SPACE FRAME MANIA

Recognizing the Beauty of Structures

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Abstract

This thesis sets out to investigate the aesthetic qualities of a structural building system. The focus has been to explore the spatial potential of a three-dimensional truss, a so-called space frame. The ambition throughout the process has been to unify spatial ambitions with structural solutions in order to achieve architectural qualities embedded in a well-performing structure.

The application of space frames in architecture followed a development of modular building systems. It started in an explorative era in the 1950s that led up to more built projects in the following decades. As more advanced techniques have been developed, more complex systems with tailored solutions have become the norm. The field is still advancing as the demand for large scale structures and optimised techniques continue to grow.

In designing a space-frame the connecting element, the joint, is the fundamental component - setting the parameters and logic of the system. The investigation on the joint and the connecting members has been made using wood, instead of the conventional steel frame. This thesis recognizes the structures modular capacities, investigating a flexible joint enabling the structure to re-assemble and rebuild in new configurations.

The project developed through an iterative process combining drawing, physical modelling and digital modelling. The investigation departures from the project hypothesis; that a building structure can be used as a tool to create an architectural concept. A building program puts the claim through test by proposing a public building - an Industry Museum located in Gothenburg. The design is focused on an exhibition path showcasing a time-line of the industrial history. The projects is concentrating on a fragment of this program in order to elaborate on the qualities to different spatial configurations possible within in the space frame structure.

The findings result in a conceptual building prototype, emphasising the structural system and its integration with the exhibition path. The exhibition path determines the organization of the space and the supporting functions are fitted around the path to make up a building. The meandering walk moves through a variation of spatial configurations, showcasing the architectural opportunities of the structural morphology.

Concluding that the building-structure was successfully used as a tool to build up the architectural concept - by using an iterative process of refining the structure in several steps to create a space where the architectural intentions are integrated with the structural solutions, coherent with the program it contains. However, this investigation is limited to a fragment of a program. If a more complex program would have been taken in to account this might become a more challenging method.

A final conclusion is that the space frame can be a spatially intriguing structure and through making use of its purely structural elements beautiful and potentially flexible spaces can be achieved.

Table of Content

Introduction/ Discourse

Claim

This thesis investigates if a buildings structure can be used as a tool to build up an architectural concept, where the construction of the building is coherent with its atmosphere, functions and the program that fills it.

The structural typology of a space frame has great architectural potential beyond its structural abilities. It's light, rhythmic and spatial interactive. It can be assembled in endless ways, allowing many different confugurations to grow out of the same system. This project combines the structures tectonic qualities with its flexible abilities to develop a building where architectural intentions are unified with structural solutions.

Definition Space Frame:

The space frame is a three dimensional truss, a lightweight structure of interlocking members forming a geometric pattern. The members are organised in open building blocks of polyhedral units. The project focuses on the simplest polyhedral unit, the tetrahedron (pyramid shape) consisting of six members meeting in four points (Sandaker et al. 2011).

(Sandaker et al. 2011)

Load bearing and space enclosing element

To understand structures in an architectural context, they can be described as having a dual function. They provide strength and stability as well as architectural space with certain qualities (Sandaker, 2011). This project investigates structures contradicting nature and seeks opportunities in the duality.

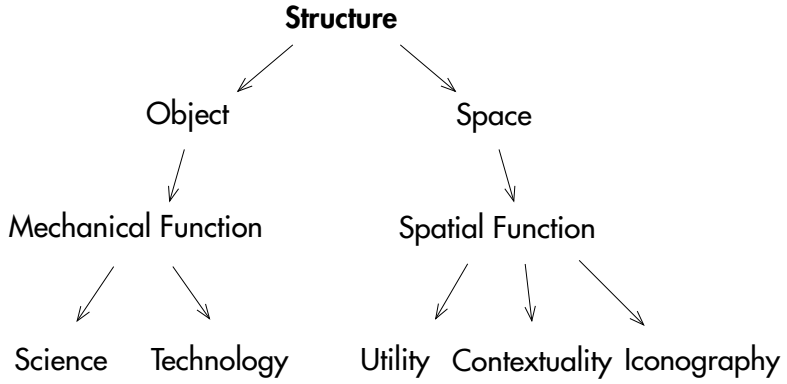


Diagram explaining structures duality (Sandaker, 2011)

“poetic of construction.. emphasising the expressive potential of structural techniques..”

Emphasising the architectural values of a structure relates to the discourse on tectonics, it can be defined as the expressive potential of construction or as the scholar Kenneth Frampton (1995) puts it “poetics of construction”. The term can also be understood in a wider meaning as structural elements have possible values beyond its initial purpose of carrying loads.

“Tectonic derives from the word tekton (Greek in origin) meaning carpenter or builder… Later the term got a poetic connotation, referring to artisan working in hard materials… The term would eventually aspire to an aesthetic rather than technological category”.

“expressivity arising from.. constructional form in such way that the result expression could not be accounted for in terms of structure and construction alone.”

“Similar combinations of structure and construction could become the occasion for subtle variation in expression… Given expression may be at variance with either the order of the structure or the method of construction. But when the structure and construction appears to be mutually interdependent the tectonic potential of the whole would seem to derive (from the eurhythmy of its parts and articulations of its joins).”

Quotes from Studies in Tectonic Culture (Frampton, 1995)

"..simplicity and complexity of the structure as something inseparable."

Repetition of constructional elements can be a method of developing interesting architectural space. Inside the limitation there is a freedom to explore the different possibilities, enabling the simple components to build up a complex unit.

"In his own house Can Lis on Mallorca, Jorn Utzon worked with a very simple constructive principle exploring it's many variations giving every part of the house and it's construction its own character. This way of working with architecture creates a strait forwardness in the appearance of the building enabling the observer to understand the simplicity and complexity of the structure as something inseparable." (Madsen, 2008)

“.. allow the building to be part of a greater cycle of resources..”

The space frame is a modular system; it provides an opportunity to develop the constructional elements in detail. The few standardized elements can be carefully design, and mass produced. This also provides an opportunity to design the ability to de-construct and re-assemble the components, to provide a longer life span of the elements as they can be re-used in new constructions.

“.. A construction must likewise be evaluated by their ability to allow the building to be part of a greater cycle of resources, such as ability to dissemble construction by the end of use in order to have materials recycled and reused in new constructions.“(McDonough , 2009).

References/ Background

Alexander Graham Bell
Tetrahedral Kites
Nova Scotia, 1902-1908

Early examples of Space Frames were put together by the inventor Alexander Graham Bell in the beginning of the 20th century, during this time "Space Frame" was not yet a concept or an elaborate system. Bell multiplied stable polyhedral units into structures, creating large and lightweight structures, so lightweight that they were actually used for making kites (Arbuckle, 2018).

The open structure enables a transparency, as one can perceive the structure in multiple layers. This shows the structures capacity as the small, lightweight components make up a strong unity when they act together.

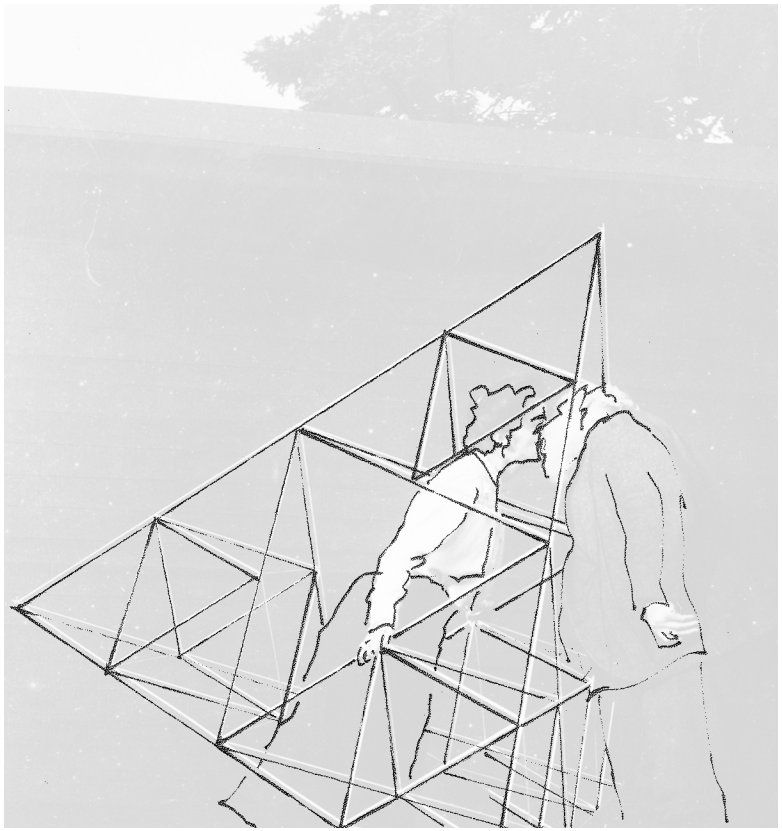


Fig 1: Alexander Graham Bell kisses his wife Mabel Hubbard Gardiner Bell inside a tetrahedral framework.

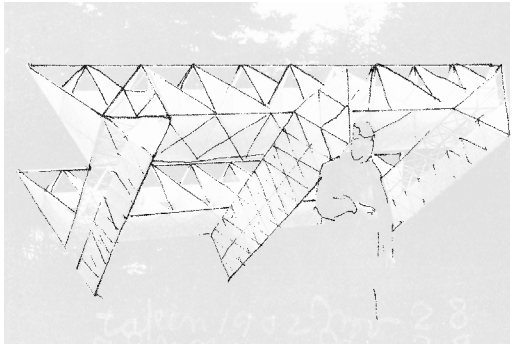
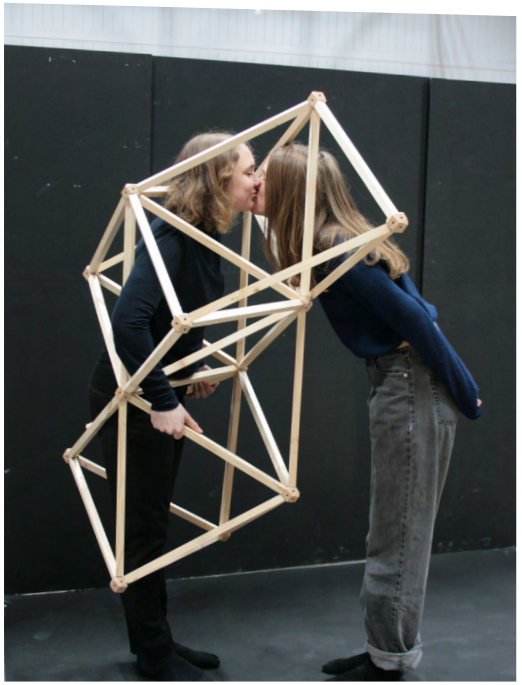


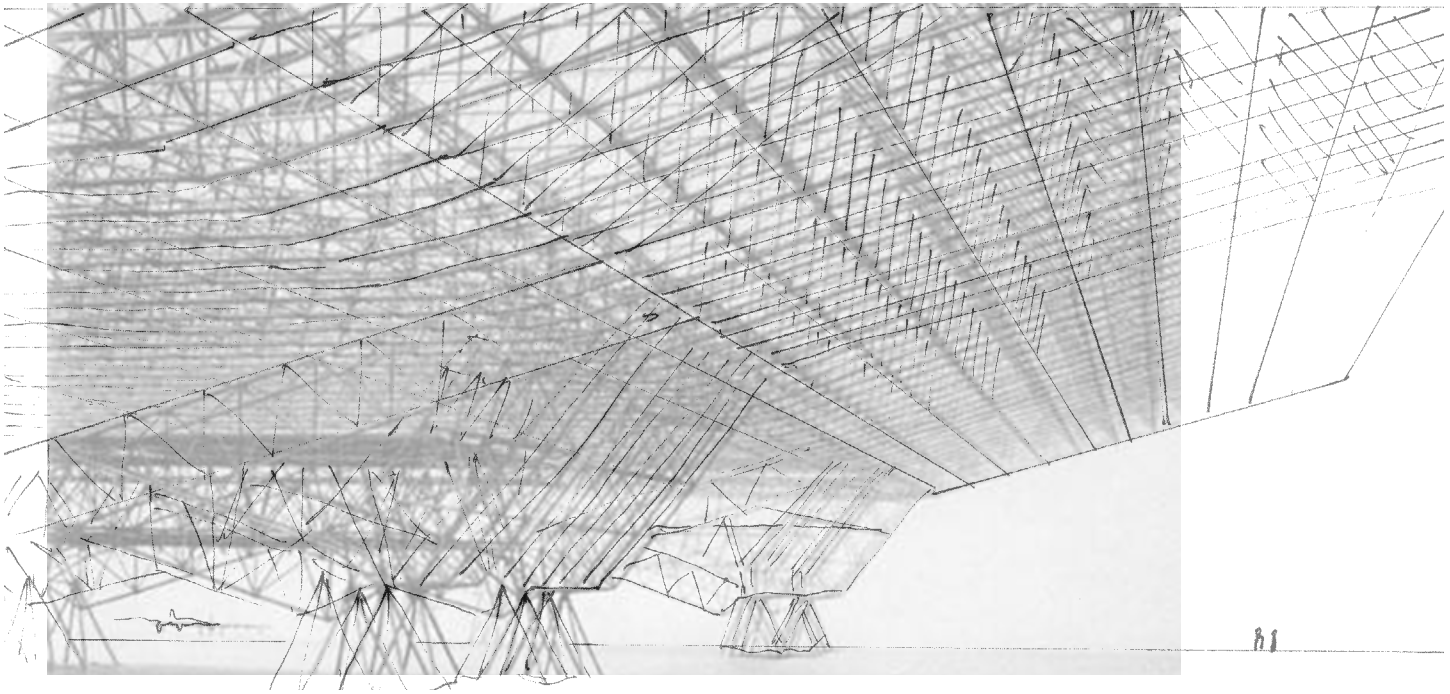
Fig 2: Floating kite built of tetrahedral cells



Konrad Wachsmann
American Air Force Aircraft Hangar
California, 1951

This aircraft hangar is an example of an early application of space frames in architecture and is displayed to demonstrate the theme of simplicity and complexity (Dpr-barcelona, 2010).

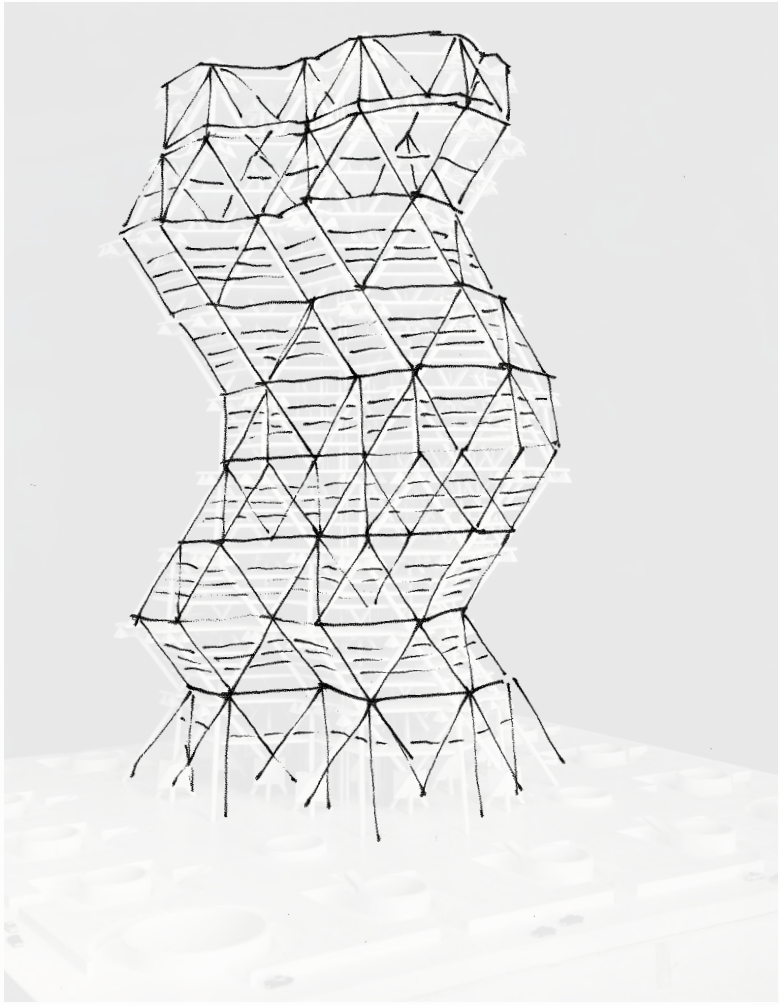
The structure is simple, based on regular repetition of identical elements. However, there is a complexity created by the configurations of the elements, making the lightweight components act as a strong unit. One can perceive the simplicity in the regular repetition following a geometric grid. One can also perceive a complexity as this grid is multi-layered, making the small parts into one structural mass.

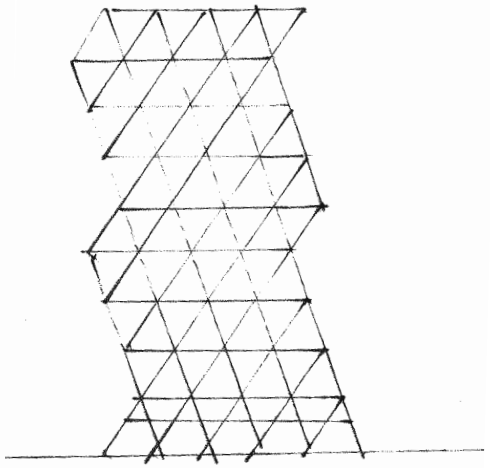


Anne Tyng & Louis Kahn
City Tower
Philadelphia 1952-1957

"Inhabiting Structure" is a phrase borrowed from this reference project, a proposal of an futuristic office building in Philadelphia (Architectuul, 2018).

The outer boundaries of the structure define the framework of the building. Within the space frame - voids constitute the spatial configuration of the interior. Dimensioning the structural elements makes the structure inhabitable and gives the voids unconventional but all the same room-like qualities.





Historic Diagram

Alexander Graham Bell, He experimented with compositions of octahedral and tetrahedral units in to structures (1903-1908)

Vladimir Shukhov Shukhov Tower, Moscow, (1920-1922)

Anne Tyng, Elementary School Buck's County, Model of roof framing (1950-1951).

Anne Tyng, Louis Kahn City Tower Philadelphia (1952-1957)

Konrad Wachsmann, American Air Force Aircraft Hangar, California, (1951)

Exploring Space Frames:

1890 1900 1910 1920 1930 1940 1950

Inhabiting structure:

Modernism

Constructivism

MONUMENTAL REDUNDANCY
Stéphen Sauvestre, Eiffeltornet (1889)

ARTISTIC APPROACH TO STRUCTURES
Yakov Chernikhov, Composition No. 28 (1925-1933). Constructivism, a form of Modern architecture in the Soviet Union in the 1920s and early 1930s.

IRREGULAR SYSTEM
Constant Nieuwenhuys, New Babilon (1959-1974)
Models and sketches on an anti-capitalist city. Example of an irregular system that grows wild.

Constant Nieuwenhuys, Two Towers (1959)

Cedric Price, Aviary at London Zoo (1961)

Kenzo Tange, Expo 70 Festival Plaza Osaka (1969-1970)

Buckminster Fuller, Thomas C. Howard, Car showroom in

Buckminster Fuller, Standing on octet truss TC Howard of Synergetics (1959).

Ray Rewal, Hall of Nations, space-frame structure built in reinforced concrete (1972)

Shoei Yoh,Oguni Dome in Kyushu (1988). Curved timber trusses in a space grid in cedar wood.

Foster + Partners Hearst Tower (2006)

1960 1970 1980 1990 2000 2010

Late Modernism /Structural Expressionism/High Tech

PLUG-IN
Yona Friedman, Spatial City (1960) & Cedric Price, Fun Palace (1959–1961)
Plug-in to structure, rather than using the structure as the space enclosing system.

SUPER EXPOSED
Renzo Piano and Richard Rogers, Centre Georges Pompidou (1971-1977)
Not only is the structure incorporated in the building experience but other technical installations as well.

The development of space frames mainly followed two trends; materials and production techniques in the wake of the industrial revolution and mathematical techniques being developed to descried and predicts structural behavior. A range of various truss formations where developed, eventually leading up to the three-dimensional structure of a space frame, also referred to as space grid or space truss (Chilton, 2000).

Some of the earliest examples of Space Frames were put together by the inventor Alexander Graham Bell the early 20th century, prior to the established concept of a three-dimensional truss. Nevertheless, Bell multiplied stable polygons into structures, creating large and lightweight structures, proving the efficiency of this structural configuration.

The application of space frames in architecture followed the development of modular building systems, with the Mero- system as a pioneer. In the 1950s- and 1960s Space Frames were widely explored in architecture, at this time building systems and joining techniques were developed further. This was mainly an experimental era that led up to more built projects in the following decades. As more advanced techniques have been developed, more complex systems with tailored solutions have become the norm. This is still where the field is advancing, as the demand for large scale structures and optimised techniques continue to grow.

This thesis departure from the earlier usage of space frames in architecture recognizing the advantages of a modular building system and inspired by the experimental attitude of that time.

Characteristics of Space Frames

Advantages

- Load sharing capacities
All the elements contribute to the load carrying capacity, unlike a planar beams or trusses. Loads distributed evenly throughout the structure and to all the supports.

- Robust
It is a redundant structure; it has more support than needed, if one or a few elements break the structure will still stand.

- Modular Components
Modular systems provide flexibility, the structure can be extended or reassembled elsewhere. The modularity also provides an opportunity to carefully design the components, as the system can be made of few elements that are mass produced.

- Lightweight
Its lightweight due to several reasons; the loads are distributed throughout the structure and the structural bars have relativity short length and they are axial members. These factors enable the structural bars to slim down in dimension.

Disadvantages

- Cost
It's often an expensive structure, especially when it's used for shorter spans where simpler structural types are reasonable in dimension.

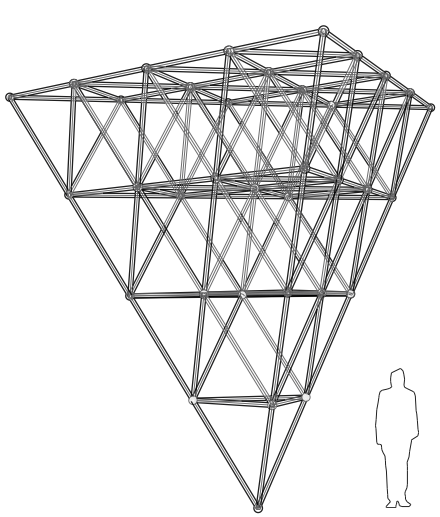
- Erection time
Connecting all the members in building the system can take long time on site, especially if the joints are complicated.

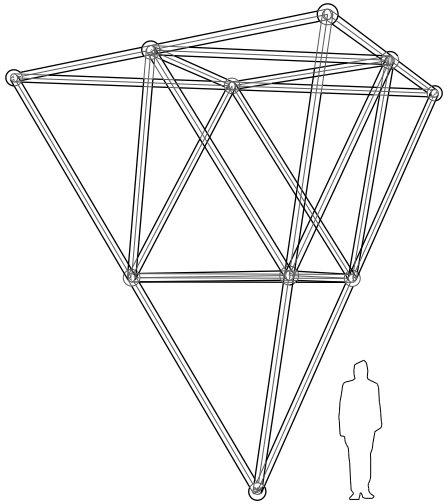
- Fire protection
As the structure consists of thin elements with a lot of surface area, this fire resistance can be short. However the redundancy in the structure can prolong the whole structures to collapse in case of fire.

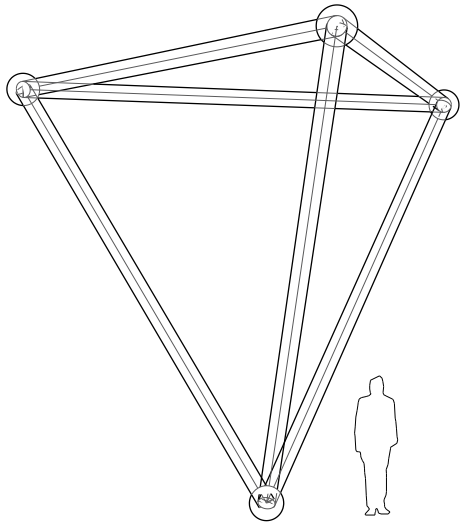
(Chilton, 2000)

Investigations/ Scale

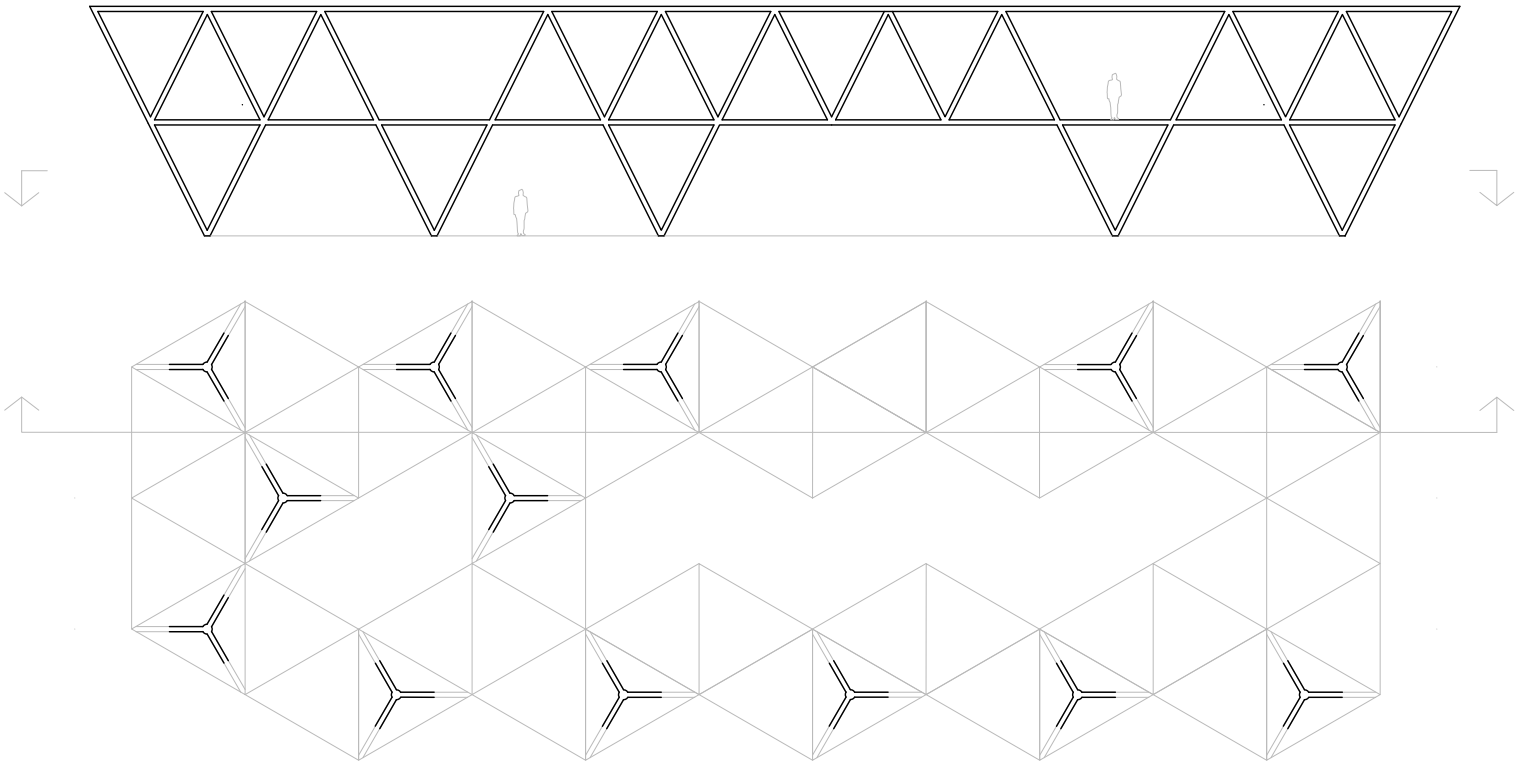
Space Frame Scale Overview



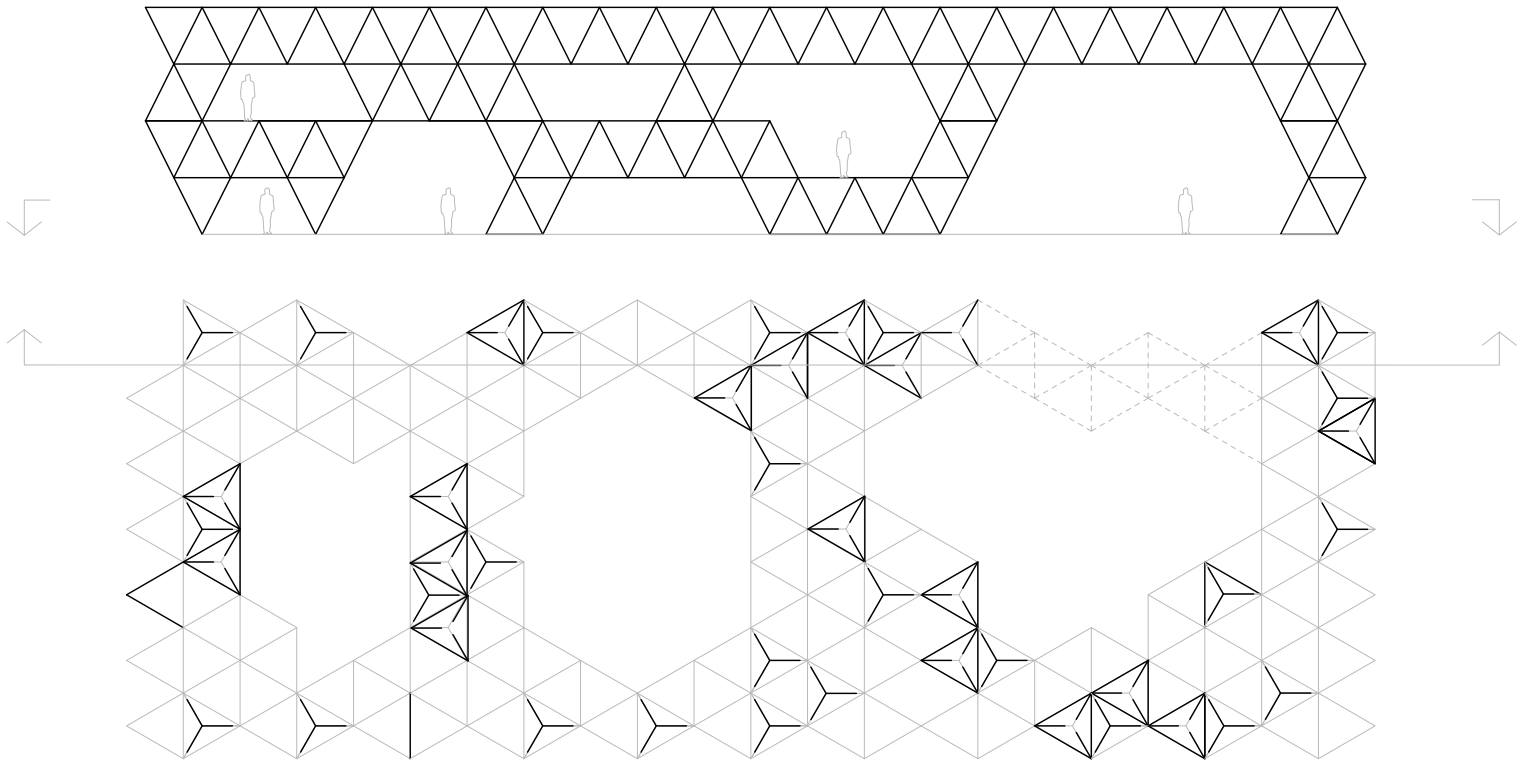




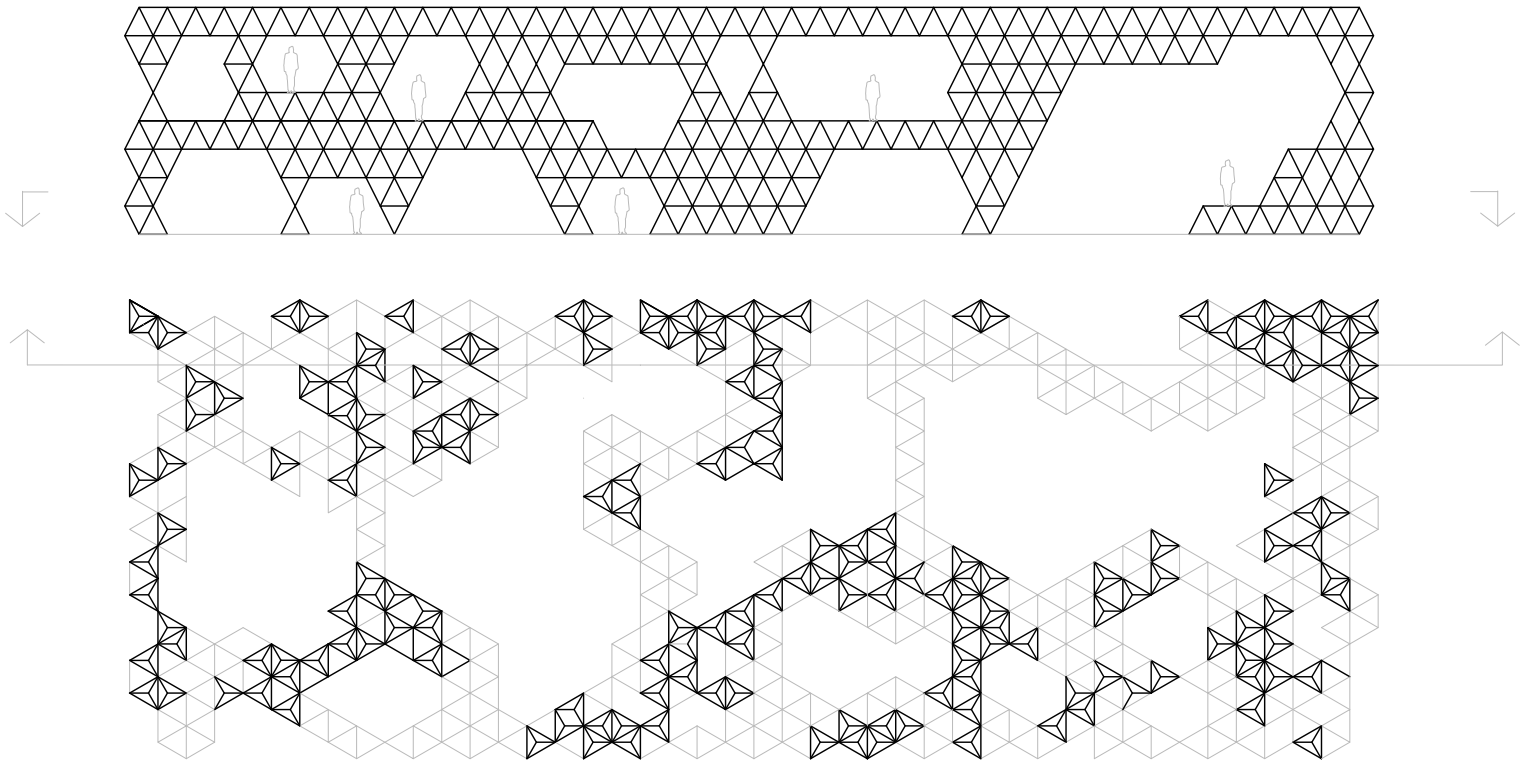
Large Scale



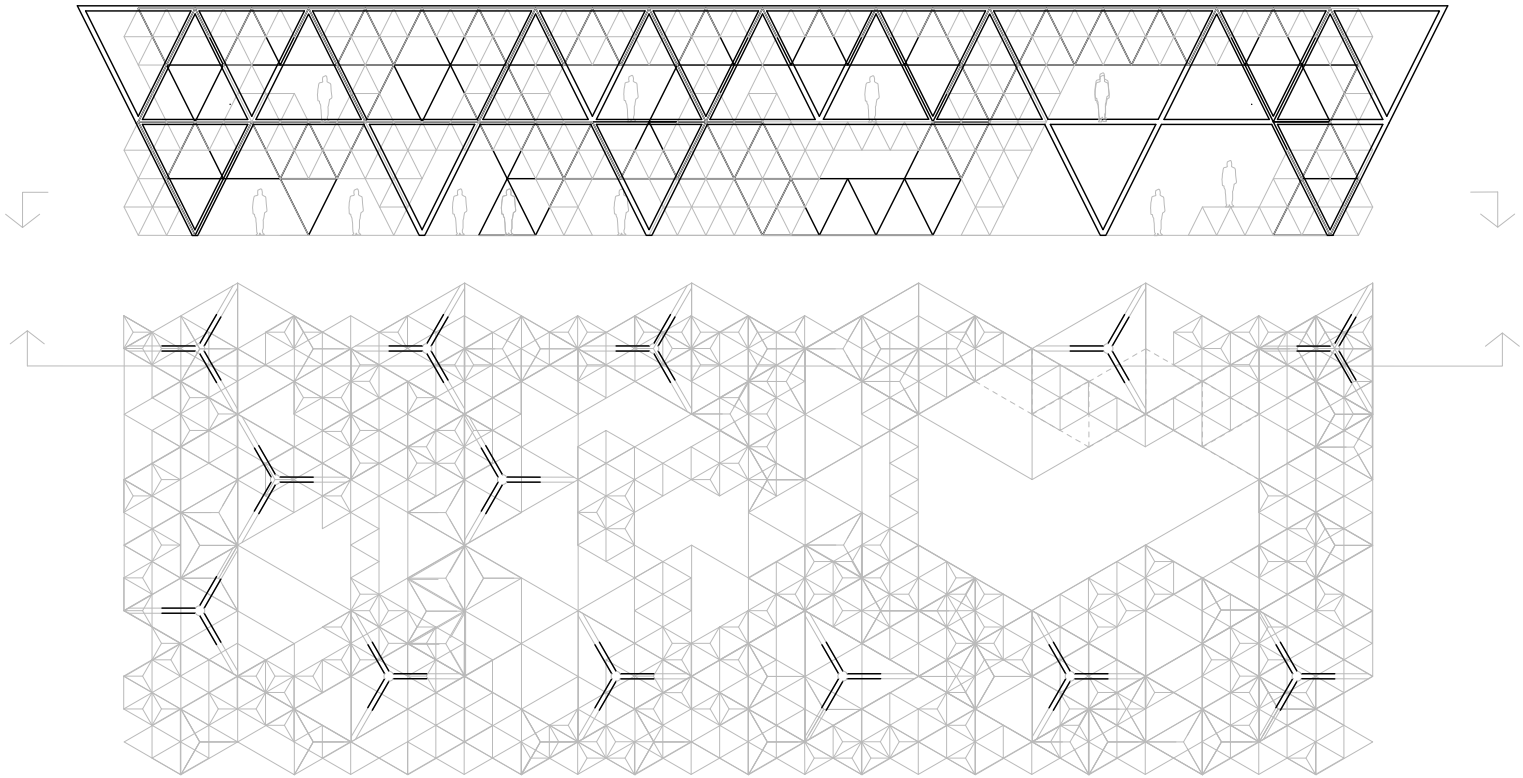
Medium Scale



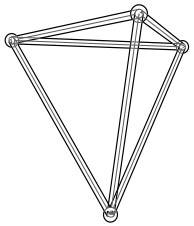
Small Scale

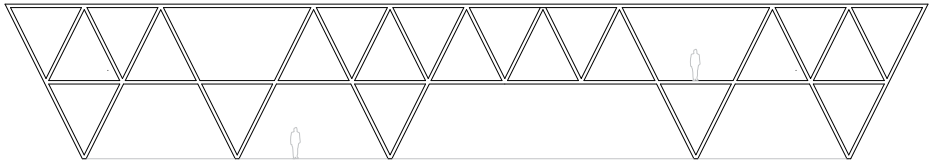


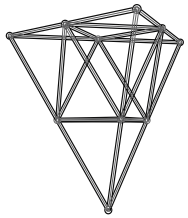
Combined Scales

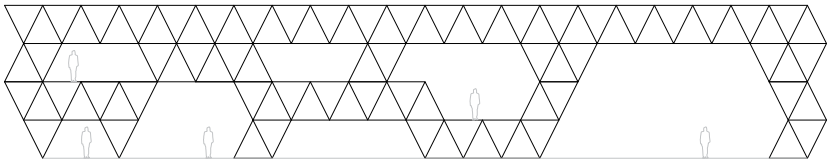


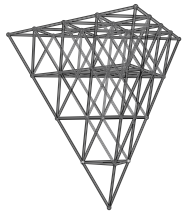
Summary

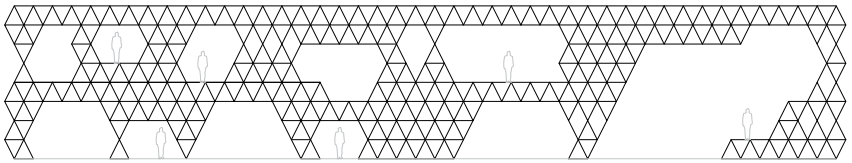


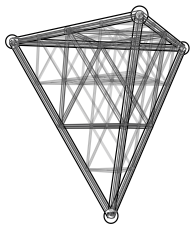


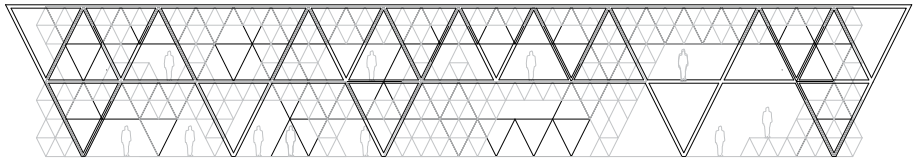


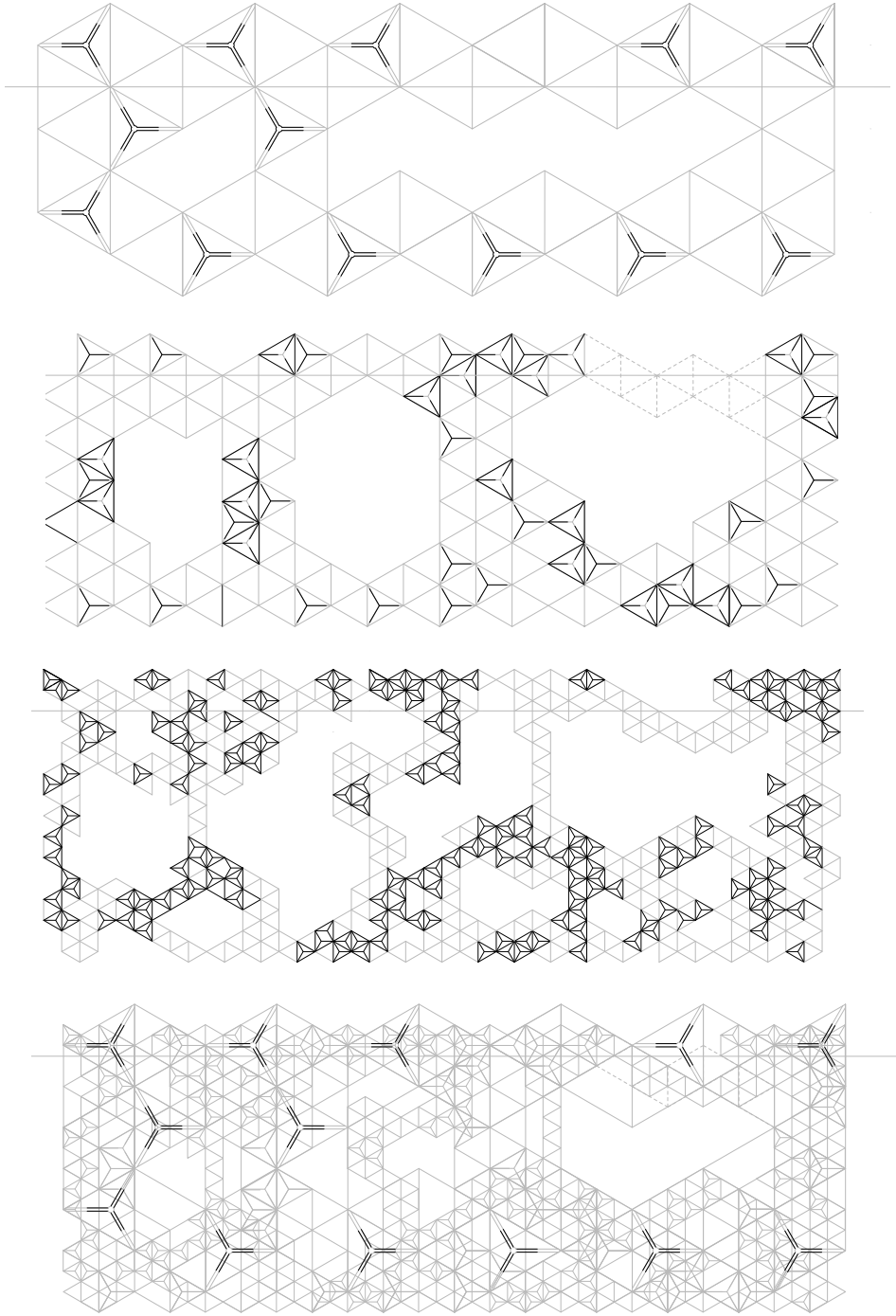




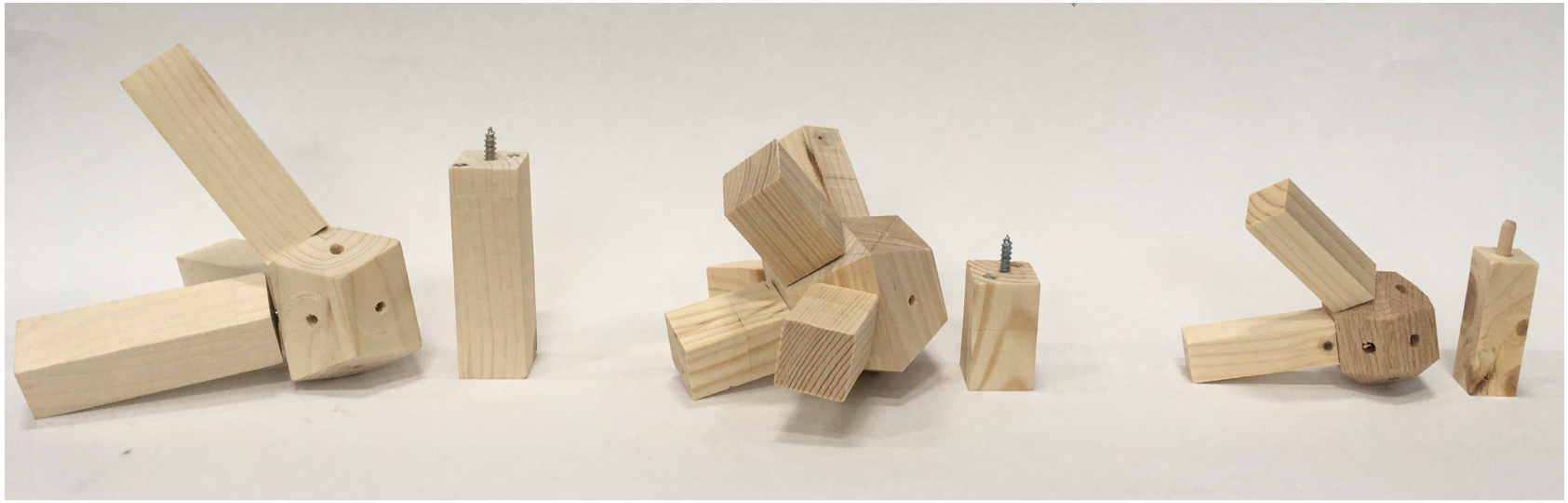






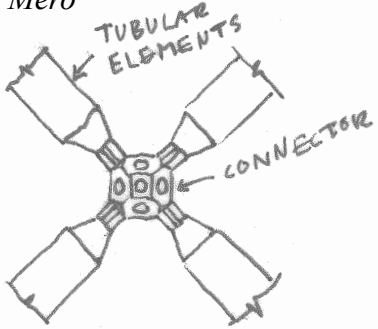


Investigations/ Joint



Examples of Joint Connections

Mero



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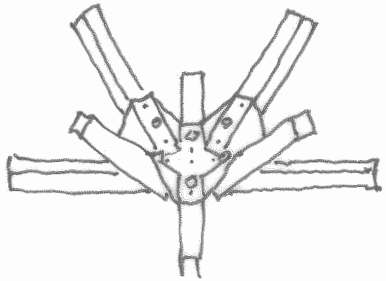

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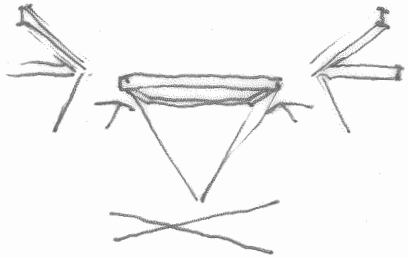
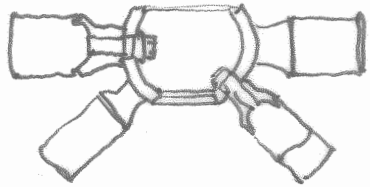
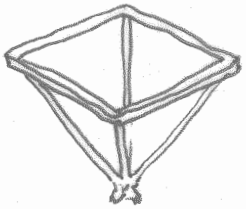
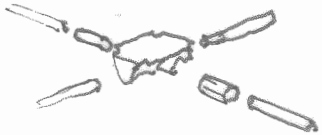


NS Space Truss

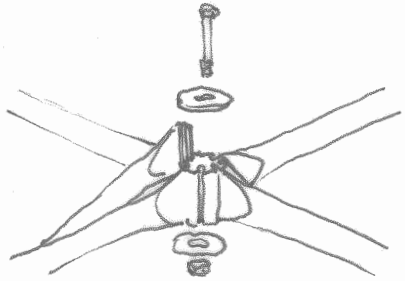


Space Deck

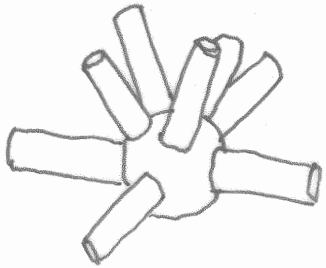




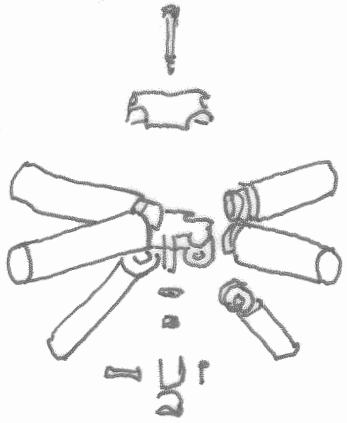
Triodetic



Oktaplatte



Nodus

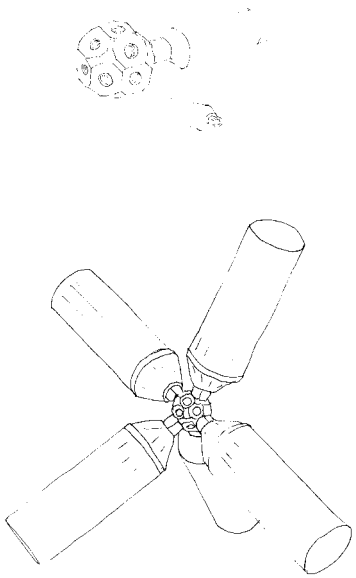


Development from the Mero-joint

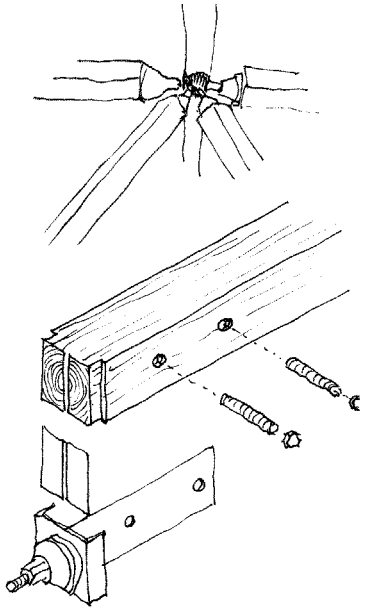
When designing a space frame the joint is the fundamental component. It keep all the members in place and it distribute the loads evenly trough out the structure as well as directing the forces to the connecting members. The joint allows the connecting bars to work as axial members, which result in slimmer dimensions making the structure lightweight.

This thesis focuses on a wooden space frame, instead of the conventional steel frame. This is possible because wood have the same structural abilities as steel in terms of handling both in tension and compression.

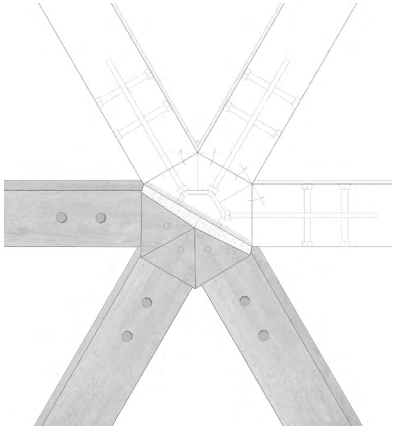
Making a joint entirely in wood would be a fixed connection as the fibres would be glued together; therefore this project proposes a wood and steel hybrid making possible a threaded connection.



Reference of a threaded steel connection; the standard Mero KK Node.

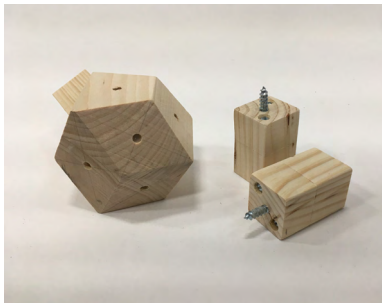


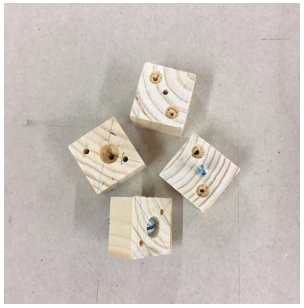
Reference from Oguni Dome by Yoh Architects, steel joint connecting wooden bars with steel plates.

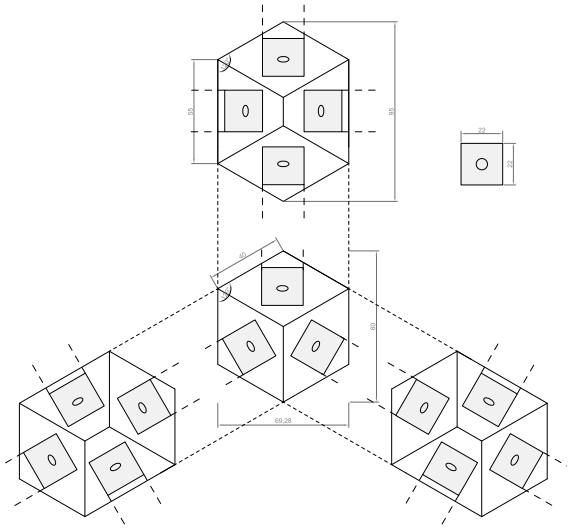


Section cut of proposed joint, where both the connected members and the joint is wooden, supported with steel plates.

Prototype 1







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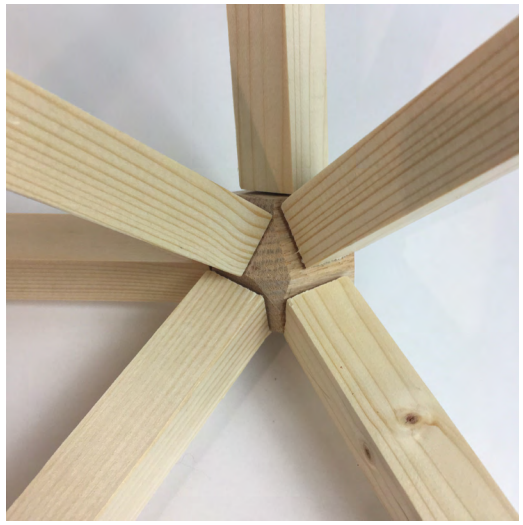
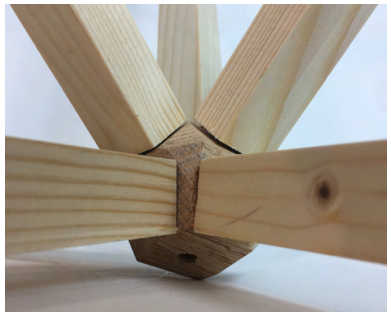
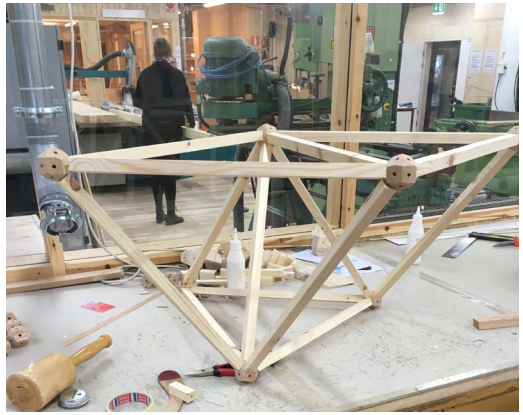
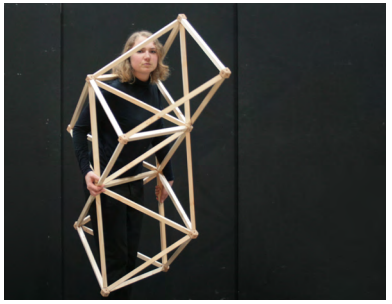
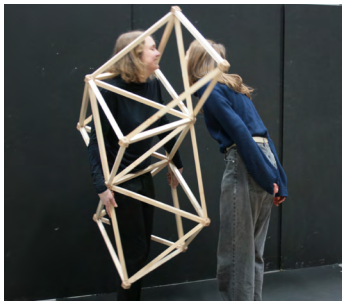
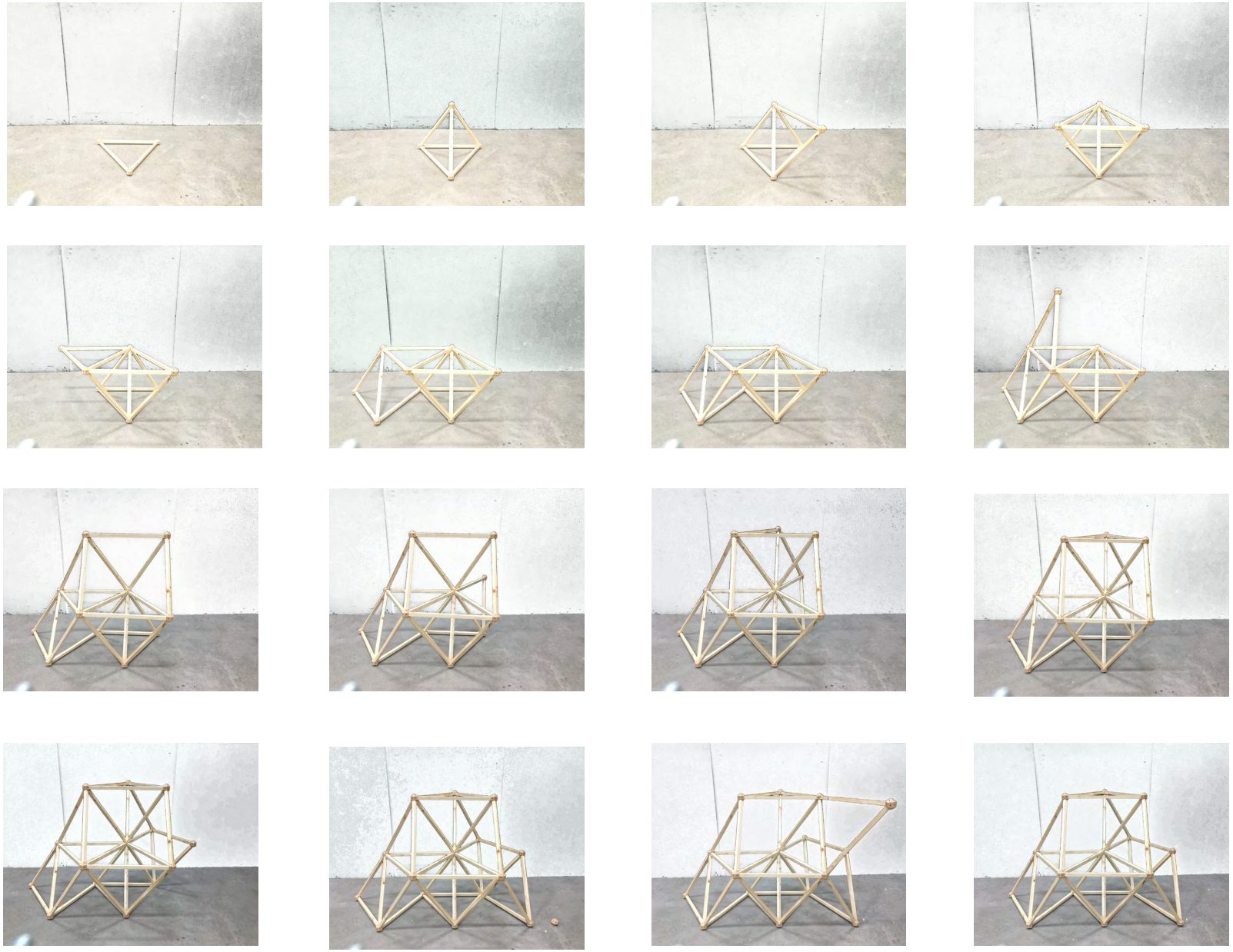






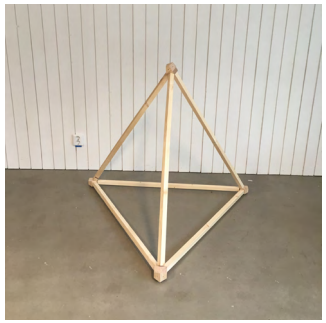


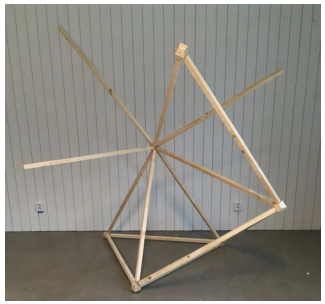


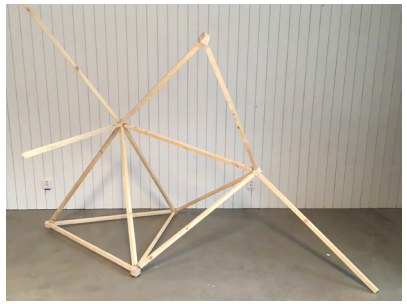
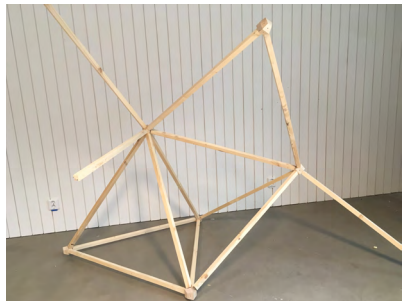




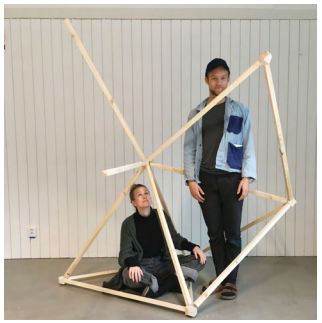




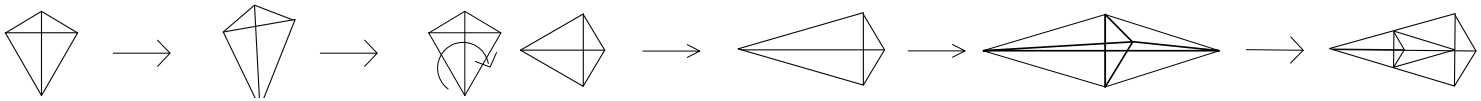




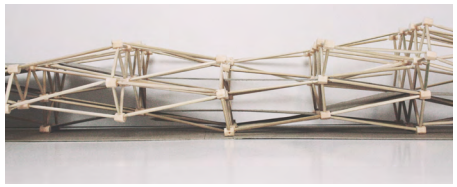
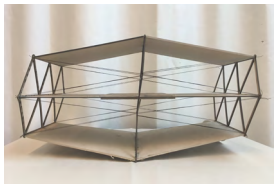


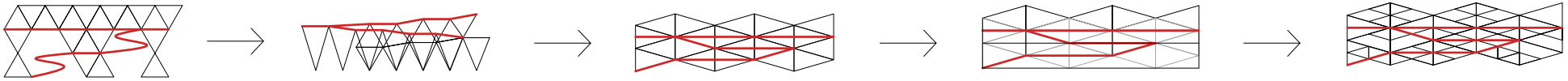



Investigations/ Timeline



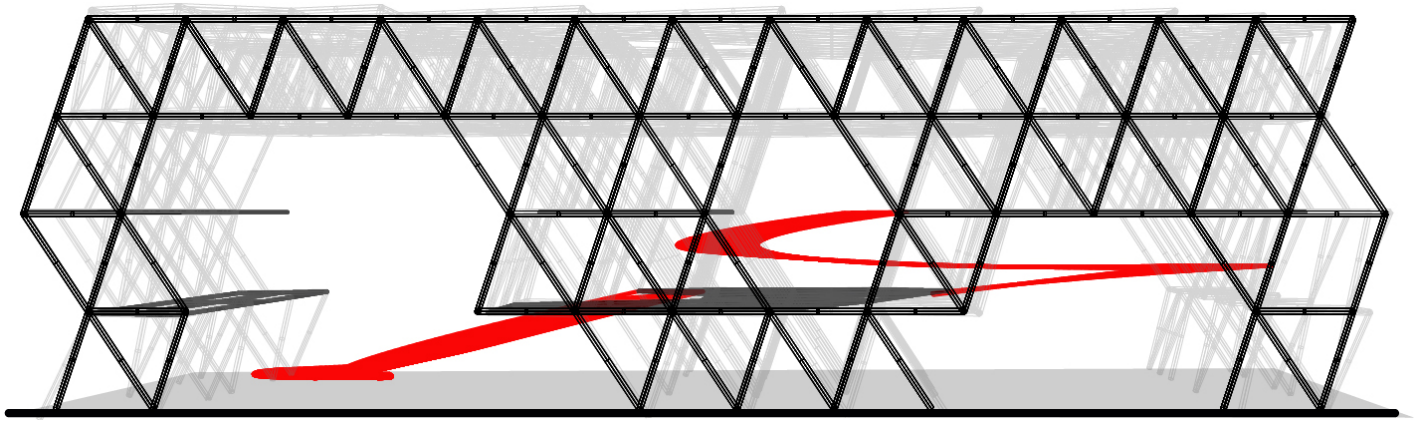
The investigation grounds itself in the project hypothesis; that a building structure can be used as a tool in building an architectural concept. A program puts the claim through test using a building proposal of a public building - an Industry Museum located in Gothenburg. The design is focused on the space of an exhibition path showcasing a time-line of the industrial history. Concentrating on a fragment of this program, in order to elaborate on, and explore, the qualities to different spatial configurations.

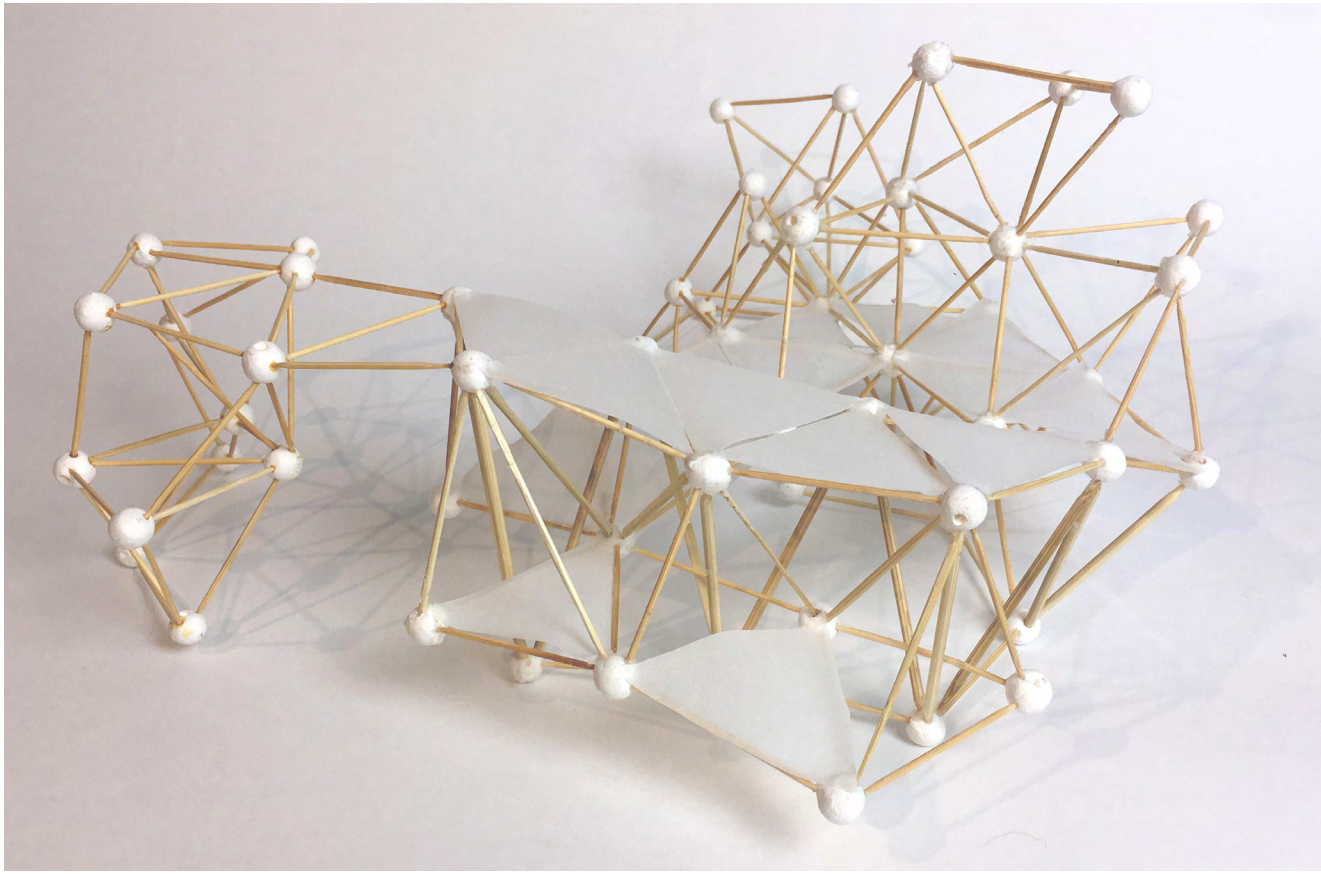
Equal tetrahedrons

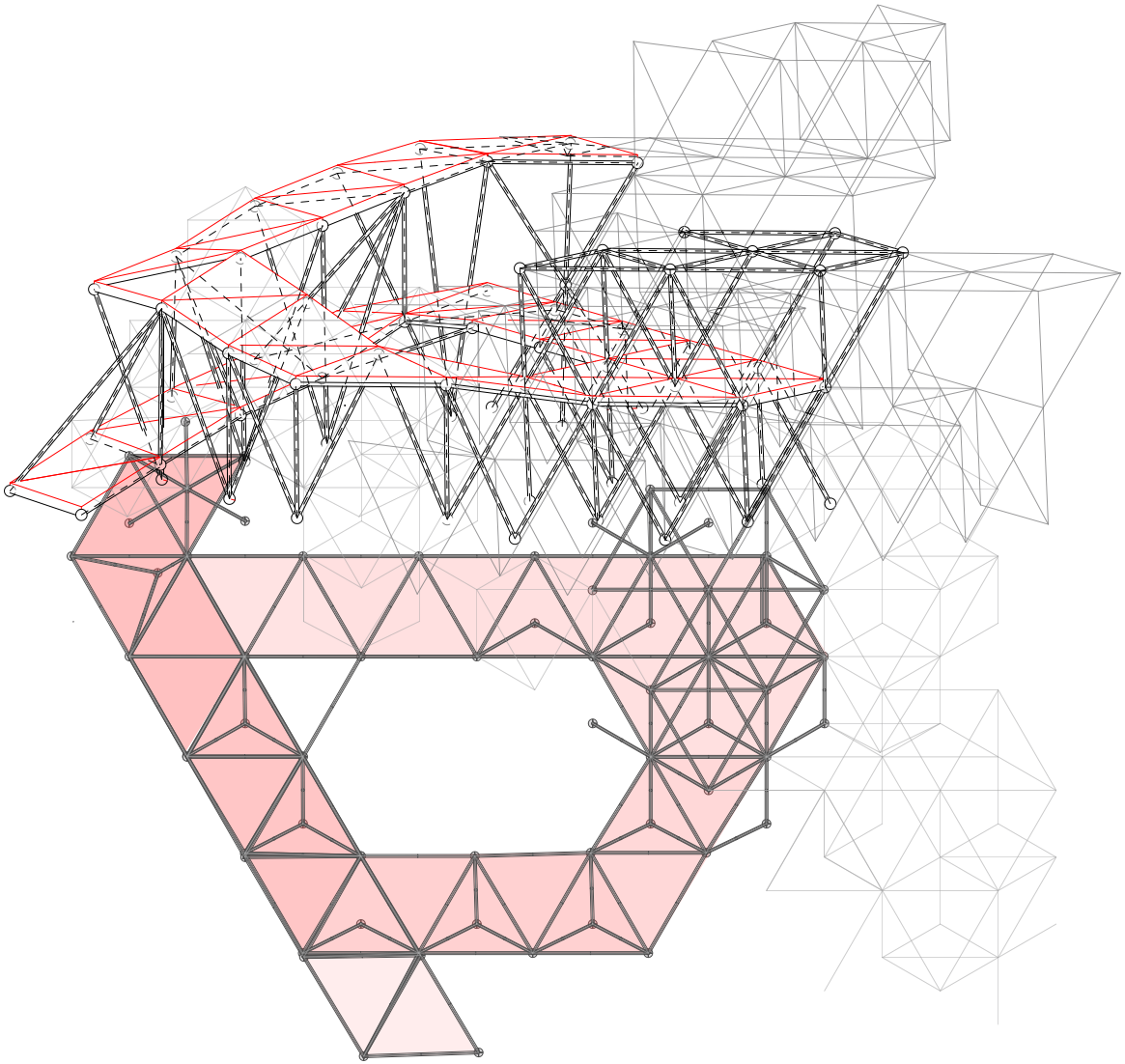
Starting with a like sided tetrahedron, it has steep angles or flat surface. Not supporting a comfy walking angle.



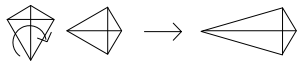
Angled tetrahedron

Stretching some members to get an inclination, it supports the path the modular system is compromised

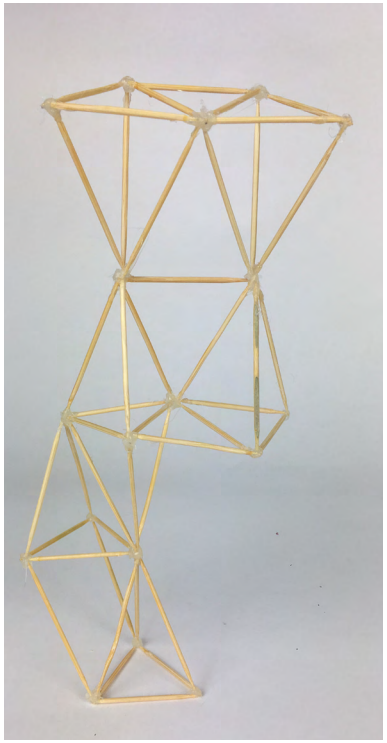


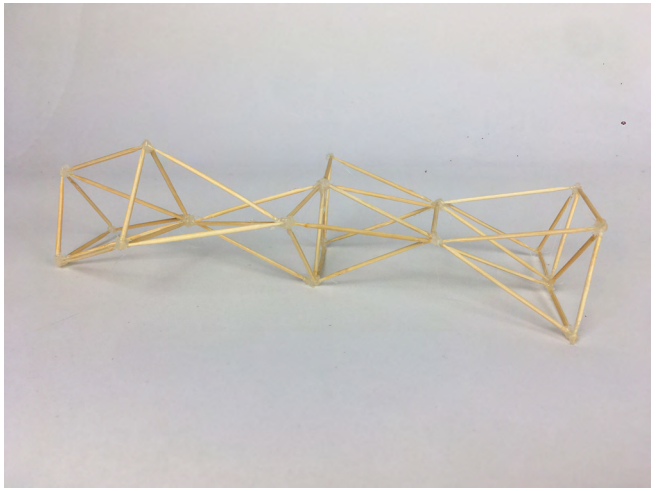


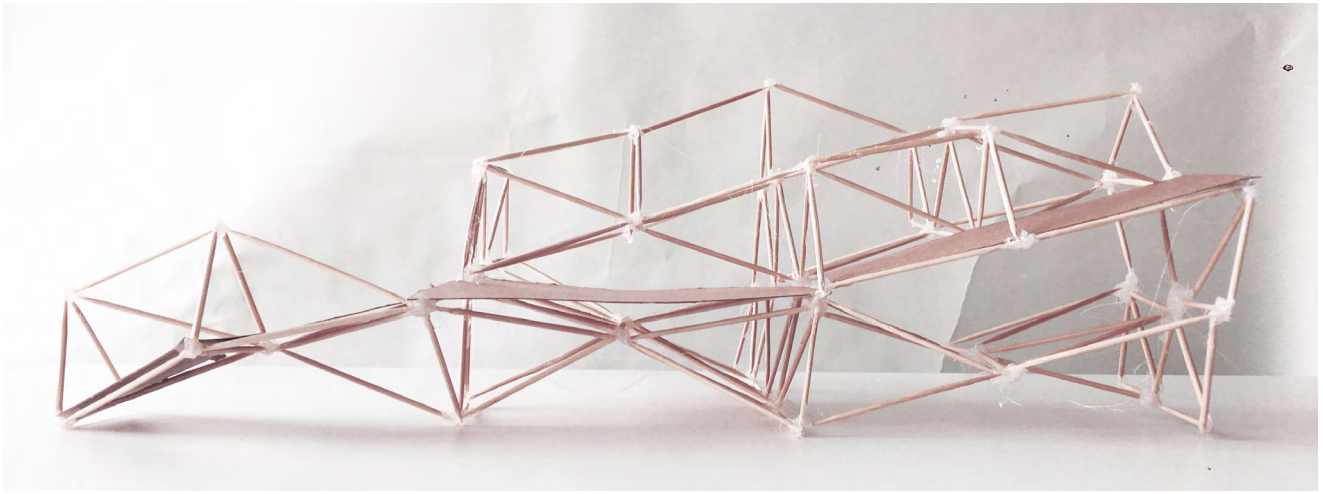
Flipped and stretched tetrahedrons

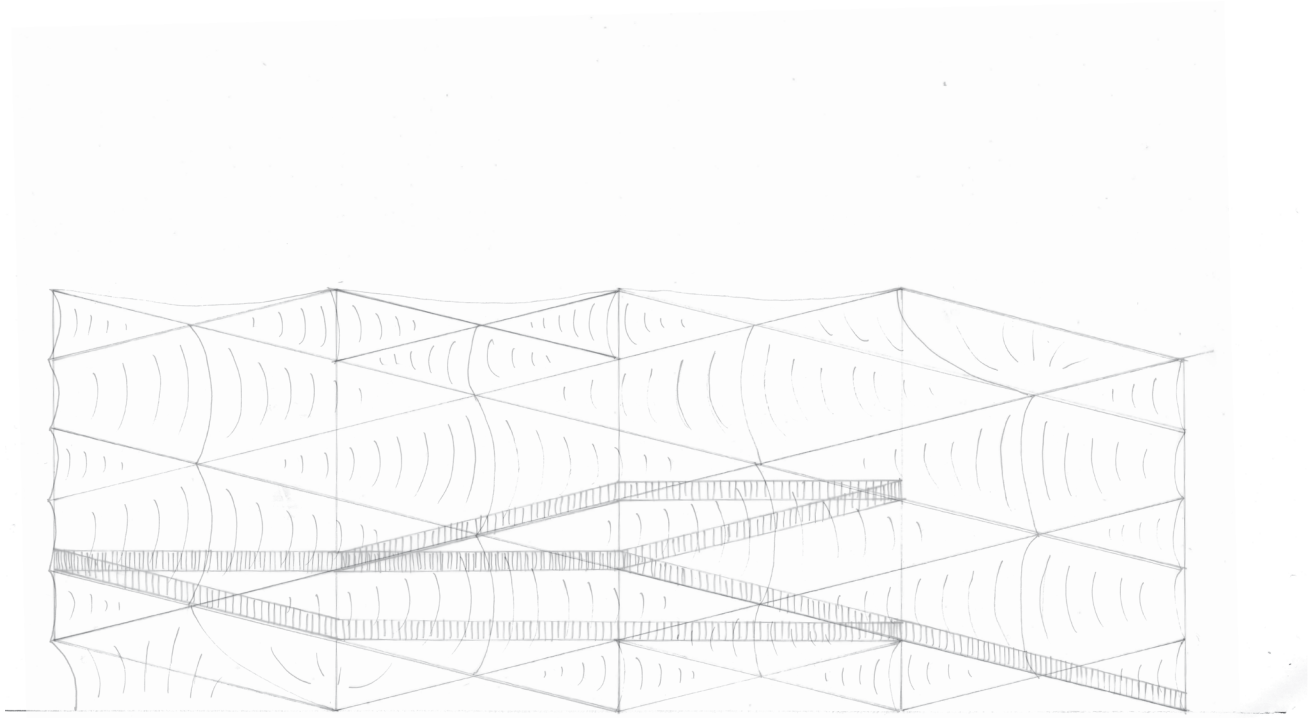


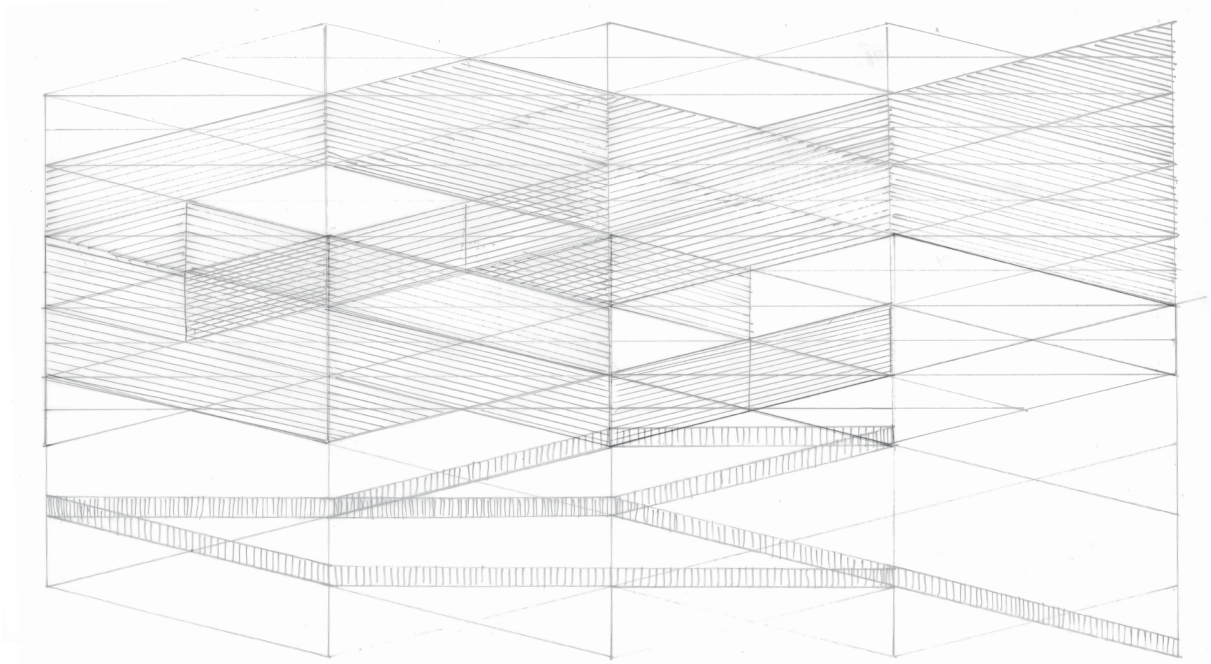
The structure is flipped and stretched to get an appropriate inclination. But the as the horizontal members are stretch they are more sensitive to bucking and have to be heavily dimensioned.



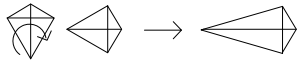


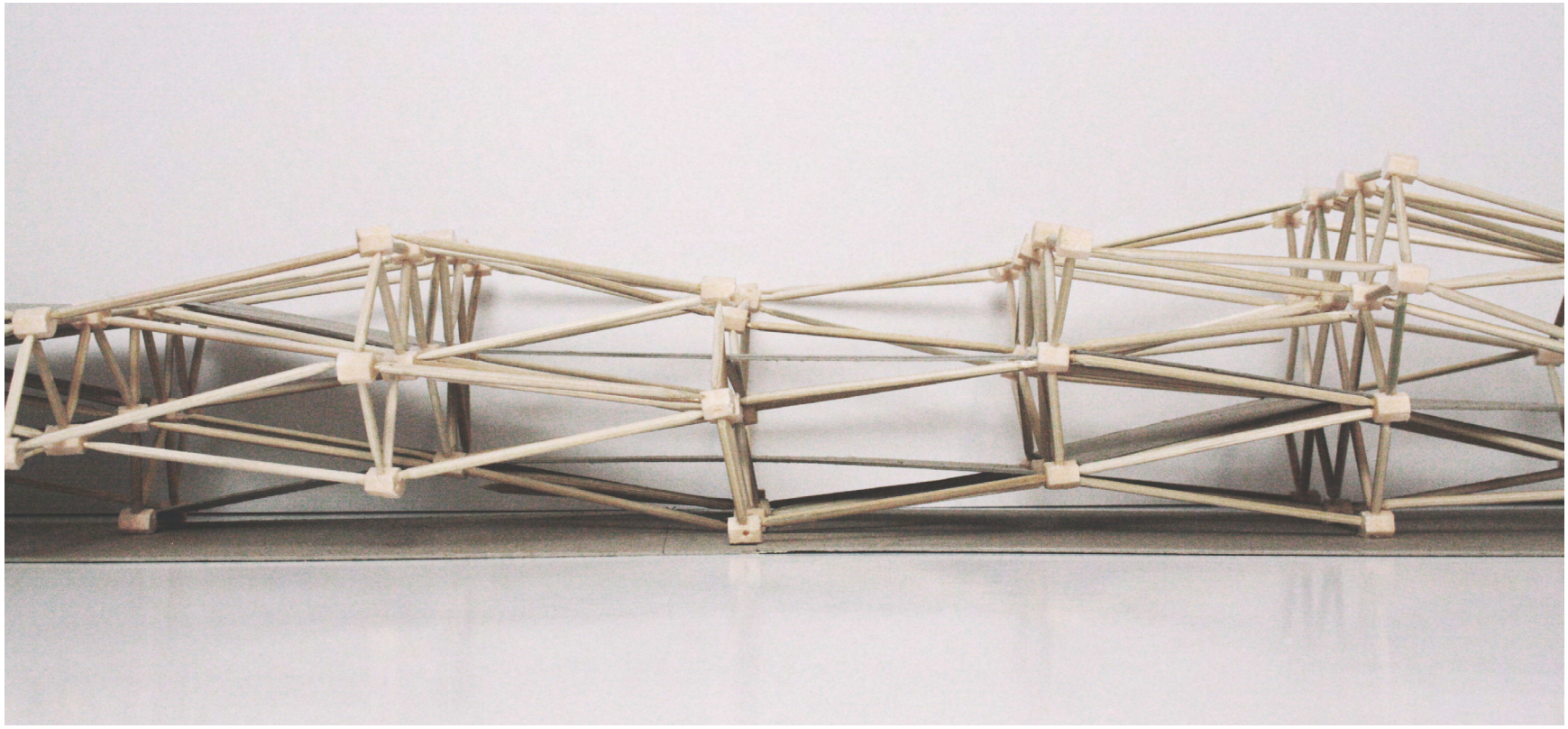


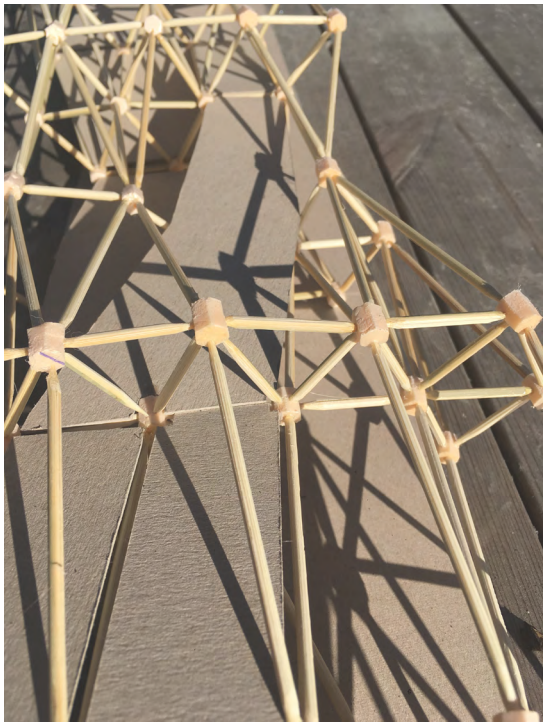


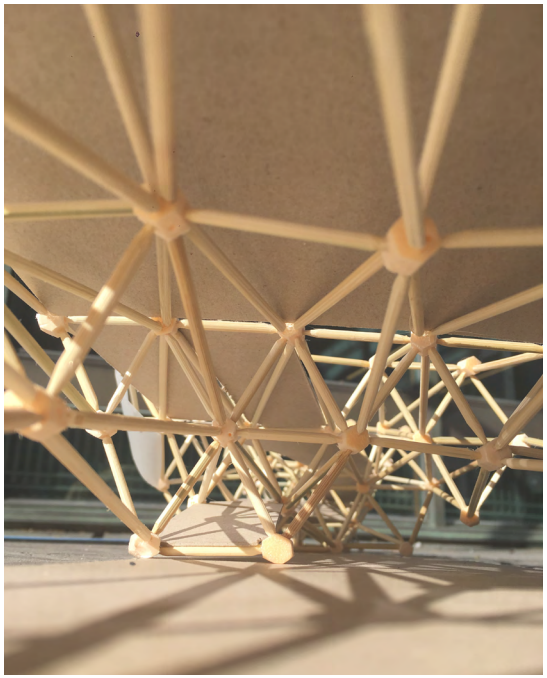


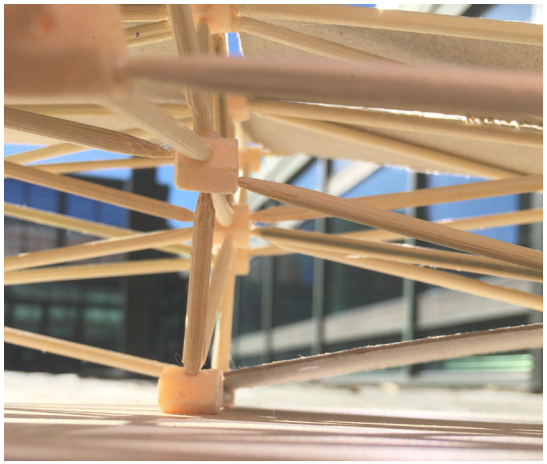
Flipped and stretched tetrahedrons



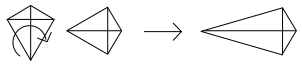


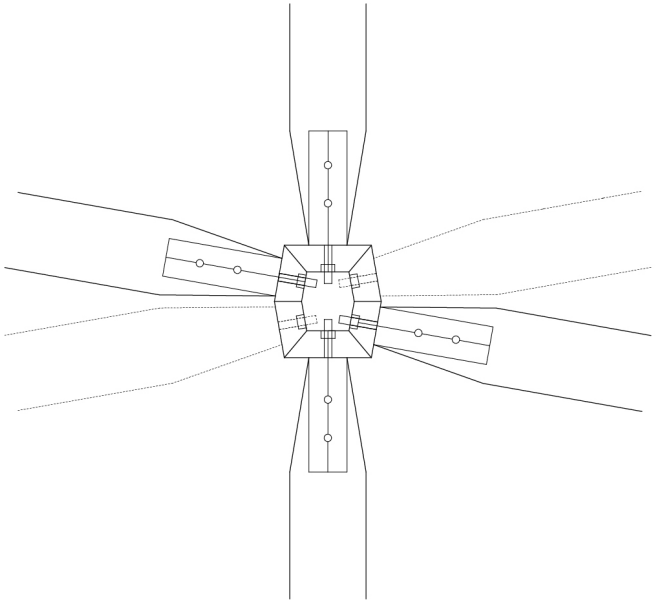


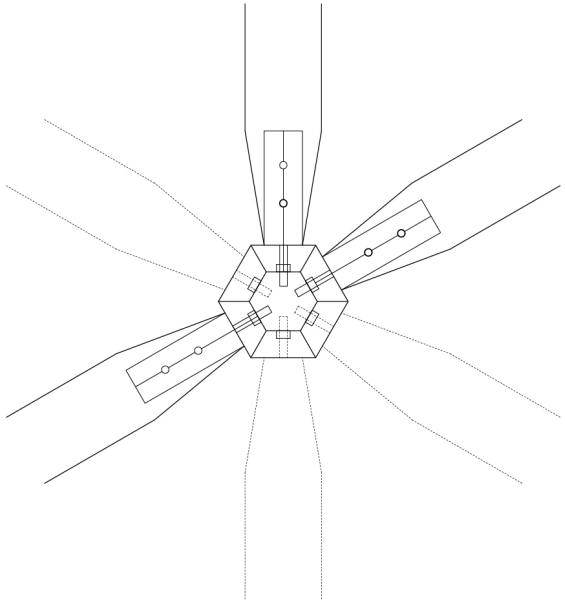


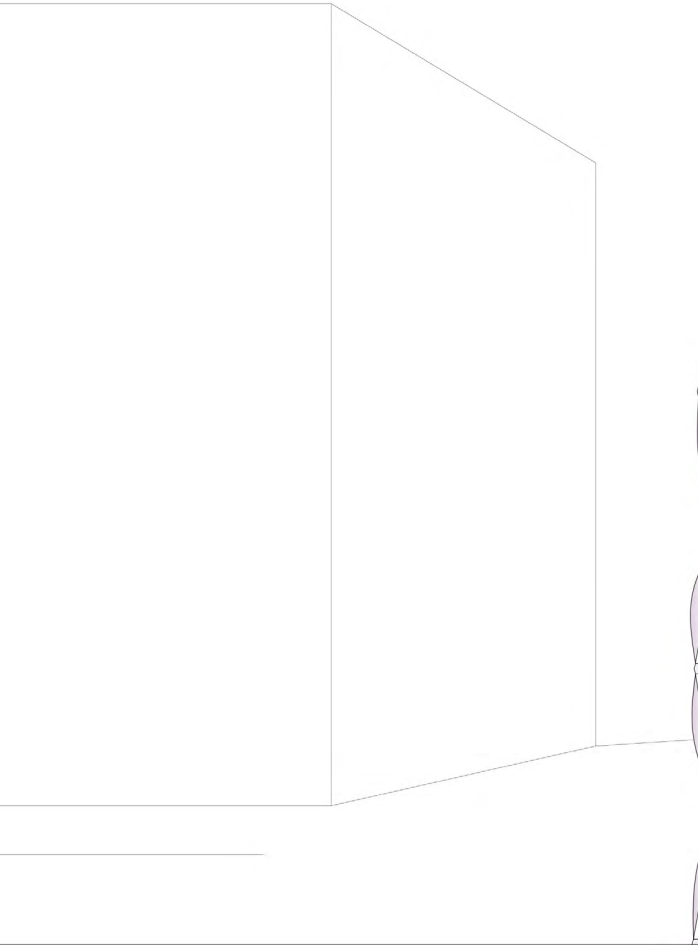


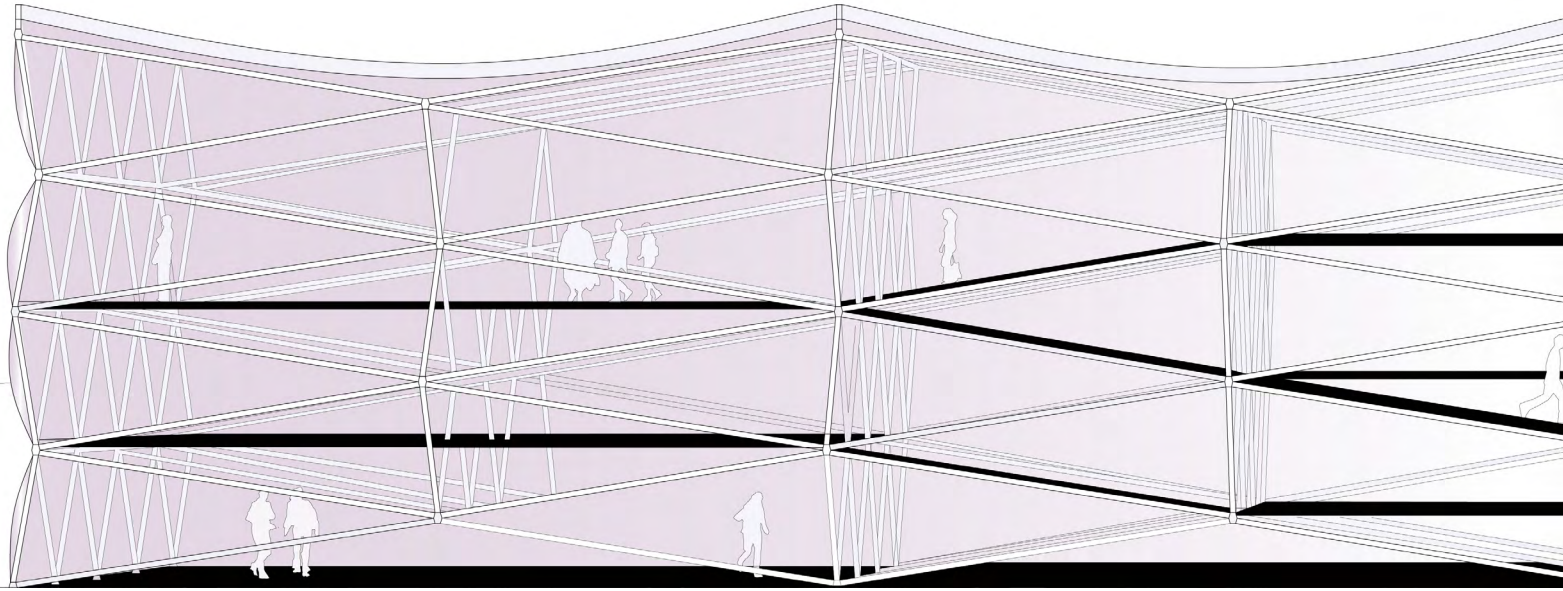
Flipped and stretched tetrahedrons

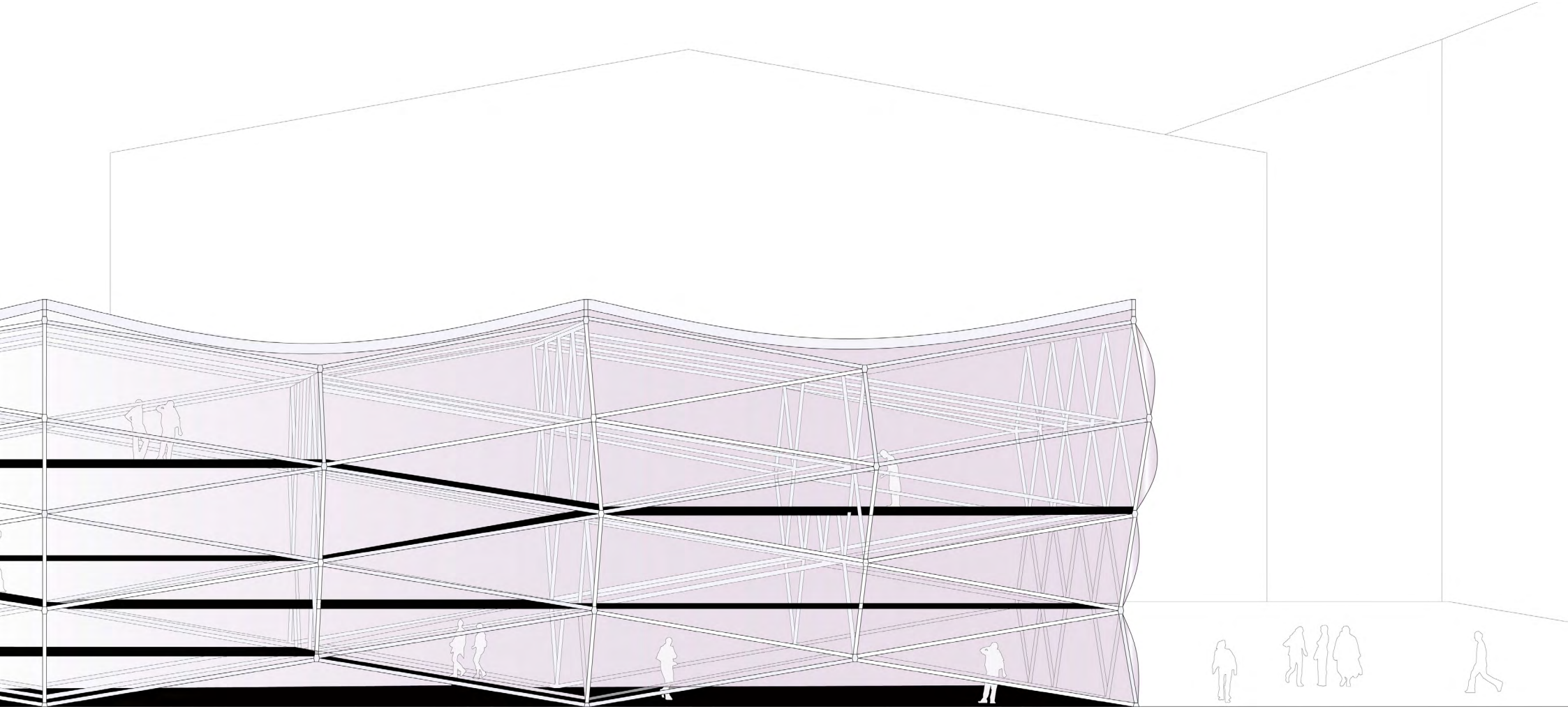




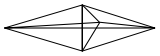






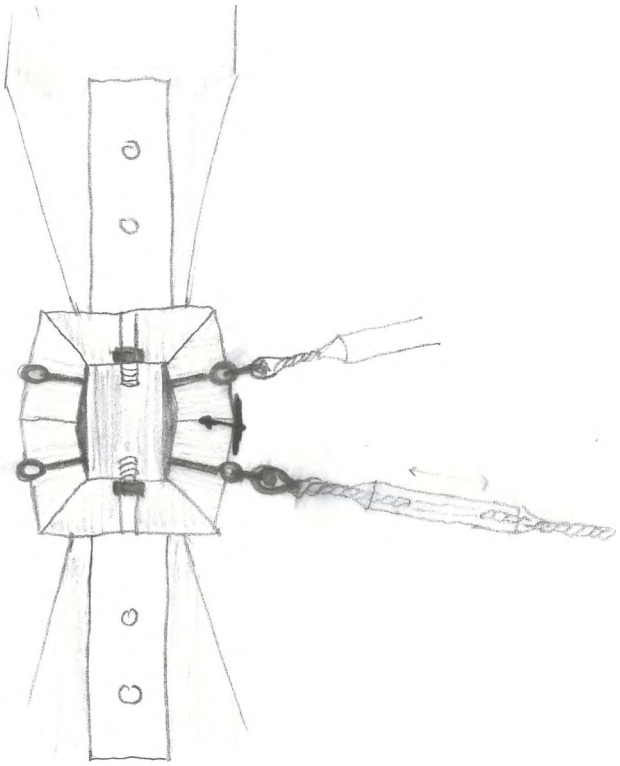


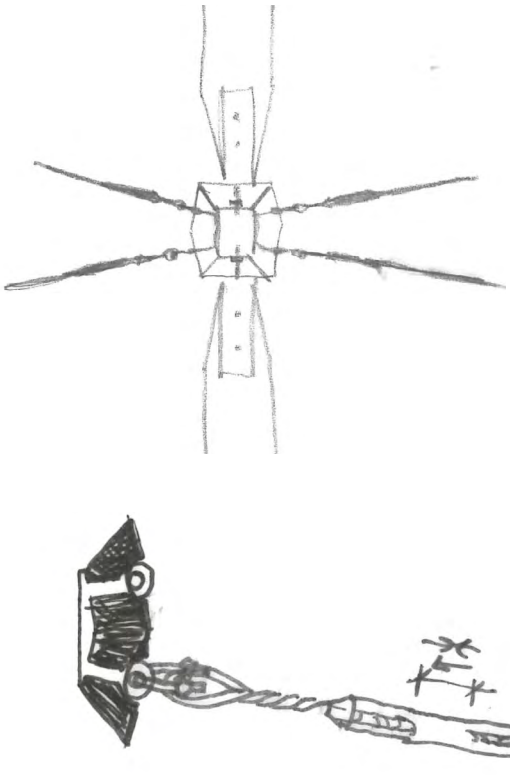
Using slabs for pre-tension

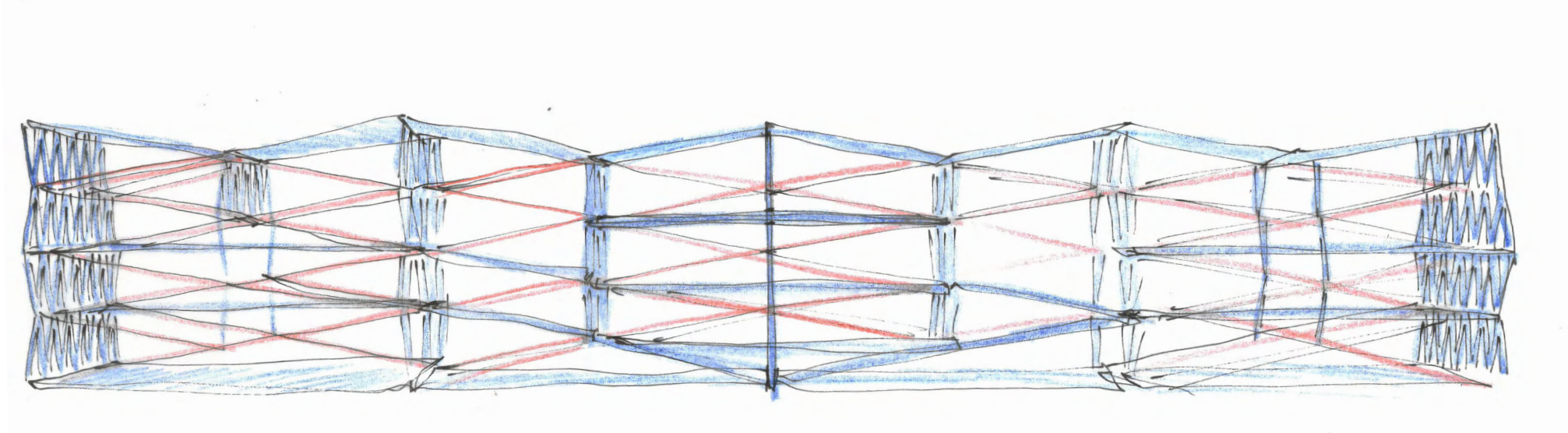


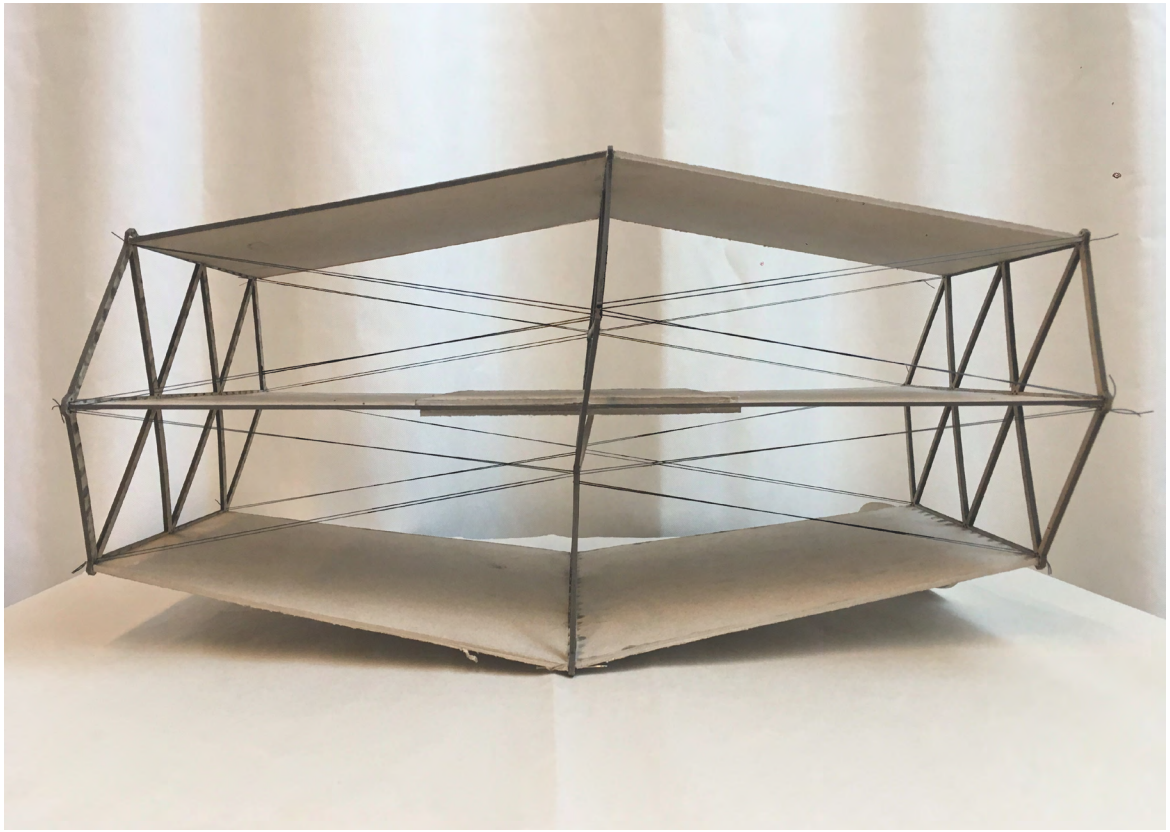
Testing out pre-tension, were the horizontal members work only in tension, using the slabs to push out the structure and horizontal wires tie it together.

This structure requires a lot of wires to stabilize, not leaving much usable space. It is also a building quite difficult to erect and not so robust.

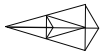




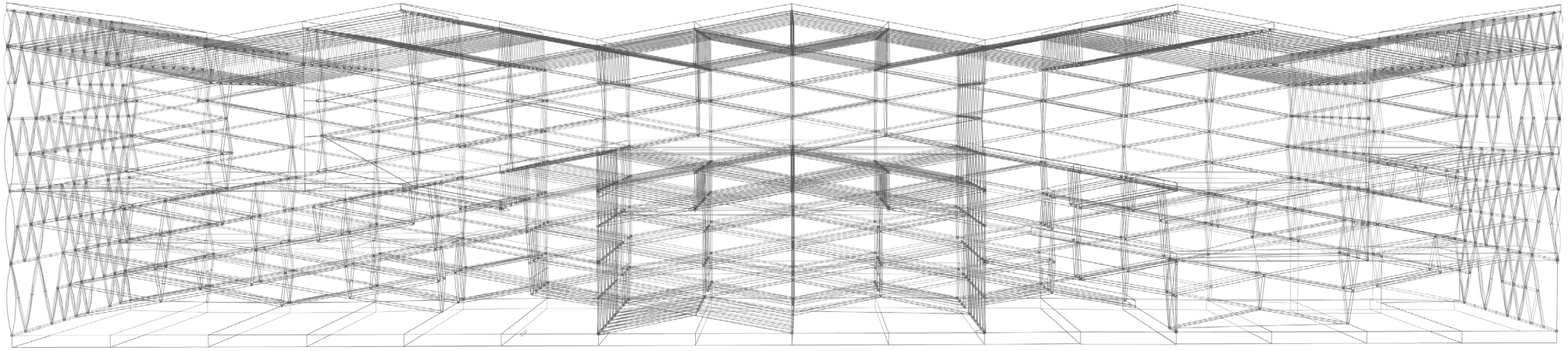


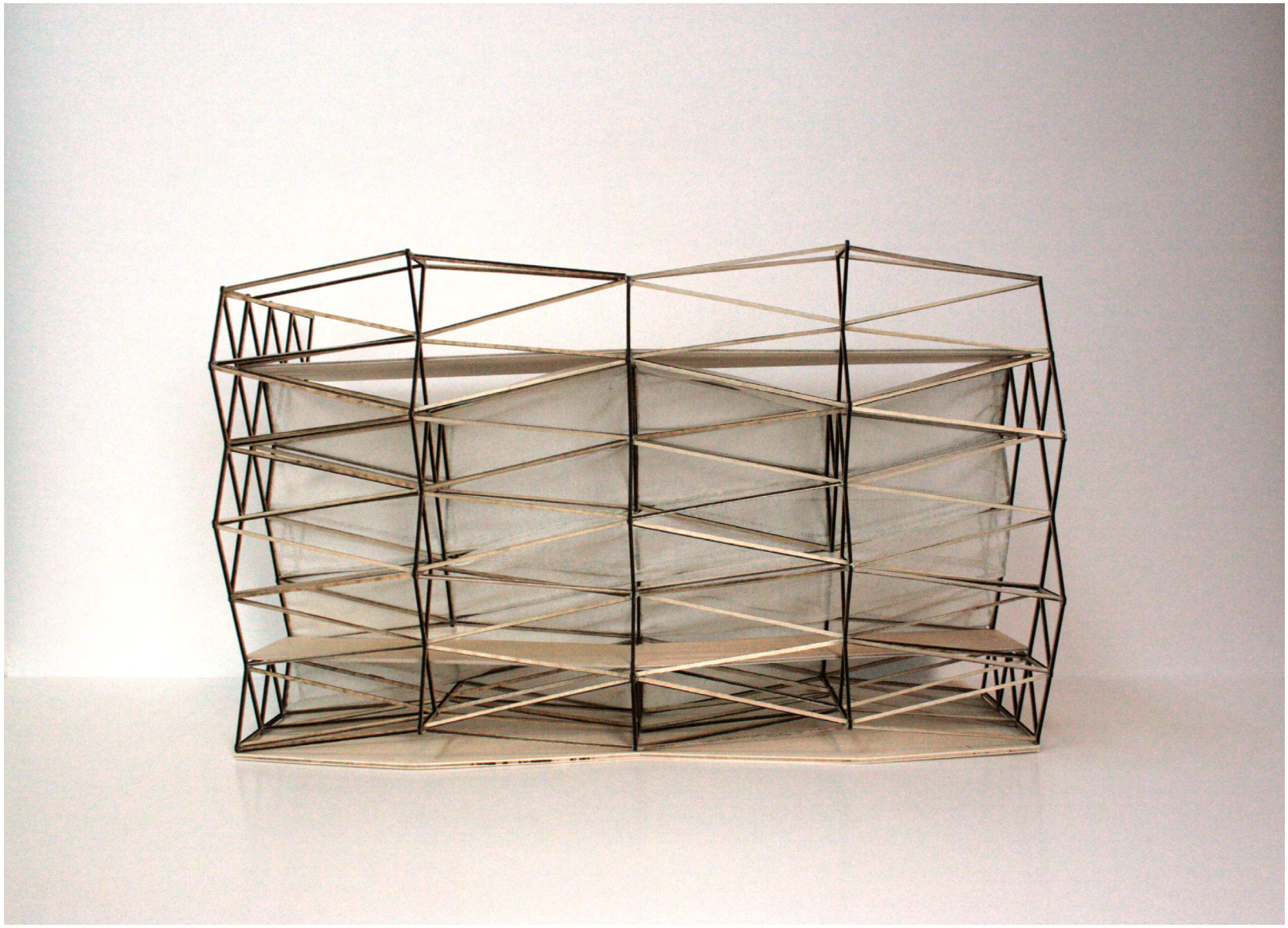


Stretched tetrahedrons in smaller scale



Back to the prior system but smaller in scale, lowering the length of the horizontal members. This system also proved to be more flexible, enabling a greater variation of spatial configurations.

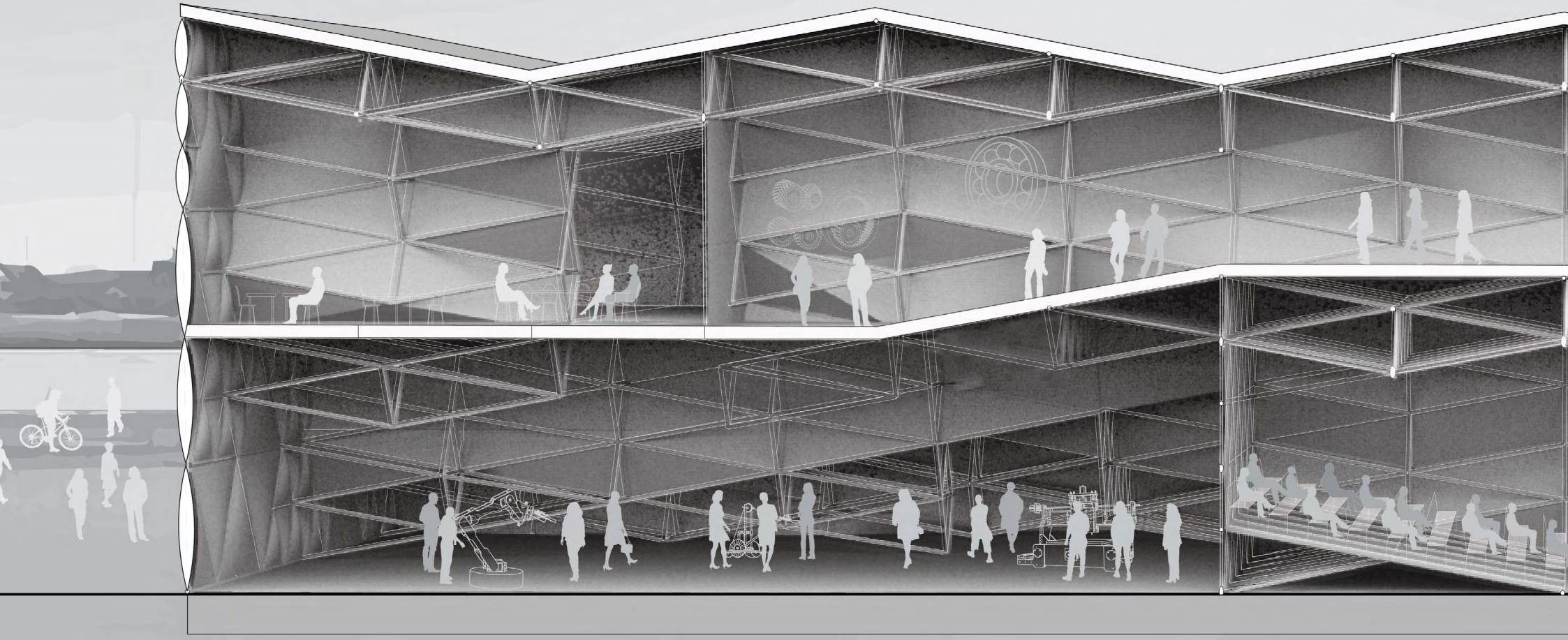


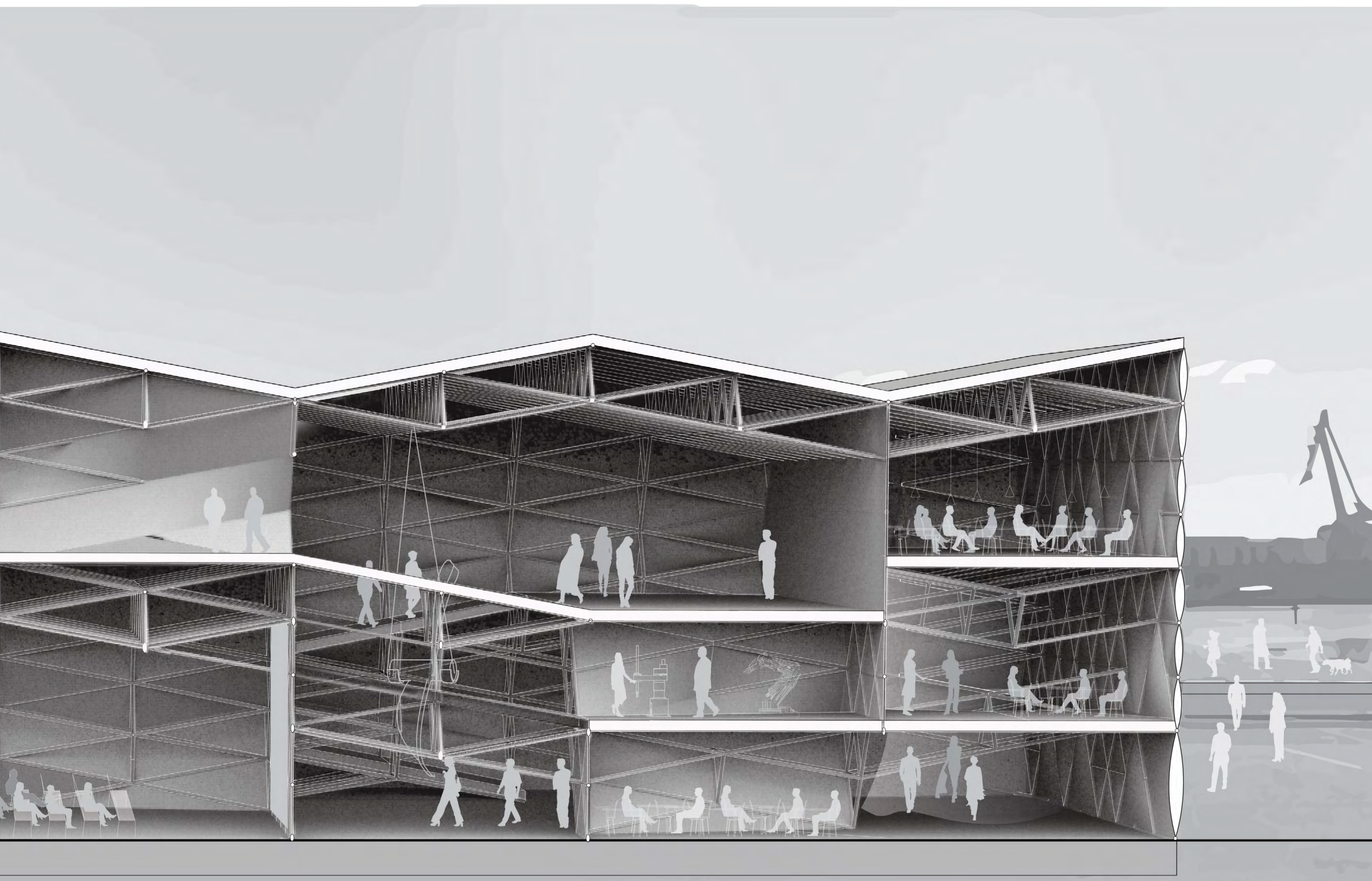


Proposal

Exterior view from Frihamnen

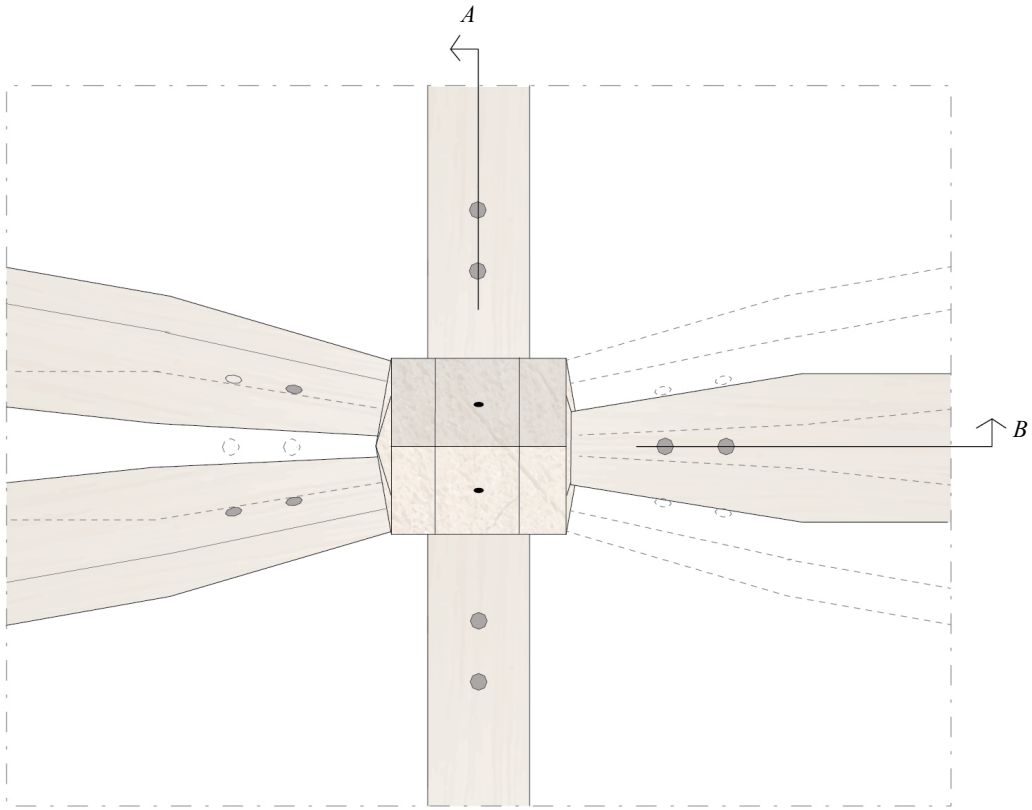
Section of final prototype



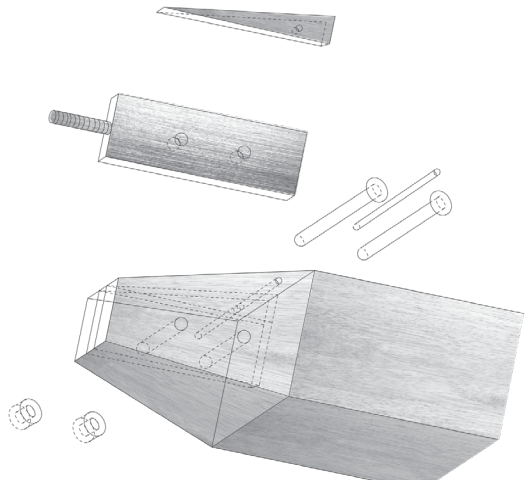


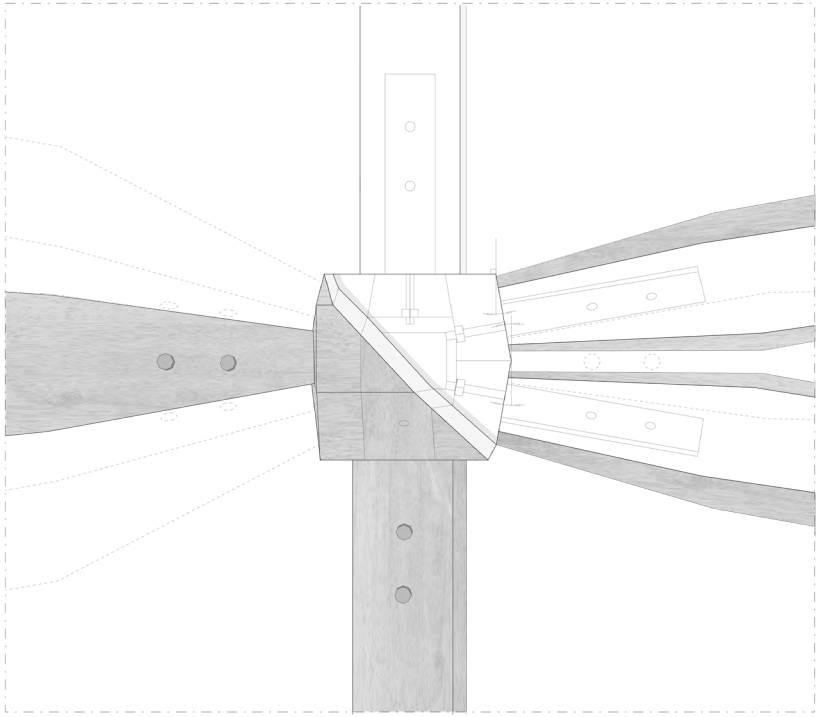
Joint

Steel-plates are connected to the wooden bars and screwed in to the joint, connecting to a hollow steel core embedded in supporting wooden parts. The wood fibres are directed towards the force of the connecting members.

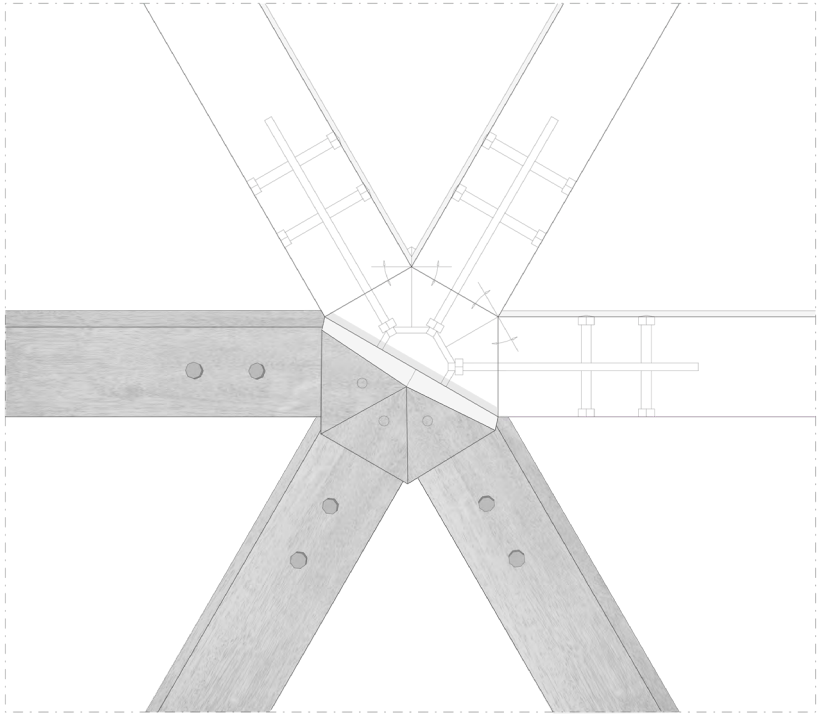


Plan view





Section B

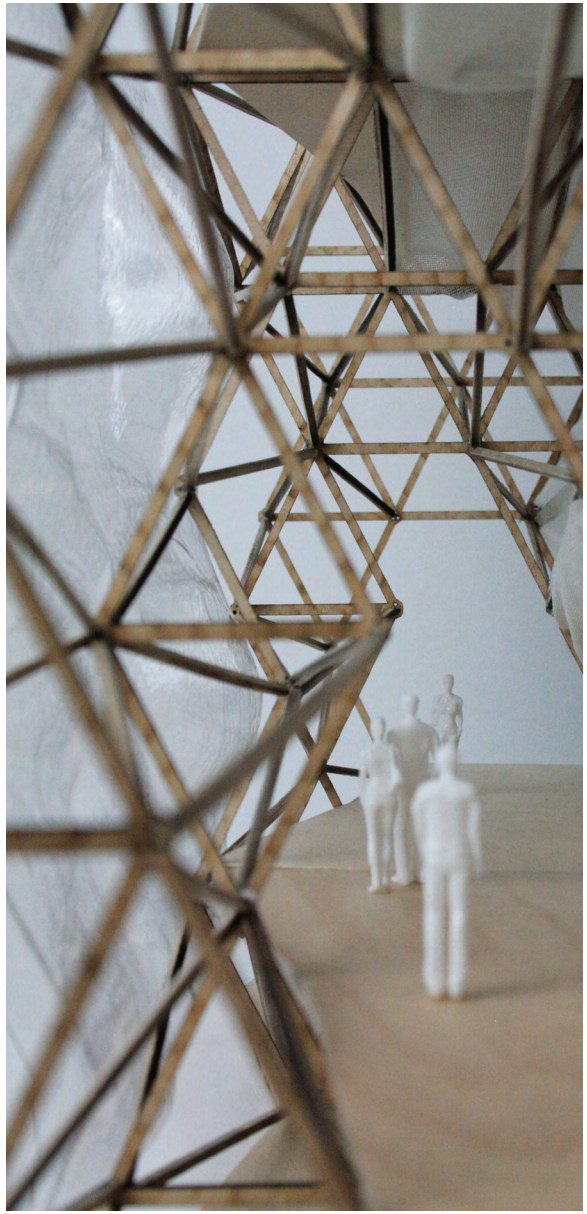


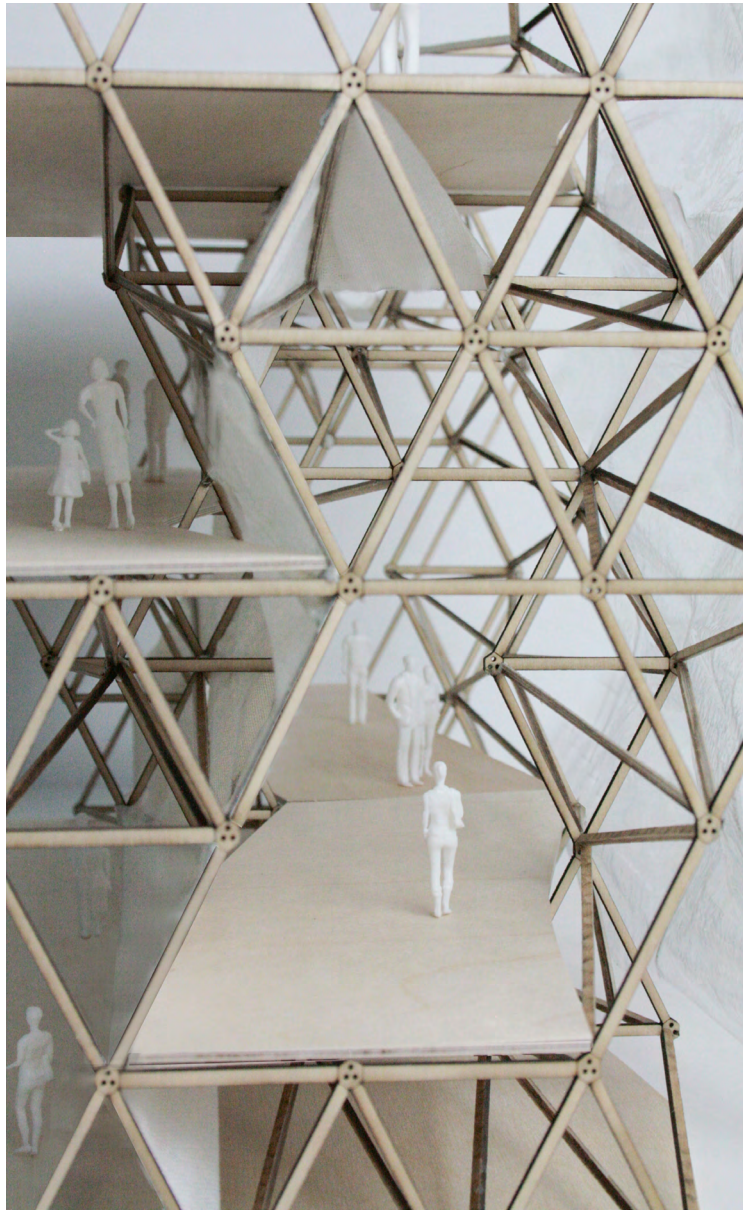
Section A

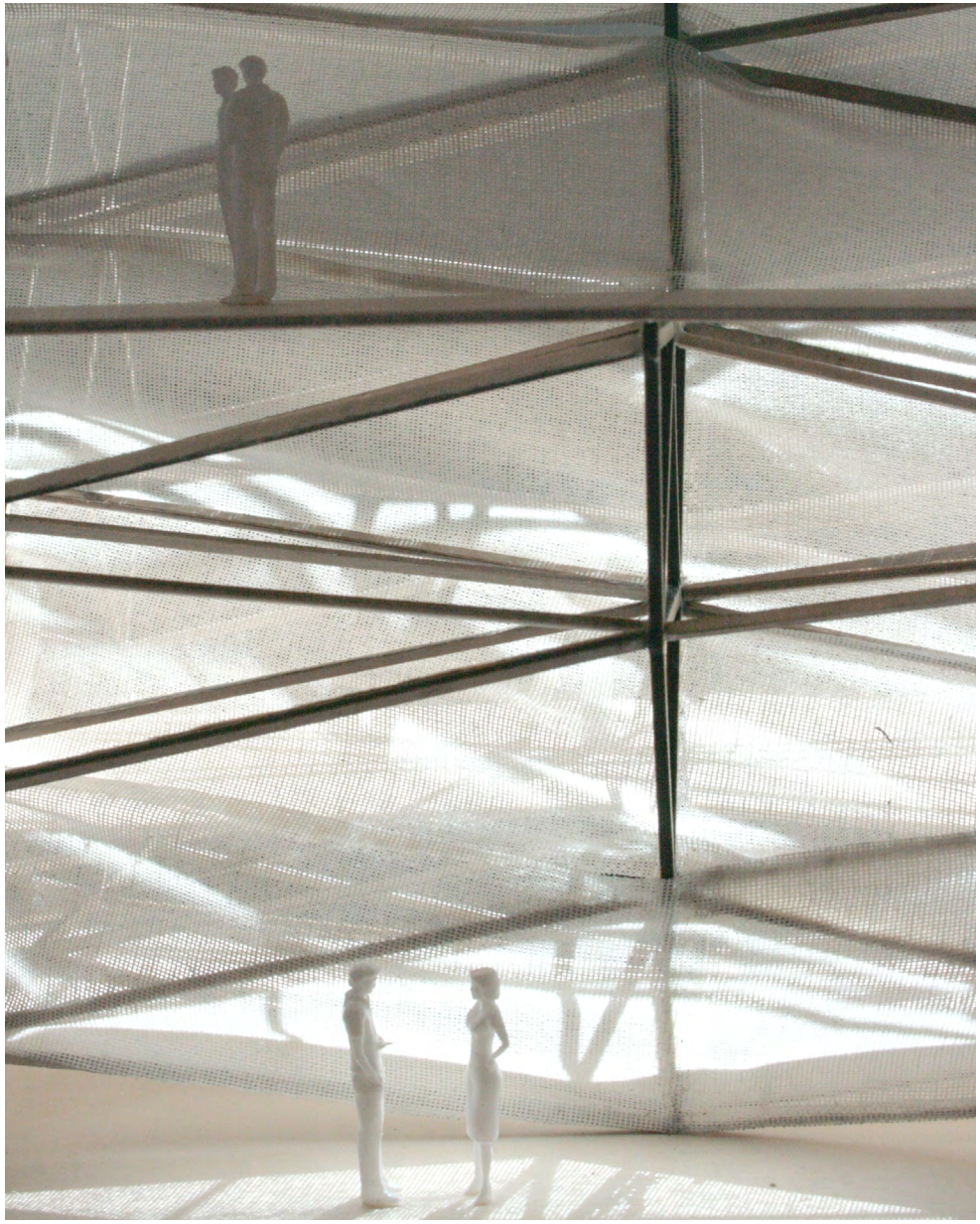
Soft Wall Addition

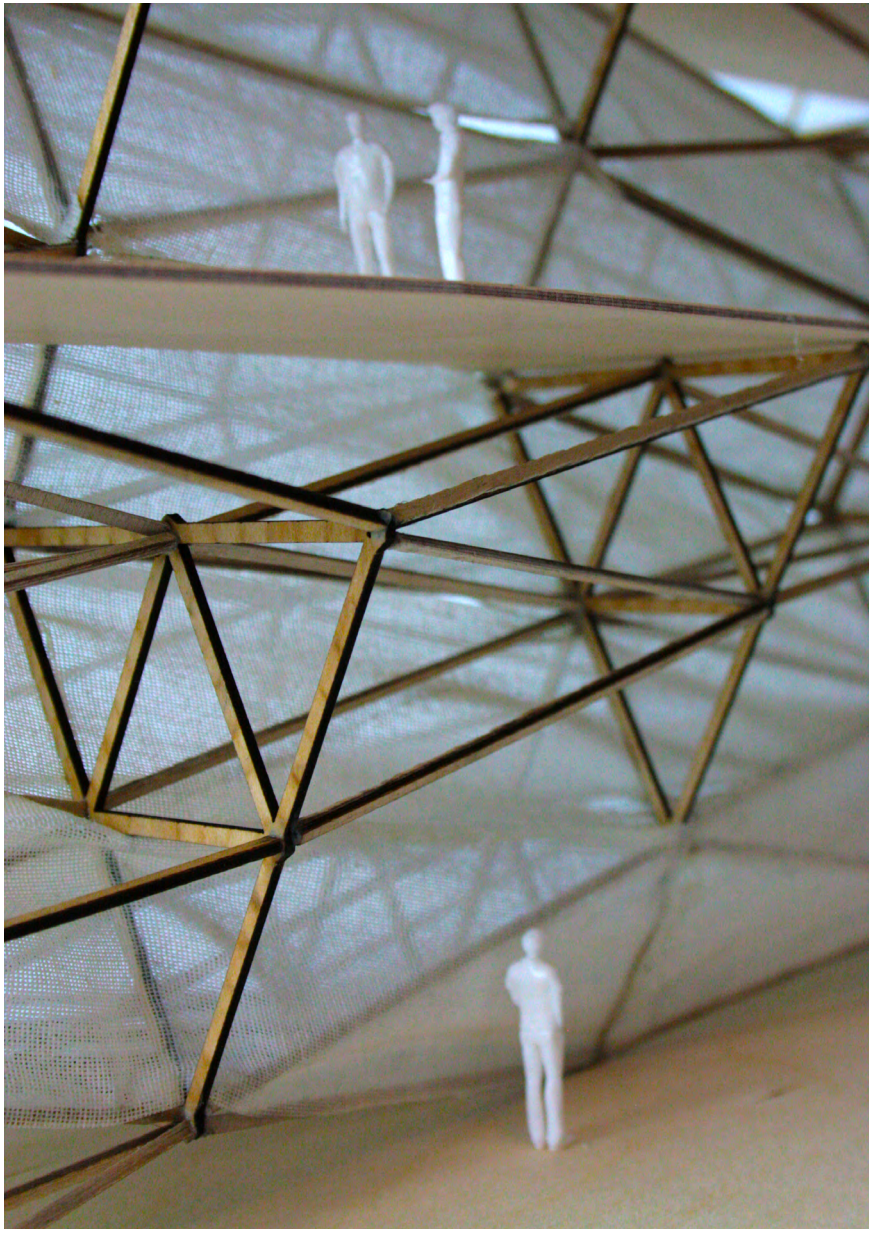
This proposal shows textile interior walls that softly follow the shifting directions of the structure. The draping contrasts the sharpness of the structure and contributes to the experience of a lightweight structure. The visitor can hint multiple layers of the structure deeper into the building.

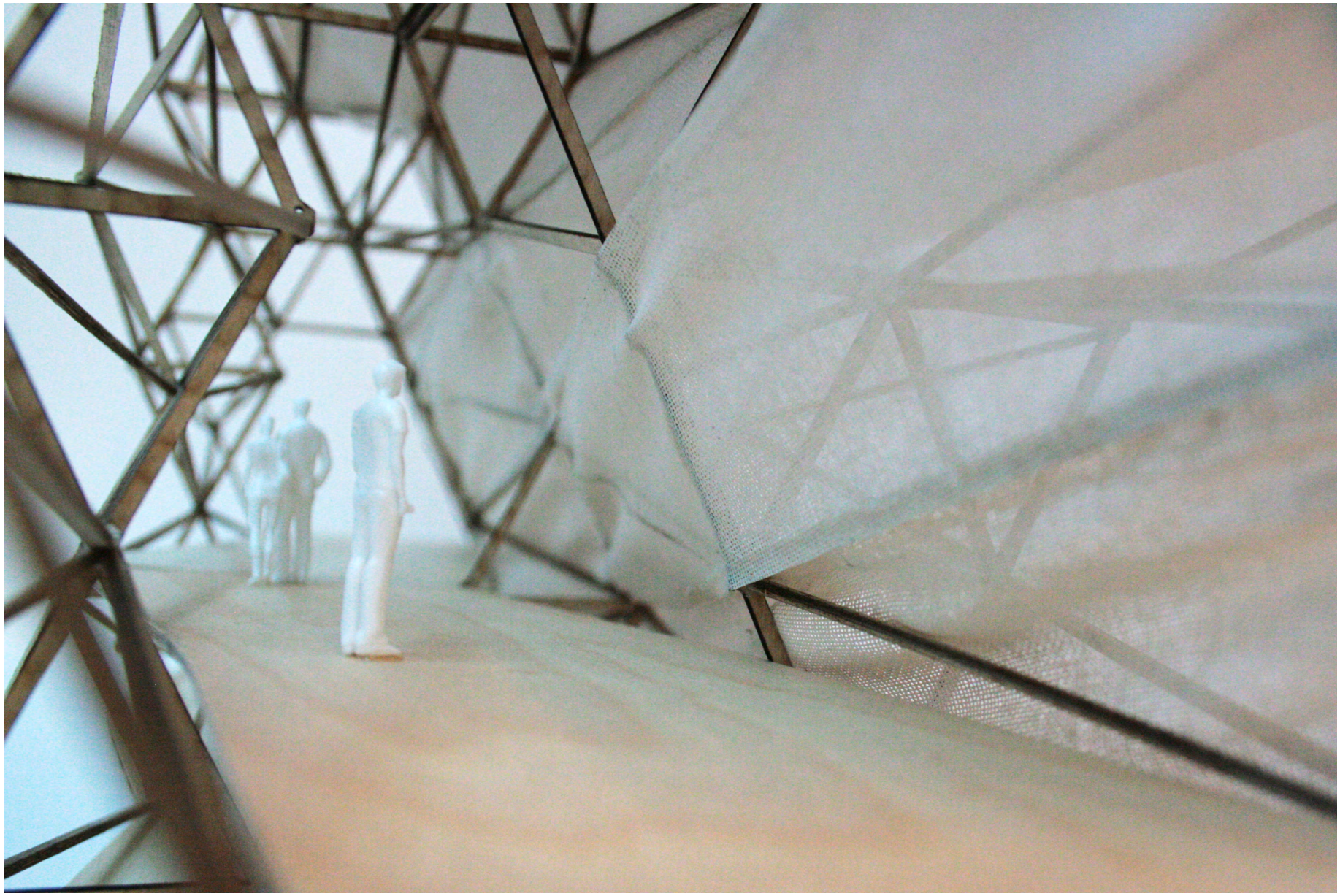
The facade is a system called ETFE, it is inflated plastic cushions that are fitted outside the structure. This is also a soft material that both contrasts the sharp contours of the building and easily follows the shifting boundaries of the structure



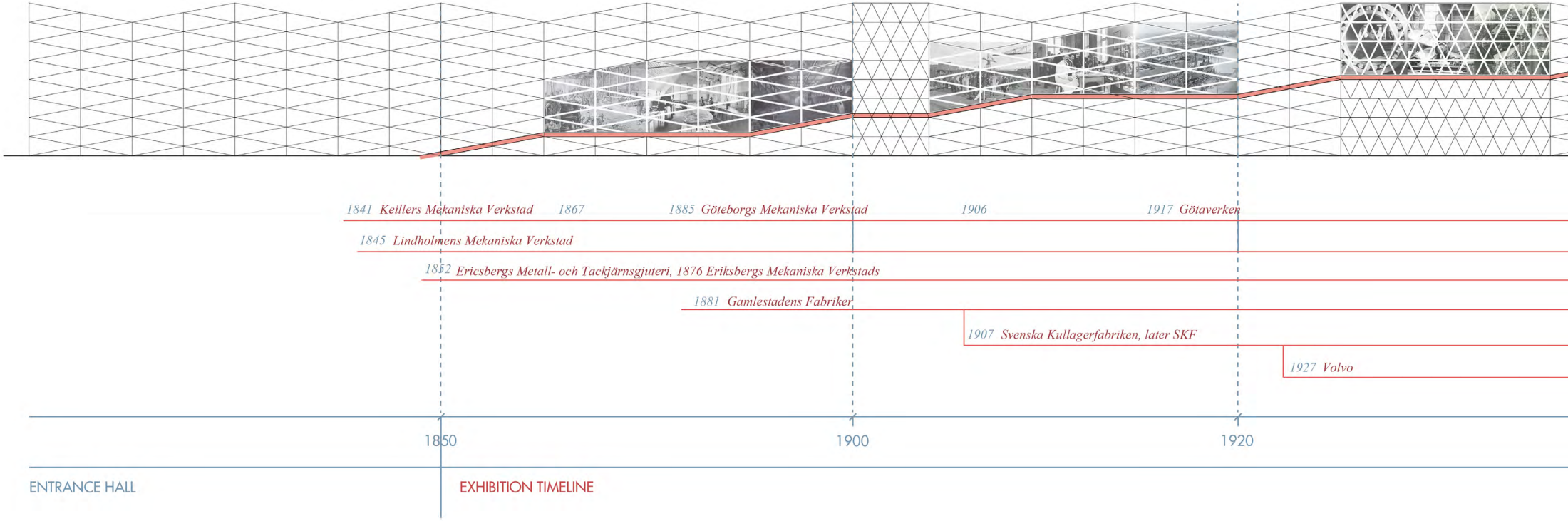


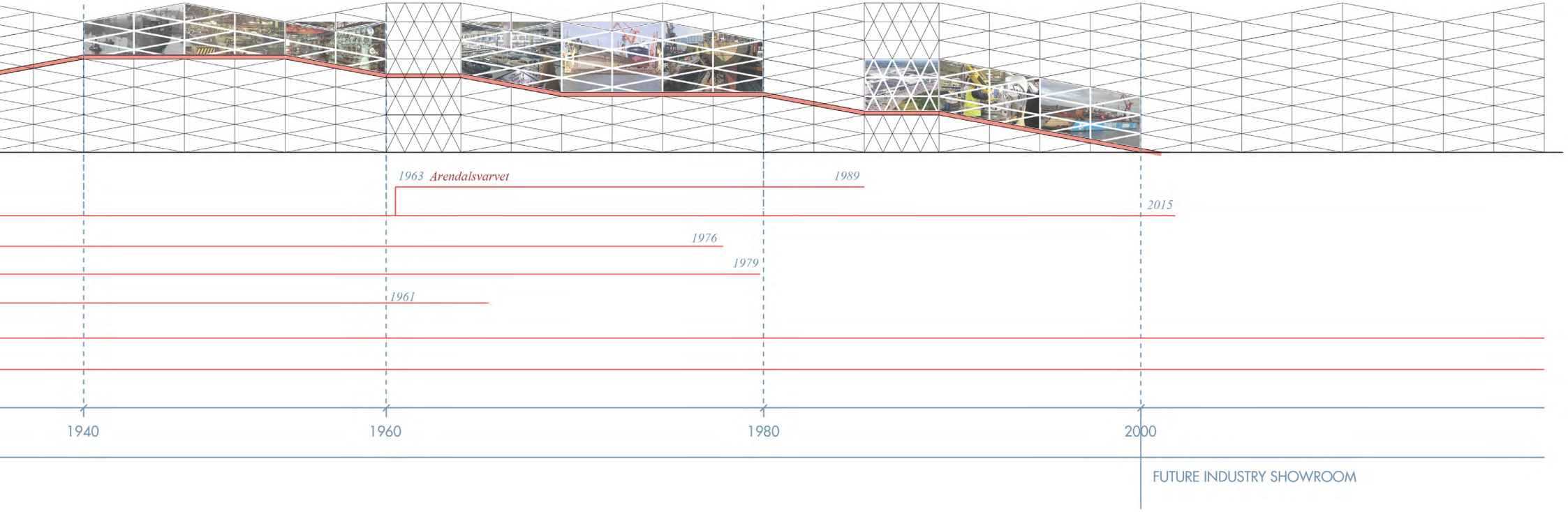




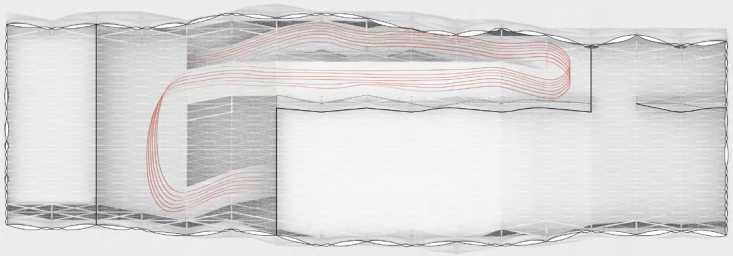


Section of Timeline

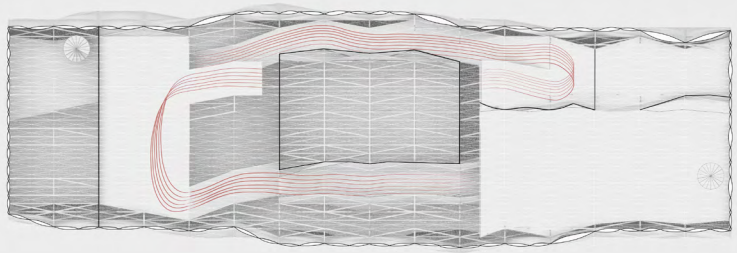



1963 Arendalsvarvet
1989
2015
1976
1979
1961
1940
1960
1980
2000
FUTURE INDUSTRY SHOWROOM

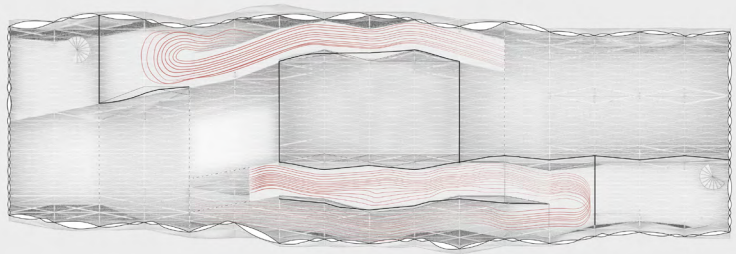
Plans / Isometric drawing



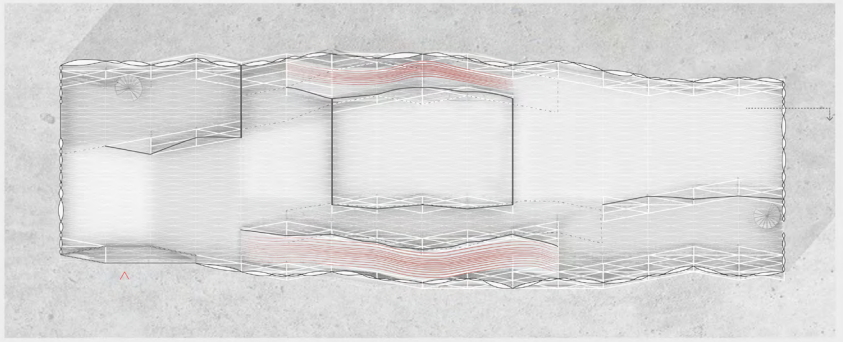
Level 4



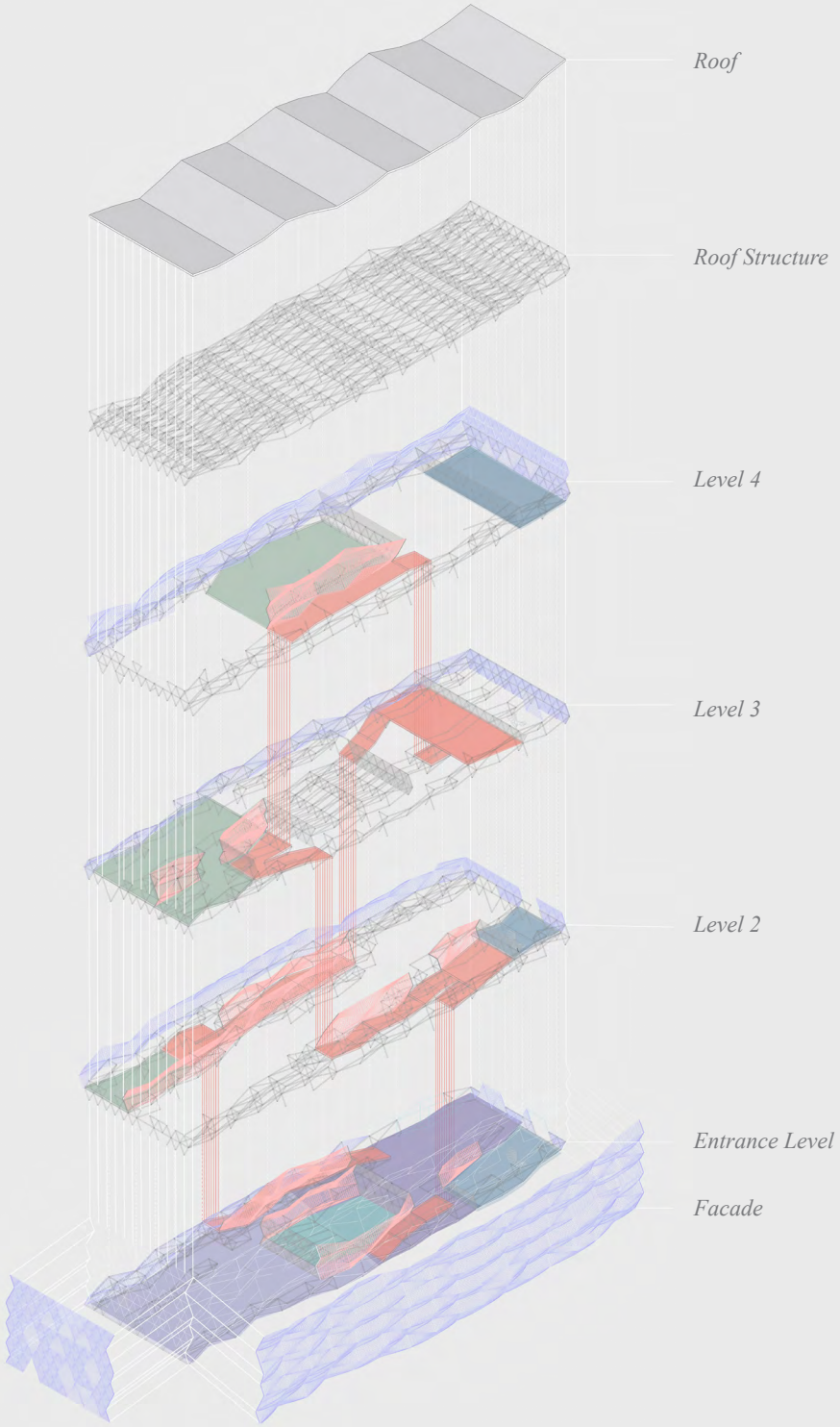
Level 3



Level 2



Entrance Floor



Textiles walls enclose the space highlighting the shifting directions shaped by the structure.

Wooden walls divide the space in the short direction of the building, were the structure allows planar divisions.

The facade is a ETFE system of inflated plastic cushions, following the angled contours of the building.

The timeline, an exhibition pathway around the building.

Entrance hall, open space with variation in celling height where were you have a good visual connections.

Large exhibition hall, big exhibition space connected to the entrance hall and the timeline.

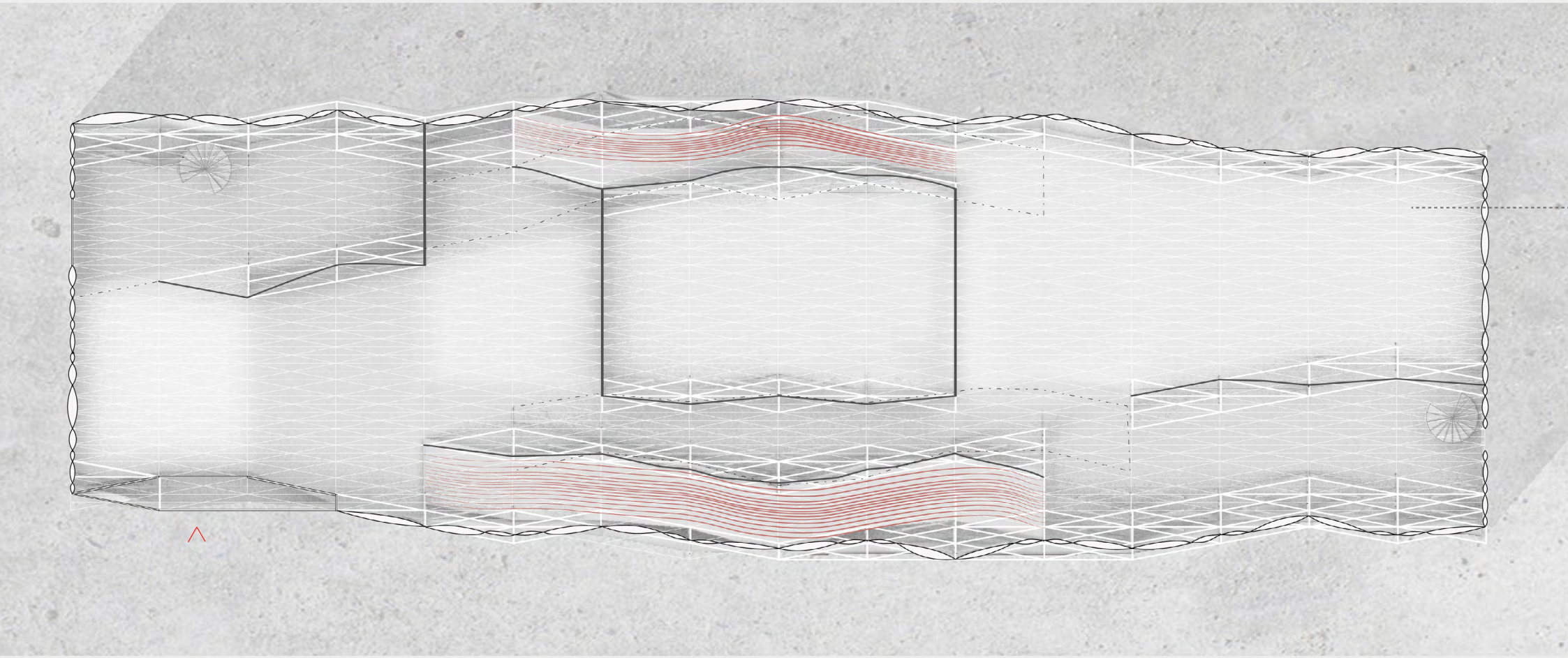
Small space with a view, a smaller space in three levels but without only connected to the entrance hall. This could for example be programmed as a restaurant or café.

Blackbox, a large enclosed space without daylight that could be used as a lecture hall for example.

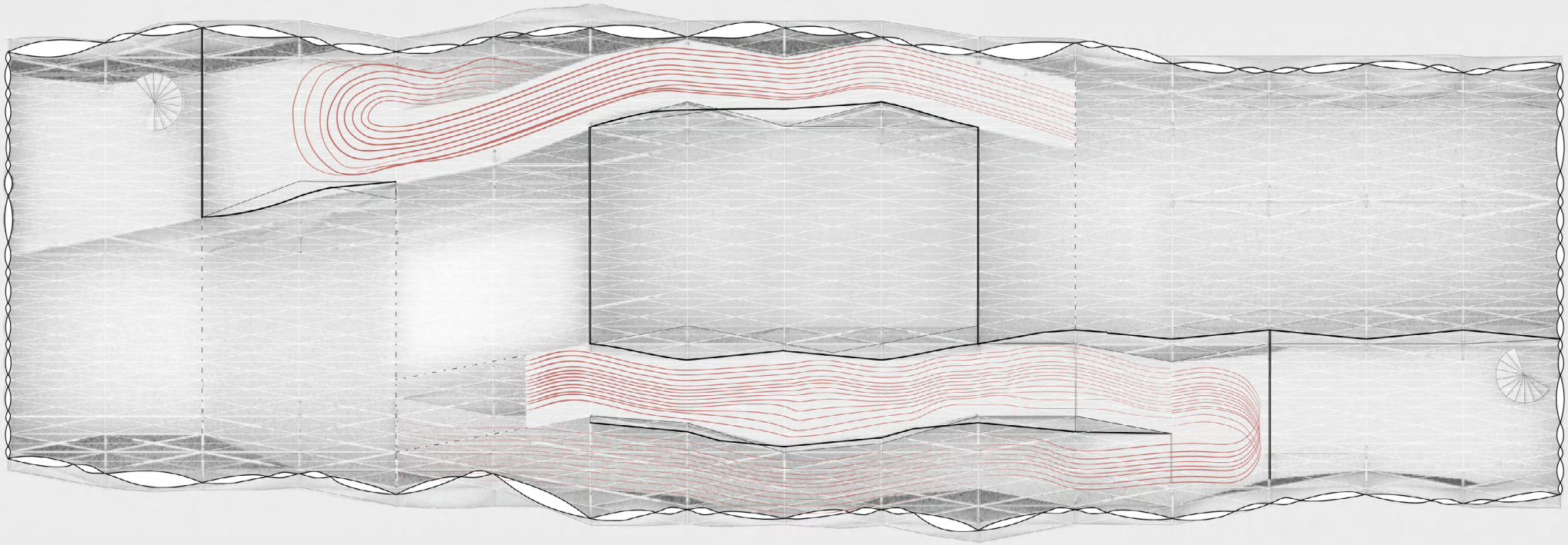
Large private space not integrated with the exhibition spaces. This could for example be used for office space, conference or educational space.

Plans

Entrance Level

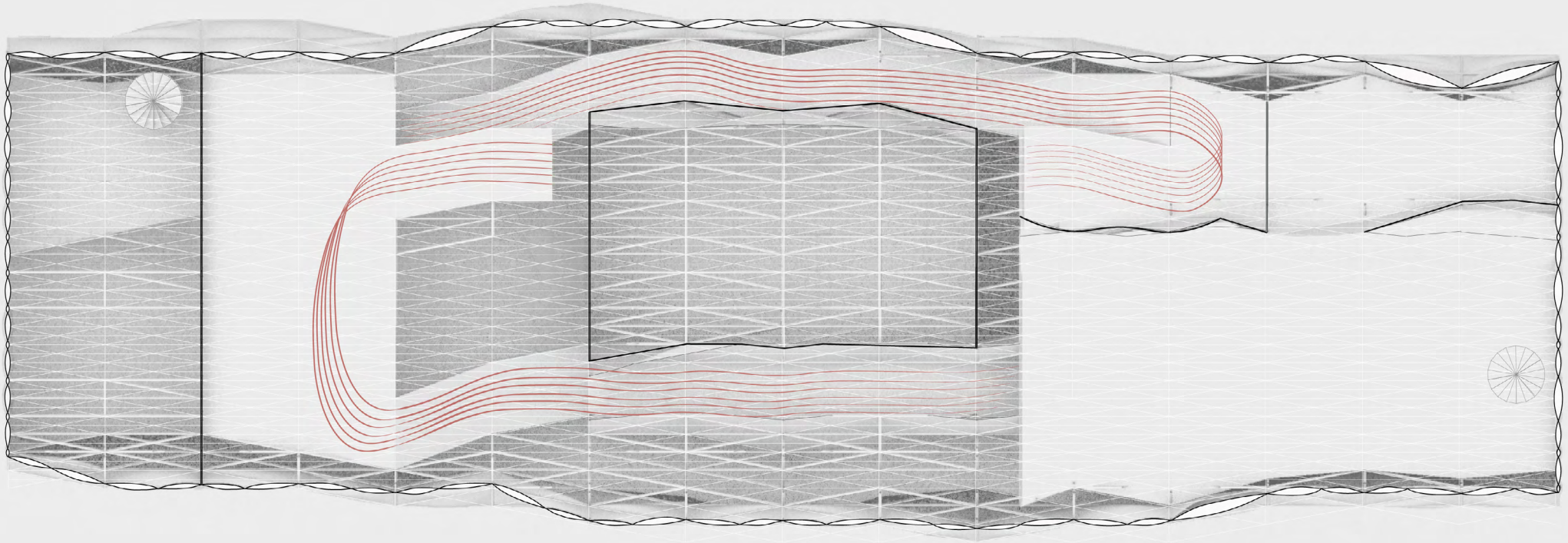


Level 2

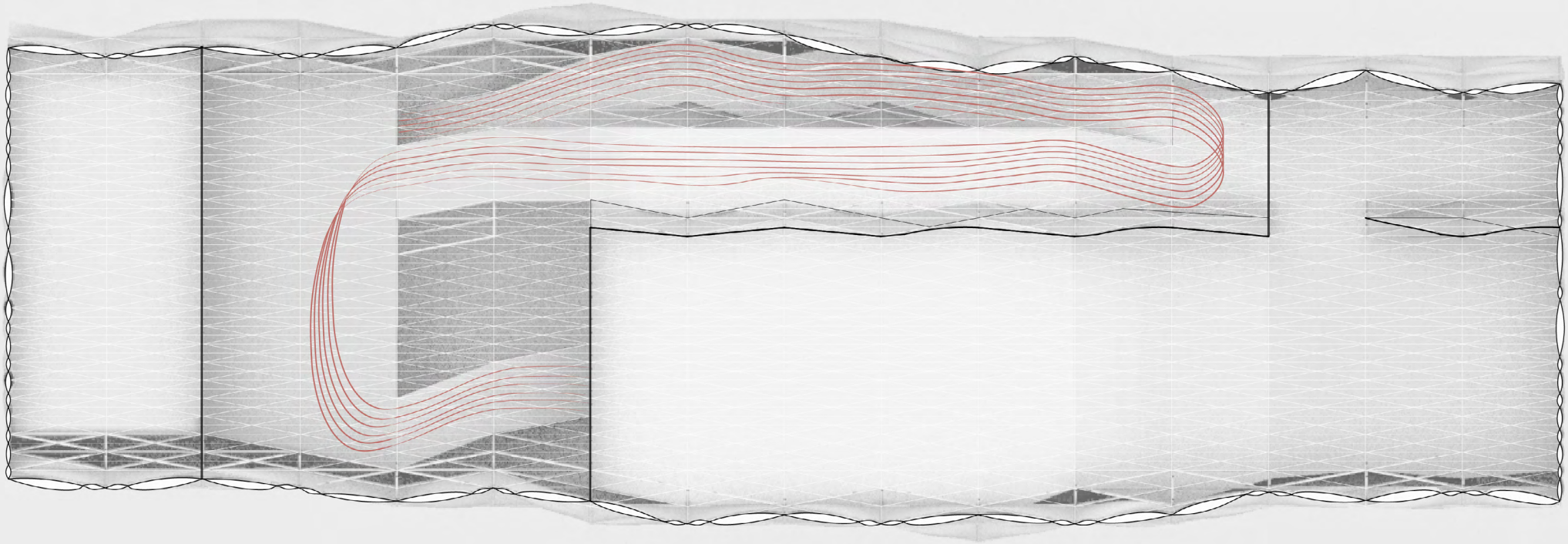


Plans

Level 3



Level 4



Conclusion:

The conclusions drawn from the research is that a building structure can be used as a tool to build up an architectural concept - by using an iterative process of refining the structure in several steps to create a space where the architectural intentions are integrated with the structural solutions, coherent with the program that fills it. However, this investigation is limited to a fragment of a program. If a more complex program would have been taken in to account this might become a more challenging method.

To summarise; a Space Frame is a spatially intriguing structure and through making use of its purely structural elements beautiful and potentially flexible spaces can be achieved.

Bibliography

Books:

Chilton, John. 2000. Space Grid Structures. Architectutral Press.

Frampton, Kenneth. 1995. Studies in tectonic culture. Cambridge; Mass. MIT Press.

Madsen, Ulrik S. 2008. Robust Arkitektur – arkitektur som en aktiv del af organisationers identitetsskabelseproces. Chopenhagen; The Royal Danish Academy of Fine Arts, School of architecture publishers.

McDonough , William. 2009. Cradle to cradle: remaking the way we make things. London; Vintage.

Sandaker, Bjorn N. Eggen, Arne P, Cruvellier, Mark R. 2011. The Structural Basis of Architecture. Routledge.

Sandaker, Bjorn N. 2007. On span and space: exploring structures in architecture. Taylor & Francis.

Web sources:

Arbuckle, Alex Q. Bell's tetrahedral kites [blog]. Retrieved from http://mashable.com/2016/02/10/alexander-graham-bell-kites/#Tk6pNco1a8qJ (2018-01-22)

Architectuul. City Tower. Retrieved from http://architectuul.com/architecture/city-tower(2018-03-14)

Dpr-barcelona (2010-01-29). Konrad Wachsmann [blog]. Retrieved from https://dprbcn.wordpress.com/2010/01/29/konrad-wachsmann (2018-01-22)

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