape in Figure 12 the modules land on top of each other in the open state. With the oval shape in Figure 13 the open state is not uniform compared to the circular shape. It is possible that customising the angle of hinge in the middle of the module for each module could fix this. According to me it when all modules move together it looks like a rotational movement however there are only to folding movements happening.

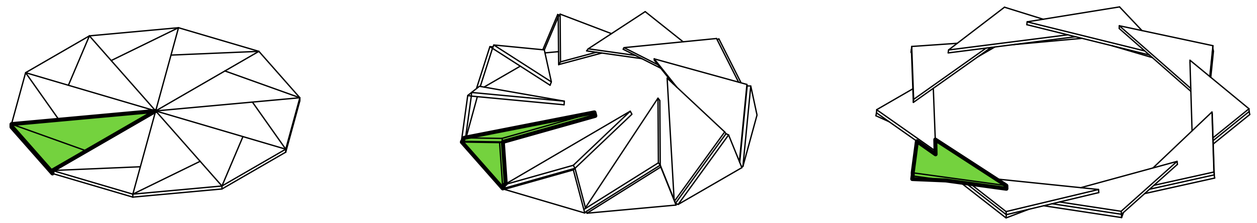


Figure 12. Circular fold concept in different stages of transformation.

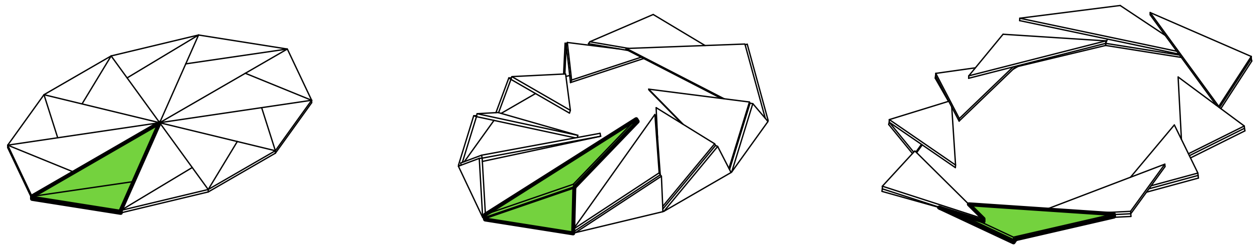


Figure 13. Oval fold concept in different stages of transformation.

ROTATE

These concepts use rotation to retract the roof. The first discovery was that six modules was the optimal number of modules as it resulted in equilateral triangles (Figure 17). More triangles than six would not allow the roof to fully open and less triangle than six would leave gaps in between (Figure 15, 16).

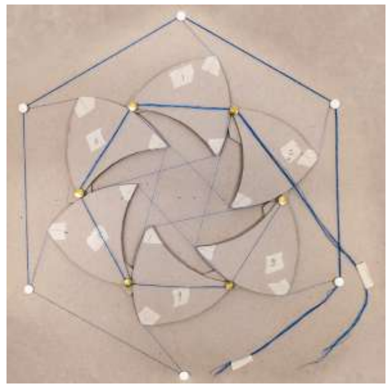


Figure 14. Flower model in middle of transition

The second discovery was that to get a round opening instead of a hexagon opening, the sides of the modules had to be curved (Figure 14, 18). This led to a shape similar to flower petals when the roof is in the open state. It sparks a question whether the likeness to a flower is favourable for a football stadium. As flowers tend to be seen as brittle and calm while football is a sport filled with energy and competition. Nonetheless, the work continued with explorations of how this concept could become a sloped roof. This resulted in two more concepts. One where the modules can be opened and turned into a stand (Figure 19). The other a more standard roof with outside parts to help with the construction (Figure 20).

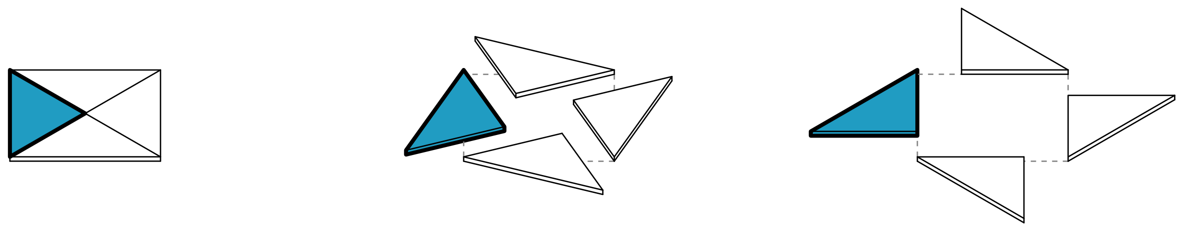


Figure 15. Rotation concept with 4 modules in different stages of transformation.

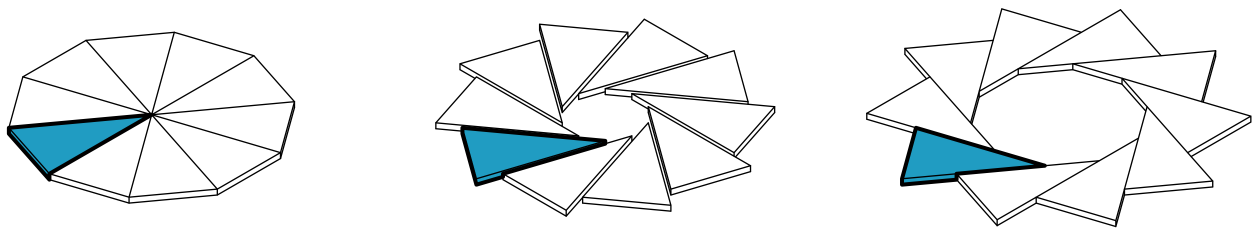


Figure 16. Rotation concept with 10 modules in different stages of transformation.

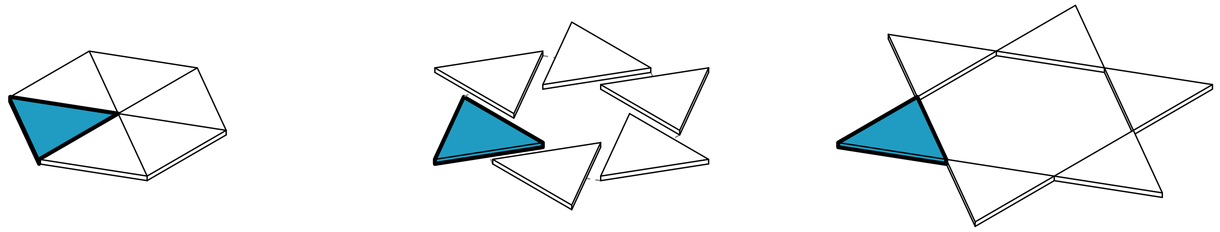


Figure 17. Rotation concept with 6 modules in different stages of transformation.

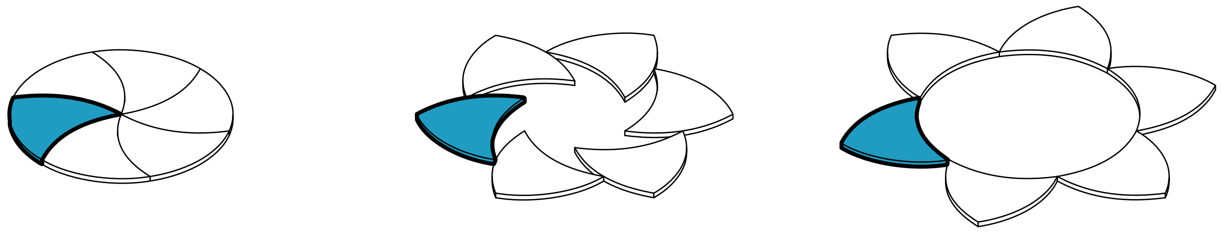


Figure 18. Flower rotation concept in different stages of transformation.

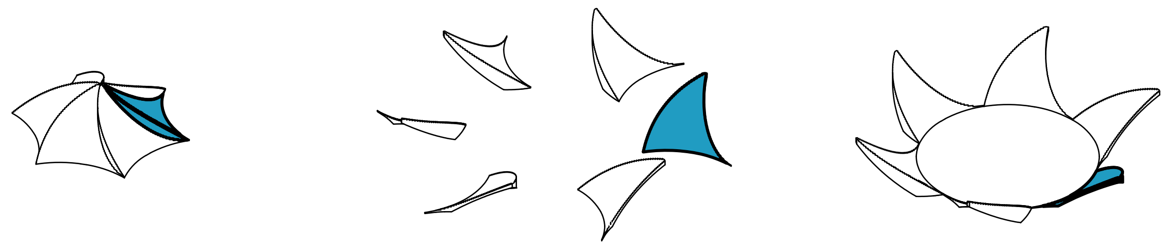


Figure 19. Stairs rotation concept in different stages of transformation.

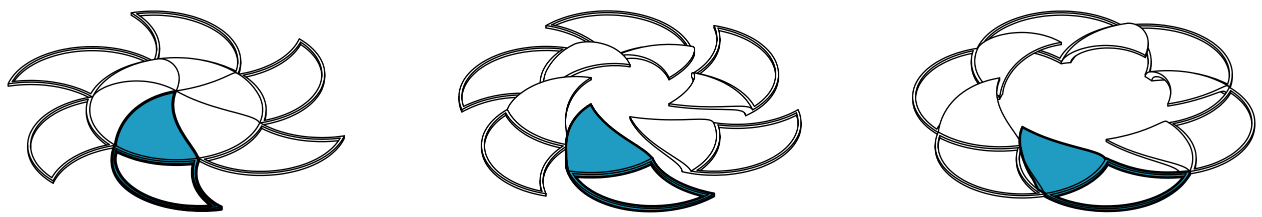


Figure 20. Sun Flower rotation concept in different stages of transformation.

ROTATE AND FOLD

The rotate and fold collection is inspired by the Evolution Door by Klemens Torggler. It is also known as "folding door" and "origami door". The connection to origami could be due to its lightness and delicacy (Geleff, 2022). Two pivot points connects the door to the wall. The door has four rectangles connected in two pairs with a hinge. The pairs are connected with a ball joint. This allows the door to move sideways in a simple yet mysterious and intriguing way.

The first roof concept I developed in this roof family was a recreation of the Evolution Door as a roof (Figure 22). It creates a rectangular opening and has 4 modules, two on each side. The second concept was an evolution of the previous concept in an octagon (Figure 21, 23). The roof in Figure 24 uses rails to fold. Creating vertical standing triangles which is an eye-catching design element however it could cause issues during heavy winds. Futhermore, considring rain and snow a non-planar design would be beneficial. The exploration in Figure 25 tested the possibility for modules to overlap in the open position.

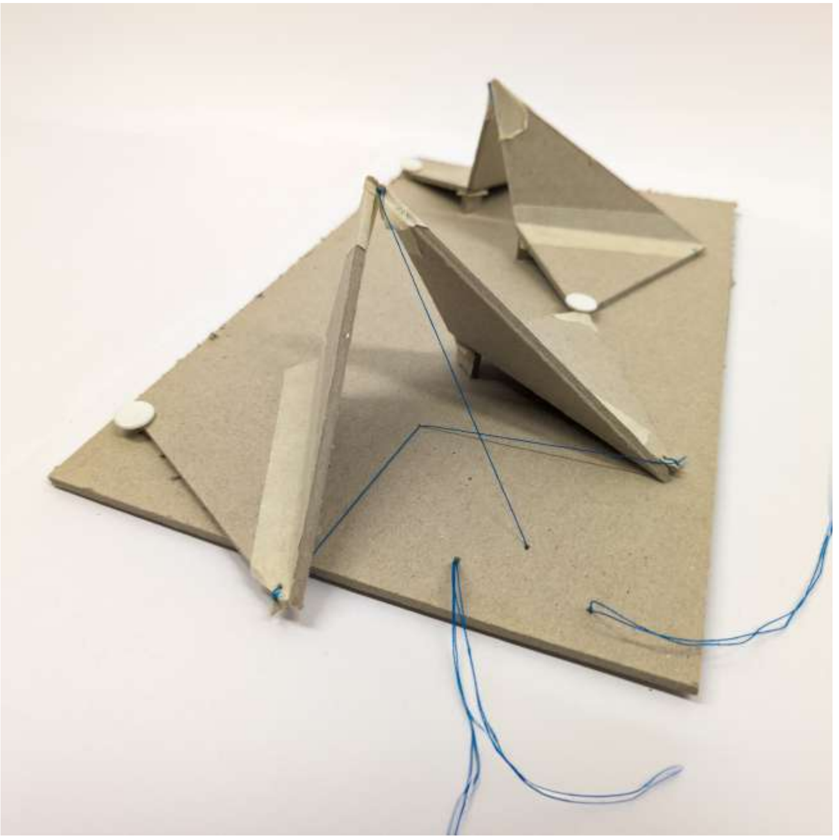


Figure 21. Star Roof model in middle of transition.

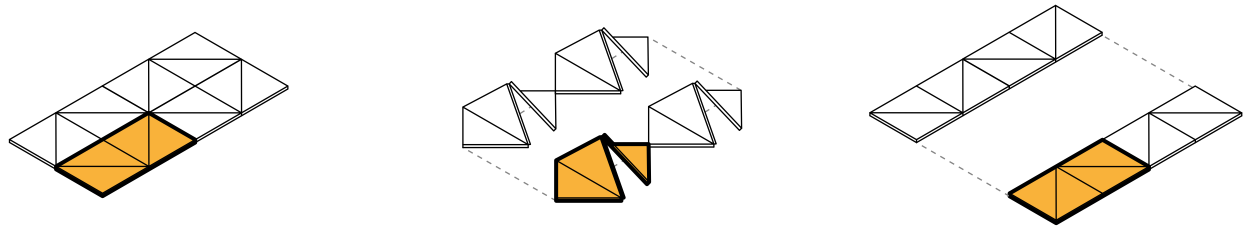


Figure 22. Evolution Door inspired rotation and fold concept in different stages of transformation.

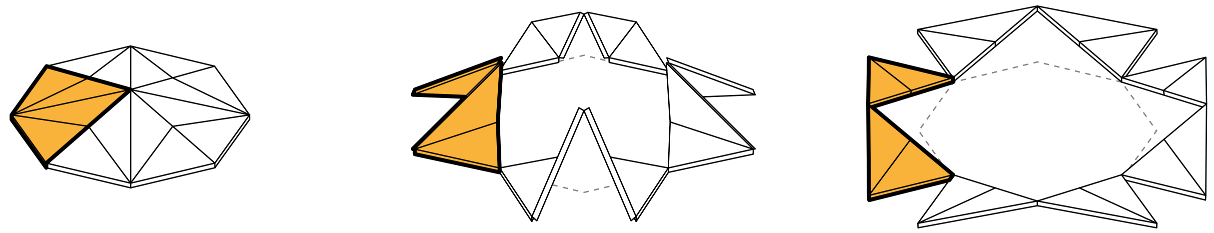


Figure 23. Star rotation and fold concept in different stages of transformation.

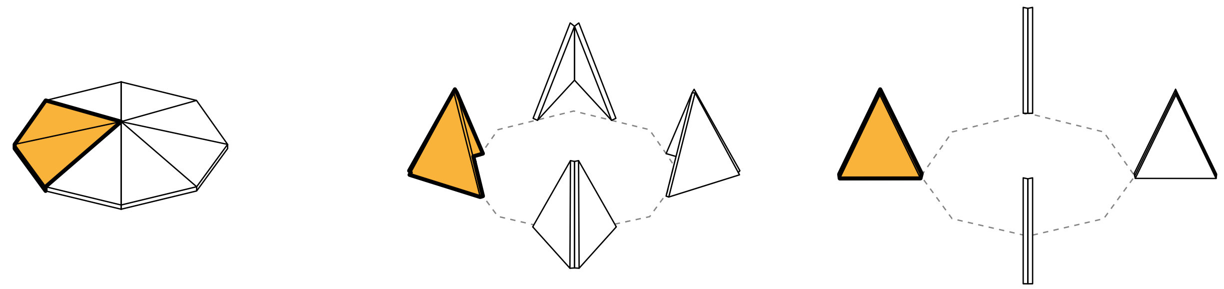


Figure 24. Crown rotation and fold concept in different stages of transformation.

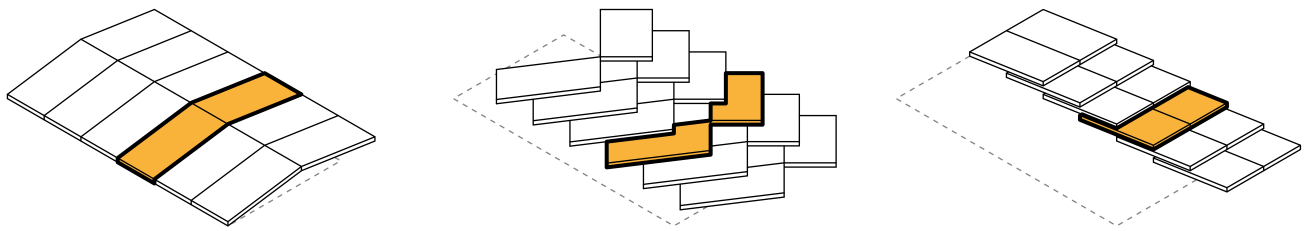


Figure 25. Overlap rotation and fold concept in different stages of transformation.

ORIGAMI

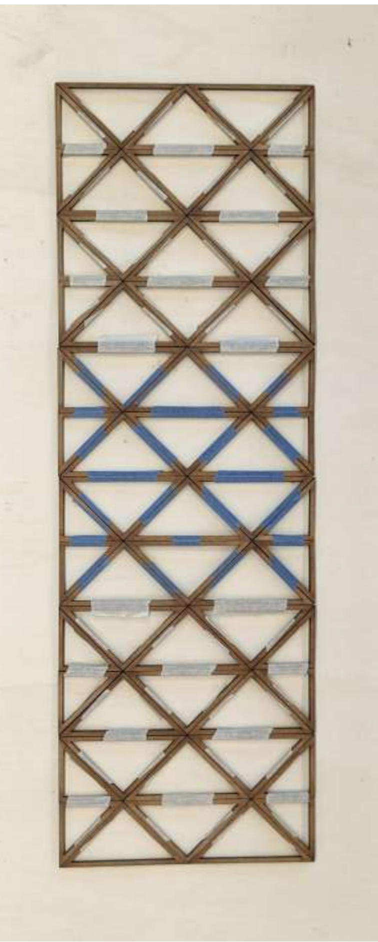


Figure 26. Yoshimura pattern model deployed.

As mentioned earlier origami is nowadays a common area of study in engineering writes Suh et al. (2021). Some of the folds, also known as patterns, that are commonly used are explored in this research. One of them is the Yoshimura pattern. This pattern is named after the scientist Yoshimaru Yoshimura who observed it for the first time when a cylinder was compressed. Suh et al. (2021) describes the pattern as consisting of "triangles sharing a single edge, which form repeated diamond shapes".

The other pattern explored is called the Miura pattern. This pattern is named after astrophysicist Koryo Miura who explored the use of origami to packing and deploy membranes in space. This pattern is described by Suh et al. (2021) as "composed of congruent parallelograms".

When using a thicker material than paper the Miura pattern cannot reach a complete fold (Figure 28). The Yoshimura pattern works well with thicker material (Figure 26, 27). The intriguing way these modules move makes it difficult to transfer it to a digital modelling software.

There is also a third roof concept in this collection that is inspired by origami to create the shape of the module however, it uses rotation to open and close (Figure 31).

Figure 27. Yoshimura pattern model stored.

Figure 28. Miura pattern model deployed and stored.

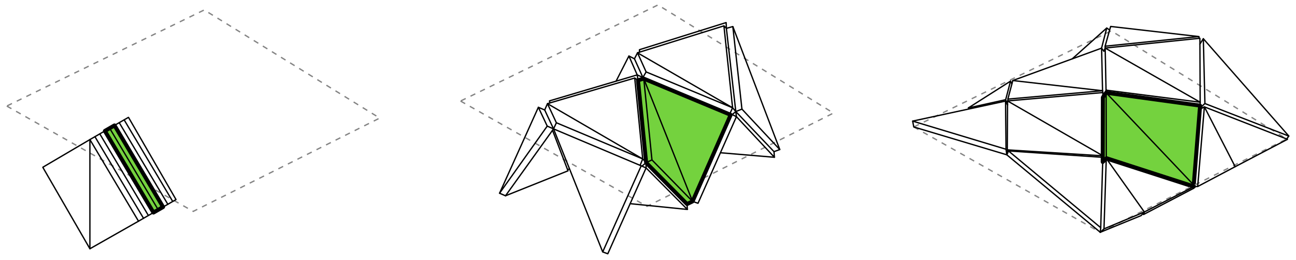


Figure 29. Yoshimura Pattern origami concept in different stages of transformation.

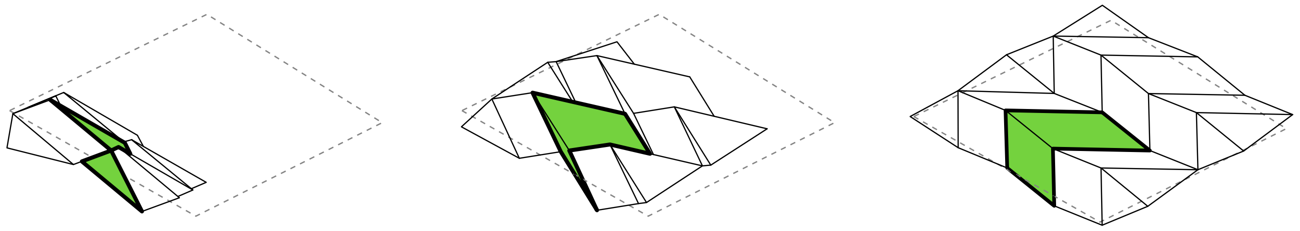


Figure 30. Miura Pattern origami concept in different stages of transformation.

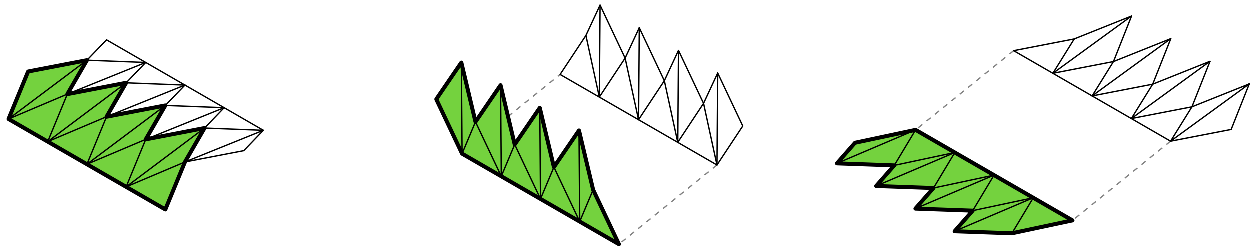


Figure 31. Roof modules inspired by origami concept in different stages of transformation.

3.2 JAPAN JOURNEY

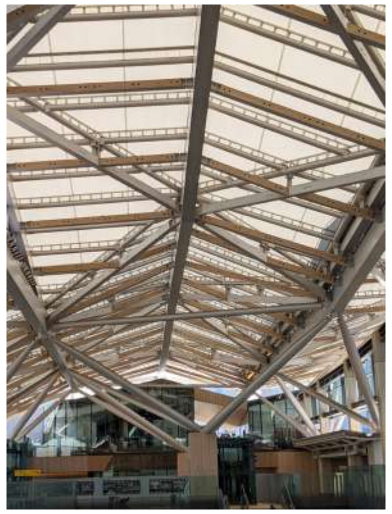


Figure 32. Takanawa Gateway Station.

To travel to learn about architecture is part of the history of architects and is to this day seen as an essential part to progress as an architect (Ewing, 2011). In a university context there is often a distinct aim with the journey, for example a clear link to an upcoming design project. Furthermore, when students learn about architecture it is important for them to experience spaces with their own movement and senses (Batič, 2011). By using their own movements, the student can get a better understanding of a building compared to viewing a building from a video or image in a classroom. Knowledge from field studies also tend to be more retained than classroom learning.

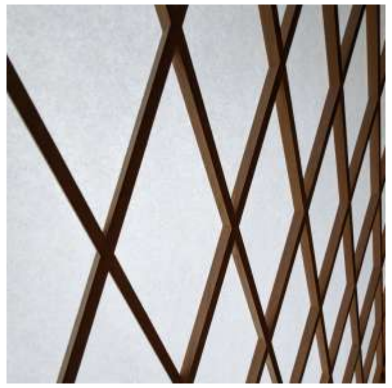


Figure 33. Shoji window covering.

After the retractable roof exploration, the design process continued with a journey to Japan to explore Japanese architecture. The journey had a focus on modern architecture and in particular wood. However, also museums and traditional buildings were visited. The most important part of the trip for the project was how traditional techniques and materials can be used in modern buildings, both directly and as inspiration. For example, the roof structure of Takanawa Gateway Station by KKAA. Beams made of a combination of steel and wood support a membrane that is translucent and thanks to its beige colour gives a warmer tone to the incoming cool daylight. It also makes the inside of the station brighter and little artificial lighting, if any, is needed during daytime. During nighttime the roles are reversed, and the building is giving a soft glow to the surrounding area. This roof was inspired by shoji screens. Shoji screens are traditional sliding doors or room dividers made out of wood frames and translucent paper (MasterClass, 2021). The screens date back to around the 13th century and was a result of a need for more economical materials and methods. The shoji screen was an affordable solution that also gave an elegant expression. The frames are known as kōshi and usually made out of bamboo or softwood. The paper is usually made of washi which is a translucent and wind-resistant paper.

Figure 34. Yusuhara Community Library.

Another topic that was relevant for the thesis was traditional wood joinery. This is something that for example Kengo Kuma is known for using. One of his projects that uses this is the Yusuhara Community Library. In this building complex wood joints are used to create chaotic yet symmetrical decorative expression. According to me, the joints used in this project was a bit too complicated however it is still interesting to use traditional techniques in modern buildings.

A museum I visited was Takenaka Carpentry Tools Museum. On display was various traditional tools and also what type of finish the different tools gave the wood. There was also a collection of wood joints that visitors could disassemble and assemble to gain a better understanding of how they worked.

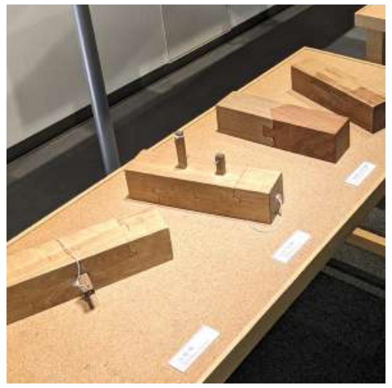


Figure 35. Joint Models at Takenaka Carpentry Tools Museum.

My general observation was that traditional wood technique seems to be a common way to decorate modern buildings in Japan, at least compared to Sweden where traditional techniques are rarely used. However, it seems as if Sweden has gotten further when it comes to modern engineered wood products such as cross-laminated timber. The trip inspired me to explored the possibilties to combine the modern wood products from Sweden with the traditional joinery from Japan.

4. DESIGN

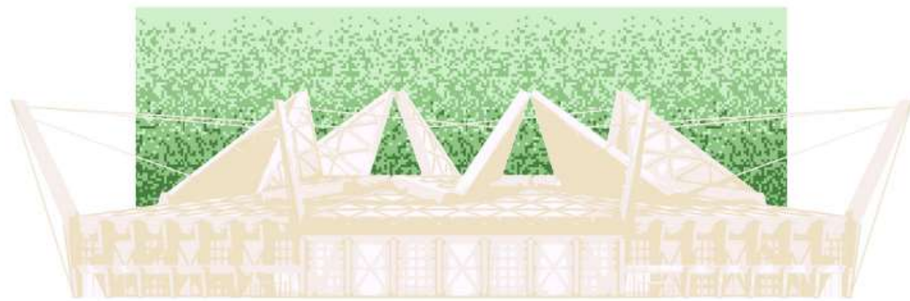


Figure 36. Building silhouette

LOCATION

The arena is made as small as possible while still having a capacity of approximately 6 500 spectators. By making the arena this small it fits in the northern corner of Heden without the need to demolish any existing buildings (Figure 37).
The stadium will take the place of an existing football pitch. However, that pitch could possibly be moved to the event area next to the bus terminal. This way the number of football pitches is unchanged and since this arena can also be used for events one can argue that the arena does not reduce event space area either. The chase to minimize the size of the arena led to an acceptable but not ideal situation near the corners of the football pitch which could have been revised if more time was available. In the current proposal the pre-exisiting buildings in the northern corner are kept. However, removing them would increase the space available.

Another location that was explored was the current event area. That proposal planned to use another retractable roof concept inspired by the Yoshimura pattern however it failed to work as planned as the roof concept has difficultues retracting in a rather horizontal movement. Moreover, the shape of this arena was mostly a rounded roof which was not as interesting as the shape of the final proposal. It is also questionable if there would have been space for support functions such as commerce areas and hospitality.

The final shape of the arena is an octagonal shape with an adjacent shape for the entrance hall and walkways to the seating. The shape departs from the retractable roof concept. The concept was originally made for an octagonal opening and octagonal shape fit on the site and the functions inside fit in the octagonal shape.

Figure 37. Site Plan
Scale 1:2000

Figure 38. Aerial view during daytime with closed roof.

Figure 39. Aerial view during daytime with open roof.

Figure 40. Aerial view during nighttime with open roof.

Figure 41. Aerial view during nighttime with closed roof.

ENTRANCE

The main shape of the arena is the large octagon. However, there is also a volume added to the south-west side of the building. This volume was needed to create space for an entrance area, commerce area and a walkway to the bleachers. The structure of this volume is based on the columns of the main shape. The entrance volume has two levels to create more space to avoid overcrowding before the game, in breaks and after the game.

The entrance is placed on one of the shorter sides of the football pitch. This is means that both sides with seating are equally important. Spectators from both sides of the pitch has to go to the short side during breaks for refreshments.

ETFE

In-between the wood elements are ETFE-sheets. This material is customisable in both transparency and colour. In the final proposal the ETFE used has a light beige translucent finish inspired by the shoji elements from Japan which for example was used in the hotel room of KUMU Kanazawa. The aim with this finish is to allow sunlight to enter the arena during the day and to let the arena give a soft glow to its surroundings during the night. This relationship with the surroundings has been realised before with the Takanawa Gateway Station mentioned in section 3.2.

An alternative solution would have been to use translucent ETFE-sheets and LED-lighting to create a colourful façade. This solution was used in the swimming arena Water Cube in Bejing mentioned in section 2.4. The reason this was not used in the final proposal was that it is a solution that would need detailed investigation and such investigation would be out of the scope of this thesis.

On the sides the walls have two different patterns, one is rectangular and one is based on the same triangular pattern as the roof. Both patterns are for aesthetic reasons and the triangular pattern also has a structural function as cross-brace.

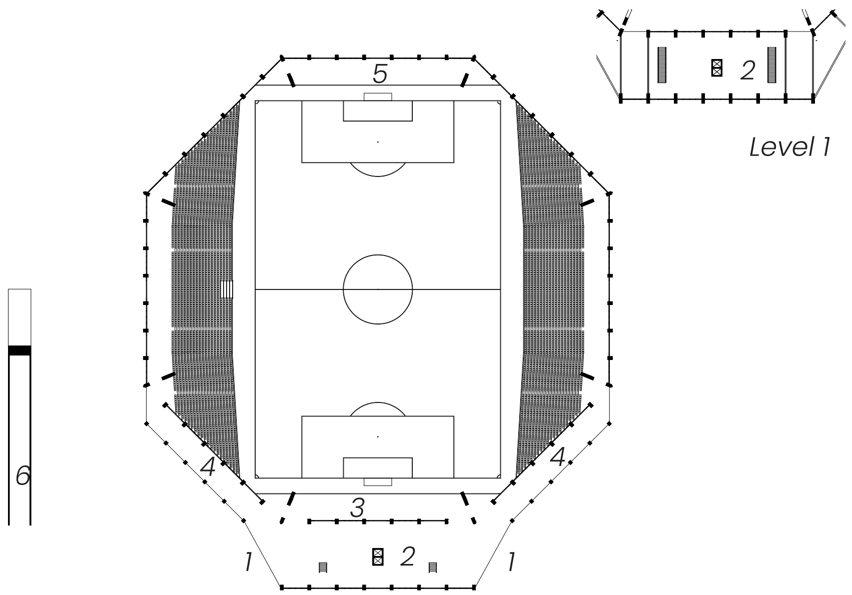
Figure 42. Entrance during daytime with open roof.

Figure 43. Entrance during daytime with closed roof.

Figure 44. Entrance during daytime with open roof.

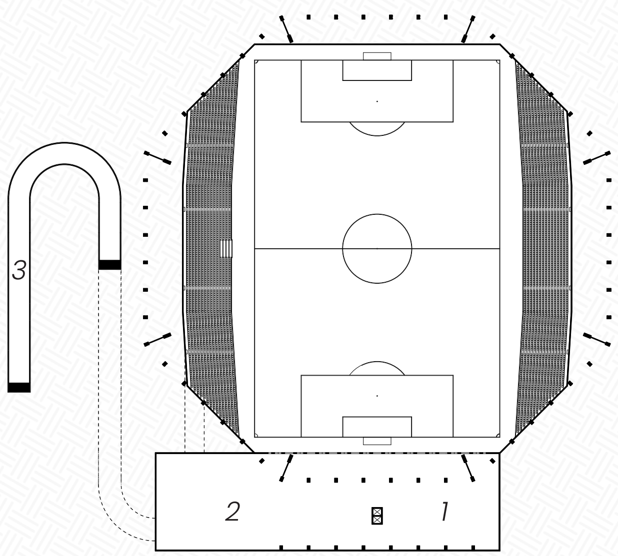
Figure 45. Entrance during nighttime with closed roof.

Figure 46. Entrance during nighttime with open roof.



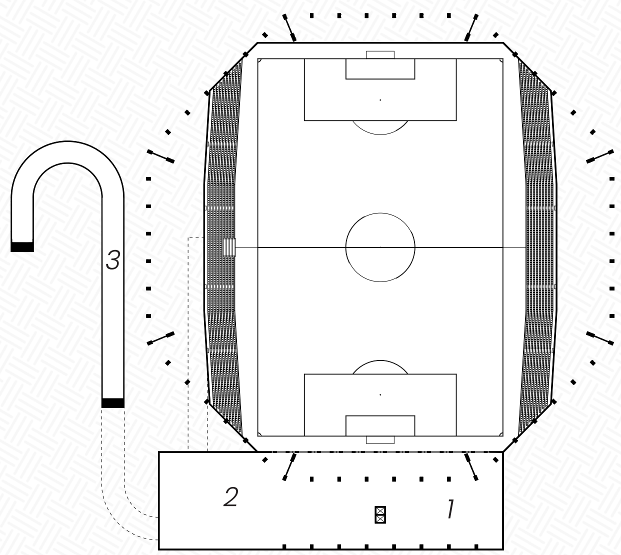
1. Entrance
2. Commerce Area
3. Bar Seating
4. Walkway
5. Broadcast Tech
6. Vehicle Access Tunnel

Figure 47. Ground level and level 1 in scale 1:2000



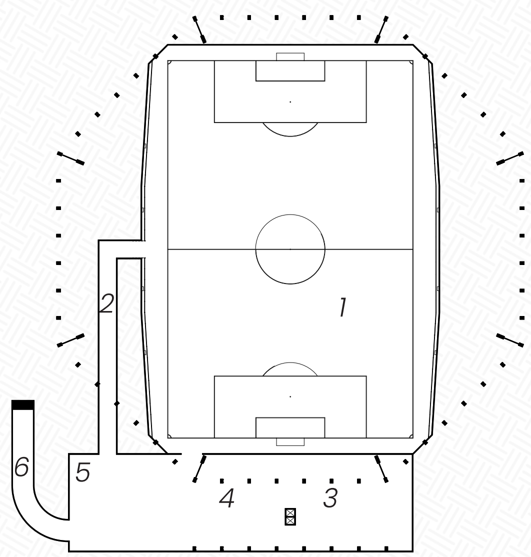
1. Hospitality Area
2. Broadcast and Media Hub
3. Vehicle Access Tunnel

Figure 48. Ground level and level -1 in scale 1:2000



1. Offices
2. Technical
3. Vehicle Access Tunnel

Figure 50. Ground level and level -2 in scale 1:2000



1. Artificial Football Pitch
2. Players Tunnel
3. Storage
4. Locker Room
5. Interview Area
6. Vehicle Access Tunnel

Figure 49. Ground level and level -3 in scale 1:2000

PITCH AND SEATING

The pitch is placed below ground level. This is mainly to reduce the height of the building which is positive both for the structure and the expression of the building. It also means that the spectators enter the stands from the top and get closer to the action as they get to their seats creating a feeling of closeness. A similar solution is found in the arena Osaka-Jo. However, instead of lowering the pitch the entrance is raised which leads to the spectators entering the stands in the middle of the stands and therefore half of the spectators walk towards the action as they find their seat.

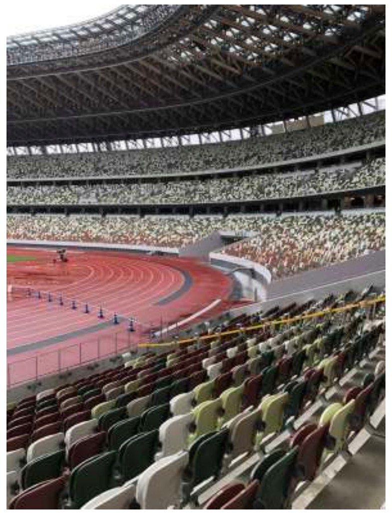


Figure 51. Seats in Japan National Stadium.

The approximately 6 500 seats in the arena are coloured in three different shades of a green colour. Inspiration has been taken from Japan National Stadium by KKAA which uses natural colours ranging from brown near the ground to white near the sky (Figure 51). This creates a more lively environment even when the seats are empty which was beneficial during the 2020 Olympics in Tokyo that did not have any spectators due to a global pandemic. In the case of the arena on Heden the aim is that the seating colouring concept will help create a nice atmosphere even when the seats are not fully occupied.

A disadvantage of lowering the pitch below ground level is that road access to the pitch becomes a bit complicated. In this case it has been solved with a tunnel dimensioned to fit a double decker bus. This access is useful for both football matches and other events such as concerts. An advantage of lowering the pitch is that a lot of supporting functions can be place below ground reducing the footprint of the building. Many rooms needed for a football arena does not necessarily require daylight. For example, changing rooms, doping control room and interview area.

The turf is artificial to handle the high usage which was something the spokespersons mentioned in the interview mentioned in section 2.8. It is also preferrable if the arena is used for other types of events such as conventions, concerts or other sports.

Figure 52. View from pitch.

STRUCTURE

Figure 53. Connection SunnyHills café.

Figure 54. Connection pylon and ground.

The structure is mainly made out of pillars and beams meaning glulam is probably the preferred wood product to use. However, there are also wooden floor slabs for two of the levels below ground level for which CLT is better suited. The roof space frame is supported by eight pylons. The pylons which can be seen in Figure 57 and 58 consist of both glulam and steel cables. The steel cables are used for the static roof and the moving roof. Moreover, there are glulam columns along the perimeter of the building.

One aim of the design was a readable structural system. To achieve this the building is to have a clear structural hierarchy and distinction between different elements. This can for example be seen in the meeting between roof and façade. The roof is supported by pillars and in-between the pillars are recessed walls. The recess creating distinction between the different elements and supports the expression that the pillar is the loadbearing element.

To avoid damage to the wood from moisture from the ground there is a steel connection to the ground (Figure 54). The connection consists of a steel base, a steel plate in the middle of the wood element as well as multiple bolts and nuts. It is inspired by the connections used in for the café SunnyHills by Kengo Kuma and Associates (Figure 53). Furthermore, there are steel wires used to connect the pylons with the roof and ground.

For the levels below ground concrete is used. Mainly due to the contact soil however also for aesthetic reasons. By using concrete below ground level a contrast is created with the wood above ground level. At the same time the materials are to exist in harmony and therefore the concrete has a stamped finish similar to the one used in the renovation of the Botanical Garden of Padua by VS Associati.

Figure 55. Meeting between roof and wall.

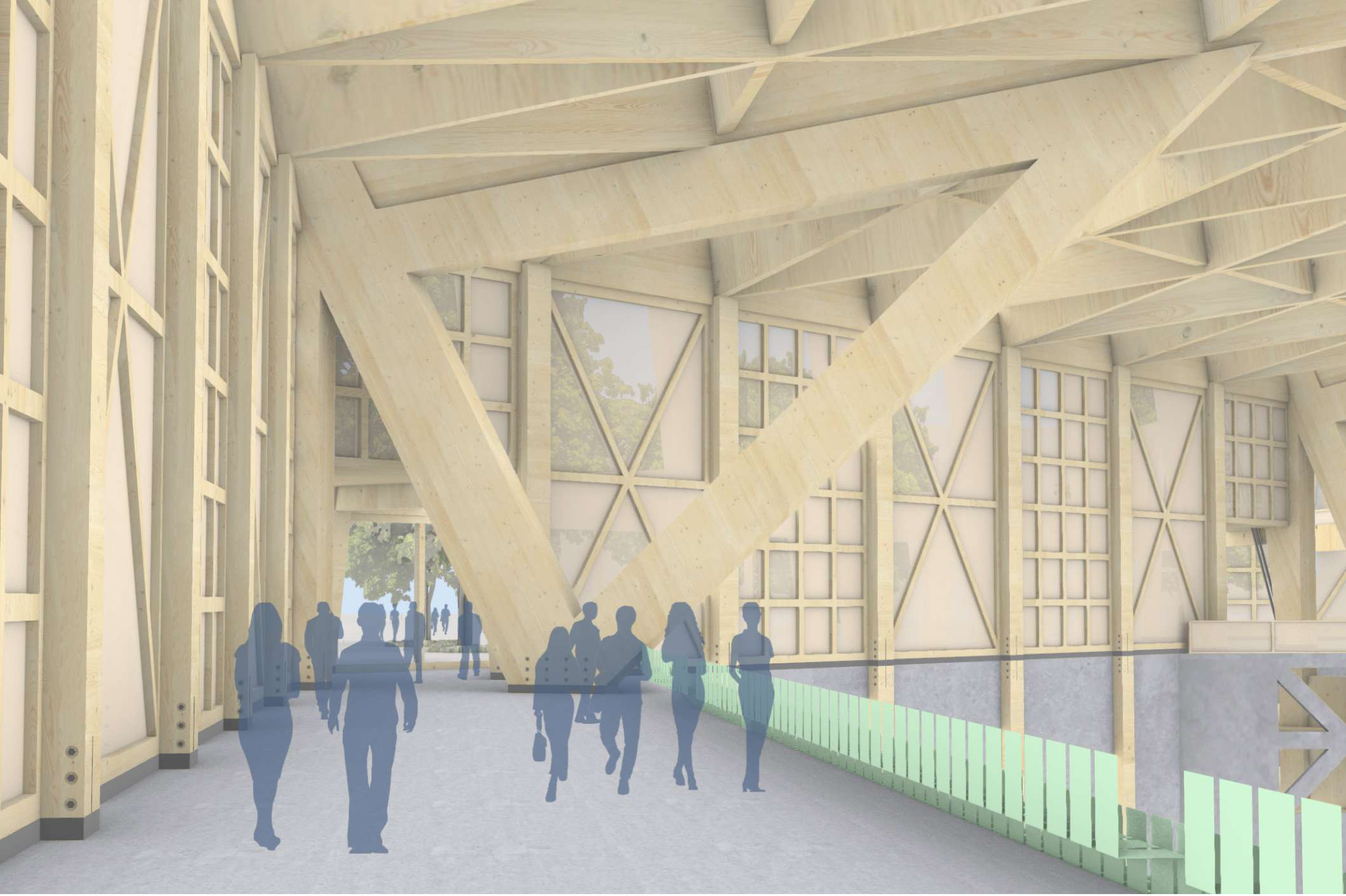


Figure 56. View from walkway.

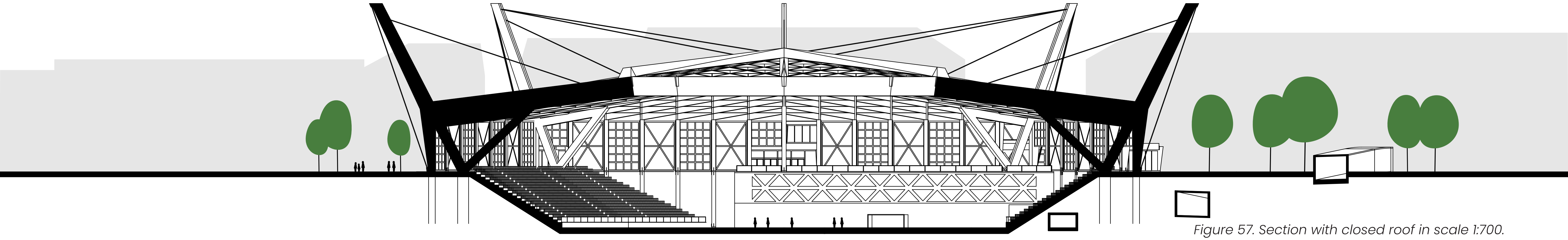
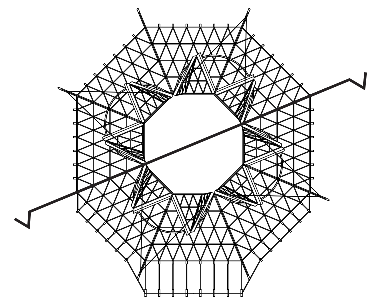


Figure 57. Section with closed roof in scale 1:700.



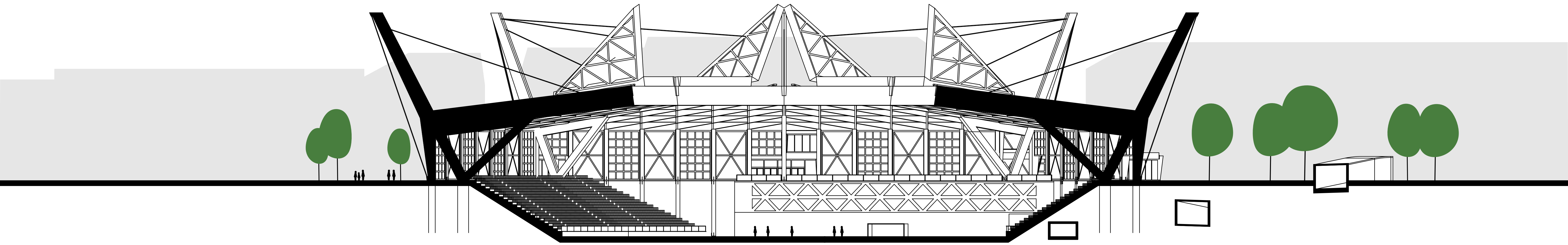


Figure 58. Section with open roof in scale 1:700.

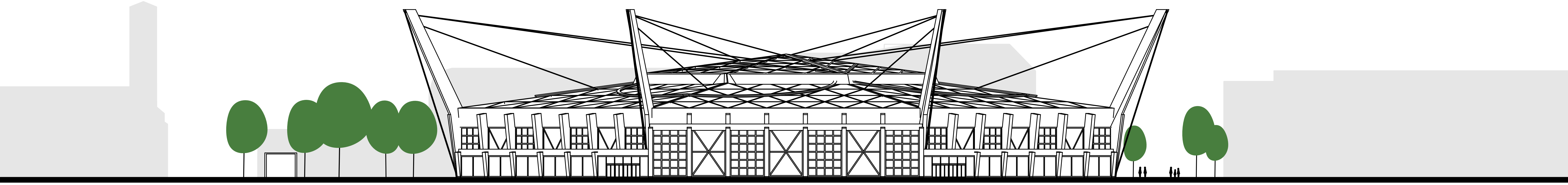


Figure 59. Southwest elevation with closed roof in scale 1:700.

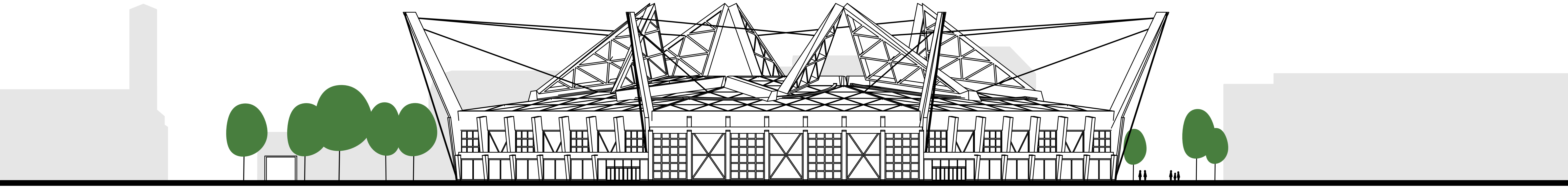


Figure 60. Southwest elevation with open roof in scale 1:700.

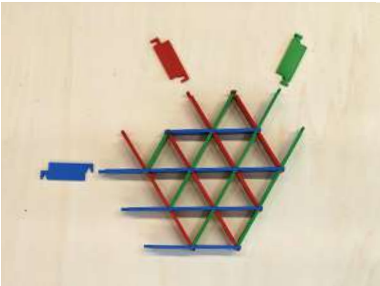


Figure 61. Model for the unfinished grid system.

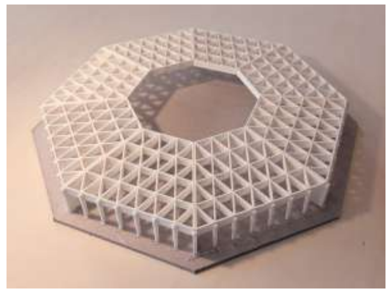


Figure 62. Model for the unfinished grid system.

Figure 63. Model for the unfinished grid system.

ROOF

As previously mentioned, the retractable roof concept was the starting point for this project. The design concept is based on the "star rotation and fold concept" from the retractable roof explorations. It was selected for its intriguing movement and the clear difference in expression between its open and closed state. The closed state is discrete while the open state is dynamic in its expression. Furthermore, it is a solution for a retractable stadium roof that is unlike the common solution which might lead to it gaining more interest from both visitors and citizens of Gothenburg.

The static roof consists of 8 identical framed triangular grids. The longest sections are approximately 50 meters which might be challenging to transport to the site. A system of smaller modules was explored however it was not finished enough to use in the final proposal (Figure 61). It would have been interesting to fully develop this system as it could potentially have simplified the construction of the building.

Another choice had to be made whether the beams of the space frame should be solid or trusses. After exploring both options the decision was made to use solid beams. This choice was mainly based on light studies made on the physical model shown in Figure 62 and 63 where the roof with solid beams created a nice shadow pattern and the light also bounced off the beams nicely. However, these interations between the roof and the sunlight might be more subtle when the ETFE membrane is added.. While the truss-based system had an intriguing expression it also came across as chaotic. The solid beams also give an intriguing pattern with an organized expression.

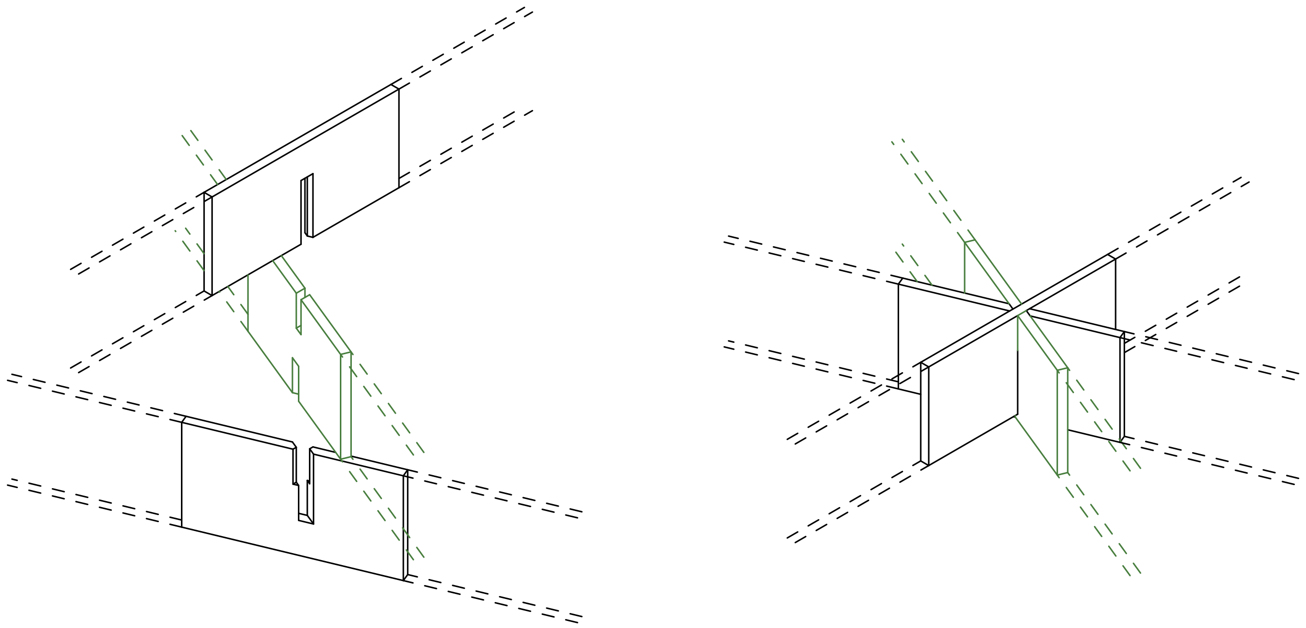


Figure 64. Roof System Cutout Axometric
Scale 1:200

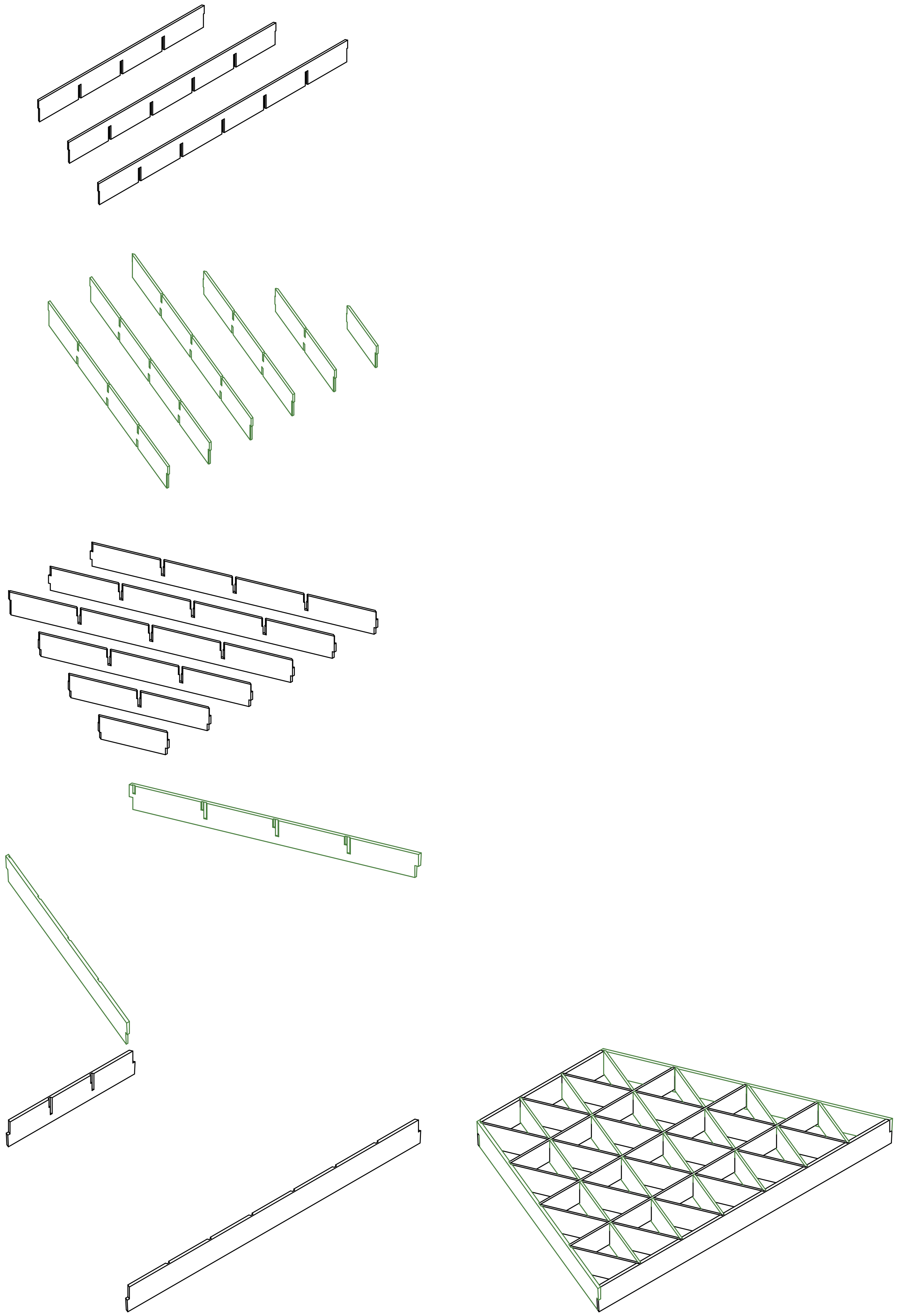


Figure 65. Roof System Axometric
Scale 1:700

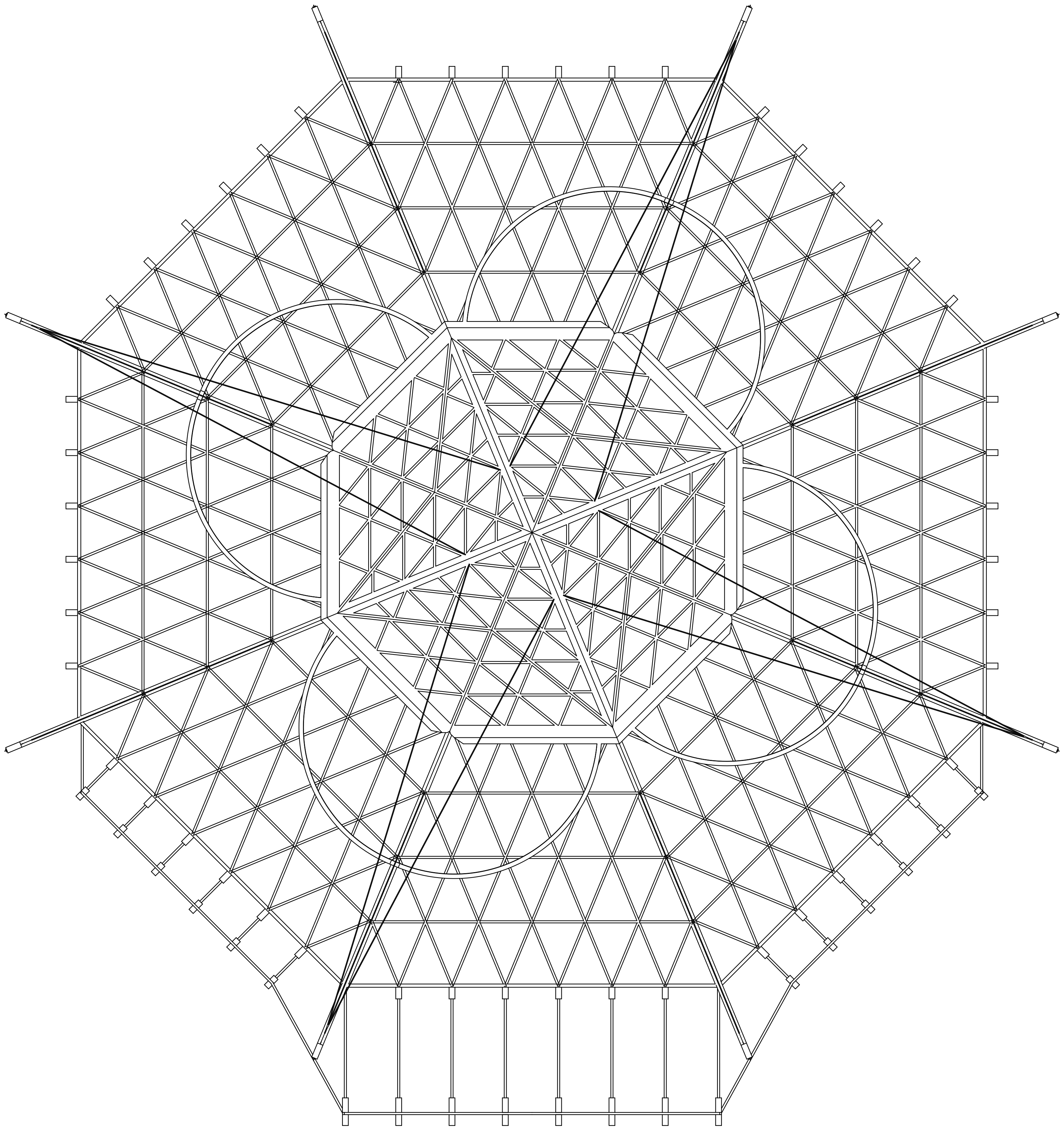


Figure 66. Roof plan
Closed position
Scale 1:700

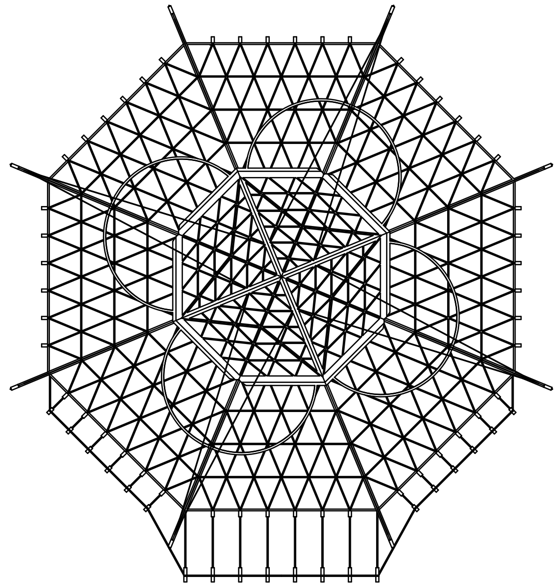


Figure 67. Roof plan
Closed position
Scale 1:2000

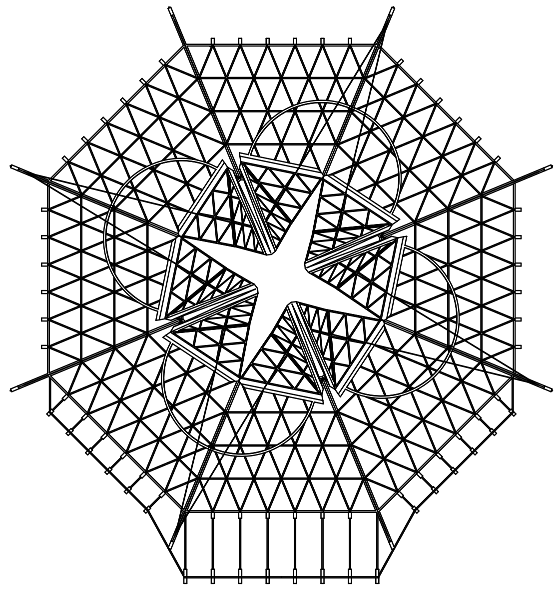


Figure 68. Roof plan
During movement
Scale 1:2000

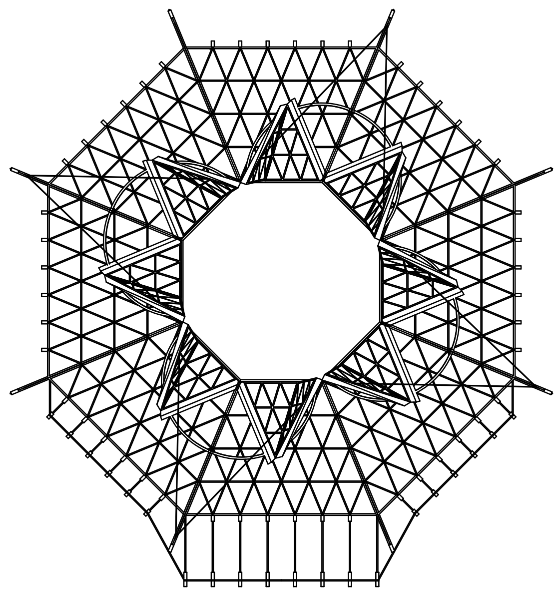


Figure 69. Roof plan
Open position
Scale 1:2000

5. DISCUSSION & CONCLUSION

DISCUSSION

I see an opportunity to create something by taking inspiration from traditional wood construction when using modern engineer wood products. When tall wood buildings were banned in Sweden a lot of knowledge seems to have been forgotten and construction standards were based on steel and concrete. While new engineered wood products such as CLT can be used in a similar way to steel and concrete it is not certain that that it is the best way to use CLT. Furthermore, it seems plausible that traditional Japanese wood joinery should be possible to use with modern wood products such as CLT. Craftsmen of the past have been able to create precision work without the precision CNC-machines that wood product manufacturers of today have at their disposal. It would be interesting to develop this project with a team consisting of experienced architects and engineers with close contact with a manufacturer of wood products. It would also be beneficial if the team consists of members from both Sweden and Japan as both countries has a heritage of wood building and extensive understanding of the material.

One of the main objectives of the project was to make the retractable roof of the stadium a design element. This seems to usually not be an objective in most sport venue projects. Probably because retractable roofs for arenas often exist purely for functional reasons and it is rather easy to argue for this approach. The roof is often out of view and if seen it is from far away. However, with the design proposed in this paper the roof is clearly visible and has an important role in the expression of the building, both in its open and closed state. To use the roof as a design element can make the stadium more unique which is shown in both the proposed design and the reference project the Mercedes-Benz Stadium.

Something that was not covered by the thesis questions but still was an important part of the project was the connection between the arena and Heden. From the beginning the pitch was lowered to reduce the building height to fit with the surroundings. During the study trip in Japan, I discovered the possibility to use inspiration of shoji-panels for the building. This creates a symbiotic exchange of light between the site and building.

CONCLUSION

How can a retractable stadium roof be a design element?

A retractable stadium roof can be a design element which is shown in the design proposed in this paper. By starting the design process with exploring retractable roof concepts the retractable roof becomes a core part of the design. By designing the rest of the building based on the retractable roof a unison expression can be achieved.

Moreover, this thesis shows that there are many ways a retractable stadium roof can be a design element. Even if only one was used in the final design other concepts such as the rotating concept and the concept based on the Yoshimura pattern were other interesting concepts.

How can traditional wood joinery be used in an architectural design with modern structural engineered wood products?

It is possible to take inspiration from traditional wood joinery when working with modern structural engineered wood products. Calculations would be needed to ensure that it is structurally sound. The reason I wanted to take inspiration from traditional joinery was because I find traditional joinery easy to read structurally. For example, seeing a beam supported by a pillar that wraps around the sides of the beam. Moreover, the attention to details in traditional joinery also inspired me. This attention to detail can be used for more than wood to wood connections. For example, in this project it is also used in wood to steel connections. While there might take a while to use traditional joinery structurally it is certain that taking inspiration from traditional wood building can be a key to well-designed buildings.

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All other figures are by the author.

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