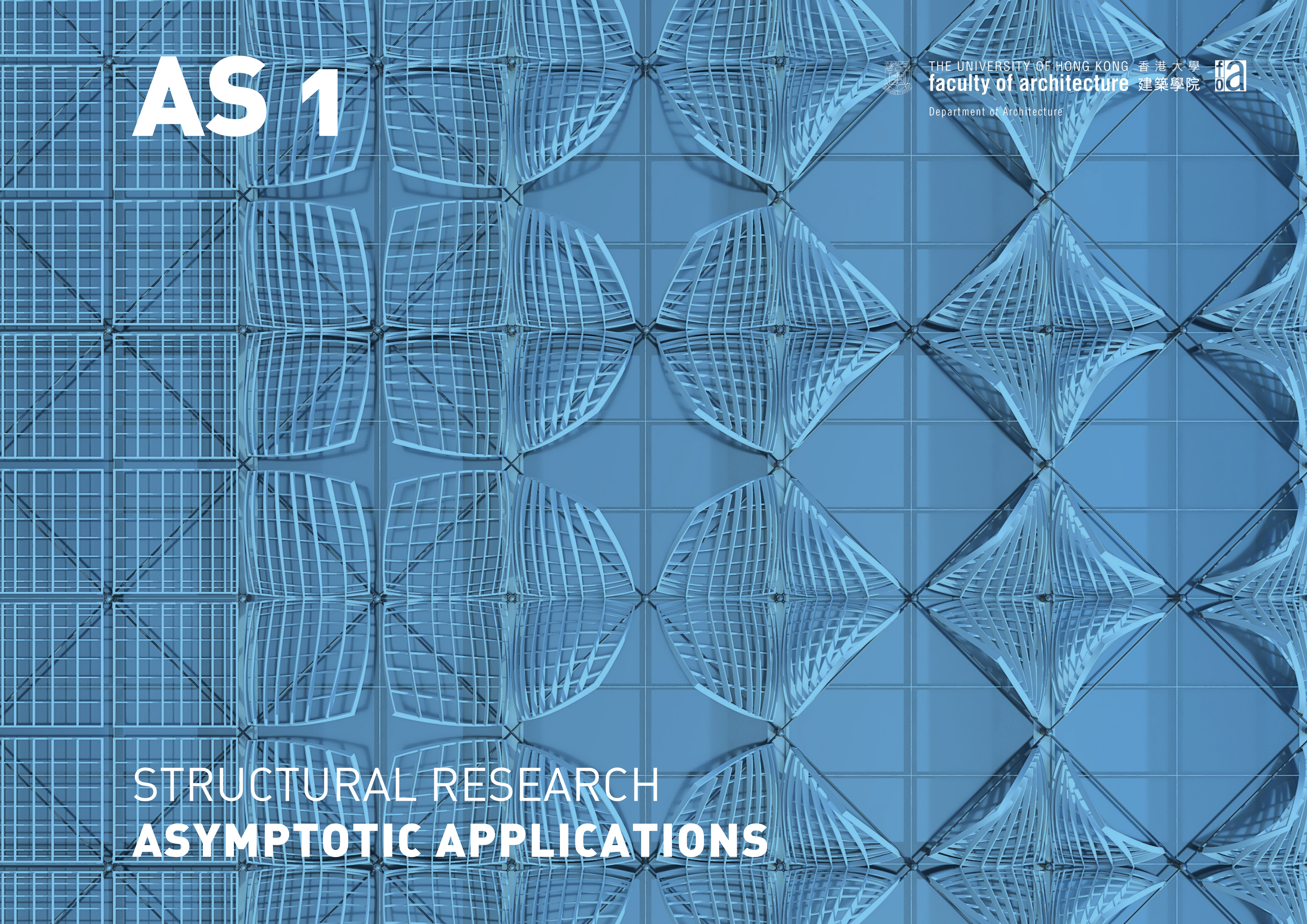

AS 1

THE UNIVERSITY OF HONG KONG 香港大學
faculty of architecture 建築學院
Department of Architecture

STRUCTURAL RESEARCH
ASYMPTOTIC APPLICATIONS

Publication Series
in Architectural Structures (AS)

The University of Hong Kong
Department of Architecture

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AS 1
STRUCTURAL RESEARCH
ASYMPTOTIC APPLICATIONS

Hong Kong, 2021

Title image:
Subin Park
Transformable Facade Sun Shading

Layout:
Sherene Ng
Eike Schling

ARCH7474

STRUCTURAL RESEARCH
ASYMPTOTIC APPLICATIONS

Spring-Semester, 2019/20
at the
Department of Architecture
The University of Hong Kong

Supervisor
Dr.-Ing. Eike Schling
Assitant Professor in Architectural Structures

TABLE OF CONTENT

PREFACE

This publication exhibits the work created by graduate and 4th-year-undergraduate students at the Department of Architecture, HKU, during the elective course „Structural Research" in the spring semester 2020.

This course specialized in the design and construction of doubly curved grid structures. Through analysis of existing structures and innovative research of independent hypotheses, students discover new potentials for digital design and fabrication. The course implemented a methodology of research-by-design, fostering self-responsible, creative research based on well-founded scientific principles. These principles were taught through theoretical inputs, hands-on workshops, model making and digital modeling of reference structures.

Due to the erupting Covid pandemic, this semester was taught completely online via Zoom, Conceptboard and Whatsapp. The semester consisted of two parts, Analysis and Design, in which students first examined reference projects and then applied their newly gained knowledge to propose new applications for asymptotic lamella construction.

The analysis focused on a variety of doubly curved gridshells, historical and modern, timber and steel, discrete and smooth, elastic and rigid. Students investigated their specific program and functionality, construction process, and detailing. Through tutorials, students learned how to conduct digital form-finding and model the spatial grids of their precedents. Finally, each student conducted a detailed curvature analysis. This research allowed the students to draw conclusions on the dependency of geometry and construction and deduce strategies to resolve the complexity of double curvature.

From this analysis phase, students developed their individual research-design concepts, looking for new applications of asymptotic lamella construction at all scales. These investigations ranged from elastic sun-shading to secondary facades, from cat cages to reusable formwork for concrete shells. Each proposal attempting to make full usage of the geometrical and constructive benefits of straight lamella construction. The design were detailed and visualized and high resolution.

Despite the short time and the highly technical subject, students managed to create architecturally and structurally sophisticated work investigating and designing complex curvilinear building envelopes.

This publication will first show all the analysis projects and then present the new design concepts.

Eike Schling

ANALYSIS

The Courtyard of British Museum, England
Subin Park

Fig. 1: The Courtyard of British Museum, England

Architect
Foster and Partners

Structural Engineer
Buro Happold

Completion
2000

Place
London, UK

Cost
100 million pound (1 biilion HKD)

Structural System
Grid Shell, 100m x 70m

Area
13,990 m2

Site

The courtyard of British Museum which is often referred to as the Great Court is located in London, UK.

On the south-east side, there is a museum's main entrance along the same direction of River Thames and the way to Covent Garden.

The Courtyard, British Museum, UK

Student:
Subin Park

Introduction

Robert Smirke, an English architect, designed British Museum in 1823, and the museum consisted of four wings with galleries surrounding a big rectangular courtyard. After the opening of British Museum in the mid-nineteenth century, the central courtyard of British Museum was an open garden with not much function until later the Reading Room with bookstacks was added to the courtyard as an extension.

There are about 6.7million visitors every year, and British Museum is a leading tourist attraction in the UK. In order to cope up with the original congested circulation system in the building, a brief was given to Forsters and Partners (architect) and BuroHappold (Engineer) to improve visitors' experience and value to the courtyard.
[1]

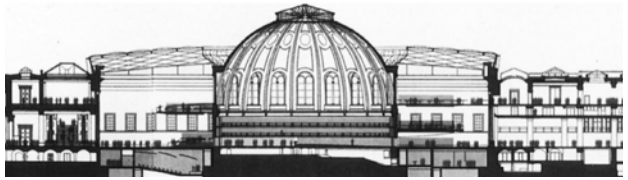


Fig. 2: Comparative section

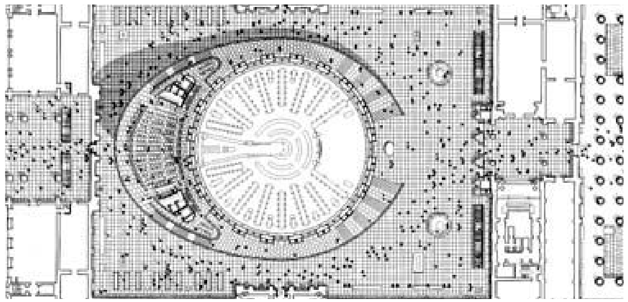


Fig. 3: Site plan

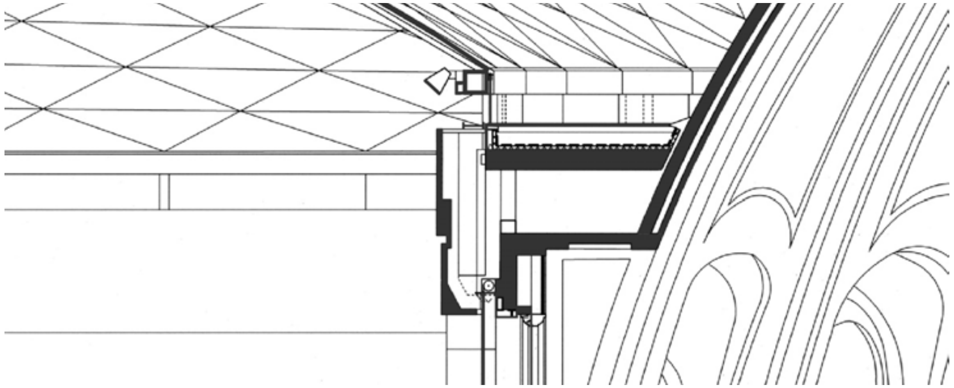


Fig. 4: Section through the primary structure

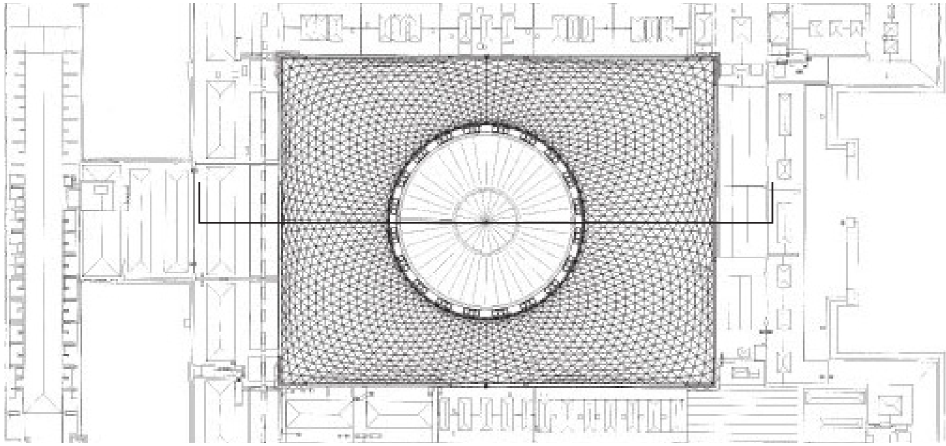


Fig. 5: Plan/top view of the primary structure

Fig. 6: Inside perspective

Architectural Concept

The annual number of visitors in British Museum is over 5 million. The museum´s popularity is as high as Louvre museum in France. However, the circulation system with no centralized circulation strategy created a serious congestion along the interior of the building affecting the experience of visitors to be unpleasant.

Hence, the concept of the courtyard as a new public focus as well as a flexible circulation space was developed by Foster and Partners.

The Great Court is entered from the museum´s main level and connected to all the galaries along the coutyard, while it is covered by a glazed canopy that is made possible with the most updated technology and engineering for its form and structure. The roof is of an irregular form spanning between the circular Reading Room and the courtyard´s facade.

4,878 steel members with 1,566 unique nodes and 1,656 pairs of glass window makes up 6,100m^2 of the roof glazing. [2]

Functions

The Great Court now serves not only as an internal circulation route but also as a pedestrian route connecting from the British Library to Covent garden and the river and the South Bank. It connects the outside public places.

Inside the Great Court, there are several information points, bookshop, and cafe. The Reading Room in the middle is also an exhibition space with the staircases encircling around it to have the visitors to the exhibition gallery and restaurants.

Typical Joint

The typical roof joint has a rectangular hollow steel profile. 5162 steel beams of the roof intersects at 1826 nodes that are unique at every node and in 6 directions. The roof glazing is tinted with frits covered on the curface in order to prevent excessive solar gain and glares. On top of the steel beams, there are bolts connected to the steel capping above and finally fixed with the glazing. The joint is closed with the steel node on top. [3]

Fig. 9: Photo

Typical Support

The roof is sitting on the masonry walls that are load bearing at the perimeter of the roof. The roof is further connected with short steel columns which are sitting on a newly added reinforced concrete parapet beams. In order to avoid later loads affecting the quadrangle buildings, there are sliding bearings to support the roof. The sliding bearings allow some movement for the structure during temperature changes or under the snow piles. It helps spreading the loads vertically along the facade of the building. [3]

Fig. 12:Photo

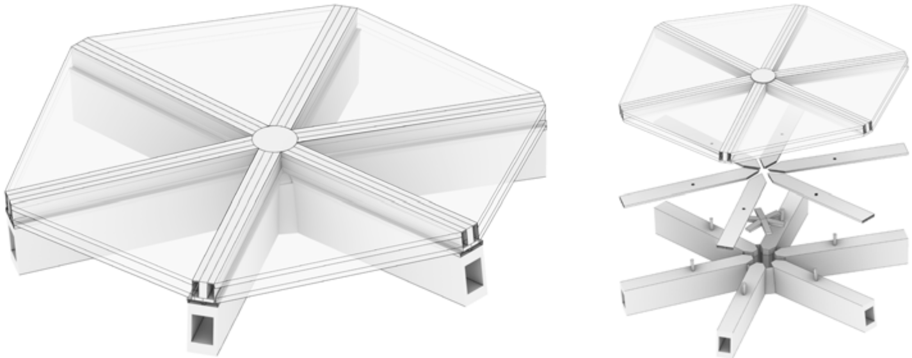


Fig. 7: Axonometric of typical joint

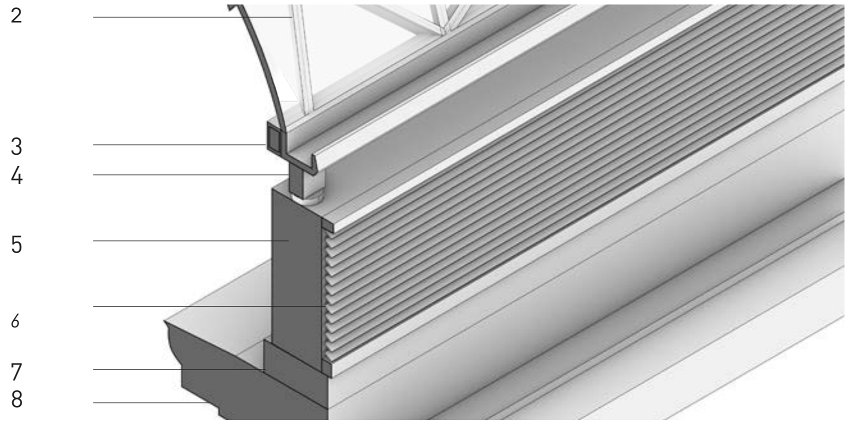
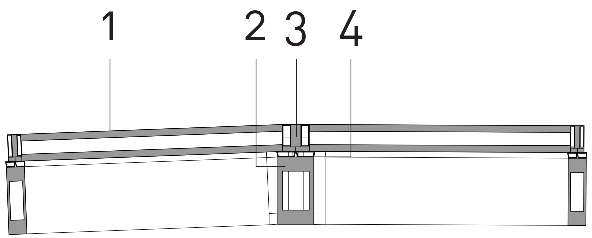


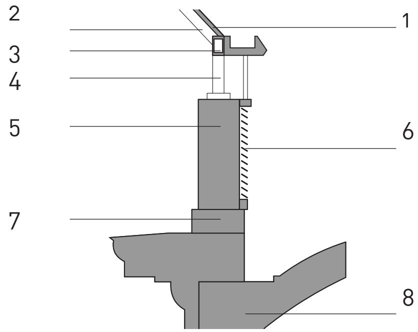
Fig. 10: Axonometric of typical support



Elements

1. Double glazing
2. Steel beam
3. Capping
4. Bolts

Fig. 8: Detail of typical joint



Elements

1. Roof glazing
2. Roof beam
3. Roof perimeter beam
4. Steel post
5. Sliding bearing
6. Ventilation louvre
7. Concrete ring beam
8. Existing stone

Fig. 11: Detail of typical support

Construction

Before the beginning of the construction, few thousands of steel members were manufactured by Waagner Biro in Vienna. These materials were shipped for the pre-assembly into a row of sections that looks like ladders. These memebrs were moved to the site by crane and welders help weld the ladders to make the main structural grid. In order to prevent the welding failure as much as possible, a high grade of steel was used which is usually used for marine. [3]

Fig. 14: Photo (before the construction)

Construction Process

A. August 1999, The temporary props suported the individual ladder-like sections and these ladders were welded on the site.

B. November 1999, The pre-assembled ladder sections made up the roof, and these sections were tranferred to the site for 6 month.

C. April 2000, The roof was nearly finished, and the construction deck supporting the roof were taken down.

D. July 2000, FInally the roof glazings were fixed on top and the construction was completed. [3]

Fig. 13: Photo (after the completion of the building construction)

Fig. 15: Construction process A, B, C, D

Design shape

The Great Court's roof is supported along the Reading Room and the surrounding exhibition area which has a rectangular boundary. The roof sits on the sliding bearings to prevent the lateral thrusts on the existing building. Hence, the roof pushes it load outward at the corners of the structure, and the load is resisted by the tension along the edge beam.

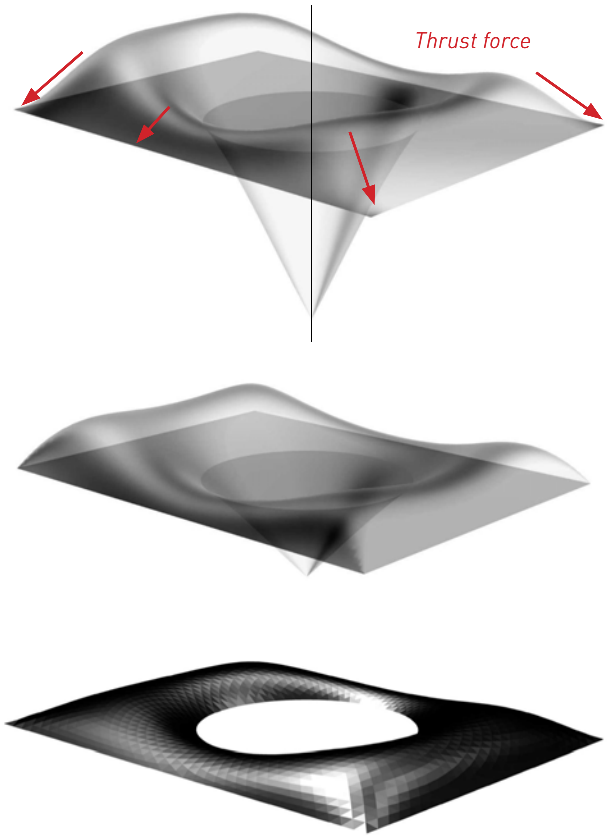
Parameters

The surface is arching up along the rectangle edges in the outer perimeter, and the origin is on the vertical axis through the center of the Reading Room.

The curvature approaches the tip of the cone, and it makes the roof arching up too high which may lead to architectural and structural problems. Therefore, the next step with shorter cone at the center was performed to control the arching of the roof.

Results

The structural grid went through many steps to achieve the grid on the right side. Initially, the grid touches the rectangular perimeter unsatisfactorily wherein some triangles are cut and sometime quadrilateral. The middle drawing shows the next step taken to resolve this problem, but it is still very rough. The final step was taken by equally spacing the rectangular boundary and the reading room boundary, then the radial lines are formed. These lines are then equally divided into segments. The final grid is produced from the mathematical grid by joining the points of equally spaced segments.



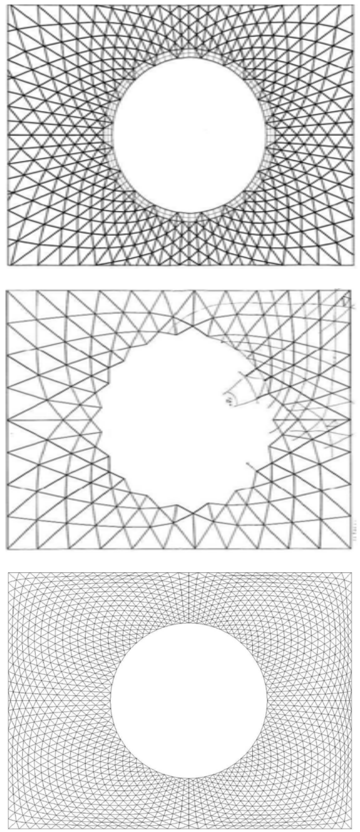


Fig. 16: Structural behaviour and form finding workflow

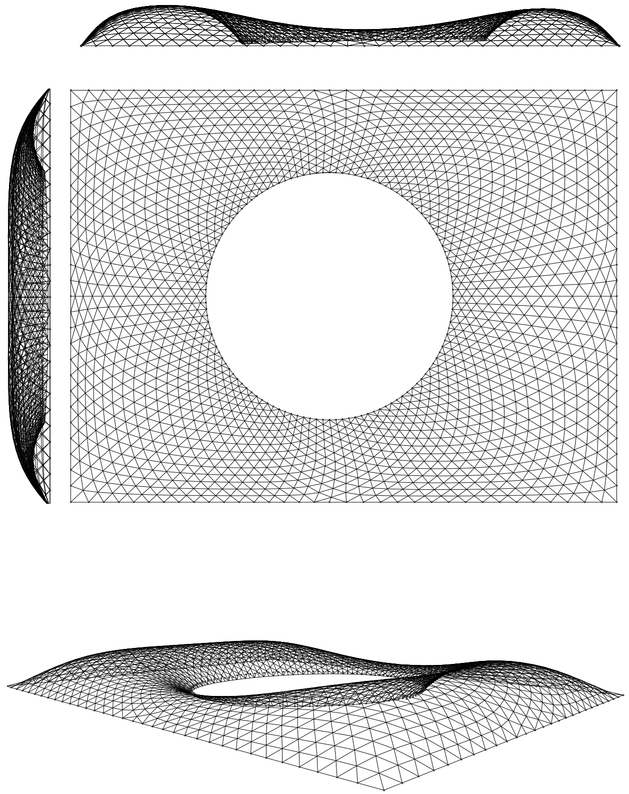


Fig. 17: Centerline model

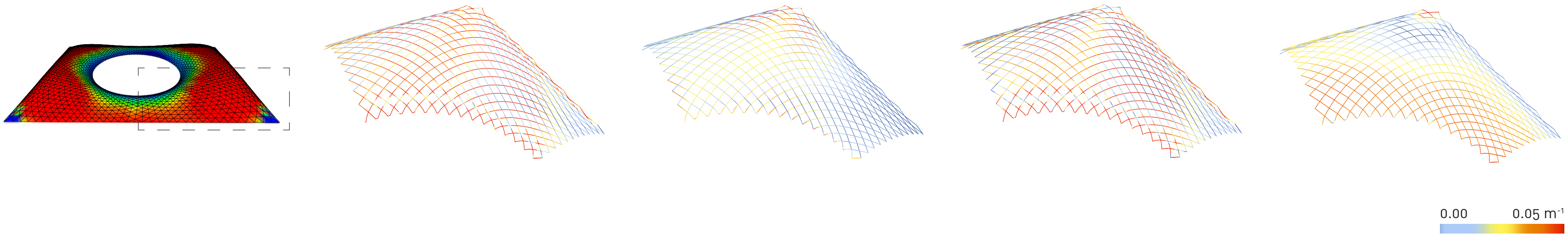


Fig. 18: Curvature Analysis

Gaussian surface curvature K

From the overall geometry of the roof, a quadrant is chosen to run the curvature analysis due to the capacity of the computer used. The surface has both postive and negative curvature while curves are mostly in positive curvature.

Spatial curvature k

The spatial curvature is at the lowest in the blue area while approaching to the outer support at the edge there is a higher curvature k (in red) with thrust coming down to the edge.

Normal curvature k_n

The red area indicate where the surface is curving the most, while the blue area is relatively less curved. Near the edge of the structure, the surface is curved more in order to withstand the load of the structure members at higher level.

Geodesic curvature k_g

The geodesic curvature at the nodes are not curved much as indicated in blue, while the outer perimeter and circular edge may be curved more as indicated in red color.

Geodesic torsion □$_g$

The geodesic torsion occurs near to the corner of the roof where line curves dramatically to reach the supporting point at the outer perimeter which shows again the thrust force is strong towards the edge of the rectangular boundary.

Fig. 19: Photo

Summary

The roof of the Courtyard at the British Museum, London is a gridshell structure with double curvatures containing both positive and negative curvature. The structural grid in which the geometry is based on has gone through dynamic relaxation method wherein the process of finding the nearest points around a node and finding the middle point to find the smooth curvature surface as possible. This well prevents sudden kinks on the surface and has an aesthetic benefits. Structurally, the forces are transmitted smoothly and the angle at which the forces come down are more consistent.

Bibliography

[1] "Queen Elizabeth II Great Court." BuroHappold Engineering. Accessed February 15, 2020. https://www.burohappold.com/projects/queen-elizabeth-ii-great-court-the-british-museum/.

[2] www.fosterandpartners.com, Foster Partners /. "Great Court at the British Museum." Foster Partners. Accessed February 16, 2020. https://www.fosterandpartners.com/projects/great-court-at-the-british-museum/.

[3] Foster, Norman, Deyan Sudjic, and Spencer De Grey. Norman Foster and the British Museum. Munich: Prestel, 2001.

List of Figures

1 Shahin, Hadeer. "Great Court at the British Museum: Foster and Partners." Arch2O.com. Arch2O, February 23, 2019. *https://www.arch2o.com/great-court-british-museum-foster-partners/.*

2,3 "The British Museum ‚Great Court': A Yolkless Egg?" The Burlington Magazine 137, no. 1102 (1995): 3-4. Accessed February 8, 2020. *www.jstor.org/stable/886395.*

4 20 December, 2016. "Great Detail: Elisa Pardini on Foster's Great Court at the British Museum." Architects Journal. Accessed February 10, 2020. *https://www.architectsjournal.co.uk/buildings/great-detail-elisa-pardini-on-fosters-great-court-at-the-british-museum/10015894.article.*

5 Shahin, Hadeer. "Great Court at the British Museum: Foster and Partners." Arch2O.com. Arch2O, February 23, 2019. *https://www.arch2o.com/great-court-british-museum-foster-partners/.*

6 20 December, 2016. "Great Detail: Elisa Pardini on Foster's Great Court at the British Museum." Architects Journal. Accessed February 10, 2020. *https://www.architectsjournal.co.uk/buildings/great-detail-elisa-pardini-on-fosters-great-court-at-the-british-museum/10015894.article.*

9,12 "British Museum, London." DETAIL inspiration. Accessed February 14, 2020. *https://inspiration.detail.de/british-museum-london-106930.html.*

13-15 Foster, Norman, Deyan Sudjic, and Spencer De Grey. Norman Foster and the British Museum. Munich: Prestel, 2001.

16 Williams, C.J.K. (2001) 'The analytic and numerical definition of the geometry of the British Museum Great Court Roof', 434-440, Mathematics & design 2001, Burry, M., Datta, S., Dawson, A., and Rollo, A.J. eds. Deakin University, Geelong, Victoria 3217, Australia.

ANALYSIS

Multihalle, Mannheim, Germany
Ji Xiang

Fig. 2: Multihalle, Mannheim, Germany

Multihalle, Mannheim, Germany

Student:
Ji Xiang

Architect
Frei Otto
Carlfried Mutschler + Partner

Structural Engineer
Frei Otto

Completion
1974

Place
Mannheim, Germany

Cost
6 million DeutschMarks

Structural System
Grid Shell, 160m x 115m

Area
Timber Lattice Roof, 9,500 m2

Site

Located in Mannheim, south western part of Germany, the building is now situated in Herzogenried park where the Federal Garden Show was held in 1975. A series of temporary pavilions and infrastructures were built including the telecommunication tower and the second bridge across the Rhine.

Introduction

This multifunction hall was designed by Frei Otto, Carlfried Mutschler and Joachim Langner in 1974. The timber lattice roof structure has widest span up to 60m, and longest span to 85m. The highest point is 20m above the ground. The building is composed by two shell structure that are connected be a walkway with canopy. The structure remains the largest of its kind in the world till now.

The structure was designed to be a temporary structure for the Federal Garden SHow in Mannheim but was preserved due to its architectural importance. The building was put under monumental preservation since 1998. The entire roof is self-supported by timber lattice with a 50 mm by 50 mm cross section. The wood lattice structure is connected by cables diagonally withing the grid. Roofs are covered with blackened PVC and was changed into white after preservation starts in the 1980s. [1]

Fig. 3: Aerial view of Multihalle

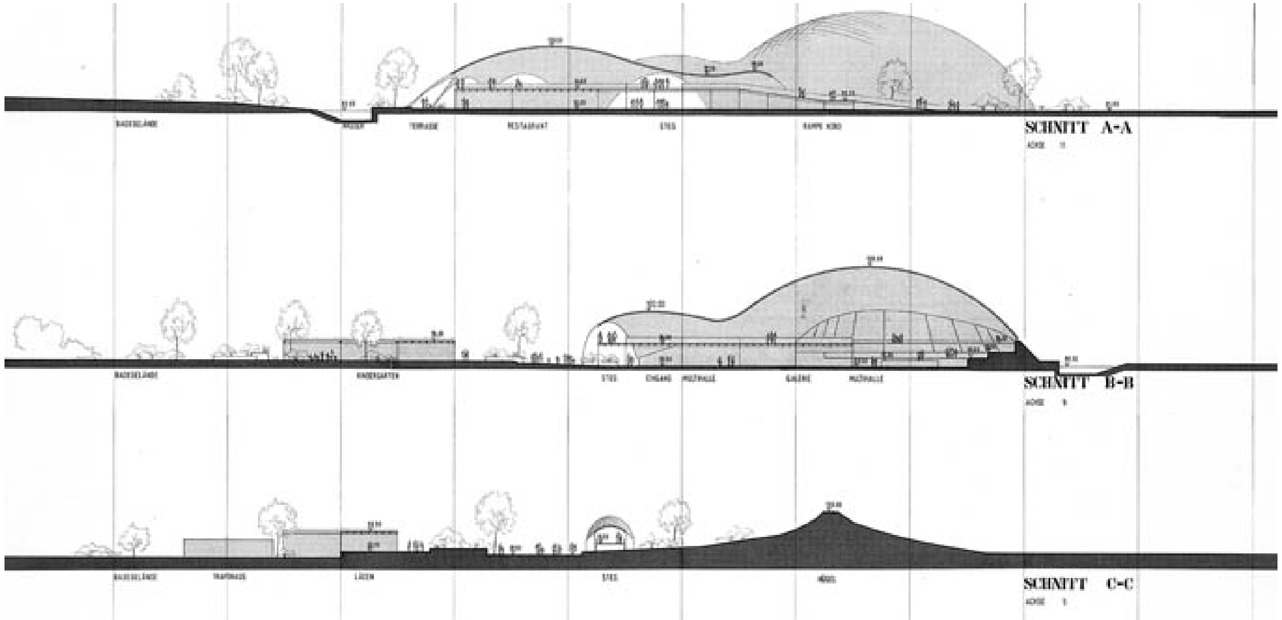


Fig. 4: Section through the primary structure

Architectural Concept

In the competition held for the Federal Garden Show, the architecture firm Carlfried Mutschler + Partner won and was designated to build structure in the central part of Herzogenried park where the meeting point from various directions could also serve as café with a terrace. The original plan was changed due to construction cost and unsatisfying structure solution. Frei Otto came into play with a grid shell structure constructed in timber which is entirely self-supported. The undulating roof structure leads to open space to the public with its open structure. The form finding process was completed with threads connecting as a net, forming a bowl shape upside down. The form should be a result of deformation under the self-weight when tension in the model becomes compression force in the actual roof structure. In order to achieve that, Otto used pins to simulate the gravitational force. The roof structure is not simply a result of mathematical calculation but an art piece that is well-defined by the architect.

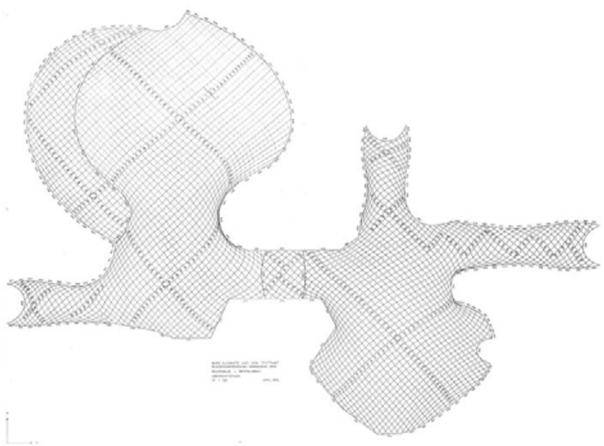


Fig. 5: Plan view of the roof

Fig. 6: Inside perspective

Functions

The building was built as a multi-function hall for the Federal Garden Show in 1975 as a temporary structure. The structure was listed under monumental preservation since 1998. Besides holding events like conference and exhibition under the undulating roof structure, a restaurant is currently operating, covered by two merging dome of timber lattice grid shell structure. The interior space is full of natural light due to the partially translucent fabric that covers the roof structure during the daytime. [1]

Typical Joint

Laths with 50 x 50mm section are joined by finger-jointing connection with various length up to 6m. They were joined in the factory into lengths 30-40m long. On-site joints were made by nailing 50 x 25mm laths on to each side. The node joint involves 4 laths. The two outer laths have holes of 8mm at 500mm spacing for taking the threaded rod. The inner two laths have slotted holes to allow the components slide during the lifting process. Disc springs are applied to take the expansion and shrinkage caused by seasonal moisture variation in the timber. [2]

Fig. 9: Photo of typical joint

Typical Support

Besides the universal joint detail proposed by Frei Otto that could accommodate all the angles of the shell where it meets the concrete wall, there are different types of boundary structure in the roof. For example, arched openings, laminated timber beams connected to steel columns, cable structures supported on steel columns.

The typical joint is achieved by attaching plywood edge board to the steel brackets with different angles and bolting the laths of lattice shell to the edge board.[2]

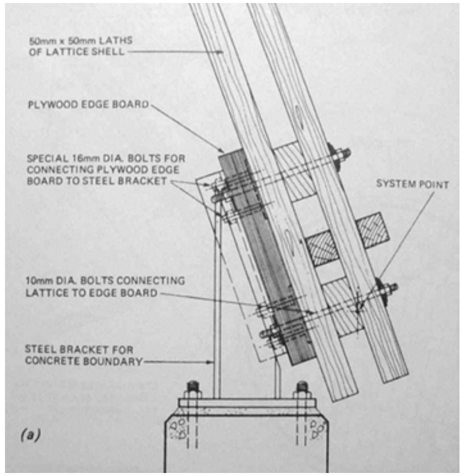
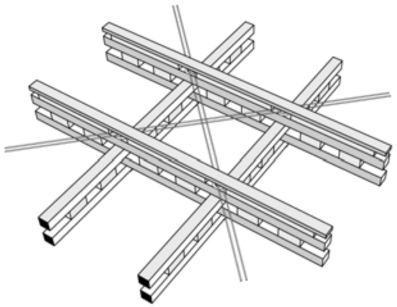


Fig. 12: Detail section of typical support



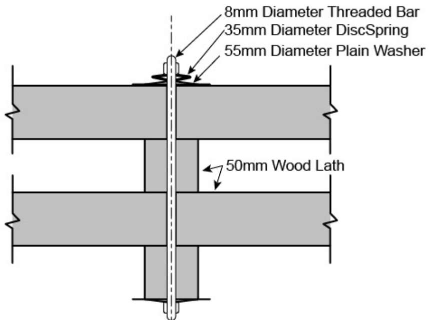


Fig. 7: Axonometric of typical joint

Fig. 10: Different boundary support

Fig. 8: Detail of typical joint

Elements

1. 50mm*50mm Lath
2. Shear Block
3. Cable Tie
4. 8mm Threaded Bar
5. 55mm Diameter-Plain Washer
6. 35mm Diameter-Disc Spring

Fig. 11: Photo of typical support

Elements

1. 50x50mm Lath
2. Plywood Edge Board
3. Steel Bracket
4. 10mm Diameter Bolt
5. 16mm Diameter Bolt

Construction

The construction begins with laying out and assembling the lath grid. The grid was then lifted by several towers from bottom on a 9 x 9m spacing. Forklift trucks were used to jack up the towers when the headroom become sufficient. Towers were over-lifted and lowered later to find the correct shape in the end.[3]

Fig. 13: Photo of Multihalle interior

Construction Process

The timber lattice grids were laid out flat on site. Two construction method about elevating the shell structure was proposed. The first one was to use crane pull up the grid which requires erecting the crane on limited site and it was abandoned because of high cost. The second one was to use towers lift up the grid from bottom of a 9 x 9m spacing. Once the grid was lifted and deflected, boundary supports at the bottom pushed inward to secure the gridshell shape.[3] As long as the shape was correct, the bolts at each node were fastened. The PVC membrane was laid out over the roof and tailor made in accordance to the curvature.

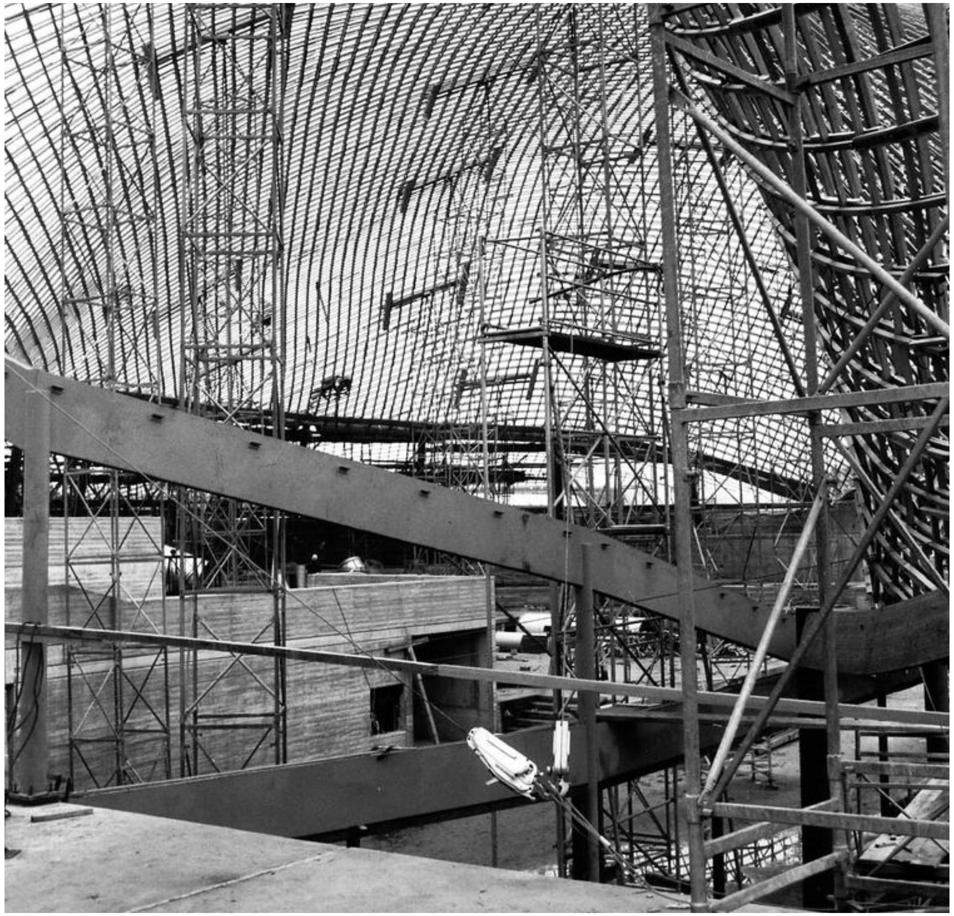


Fig. 14: Photo during construction

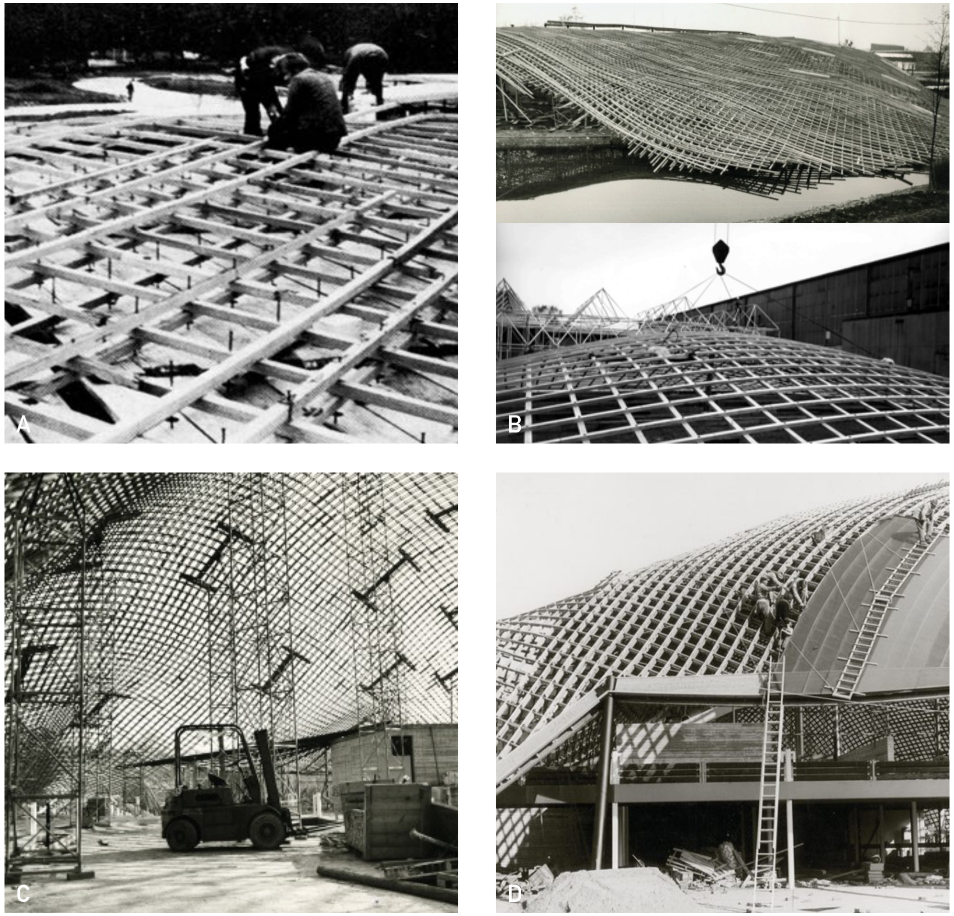


Fig. 15: Construction process A, B, C, D

FORM FINDING

Design shape

The gridshell roof form was generated via an experiment by hanging a funicular net at edges. Under ideal conditions, the tensile force would transform into purely compression when reverse the shape on horizontal plane. The roof construction went from flat timber lattice grid to shell form by pushing inward the boundary and pushing upward the lattice grid through multiple points.[1]

Parameters

During the form-finding process, the edge of grid shell and supporting points were set at first. Then the lattice grid with spacing of 1.5 m was set inside the contour lines. The grid is perceived as tensile net with edge support and pint support. The funicular shape was automatically generated, and the shape was refined by adjusting the load and net strength.

Results

In the Multihalle the highest point was 20 m above the ground with longest span of 85 m. The final shape in the form-finding process was determined by seeking for the 20 m tallest point in the model, which happens at the area with longest span.

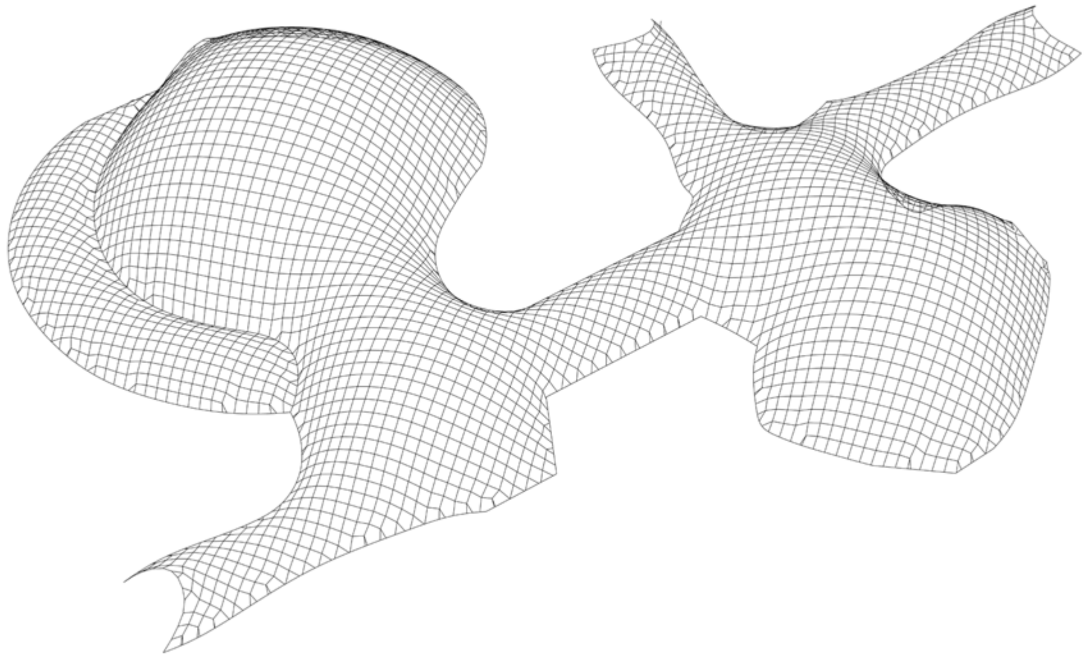


Fig. 16: Centerline model

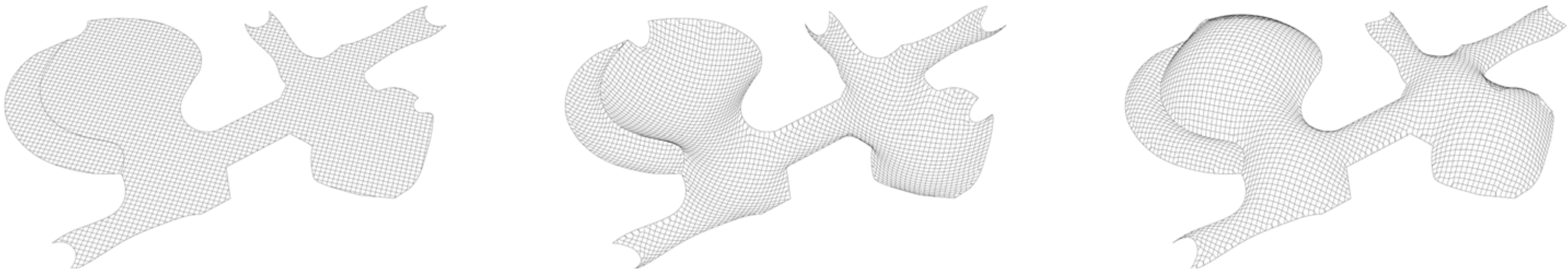


Fig. 17: Form finding workflow

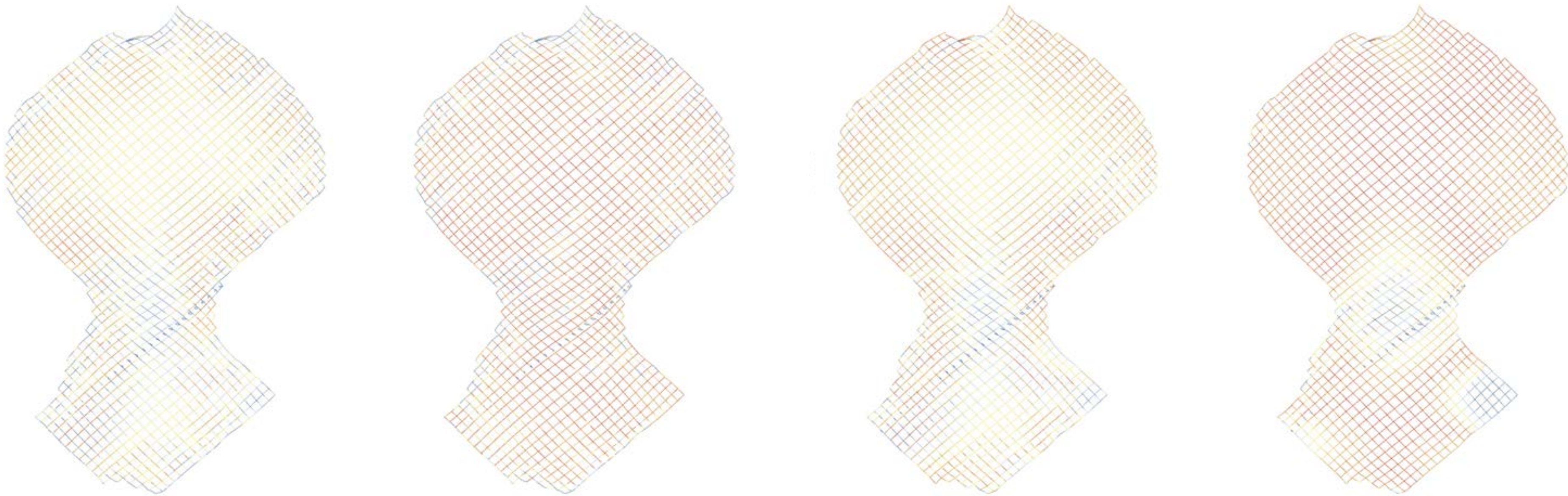


Fig. 18: Curvature analysis

Spatial curvature k

The gaussian curvature is the highest at top and gradually reduces from top to bottom.

Normal curvature k_n

The normal curvature is the highest at the dome top and reduce at the the junction part.

Geodesic curvature k_g

The geodesic curvature remains relatively the same on top of the dome structure. Geodesic curvature starts shifting when coming to the boundary and at the junction.

Geodesic torsion τ_g

The geodesic torsion becomes gradually higher when surface transit from dome to irregular arch shape.

Fig. 19: Exterior view of Multihalle

Summary

Integrated with structural beauty and undulated form, the Multihalle designed by Frei Otto is truly remarkable. The long-span wood structure gained its strength via double curvature surface while using much less material comparing with other long-span roof structure.

From deign to construction, the funicular net model played crucial role in the entire process. The gridshell of equal spacings made it easy for the earlier construction stage. Sandwiched design and slot detail at the joint provide flexibility when raising the entire grid from ground. [3]

Bibliography

[1] Lothar Quast, Stephan Weber, Multihalle Mannheim, https://mannheim-multihalle.de/en/architecture/

[2] Ian Liddell, Frei Otto and the development of gridshells, Case Studies in Structural Engineering 4, 2015, 39-49

[3] Jarred Mihalik, Melody Tan, and Sekai Zengeza, A Pavilion for the Bundesgartenschau, 2013, http://shells.princeton.edu/Mann2.html

List of Figures

ANALYSIS

Production Hall, Vyksa, Russia
Hwanseo Lee

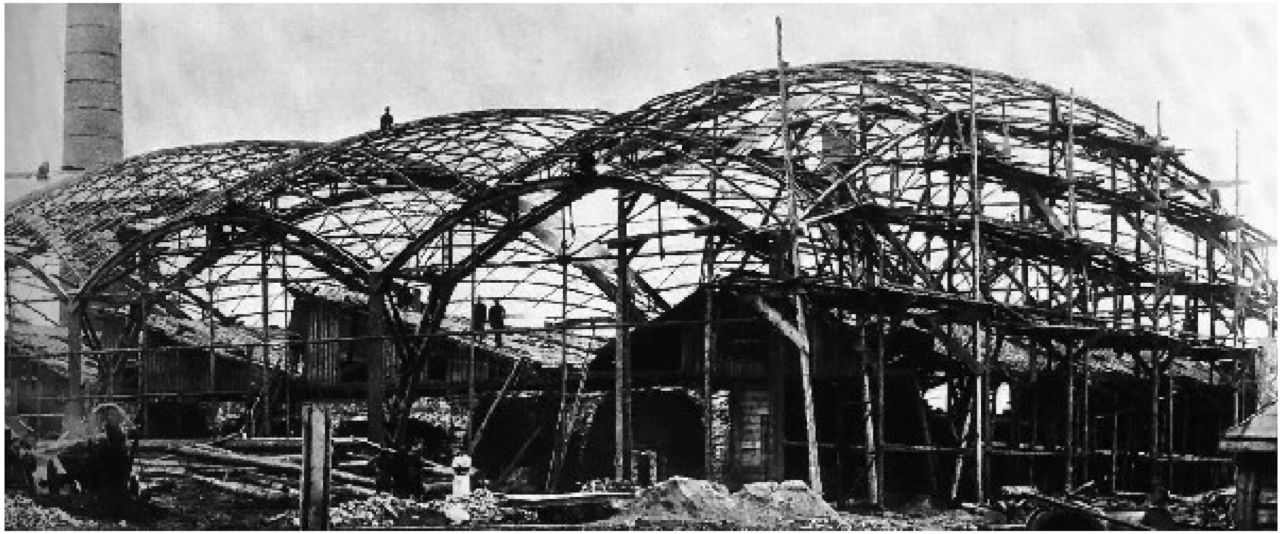


Fig. 1: Production Hall by Vladimir Shukhov in Vyksa

Production Hall, Vyksa, Russia

Student:
Hwanseo Lee

Introduction

In a small town of Nizhny Novgorod called Vyksa, the production hall was constructed, and it was the introduction of the first doubly-curved structure by Vladimir G. Shukhov (1853 - 1939) to the world. The gridshell structure was built in 1897 and constructed a year after. In 1980s, the building was abandoned and left for tow decades. The gridshell covered 73.00m x 38.40m consist of five 14.60m wide bays with 4 trussed arches [1].

Architect
Vladimir G. Shukhov

Structural Engineer
Vladimir G. Shukhov

Completion
1898

Structural system
Truss, 38.4m

Area
2,803.2 m²

Place
Vyksa, Russia

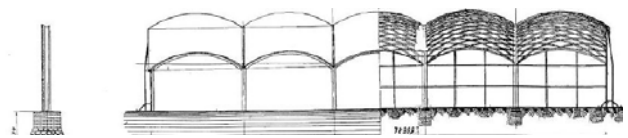


Fig. 3: Comparative section

Site

The production hall is constructed in Vysksa where 150km southwest of Nizhny Novgorod. The production hall is owned by Vyksa Steel Works, producer of metal products founded in 1757. The town, Vyksa was founded in 1765 and was granted town status in 1934. The population is around 56,201. [2]

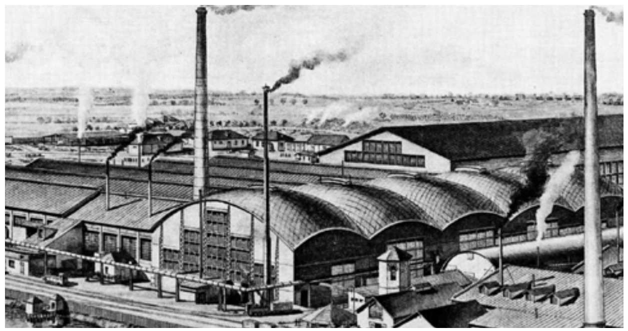


Fig. 2: Site plan

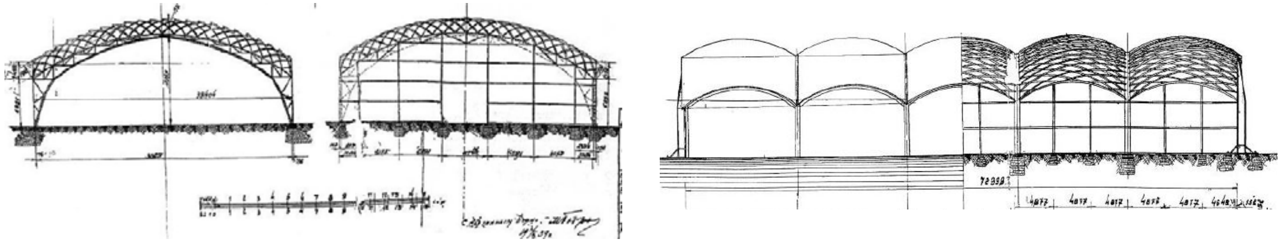


Fig. 4: Section through the primary structure

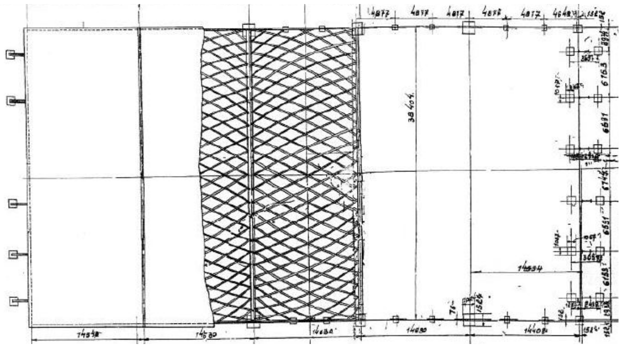


Fig. 5: Plan/top view of the primary structure

Fig. 6: Inside perspective

Architectural Concept

The gridshell roof is divided into five parts by four columns/ arches which are trussed and three-hinged. The roof covers 73.00m x 38.40m which is 14.6m wide for each bays. Looking at the longitudinal view of the hall, six vertical cantilevers are bracing the building and create four arches on the facade. Those six cantilevers are connected to the arches with tie rods. With the main structure, arches, the polygonal top chord becomes the gridshell roof.
There is no historical document that mentions about geometrical elements of the gridshell. Also, from the drawing of the structure, it is hard to know the shape of the structure is from a circle, a parabola, an ellipse, or other curves. The drawing tells us that the rise of the shell is 1.98m.[2]

Functions

The gridshell is an industrial architecture that has to protect machines from wind, rain and other climate factors. Besides the protection from the weather, the industrial architecture should provide high headroom with large space without obstacles that avoid any disturbance when the machines are running and moving in the space. The production hall carried out manufacturing metallurgical products and the wide span allowed people to use the space more flexibly.

Typical Joint

The Z-shaped steel members from the gusset plates intersect each other and form a diamond mesh. At the intersection, the members are connected to 8mm thick shim plates which are equilateral triangles with a 120mm edge. The shim plates connect the upper and lower layer of the grid-shell members with three bolts to create a soft moment connection.[3]

Fig. 7: Detail of Z-shaped steel structure

Typical Support

The gusset plate is the joint between the Z-shaped steel members and the arch structure. The Z-shaped steel members (h=80mm, b=50mm, t=7mm) form the parabola shape and fixed on the gusset plate (8mm thickness) which is bolted on the top chord of the arch. Some of the gusset plates are shifted to compensate for the height of the polygonal top chord and it provides higher stability to the gridshell.[3]

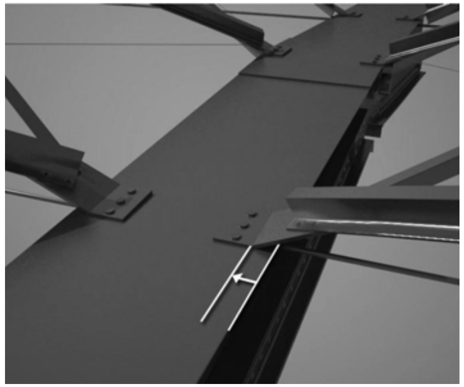


Fig. 10: Gusset plate

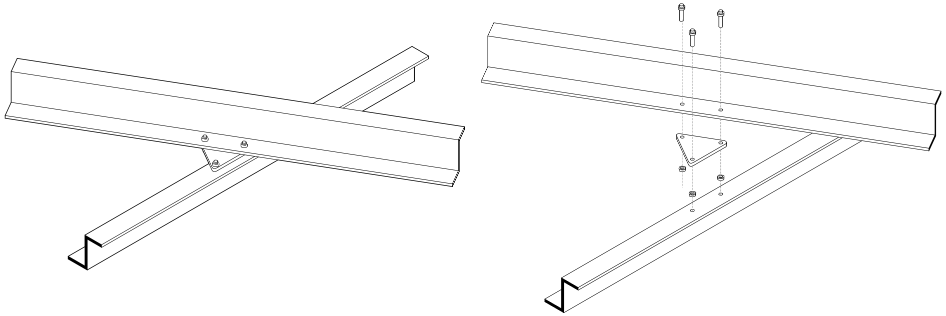


Fig. 8: Axonometric of typical joint

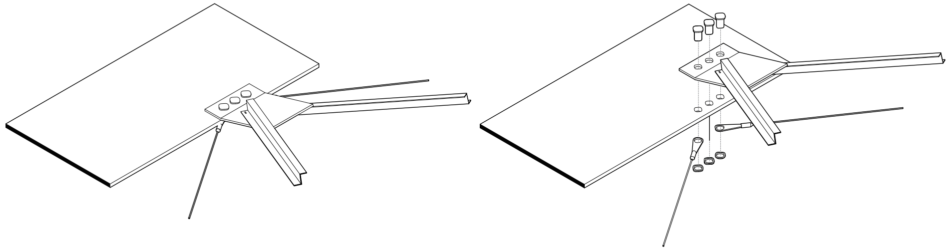


Fig. 11: Axonometric of typical support

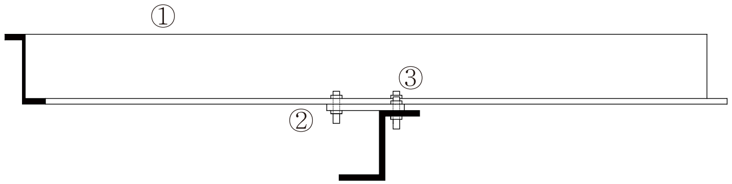


Fig. : Detail of typical joint

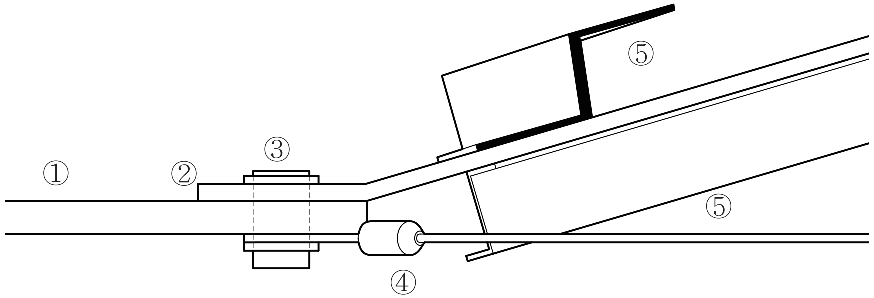


Fig. 12: Detail of typical support

Elements

1. Z-shaped steel section
2. Shim plate
3. Bolts

Elements

1. Steel arch structure
2. Gusset plate
3. Bolts
4. Steel wire
5. Z-shaped steel section

Construction

The structure that supports gridshell is trussed arch which is made out of steel L beam. At the top of the arch, each halfs of the arch is connected with a flexible joints.

Fig. 13: Prototype

Construction Process

The structure of the façade on the front and rear side of the building consists of six vertical cantilevered trusses and an intermediate orthogonal grid of cross beams.

The cantilevered trusses and intermediate vertical members carry the L-shaped ridge beam, which follows the same parabolic curve as the trussed arches. The arrangement of the cantilevered trusses in the front façade does not follow the spacing of the vertical posts in the trussed arches.

Nor does it comply with the spacing of the longitudinal running tie-rods that balance the shear of the gridshells. Only the outer vertical cantilevers align with the rods that brace the inner corners of the trussed arches.

The spacing of the vertical cantilevers decreases from the center towards the sides, refuting the assumption that the spacing might reflect equal contributory façade areas. Most likely, the layout of the cantilevers was determined by functional requirements, like the widths of the portal doors at the front facade or others.[1]

Fig. 15: Steel structure

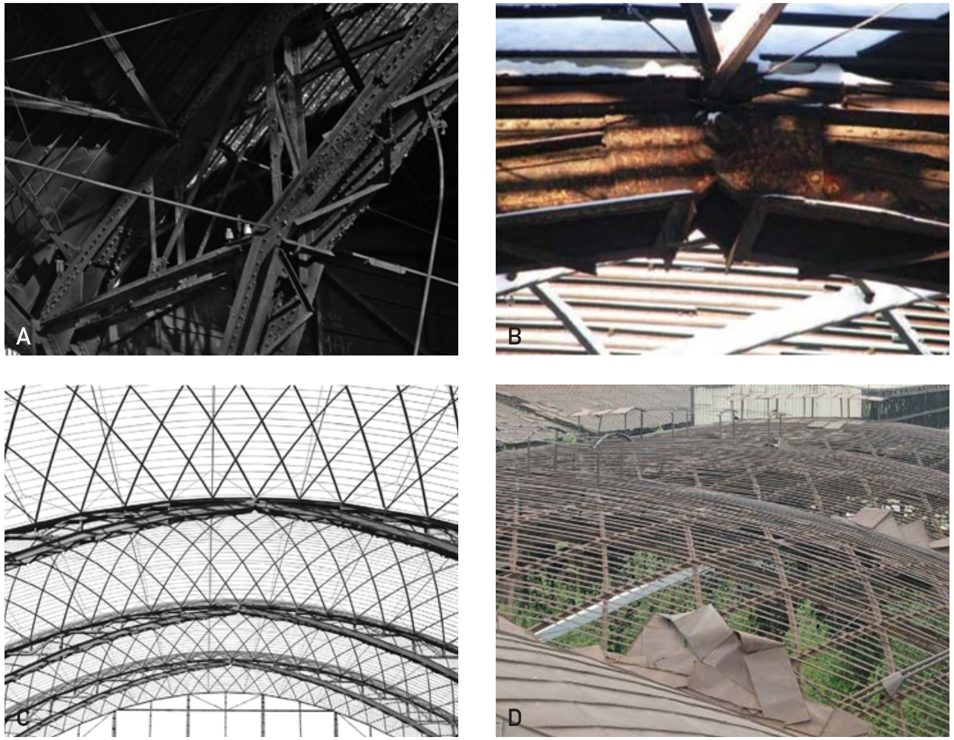


Fig. 15: Construction process A, B, C, D

Design Shape

There is no historic evidence on how Shukhov generated the form of the gridshell in Vyksa. Neither are written documents available, nor do the existent construction drawings yield any precise information about the geometric principles that determine the surface. The curved members of the gridshell run diagonally, meaning that start and end point are offset by four bays. The exact shape of these members could not be measured accurately enough to discern whether the curve stems from a circle, a parabola, an ellipse or some other curve of higher order. (Parabolas and segments of circles with small rise-to-span ratios differ only slightly). The historic drawings only indicate that the clear rise of the shell is 1.98m, measured perpendicular to the parabolic curve of the top chord.

Parameters

Most likely the geometry was generated by moving an obliquely oriented segment of a circle along the parabolic top chord of the truss, as shown in figs. 4d. The segments were all identical, with the same fixed radius and chord length. With the clear span of the shell between the top chords of the trusses, the horizontal distance between start and end point of the member at the apex, the chord length can be approximated with 15.39m. The vertical distance between start and end point and the apex of the parabola and the rise of the shell according to the construction documents the arch rise of the circular segments can be obtained. With the chord length and the arch rise, the approximate radius of the circular segments can finally be gained as 14.80m.[1]

Results

The resulting surface is again a freely defined translation surface. This approach seems to be the most practical, as all the members are identical and can be manufactured using the same template. However, the usage of only identical elements has implications on the arrangement of the members. As the gradient of the parabola varies and gets higher towards the endings, the arc lengths of the equally divided parabola increases likewise. Thus, the start and end points of the members don't line up with the spacing of the truss anymore as one moves outwards. This effect can be witnessed at the springs of the trussed arches, an observation that affirms that the supposition of identical elements of the same lengths is correct.[2]

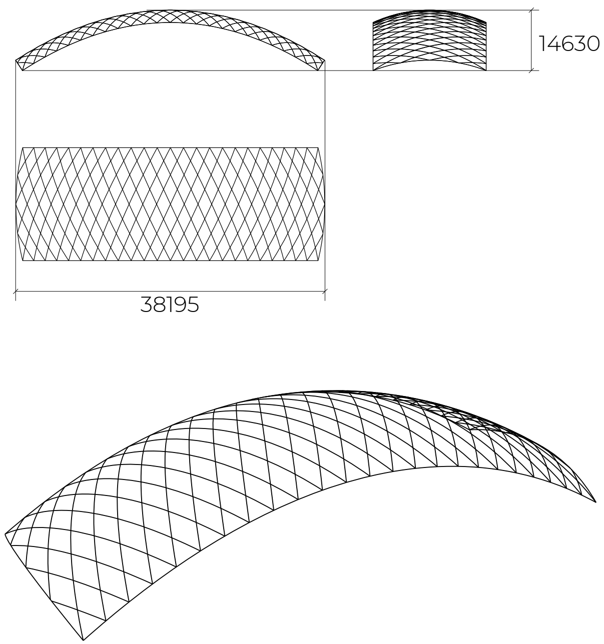


Fig. 16: Centerline model

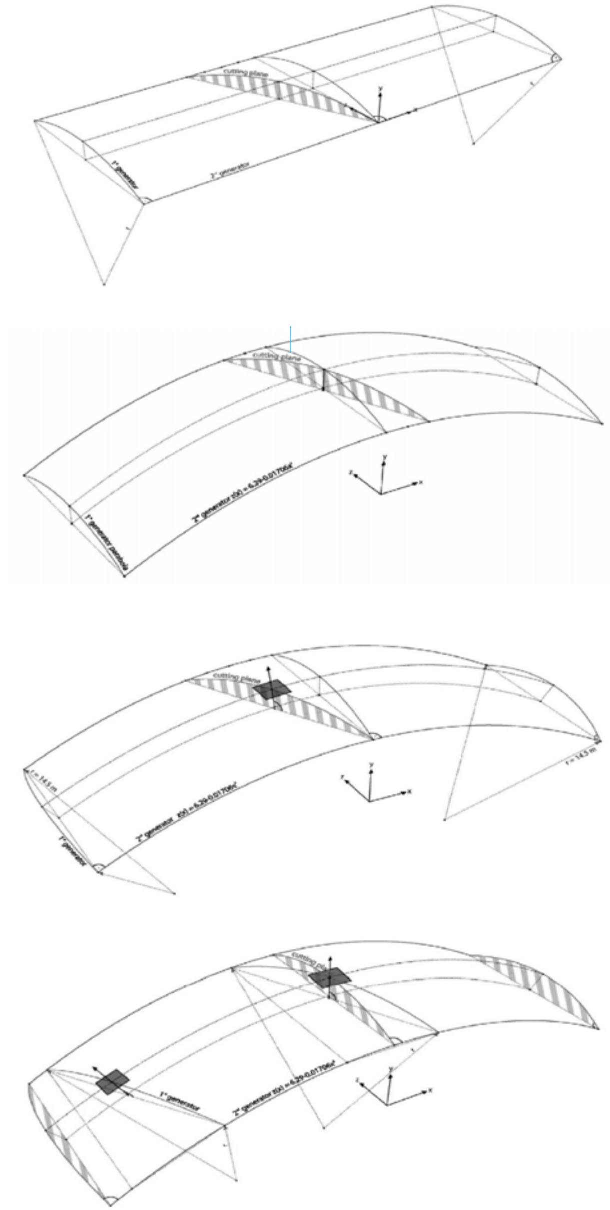


Fig. 17: Structural behaviour and from finding workflow

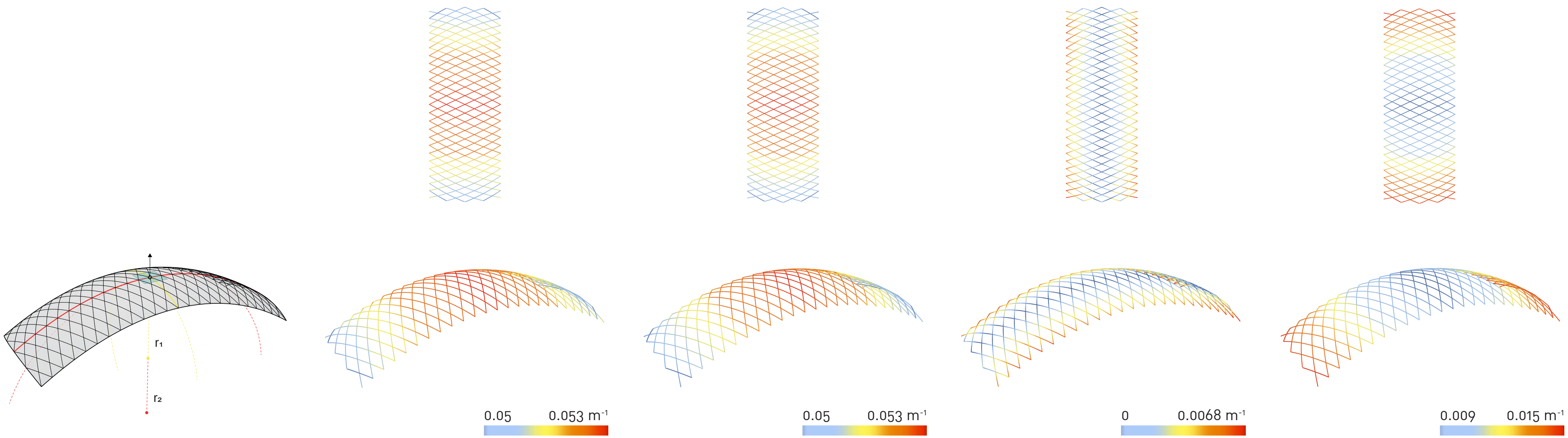


Fig. 18: Curvature Analysis

Gaussian surface curvature K

The surface of the gridshell has positive (synclastic) curvature which means the value of k1 and k2 is both possitive. r1 and r2 are the radius of circle that is tangent to the curves on normal plane. r1 has less value compare to r2.

$$K = k_1 \times k_2 = 1/r_1 \times 1/r_2$$

Spatial curvature k

In the curvature of the grid shell is shown on the analysis of spatial curvature. The gridshell has various range of curvature on the corner part. The curves starts from lower part of the edge of the gridshell and attached to the upper part of arch. The curviture is lowest where the curve is attached to the lower part especially the corner, and highest where the curve is attached to higher edge of the arch.

$$k_n^2 + k_g^2 = k^2$$

Normal curvature k_n

The normal curvature is occuring the most of upper part in this gridshell. The normal curvature is largest at the top of the chord of the gridshell. However, like the analysis of the spatial curvature, the curves at the corner have lowest normal curvature on the nearest part of the corner. The range of curvature is from 0.05 to 0.053 which is very similar. The reason of the small range is the normal curvature is similar on all the structure.

Geodesic curvature k_g

The geodesic curvature occurs where the curvature of the curve is projected on the surface's tangent plane. The geodesic curvature is mainly concentrated along the two longest sides of the form. At the center of the lonsgest side, the geodesic curvature is relatively less.The middle of the gridshell has low geodesic curvature as shown on the diagram.

Geodesic torsion $\square_g$

The geodesic torsion is mainly occurs when the curve is twisted. In this gridshell, the geodesic torsion is highest along the short side of the form, and very less torsion at the top of the gridshell. Interesting point is the geodesic torsion is opposite from the normal curvature.

Fig. 19: Photo

Summary

Vladimir Shukov's gridshell is the first generation of gridshell, so it cannot be introduced as a perfect example of the gridshell. However, the invention of the new type of structure enlightened other architects. The project contains a lot of knowledge about the curvature and teaches a lot of informations regarding structure.

It was astonished by the technology of the earliest gridshell, and also how the information of shuchov's gridshell is not as known as his other projects.

Bibliography

[1] Matthias, Rainer: The First Doubly Curved Gridshell Structure - Shukhovs Building for the Plate Rolling Workshop in Vyksa, Germany 2009.

[2] Agkathidis, Edemskaya. Rethinking Complexity: Vladimir Shukhov's Steel Lattice Structures. Journal of the International Association for Shell and Spatial Structures. 2016

[3] Graefe, R. Netzdächer, Hängedächer und Gitterschalen. In: Graefe, R. et al. (eds): Vladimir G. Šuchov(1853 - 1939) – die Kunst der sparsamen Konstruktion. Stuttgart: Deutsche Verlags-Anstalt. (1990)

List of Figures

ANALYSIS

Centre Pompidou-Metz, Metz, France
Ying So Yi

Fig. 1: Photo of the Centre Pompidou, Metz

Centre Pompidou, Metz, Paris

Student:
Ying So Yi

Architect
Shigeru Ban Architects
Jean De Gastines
Gumuchdijian Architects

Structural Engineer
Cecil Balmond, Arup Ingenieros

Completion
2010

Place
Metz, Paris

Cost
$69.33 million euro

Structural System
Timber Hexagonal Roof

Area
11330.0 m^2

Introduction

The Centre Pompidou in Metz was built to house the temporary and permanent exhibitions from Musee National d'Art Moderne. [1] It was a first experiment in French cultural decentralization, storing 65,000 artworks and being the institute that own Europe's largest collection of contemporary art. The modular exhibition spaces were offering the dimension to facilitate the very large pieces and huge installation, in order to solve the problem of that some artworks cannot be shown in the Paris museum due to the 5.5m ceiling height under the beam.

The three 15m modular structures are surrouding the central spire rising 77m above ground. The hexagonal roof structure corresponse to the floor plans and cover the building. With the help of CAD systems and CNC milling machine, it enables multi-directional curves for the grid shell and pre drilling for the final assembly. The preparation and installation of the wood mesh, which comprises of 18km of glue laminated timber beams, has taken 10 months.[3].

Site

Metz is a city know for many parks and green spaces. The Centre Pompidou-Metz is part of the redevelopment plan of a 50 hectre zone, named as Quartier de l'Amphitheatre, which is a deserted industrial wasteland. The Centre took up 2.8 hectre and located at the western half of the zone, which is at the closest point to the city centre, which can be access easily by train. [2]

The Centre Pompidou-Metz is surrounded by a terrace and two gardens. The sloping terrace provides a direct access to the railway station. The five-arce garden is planted with flowing cherries, which can use the rainwater collected from the roof and terrace. Numerous pathways are created for the vistors.

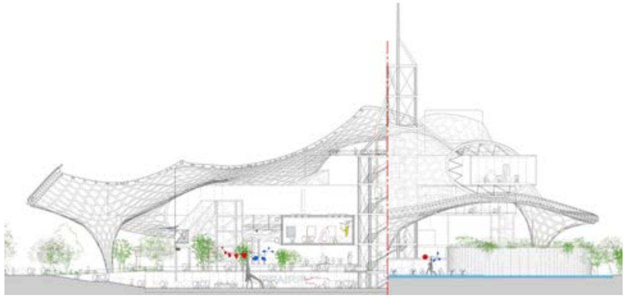


Fig. 2: Comparative section

Fig. 3: Site plan

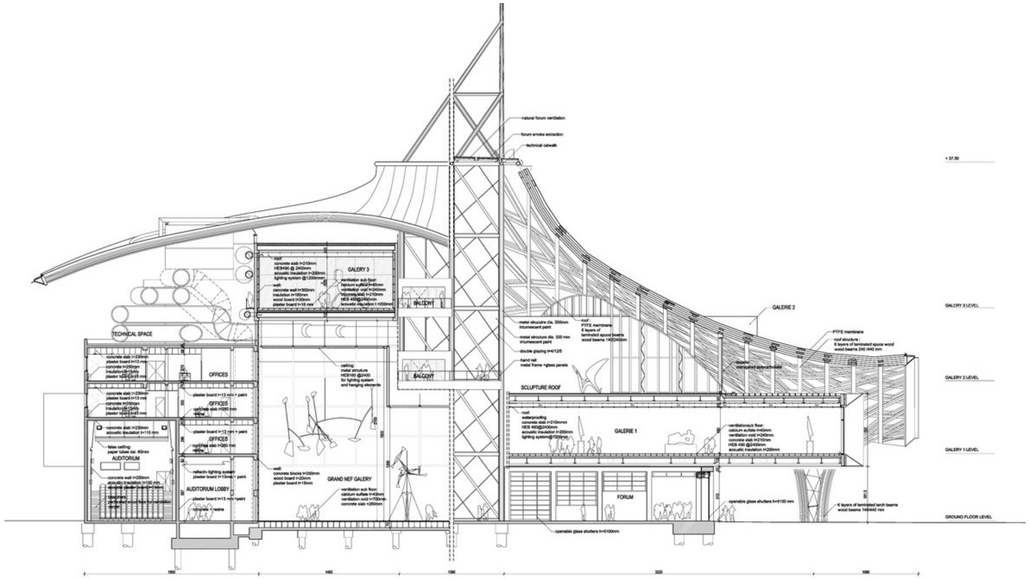


Fig. 4: Section through the primary structure

Fig. 5: Plan/top view of the primary structure

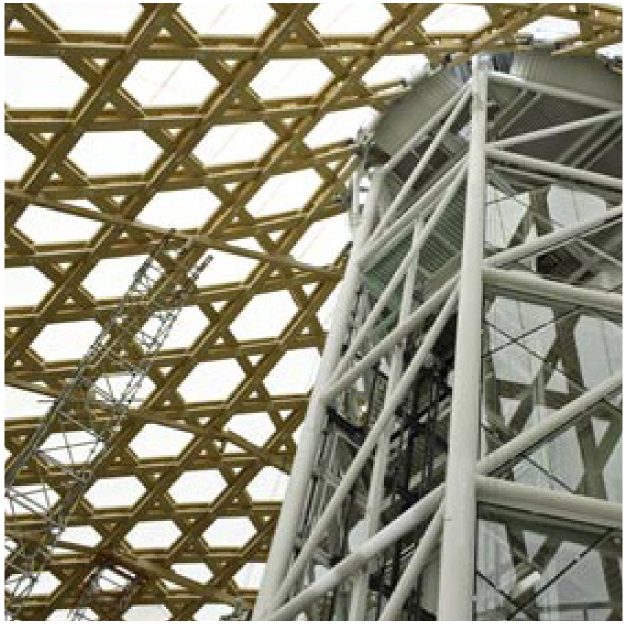


Fig. 6: Inside perspective

Architectural Concept

Inspired by the Bilbao effect from Guggenheim Museum, the Centre Pompidou-Metz aimed to form an interesting three-dimensional interior space and increase the ease of displaying and viewing art, thus architecturally leaving a deep impression. [4]
One of the goals for the redevelopment of the Amphithéâtre district was preserving the environment and achieving sustainability [3]. Using the minimum amount of materials is one of the requiremnets for the project. Hence, the idea of creating a roof with grid shell structure using laminated timber was popped up, as it can be adopted as roof, walls and column at the same time.

Functions

It is aimed to create simple volumnes with a clear circulation among them. For the spatial arrangment of gallery in the museum, 3 simple square tubes with long, 90m deep rectangular volume arranging around a hexagonal steel frame tower with stairs and elevator.[4] The 3 tubes extrude out fo the envelope and face towards to the landmarks of the city. The tubes are rotated so that the natural light can be able to come in.
Gallery Tubes 1 and 2, it is an exhibition space for displaying sculptures, which takes advantage of the natural light permeate through the roof. At the ends of the 3 gallery tubes frame the views to the city's monuments. Interstitial areas between the large roof and the gallery tubes have various funtions and create space for gathering, such as cafe, auditorium and studio for live performances.

Typical Joint

The roof is a double layered timber grid-shell with a 3-way parallel grid. The planks are overlapping each other in 3 directions, then, the second layer of planks are placed with a wood spacer in between, which helps to increase the depth and the structural performance. [5] The 3 way woven timber grid was induced with the 6 layers of glue laminated timber planks at 16inch offsets with steel bolts joining the hexagonal node points [5].

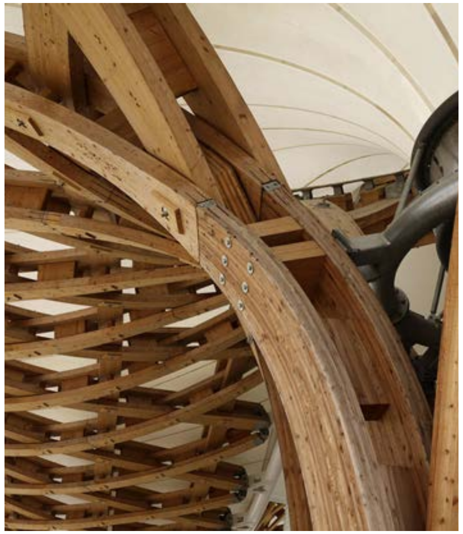


Fig. 9: Photo of the hexagonal lattice

Typical Support

The whole roof is supported by the hex-agonal 77m truss spire and also the four inverted conical downward extensions of the grid shell which extended downward to reach the ground [6]. The timber has become a space frame system, they are deformed and become the piers and meet the four pile caps in the foundation [7]. They made the roof evenly spaced from the center and supported at the foundation, that is structured at the similar way with the Canopy [7]. The extensions are rein-forced by the pre-stressed bolts and metal rings. Gravity and lateral force are resist-ed by the complex timber lattice, transfer-ring load down through the timber then gradually to the friction piles.

Fig. 12: Photo of the downward extension

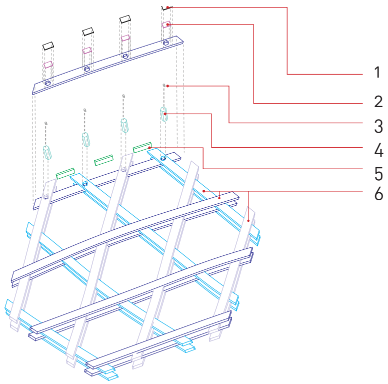


Fig. 7: Axonometric of typical joint 1:200

Elements

1. Wood plate cover (320*200*25mm)
2. Steel plate (260*160*15mm)
3. Bolt M24
4. Hexagonal plywood node (150mm)
5. Wood spacer (615*225*60mm)
6. Glue laminated timber beams (L*440*140mm)

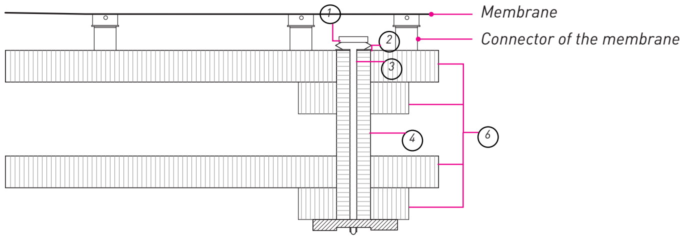
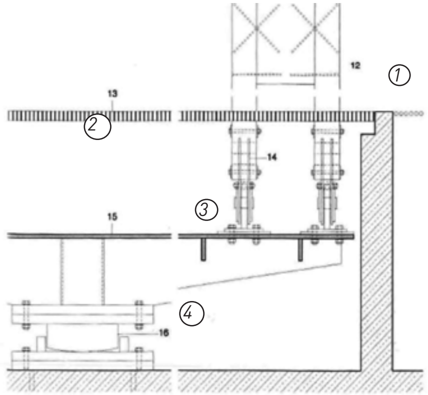


Fig. 8: Detail of typical joint 1:30

Fig. 10: Axonometric of typical support, metal ring fixing the place of the timber



Elements

1. Laminated timber grid shell
2. Concrete
3. Extruded Steel tubes
4. Pier footing

Fig. 11: Detail of typical support/ Section of pier footing

Construction

Unlike conventional grid shell structure, the glue laminated timber allows to perform planks with specified angle. Each pieces of timber are fabricated in its own length and predrilled. Through adopting CNC, the timber was then adjusted to its unique curvature, allowing more flexibility to the curvature of the grid shell [6]. But at the same time, it wasted a lot of materials. Steel formwork was made to hold the timber pieces so that grid shell can be built according to the 3D model that is prepared in the CAD.

There is a 12 inch gap left between the timber and the membrane in order to let the air flow. [7]

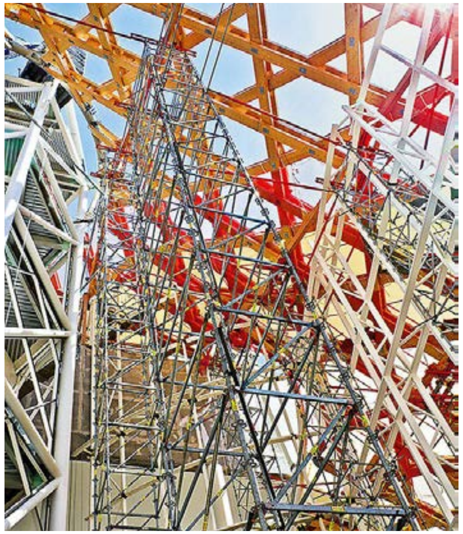


Fig. 14: Photo of the supporting tower

Construction Process

Firstly, the trussed hexagonal steel tower was constructed as it was the main structure that holding the 3 gallery modules. Then, the 3 gallery tubes and other buildings are constructed.

Then, the formwork for the grid shell help to stablize the position of each timber beam was built. Construction of the roof was begun at its highest point. The scaffold supported helps to support the tower and allow the timber framework to be built from the central tower to the edge[5].

The load of the roof are supported by the shoring tower through out the construction [8].

The grid shell is then covered by the PTFE, a kind of water proof membrane. It is connected to the timber beam by the T-section steel elements.

Fig. 13: Photo of the Center Pompidou Metz during construction

Fig. 15: Construction process A, B, C, D

FORM FINDING

Design shape

The timber roof structure was inspired by traditional Chinese woven straw hat. It was composed of a pattern of hexagons, which is the symbol of the geographical shape of France.[4] and equilateral triangles inspired by woven bamboo basket. The grid shell was position to be an unconventional and iconic design as it was aimed to create an bilbao effect. It was a double curvature grid shell. Each of the elements are prefabricated and the shell is fixed by the timber nodes.

Parameters

A. Modelling the patterns
1. Create a hexonagal repetitive pattern
2. Connect lines in the middle points of each segments. The network has applied two of the common tessalations, which is a hybrid of hexagonal and triangular network.[9]
3. Trim off the excessive lines to create a regular pattern only with hexagon and equilateral triangle

B. Modelling the surface and projection of the pattern to the surface
1. Confirm the positions of the 3 gallery tubes and other building blocks in order to determine the opening of the grid shell
2. The pattern was then projected to the mesh of the shell.

Results

A wireframe model was then determined and confirmed the geometry of the grid shell. Wooden glu-lams were used to replace the wireframe, which produced nearly 1,800 double curved segments. [10] It results in a 3 way doubled layer structure. zDue to the complicated curvature, each of the timber components were fabricated with a custom curve along its length, then CNC to be milled with a second curvature and additional twisting so as to laminate the timber plants in two directions [5] .

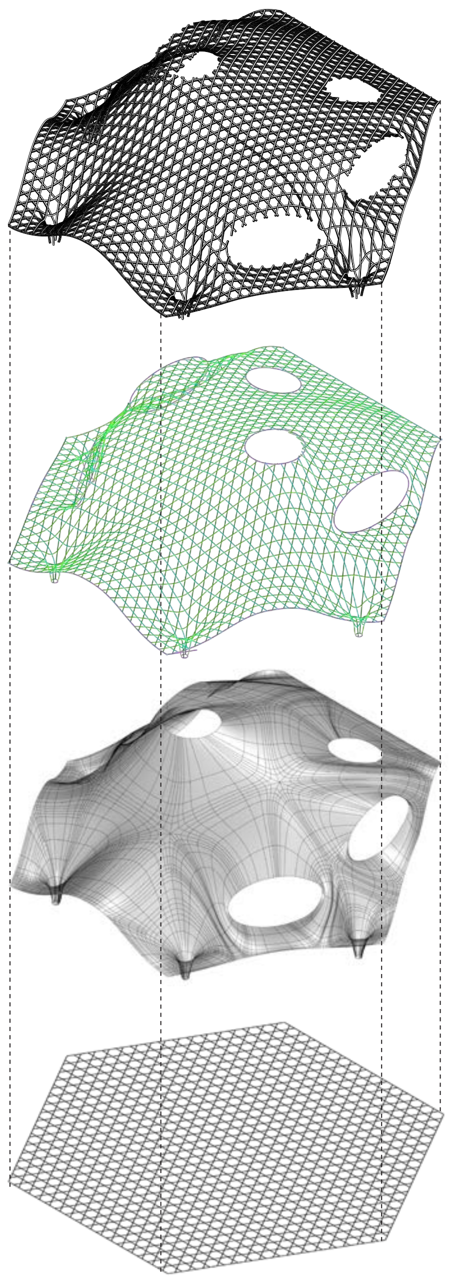


Fig. 17: Form finding workflow

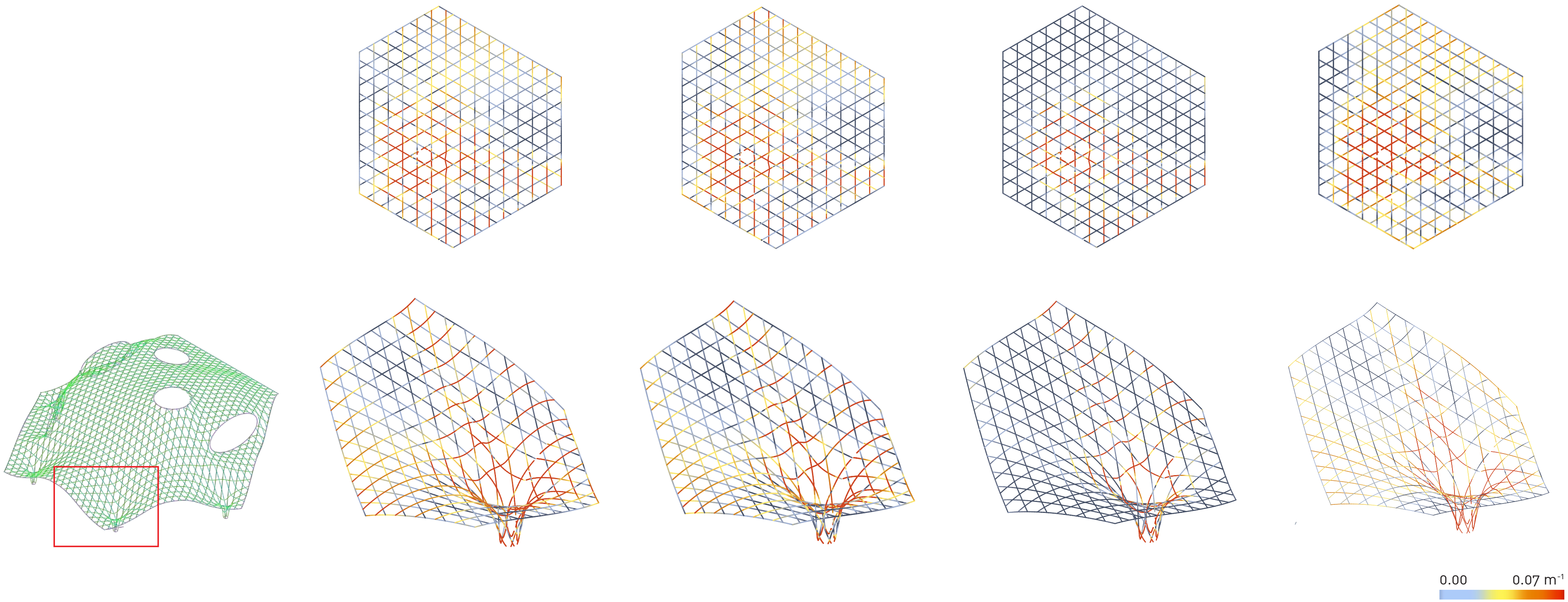


Fig. 18: Curvature analysis

Gaussian surface curvature K

Centre pompidou has a complex double curve structure. The downward extension experience a variation of curvature.

$$K = k_1 * k_2 = 1/r_1 * 1/r_2$$

Spatial curvature k

As the pattern is projected to the surface, the pattern at the supporting part of the grid shell is elongated and steep. Thus, the part which brace the supporting element together experience great curvature. For the curves that is broken down and reach the ground, it has the least curvature.

$$k^2 = k_n^2 + k_g^2$$

Normal curvature k_n

Normal curvature refers to the curves that is tend to the normal section. The beam that is elongated to the foundation and prone to Y axis tend to experience less normal curvature, whereas the beams that is blended into the horizontal plane experience more normal curvature.

Geodesic curvature k_g

Geodesic curvature refers to curves that are tend to the tangent of the surface. If the slope of tangent of the curves are steep, it will tend to engage with a higher geodesic curvature. Hence, the beam in the x direction tend to have a higher k_g

Geodesic torsion τ_g

Geodesic torsion refers to the twisting of the cruves. The elongated part experience the greatest torsion as they were twisted to meet the ground.

Fig. 19: Interior view of the entrance

Summary

Centre Pompidou undoubtedly has a provoking form of gridshell, giving a unique and attractive shape, making it become a landmark in Metz. It was a product that heavily relied on CAD and 3D stimulation, that each component are precisely model in the computer. With the help of technology, the fabrication of roof has been easier, which allows to build a grid shell with freeform surfaces and hybrid patterns.

Bibliography

[1] Official website of Centre Pompidou-metz. (2020) [Online] .Available from: https://www.centrepompidou-metz.fr/en/welcome

[2] Self, R. (2014). The architecture of art museums : A decade of design : 2000-2010. Abingdon, Oxon ; New York: Routledge.

[3] Rose, E. Centre Pompidou-Metz by Shigeru Ban Dezeen. (2010). Available from: https://www.dezeen.com/2010/02/17/centre-pompidou-metz-by-shigeru-ban/

[4] Archdaily (2020). Centre Pompidou-Metz / Shigeru Ban Architects [Online]. Available from https://www.archdaily.com/490141/centre-pompidou-metz-shigeru-ban-architects

[5] Silver, P., McLean, W., & Evans, P. (2013). Structural engineering for architects [electronic resource] : A handbook. London: Laurence King Pub.

[6] Chilton, J., & Tang, G. (2017). Timber gridshells : Architecture, structure and craft. New York: Routledge.

[7] Centre Pompidou-Metz." Detail: Timber Construction (2010): 1040-045. Print. 1044.

[8] PERI Group. (2020) [Online] Available from: https://www.peri.hu/projektek-attekintese/centre-pompidou.html

[9] Schling, Eike. (2018). Repetitive Structures.

[10] Marble, S. (2012). Digital workflows in architecture : Designing design -- designing assembly -- designing industry. Basel: Birkhäuser.

List of Figures

ANALYSIS

Chadstone Shopping Centre, Melbourne, Australia
Lai Cheuk Yan, Joyce

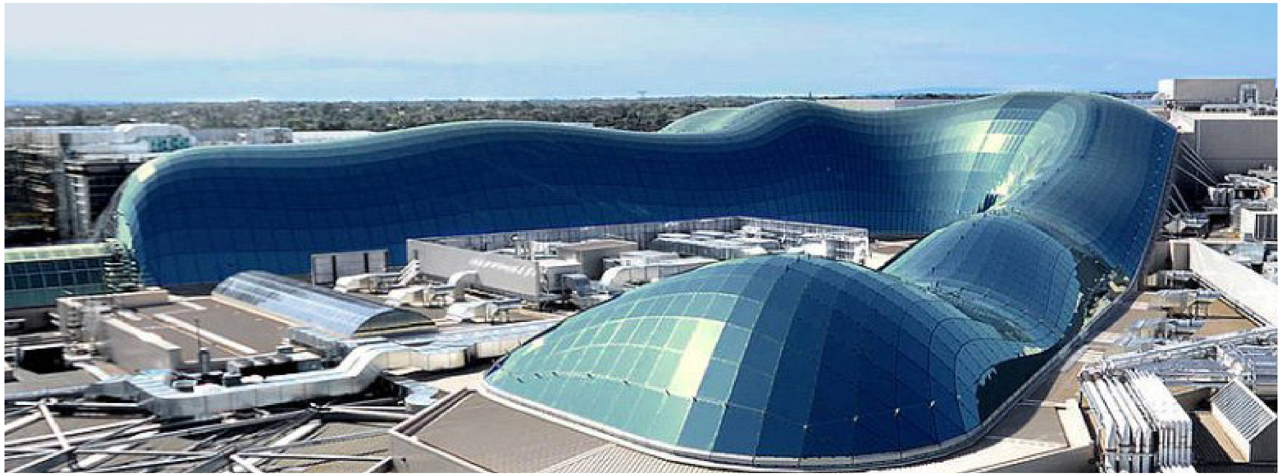


Fig. 1: Chadstone Shopping Centre exterior view

Architect
CallisonRTK (Designer)
The Buchan Group (Architect)

Structural Engineer
Atelier One

Completion
2016

Place
Melbourne, Australia

Cost
AUD $660 million expansion

Structural System
Steel & Glass , spanning 44m

Area
7,080sqm free-form grid shell

Site

Chadstone Shopping Center located not far from the center of Melbourne, the extensive scale of this curvy roof opens a new identity to the existing shopping mall. The new expansion on the north end of the existing shopping center which is where the grid shell structure constructed. [2] Base on the extreme weather of Australia, the selection of materials was highly considered to coordinate with this complex structure [3].

Chadstone Shopping Centre, Melborne, Australia

Student:
Lai Cheuk Yan, Joyce

Introduction

Chadstone Shopping Center located in Melbourne of Australia, it is a seamless synthesis celebration on the techniques of engineering and architecture. The Centerpiece of the project is the extensive grid shell glass roof that rises right on top of the atrium, the design of the mall which makes it the most popular and largest shopping center in the area of Southern Hemisphere. [1]

The Shopping Centre will be expanded with major international retailers, upscale dining options and family-focused entertainment area.
The 25 meters high, 7,080-square meter roof was a collaborative work among designers, architects and engineers, they also collaborate with the research departments from the University of Stuttgart and the University of Bath. The design team focused on parametric 3D modeling to optimize the massing by integrating video animation and computer rendering. [2]

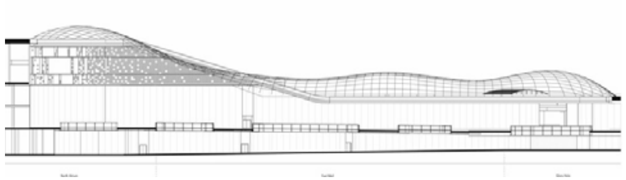


Fig. 2: Comparative section

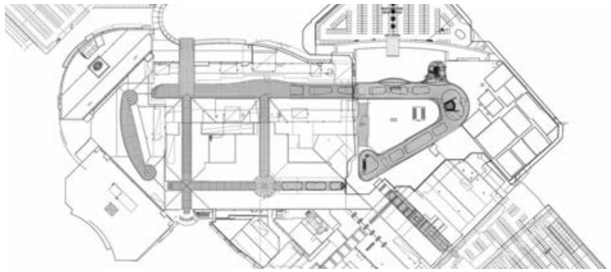


Fig. 3: Site plan

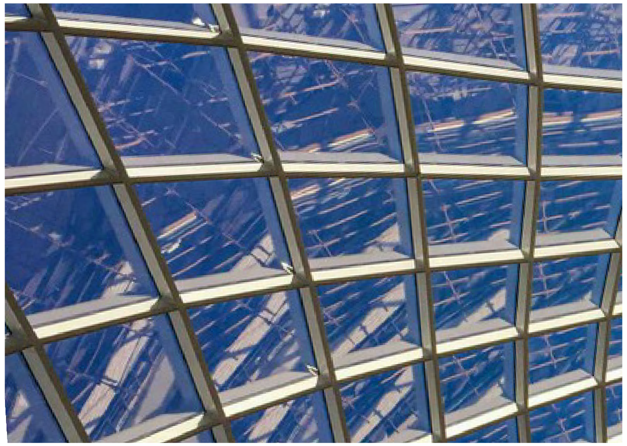


Fig. 4: Primary structure and glazing

Fig. 5: Inside perspective

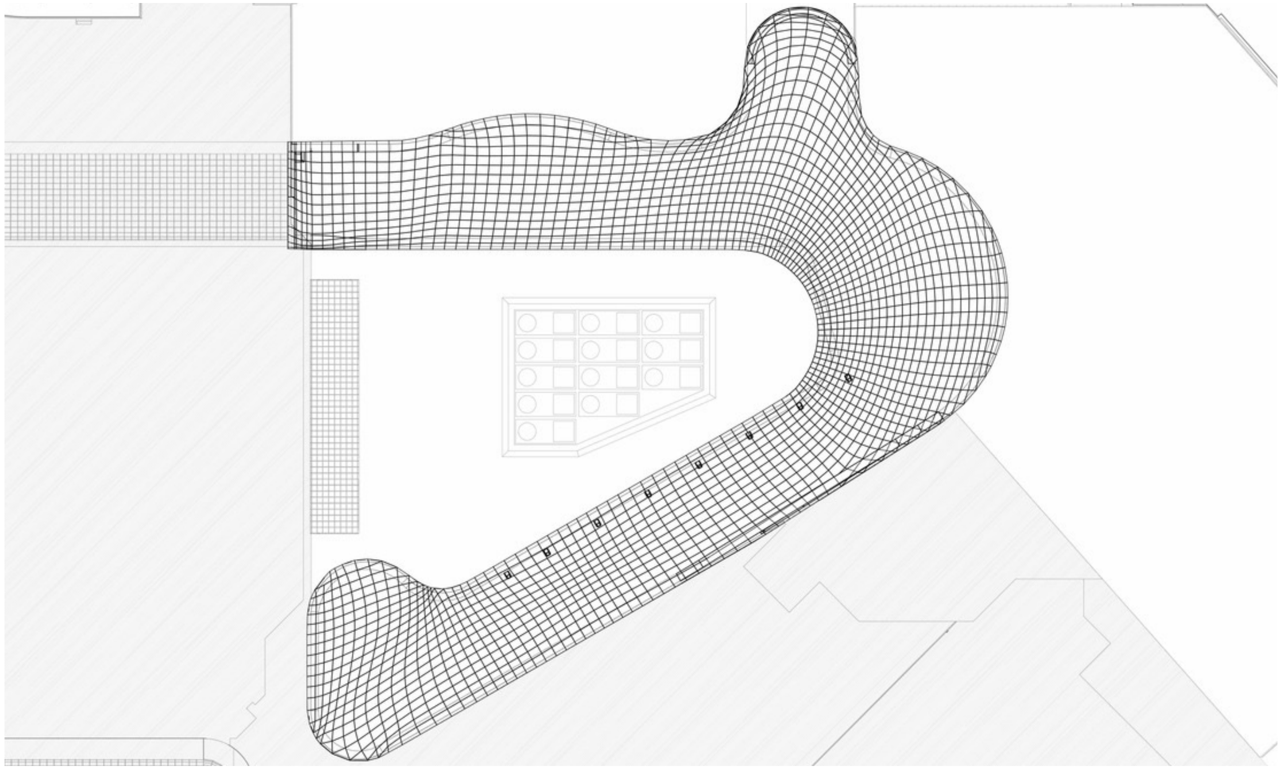


Fig. 6: Plan/top view of the primary structure

Architectural Concept

Chadstone is well known for its iconic feature of the grid shell roof structure, 1-M high, 7,000-SM grid shell glass roof, resulting in a dramatic, column-free space. The grid shell device, which is sourced, fabricated, and designed in Europe. With the minimal use of materials, the grid shell structure is the most effective solution to achieve this complicated form. [3]

Arching over the shopping mall's expansion area and rising 25 meters above the ground, the design illustrates the feeling of the European, outdoor shopping area to an Australian interior mall. [5]

The glass roof must follow the geometry of the shopping malls layout and so the result is a complex free-form grid shell with spans of up to 44m. The design of the structure creates its openness and its gallery-like continuous atrium to the building. [6] In the main while, its high, dome-like glass roof could successfully give access to the daylight, penetrating the natural lighting to the double-height shopping mall. [6]

Melbourne's climate was another unique aspect that had to be considered. With a glass roof up to 260 m long, the site's high temperatures might lead to deformations up to 135 mm for the roof. Therefore, the glass roof supports need to hold the high roof loads, but also include a sliding detail to accommodate the roof's deformations caused by the extreme climate. [4]

Functions

The expansion accommodates over 100 new retailers; it includes an extensive line of leisure and food operators. In order to turn the flourishing and thriving shopping center into a lifestyle venue. The compositions of the curvature conducted multiple waving to the grid shell canopy; it successfully provided an iconic design to the users, also, gave a sense of openness to the shopping center. [6]

Typical Joint
(individual Steel Connection)

The steel frame is high strength steel profile sizes vary and are factory finished, fixed with the custom precision machined reliable steel node. [7] Through the bolt access holes, they are connected with corrosion-resistant high strength bolts three on each side. [8] The bolt access holes can be capped, and the joint could penetrate well around the perimeter contact, which resulted that connection is not highly visible from the outside. [6]

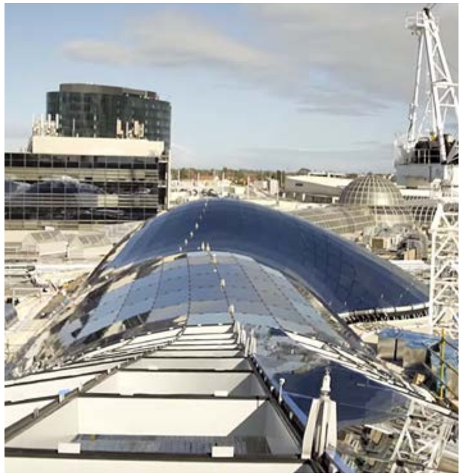


Fig. 7: Photo

Typical Support

The gridshell structure contains its strength, which derived from its double curvature and its lattice framework. The overall form is slightly started with a lower point on the long inner edge and raising higher on the other. [9] The gridshell was designed by CallisonRTKL and manufactured by Seele. The roof consists of a catenary steel gridshell glazed with quadrilateral panels of varying sizes. The load would be more massive on the lower side [9], in which edge beams were installed to support the heavier loads of the gridshell. [10] The form is highly efficient with its 210 mm thick framework, covering the area of around 7000 sqm and allows clear spans of up to 42 meters in some areas.

Fig. 11: Photo

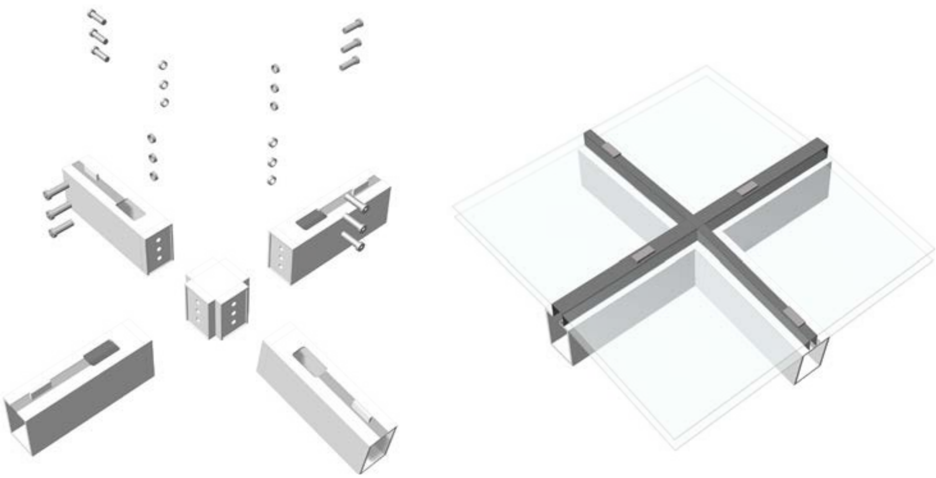


Fig. 8: Axonometric of typical joint

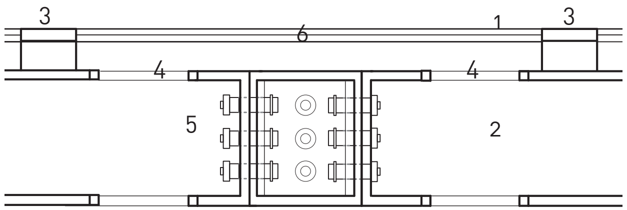


Fig. 9: Detail of typical joint

Elements

1. Insulating glass
2. Steel frame member
3. Glazing fixtures
4. Bolts access hole
5. Bolts
6. Steel nodes

Fig. 10: Axonometric of typical support

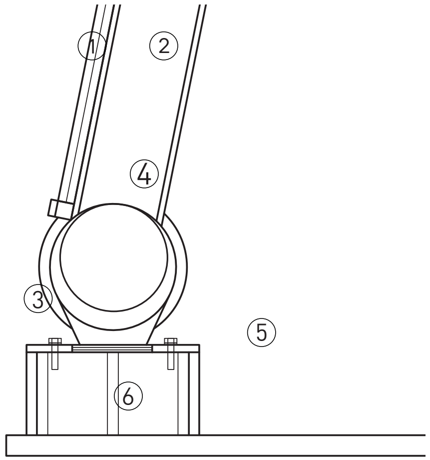


Fig. 12: Detail of typical support

Elements

1. Insulating glass
2. Steel frame member
3. Bolts
4. Edge Beams
5. Steel Plates
6. Foundation

Typical Joint
(Connection of Frame Member)

The frame members were prefabricated within the dimension of 18x 4.5 m as the limitations for ease of transportation. 5,168 frame members, 56 edge beams, and 2,810 steel nodes were transported to the building site, lifting them to the right position and installed. [15b] Each of the frame members will be connected one by one, connecting with the steel nodes and fixed with three bolts on the steel plate at the end of each frame to form the free form grid shell structure. [12]The insulating glass panels would be installed on top of the steel frame, and panels were fixed with 3 or 2 rectangular fixtures on each side, which matched and connected the steel frame. [12]

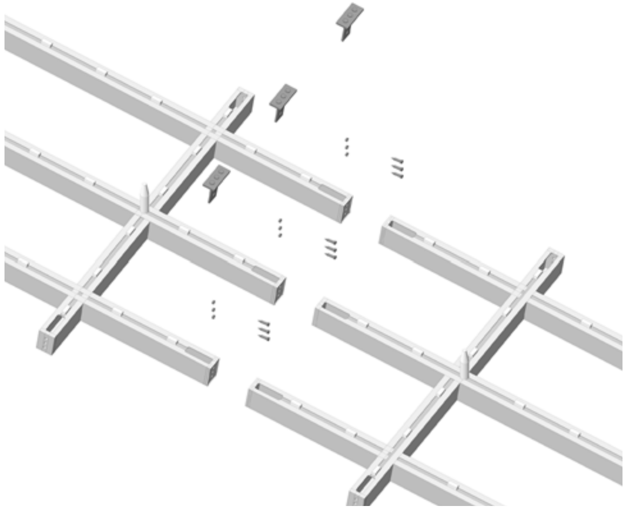


Fig. 13: Typical joint

Fig. 14: Photo

Construction & Construction Process

The fluctuating weather conditions and the strict local requirements of the on-site logistics created a tight construction schedule for this project. The steel frame manufacturer Seele developed an effective solution for the steel and glass roof; the roof segments were pre-assembled primarily at a site 35 km away under much more robust conditions. These segments, measuring up to 18 x 4,5 m, with perfectly coordinated operations, could lift into place and fixed one by one effectively to prevented interruptions caused by the steady wind flow on-site. [13]

The construction started from the edge beams, then connected them according to the order of the frame members. After each frame member connected with the node, insulating glass panels are installed on top. [14]

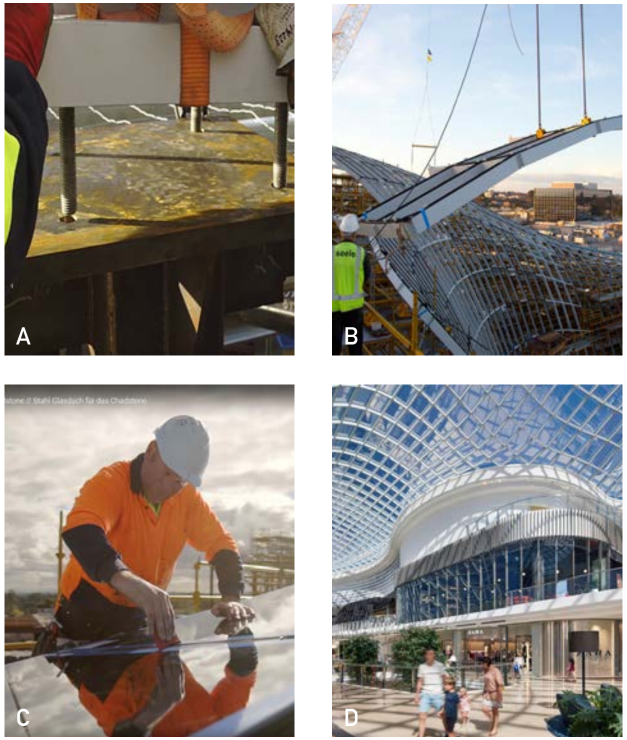


Fig. 15: Construction process A, B, C, D

Design Shape

The building roof is in a U shape composition, and the gridshell is formed under a Square grids layout. The boundaries are fixed on the edge; the node bolts effectively help as retaining the overall shape. [15] The double curvature of the shell generates fundamental structural action in resisting the asymmetric loads along with a long linear U shaped plan layout. [15]

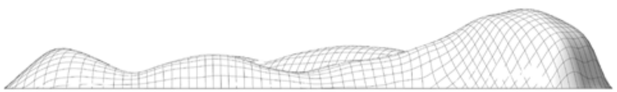


Fig. 16 [a] Elevation A

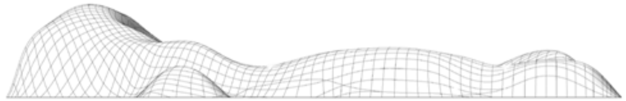


Fig. 16[b] Elevation B

Fig. 16 [a], [b]: Centerline model

Parameters

The panel layout has been seamlessly mapped to the building perimeter to provide an elegant boundary between the roof and supporting structure. Under the collaboration with the University of Bath, they developed a specific script that could be used to translate 2D point-controlled quadrilateral grid into a 3D parametric mesh. By combining the critical interrelated aspects of the roof form, the glass panels and structural efficiency were articulated for the construction. [16a]

Double curvature with projecting sqaure grids on top, The grid shell structure is in discrete to coordinate with the glass panel installations, more efficient on installations, and with less bending was conducted. [16b]

Results

The structure containing various concave and convex formation, double curvature are conducted along with a linear plan layout. The gridshell is completed with 124 m x 105 m grid layout, the gridshell structured within the height from 5.7m to 12m. [16a].

The overall gridshell is arching high, it is slightly started with a lower point along the inner edge and raising higher on the outer edge. [16b] The load would be more massive on the lower side [16], in which edge beams were installed to support the heavier loads of the grid shell covers the area of around 7000 square meters and allows clear spans of up to 42 meters in some areas. [16b]

[a]

[b]

[c]

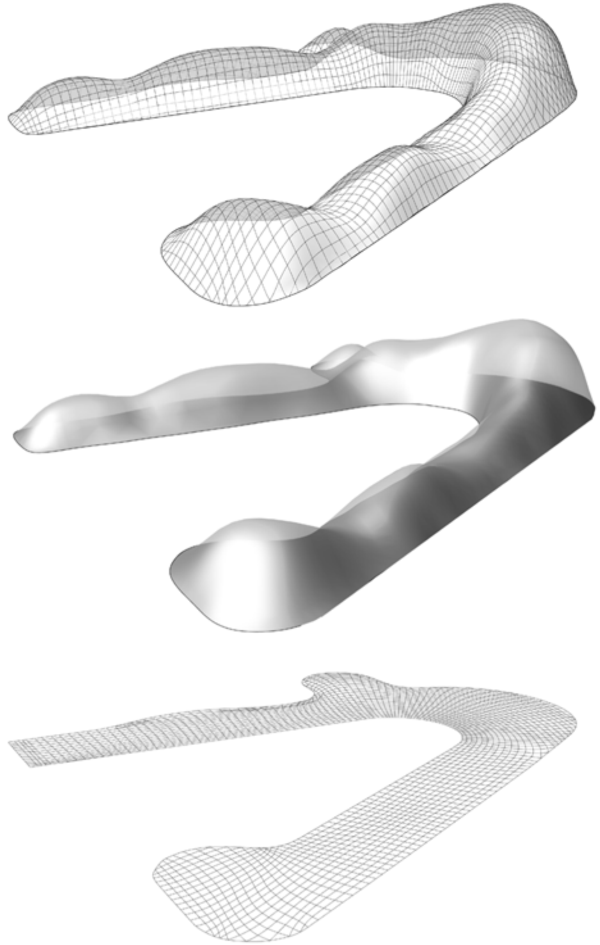


Fig. 17: Structural behaviour and from finding workflow

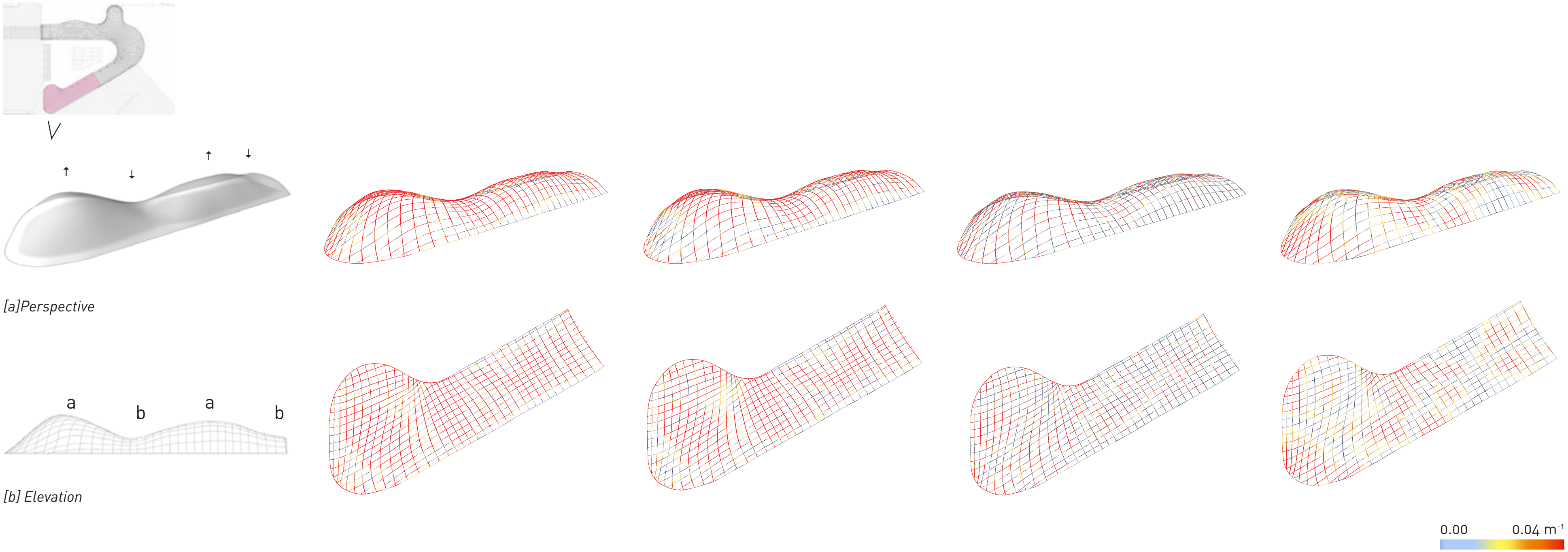


Fig. 18: Curvature Analysis

Gaussian surface curvature K

The south portion of the gridshell is being chosen for the curvature analysis. The radius of the tangent circles conducting positive value at where "a" point is located on the surface, while the "b" point is maintaining a saddle shape; it would contain a negative value. The gridshell consists of both positive and negative curvatures, creating an overall gridshell consist of various concave and convex treatment to balance the loads under this long linear plan layout. [17]

Spatial curvature k

Spatial curvature contains the data of normal curvature and geodesic curvature

$$kn^2+kg^2= k^2$$

Normal curvature k_n

Normal curvature are mostly happened on top of the convex region, conducted larger area in red with normal curvature, while less normal curvature happens when the shape get to transforming into a concave form.

Geodesic curvature k_g

More of the Geodesic curature are evenly distributed among the gridshell, the curves turns side ways the most.

Geodesic torsion $\square_g$

Geodesic torsion happens when each vector are not aligned with each others, the highest tosion happens near the concave area of this gridshell, the curves are tiwsting which resulted geodesic torsion.

Fig. 19: Top view of the gridshell roof

Summary

The overall design of the gridshell is effective and efficient, since the repetitions on the use of materials, it shows the effectiveness and benefits to the cost for constructions. The ideas of the joints details and support increase the stability of the construction, while the connections are highly concealed to provide a clean surface on the exterior.

The most exciting condition from the analysis would be the discoveries to its form-finding and how it coordinates the decision-making of the network system. The structure is conducted by various concave and convex formation to achieve this extensive long plan layout. The overall dramatic form with a discrete steel structure could maintain a stable and durable framework for the roof.

Bibliography

[1] Architect. 2017. Chadstone Shopping Centre. [Online]. [16 February 2020]. Available from: https://www.architectmagazine.com/project-gallery/chadstone-shopping-centre

[2] Archdaily. 2017. Chadstone Shopping Centre / CallisonRTKL + The Buchan Group. [Online]. [16 February 2020]. Available from: https://www.archdaily.com/804275/chadstone-shopping-centre-callisonrtkl-plus-the-buchan-group

[3] A4 Seele. 2017. Glass roof for shopping giant by seele: chadstone shopping centre. [Online]. [16 February 2020]. Available from: https://seele.com/references/chadstone-shopping-centre/

[4] Callisonrtkl. 2017. Chadstone Shopping Centre CallisonRTKL + The Buchan Group. [Online]. [16 February 2020]. Available from: http://www.rushi.net/Home/Works/detail/id/222960.html

[5] Novum Structures. n.d. Front Page - Novum Structures. [online] [9 March 2020].Available from: https://novumstructures.com

[6] Singer, M. 2016. Sky's the limit: first look at $660m Chadstone shopping centre expansion, hotel to come next. [Online]. [16 February 2020]. Available from: https://www.smh.com.au/lifestyle/skys-the-limit-first-look-at-660m-chadstone-shopping-centre-expansion-hotel-to-come-next-20160920-grk9dr.html

List of Figures

ANALYSIS

Solemar Brin Baths, Bad Dürrheim, Germany
Gyuhyeon Choi

Fig. 1: Solemar Brine Baths

Architect
Geier + Geier

Structural Engineer
Hezel+Stehle / Wenzel Freese Pörtner Haller

Completion
1987

Place
Bad Dürrheim, Germany

Cost
ca. EUR €19.8 million

Structural System
Timber Grid Shell/Rib Shell, 20m

Area
Membrane Roof, 2,500 m²

Site

The Brine Baths is located at Bad Dürrheim, a relative small town, situated on the east of Black Forest a large, forested mountain range. Bad Dürrheim is recognised as a place for spa and health resort with a therapeutic climate. [1]

Solemar Brine Baths, Bad Dürrheim, Germany

Student:
Gyuhyeon Choi

Introduction

Solemar Brine Baths is a public bath in Bad Dürrheim.

Over past years, public baths have undergone a drastic change. From simple body-cleaning institutions, to sports centres and multiform recreation centres with adventure pools. There has been not only a proliferation of the bath types, one can enjoy warm water, cold water, artificial wave, whirlpool baths, and supplementary facilities as saunas, solaria, therapy rooms and relaxing rooms are now also proliferate. This has given rise to new spatial concepts that underline individual areas without physical separation of each fluid spaces.

Glued laminated timber ribs assembled to form gridshells draped over five column trees, as wood offers greatest resistance to the vapours from the salt water of the baths, also to reflect on the wooded region around it. [1]

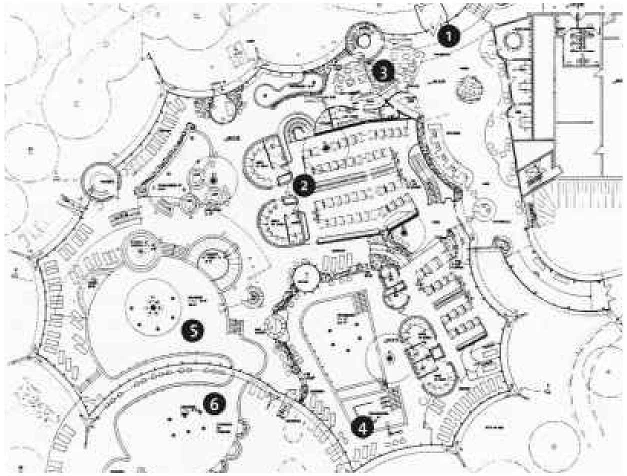


Fig. 2: Site plan

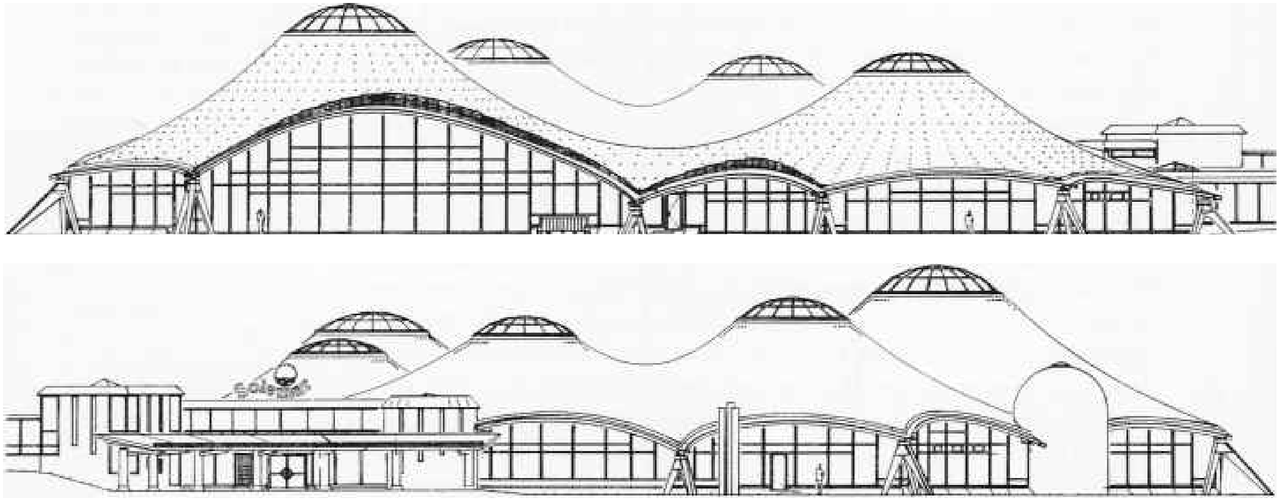


Fig. 3: West elevation (top) and east elevation (bottom)

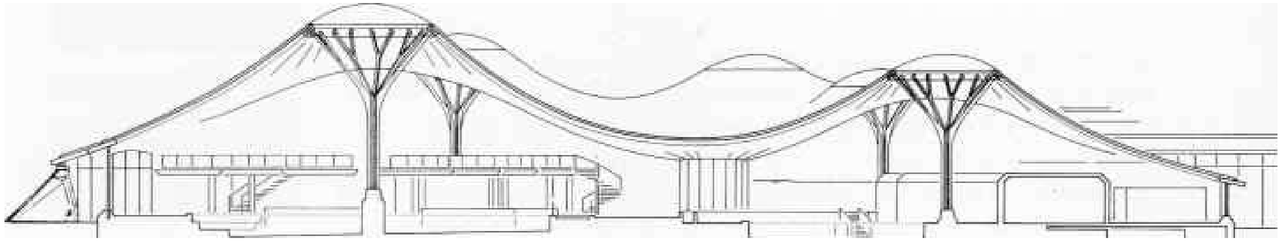


Fig. 4: Section through the primary structure

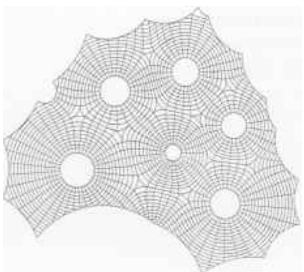


Fig. 5: Plan/top view of the primary structure

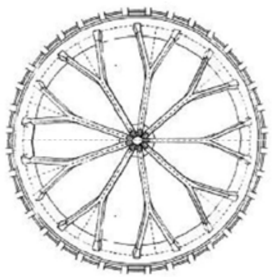


Fig. 6: Reflected plan view of primary support

Fig. 7: Photograph of inside perspective

Architectural Concept

The Brine Baths, is a transferred idea of the tent constructions developed for the Munich Olympic Stadium, material change to wood, which due to its building physical properties that is well suited for the roofing of swimming pools and brine pools. For the free floor plan, five 9.1m to 11.5m high tree supports were created which stand around a small courtyard. They support the rib shell on 6 or 8m diameter rings, hanging meridian ribs and ring ribs. [2]

The forms were generated digitally and follow stress trajectories. The shells are formed from a combination of meridians hanging to natural canary lines between the five column trees and annular rings. [1]

Functions

The glued-laminated timber offers the greatest resistance to the aggressive vapours from the salt water of the baths. [4]

The ground, including the floor and each individual units of brines, stairs, shower cubicles are casted in-situ with concrete.

The whole multifarious panorama is covered by a brad roof with a total area of 2,500 square metre. The roof shell rises from five column trees, from one and down to the arched boundaries to next. The arched surfaces between the columns split up the interior areas. Highest "tree" is 11.5m, stands on an island large swimming pool and brings natural light in, in 8m diameter ring, centred on a 36m diameter space. Second highest "tree" is 10m, supporting 7m diameter ring, centred on a 30m across space. Allowing free floor plan with only 5 column trees, allows users to circulate freely from a bath to another. [2]

Typical Joint

The position of the ribs has been adapted to the principal stress trajectories, as a result of which they are mainly subjected to tensions and compression.The ring ribs are embedded in the meridian ribs at a distance of 80 cm with thickness dimensions of 8 x 8cm and 12 x 14cm. [3]

The meridian ribs and ring ribs are connected to each other by true pin connection, then layered with two layers of diagonally layered shear-resistant timber sheet strips [1].

Fig. 8: Photograph of typical joint

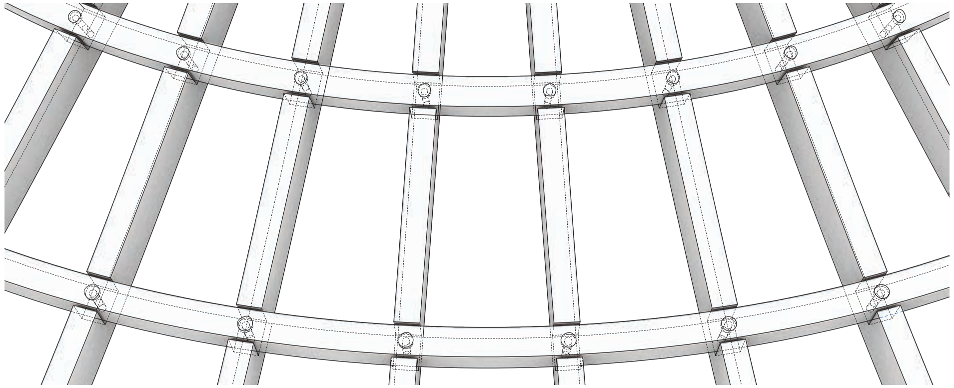
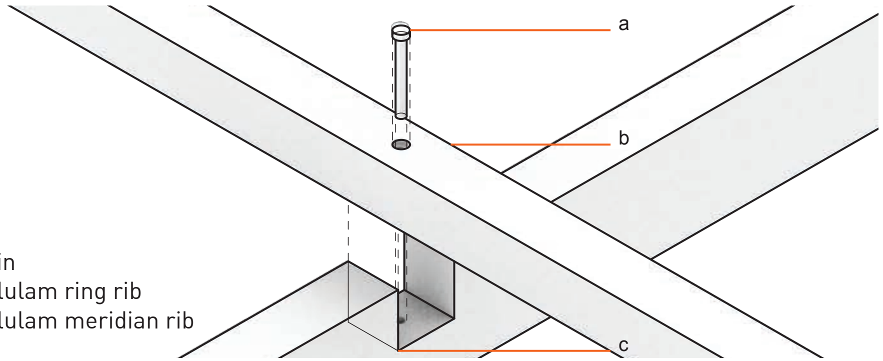


Fig. 9: Axonometric of typical joint



a. Pin
b. Glulam ring rib
c. Glulam meridian rib

Fig. 10: Detail of typical joint

Typical Support

Tree columns are joined with the meridian ribs on one ring. The meridian ribs run in the middle of the ring and connected with dowels. The tree supports are composed of 9 segments, which spreads like a branch of a tree, with the ring fixed at the end, joint with the meridian ribs.

In the corners of the shell, cast steel bearings embedded in beech plywood panels, which mainly absorb the horizontal support forces. The weight of the edge arches is removed via the facades. [3]

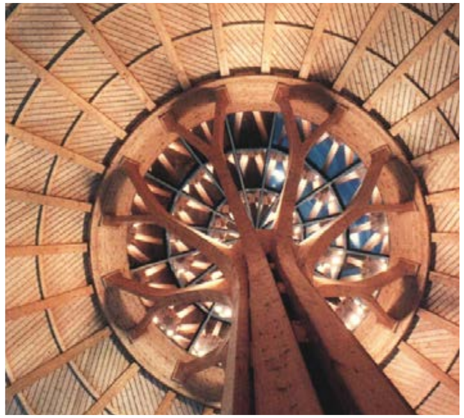
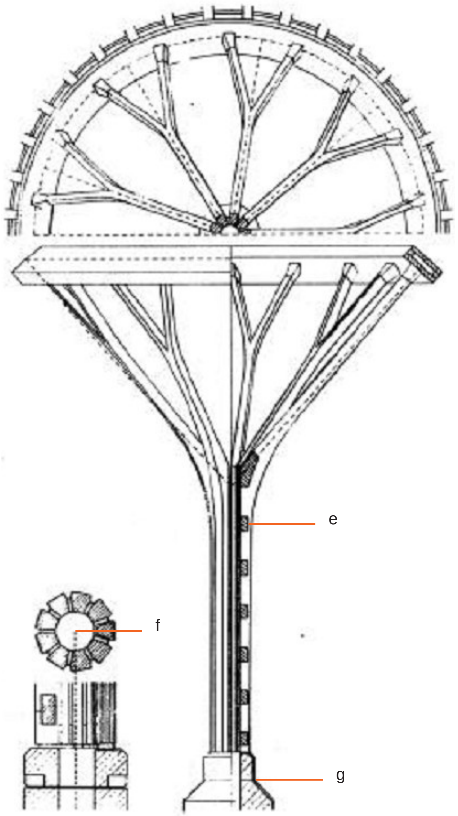


Fig. 11: Photograph of typical support

a. Glulam meridian ribs
b. Glulam column ring
c. Timber dowel rods
d. Branch of a tree column
e. Glulam joint
f. 9 segments of tree column
g. Reinforced concrete base



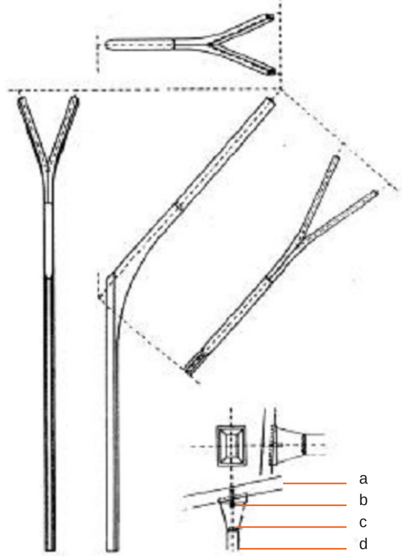


Fig. 12: Detail of typical support

Construction

Brine bath is designed through digital modeling. It was designed with the computer program EASY, for form finding membrane structures, in respect to the stress loads. [5]

With digital calculations on the stress load on the roof, Glued-laminated timber products are pre-fabricated in the factories under controlled conditions. To create complex double curvature and sometimes twisting elements, the glulam ribs are built up from number of laminates. First curving on one plane, then bonded a second time to create the curvature needed.

Fig. 13: Photograph of tree column

Construction Process

A. Tree columns are lifted up by Jacks, meridian beams hanging from the tree columns are pin connected to the boundary box panels and corner cast steel bearings.

B. Each pieces of ribs are held together by finger jointing.

C. Two layers of diagonal timber boarding is applied, for its shear strength.

D. Finally, the roof is covered by PVC membrane. [1]

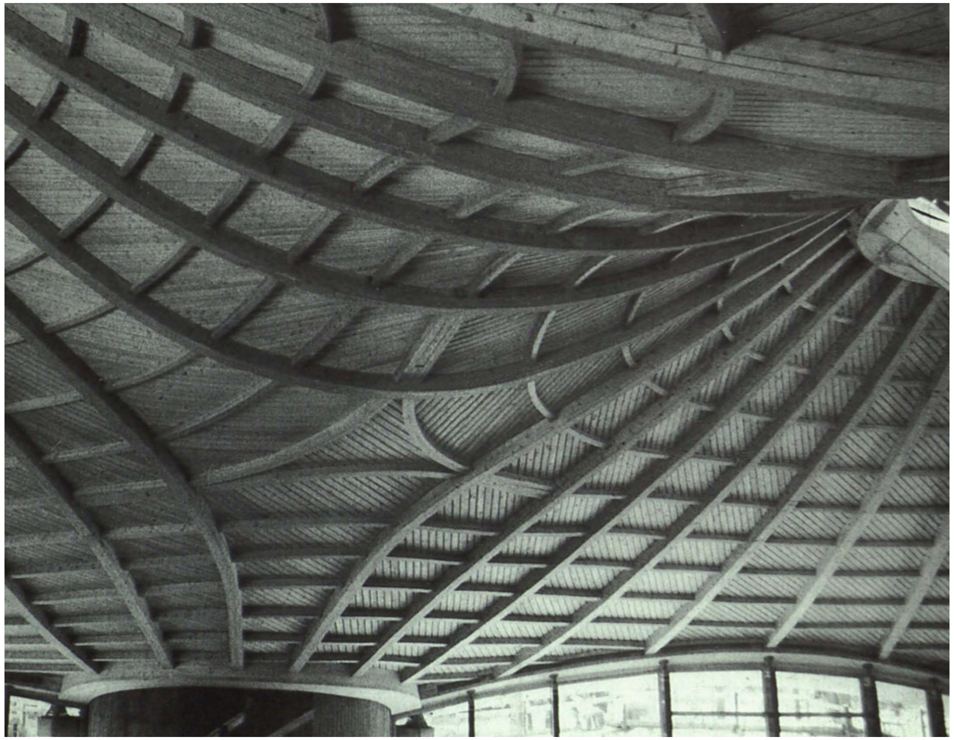


Fig. 14: Photograph of radial rib shell

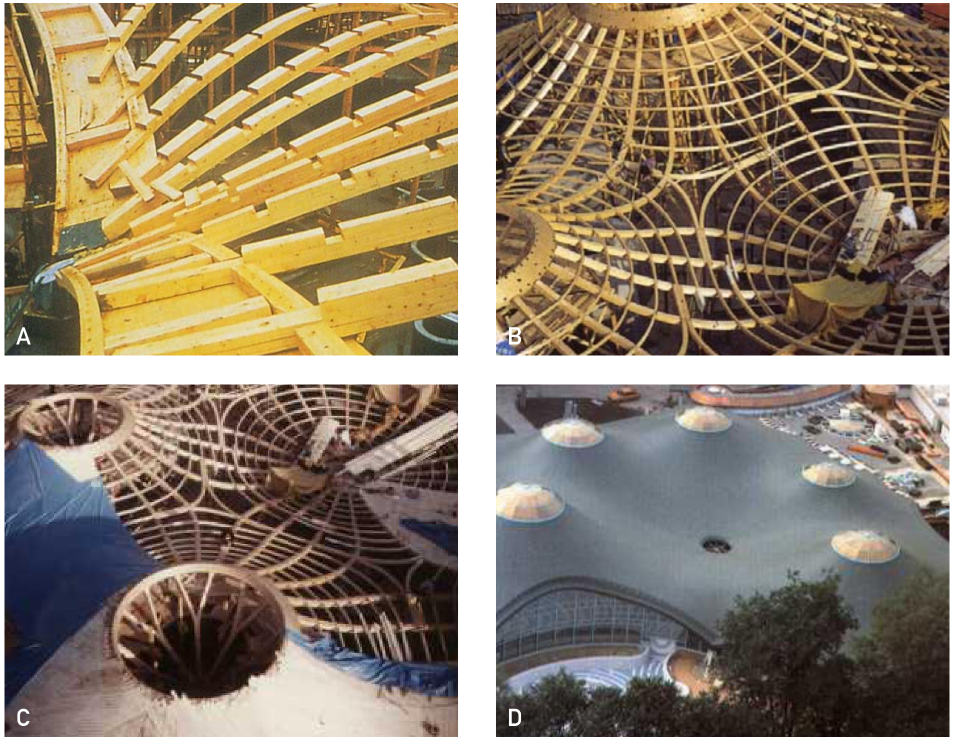


Fig. 15: Construction process A, B, C, D

FORM FINDING

Design Shape

The timber roof structure was a transferred idea of the tent construction developed for the Munich Olympic Stadium, changing material to wood, due to it building physical properties that is well suited for brine bath. The whole timber roof structure is a tension roof, combination of 5 tent structures, supported by 5 column trees joined together, and supported by the local points of supports in compression on the outer edge. [4] The position of the column trees is determined such that the load could essentially carried as membrane stresses, modelled through the computer program.

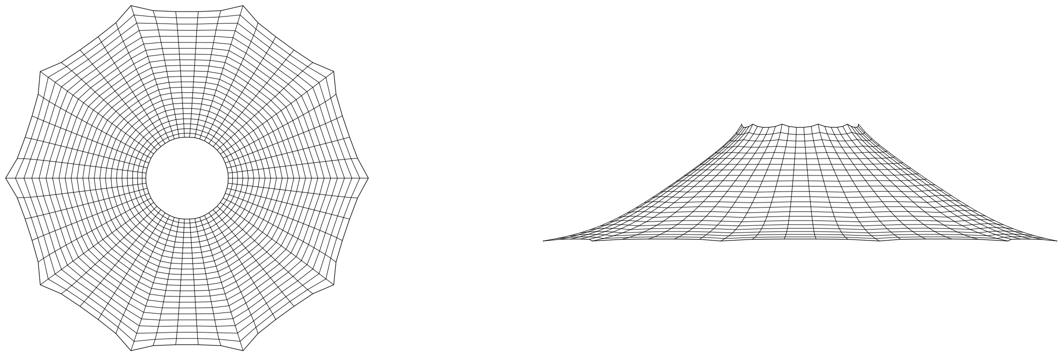


Fig. 16: Centerline model

Parameters

a. Grid of the structure is settled by subdividing the circle into multiple segments to form a polygon. Unlike most of the shell structure, it has a cylindrical grid, origin being the centre of the circle. The upper ring and the lower circle had to be divided into same number of sides of the polygon, joining them and lofting to form a cylindrical surface. Then this surface turns into a mesh with uv curves and control points.

b. Number of timber beams and rings, that defines tension and physical property of the roof, are defined through the uv curves along the structure, u value being meridian curves, whereas v value being circular curves.

Results

Overall shape of one section from five column tree has resulted. With imposition of centre tree column supporting the highest ring, and facade supporting the edge arches, will allow free floor plan as like the function of Brine Bath.

The combination of 5 different shells to one full structure needs to be further studied.

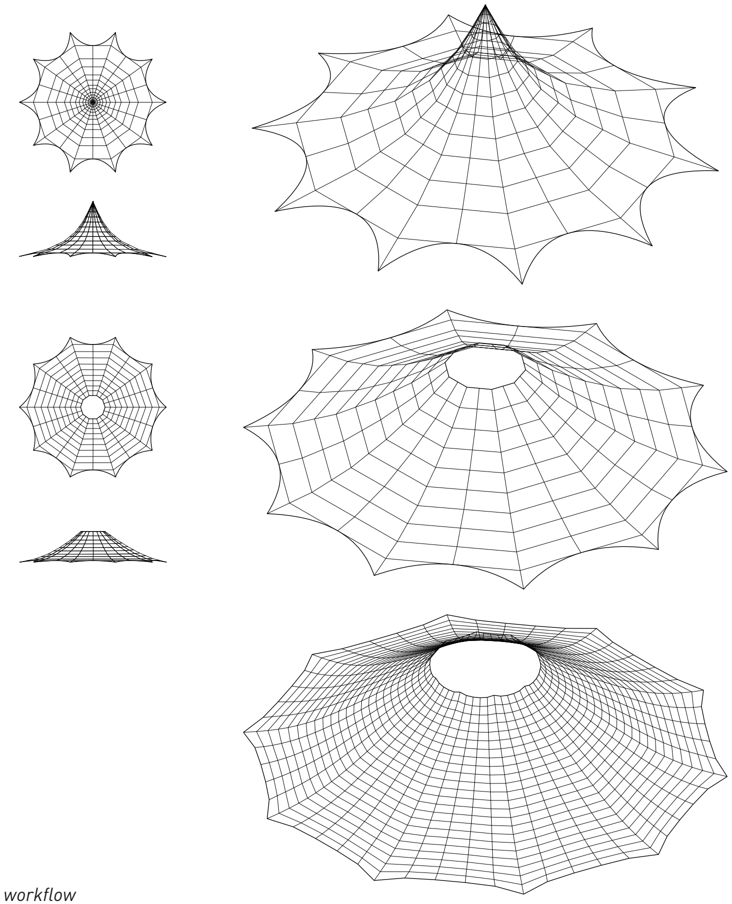


Fig. 17: Structural behaviour and form finding workflow

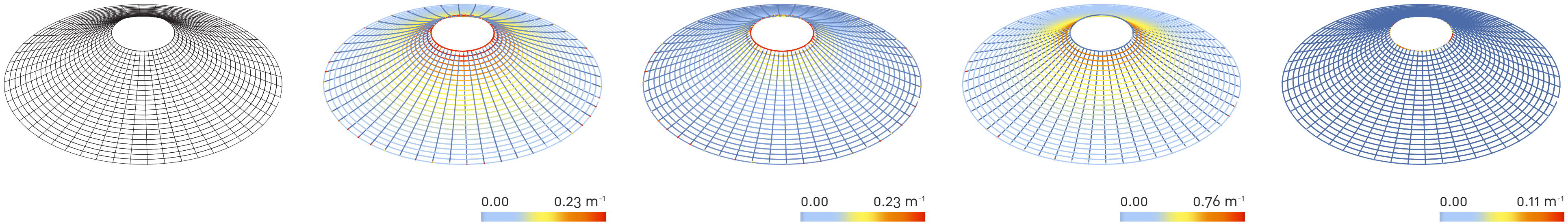


Fig. 18: Curvature Analysis

Gaussian surface curvature K

Brine Bath has negative curvature throughout the surface, since it was modeled to follow tensile structure. With its highest point on the column ring, and negatively curved shape touches the facade on the outer ring. (will be modified after modelling two rings of tree columns)

Spatial curvature k

The curvature of the grid shell The curvature is low on lower parts of radial rings, and high on higher parts of radial rings.

Normal curvature k_n

The normal curvature is when the curve is corresponding to the normal section. The highest normal curvature is on the upper part of the radial rings, where it gradually lowers after, as shown on diagram.

Geodesic curvature k_g

The geodesic curvature is where the curvature of the curve is projected on the surface´s tandgent plane. The highest geodesic curvature is focused on the radial rings, rising as the meridian ring gets steeper, and on the outer edge, it is relatively low, as shown on diagram.

Geodesic torsion t_g

The geodesic torsion is when the curve is twisted. For Brine Bath, the geodesic torsion remains low on all parts of the grids, since the structure is designed through computer programme and prefabricated before construction.

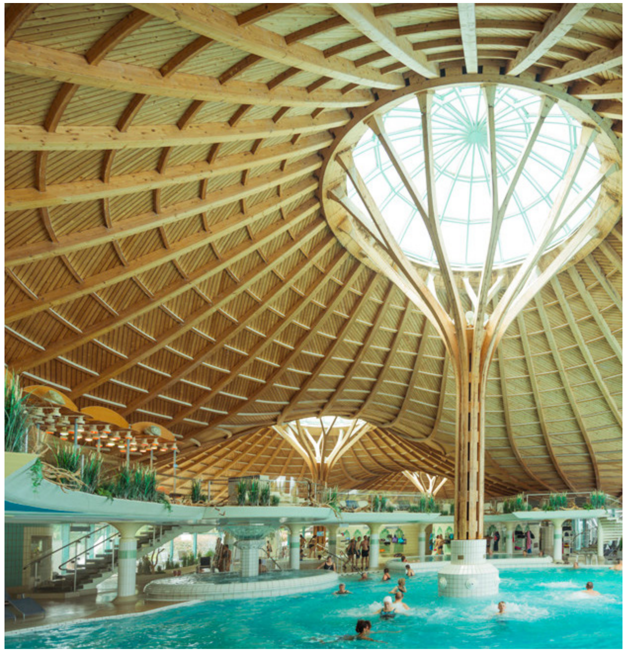


Fig. 19: Photograph of interior view

Summary

Solemar Brine Bath is one of the first computer modeled, prefabricated gridshell in the history. From tensile structural method, change in material to timber adapt its wet environment, while main tree columns in the centre and casted steel bearing on the outer facade, creating space for programme. Its complicated computer design at the time period is greatly appreciated, it still stands and functions in present.

Bibliography

[1] John Chilton, Gabriel Tang. Timber Gridshells: Architecture. Taylor & Francis. Structure and Craft. 2016. 179-180.

[2] Therapiezentrum »Solemar« in Bad Dürrheim, deutsche bauzeitung. https://www.db-bauzeitung.de/150-jahre-db/therapiezentrum-solemar-in-bad-duerrheim/

[3] Müller, Christian. Entwicklung des Holzleimbaus unter der Wahrnehmung der Erfindungen von Otto Hetzer - Ein Beitrag zur Geschichte der Bautechnik, Berlin, 100-101.

[4] Jian-Min Li. Timber Shell Structures: From Finding and Structural Analysis of Actively Bent Grid Shells and Segmental Plate Shells. Stuttgart : Institut für Tragkonstruktionen und Konstruktives Entwerfen, Universität Stutgart. http://dx.doi.org/10.18419/opus-9192

[5] A Design Tool for Timber Gridshells, Delft University of Technology. https://homepage.tudelft.nl/p3r3s/MSc_projects/reportToussaint.pdf

List of Figures

ANALYSIS

Munich Olympic Stadium, Munich, Germany
Ho Wing Hei, Christy

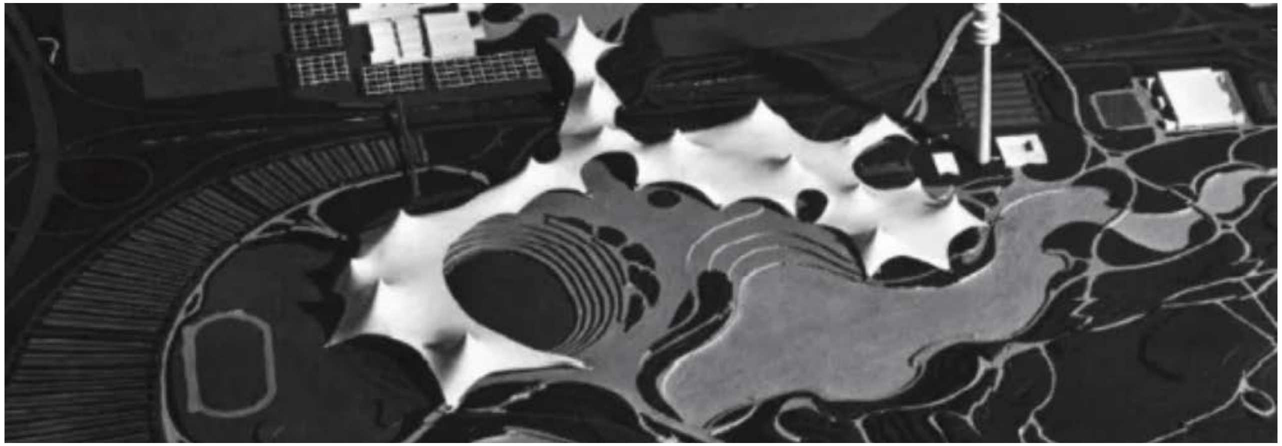


Fig 1: Munich Olympic Stadium, Munich, Germany

Munich Olympic Stadium, Munich, Germany

Student:
Ho Wing Hei, Christy

Introduction

The Munich Olympic stadium is one of Germany's most revolutionary and culturally distinctive landmarks. Its structure was designed by Frei Otto and Gunther Bahnishch for the 1972 Olympic Games in after World War 2, and they were given an important task of creating a structure that showcased Germany in a new light.

Today, the stadium itself stood the test of time and has remained an incredible architectural feat and local landmark in post-war Germany. The Olympic stadium itself can seat more than 80,000 spectators at the time of the Olympics. [1]

During its construction, the project itself evoked local outcry as the price of construction sky-rocketed to over 137 million German marks. [2] The new and revolutionary approach of the design also caused concerned over the erosion of local German history and heritage. At the time of the Olympics, this was overshadowed by the unfortunate news of the Palestinian terrorists hostage attacks which ultimately ended in tragedy. [3]

Architect + Structural Engineer
and Partners, Frei Otto

Completion
1972

Place
Munich, Germany

Cost
137 million German marks

Structural System
Large pipes and steel cables

Area
74,000 m^2

Site

The site provided the main source of inspiration of the then architect Frei Otto and his partner Günther Behmisch. The design of the canopy structure was designed to emulate the nearby Swiss Alps. [4] The stadium is located in the centre of Olympiapark München, which is situated at the north of Munich, Germany.

The site itself was originally an airfield and former train ground for the Bavarian Royal Army as well as Munich's first airport. It offers a series of gentle slopes that descends along the landscape. The formation of the terrain was built after World War 2 with post-war rubble that was transported to this part of the city. [5] Visitors of the stadium can climb up the stadium and the roof of the tensile structure as well to fully witness and immerse themselves into the natural landscape.

Fig 2: Elevation

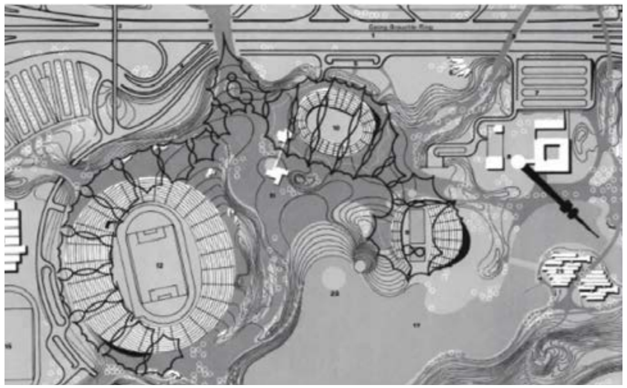
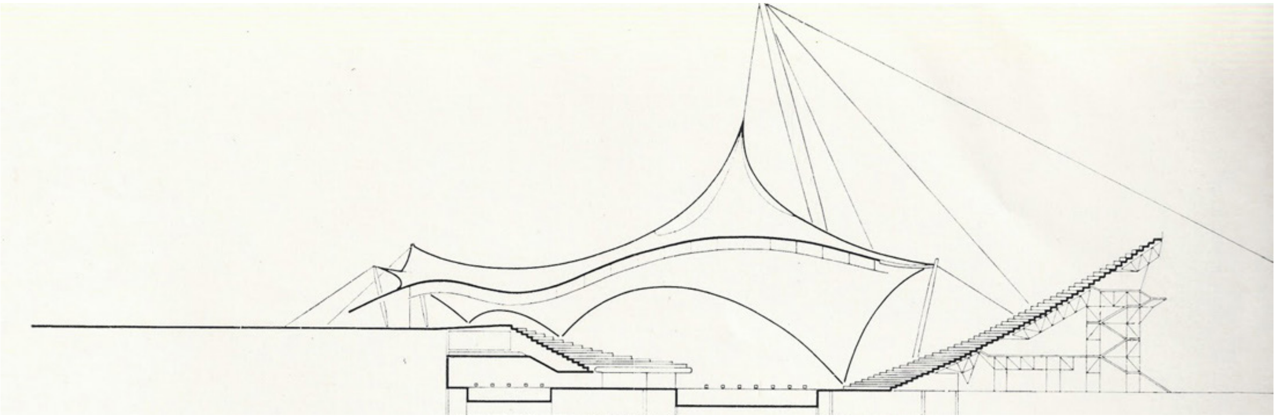


Fig 3: Site plan



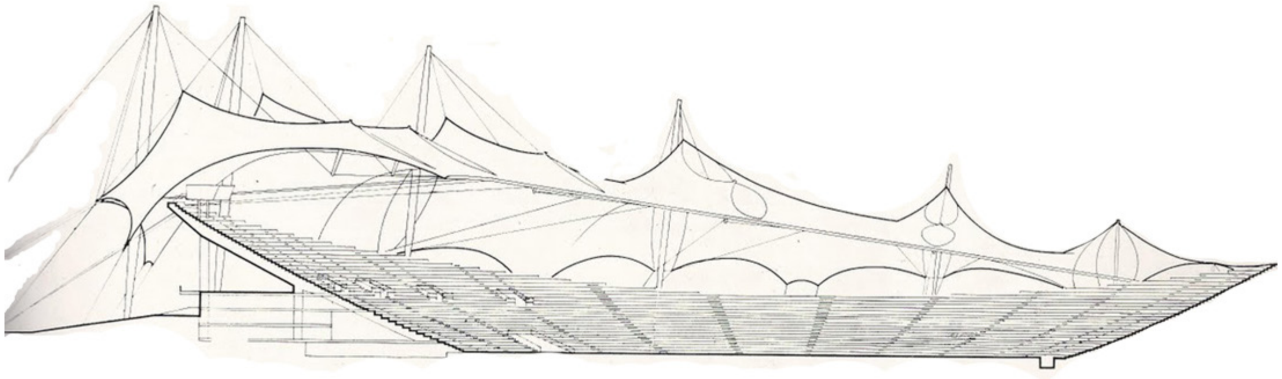


Fig 4 & 5: Section through the primary structure

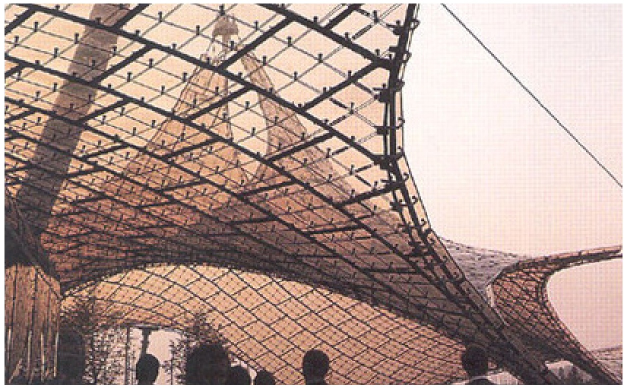


Fig 6: Detailed view of the primary structure

Fig 7: Inside perspective

Architectural Concept

Frei Otto designed the lightweight canopy structure with a vision to emulate the draping rhymes of the Swiss Alps, which resulted in this sweeping landscape of acrylic glass onto of the stadium that is both distinctive and outstanding. The translucency of the structure's glass material was designed symbolise the new democratice Germany after the World War 2. The light canopy is suspended over the main stadium and branches over to the olympic gyms and pools. The stadium was inspired by "Earth Stadiums", which took use of the topography of the site by carving into the ground to accommodate for the seats of the stadium. [6] This concept allows the structure to blend in and become one with the beautiful landscape.

Function

The function of the lightweight structure was to create a cover as spectators sat to watch the games, and also to create shelter for athletes as they competed. Tensile structure are more advantageous compared to traditional buildings in terms of its lack of stiffness and light weight. Its surface geometry is anticlastic, which allows itself to derive its strength from its own built-in tension. It was important that the overhead structure did not cast uneven shadows on the field as it would disturb competitors. As a result, the material of the suspended roof was designed to be translucent. [7] The translucency of the structure also prevented the canpy from blocking the views of spectators as they watched the games.

In addition to that, the stadium had the very important social role of redefining Germany's image to the whole world. The proposed stadium was seen as a new opportunity for the country to forge a new impression of themselves especially after the war. The location itself was also especially significant since the previous Olympics in Berlin was held under the Nazi regime, which German was desperately trying to prove that was not a part of anymore. [8] The design needed to serve a political function to prove that Germany was no longer part of its past, and has moved on since its defeat in the war.

Typical Joint

For the typical joint, cables are arranged in pairs and they are connected with the swagged clamp connection which forms a 75 by 75 cm mesh. This ensures easily construction of joints since it only requires clamps and screws, with one bolt per joint. The joint goes through two layers of clamps which secures the 4 cables together. This allows for a network of twin strands with nodes that are freely rotatable. [9]

These cable nets created by the typical joint are all assembled on ground and then lifted upwards to their final positions. This allows for the pre-stressing of cables before they are put into position.

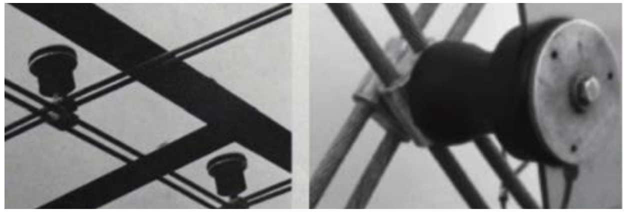


Fig 8: Photo of typical joint

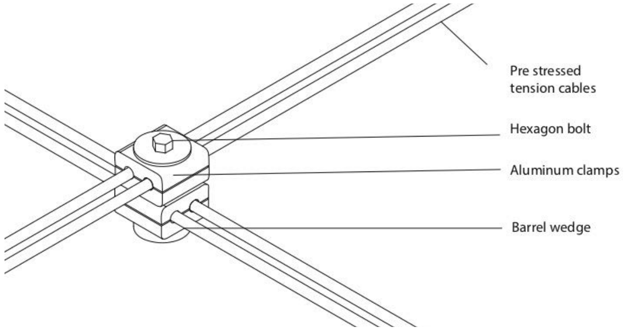


Fig 9: Axonometric of typical joint

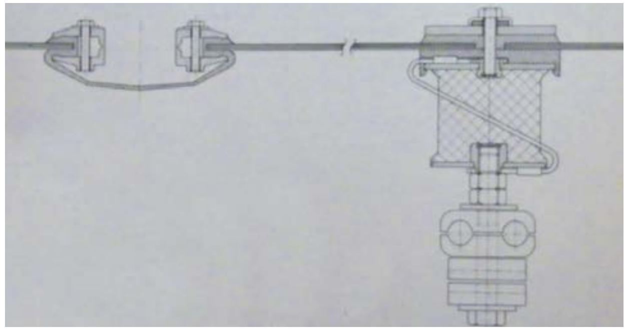


Fig 12: Detail of typical joint

Typical Support

A typical support of the structure is the edge mast-support cable connection. The edge cables are made of locked coil ropes and they frame the entire tensile structure and suspend it from the masts.

The edge cable connection is secured with a steel anchorage connector, which is the body of the connection. A barrel cap fastens the cable to the connector and makes sure that it will not be undone during extreme weather conditions.

Fig 10: Photo of typical edge cable support

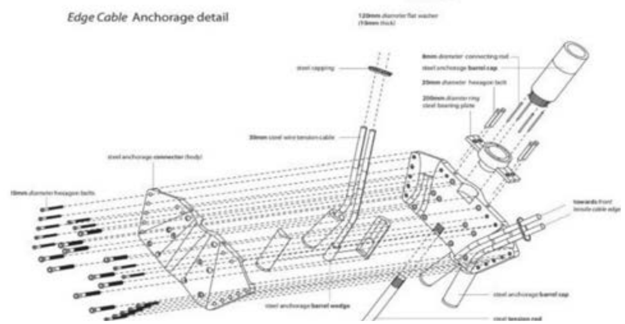


Fig 11: Axonometric of edge cable connection

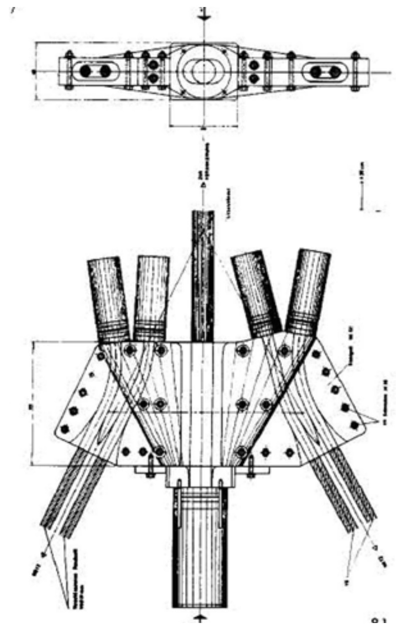


Fig 13: Detail of edge cable connection

Construction

Each of the crossed pair of cables create grids of that span 75cm long to ensure the safety and convenience of construction workers. The interaction joints of the grids were pre-stressed through an automatic process, so that the aluminium clamps with central holes would be pressed and secured onto the strands, assembled on ground and then lifted upwards to their final positions. This allows for the pre-stressing of cables before they are put into the position.

Fig 14: Erection of cable networks

Construction Process

There are 4 main steps for the construction process:

A. Construction of concrete piles and seating: The first step is to construct concrete piles and seating of the stadium for a strong foundation.

B. Installation of pre-manufactured steel masts: They were erected and drilled into the base. The masts act as tension foundations that anchor the main cables down into the ground.

C. Installation of saddle type net and plexiglass: the main cable was attached to the base and the secondary cables were next to the masts and the base. Tertiary cables were attached from the grid shell to the base.

D. PVC coated polyester and fabric was inserted into the gridshell one by one: The transparent panels were already pre-stressed and chosen and secured onto the upper side of the network.

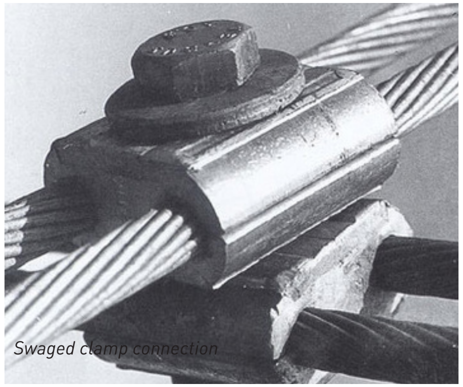


Fig 15: Summary of cable connections

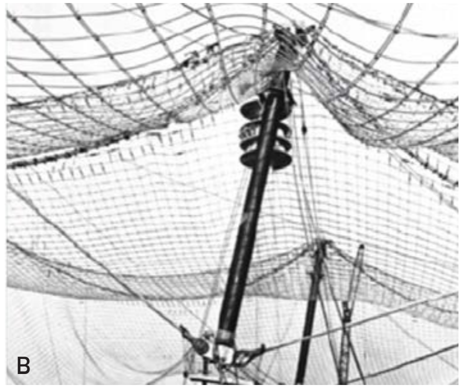


Fig 16: Construction process A, B, C, D

FORM FINDING

Design Shape

In plan, the tensile structure itself is a semi-circle that wraps around the stadium and the Olympic Park. The form of the design is discrete since the kinks on its facade create distinct nodes. The structure acts similar to soap membranes. The stadium's architect, Frei Otto, used soap bubbles to find the smallest possible surface area for the tensile structure.

Parameters

The design begins with a flat square surface. Its vertices and points in between are anchored downwards. Two points are attached and anchored at the middle of the mesh and lifted upwards to create a tent-like structure.

Results

This creates a self standing structure that are anchored to the ground with its surrounding edges, with spaces in between for stadium space.

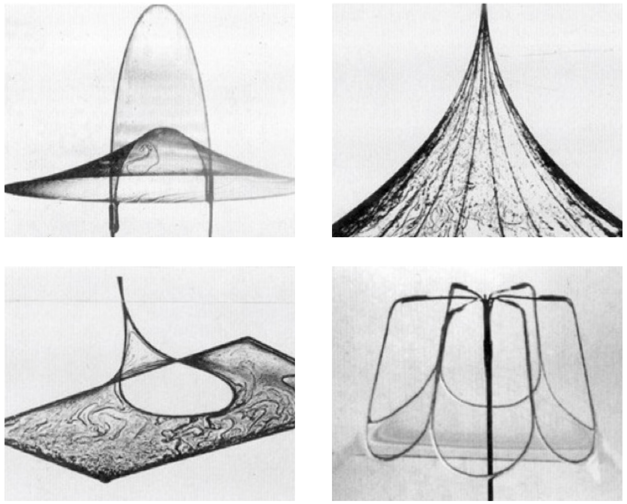


Fig 17: Minimal surface studies by Frei Otto

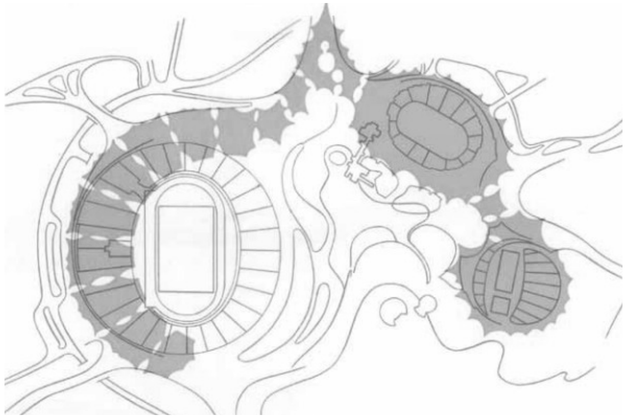
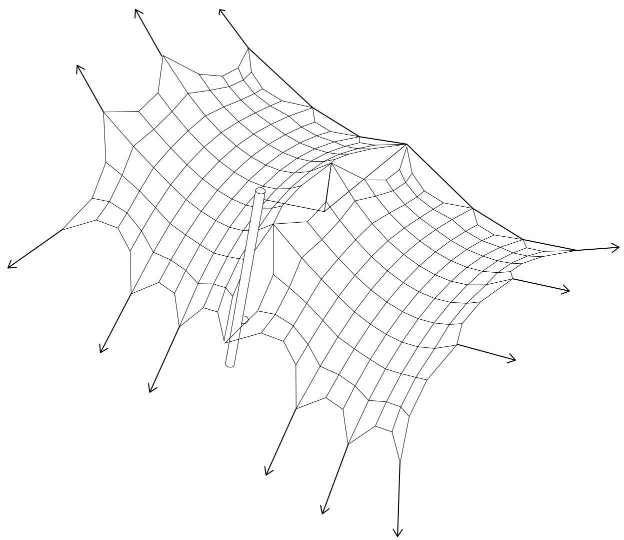
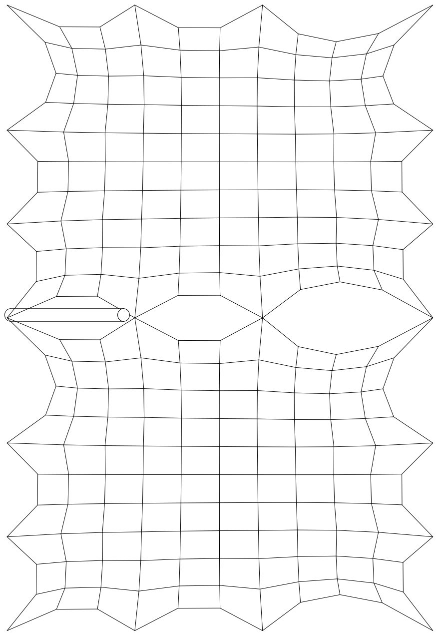


Fig 18: Centerline model





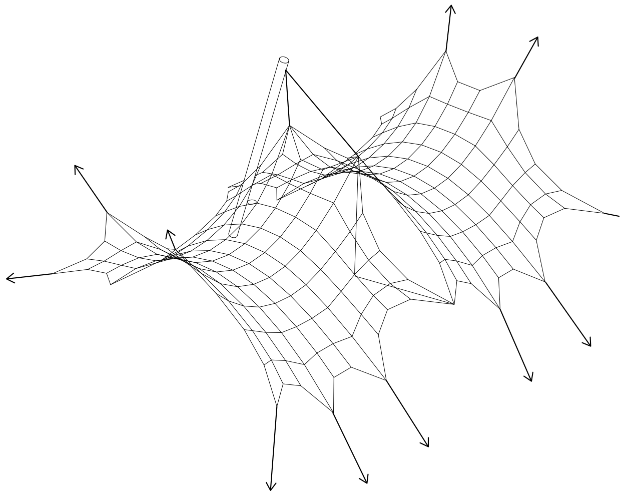


Fig 19: Structural behaviour and form finding work flow

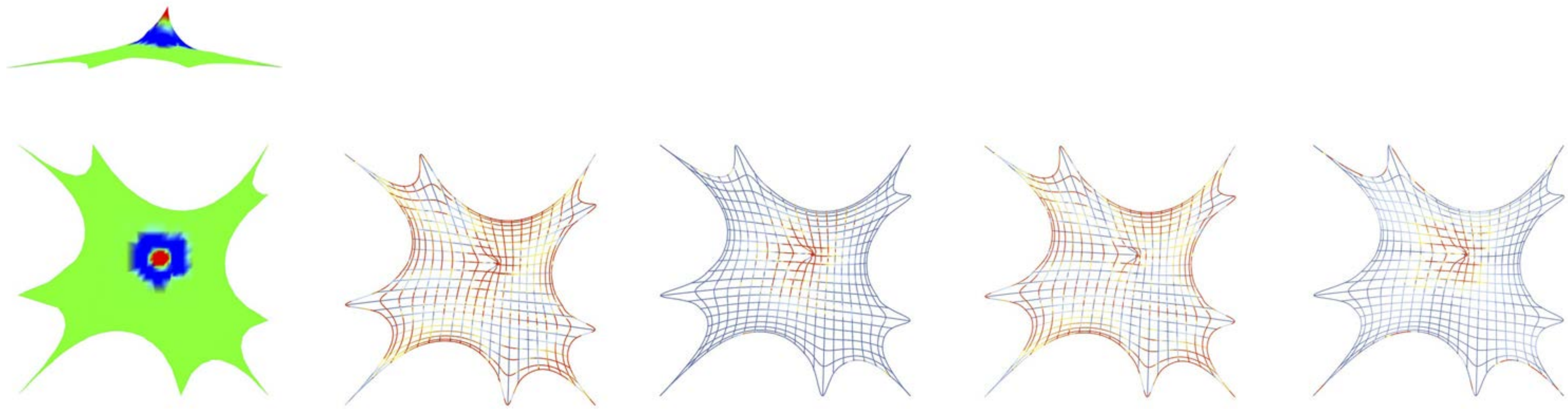


Fig 20: Curvature Analysis

Gaussian surface curvature K

The Gaussian curvature is the most positive and the highest at the peak of the structure, whereas nearer to the bottom of the peak, the gaussian value is more negative since it is a tensile structure. At other parts of the tensile structure, the gaussian surface curvature is closer to zero.

Spatial curvature k

The spatial curvature is how bent the surface is. The k value is the highest especially at the edges of the structure, since it is where the surface is anchored down, causing high stress. This is also true at the peak, where there is a lot of bending

Normal curvature k_n

The normal curvature is the highest at the center of the peak, since it is where the curve's curvature in the direction of the surface normal is the highest. At other points of the structure, the normal curvature is close to zero.

Geodesic curvature k_g

The rate of rotation of the tangent around the normal is the highest at the peak and the edges of the structure. This measures the projection of the vector of the angular rate of rotation of the tangent.

Geodesic torsion τ_g

The rate of rotation of the tangent plane is also the highest near the peak of the structure. This rate is measured with respect to the arc length during the movement of the tangent lines.

Fig 21: Bird's eye view

Summary

The Munich Olympic Stadium can be considered as one of the most significant projects of Frei Otto. It utilizes the soap film technique to find its optimal and most efficient form, and it has created a strong, efficient, yet lightweight tensile structure that can be still used today.

Frei Otto, being one of the pioneers of tensile structure, has allowed generations of architects to understand the importance of utilising everyday things that we use in our lives to re-envision how we can design new and efficient architecture.

Bibliography

[1] Olympic Stadium - Data, Photos & Plans." WikiArquitectura,en.wikiarquitectura.corn/building/munich-olympic-stadium/.

[2] GmbH, Olympiapark München. "Olympic Stadium Event Highlights." Olympiapark München :: Olympic Stadium :: Olympiapark München, Muskelaufbautraining, Bodystyling, Lauftreff, mvw.olympiapark.de/en/olympic-park/event-locations/olympic-stadium/.

[3] Fiederer, Luke. "AD Classics: Olympiastadion (Munich Olympic Stadium) / Behnisch and partners & Frei Otto." ArchDaily, ArchDaily, 11 Feb. 2011, www.archdaily.com/109136/ad-classics-munich-olympic-Stadium-frei-otto-gu nther-be

[4] Ermengem, Kristiaan Van. "Olympiapark, Munich." A Vlew On Cities, www.aviewoncities.com/munich/olympiapark.htm.

List of Figures

ANALYSIS

Downland Gridshell, Singleton, England
Mirae Nam

Downland Gridshell, Singleton, England

Student:
Mirae Nam

Introduction

The Downland Gridshell was designed by Edward Cullinan Architects with structural engineers Buro Happold and Green Carpentry Company, completed in 2002. This was the first double-layer timber gridshell building constructed in the UK. It was built with green oak by using traditional and innovative building techniques. As the result, its curving form and natural material beautifully harmonize with the surrounding South Downs landscape.
The Downland Gridshell is part of a new building for the Weald and Downland Open Air Museum in Sussex. The building serves as a workshop for conservation, restoration and training, and an archive storage for tools and artifacts spanning six centuries [1].

Fig. 1: Interior view

Architect
Cullinan Studio

Structural Engineer
Buro Happold

Completion
2002

Place
Singleton, England

Cost
£ 1.3 million

Structural System
Oak gridshell, 48m lo

Area
Floor area, 1,220 m²

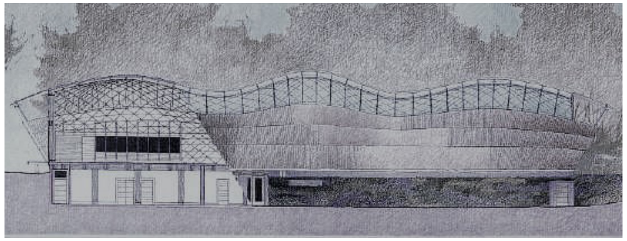


Fig. 2: Elevation

Site

On the South Downs, the Downland Gridshell is located close to natural resources. There are rich timber resources and to harmonize with historic timber buildings, the architect chose to use the timber as the major material. Along a path to the building, there are mature beech and ash trees which creates nice shade.

Fig. 3: Surrounding landscape

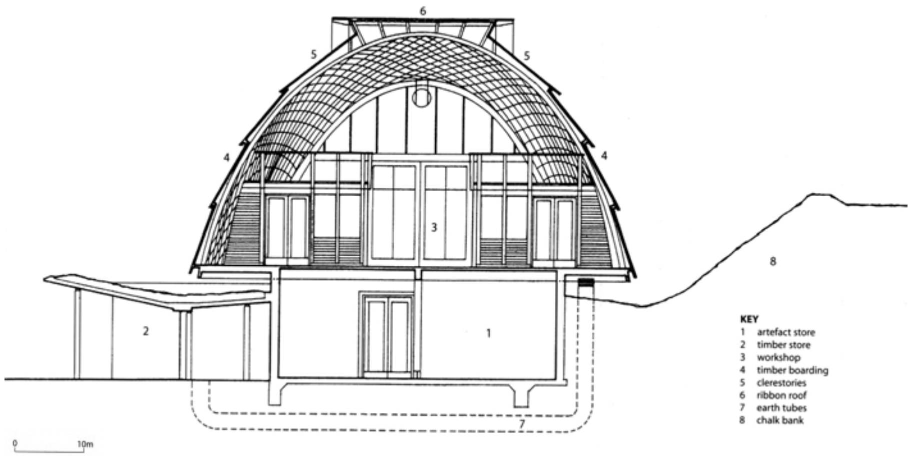


Fig. 4: Cross section

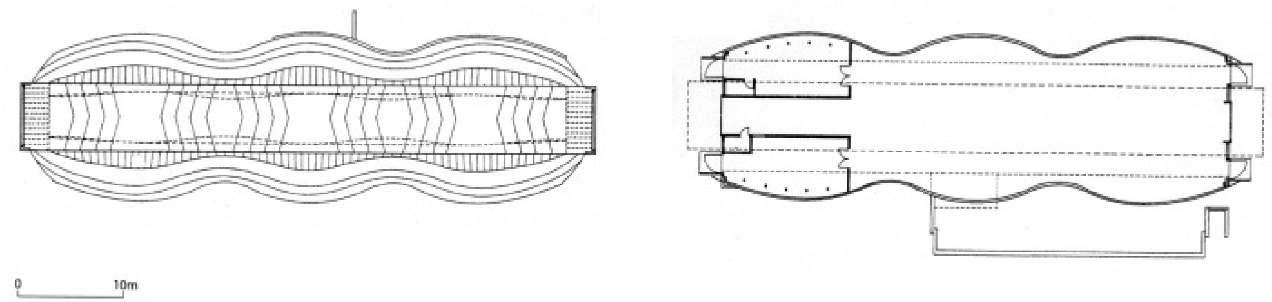


Fig. 5: Plan/top view of the primary structure

Fig. 6: Structure

Architectural Concept

Edward Cullinan architects proposed an innovative building that would respond to the physical demands of the Museum and the sense of foresight held by its directorship. Rather than mirror the past, the new structure was to celebrate the special environment of the Weald and Downland region and serve as an exemplary structure for modern rural buildings.

A gridshell is a structure that gains its strength and stiffness through its double curvature configuration. Its advantages are a minimum use of materials, structural efficiency and the creation of a large volume, as well as the potential for quick and cost-effective construction [1].

Functions

Edward Cullinan Architects were asked to add a workshop and education center to the existing museum complex, the design for which would need to respond to the museum's collection of buildings and reinforce its aim to explain the design concept and building techniques trough architecture forms. The space needed to be large enough to reassemble and display salvaged medieval timber-framed buildings and house workshops, teaching sessions and display spaces. ECA's response to this was the concept of a rural 'barn' that could be built as a functional enclosure [2].

Typical Joint

The clamping assembly consists of a galvanized steel plate with steel pegs protruding on both sides which are inserted into holes drilled into the innermost laths in order to exactly locate the intersection. Plates on either side with four bolts clamp the whole assembly together. The two outer laths are not drilled as they will need to move slightly to accommodate the curvature of the structure [3].

Fig. 7: Photo of typical joint

Typical Support

Prior to the assembly of the gridshell, marine ply fascias were attached to the floor and the ends of the Glulam beams. Blocks have been laminated at each point on the fascia where a bracket exists inside the fascia. A further layer of marine ply matching the inner fascia is added to form a sandwich consisting of two layers of marine ply and four thicknesses of lath. The sandwich will be secured with bolts through the ply and laths and the whole sandwich will be bolted to the brackets at the end of the Glulam beam forming a fully rigid fixing at the base of the structure [3].

Fig. 10: Photo of typical support

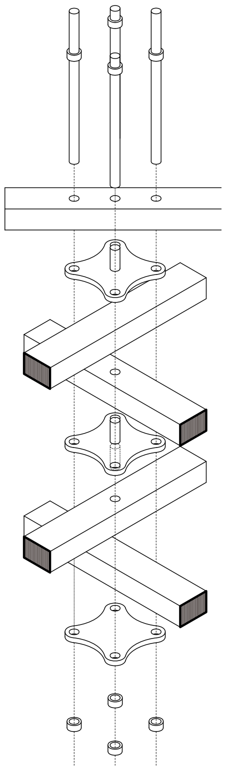
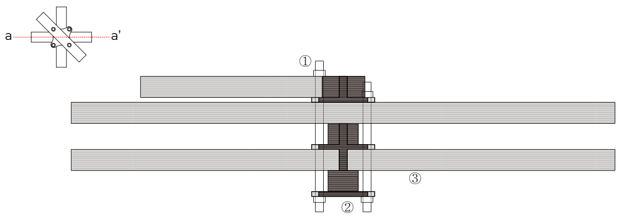


Fig. 8: Axonometric of typical joint



Elements

1. 30x50mm loak rib lath
2. 105x105x8mm galavanized steel clamping plate
3. M6

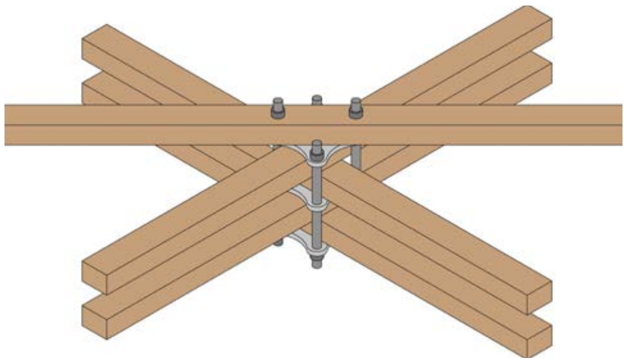
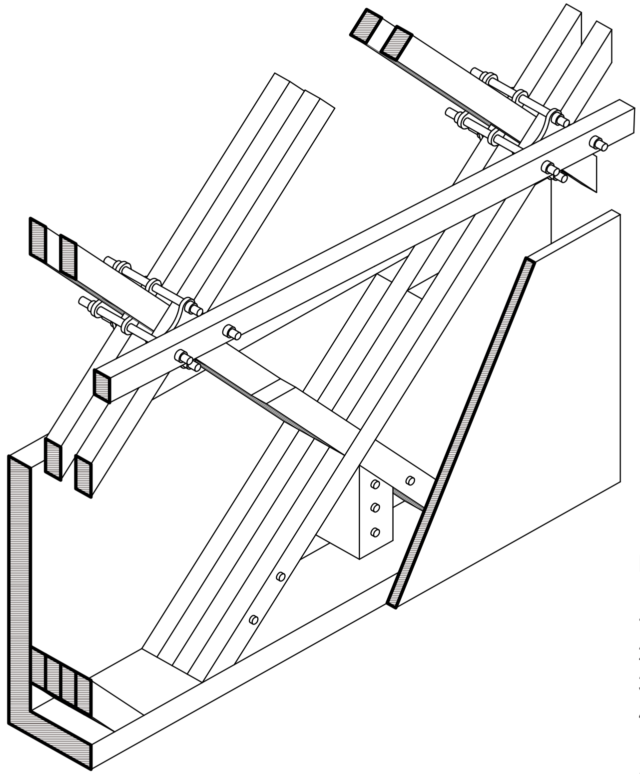


Fig. 9: Detail of typical joint



Elements

1. Marine plywood fascia
2. Glulam beam
3. Angle brasket
4. Bolt

Fig. 11: Detail of typical support

Construction

The workshop space was built of green oak strips joined together to form long laths. A diagonal grid of these laths was initially formed flat on top of a supporting scaffold. Using gravity, the edges of the grid were then lowered gradually a few centimetres each day into a three-dimensional shape resembling a three-nut peanut shell. This was secured to the edges of the timber platform above the lower level. Cladding, roofing and installation of the ventilation system were then added [4].

Construction Process

A. Grid laid flat on scaffolding

B. Scaffold is lowered and the Gridshell starts to take shape

C. The roof is added

D. The gridshell structure is clad in Western Red Cedar

Fig. 12: During construction

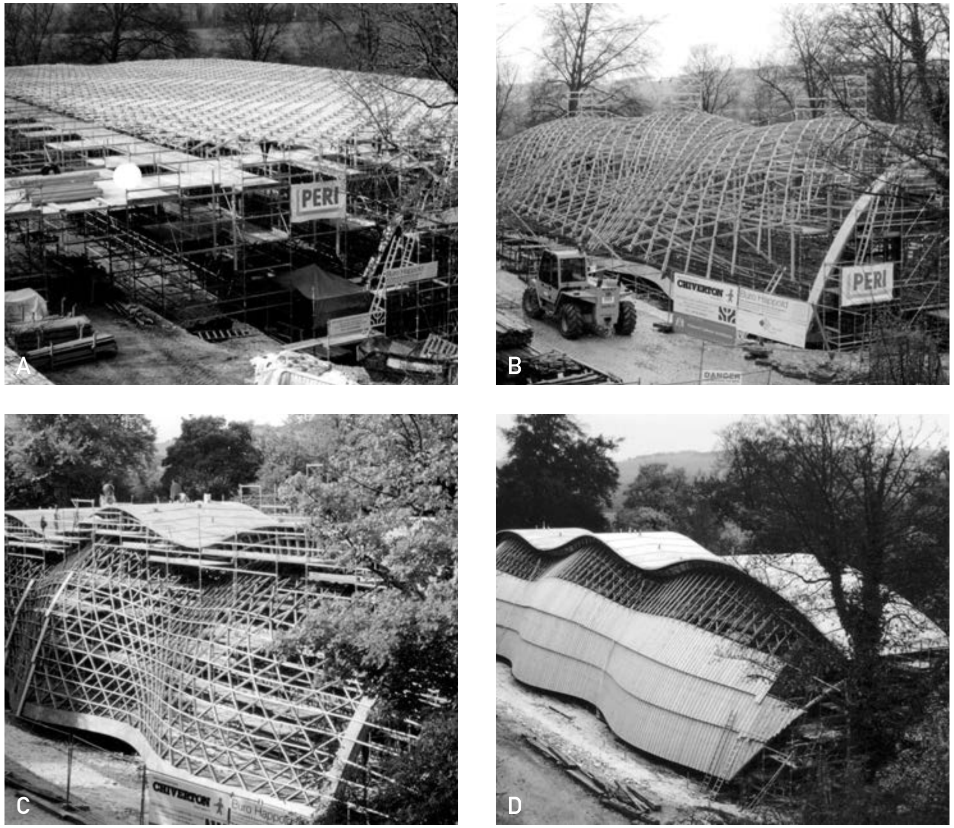


Fig. 13: Construction process A, B, C, D

Design shape

The Downland Gridshell has a triple bulb hourglass shape. The shape of the gridshell is primarily driven by stiffness requirements; the double curvature of the shell generates geometric stiffness and is fundamental to its structural action in resisting asymmetric loads.Both physical and computer modelling played an essential role in determining the final geometry [5].

Parameters

The lattice was laid out as a flat mat composed of squares with a 1m edge length; the resulting lattice mat would be 47m long x 25m wide stretched longitudinally to achieve the 50m length of the completed structure. In this way the central node in each of the three domes was positioned according to their final
longitudinal and transverse location. This meant that longitudinal changes in length were minimised adding a control; the central node of each dome could be monitored to check that their movement was vonly vertical [5].

Results

It is 50m long, varies in width from 12.5m at the valleys to 16m at the crowns, while its height varies from 7.35m in the valleys to 9.5m in the central dome.

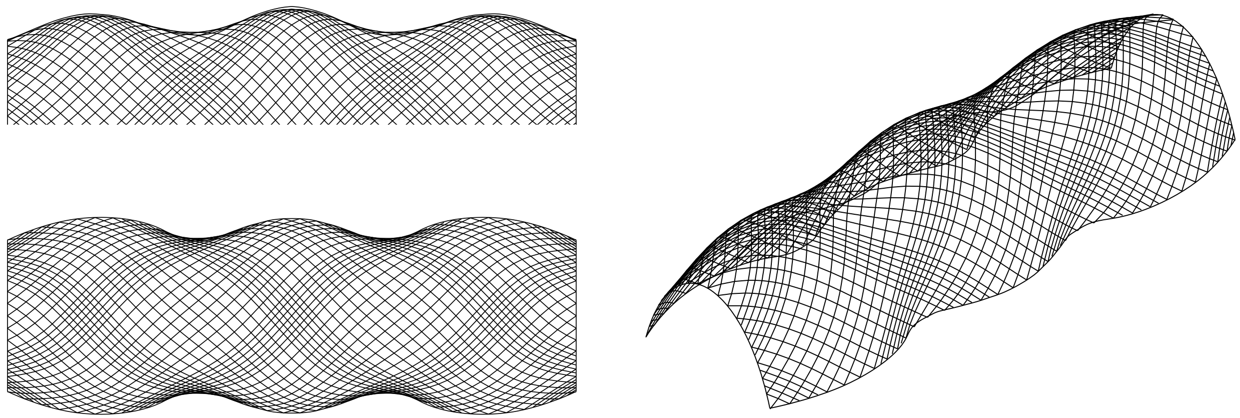
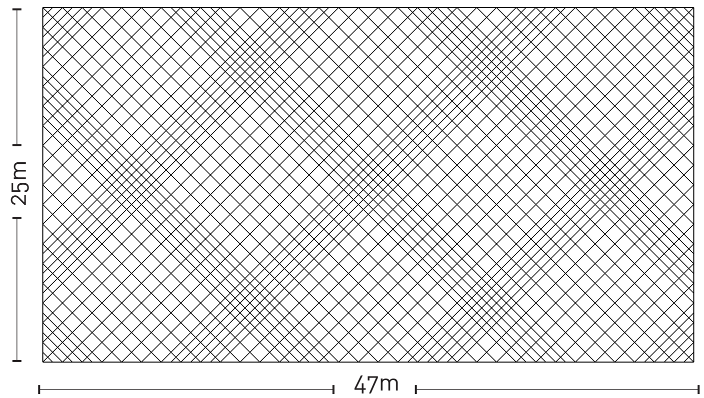


Fig. 14: Centerline model



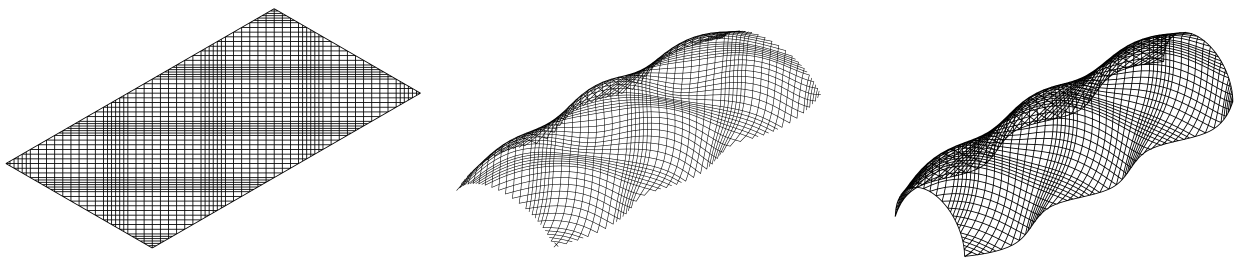
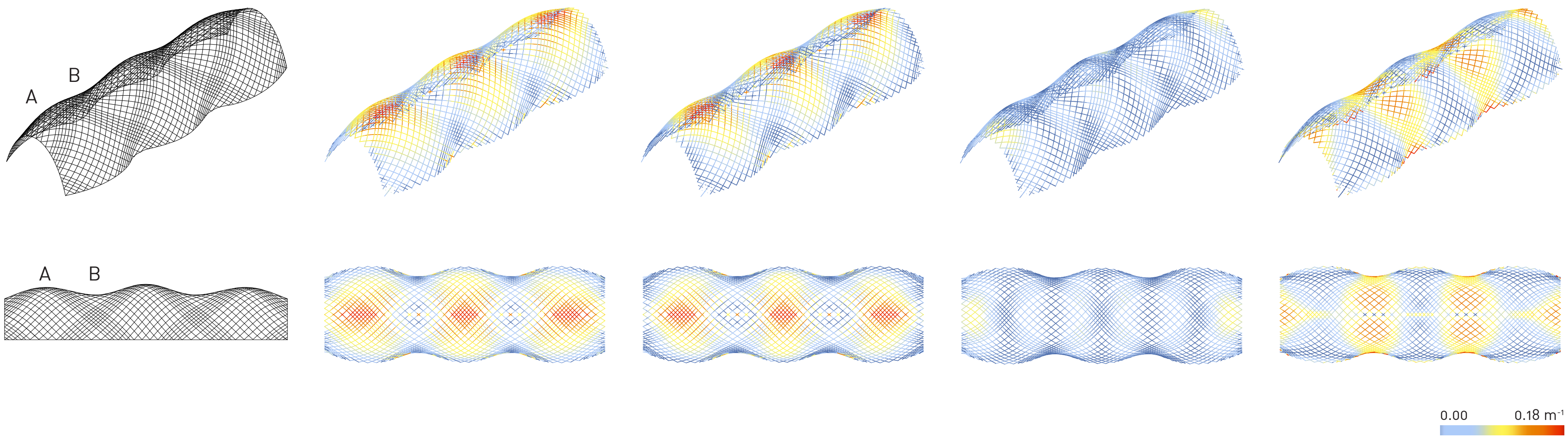


Fig. 15: Form finding workflow



Gaussian surface curvature K

This gridshell shape has both positive and negative curvatures at different parts. At the A point of the diagram, radius of tangent circles are both having positive value, however, point B has one negative and one positive value. Therefore, A is positive curvature and B is negative curvature.

Spatial curvature k

This diagram shows the spatial curvature of the gridshell. The value of k varies along its flexion of the surface. This form has highest curvature on the top of the hill, and intermediate part which connect the hills has relatively low values.

Normal curvature k_n

Normal curvature is a curvature value happens only in the normal section. Most of red range occurs on the top of there humps. And, gradually gets lower at the bottom.

Geodesic curvature k_g

Geodesic curvature is the bending force generated toward side to side. For the downland gridshell model, Geodesic curvature value is very low, as the curves are mostly bending logitudinally, but not transversly.

Geodesic torsion □$_g$

When the normal of the point changes along the curve, it will create Geodesic torsion. On this form of girdshell, highest torsion generated on the concave area. As the curve on intermidiate area need to change the direction drastically, it results the high geodesic torsion.

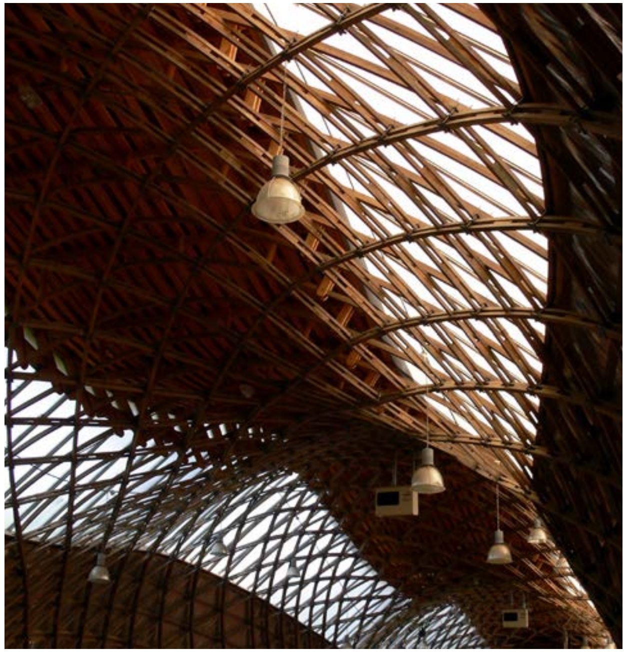


Fig. 17: Photo

Summary

Downland Gridshell is a typical type of gridshell that has various characteristics. They used timbe material to blur into the surrounding, also it created an unusual double curvature volume in single large plane using the properties of elastic material.

To achieve this result, the architect and engineers had been gone through numerous tests on physical and technological prototypes. After they sorted out with most difficult part, computing and calulating, the small details followed to make the architecture more subtle.

Bibliography

[1] Harris, Richard, John Romer, Oliver Kelly, and Stephen Johnson. "Design and Construction of the Downland Gridshell." Building Research & Information 31, no. 6 (2003): 427–54.

[2] Farrelly, Lorraine. Construction Materiality: n the Action or Process of Constructing a Building or Other Structure: n the Matter from Which Something Is or Can Be Made. Lausanne: AVA Academia, 2009.

[3] "Assembling the Grid." Weald and Downland, November 5, 2014. https://www.wealddown.co.uk/explore/buildings/further-reading/assembling-grid/.

[4] Cullinan. "Downland Gridshell: Cullinan Studio." Downland Gridshell | Cullinan Studio. Accessed March 1, 2020. http://cullinanstudio.com/project/downland-gridshell.

[5] Harris, R., and O. Kelly. "The Structural Engineering of the Downland Gridshell." Space Structures 5, 2002. https://doi.org/10.1680/ss5v1.31739.0018.

List of Figures

1 Bray, Charles. "Downland Gridshell Building Conservation Workshop." Flickr. Yahoo!, February 24, 2008. *https://www.flickr.com/photos/c_a_bray/2288897173/in/photolist-4uke-Vu-4ugcon-4ukf2o-4ukeXA/.*

2 "Downland Gridshell - Project History and Design Brief." Weald and Downland, October 26, 2014. https://*www.wealddown.co.uk/explore/buildings/further-reading/downland-gridshell-project-history-design-brief/.*

3 Cullinan. "Downland Gridshell: Cullinan Studio." Downland Gridshell | Cullinan Studio. Accessed March 1, 2020. *http://cullinanstudio.com/project/downland-gridshell.*

4 "The Downland Gridshell." EUMiesAward. Accessed March 1, 2020. *https://miesarch.com/work/1192.*

5 "Browsing the AJ Buildings Library: Julia King on the Downland Gridshell." Architects Journal. Accessed March 1, 2020. *https://www.architectsjournal.co.uk/buildings/browsing-the-aj-buildings-library-julia-king-on-the-downland-gridshell/8669780.article.*

6 "Undulating Downland Gridshell in England Is a Self-Supporting Structure Built from Local Oak." Inhabitat Green Design Innovation Architecture Green Building. Accessed March 1, 2020. *https://inhabitat.com/undulating-downland-gridshell-in-england-is-a-self-supporting-structure-built-from-local-oak/.*

10 "Assembling the Grid." Weald and Downland, November 5, 2014. *https://www.wealddown.co.uk/explore/buildings/further-reading/assembling-grid/.*

12 & 13 Cullinan. "Downland Gridshell: Cullinan Studio." Downland Gridshell | Cullinan Studio. Accessed March 1, 2020. *http://cullinanstudio.com/project/downland-gridshell.*

17 Jones, Tony. "Gridshell." Flickr. Yahoo!, August 18, 2006. *https://www.flickr.com/photos/flambard/218487127.*

ANALYSIS

Aquatoll, Neckarsulm, Germany
Muye Ma

Fig. 1: The interior of Aquatoll Neckarsulm

Architect
Kohlmeier und Bechler

Structural Engineer
Schlaich, Bergermann und Partner

Completion
1990

Place
Neckarsulm, Germany

Cost
Unknown

Structural System
Gridshell

Area
560 m²

Span
25 m

Grid Width
1 m x 1 m

Radius of Dome
16.5 m

Rise
5.75 m2

Aquatoll, Neckarsulm, Germany

Student:
Muye Ma

Introduction

In 1988, Schlaich Bergermann und Partner were selected to design the swimming complex in Neckarsulm. The scope entailed covering the pools with a glass dome that was to be as transparent as possible. In the end, the gridshell structure became a 1

Site

The swimming complex is located in Neckarsulm, a city in northern Baden-Württemberg, Germany, near Stuttgart, and part of the district of Heilbronn. The residential community has a big green space that covers the whole area where most buildings are low-rise. The swimming complex provides multiple water activities, and the gridshell is performing as a roof structure covers a public swimming pool and connects the indoor space with other facilities.

Fig. 2: Site plan

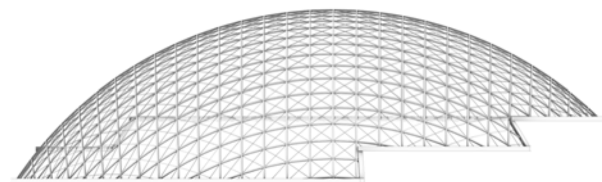


Fig. 3: Comparative section

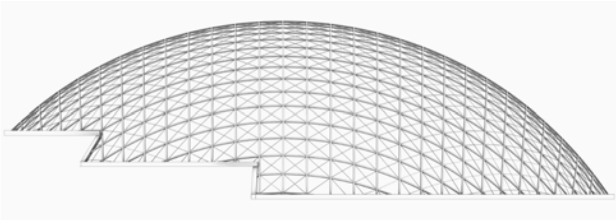


Fig. 4: Section through the primary structure

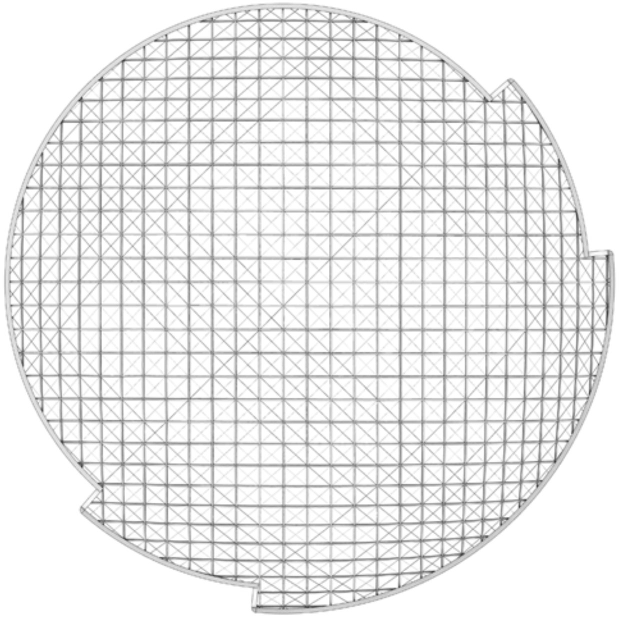


Fig. 5: Plan/top view of the primary structure

1, 4, 5, 6. Schober "Transparent Shells", 2016
2, 3. Schling "Repetitive Structures", 2018

Fig. 6: Inside perspective

Architectural Concept

The initial considerations for the scheme were based on rotational-symmetric domes But these were unsatisfactory, because of the bar density increased towards the centre, where the highest level of transparency was desired.4

Furthermore, in the spirit of the firm's philosophy something entirely new was to be created. Rather than repeating existing methods, the aim was to make a contribution towards building innovation. Innovations do not fall into one's lap; they are the results of development. They are based on knowledge, experience and creativity. In engineering there are practically unlimited solutions.4

In the end, the idea of applying the principle of quadrangular mesh with rotatable node connections on domes under compression loads is used.5

Functions

The roof structure is using the quadrangular meshes; it makes sure that there is enough light going through the glazing, and it creates a simple, clean look of the structure. The quadrangular shape is shiftable, meaning that the parts around the edge are more deformed than that in the centre. Hence, the grid has an advantage to make sure that the length of each number is equal to 1 meter; therefore, it makes the construction much simpler.6

CONSTRUCTION DETAILS

Typical Joint

Because the mesh angles become rather acute from the center to the edge when the structure expands, the joint needs to be flexible and adjustable with a certain angle in order to be feasible in all over the dome. Bars are bolted and curved following the dome radius R; a twin cable clamped with a centre bolt is to allow the joint rotating in a certain angle.[7]

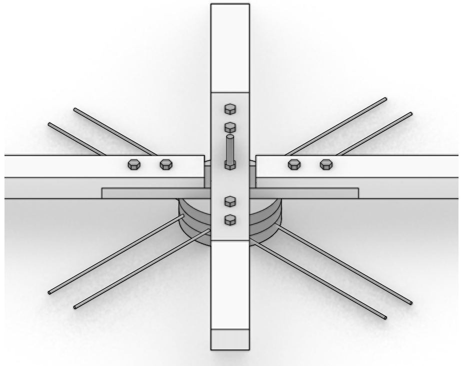


Fig. 9: Perspective of the joint

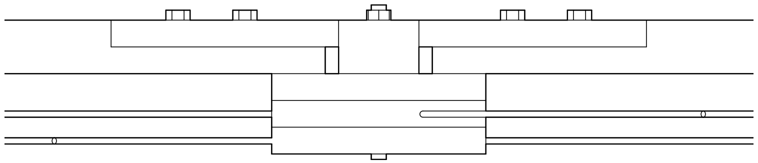


Fig. 8: Detail of typical joint

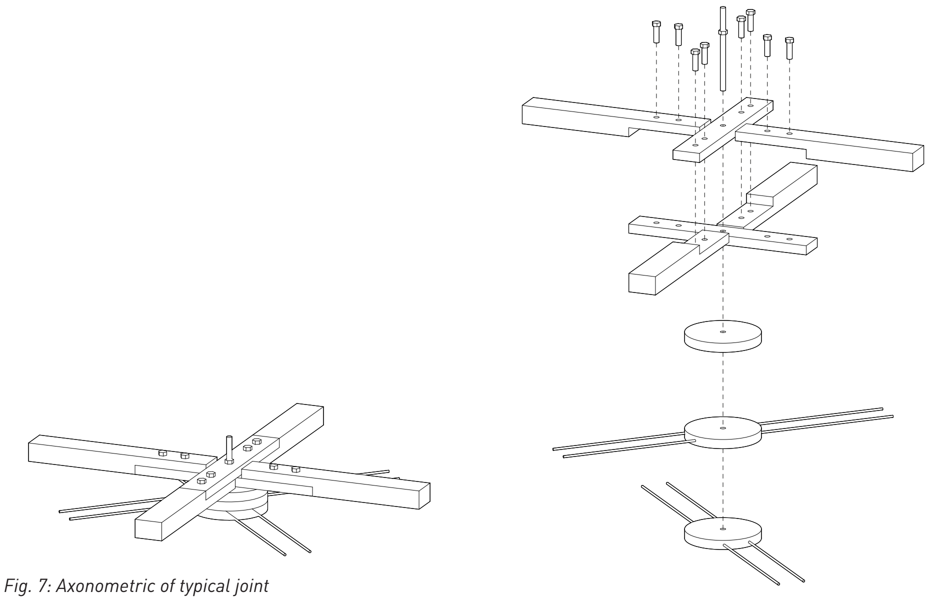


Fig. 7: Axonometric of typical joint

Typical Support

The primary grid is assembled by flat bars made of S235 structural steel, with 60 * 40 mm the bar size. The grid is also cross-braced by twin cables with a diameter of 5mm. The glazing is employed by spherical curved insulating glass panels, which are having the same radius with the dome, directly placed on to the bars to avoid the torsions of the bars.[8]

Fig. 12: Detail picture of the joint on the grid

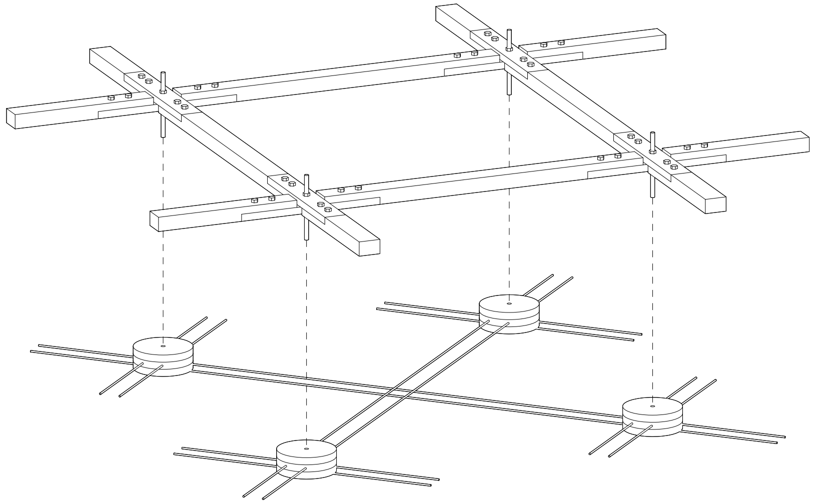


Fig. 10: Axonometric of typical support

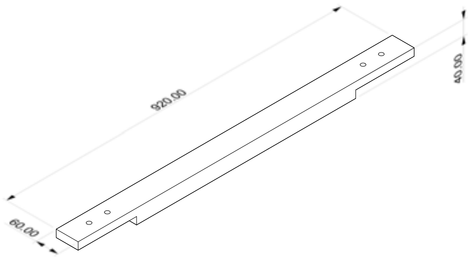


Fig. 11: Detail of typical support

Construction

The dome is constructed by using a single node type, and all bars are equal. All the dimensions of prefabricated bars are highly controlled by the CNC machines, all glass panels are prefabricated. Therefore, there is one type of joint strap; one type of flat bar, and one type of cable clamp. The only disadvantage is that the glass panels are different, which increases the cost of manufacture.[9]

Fig. 14: The top view of the dome

Construction Process

The assembly process is relatively more straightforward since all the parts are prefabricated. The workers started to assemble the bars from the edge of the dome.10Since all the members are precisely calculated when the workers put all the bars together, they naturally formed the shape of the dome, and the glass panels were placed and sit on the grid.[11]

Fig. 13: The grid in the sunset

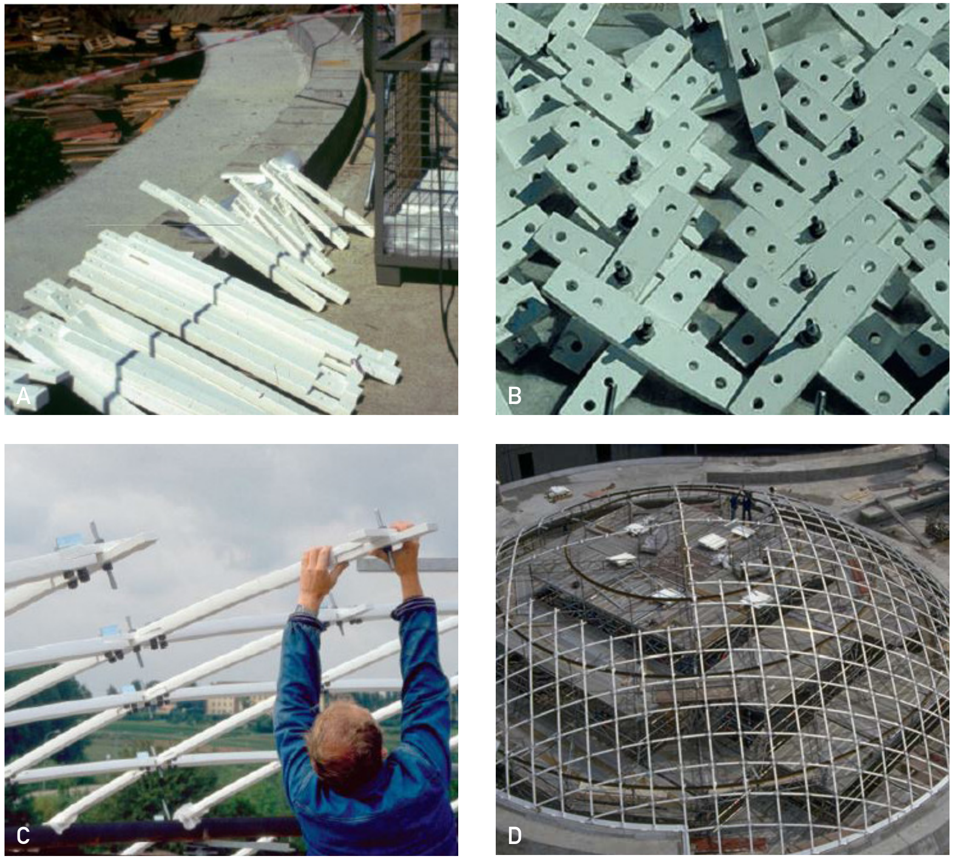


Fig. 15: Construction process A, B, C, D

FORM FINDING

Design shape

The dome is originally generated from a sphere with a radius of 16.5 meters. The footprint of the structure is an irregular shape, which combined by five arcs with three different radii that share the same central point on the plan view. the irregular shape provides the interior more sunlight from a certain time of day.

To generate this shape, I used a mesh geometry that has 1 meter for the spacing of the grid on top of the sphere; then, the mesh geometry was pulled into the sphere to create a uniformed mesh, so the mesh length is smooth and always equal to 1 meter, which represents the bars on the dome.

The diagonal cables are generated from the dome grid, which are discrete.

Parameters

To generate this shape, I used a mesh geometry that has 1 meter for the spacing of the grid on top of the sphere; then, the mesh geometry was pulled into the sphere to create a uniformed mesh, so the mesh length is smooth and always equal to 1 meter, which represents the bars on the dome.

The diagonal cables are generated from the dome grid, which are discrete.

Results

The final result has the smooth curves that represent the bars and the discrete diagonal numbers that represent the cables.

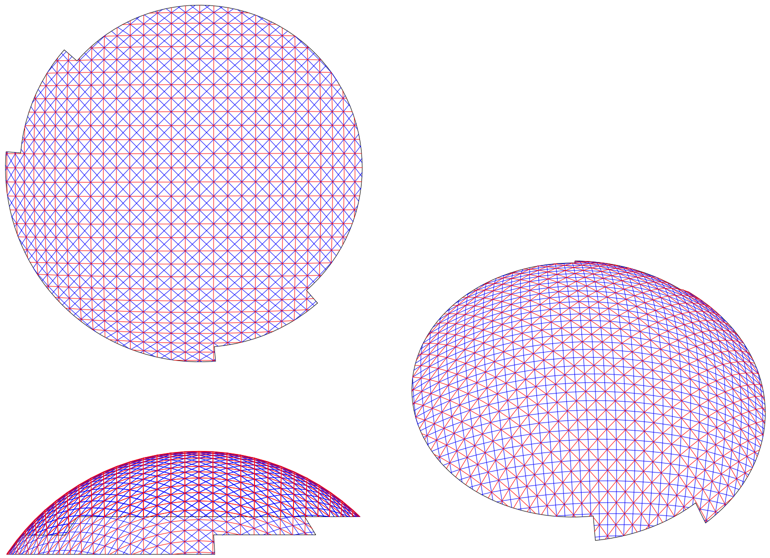


Fig. 16: Centerline model

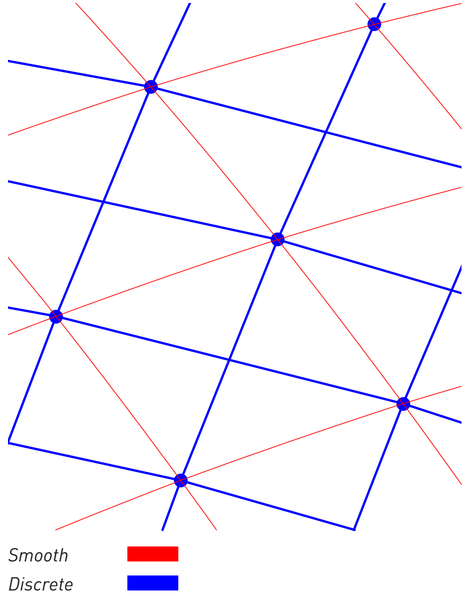
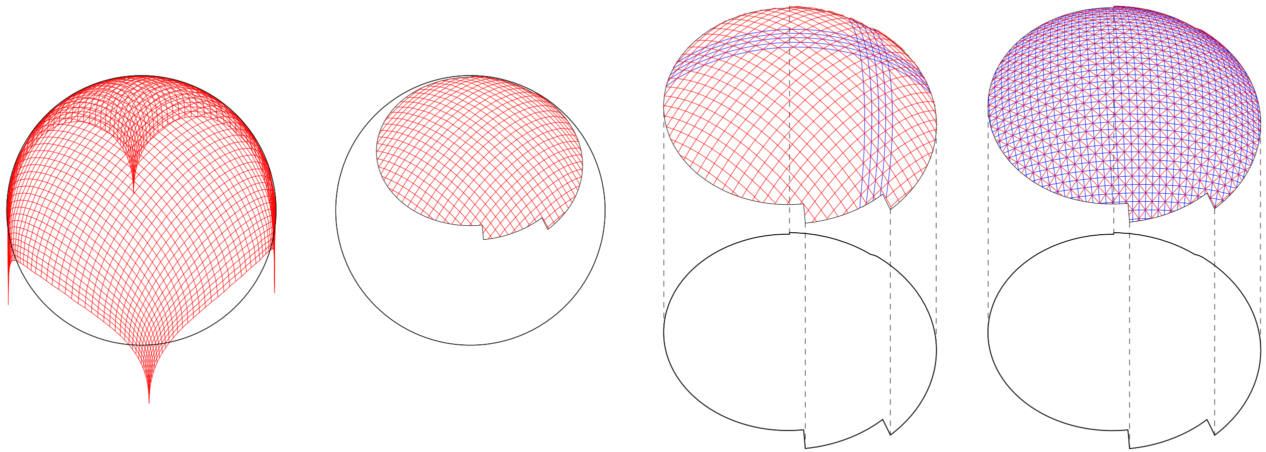


Fig. 18: Smooth vs discrete



1. Pull the grid onto the surface

2. Trim the grid from the outline

3. Creating the diagonal discrete cables

4. Clean the edges to get the final result

Fig. 17: Structural behaviour and from finding workflow

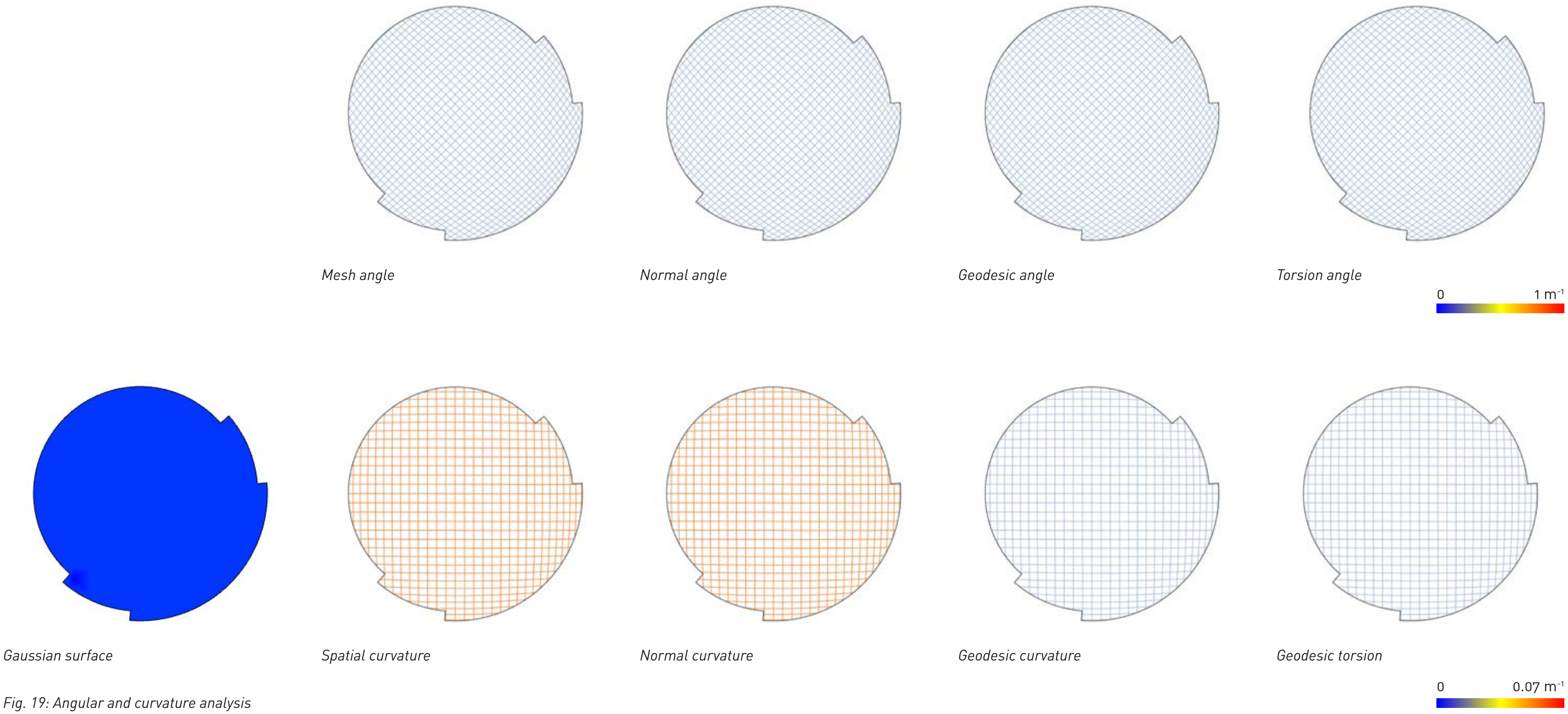


Fig. 19: Angular and curvature analysis

Gaussian surface curvature K

Because the dome is cut from a sphere, the gaussian curvature is the same all over the geometry, which is equal to 0.003673.

Spatial curvature k

The spatial curvature on is consistent on the dome, which is $k^2 = k_n^2 + k_g^2$, since the geodesic curvature is equal to 0, the spatial curvature is equal to the normal curvature, which is 0.06.

Normal curvature k_n

The normal curvature is consistent on the dome, which is 0.06.

Geodesic curvature k_g

The geodesic Curvature is consistent on the dome, which is equal to 0.

Geodesic torsion τ_g

The geodesic torsion is consistent on the dome, which is equal to 0.

Fig. 20: The exterior view

Summary

The Neckarsulm Aquatoll dome is a very cleverly designed structure to maximize the functional efficiency and minimize the cost. By studying this geometry, we can easily find that the design makes the manufacture and the assembly in a very refined way. A good grid sheld design is choosing the most optimized option to fulfill the function while reducing the cost; therefore, the Neckarsulm Aquatoll dome perfectly achieved the goal.

Bibliography

[1] Schling, Eike. Repetitive Structures: Design and Construction of Curved Support Structures with Repetitive Parameters. München: Technische Univerität München, Fakultät für Architektur, Lehrstuhl für Tragwerksplanung, Prof. Dr.-Ing. Rainer Barthel, 2018.

[2] Schober, Hans. Transparent Shells: Form, Topology, Structure. Berlin: Ernst & Sohn, 2016

List of Figures

1 Fig. 1. 6. 13. : Photo From Schlaich Bergermann Partner
"https://en.wikipedia.org/wiki/File:Kwong_Fuk_Bridge.jpg"

2 Fig. 2: Project: The site plan from google earth
"https://https://www.google.com/earth/"

3 Fig. 12. 15:
Picture From Transparent Shells. Form, Topology, Structure. 1. Edition. Hans Schober. 2016

ANALYSIS

Eiffel Tower Pavilion, Paris, France
Xiaopei Zhang

Fig. 1: Photo of Eiffel Tower Pavillion

Architect
Moatti-Rivierel architecture studio

Structural Engineer
RFR

Completion
2014

Cost
25,000 Franc

Structural System
Gridshell

Area
4,260 m²

Eiffel Tower, Paris, France

Student:
Xiaopei Zhang

Introduction

For thirty years, Eiffel Tower finally got the opportunities to update the first level. Due to the heavy population of the visitors to the tower and monument, the previous public spaces is unsuited for the tower. The upper levels of Eiffel Tower owns smaller space but better scenery of Paris. There are always being crowded on the upper floor but less visitors on the first level. It should be attractive and modern and functional. The new series of pavilions are 57 meters above the Paris, designed by Moatti-riviere Architecture Studio. The project proposes an imroved experience of the tower which will elevate the positive associations within the city. The 1st floor of the Tower is still inaccessible to people with reduced mobility, the project will give them access to these spaces.

Site

Eiffel Tower Pavilion is located on the 3 sides of the first floor of Eiffel Tower, which was built for entertainment facilities, 57 meters above the Paris and the monument.

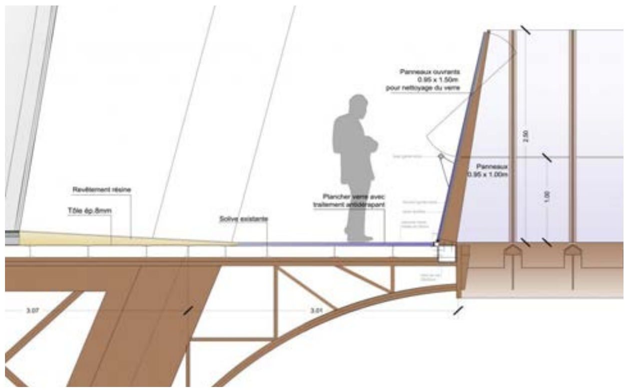


Fig. 2: Comparative section

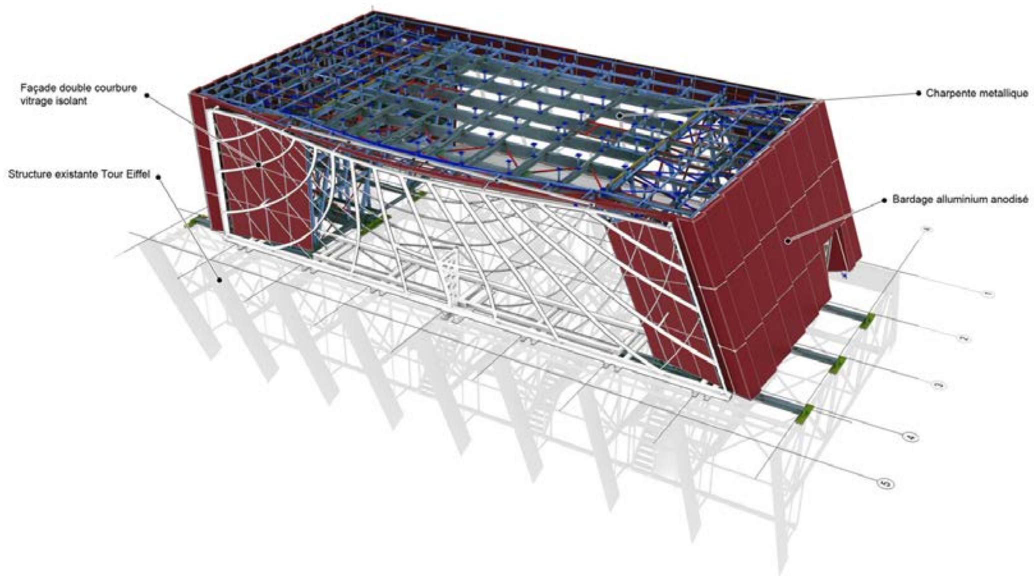


Fig. 3: Section through the primary structure

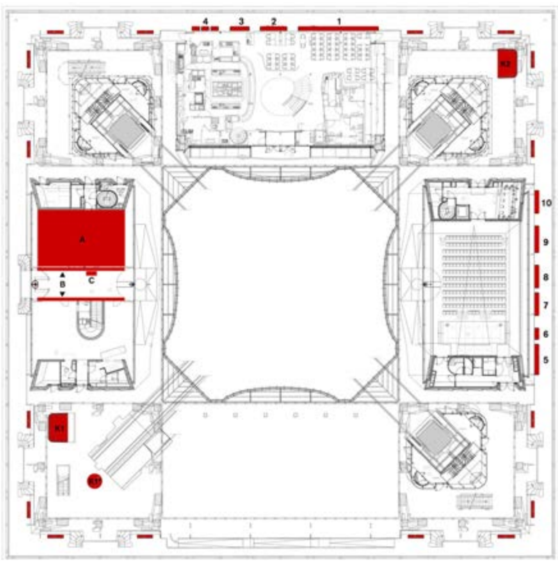


Fig. 4: Plan/top view of the primary structure

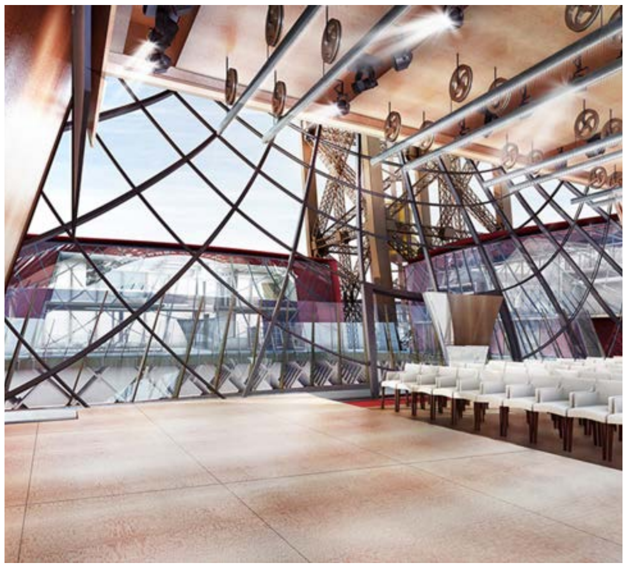


Fig. 5: Inside perspective

Architectural Concept

The architecture firm designed this crazy project aims to provide an experience augmented by the Tower and the open space on the first level. In all, 4,260m² of space area will be seperated into several distinct spaces for the enjoyment and entertainment of visitors. Renovation and modernization went through the whole project. The goal of the pavilions is to give the public more access to all the levels so that it can strengthen the Eiffel Tower's power of attraction and make it even more spectacular. It cantains technology, transparency, a playful, sensory experience in the heart of the Paris.

Functions

The new functions will replace the original reception and conference rooms into dedicated visitor information booths, restaurants, shops, boutiques, and attractions.

Sitting between the pillars of the metal columns, the current opaque floor and balustrade grille will be replaced by glass to enhance the views below. The two new structures will utilize transparent facades where the gridshell and roofs with brown and red sheet metal skins will be installed. Each interior unit's flooring will be covered by wooden panels and steel strips.

Typical Joint

All mounts requiring drilling, bolts or welding were not permitted,In order to avoid any damage to the iron lattice structure. Each of the newly added elements had to be clamped onto the existing structure. Standard bolted constructions are normally around ten times more stable than clamped solutions, so construction planning and execution of the work needed to be painstakingly accurate.

Fig. 8: Photo of joint

Fig. 6: Axonometric of typical joint

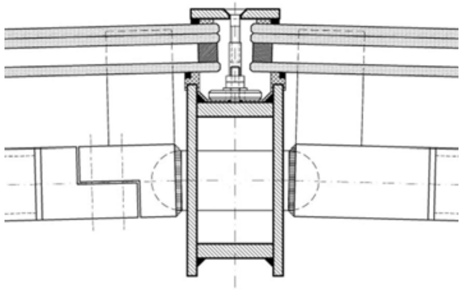


Fig. 7: Detail of typical joint

Typical Support

Geometrical optimisation studies were performed in order to design these façades with panels having a constant single curvature (quadrangular cylinder) enabling the panels to be bent using an automated process, thereby avoiding the need to use moulds that would be costly for small production runs. Moreover, by controlling surface geometry, three-dimensional uprights can be built that adapt to the curved facade without twisting, using developable components only.

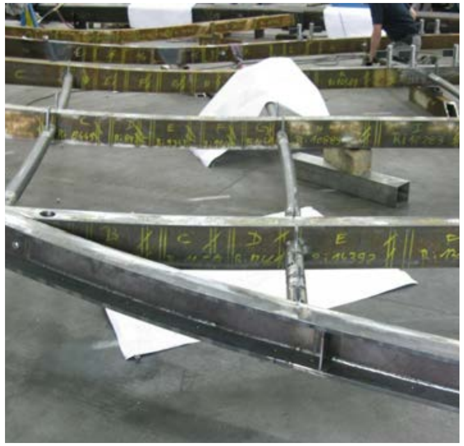


Fig. 11: Photo of typical support

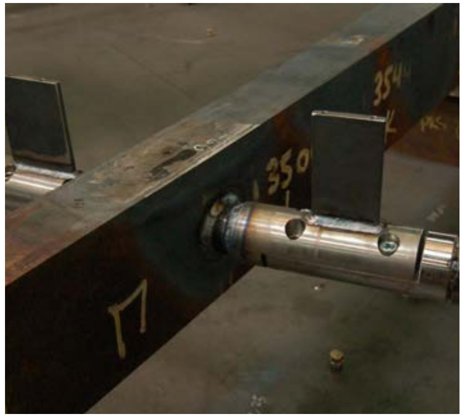


Fig. 10: Detail of typical support

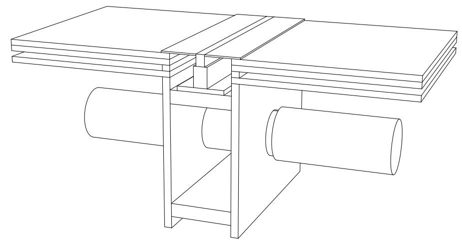


Fig. 9: Axonometric of typical support

Construction

RFR asked the competing teams to work on the pavilion to resolve the mass transit of materials that would allow people to visit the rest of the tower. Moatti-riviere and contractor Bateg came up with a very elegant solution, placing four slender pillars in the 85-square-foot central space on the first floor, allowing the platform to rise 187 feet from the ground, replacing the heavy cranes.

Fig. 13: Photo of construction

Construction Process

Issues of weight distribution and the special requirements to be met due to the height of the building site and equipping it with the services needed called for special procedures. Before any new strain was put on the structure, the corresponding weight had to be first removed from the existing building. Every component delivered was first weighed before it was loaded onto the lift going up to the central platform, which was used as a supply zone and an extended first floor work area. The 200 m² platform that was specially constructed for this purpose served as a floating 57 meters high building site throughout construction, and was a major factor that allowed the Eiffel Tower to remain fully open to the public throughout the entire construction period.

Fig. 12: Photo of Eiffel Tower

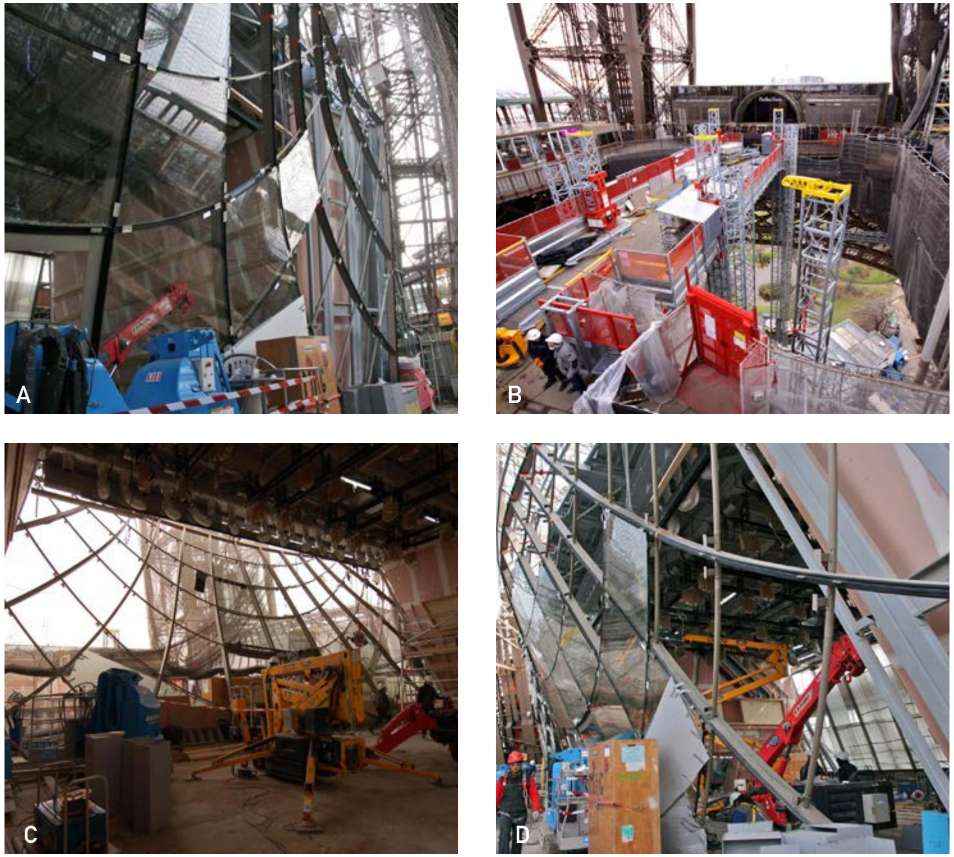


Fig. 14: Construction process A, B, C, D

FORM FINDING

Design Shape

The Gridshell is made by steel, which is a rigid hybrid structure. The vertical steel strips are continued smooth curve, while the horizontal one is discrete, being installed seperately by points. From the elevation, the shape of overall facade is a a symmetrical trapezoid. From the top view, the design can be seen as a slanted curved surface.

Parameters

From the elevation, the whole geometry is a symmetrical trapezoid. However, in 3D view, the top edge is curved and antevered compared to the bottom edge.

Form-making steps:

1. Draw the elevation grid:

Seperate the four edges into multiple equal distance, highlighting the points that have already listed on the elevation picture. Using a continued curve lines to draw the vertival strip line. and then finish the horizontal strips individually by connecting the rest of the points.

2. Create the Surface:

Using the position of top and bottom lines from the top view. Ordering „Loft“ in Rhino to create the curved surface.

3. Get the double curvature gridline:

Split the curved surface by using the lines from elevation. Duplicate the edges to get the final gridshell.

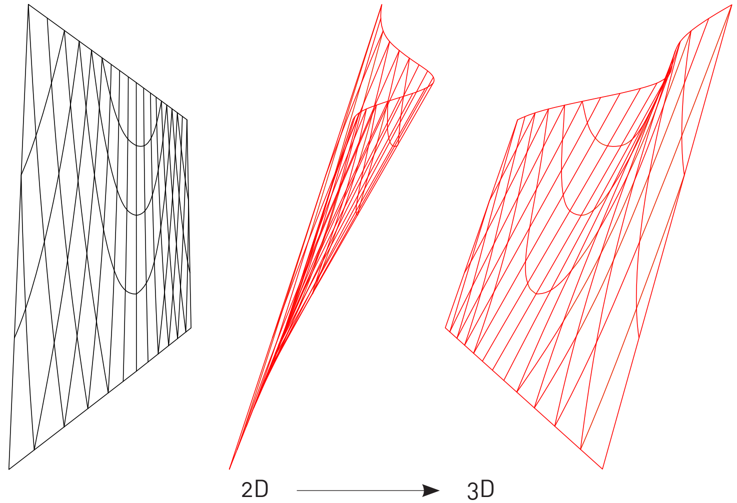


Fig. 15: Centerline model

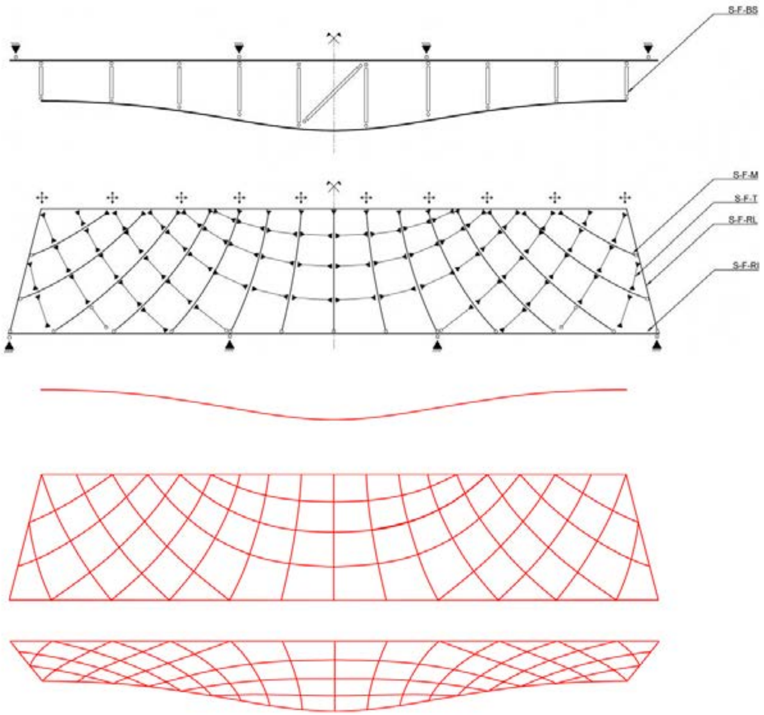
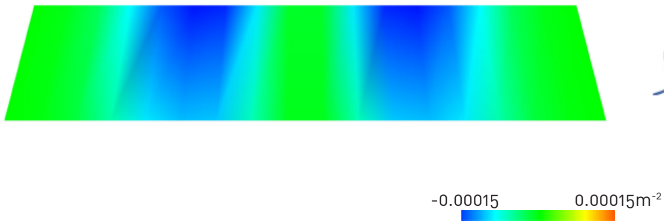
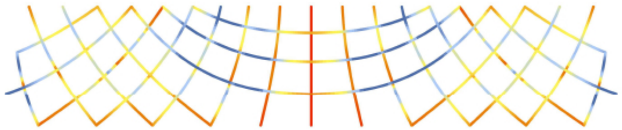
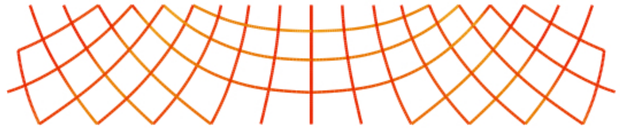


Fig. 16: Structural behaviour and form finding workflow







Gaussian surface curvature K

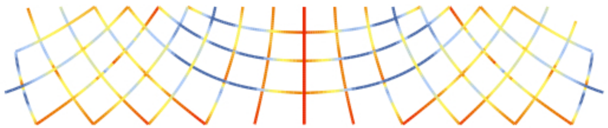
The Gaussian curvature varies from 0 to negative. The middle and two ends are the highest.

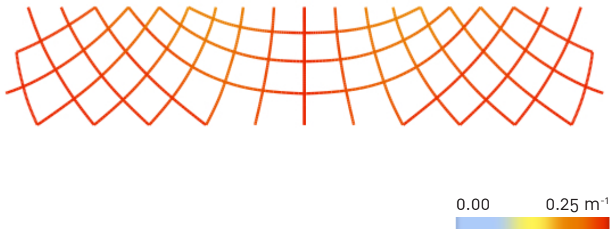
Spatial curvature k

The spatial curvature is lowest at the middle point, and then lower than the two ends of the surface.

Normal curvature k_n

The normal curvature is lowest in the middle and then gradually become higher and then goback to the lowest again.





Geodesic curvature k_g

Geodesic curvature varies from zero to 0.025 in a large area. The middle area is the lowest, the flowing area on the top is highest.

Geodesic torsion τ_g

The geodesic tortion is almost same, that overall is around 0-0.02. The symmetrical flowing areas on the top is higher than other areas.

Fig. 18: Photo

Summary

The Gridshell design of Eiffel Tower Pavilion give the oppotunities for visitors to enjoy the view from interior to outside. And also using the double curvature to create the simple geometry but modern posture of the facade.

The design of the pavillions gives more access for people to relax and entertain themselves. Making the space of Effel Tower more efficient and functional highlight the success of the whole design.

Bibliography

Press Report. Eiffel Tower Paris Refurbishment of the First Floor, Klaus Sikora Kommunikation [online]
Available From: *https://www.pohl-facades.com/fileadmin/content/Downloads/News/Projektberichte/christian-pohl-projectreport-eiffeltower.pdf*

RFR
Available from: *https://www.rfr.fr/en/projets/eiffel-towers-first-floor-renovation*

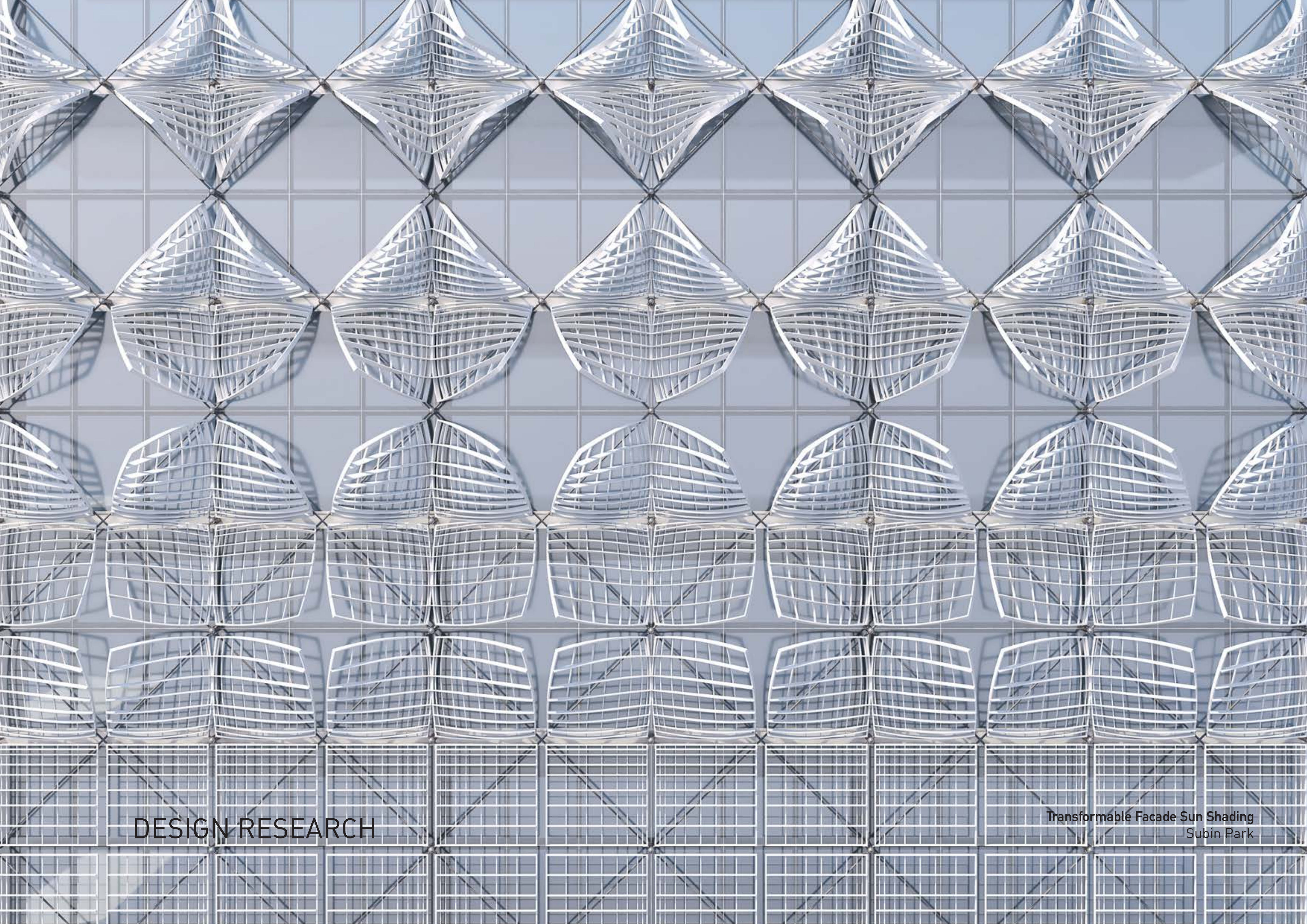
Architect, November 11, 2014. Towering Expectations: An In-Depth Look at the Eiffel Tower's Latest Update [online]
Available from: *https://www.architectmagazine.com/technology/towering-expectations-an-in-depth-look-at-the-eiffel-towers-latest-update_o*

Designboom
Available from: *https://www.designboom.com/architecture/eiffel-tower-pavilions-redesigned-by-moatti-riviere-architecture-studio/*

Paris Attitude
Available from: *https://infos.parisattitude.com/en/first-floor-eiffel-tower/*

Schling, Eike. Repetitive Structures:
Design and Construction of Curved Support Structures with Repetitive Parameters. München: Technische Univerität München, Fakultät für Architektur, Lehrstuhl für Tragwerksplanung, Prof. Dr.-Ing. Rainer Barthel, 2018.

List of Figures



DESIGN RESEARCH

Transformable Facade Sun Shading
Subin Park

SCENARIO PROPOSAL

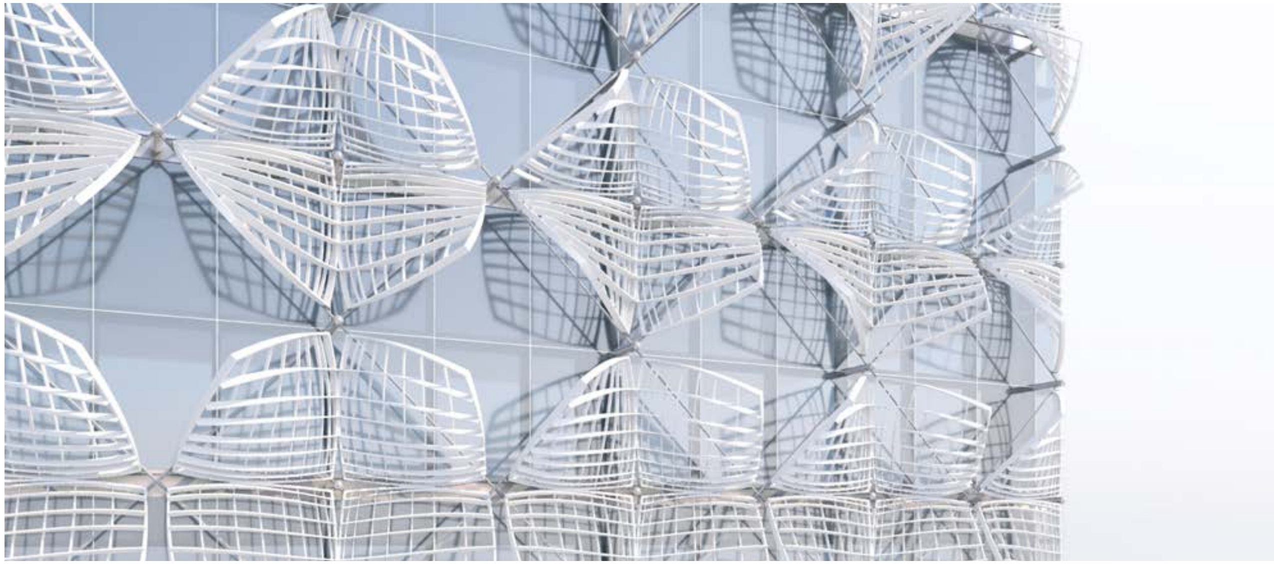


Fig. 1: Transformable facade sun shading

Span
1 - 3 m

Material
Glass fiber reinforced plastic

Construction Method
Smooth elastic

Target Group
Curtain wall facade

Introduction

The gridshell sun shading panels are transformable. Openings of the panel through the structural system of the gridshell coming from its double curvature allows the blocking of the sun and letting in a degree of daylight during the day especially in hot climate sites.

The control system of the shading device could be through technology with automation system or can be through manual pulling through the pulley system. This scenario allows only part of the shading device to be opened letting a degree of sunlight to come in, but it cannot be opened fully. Hence, it may be suitable for countries like Saudi Arabia or any other tropical countries that have a year-round high temperature.

The grid will be generated on a flat surface, while two corners of the rectangular gridshel will be fixed onto mobile connectors and two corner be lifted up to create a small opening.

Potentials

The repetition of the module allows lower cost of construction as all the structural members are in same dimensions and shapes. This repeated sunshading panels may be more suitable for large scale buildings such as towers because some patterns can be generated on the facade. The modules resting on wire frame allows more transparency to the building facade and create a depth on the facade.

KEY CONCEPT

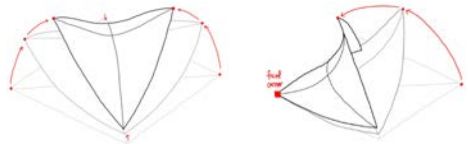
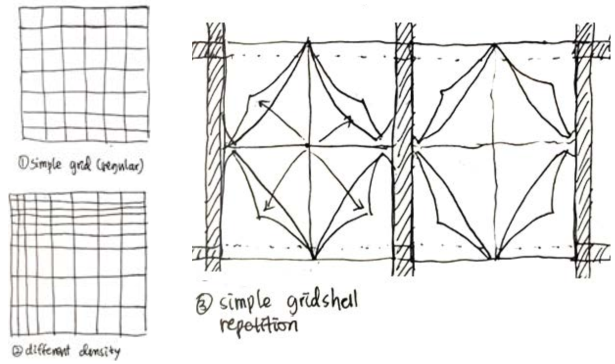


Fig. 2: Initial sketches



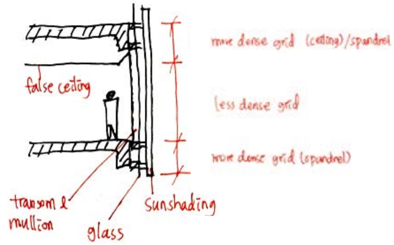


Fig. 3: Concept sketches

Challanges

The deformation of the device into asymptotic gridshell may not be easily come back to the flat grid form, and it needs to be tested out. The density and dimensions of the grid may block the views from the interior. The transformable shading panels make use of compliant mechanism where it requires a complex system of the whole panel structure to act accordingly with flexible joints and elastic materials.
The deflection of the gridshell is limited to the strength of the deflecting members or lamellas. Hence, the motion may be limited.

Case Study 1: Asymptotic Lamella Networks

Type: Poster & Model
Year: 2016
Team: Denis Hitrec, Eike Schling
Office: Technische Universität München, Chair of Structural Design, Prof. Dr.-Ing. Rainer Barthel
Exhibition: Advances in Architectural Geometry 2016, ETH Zurich

Architectural Concept

This is a model of an anticlastic surface (commonly described as saddle shape), and its material is polystyren made into strips. The strips are in right angle to the surface below it. The flat strips become a doubly curved network through the elastic transformation of the flat grid.

As in figure 5, the flat grid of the steel prototype transformed into spatial geometry when it was pushed up by the support below. When the prototype deforms into an ideal shape of gridshell structure, the edge lamellas are added to stiffen and fix the whole structure together.

Source: E. Schling, D. Hitrec and R. Barthel, 2017: Designing grid structures using asymptotic curve networks. In: Design Modelling Symposium, Paris, In press: SpringerVerlag

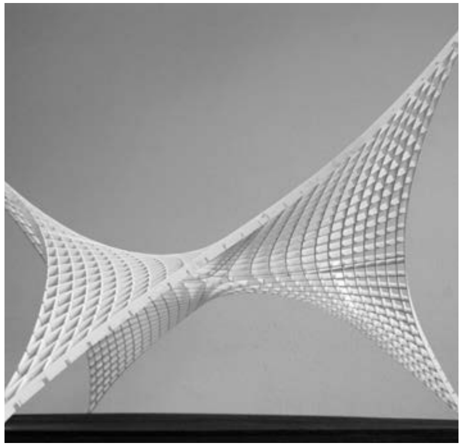


Fig. 4: Outside view

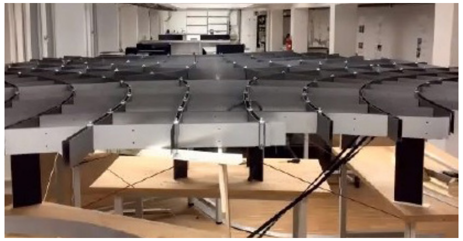


Fig. 5: Steel prototype

Case Study 2: Building a surface from asymptotic curves (straight planar plywood laths)

Type: Plywood & Model
Year: 2019
Team: Isak Näslund, Emil Adiels

Architectural Concept

It is a physical model of a minimal surface made of 1mm plywood. It could be stretched to form a flat grid as in the below image, but without force, it will deform into the upper image due to the bending of the plywood laths.

Source: 2019. Vimeo. May 20, 2019. https://vimeo.com/311905217.

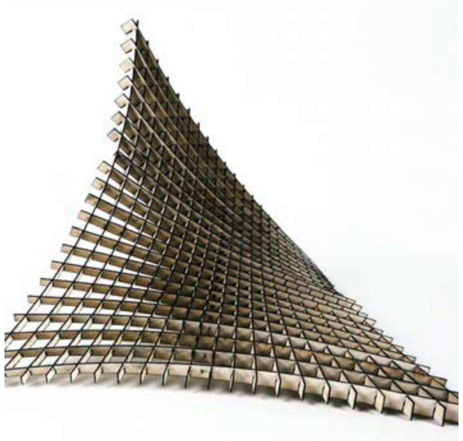


Fig. 6: Asymptotic curves deformed

Fig. 7: Flat asymptotic curves

Case Study 3: King Fahad National Library

Type: Cultural Building
Year: 2013
Office: Gerber Architekten
Location: Saudi Arabia

Architectural Concept

The facade of the library has the sunshading device for its concept. The sunshading is made up of rhomboid textile awnings and provides some degree of opening and closing on the facade. The white membranes are supported by 3 dimensional tensile stressed steel cables to create a visual effect reflecting Arabian traditional tent structure.

Source: Sánchez, Daniel. "King Fahad National Library / Gerber Architekten." ArchDaily. ArchDaily, January 22, 2014. https://www.archdaily.com/469088/king-fahad-national-library-gerber-architekten.

Fig. 8: Outside view

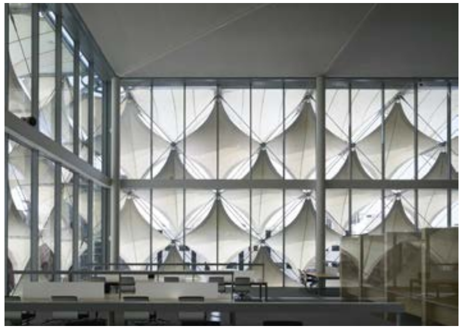


Fig. 9: Inside view

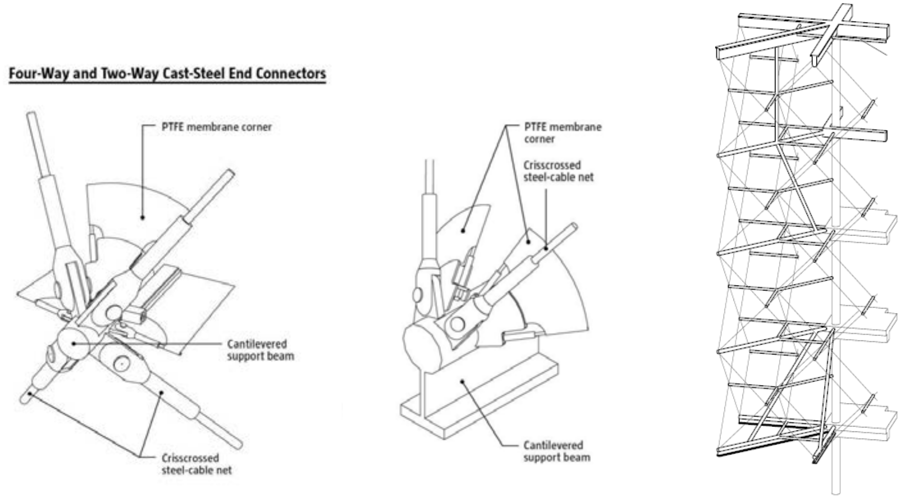


Fig. 10: Typical joints and supports

Case Study 4: Al-Bahr Towers in Abu Dhabi

Type: Tower (29-storey)
Year: 2012
Office: Aedas
Location: Abu Dhabi

Architectural Concept

Abu Dhabi has an intense sunlight, and temperature is steadily above 38 °C creating an extreme weather conditions. Hence, Aedas designed this sunshading device that reflects the traditional Islamic lattice work called mashrabiya and was able to effectively provide comfortable indoor environment. The shading facade panels responds to the sun exposure and change the angle during the year.

Source: Babilio E, Miranda R and Fraternali F (2019) On the Kinematics and Actuation of Dynamic Sunscreens With Tensegrity Architecture. Front. Mater. 6:7. doi: 10.3389/fmats.2019.00007

Source: Cilento, Karen. "Al Bahar Towers Responsive Facade / Aedas." ArchDaily. ArchDaily, September 5, 2012. https://www.archdaily.com/270592/al-bahar-towers-responsive-facade-aedas.

Fig. 11: Outside view

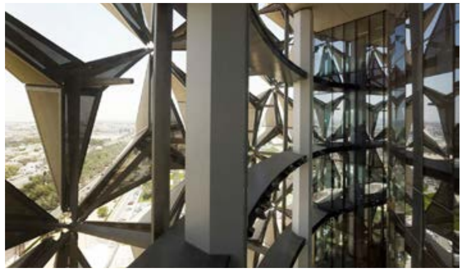


Fig. 12: Inside view

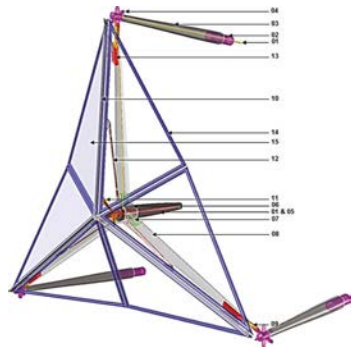


Fig. 13: Typical joints and supports

Site

Abu Dhabi, United Arab Emirates has a hot desert climate and clear and sunny sky is expected throughout the year. The sunlight is intense, and the weather shows a rare sign of rain over the year. From June to Spetember is the hottest season with high humidity, so the climatic condition is not desirable for a bare curtain wall system without any sunshading.

In this extreme weather, coping up with the intense heat and glare is a challenge for a high rise building with curtain wall system. Thus, the design of the sunshading facade system is important for reducing the heat gains and creating comfortable indoor environment.

Design Concept

As the project is located in Abu Dhabi where the extreme climatic condition due to heat and strong sunlight affects the indoor environment of high rise buildings, the transformable sunshading facade on the curtain wall buildings are desirable. The sun shading module takes advantage of the transforming ability of gridshell through the deformation of its elastic material. As the gridshell deforms from the flat grid, it allows a certain amount of daylight to come in and opens up the view from inside to outside.

Functions

Throughout the different time of a day, the sun shading device on the facade will open and close. When the sun angle is direct to a side of the building, the sun shading device will remain closed to provide the maximum blockcing of the direct sunlight. As the sun moves away from the side of the facade, the sun shading device will slowly open up by diagonally pushing the two coners closer. The sun shading almost blooms to open up the views to outside at the eye level and allows the comfortable daylight to come into the indoor space.

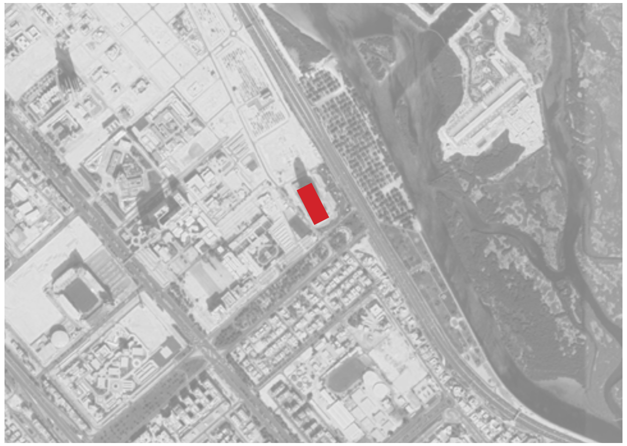


Fig. 14: Site plan

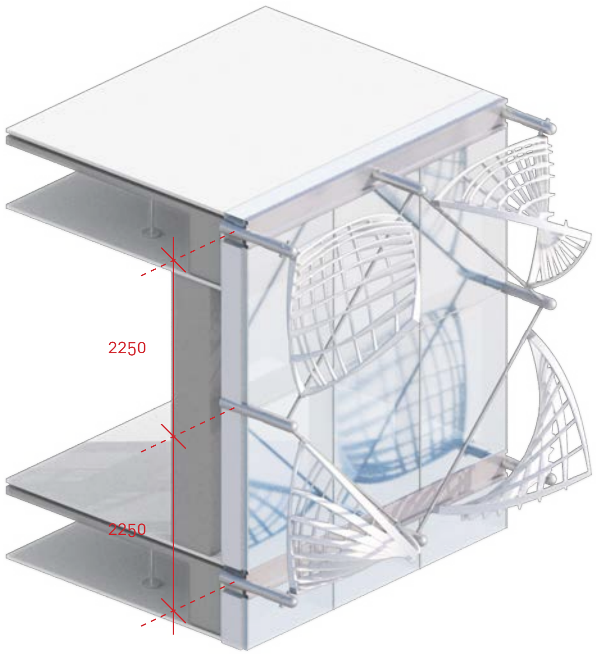


Fig. 15: Design system

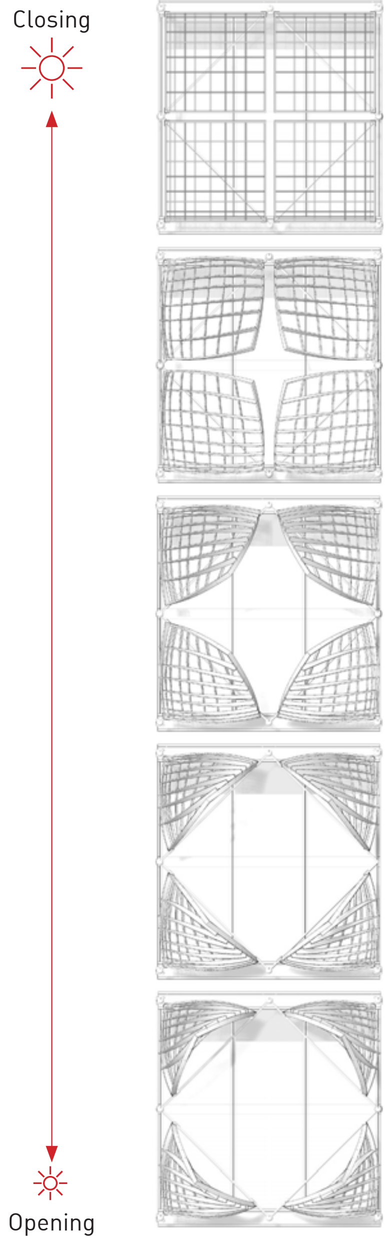


Fig. 16: Grid transformation

Fig. 17: Render

Compliant Mechanism

A compliant mechanism is a mechanism that gains some of its mobility and flexibility from the deformation of a flexible member such as lamella in gridshell. The mobility is improved through the movable joints as well. Some examples of compliant mechanism that can be often found are the plastic lids of ketchup or mouse buttons.

Typical Joint

The flat lamellas that are prefabricated will be interlocked and a nail will penetrate through the two lamellas to connect them together.

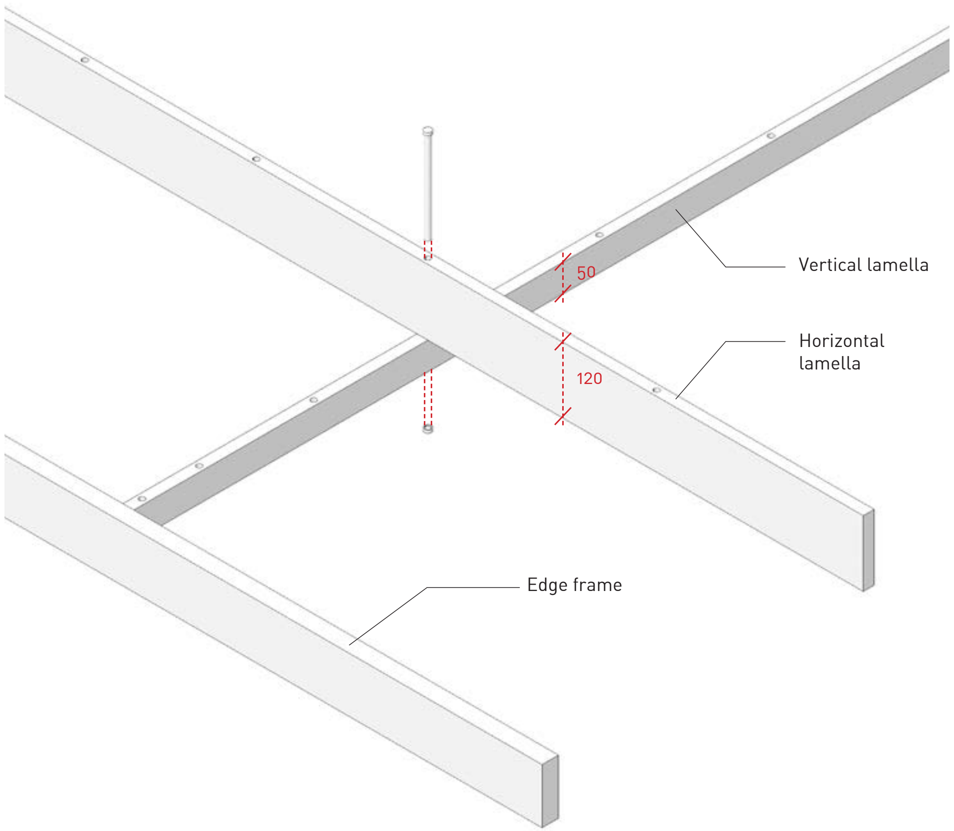


Fig. 18: Detail of typical joint

Typical Support

The typical shading module is supported on the mobile pin connectors. These connectors move diagonally from the X structure ring hub that caps the supporting cantilever strut in clean manner. The connectors move along the ring arms which stretch to the surrounding nodes. The cantilevering strut holds the modules and penetrates the curtain wall system to be fixed on the structural transoms.

The shading modules are fixed at two corners while the other two corners are more flexible when the module transforms its shape into opening and closing.

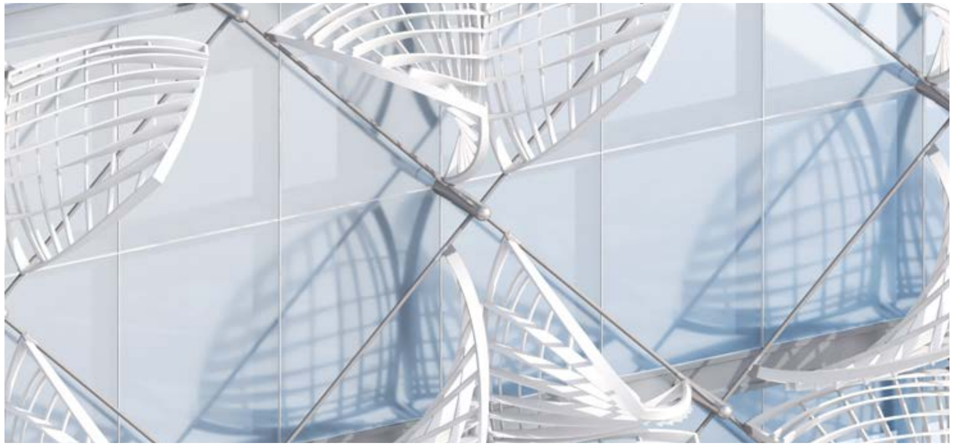


Fig. 19: Axonometric of typical support

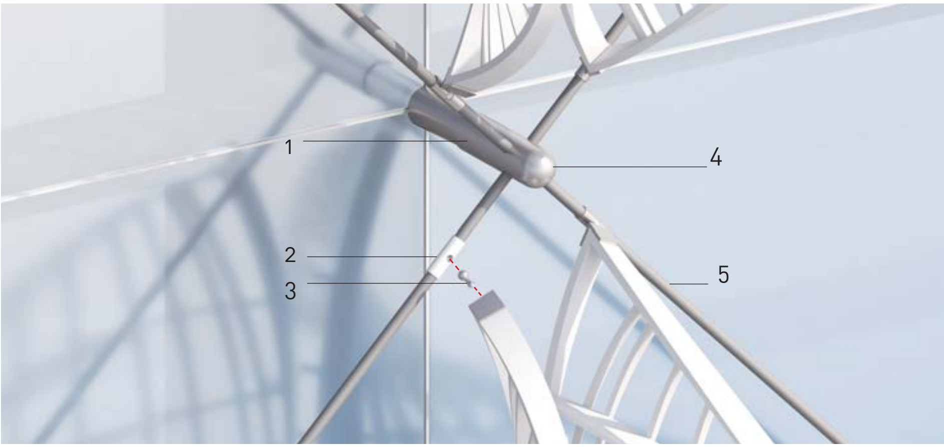


Fig. 20: Detail of typical support

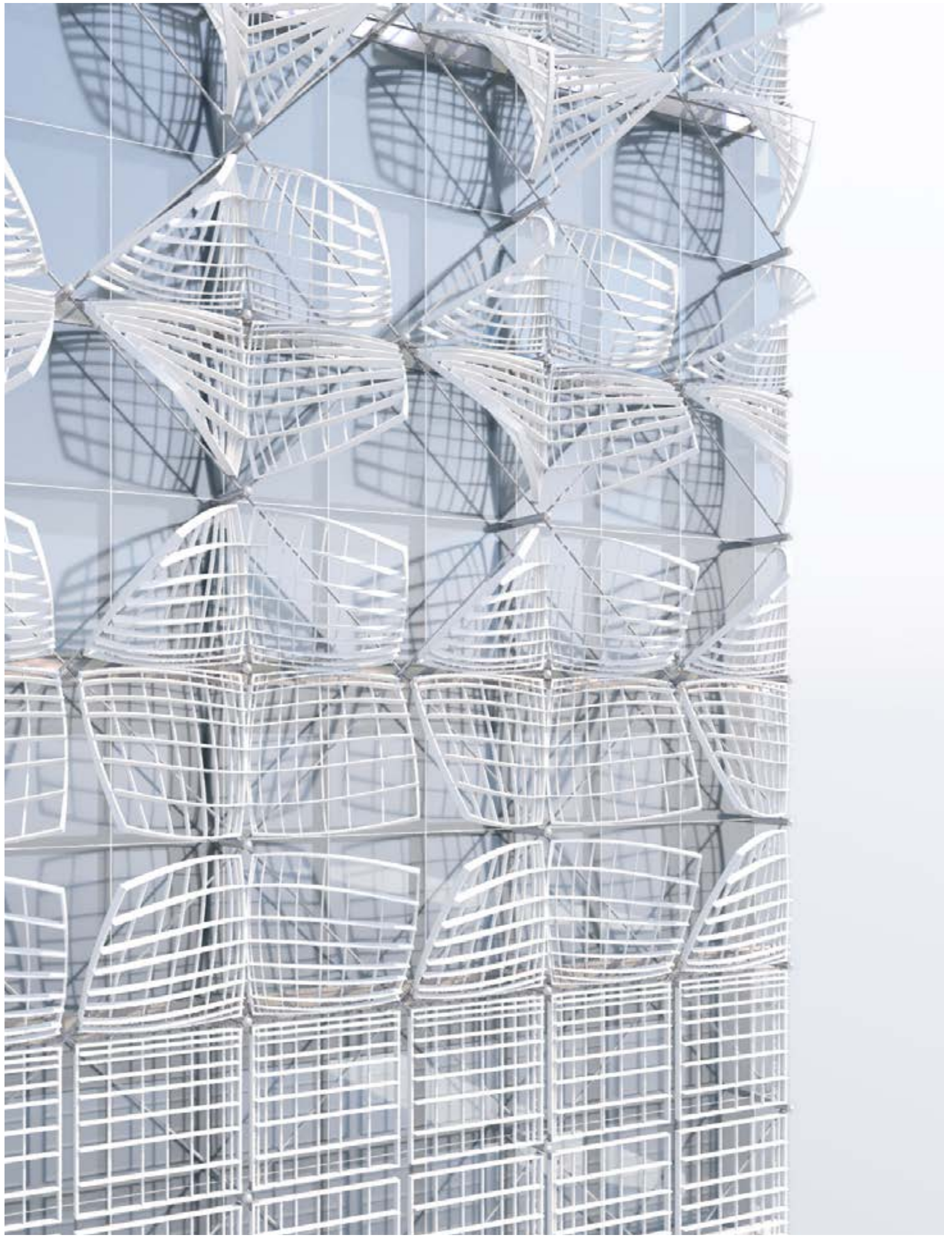


Fig. 21: Render

Material
: Fiber-glass-reinforced Plastics

The fiber glass reinforced plastics (FRP) has a high corrosion resistance (higher the resin content the more corrosion resistant) and strength. Its advantage is low weight-to-strength ratio meaning relatively light in the weight when compared to the material strength. It is also economic solution with flexibility and elasticity allowing the form to transform in many shapes.

Construction Process

1. Strips of grid members will be fabricated in its correct dimensions with holes where the nail connects them together later.

2. The members will be assembled into a flat grid.

3. The joints are added to fix the lamellas together, but it should leave some tolerance for the flexibility.

4. The struts that are fixed onto the transoms of the curtainwall system hold the shading module through the hub. The shading module will be fixed onto the ring arms with rails. Two corners are fixed onto the mobile pin connector to move diagonally, while one corner is fixed.

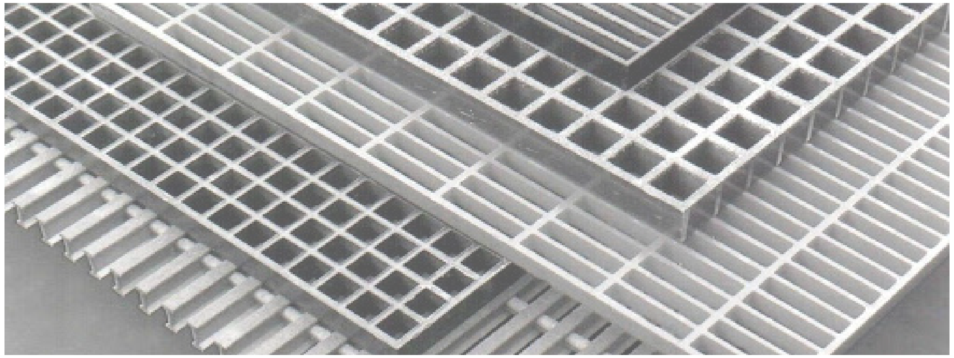


Fig. 22: Photo

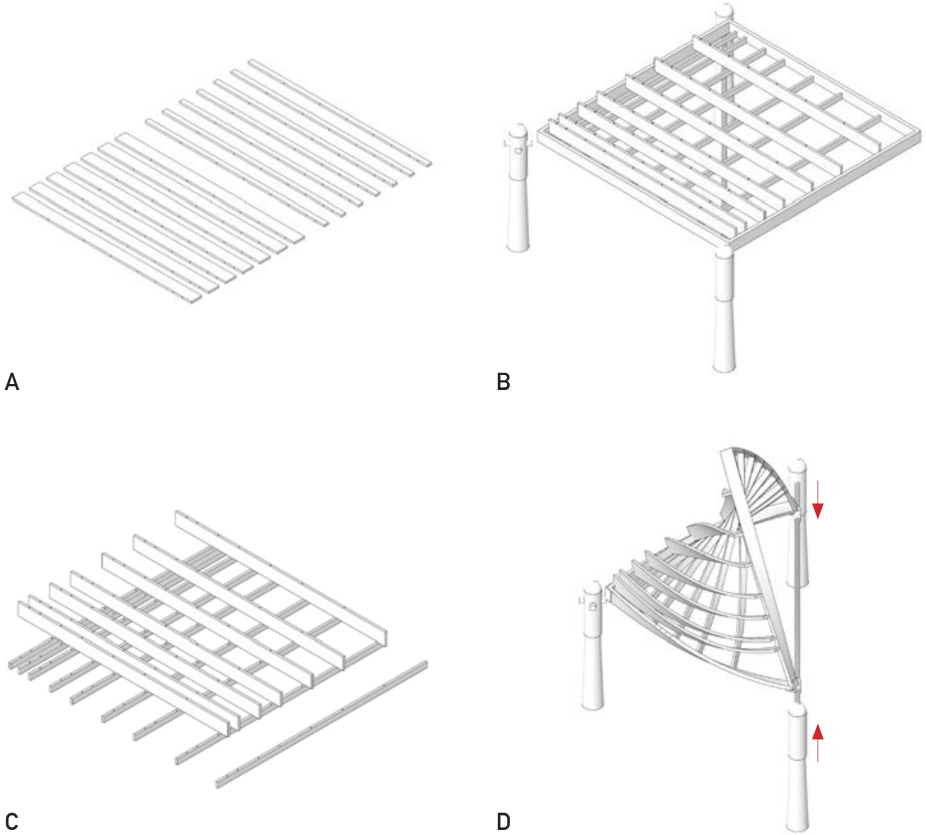


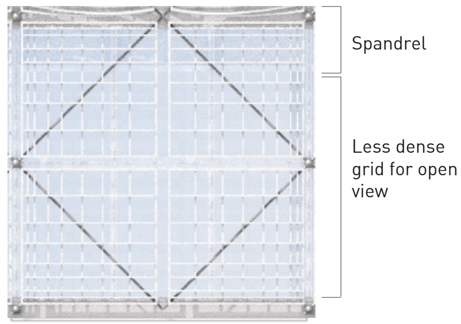
Fig. 23: Construction process a, b, c, d

SCENARIO DESIGN

Architectural Concept

The transformable sun shading panels is programmed in a way that reacts to the changing sun angles during the day. Hence, it allows a dynamic movement on the buildings facade that not only shades the interior but also responds to the unique and extreme site condition.

The simple gridshell design with a chaging density in diagonal direction opens up the view from the inside at eye levels. The simple grid patterns reflects the traditional mashrabiya patterns of UAE used for decoration of house facades or sunshading purposes.



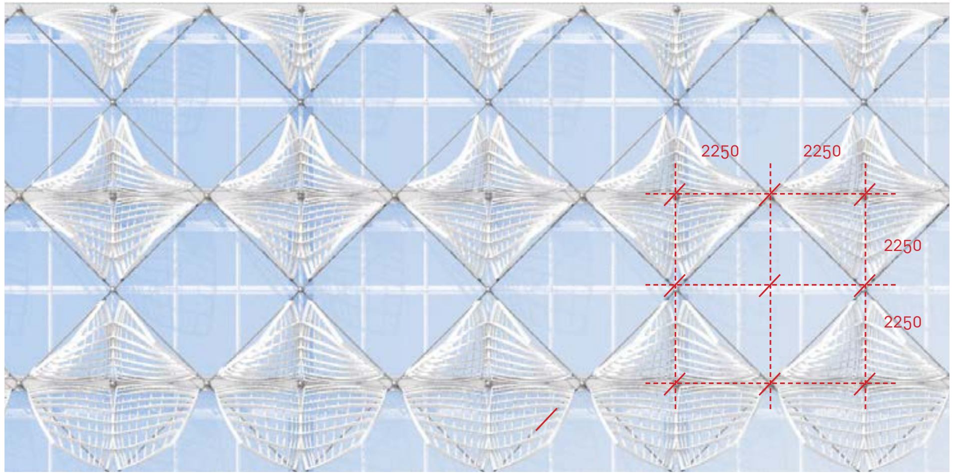


Fig. 24: Elevation

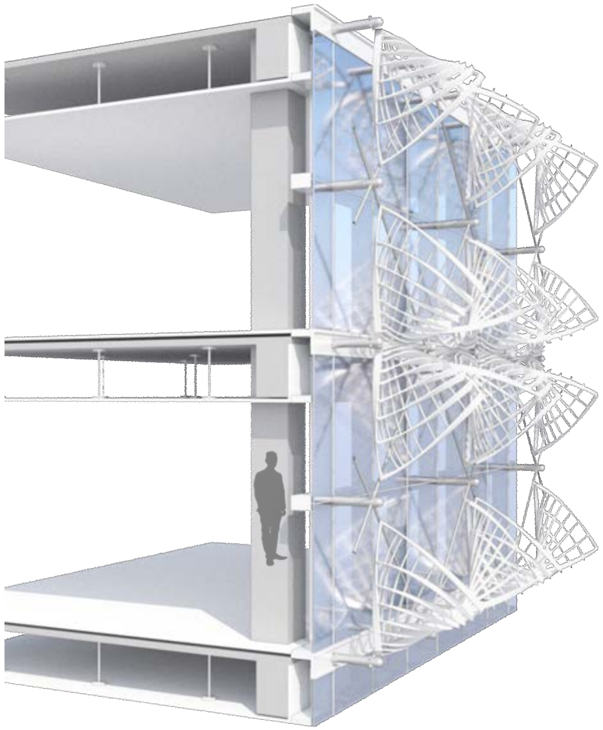


Fig. 25: Sectional perspective

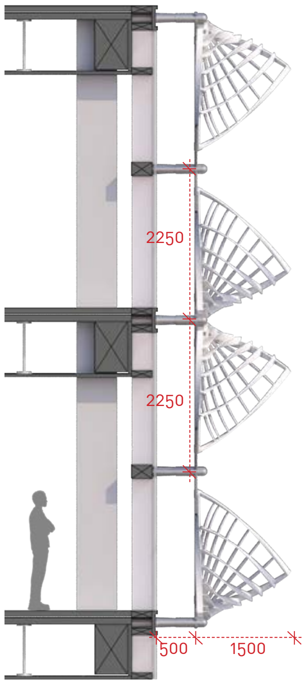


Fig. 26: Section

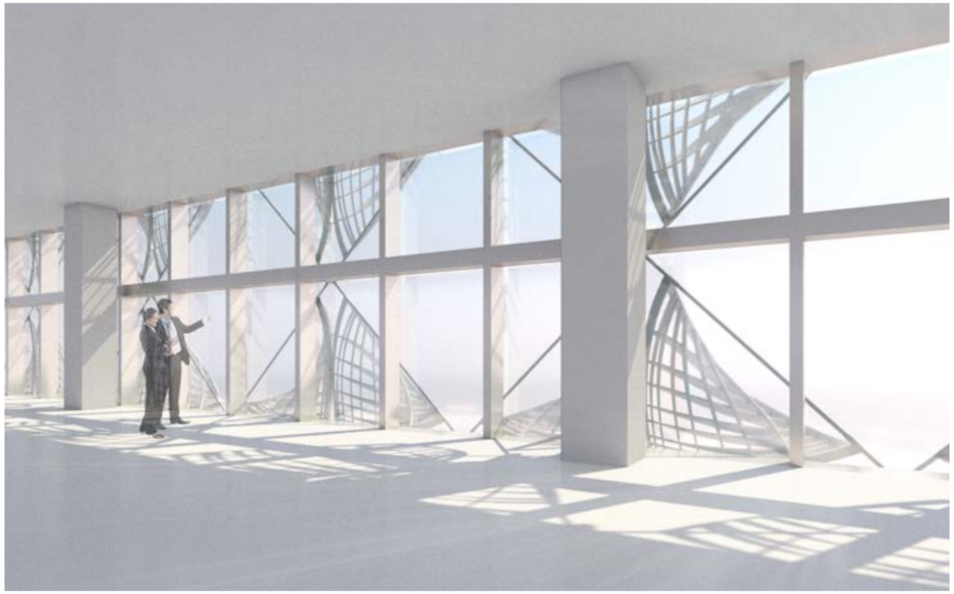


Fig. 27: Interior render for opened shading scenario

Fig. 28: Interior render for closed shading scenario

Surface Construction Sequence

A. 4 curves with 3 controls points form a rectanlge.

B. Move the control points to for the surface shape.

C. Divide the diagonal line into 20.

D. Asymptotic grids are formed by the script.

E. The vertical lamellas are placed inside, and the horizonal lamellas are placed outside with larger depth. The position and depth of the horizontal lamellas are more effective in creating the space for shading compared to placing the vertical lamellas outside.

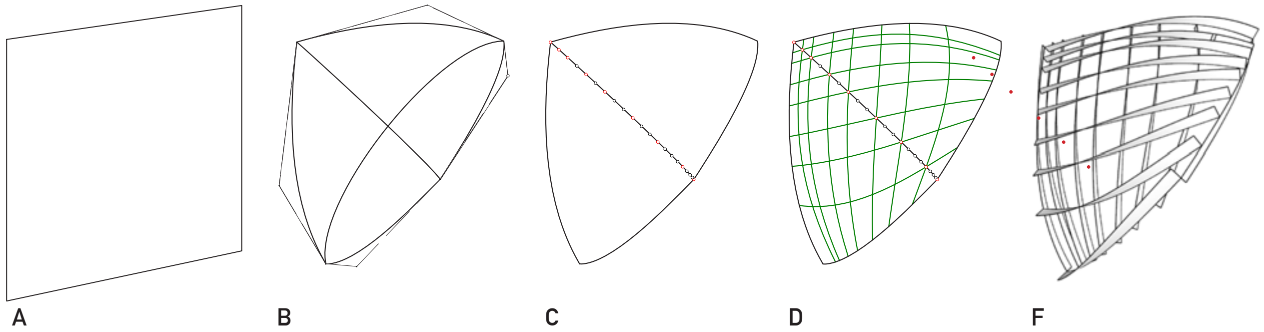


Fig. 29: Surface construction sequence

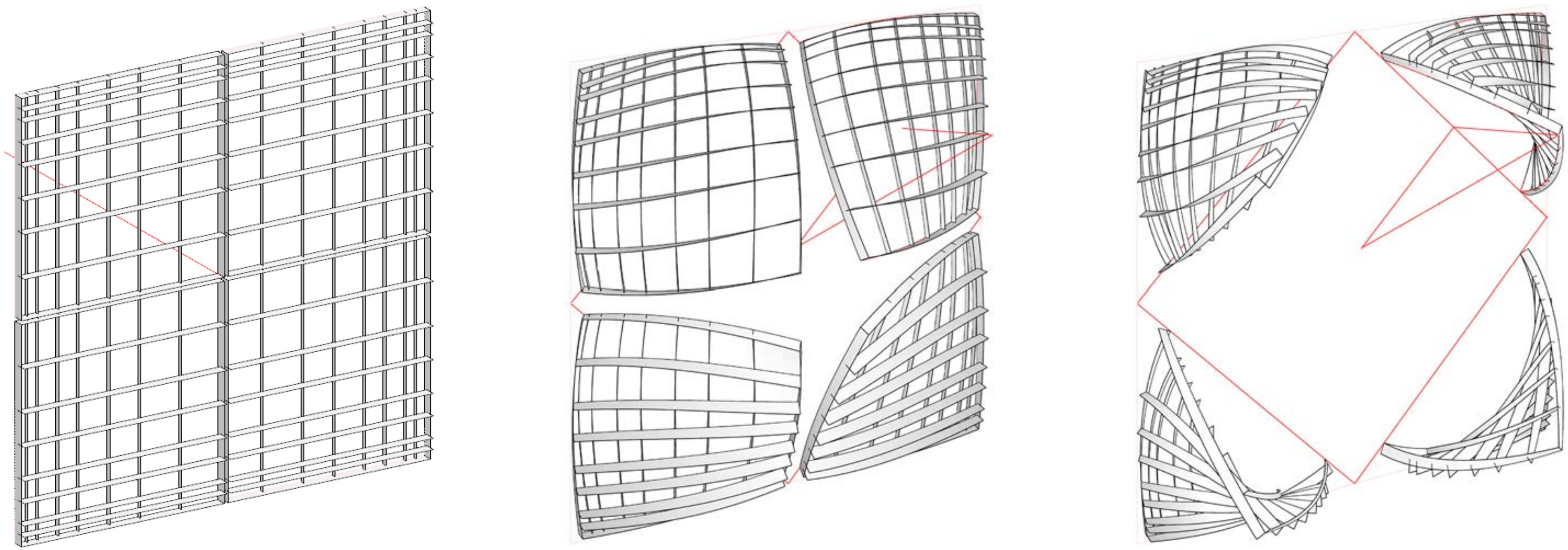
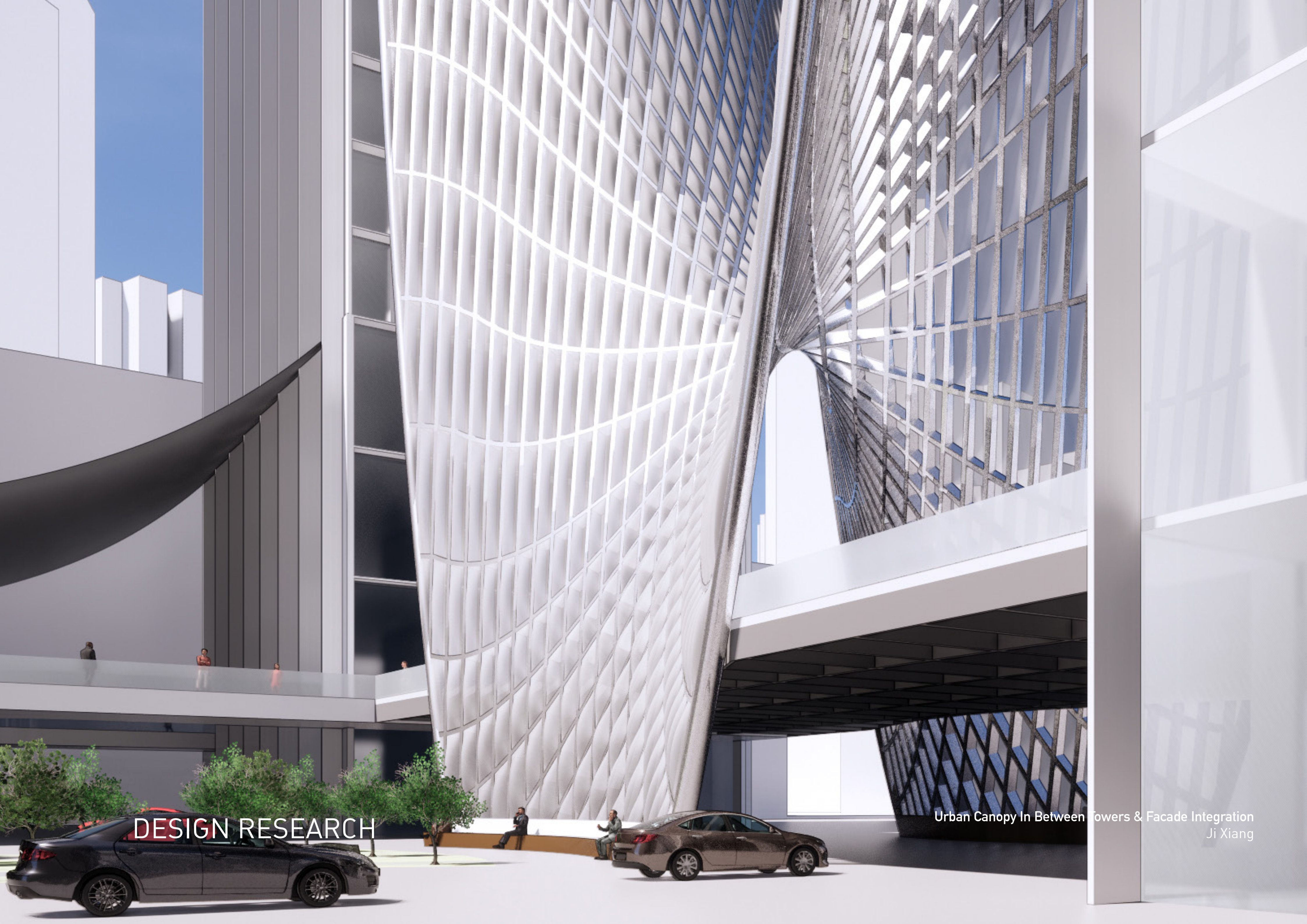


Fig. 30: Set of modules 4.5m x 4.5m, fully closed, half closed, and fully opening shading (from left to right)



DESIGN RESEARCH

Urban Canopy In Between Towers & Facade Integration
Ji Xiang

Fig. 1: Perspective over the footbridge

Span
40-50 m

Material
Steel

Construction Method
Prefabricated components, transport to site

Target Group
Urban Inhabitants

Introduction

Gridshell structure is widely used as canopies that provide shading to shelter in various scales. The dense urban context of Hong Kong and the extensive use of elevated footbridge in commercial area requires connections with covers in between towers. Gridshell structure could provide stiffness in structure and organic form through its double-curved shape. The construction logic is simple yet clear while at the same time the construction period is relatively short. Members are usually prefabricated in the factory and assembled on site. The gridshell structure could blend into Hong Kong's unique urban context while provide interconnections in between buildings. The grey space in between the building facades could be activated by either temporary or permanent structures like this.

Challanges

The form of gridshell needs to be considered from the urban context or using tower façade as reference. The design of gridshell joint should relate to its overall scale and the material applied. As an add-on structure, the supports should be detached from the building and yet integrated with some of its elements. Construction should be quick and non-harmful to the environment. The bridge hanging from the gridshell structure should be in tension and minimize its movement when giving the live loads. Junctions over gridshell should be designed with the consideration of bridge structure.

KEY CONCEPT

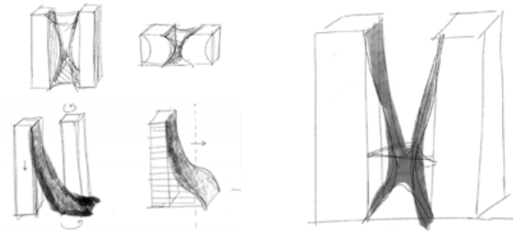


Fig. 2: Concept sketches

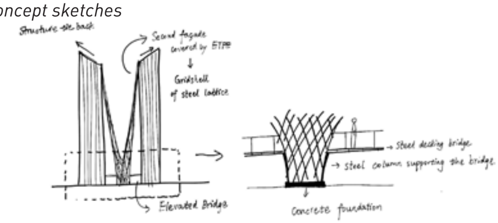


Fig. 3: Structure concept sketches

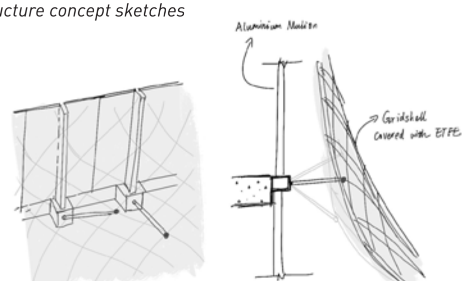


Fig. 4: Joint detail sketches

Potentials

The gridshell structure could be derived from the surrounding buildings or freestanding next to the towers. Double-curved surface allows the surface flow from various directions which means that gridshell could evolves from façade to roof or even vertical supporting elements. Bridge could be connected to gridshell via pre-tensioned cables while provide support at two ends.

Case Study 1: Capital Gate by RMJM

Architectural wire mesh for solar protection at the ADNEC Tower in Abu Dhabi. The flowing metal mesh covers the lower parts of the tower and extend down to the ground which provides a continuous shading. The hotel entrance and facade is integreated and further express the undulated twisting shape.[1]

Functions

The frame extends from the building facade to ground level which becomes canopy that connects the tower and surroundings. The flowing form provides sunshade for both tower and the grand seating. he mesh cladding of the façade comprises 580 panels of differing size and uses a total of 4915 square meter metal mesh. The panels had to be shifted horizontally by up to 25 degrees to fit the unusual form. The metal mesh is lightweight yet provides solar protection to the building.[2]

(From GKD World Wide Weave, https://gkd-group.com/us-en/metalfabrics/capital-gate/)

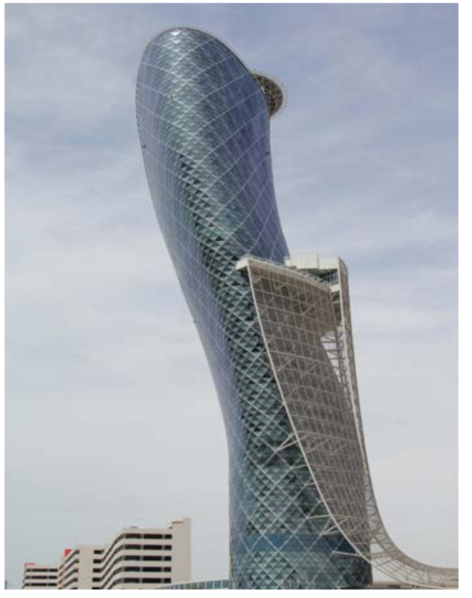


Fig. 5: Overall view

Fig. 6: View from below

Fig. 7: Typical joints and supports

Case Study 2: Swatch Headquarters by Shigeru Ban

Swatch Headquarters is covered by a continuous wood lattice roof structure with a snake shape. The timber shell is up to 240 meters long which makes it the largest wooden structure in Europe. The wood joints are interlocked with each other on site. Each member is constructed on site after measurement. Rigid panels that comes with three varieties, opeaque, transparent and translucent, are partially installed on to the roof to provide lateral stabilities while strengthen in securing the shape.

Functions

The building under the wood gridshell covers a three-storey height atrium. Timber structure is let open at the slab edge while also at the upper level where the roof meets the podium.

A gondola-shaped connection on the upper level protrudes from the building, leads to a 400-seat elliptical conference hall. The roof panels provide various transparency which could control the sunlight and privacy.[3]

Fig. 8: Outside view

Fig. 9: Inside view

Fig. 10: Typical joints and supports

Case Study 3: Yas Viceroy Abu Dhabi Hotel by Asymptote Architects

The Yas Hotel in Abu Dhabi by Asymptote Arhitects is wrapped up by a sunshading surface with diamond-shaped glass panels. The hotel is located at the Formula One Race Track in Abu Dhabi.

Functions

The glazing is supported by the diamond-grid of steel frame which rests on the circular beams at the boundary. The canopy is supported by steel columns while at the same time, rods in tension tie back the canopy to the building facade. The canopy nodes and building envelop is integrated. Rectangular beams forms a shell structure that wrapp around the building. [4]

(Boake, Terri Meyer., and Vincent. Hui. Understanding Steel Design : An Architectural Design Manual. Basel, Switzerland: Birkhauser, 2012, 201)

Fig. 11: Outside view

Fig. 12: Inside view

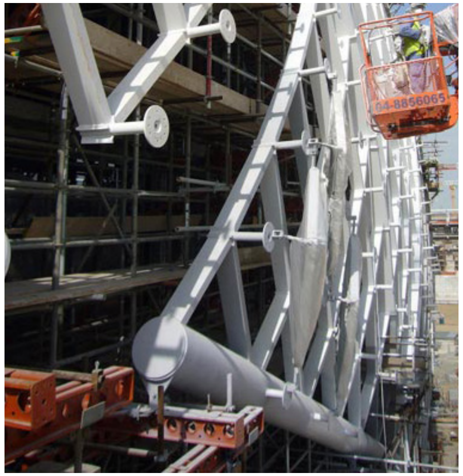


Fig. 13: Typical joints and supports

Form Finding

The surface is controled by 4 curves of 3 degree with 5 control points. The surface between two tower facade emerge from top and gradually merge down to the ground. The aim is to create a gently curved double curved surface so that the asymptotic curves will less distorted. At the same time, the elevated footbridge at +6.00m level should have sufficient head room. The center point should be at least 12m high. When the surface touches the ground, the intersection line becomes support.

Network Integration

Asymptotic curves might not smooth and the form is not ideal. The distance between these 4 control curves influence the surface curvature. After adjust the distance and secure the surface form, guidelines at floor levels intersect with the outer control curves. Script finds the asymptotic curves through these points to ensure that the network will be connected to the slab at two ends. Asymptotic curves near the edge is adjusted to fit into the facade system at top.

Fig. 14b: Asymptotic curves merge into facade

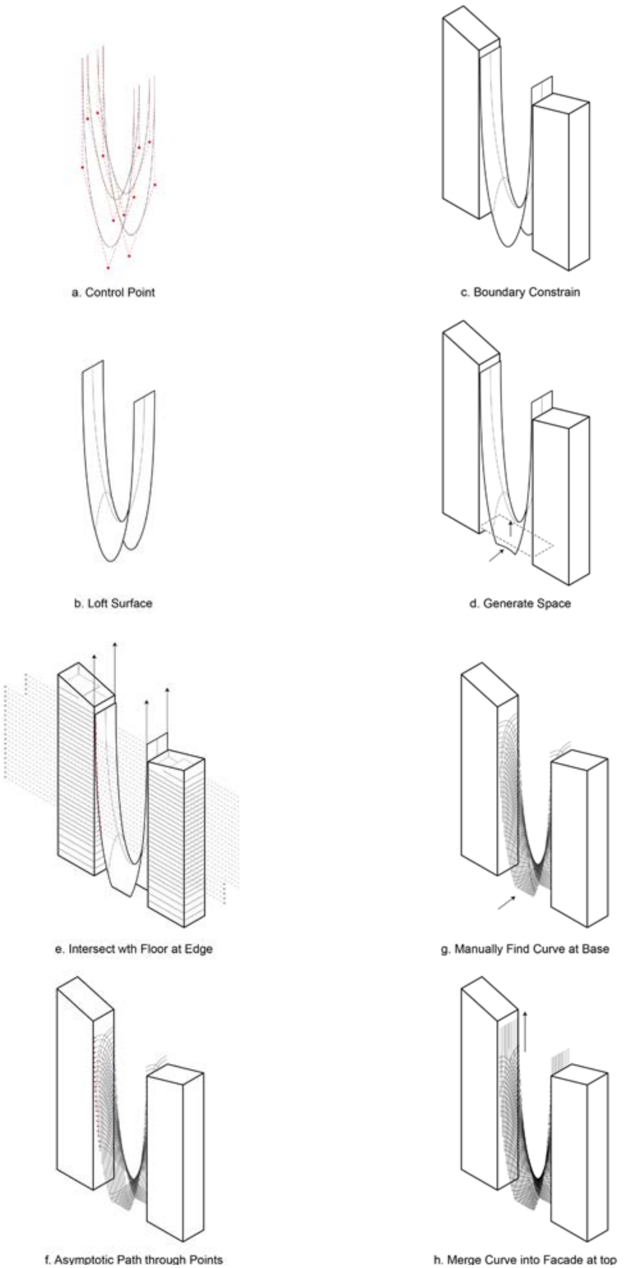


Fig. 14a: Form finding and network integration

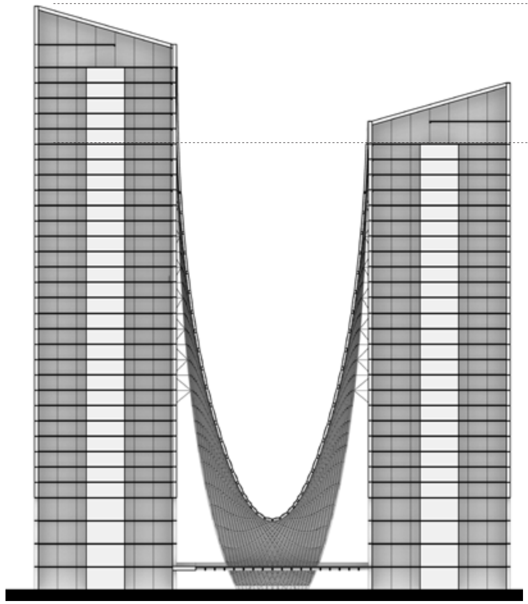


Fig. 15: Longitudal section

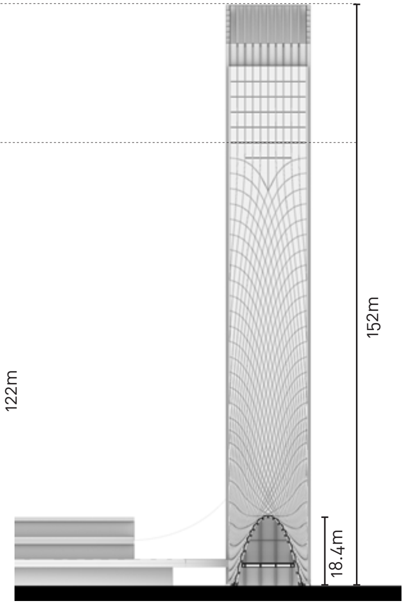


Fig. 16: Cross section

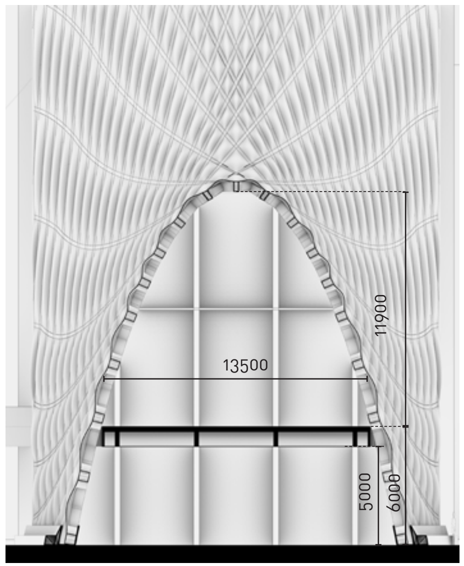


Fig. 18: Cross section

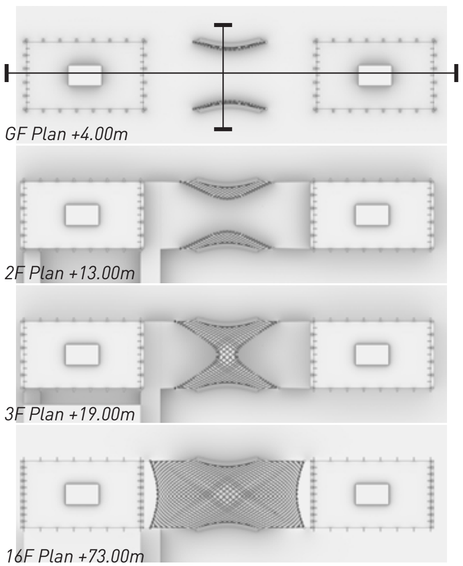


Figure 17: Plan

Typical Joint

Two slices of steel laths of 500mm in depth running parallel to each other and interlocked with another two steel members on the other direction. The intersection point is fastened by steel frame that carries the ETFE substructure. Steel tubes are attached in between the two steel laths, supporting the ETFE membrane and air ducts. ETFE membrane is secured by the channel-shaped steel caps on top.

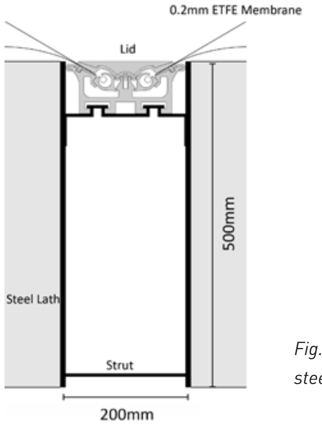


Fig. 20: ETFE and steel lath detail joint

Typical Support

The gridshell structure is supported by two parts. One is the substructure reaching out from the tower façade that connects the gridshell and a sphere-shaped joint from the building slab. The other one is the ground support where the gridshell meets the concrete beams. The boundary is welded with the C-channel steel that wraps up the network. Additional anchor points are provided on the tower rooftop where a deep beam defines the upper boundary of the gridshell.

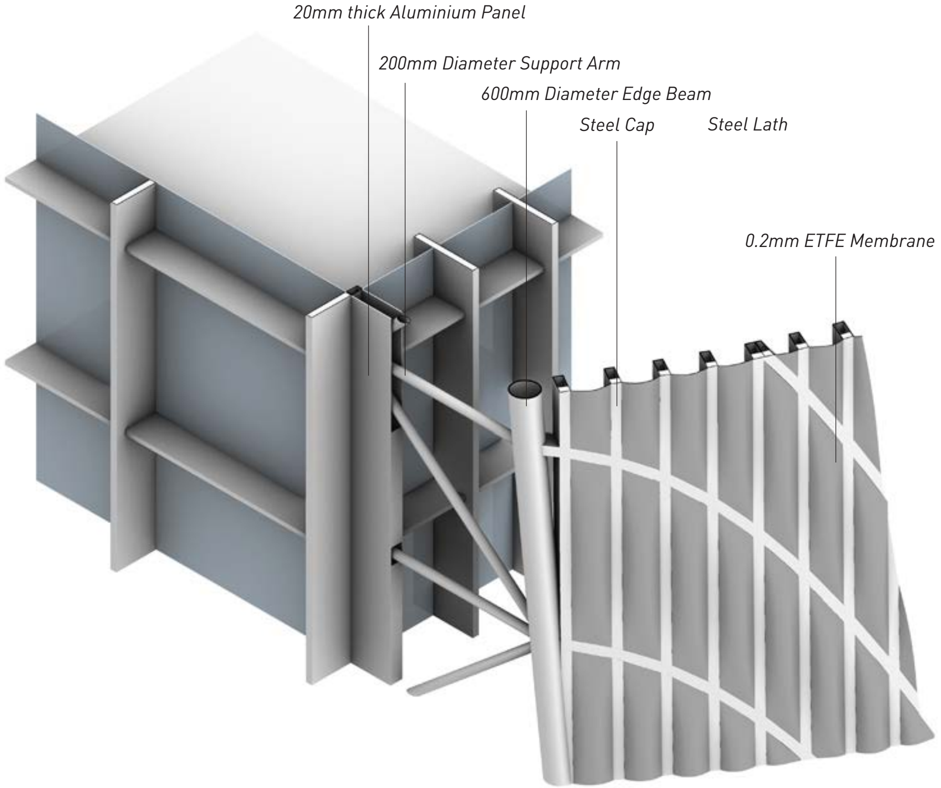


Fig. 19: Axonometric of typical joint

Fig. 21: Ground support integrated with bench

Construction

Once the design is finalized, production of steel lath with slots will be prefabricated. Since the dimension of this structure is extremely large, the construction would be processed in different stages. The members will be prefabricated and welded in the factory and transported to site.

Construction Process

The construction process is divided into several parts, the lower level which involves the support and bridge structure, the upper level connected to the rooftop, and the levels in between. The upper part and ground part will be constructed in the first place. Assembled modules will be elevated in the air and welded with the upper networks later. Once the gridshell structure is completed, the edge beam will secure the shape. ETFE membranes will be installed from the scaffoldings extending from tower slabs.

Fig. 23 Office view

Fig. 22: Perspective over the footbridge

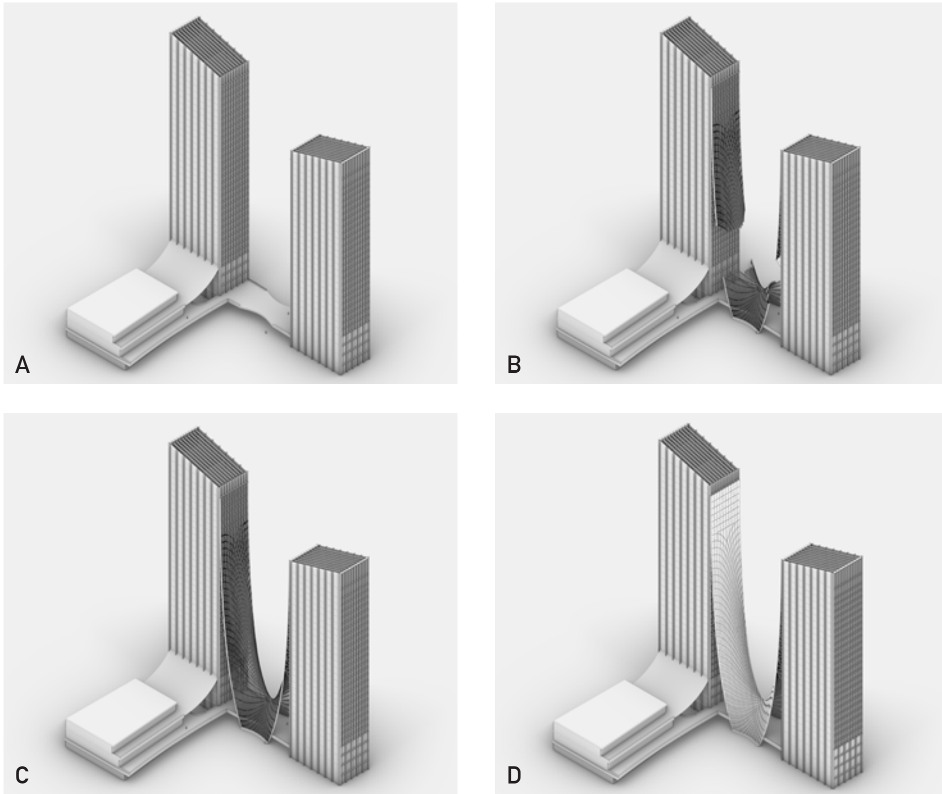


Fig. 24: Construction process A, B, C, D

Site

The gridshell structure is integrated with the commercial complex development in certain condensed urban context. Site could be penetrated by the inner roads in the middle while the connection between two towers requires elevated footbridge. In order to integrate the district into one strong image, the shopping complex annexed to the tower would follow the fluid form. The canopy for the footbridge gives an opportunity in relating to the tower façade while makes a strong gesture to the site.

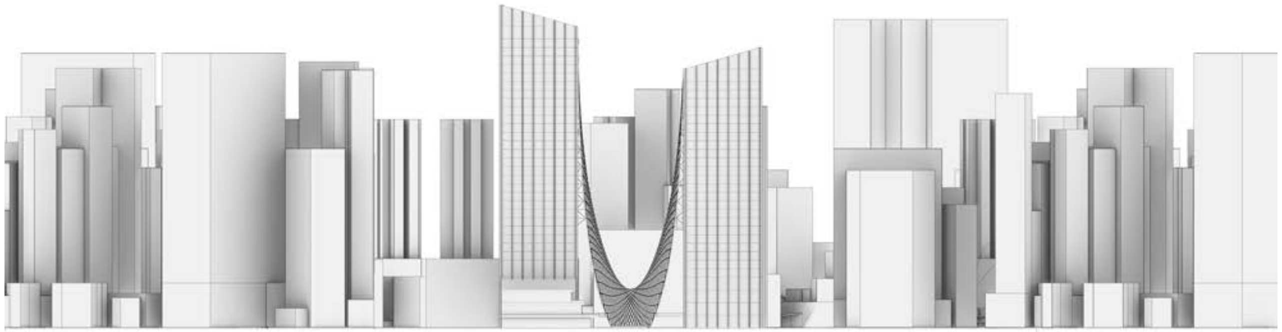


Fig. 25: Comparative urban section

Design Concept

The space in between two towers can be interconnected by a continuous surface from one tower to another. The surface is generated from the mullion spacing pattern of one tower and gradually introducing double curvature when the surface goes down to the ground. The anticlastic-shaped surface is more rigid structurally. Gridshell covers the elevated footbridge connecting tow towers and meets the concrete anchor beam on the ground that supports partially the weight of this immense façade structure.

Functions

The gridshell not only provides coverage for the bridge but also sunshades for the towers through the ETFE membranes installed over the gridshell. Balconies extruding from the tower façade while the residents can enjoy the open air protected by the surface. The surface also strengthen the connection between towers, providing a solid and robust image of the district.

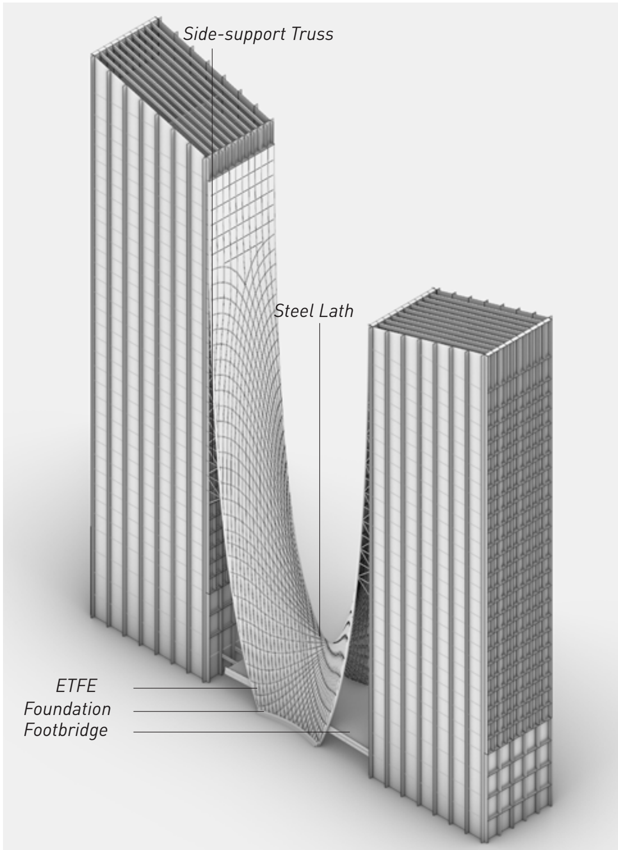


Fig. 26: Design system

Fig. 27: Perspetive view from the podium

Architectural Concept

The continuous surface blends the tower into the commercial complex while integrates the frame network with the mullion patterns. The canopy or exterior façade blurs the boundary between façade and roof structure. The elegant curve makes a strong gesture for the building complex that would become a landmark of this district.

Environmentally, the ETFE membranes can reduce the excessive use of air-conditioning by reducing certain degree of sunlight entering the building. The shape also encourages hot wind rising from the street level, creating natural ventilation running along the tower surface.

Fig. 28: Exterior view

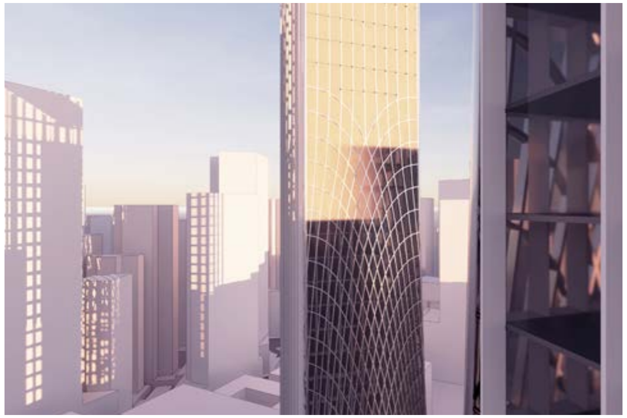


Fig. 29: Urban view with context

Summary

The secondary enclosure serves as a facade that reduce the direct sunlight and protect people from heavy rain, while also imposing a strong formal gesture to surrounding. The surface is generated from the tower facade, evolving from vertical plane to horizontal and then vertical plane again, merging into each other's facade. The asymptotic curves provides convenience for construction and the double-curved form is robust and stable. The gridshell structure takes its structural advantage and blends into the tower grid system, enabling physical dialogue between highrises.

Bibliography

[1] Capital Gate / RMJM, 28 Apr 2018. ArchDaily.https://www.archdaily.com/889854/capital-gate-rmjm

[2] GKD World Wide Weave, https://gkd-group.com/us-en/metalfabrics/capital-gate/

[3] Swatch and Omega Campus / Shigeru Ban Architects" 10 Oct 2019. ArchDaily. https://www.archdaily.com/926166/swatch-and-omega-campus-shigeru-ban-architects

[4] Boake, Terri Meyer., and Vincent. Hui. Understanding Steel Design : An Architectural Design Manual. Basel, Switzerland: Birkhauser, 2012, 201

List of Figures


DESIGN RESEARCH
Cat Tower
Hwanseo Lee

SCENARIO PROPOSAL

Fig. 1: Cat tree tower

Span
1.7 - 10 m

Material
Laminated bamboo

Construction Method
Thin timber lamella with slit joints

Target Group
Pet owners, Cats, and Pet Shop

Introduction

From the gridshell structure, we have created many possibilities in terms of efficiency and aesthetic quality. Hopefully, we can find the structure from our surroundings. Many roofs and pavilions have this structure which is very huge. However, I could not find other examples on a larger scale. I looked at the different applications of the structure in different scales. Furniture was an example of the different applications of the structure. Also, I have looked at another perspective which is the pet. Pets are always around us and I wanted to create a shelter for them with the gridshell structure.

The laminated bamboo structure is extracted from bamboo culm and sliced into several pieces and reassembled together to be stronger and easily cut into specific size. The bamboo lamellar is very flexible and easily bent.Thus, the structure is strong against cracking and snaping. Also, the structure is very light and elastic, so it can be used for DIY cat tree tower.

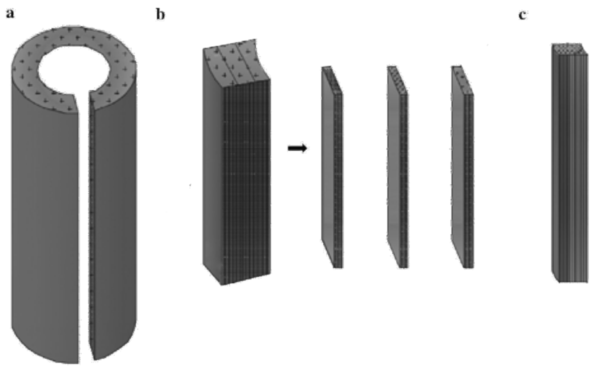


Fig. 2: Laminated bamboo structure

KEY CONCEPT

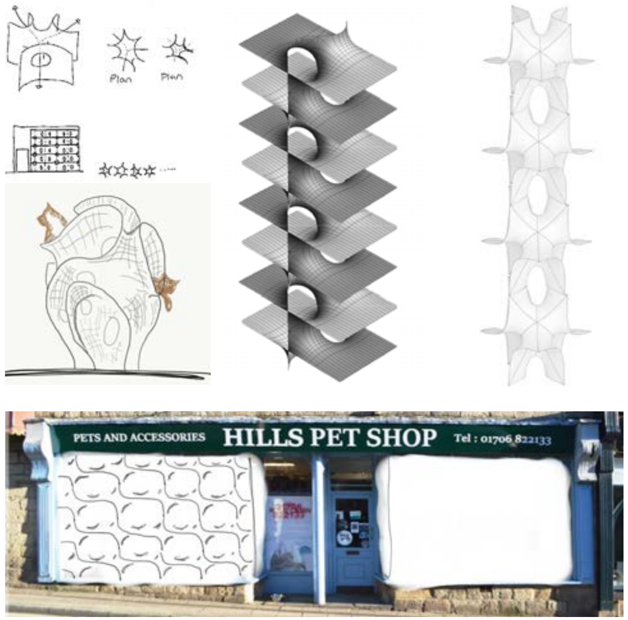


Fig. 3: Concept sketches

Challanges

1. The structure needs to be very stable so it can resist destruction by jumping and scratching cats.
2. It should be very easy to construct.
3. It has to provide different quality of spaces(small) for cats.
4. It should be able to be repeated in a vertical direction.

Potentials

The gridshell structure is one of the most efficient structures in the world. It saves a lot of materials as well as very stable. Also, the surface is produced by the repetition of a simple negative surface. Thus, by repeating a module, it can be a small tower as well as a whole facade of a pet shop which can be a cat tower or cage. The minimal surface, the batwing surface is smooth and beautiful to be placed in many houses. The gridshell structure is also very good for cats which need to climb up and scratch. The structure provides hiding, sitting, climbing spaces for cats.

Case Study 1: General Idea of Cat Tower

These are photo and assembly instruction drawing for a typical cat tower. The cat tower is to fulfill the needs of cats in an interior space. The cats have nature which is climbing, hiding, and scratching, etc. These activities are very significant for cats like dogs need to walk outside every day. The cats always occupy desk, top of a cabinet, and bookshelves which are very high. The cats are territorial animals and it occupies vertical space. Thus, in the house where the cats living, there should be numerous vertical space and it takes a large amount of space. [1]

Functions

The cat tower has different spaces for the cats. Mostly, the top of the tower is the viewing spot where cats enjoy the moving objects in their safe zone. Also, the tower has at least one hinging spot where cats take rest. Each step of the tower is at a certain height so the cats are able to jump on. The tower is made out of wood and covered with soft cotton and scratchable rope. Most of the parts are prefabricated and can be assembled easily by customers.[1]

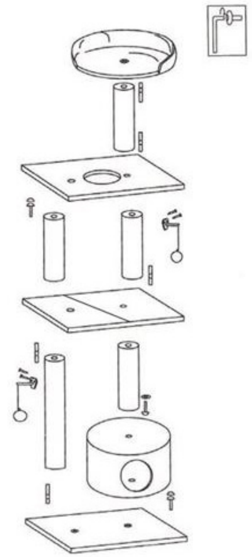


Fig. 4: Assembly instruction of a typical cat tower

Fig. 5: Typical cat tower

Case Study 2: Wooden Orchids

Architectural Concept

Vincent Callebaut Architectures have received honorary mention for their "Wooden Orchids" proposal in the International Union of Architects' (UIA) Mount Lu Estate of World Architecture Competition. Based in Ruichang, China, the competition tasked participants with designing several cultural and commercial complexes near one of the world's largest flower theme parks. Wooden Orchids consolidates these functions in a green shopping hub that speaks to the area's demographic and climatic influences.

Inspired by numeric sequences found in nature, Wooden Orchids derives its form from the golden section and a biomimetic pattern. The shopping complex uses prefabricated wooden structures to emulate the petals of orchids. The petal module is applied 16 times within the space to compose a complete „orchid box." In both of the site's plots, the orchid box is replicated six times, resulting in a collection of 12 cells connected by footbridges.[2]

Functions

The cells themselves employ additive and subtractive processes in response to their programs. The movie theaters, library, fitness facility, and food service areas rely on solid facades, while the farmers market and shops interlaced with gardens bring in natural light through transparent ones. In addition, each division of the site maintains a unique character enhanced by its own biodiversity and colors, while a network of bicycle and pedestrian paths creates an internal linkage system.[2]

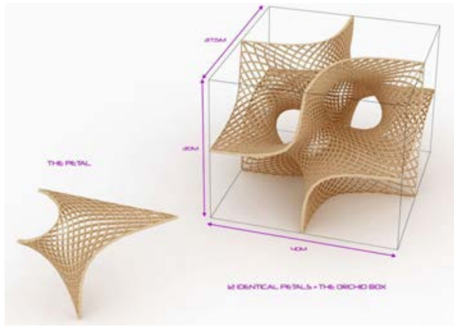


Fig. 6: Batwing surface with asymptotic curvature

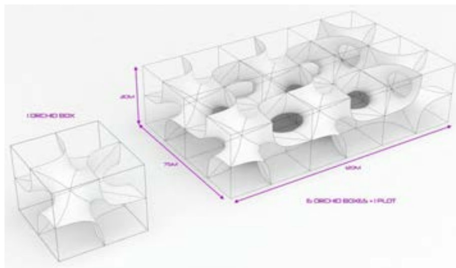


Fig. 7: repetition of module

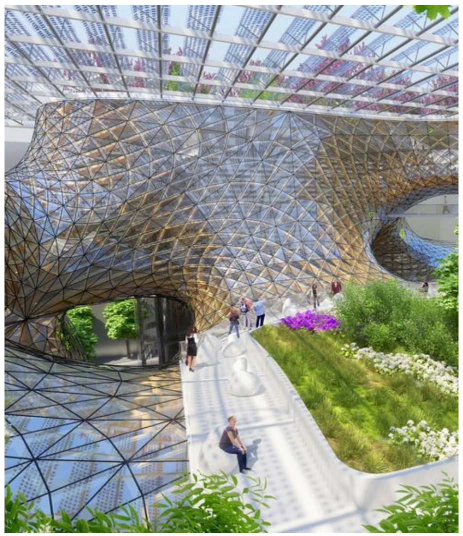


Fig. 8: render view

Case Study 3: Asymptotic Pavillion

Architectural Concept

This is an Asymptotic pavilion designed by Denis Hitrec. The pavilion has asymptotic curvature with steel lamellar structures. The steel lamellas only have geodesic curvatures to form a stable and sinuous form of the pavilion. The real constructed structure is steel, yet in the test models as seen in Figure 12, 13 and 14 are made out of wood lamellas.[3]

Functions

These thin wood lamellas are very fragile and if the slit joints are almost half of the width of the wood lamellar, it will be broken easily. As in the Figure 4 and 6, the slit is less than half of the width of the lamellar. This type of joint is very simple to construct and assemble together [3]

Fig. 9: Strip fabrication

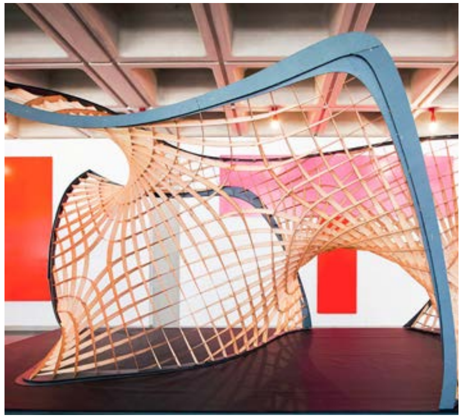


Fig. 10: Timber model

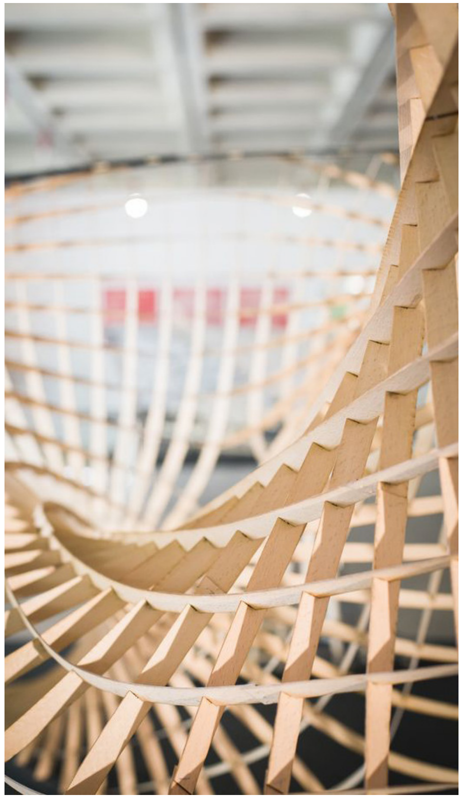


Fig. 11: Close-up

Typical Support

The support is divided in to two pieces and has the joinery which is Mortise and Tenon joinery. The support has several functions. Firstly, it fixes the grid structure with the slit on one piece of the support. Secondly, between two support, before juxtapose two supports, the fabric can be fixed by velcro on the surface which is facing other support. Thirdly, it allows to join with other modules through bolts and nuts to create the tower and facade.

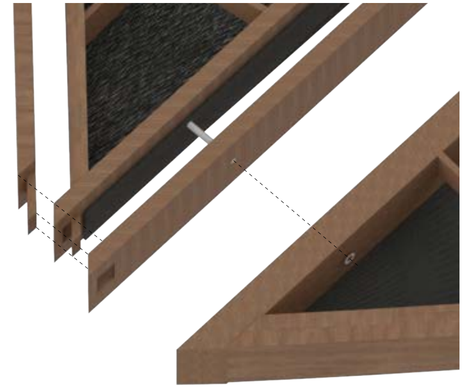


Fig. 14: Detail of joinery

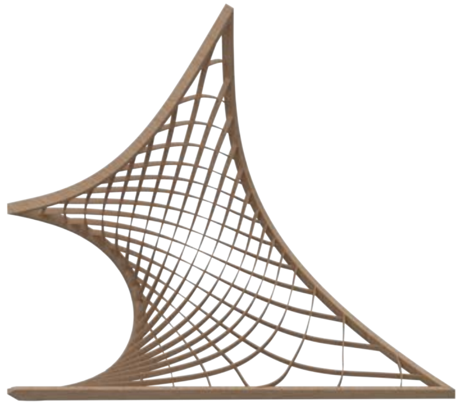


Fig. 12: Axonometric of support

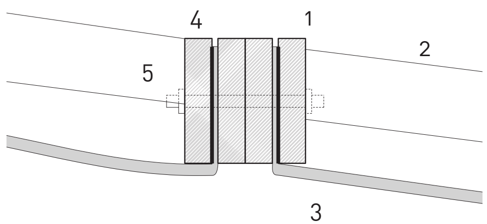


Fig. 13: Detail of typical support in real size

Elements

1. Timber supprot
2. Laminated wood lamellar
3. Non-woven fabric
4. Valcro
5. Bolt and nut

Typical Joint

The joint has no bolts and nuts , but it is a simple waffle structure and this type of structure is easier to construct. The thickness of grid structure is 2mm and 12mm in width. Thus, the structure is quite fragile if the slit of the structure is half of its width which is 6mm. The slit of the stucture has 2mm deep slit. The slit fixes its own position and with several grid structure, it becomes stable and light structure.

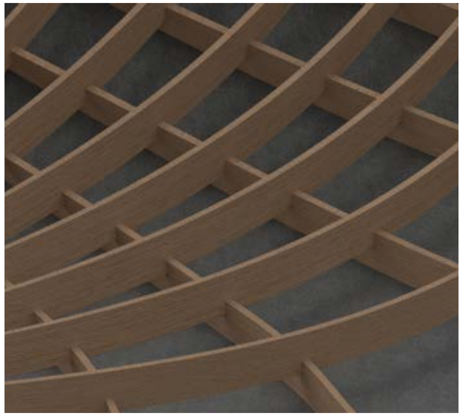


Fig. 17: Detail of grid structure

Construction

The whole structure is divided into 3 parts: grid, support, and surface. Each timber lamellas have different lengths so numbers will be written on each lamella.

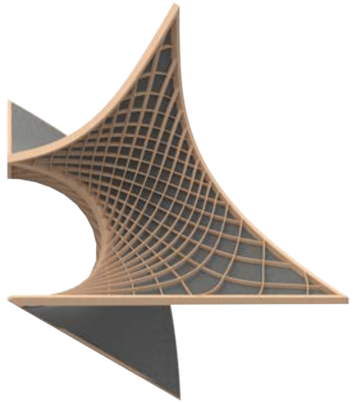


Fig. 19: Render of 2 modules

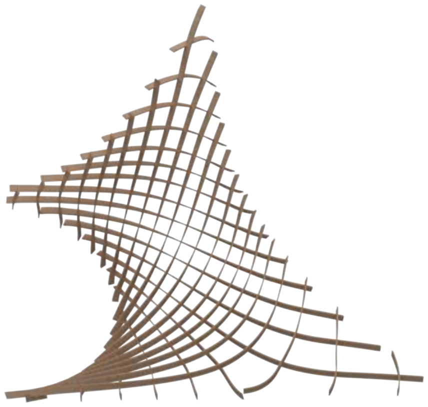


Fig. 15: Axonometric of grid structure

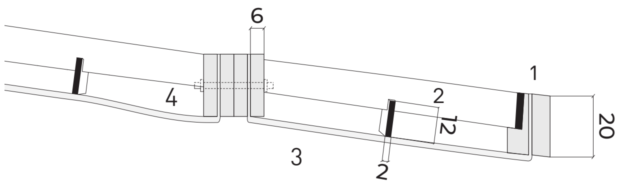


Fig. 16: Detail of typical detail 1 : 2

Elements

1. Timber support
2. Laminated wood lamella
3. Non-woven fabric
4. Bolt and nut

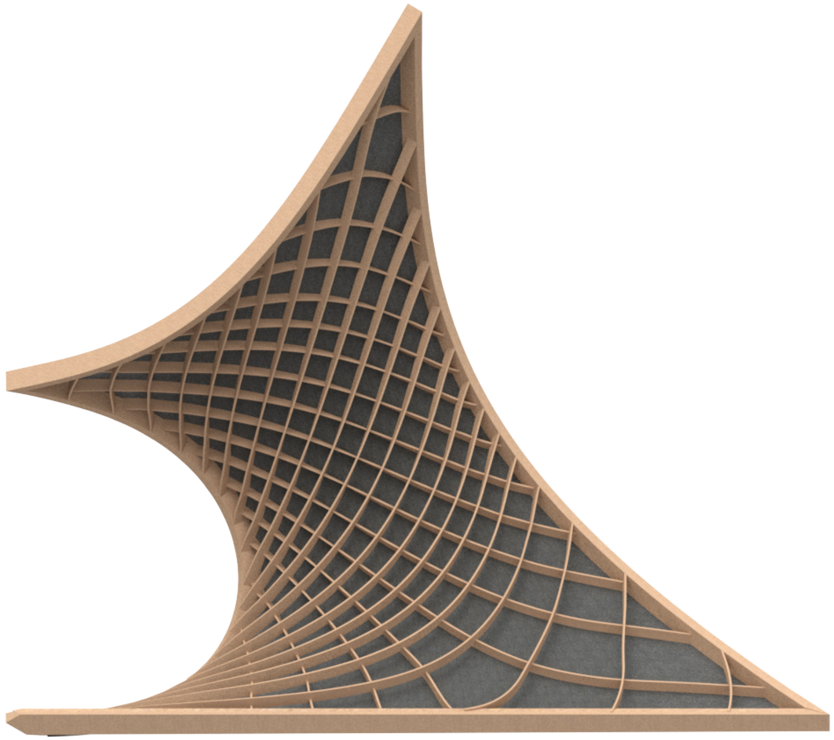


Fig. 18: Single module render

Construction Process

A. Each timber lamellar is assembled together according to the order and the shape is fixed by slotting the assembled grid into the inner support.

B. Fix the non-woven fabric on the velcro which is on the outer face of the inner support.

C. After the fabric is fixed, outer support is added to fix with other pairs of supports to form a module

D. A module will be rotated and repeated to form a tower of a facade and the modules will be fixed with few bolts and nuts.

Module Design

The repetition of the module can create diverse shapes of the tower or a wall. Thus, it can be placed in different places. Mostly, the tower will be used in interior space such as the living room, and pet shop.

This is the potential of this modular design that can be placed everywhere. The size can vary so the customer can decide the size and site of the furniture.

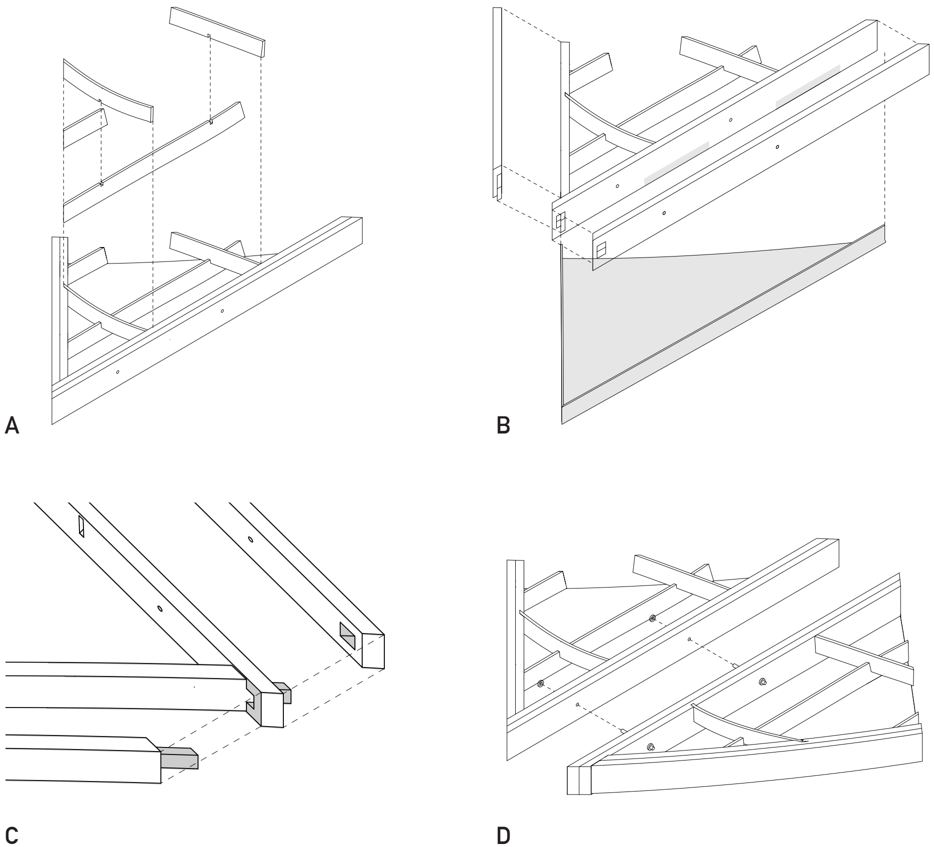


Fig. 20: Construction process A, B, C, D

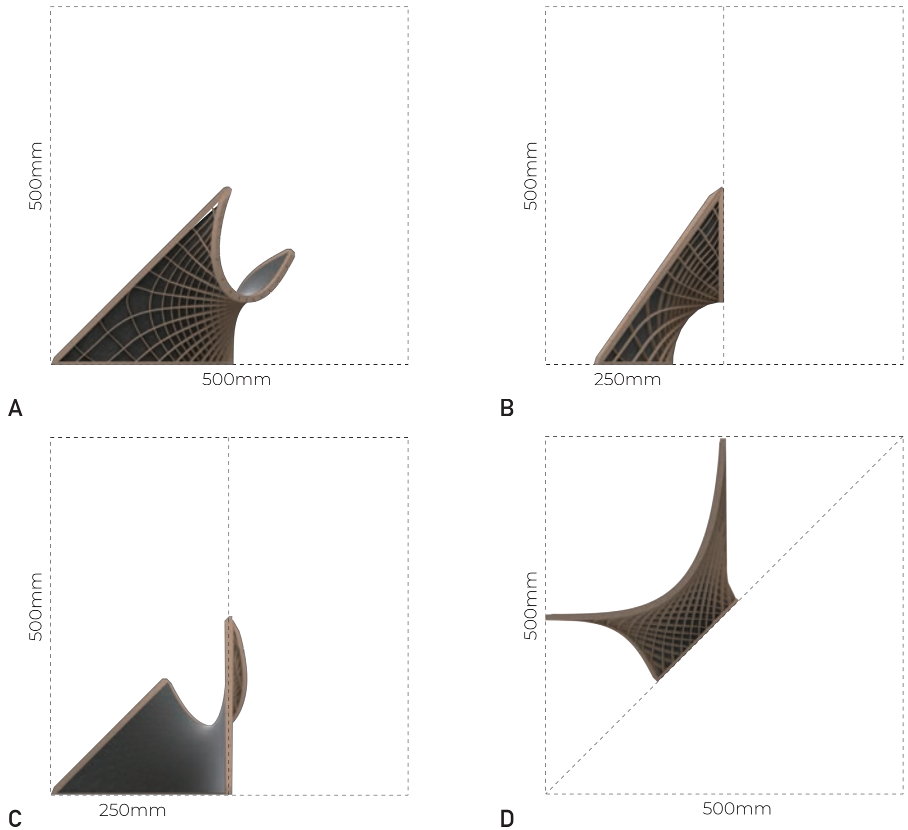


Fig. 21: AS module elevation(a, b, c) and top view(d)

Design Concept

The minimal surface is a kind of small miro which is a type of a loop. In this batwing surface, there are many ways to climb up to the top. Also, the repetition of the surface create different quality of spaces, for example, there will be cantilevered steps, enclosed spaces, and vertical spaces. And the number of different spaces can be designed by owner self.

Functions

The cat tower is to fulfill the needs of cats in an interior space. The cats have nature which is climbing, hiding, and scratching, etc. These activities are very significant for cats like dogs need to walk outside every day.

The cats always occupy desk, top of a cabinet, and bookshelves which are very high. The cats are territorial animals and it occupies vertical space. Thus, in the house where the cats living, there should be numerous vertical space and it takes a large amount of space.

This cat tower fulfills all the needs of the cats and it becomes a playground for the cats. Also, it will be an exciting exercise for pet owners to design the cat tower for their pets themselves. The owner will know better about the characteristics and preferences of their pets. Furthermore, the smooth minimal surface will be an aesthetic art piece in the living room.

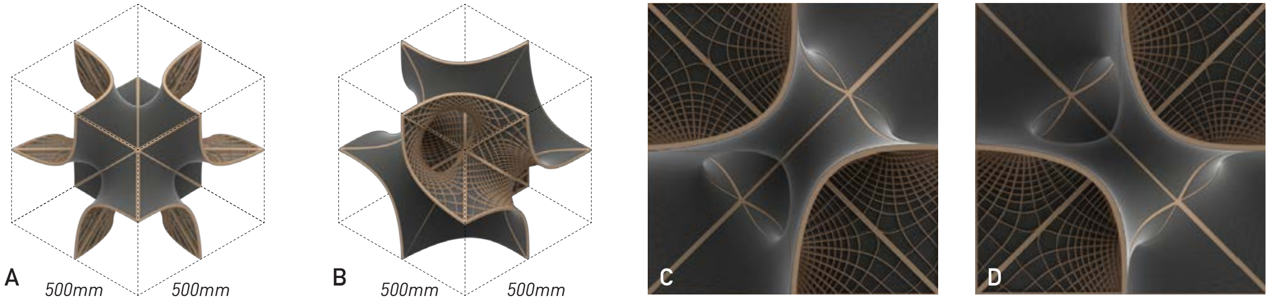


Fig. 22: Isonometric view(a,b) and elevation(c) and top view(d)

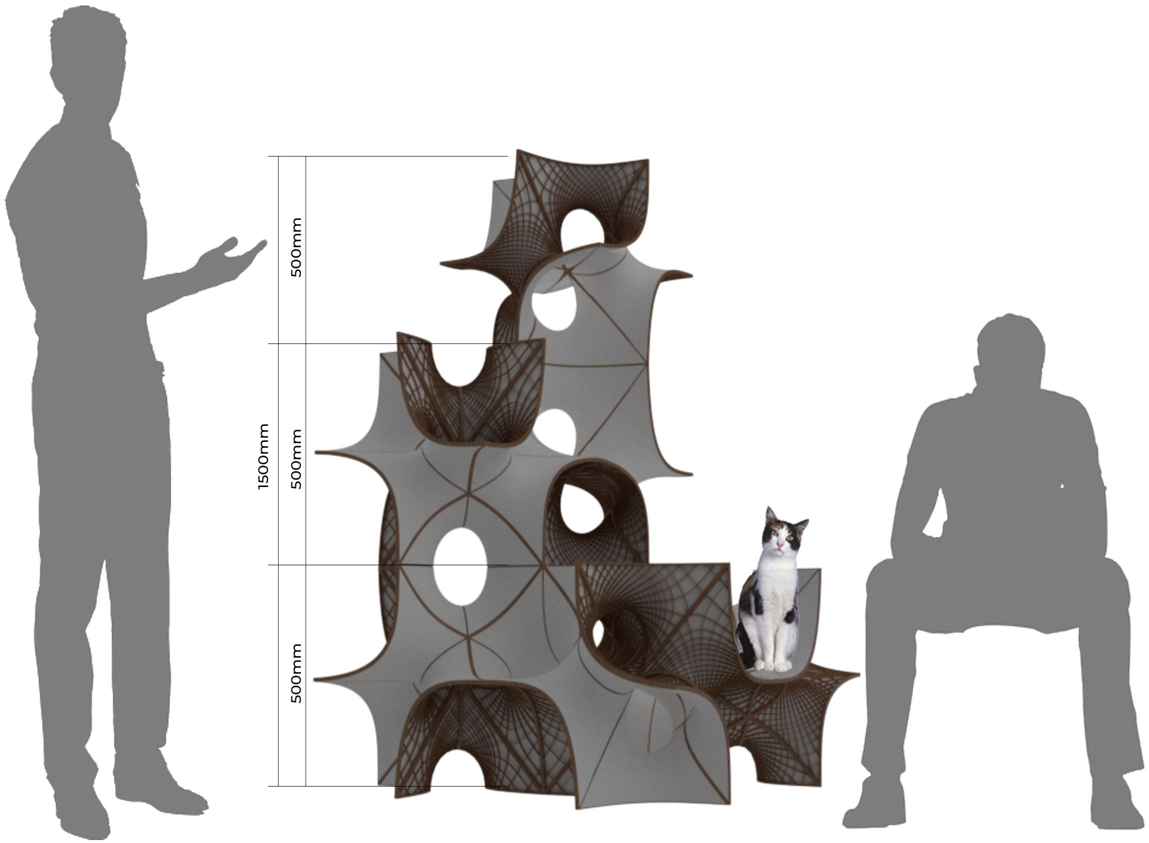


Fig. 23: An example of assembly of modules

Architectural Concept

The minimal surface is suitable in different living space. The sculptural form of the tower vitalize the living space as well as vitalize the cats. The Cat tower is not only furniture for cats but also installation for the pet owners.

Assembly of a module will create a sculptural form of cat tree tower and cage for small animals. It can be placed on whole facade of pet shop to replace cube shape glass cages. Also, the module becomes cat tree tower in living room. The beautiful cat tree tower will vitalize the living room and the sculptural cat tower will be a hot place to the pet.

When get bored on the same shape of the tower, it can be easily re-shaped

As the living space is shared by human and cats, it should be flavoured by both of them and this cat tree tower will fulfill the need of cats and aesthetic need for human.

Fig. 24: Close up render

Fig. 25: Render of a facade of pet shop

Fig. 26: Render of cat tree tower

Fig. 27: Render of cat tree tower

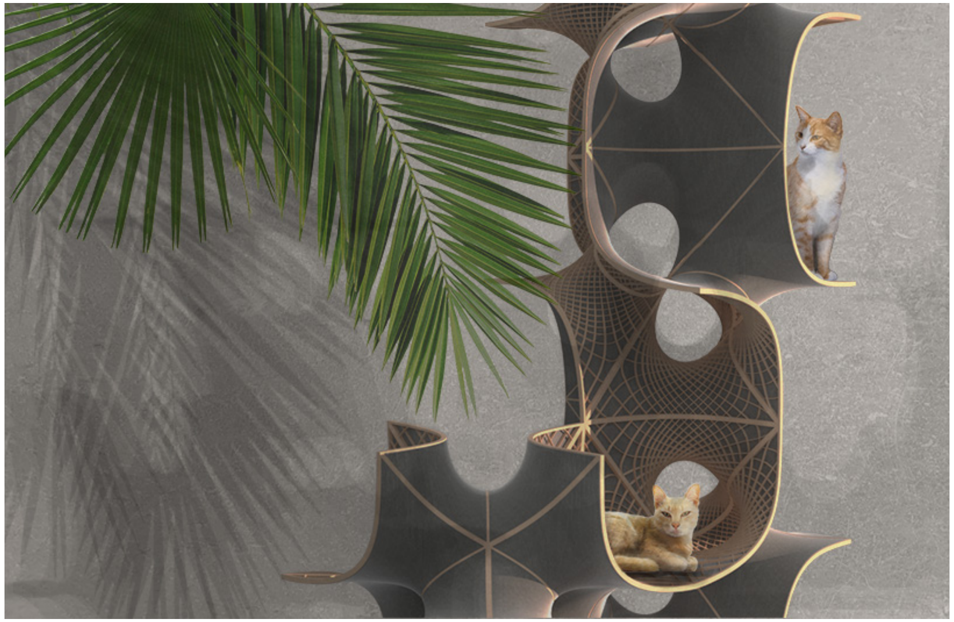


Fig. 28: Close-up render

Fig. 29: Render of a facade of pet shop

Summary

Cat tree tower is nessesary furniture for cat and the tower take a huge space of living room or bed room. Not only to fulfill needs of cats, but also to decorate the living space, the asymptotic cat tree tower is aesthetically interesting.

The furniture is also easy to construct and assemble together. The module can be repeated to form a tower with different spaces for cats or a facade of a pet shop to replace ugly glass cage.

This aesthetic feature, convenience, and possibility of diverse design are the main competitiveness of the cat tree tower.

Bibliography

[1] "General Cat Care." ASPCA. https://www.aspca.org/pet-care/cat-care/general-cat-care.

[2] Giermann, Holly. "Vincent Callebaut Proposes 'Wooden Orchids' Green Shopping Center for China." ArchDaily, May 27, 2014. https://www.archdaily.com/635899/vincent-callebaut-proposes-wooden-orchids-green-shopping-center-for-china.

[3] "Asymptotic Gridshell." Eike Schling, September 6, 2016. https://eikeschling.com/2016/09/06/asymptotic-gridshell/.

List of Figures

DESIGN RESEARCH

Hong Kong Public Housing Bamboo Shading
Ying So Yi

SCENARIO PROPOSAL

Fig. 1: Bamboo scaffolding in Hong Kong

Span
3 - 10 m

Material
Bamboo

Construction Method
Scaffolding

Target Group
Hong Kong Public Housing's residents

Introduction

Bamboo scaffolding is a common formwork for the construction of buildings and temporary theatre in Hong Kong. It helps worker to assmeble the building components in place. Yet, this unique and traditional craftmanship has been gradually out of the limelight.

Bamboo is a material that is commonly found and environmentally friendly. On the other hand, grid shell are able to give a structure with the least amount of materials. It will be very cost effective if these two elements are combined. Public housing in Hong Kong is densely arranged. Therefore, public space is very important as it allow the residents to have a place to social, do exercise or relax. Yet, most of the public space are not covered. These spaces are abondoned during the rainy days.

This proposal aims to provide a economic shelter for people to enjoy their time in the public space. At the same time, it helps to promote the usage of bamboo as a materials for the building, but not only as the formwork or work station for the workers during construction and promote traditional craftmanship of bamboo scaffolding in Hong Kong.

KEY CONCEPT

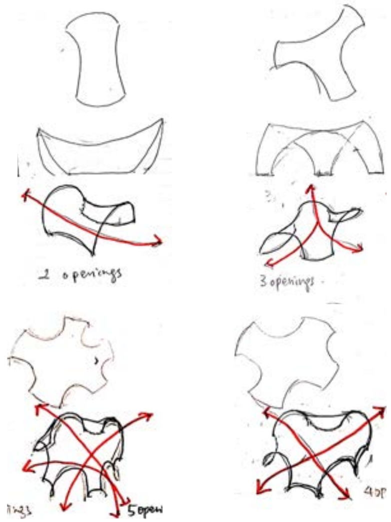


Fig. 4: Concept sketches

Challanges

1. Bamboo is a not a homogenous materials and has variable properties, the structural behavior is hard to estimate.
2. Limited durability, bamboo will be worn and tear due to insect attack and weathering.
3. Good construction company is needed in order to make sure the joints are tied tightly by the workers.

Potentials

1. A traditional craftmanship, local construction workers are experienced in scaffolding. No special tools are required.
2. Bamboo are easy to produce and cheap to buy, it is economical.

Advantage of using asymptotic curves

Through adopting asymptotic curves, the joints of the bamboos will be stacked vertically, which make the grid shell become structurally stable. Hence,, several bamboo layers are able to lift up from flat together. It helps to give a simple and fast construction.

Case study 1: ZCB Bamboo Pavilion

Introduction

The Bamboo Pavilion was situated the Construction Industry Council's Zero Carbon Building (ZCB), which is built for a summer public event in 2015. It was four-storey-high long-span bending-active bamboo gridshell structure, which can house around 200 people. It aims to recall the importance of one of the traditional craftsmanship in Hong Kong, craftsmanship of bamboo scaffolding construction.

Structure

It was a triangulated diagrid shell. built up with three layers of bamboo go to three directions. 475 large bamboo poles are bent on site so as to shape the desirable structure. It is a bending active grid shell that spans for 37m. Internal bending transfers between the bamboo members and reached its equilibrium at the nods.

Typical Joints

Bamboos are hand tied together with metal wire using techniques based on Cantonese bamboo scaffolding craftsmanship. The intersection points of the bamboo are hand marked which contain number information of the bamboo intersecting at the specific points. The joints are rigid so as to make sure all the members stay at the suitable place.

Typical Supports

The diagrid shell structure wrap into three hollow columns with triangulated and free hanging linear members, which rest on three circular concrete footings. The bamboo are anchored to the footing, concrete was used to fill the cavity in the bamboo.

Fig. 4a: Outside view

Fig. 4b: Inside view

Fig. 4c Photo of the supports

Fig. 4d Photo of the joints

Case study 2: Haduwa Arts and Cultural Institute

Introduction

The shell was the stage for the Haduwa Arts & Culture Insitute in Apam. It was situated at the Atlantic coastline of Ghana´s Central Region. It aims to triggers the promotion of arts and raise social engagement in the arts made in Africa. An array of indoor and out door activities had been planned, integrate mixed-use activities with sustainable solutions., providing a comforatble shelter for the inhabitants. It was planned to serving as a rehearsal space, dance studio, and gathering place.

Structure

It is a giant dome comprise of 41 bamboo arches with three openings facing in different directions. Two bamboos were tied together and become one member in order to strengthen the structure and prevent from bending. It was a quadrilateral diagrid structure. with smooth lines and rigid connections. 2 layers of bamboo members form the diagrid. Another network of bamboos were used to reinforced the structure, three bamboos were tied together as one member for this layer.

TypicaL Joints

The joints are hand tied together by using strings through using traditional method.

Typical Supports

The bamboo was fixed at the concrete bases supplying the structure from underneath.

Fig. 6a: Outside view

Fig. 6b: Inside view

Fig. 6c: Photos of the joint

Fig. 6d Photo of the supports

Case study 3: Camboo (Unbuilt)

Introduction

It was concieved as the landmark in the Phnom Penh's Freedom Park, providing a temporary pavilion with low tech and sustainable bamboo roof structure. It takes reference of Frei Otto's soap film experiments and Felix Candela's hyper shell. It aims to raise people's awareness of the tradtional weaving techniques in Cambodia.

Fig. 7a: Outside view

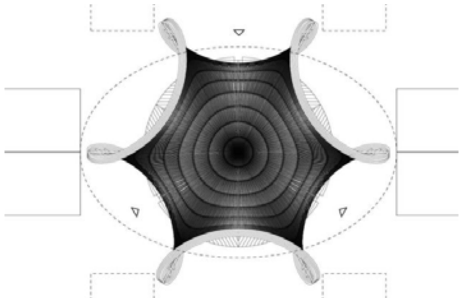


Fig. 7b: Plan

Structure

Adopting Ennper minimal surface, the arches of the structure symbolize the radiating arms of the ancient Goddess Prajnaparamita. It takes reference of Cambodia's traditional weaving. It created a self support system.

It adopted a quadrilateral principle curve gridshell structure, with smooth network. The edges coming ups and downs which creating openings and support for the pavilion, creating a natural shape.

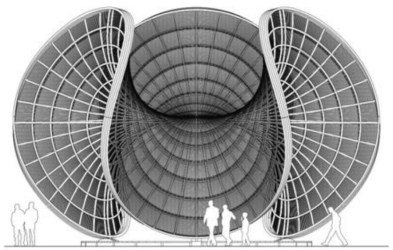


Fig. 7c: Elevation

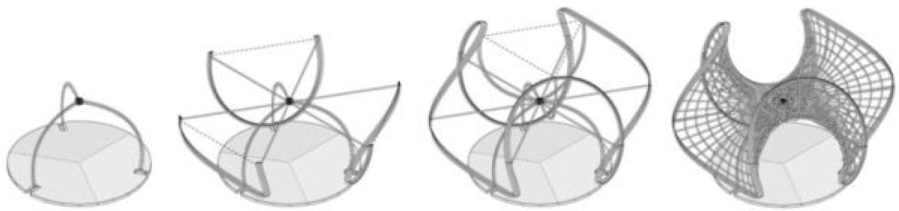


Fig. 7d: Construction process

Typical Joints

Option 1:

The design is created by 4 layers of networks and spanning to 2 directions.
Knowing that a single bamboo stick will not have enough strength to stablize the structure and tend to deform and buckle, 2 bamboo sticks are needed for each member. Taking reference of CUHK ZCB Bamboo pavilion, the outer layer is consisted of bamboo that are splitted in the middle, whereas the inner layer is consisted of bamboo with a hole in order to allow a wooden strip connected the four layers of bamboos together. The wooden strip acted as a rigid joints of the bamboos.

To shorten the distance between the joints, taking refence of the joints in Center Pompidou Metz, wooden blocks are used to strengthen the structure and prevent from bending.Adopting traditional scaffolding techniques, the bamboo members are holding together with metallic strings.

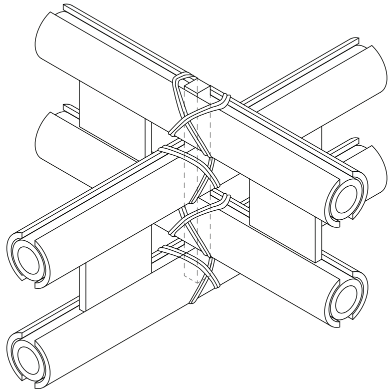


Fig. 8: Axonometric of typical joint

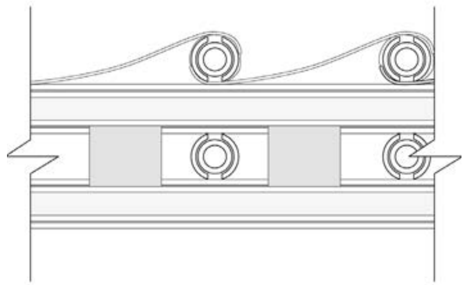


Fig. 9b: Detail of the connection of the membrane

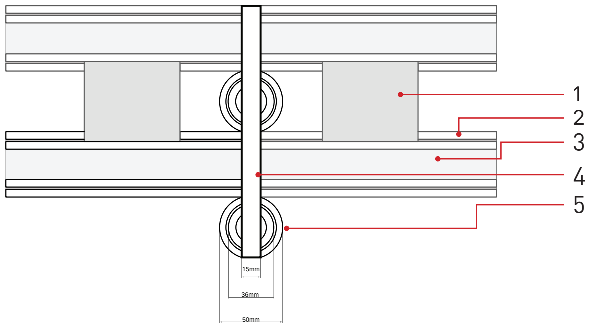


Fig. 9a Detail of typical joint 1:6

Elements

1. Wooden block 60*75*15mm
2. Splitted bamboo
3. Bamboo
4. Wooden strip 15*15
5. Metal string

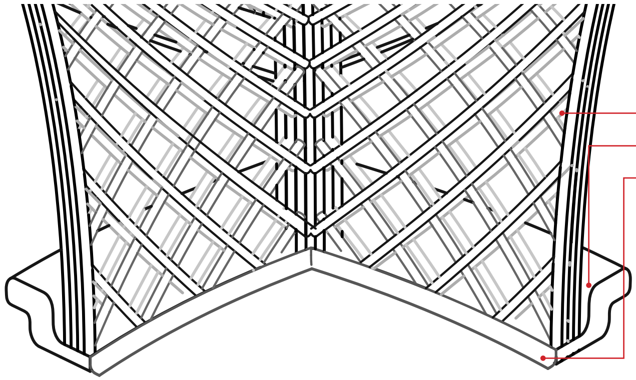
Typical Support

Taking reference of ZCB's bamboo Pavilion and Haduwa Arts and Cultural institute, the bamboos members that reached the ground is connected to the concrete footing. The concrete footings act as the shallow foundation of the structure. It shows that a heavy block is needed in order to stablize the bamboo grid shell.

A thin concrete slab are used as the support of the bamboo shell. It is also acted as the seats for the users. It was a precast slab and there are some pockets to allow the bamboo sit on it. Hence, the steel gutter is used to drain the rain water and also hide the joints between the bamboo and the concrete slab.

Construction

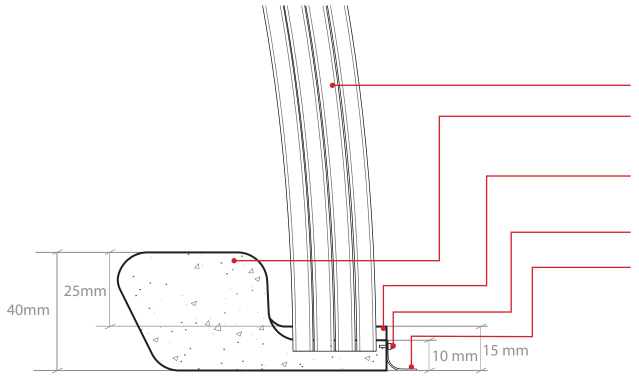
The construciton of the shell aimed to be fast and easy. Local construction workers will be hire as they are familiar with the bamboo scaffolding techniques. The construction method will be similar with the Mannheim Multihalle by Frei Otto. The timber lattic is first laid out flat, then use the crane to pull up the grid.



Elements

1. Bamboo
2. Concrete slab
3. Steel gutter

Fig. 10: Axonometric of typical support



Elements

1. Splitted bamboo
2. Precast concrete slab
3. Site casted concrete
4. Bolt
5. Steel gutter

Fig. 11: Detail of typical support

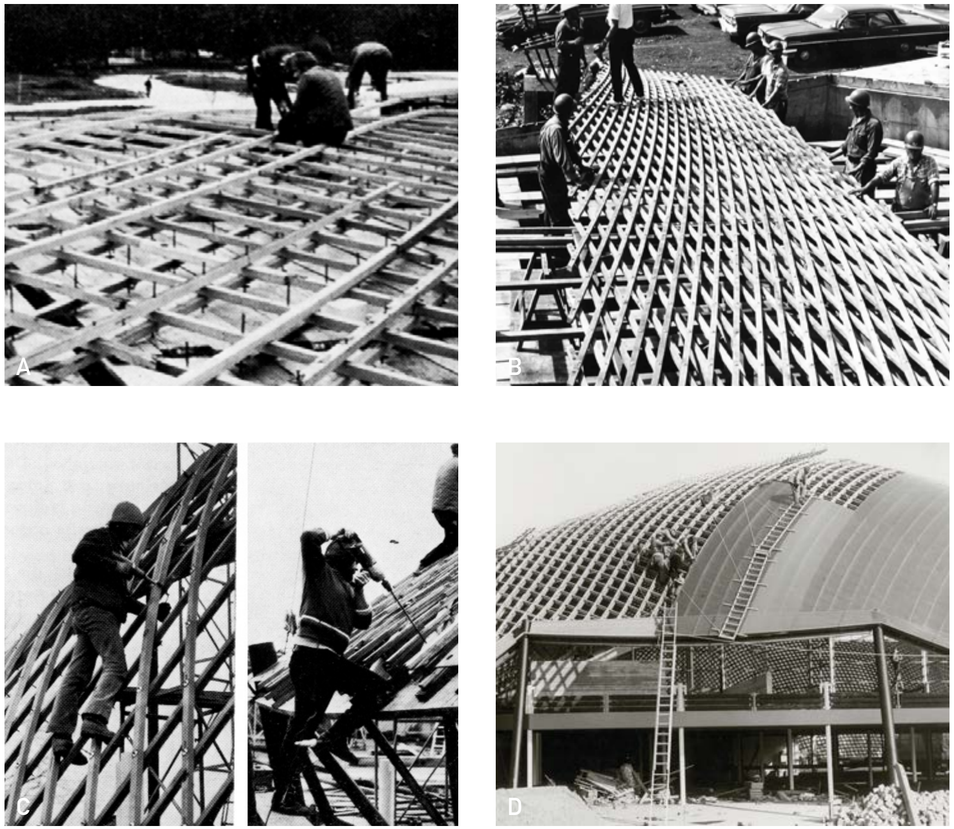


Fig. 12: Construction photos of Mannheim Multihalle by Frei Otto

Construction Process

Using asymptotic curves allow the construction of the grid shell to be first laid out flat then push up to its desirable shape.

1. Each of the bamboo members should be trimmed to their suitable lengths
2. Mark the points that is needed for the rigid joints.
3. The nods are tied on the flat ground, then later raised to create the double curved grid shell.(refer to Fig 13.1 and Fig 13.2)
4. Make sure the bamboo members in the suitable directions and tie the nods by hand using metal string
5. Tie the membrane with the bamboo (refer to Fig 13.4)

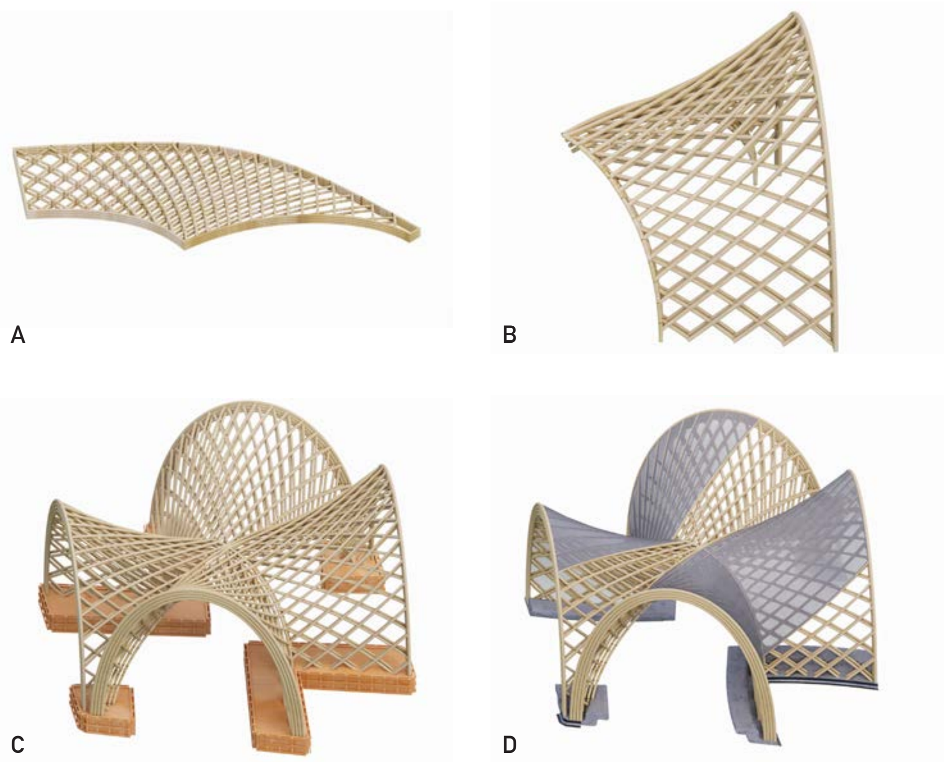


Fig. 13: Construction process A, B, C, D

Site

Public estate was set as the scenario for the project. The public space in the public estate are shared by numerous residents. Many elderlies will do exercise or have a walk in the public space. Children will treat the open space as their playground. It is a platform for people from different age groups to gather and social.
Hong Kong's rainy season makes those open spaces cannot be used, thus left abondoned during the rain. In light of this, an economical and simple grid shell can help to ease the situation through providing a temporary pavilion.

Fig.14 Image of the site

Design Concept

The design idea is to create a shell that is efficient and easy to be built. Through creating an asymtotic grid shell, the scissored grid is easily stiffen. Hence, the structure can be assemble on the ground first, than push it up into the the desinated place. Hence, the water block are both functioned as the seat bench and also the support of the structure so as to prevent from the deformation of the bamboo structure. To create a symetrical grid shell with a simple shape, a simple nurb surface with 90 degree control point are help to form the basic unit. Then, the surface are trimmed then mirrored.

Functions

The function of these pavilion can be adopted during the spring and summer time. As it is a temporary pavilion, it can be taken off easily when it is not in used. The function of the pavilion is for 2-4 people use.

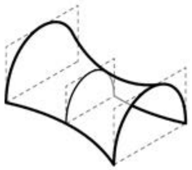
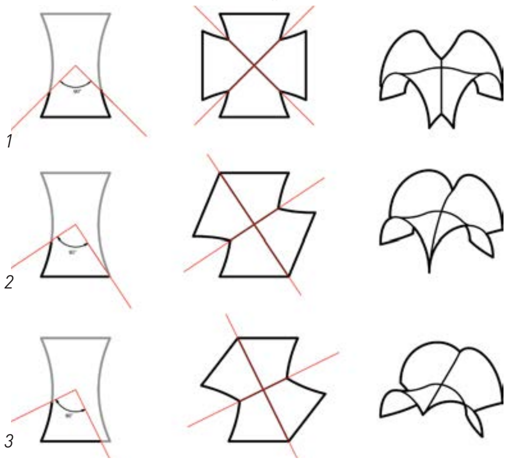


Fig. 15a. Basic unit



Option 1

Option 2

Option 3

Fig. 15b. Design parameter

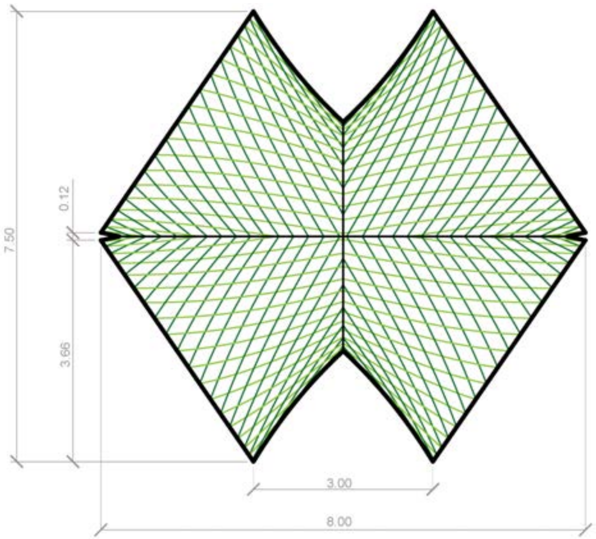


Fig. 17 Plan of the asymtotic curves

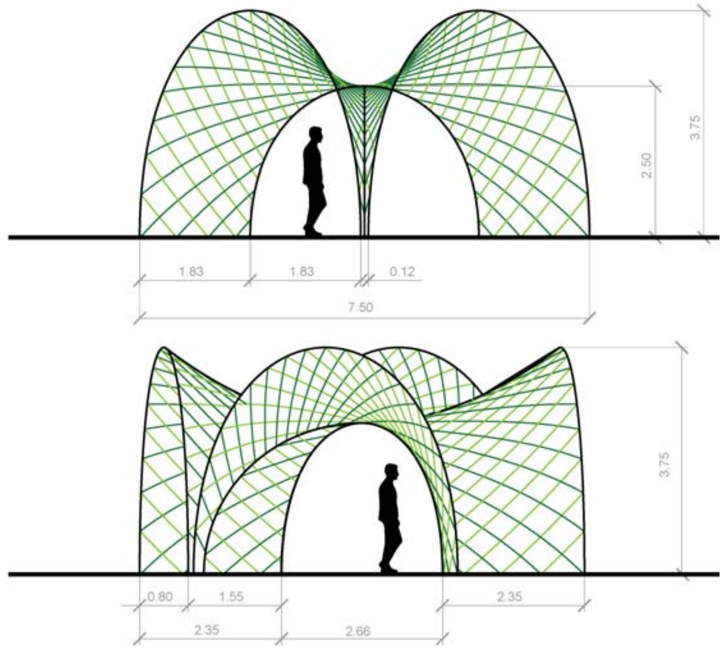


Fig. 18 Elevations of the asymtotic curves

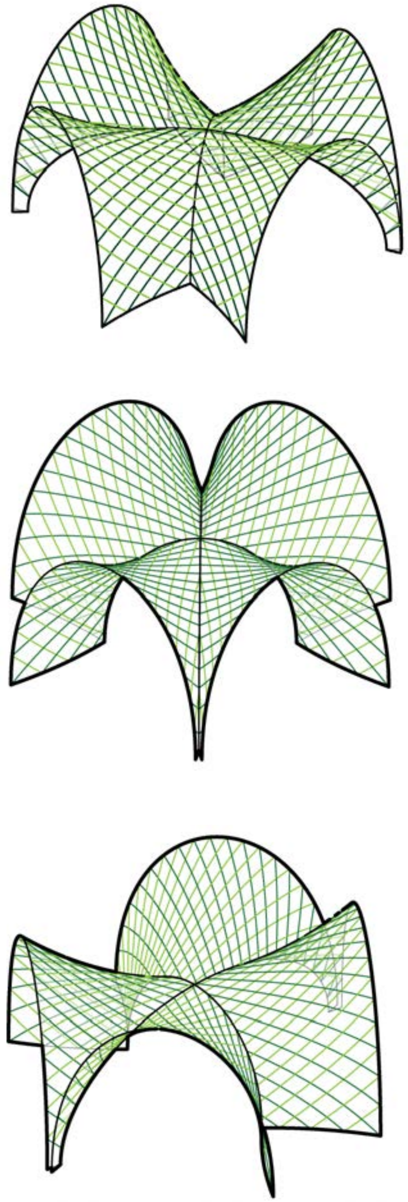


Fig. 19 Isometric of the asymtotic curves

SCENARIO DESIGN

Architectural Concept

The design is symetrical. The upward curvature at the openings welcomes the visitors to come in. It is like a butterfly in the garden, creating comfortable area for the citizens to have a rest or social. The beams at the edge and middle is thicker than the others, as it act as the frame of the grid shell. The bamboo pavilion is covered by canvas, which is cheap and waterproofing.

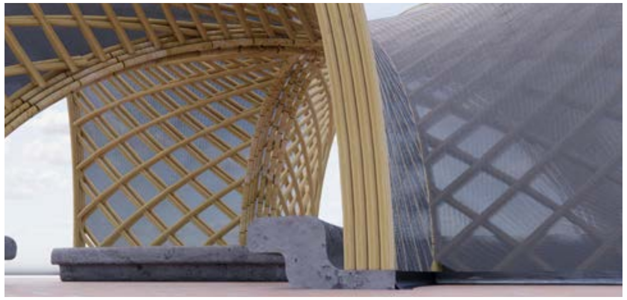


Fig 23 Render of the support

Fig 24 Render of the joints

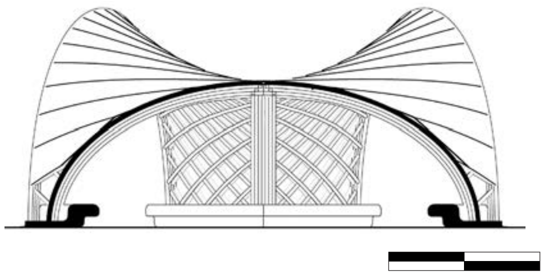


Fig. 22: Section 0 2 4m

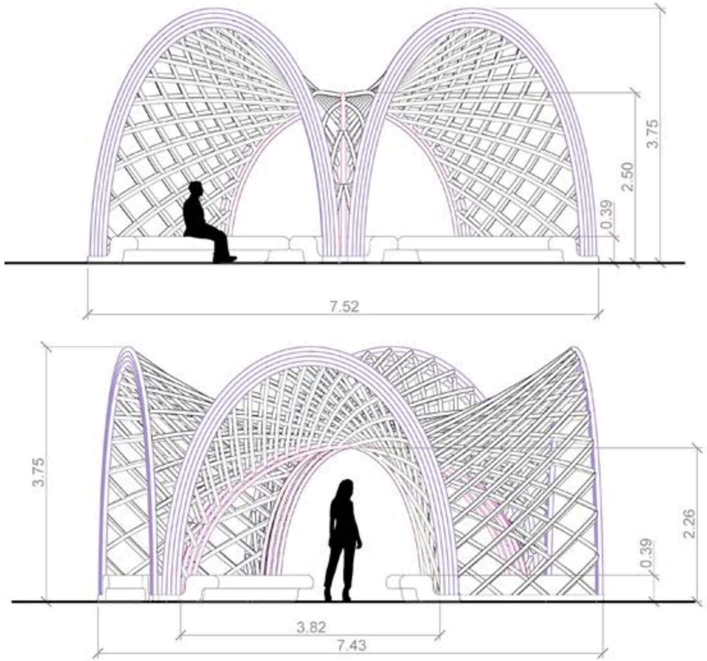


Fig. 20: Elevation of the bamboo shell

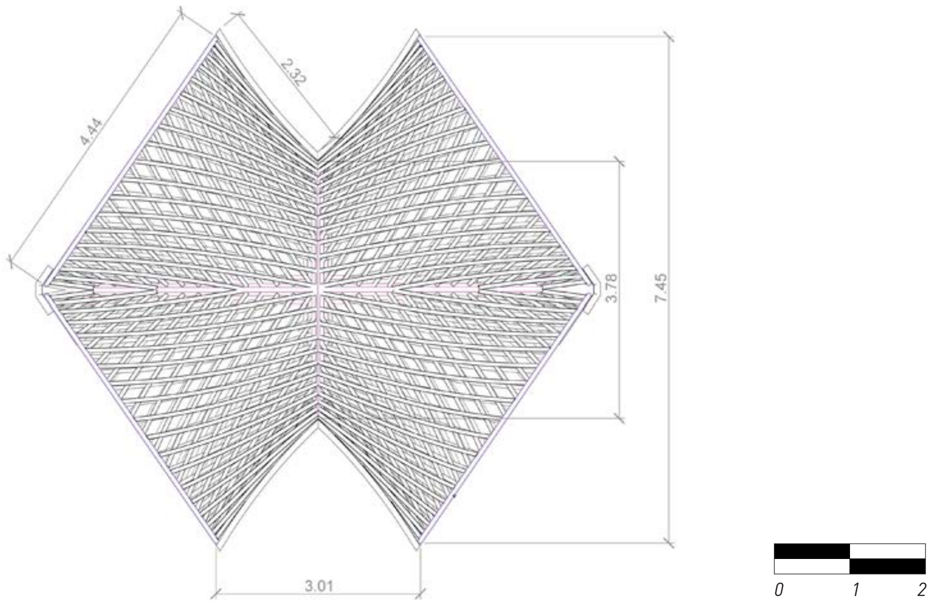


Fig. 21: Plan of the bamboo shell

0 1 2

Fig. 25: Render

Fig. 26: Render

DESIGN RESEARCH

Modular Shading Device
Lai Cheuk Yan, Joyce

PROJECT DESCRIPTION

Fig. 1: Exisitng project

Span
3 - 10 m

Material
Laminated Bamboo

Construction Method
2010

Target Group
Munich, Germany

KEY CONCEPT

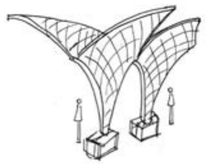


Fig. 2a: Concept sketches

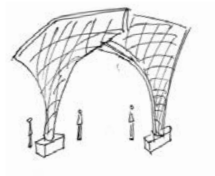


Fig. 3a: Concept sketches

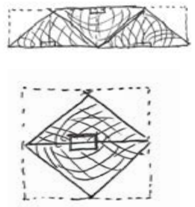


Fig. 2b: Concept sketches

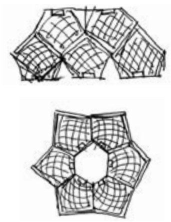


Fig. 3b: Concept sketches

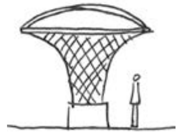


Fig. 2c: Concept sketches

Fig. 3c: Concept sketches

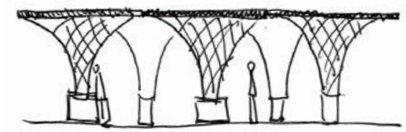


Fig. 3d: Concept sketches

Introduction

This design proposal aims to design a modular canopy structure for different waterfront promenade within Hong Kong. Nowadays, most of the park canopy in Hong Kong is built with heavy steel structures in a simple design. They are all in repetitions and work as an individual device. [1]

However, in my scenario, I propose a modular system of a canopy, with the flexibility to adapt to various waterfront or park destinations. While it could achieve a different layout, it could be interpreted differently to extend its uniqueness as a site-specific canopy.

Option Scenario (triangular):

Span:
3-10 m
Smooth grid

Material:
Steel Stripes
Steel Joints

Functions and Context:
Local parks benches
Bus stop waiting area
Pavilion for picnic area
Pavilion for BBQ area
Shading device for water-front promanade

Construction Method:
Started with flat square grids, and lift the structure up to articulate the form, fixed the construction with the edge structure and joints connection to hold the overall form.

Potentials

The repetition in materials could re-duce costs and increase structural efficiency. Steel Stripes and joints could be easily prefabricated. The design ideas are to use the triangular or pentagonal top plane to create repetitive modular. The repetition of the tree structure could contain flexibility for various layout, able to adapts to extensive destinations. [2], [3]

Target Group:
Canopy For Outdoor Leisure Space as shading devices

Case Study 1: Canopy for the Hotel Intergroup in Ingolstadt

Type:
Canopy

Location:
Ingolstadt, Germany

Year:
2019

Status:
Construction completed

Planning Team:
Eike Schling, Jonas Schikore
Partner: Brandl Metallbau, Eitensheim

Functions

This project is a Asymptotic grishell canopy designed for the hotel entrance. It is constructed with steel and a smooth structure. [6] The fabrication of the stripes and joints are repetitive components, which benefits the construction method by being efficient and environment-friendly. [4], [5]

Fig. 4: Outside view

Fig. 5: Inside view

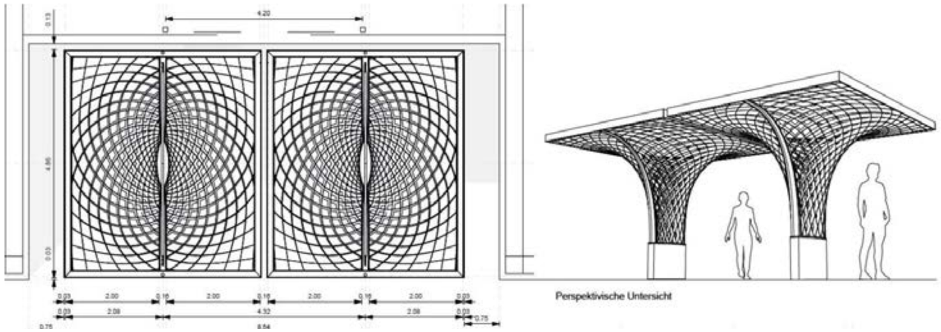


Fig. 6: Structural reference, typical joints and supports

Case Study 2: Aldrich Bay Park

Architect :
Architectural Services Department

Location :
Sai Wan Ho, Hong Kong

Client :
Leisure and Cultural Services Department, HKSAR Government

Project Type :
Leisure and Cultural

Completion Year :
2011

GFA :
Approx. 22,000 sq m

Functions

The composition of the gridshell are conducted with a repetitive organisation, which would be benefitial on fabrication of the materials and construction. [7], [8]

Fig. 7: Outside view

Fig. 8: Inside view

Fig. 9: Supports and design implication

REFERENCES

Case Study 3: Proportion and dimensions on different canopy and benches

Type:
Canopy
Benches

Functions

By taking consideration on the proportions and dimensions of these canopy and benches, it helps on creating an effective device for my design proposal. The Design would need to contains at least 2000mm deep in order to act as a sun shading and rainscreen, while the benches are designed to fit for 4 users at once, the benches also need to fit for the human proportion.[10,11,12]

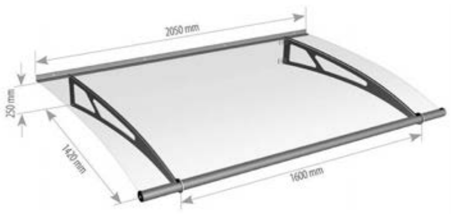


Fig. 10: Outside view

Fig. 11: Section

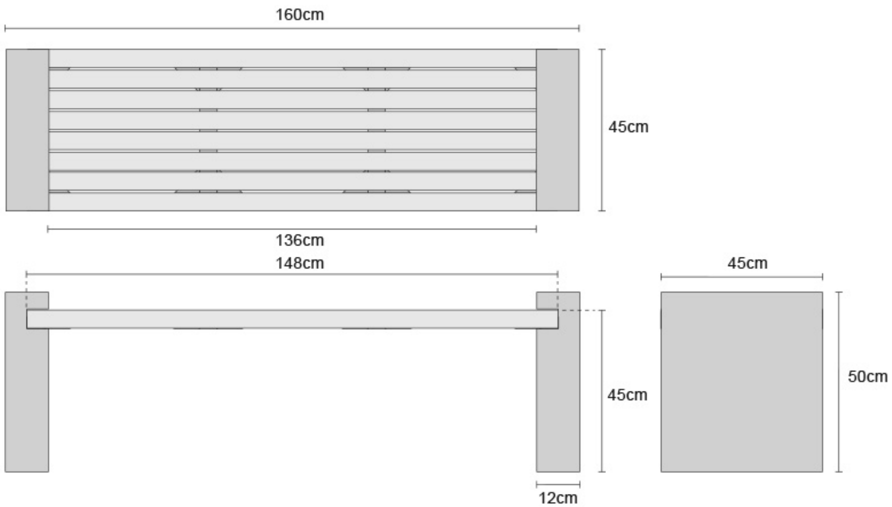


Fig. 12: Supports and design implication

CONSTRUCTION DEVELOPMENT

Typical Joint

Impermant Joints are used at the intersections of the lamallas when it is in construction procceses. the joint fixtures need to be removed when the edge support are positioned in place. [14] Therefore, the prefebricated slots on the lamallas allow the constructure to be stable and durable by interlocking at the iintersections [13]

Fig. 18: Photo

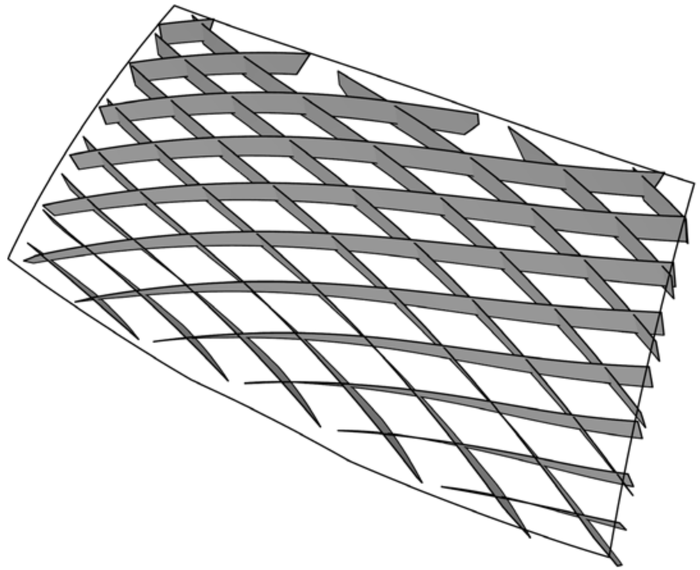


Fig. 13a: Axonometric of typical joint

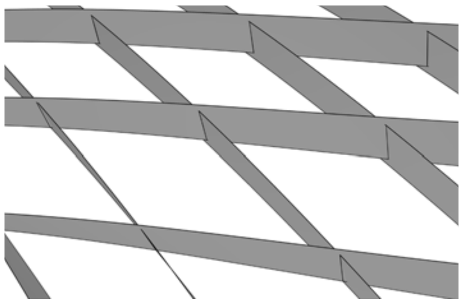


Fig. 13a: Zoom-in of typical joint

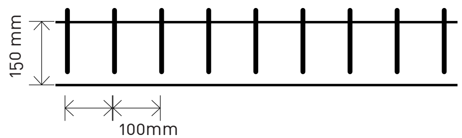


Fig. 14: Detail of typical joint

Typical Support

The slots on the strips are matched at the slots on the support edge, therefore the lamellas could stay at the proper spot. [16] A second layer of the edge support is added as the outer surface to cover the extentions of the lamallas. Therefore, it could hold the curvature shapes and achieving a cleaner surface. [17]

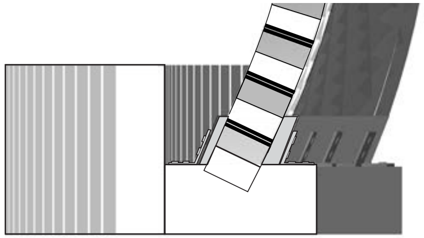


Fig. 18: Detail of the edge support

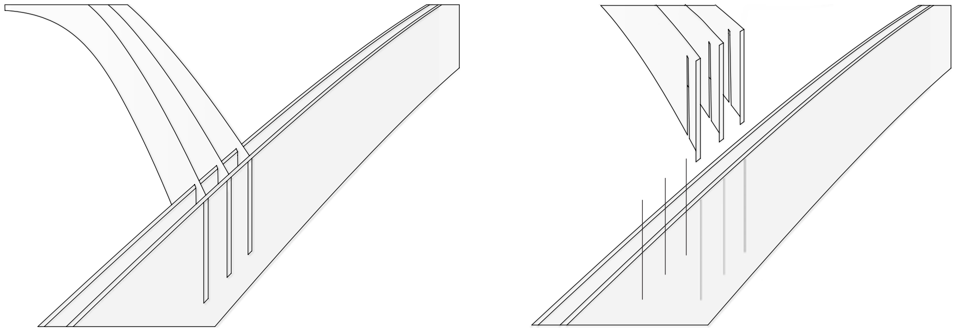


Fig. 15: Axonometric of typical support

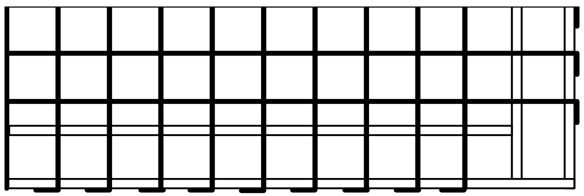


Fig. 16: Detail of typical support- plan

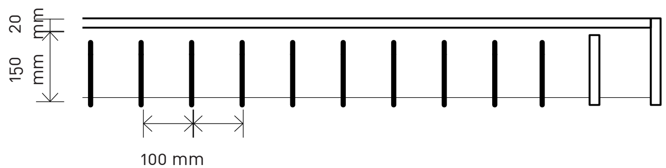


Fig. 17: Detail of typical support- section

Constructions Materials

The construction materials are mainly in 3 categories, simple and useful to be pre-fabricated. It could reduce the construction cost and being environmental friendly compared to the other shading devices in HK [19], [20], [21]

Fig. 19: Edge support

Fig. 20: Lamella

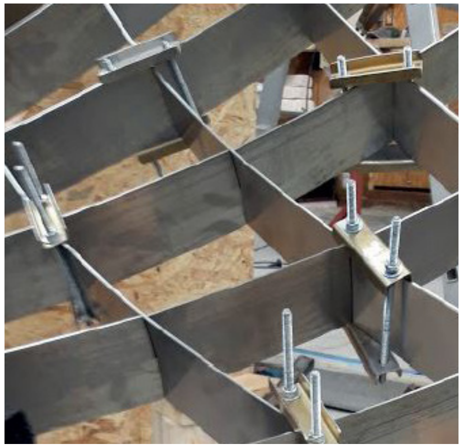


Fig. 21: Lamella impermanent fixtures

CONSTRUCTION DEVELOPMENT

Construction Process Reference

Considering this construction process as a reference, they started building the canopy with the flat square grids, [22a]. They lifted the structure to articulate the form, [22c] fixing the construction with the edge structure and joints connection to hold the overall form. [22g] Therefore, this understanding is applied to develop the construction considerations and procedures of the design proposal on the next page.

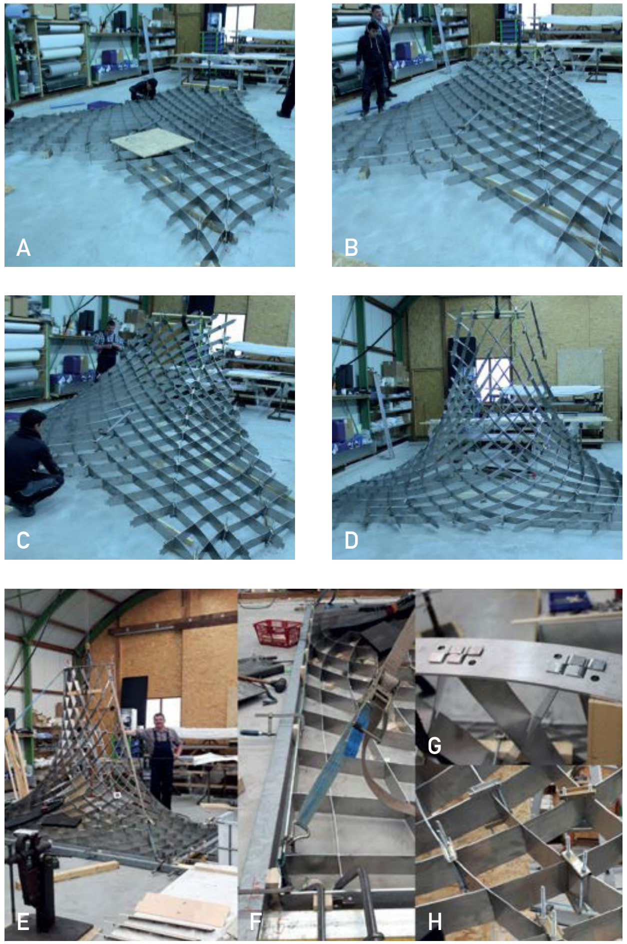


Fig. 22 [A-H]: reference construction process

SCENARIO DESIGN

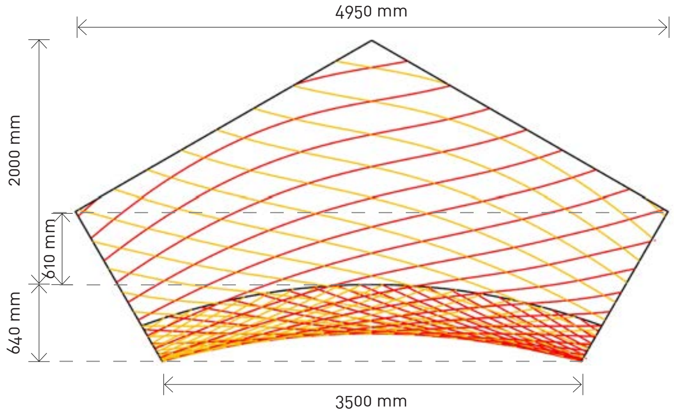


Fig. 23: Surface plan

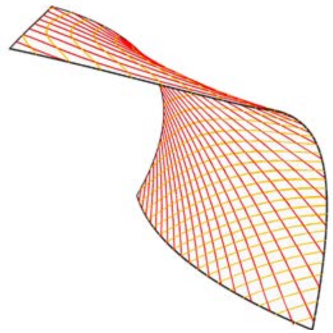


Fig. 24: Surface perspective

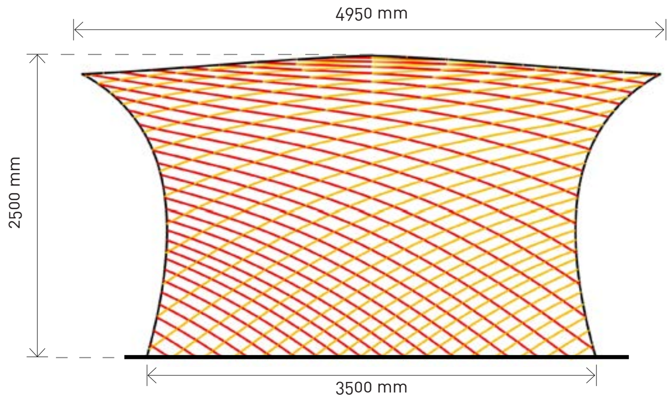


Fig. 25: Surface elevation

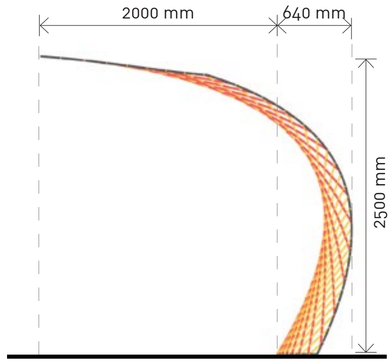
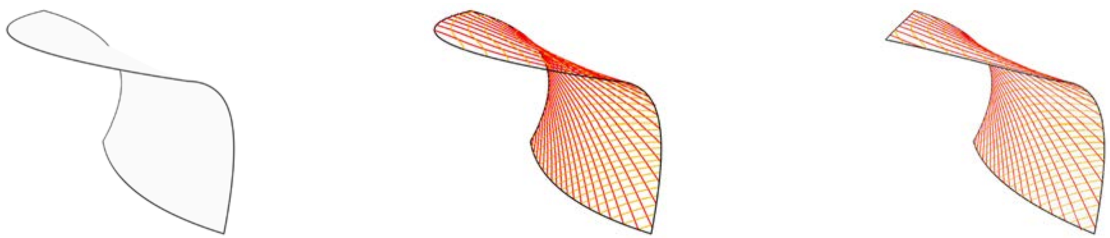


Fig. 26: Surface elevation

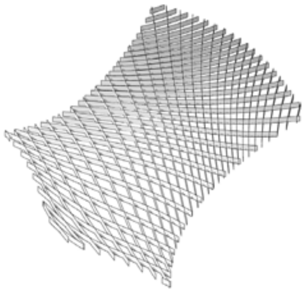


[a] Surfaces arching up to 2500 high, to achieve an appropriate height

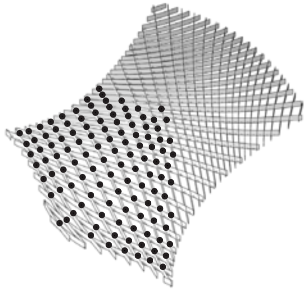
[b] The top extended horizontally with at least 2000mm deep to act as a rain screen and sun shading device

[c] Trimmed the overall network with a pentagonal top plane for the design intension, to achieve varies layout

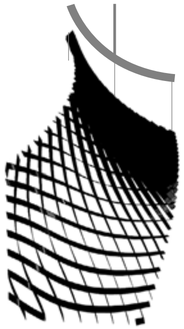
Fig. 27: System forming proccess- surface to grid network



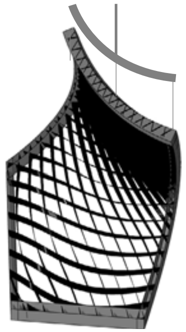
[a] Flat grid network constructed with lamellas



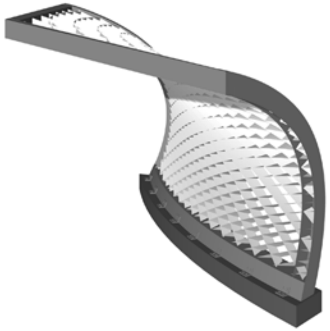
[b] Hold the grid system with impermanent joint at the intersection point



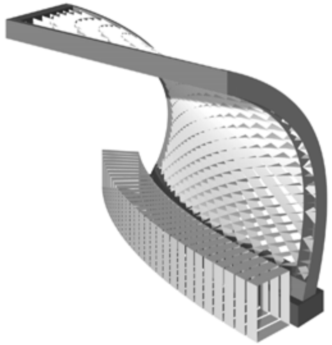
[c] Lift up the grid network into form



[d] Fix the ideal form with double layers of edge support



[e] Gridshell canopy formed, the gridshell structure would connected to the concrete block, hold with steel plate to sit still



[f] Sitting bench designed with steel stripes could be installed base on customers preferences

Fig. 28: Proposed construction process

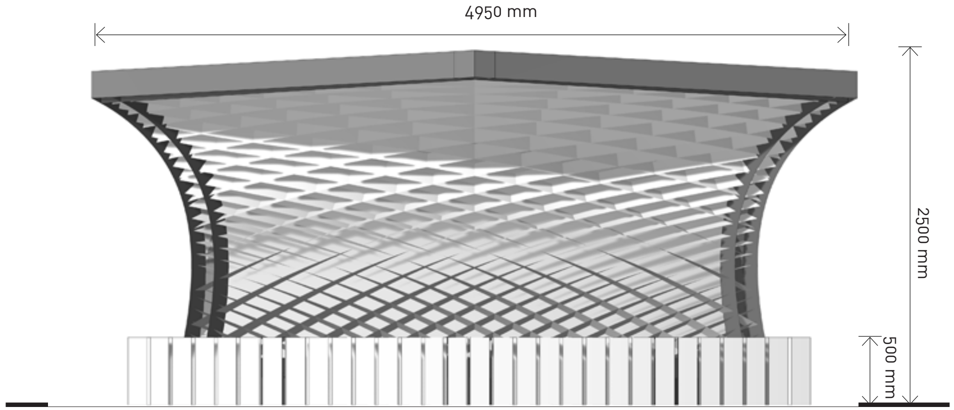


Fig. 29: Design elevation

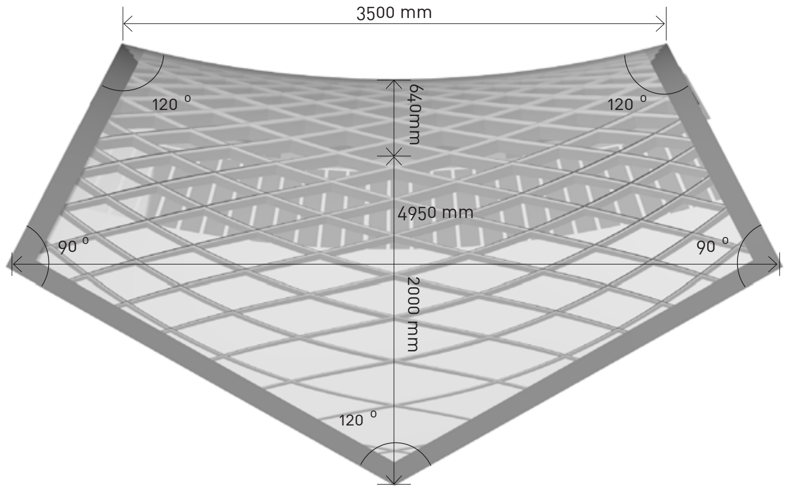


Fig. 30: Design plan

Under the constructional considerations: lamellas are in 150 mm width, while the support edge would be in 200 mm to cover the interlocking differences differences.[30] The proportion of the bench are designed ideally to fit three users at once. [29]

Design Scenario (Pentagonal):

Span:
3-10 m, Smooth grid

Material:
Steel Stripes , Steel Joints, Steel Support edge

Target Group:
Canopy For Outdoor Leisure Space as shading devices

Architectural Concept

The Repetition in materials could reduce cost and increase sturctural efficiency. Steel Lamallas and joints could be easily prefrabricated, enhace the frabrication efficiency. [31] ETFE membrane attched on top for water proofing. [33]

The design ideas is to use of the pentagonal top plane to create repetitive modulars. The repetition of the tree canopy structure contians flexibility to achieve serveral layout, either to form a shaded corridoor, back to back or in circular layout. [34]

The Bench could be install or remove base on different preference, it is in steel stripes design to response a similar logic of the gridshell. [33]

While most of the canopy design in hong kong are in boring repititions format. This design could use the same modular system to achive wide range of variations. Fits for different destinations, but still contain its uniquness as a site specific device, it is the more efficeint to fiited into any waterfront or park or outdoor location in Hong Kong. [34]

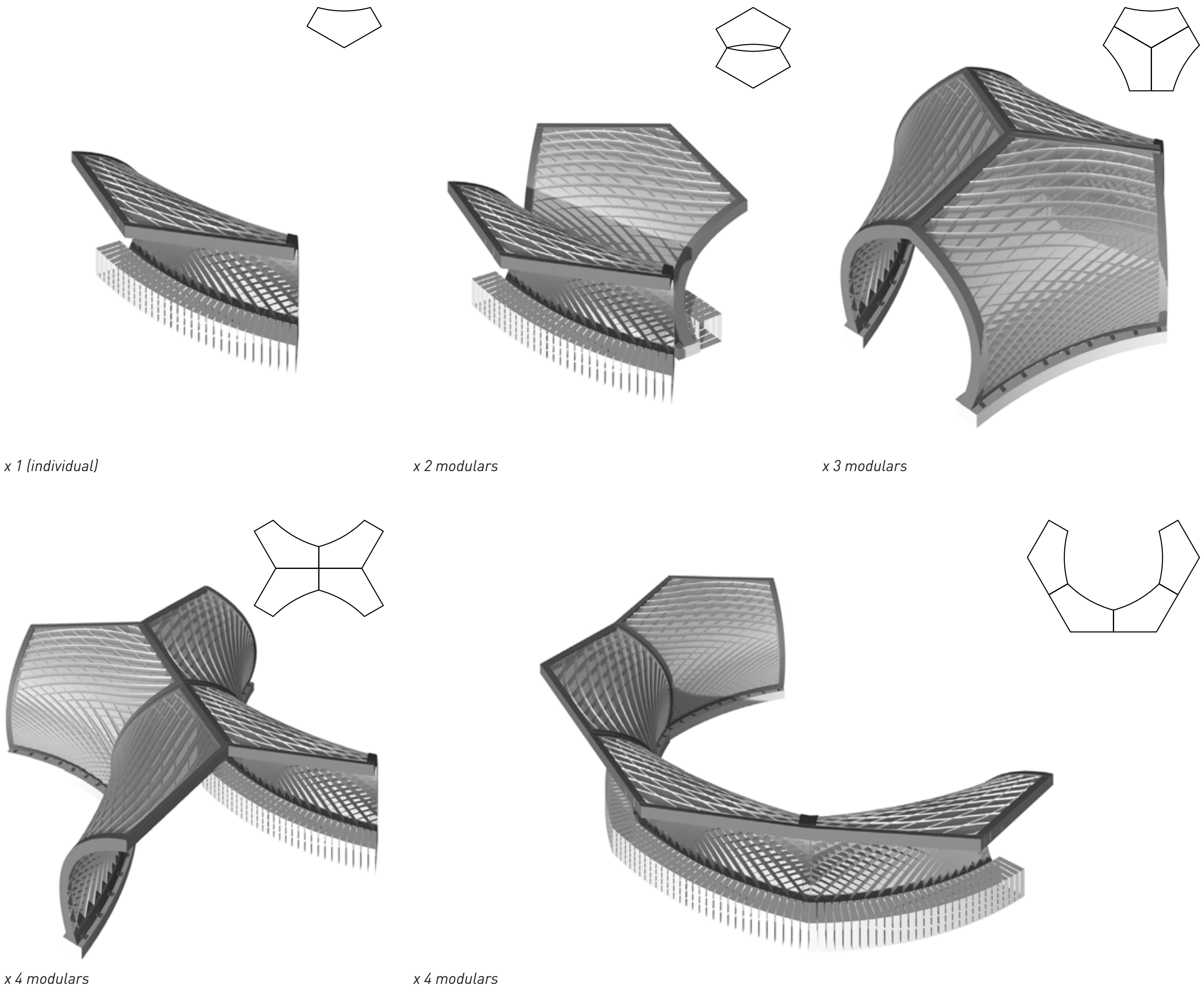


Fig. 34 Recommended pentagonal modular variations

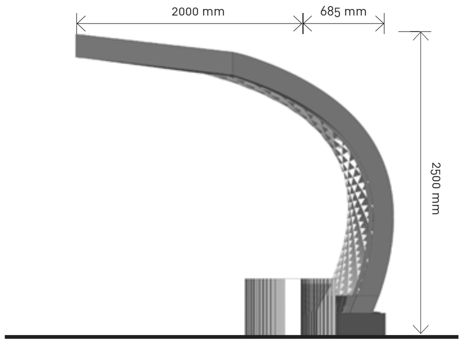


Fig. 31: Design elevation

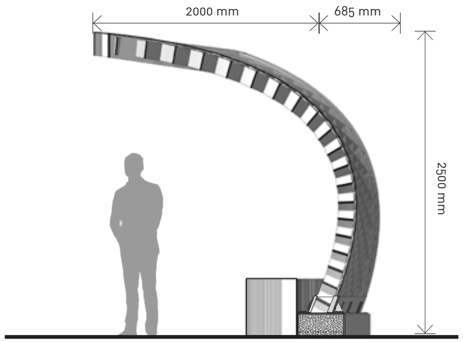


Fig. 32: Design section

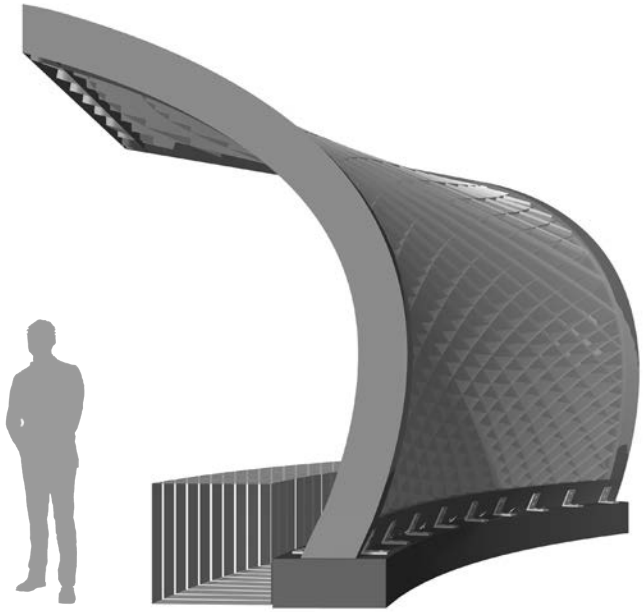


Fig. 33: Design perspective view

Design proposal with bench in-stalled, ETFE membrand attached to the edge support for water proofing

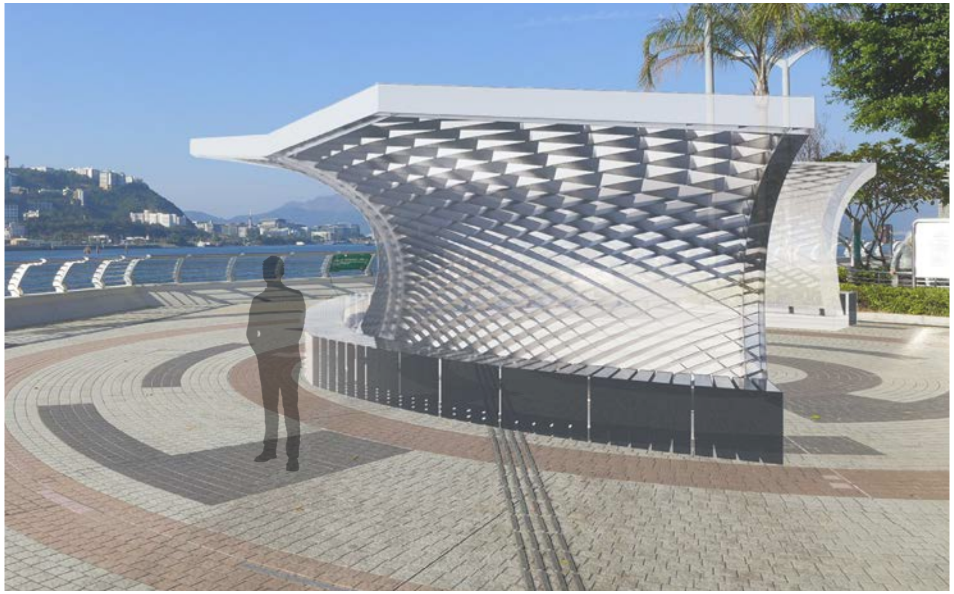


Fig.35 Rendering- design shading modular fitted to various site

Fig. 36 Rendering- design shading modular fitted to various site

DESIGN RESEARCH

Asymptotic Concrete Formwork
Gyuhyeon Choi

SCENARIO PROPOSAL

Fig. 1: Current typical concrete construction and innovative construction method by Block Research Group

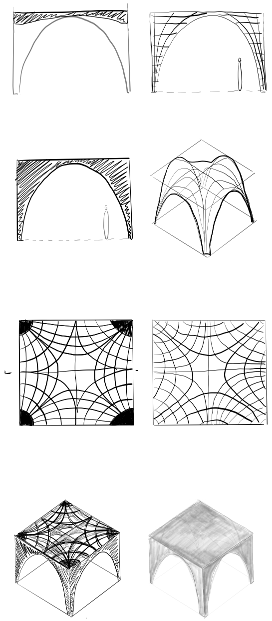
Span
10m

Material
Reinforced Concrete

Construction Method
Smooth Elastic Gridshell with Fabric formwork

Target Group
New Structural Skeleton

KEY CONCEPT



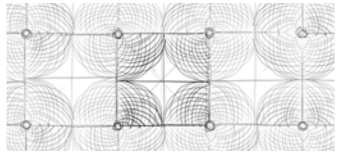


Fig. 4: Plan Sketches

Fig. 5: Section Sketches

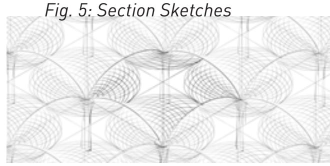


Fig. 6: Axonometrie Sketches

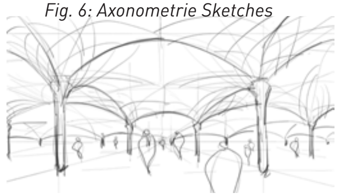


Fig. 2 & 3: Initial proposing skeches

Fig. 7: Perspective Sketches

Introduction

Urban context of Hong Kong, with various highrises, production of architectural skeleton has been developed to fasten the construction, prefabrication. Usage of bamboo has also allowed environmental friendly way reusing formwork for building constsruction, yet having slow construction speed.On the other hand, asymptotic gridshell can be prefabricated, constructed easily flat on ground, shaping into desired shape, then requires minimum formworks to create structure, due to its resuability. Double curvature allows strength to the structure, while minimizing the material use, while introducing another interest to the building structure.

The gridshell formwork could fasten on-site construction of architectural skeleton, while using less concrete and minimum formwork and scafolding, yet strong and beautiful architectural skeleton for the buildings.

Challanges

There are few chanlleges to be solved, considering current methodology of on-site construction, also detailed construction procedures for the new possible method using gridshell.

First, is solving the complicated current on site construction methodology. While also solving the process of new the construction process of layering gridshell, fabric, reinforcement and concrete casting. Second, is finding a simple efficient and elegant shape for new possible concrete slab construction. Last, is finding a simple and efficient network for gridshell. While minimizing large void spaces for the gridshell, since it is the hollow parts are the weakest part of the structure.

Potentials

The benefits for asymptotic concrete structure, is to be possible to make thinner floor slab, that increased material and structural efficiency with reduce the cost. The repetition of the asymptotic lamella formwork can be easily prefabricated, with certain dimensions and length, and can also be reused.

The new proposing asymptotic concrete structure could bring efficiency in construction, bringing much simpler construction method. While it brings new elegant interior shape and experience to the current common rectangular structures. Shell structure is also structrually more stable and stronger than a typical flat slabs.

The asymptotic steel lamella and fabric formwork for concrete casting will be required. The asymptotic gridshell can be constructed flat on ground, pushed in desired position and shape, and can be repetively casted throughout the residential tower or other type of buildings.

Case Study 1: Heimberg Tennis Hall, Heimberg, Berne, Switzerland
Heinz Isler

Type: Roof
Year: 1978
Team: Heinz Isler

Architectural Concept

Heinz Isler is a Swiss artist-designer-engineer, who developed new concepts and methods for thin shell concrete structures, for efficient and sustainable design, that was emphasized during the time period of 1950s to 80s. He directed his efforts away from the mathematics of engineering and focused on the physical model, emphsizing on form and stability. With his studies of 3 types of formwork, molded earth, inflated rubber membranes, and draped fabrics. The studies of fabrics were the most interesting, because of the relationship between the fabric's capacity for tension and the concrete's capacity for compression. From the small scale model, the draped fabrics defined most effective structural curvatures, in tension, where Heinz applied the same curvature to concrete, by "frozing" the model with epoxy resins and flipping 180 degrees, there by putting the material into compression. [1]

Functions

The Heimberg Tennis Hall is still in service now, as an indoor tennis courts. The whole architecture is built with repeating modules on side of each modules. After completion of one module, reusing the same formwork for the next module, allowed economic, yet environmentally friendly method of construction.

Fig. 8: Outside view

Fig. 9: Inside view

Fig. 10: Timber formwork

Fig. 11: Reusability of timber formwork

Case Study 2: HiLo Construction Prototype for Ultra-Thin Concrete Roof
ETH Zürich

Type: Roof Shell
Year: 2017
Team: Block Research Group lead by Philippe Block & Arno Schlüter

Architectural Concept

Thin shell roof that features a mesh-reinforced concrete and PU foam sandwich structure, with inner hydronic radiant heating and cooling system. Also, thin-film photovoltaic cells on the outside allows to generate more energy than it consumes. [2] Ultra-thin concrete roof is constructed using a prestressed, cable-net and fabric formwork. The shell has a thickness of 3-12 cm, 8 cm on average, features spans in the range of 6-9 m with its support on five 'touch-down' points with free edges along its entire perimeter. [3] Thin layer of concrete is sprayed through the carbon-fibre reinforcement onto the fabric formwork. Spraying concrete onto the fabric formwork, also gave pillowing effect under the structure, creating interesting shape ceiling in the interior. The node of the cables was designed to allow freedom for shaping the net, while allowing precise location and guidance for the placement of fabric and the reinforcement. [4]

Functions

Researchers from ETH Zurich have built a prototype of an ultra-thin, curved concrete roof using digital design and fabrication methods. The shell is part of a roof-top apartment unit called HiLo that will be built in 2020 on the NEST, the living lab building of Empa and Eawag in Dübendorf.

Fig. 12: Outside view

Fig. 13: Inside view

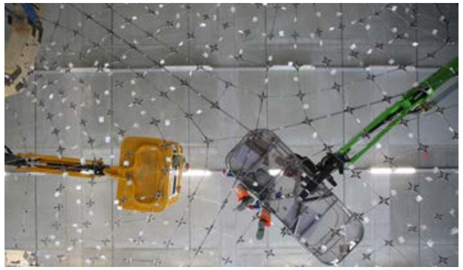


Fig. 14: Typical joints

Fig. 15: Joint nodes

REFERENCES

Case Study 3: Hybrid Structural Skin-prototype of an elastic gridshell in composite material, braced by a thin fiber-reinforced concrete envelope
Lionel Du Peloux, Pierre Cuvilliers, Cyril Douthe, Robert Le Roy (École des ponts ParisTech)

Type: Roof Shell
Year: 2017
Team: Lionel Du Peloux, Pierre Cuvilliers, Cyril Douthe, Robert Le Roy

Architectural Concept

The main idea is to use the gridshell as a hanger for pouring a thin fiber concrete casing over it. A mechanical connection is ensure between the mesh and the concrete to allow the envelope to play the role of bracing on the one hand; and minimizethe thickness of
concrete required on the other hand.

Functions

This idea tries to solve the issues through a concept of a hybrid structural skin made of an elastic gridshell braced with a concrete envelope. The idea is to use the gridshell as a formwork for the concrete and to guarantee mechanical connection between the thin concrete skin and the main grid, so that the concrete ensures the bracing of the grid and that the thickness of the concrete is reduced to a minimum. To demonstrate the concept, a 10 m^2 prototype has been built. [5]

Fig. 16: Outside view

Fig. 17: Construction process

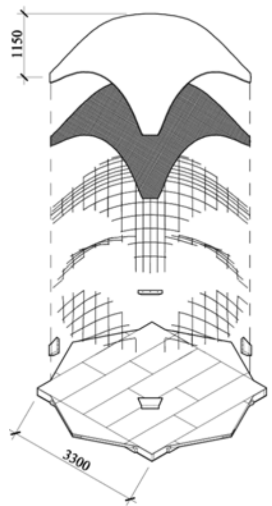


Fig. 18: Structural details

CONSTRUCTION DEVELOPMENT

Typical Joint

For the strength of the structure to allow withstand the load of concrete casting on top, steel lamelas are used. The intersection of lamelas should be easily joined, since it will only be temporary formwork, and to fasten assembly on the ground. Prefabricated steel lamellas with slits allowing easy assemble as waffle, then steel plates and bolts, but allowing flexible horizontal movement.

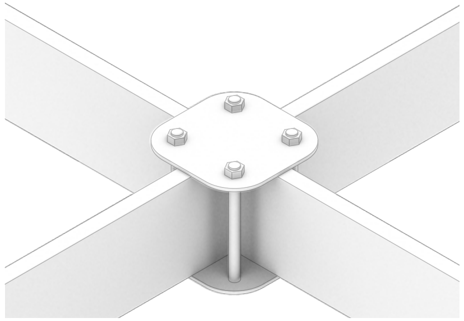


Fig. 19: Render

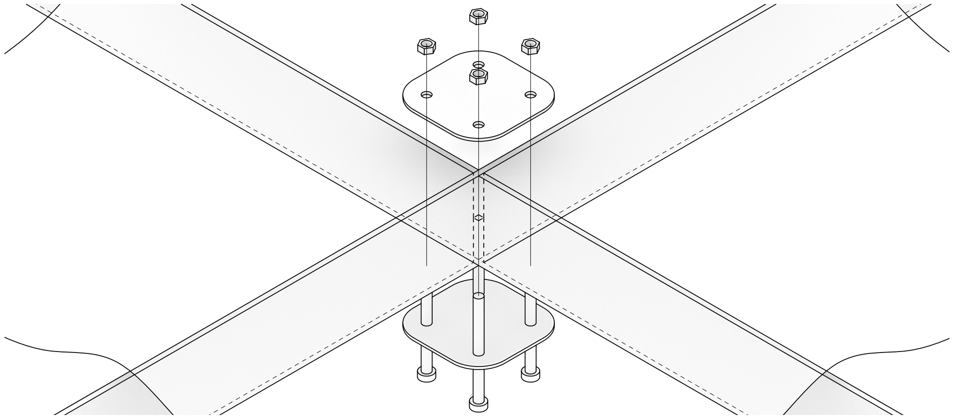


Fig. 20: Axonometric of typical joint

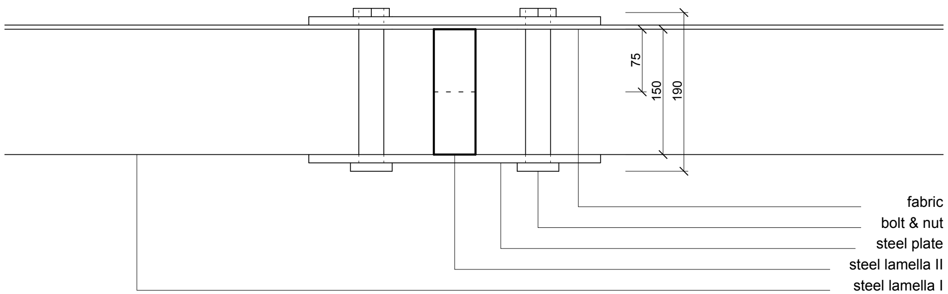


Fig. 21: Detail of typical joint

Typical Support

Asymptotic gridshell is held up on the column, that the concrete shell will be jointed and to be casted with the column. The support for the gridshell is part of the overall skeleton of the architecture.The steel lamellas will be inserted into the slots, fixed with simple connection, since the gridshell will be taken down after the concrete casting, for next module.

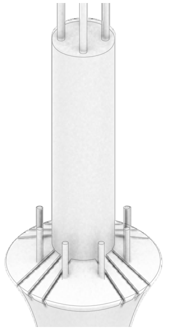


Fig. 22: Render

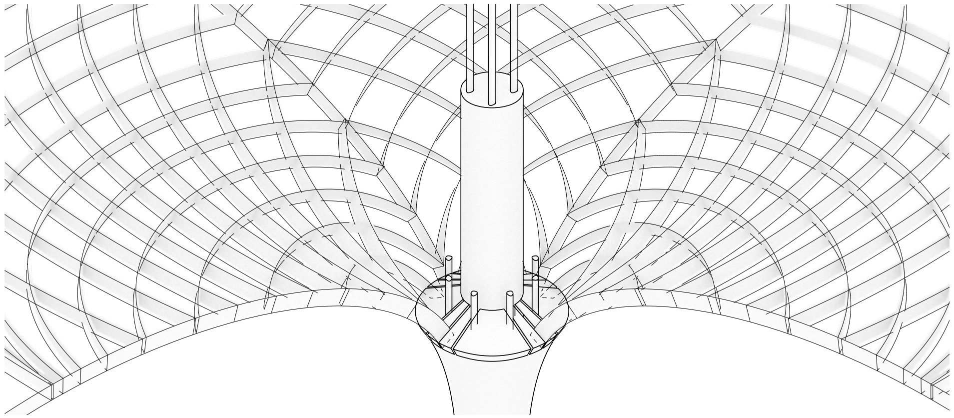


Fig. 23: Axonometric of typical support

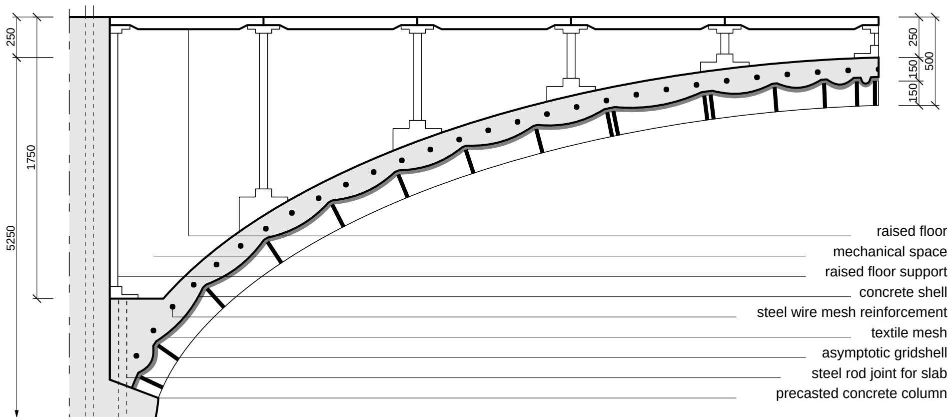


Fig. 24: Detail of typical support

Construction

The construction of the shell should be fast and easy, concept of modules. Gridshell performs as formwork for the concrete shell casting. The gridshell will be taken down after the concrete is dried, repeating the process throughout the building will fasten the construction process. Later, raised floor supports will be positioned, with raiased floor tiles, for flat ground to inhabit.

Construction process

1. Prefabricated columns with steel rod will be positioned.
2. Assembling the gridshell, flat on ground, joined with simple joint of steel plate and bolt and nuts.
3. Gridshell held in shape and position on the column, with cross scaffolding in the centre, for positioning and stability.
4. Layering fabric mesh for the formwork, and steel wire for the reinforcement for the concrete casting.
5. Spraying concrete with even thickness. concrete slab will be joined to columns via steel rods on the column.
6. After the concrete as settled and dried, gridshell can be disassembled, for the next module.

Fig. 25: Render of concrete shell

CONSTRUCTION DEVELOPMENT

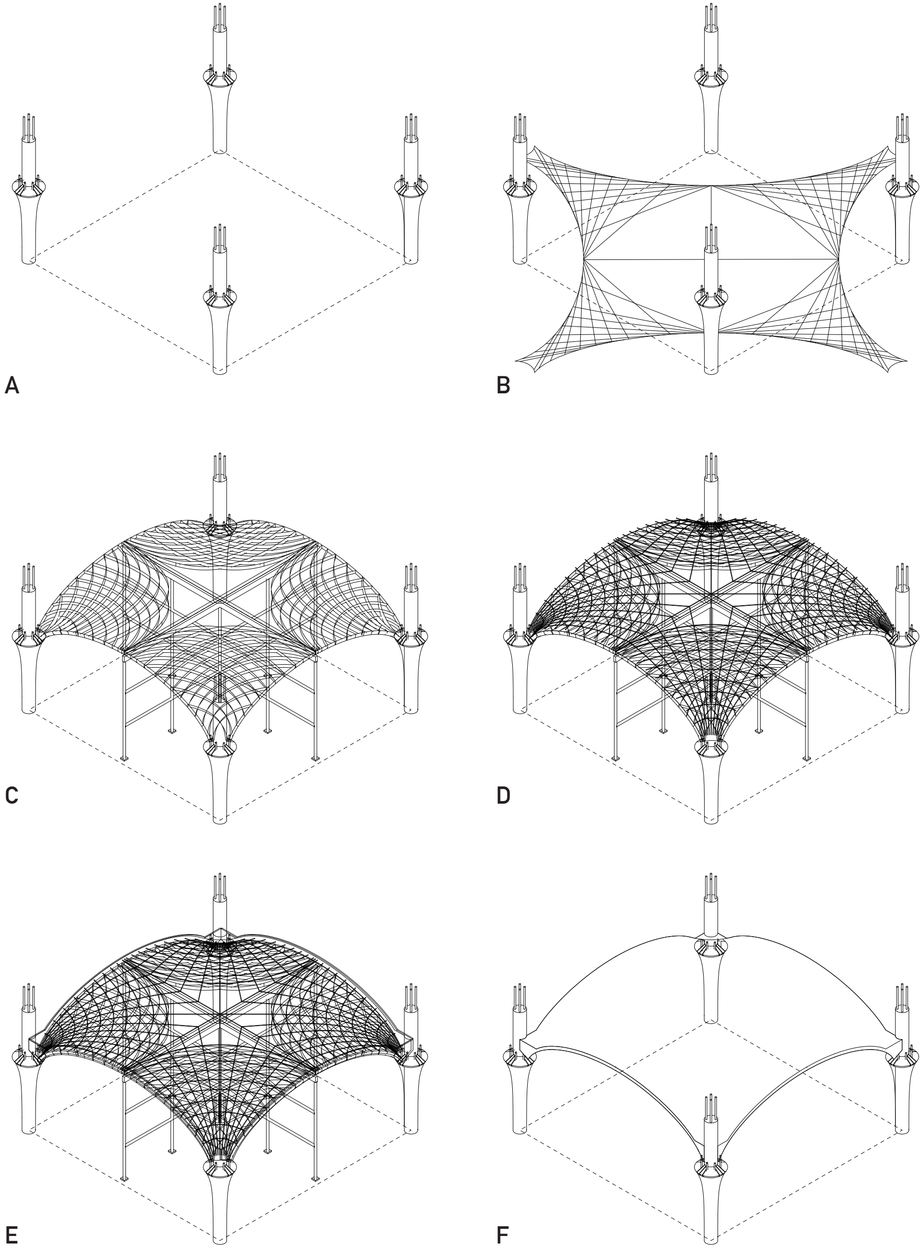


Fig. 26: Construction process A, B, C, D, E, F

SCENARIO DESIGN

Site

Main approach of this research is to explore new building structure, with lighter structure and easier and faster construction. Given this research approach, the site could be anywhere with a land for a new building. In an urban context of Hong Kong, this research could propose a new building skeleton for residential housing, office building, and industrial buildings.

Design Concept

The formfinding process is the combination of two crossing vault structure, then smoothening intersecting boundaries to create negatively curved surface.

The concept for the light concrete slab has two different parts. First, the asymptotic grid and fabric form work allows efficiency in time and material. The formwork could be assembled on the ground, with fabric attached, then pushed up to designed shape and move to desinated place for concrete casting process. Second, double-curved shape of slab allows stronger and lighter structure for the buildings. The module in 10m x 10m, allows repetition of the system, looking for new possible structural system for the buildings.

Functions

This light weight concrete slab suggests new structural system, which could be implemented for various type of buildings: residential, office and industrial buildings . This system of new structural skeleton can be scaled differently in span and height, to allow suitable structure for different programmes.

5m x 5m in span and 1m in height for residential, every module could be a housing unit, and allowing flexible housing planning. 1m of concrete shell and 2m of column will be efficient height for residential housing. Also, the raised floor could be used for electric wires for air conditioning and lightings on the ceiling.

10m x 10m in span and 2m in height for office buildings, allows bigger column free space for greater people working in the office. 2m height of concrete shell and 2m of column height will allow suitable raised floor for electrical wires in the offices. 20m x 20m in span and 5m in height for industrial buildings, will have deeper concave for structural stability, while allowing greater interior space for machines and manufacuturing use, and bigger service space between the raised floor and concrete shell.

Fig. 27: Site plan

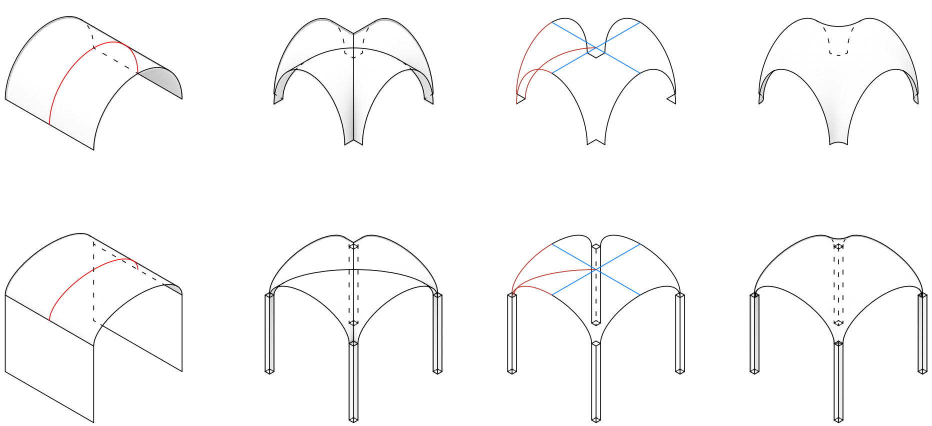


Fig. 28: Form finding process and design concept

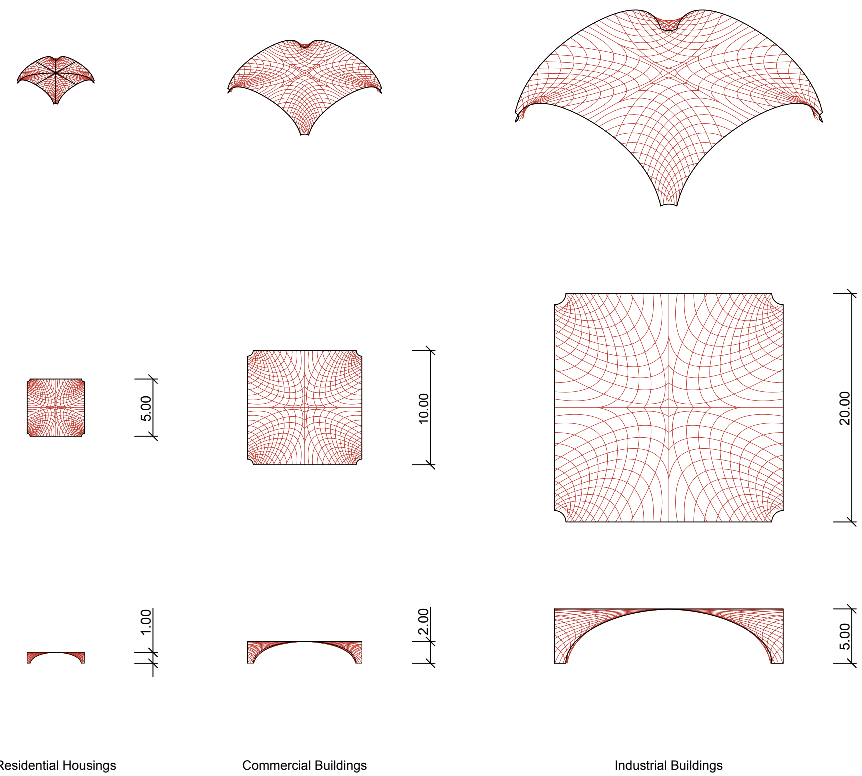


Fig. 29: Design flexibility for residential, office, industrial buildings.

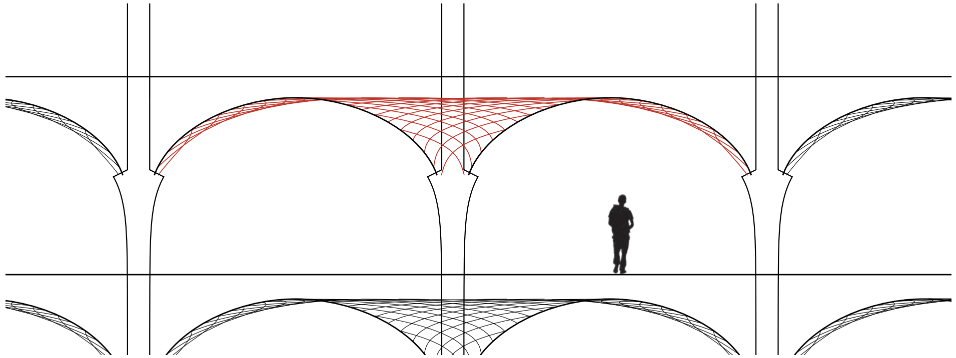


Fig. 30: Diagonal section of office building type

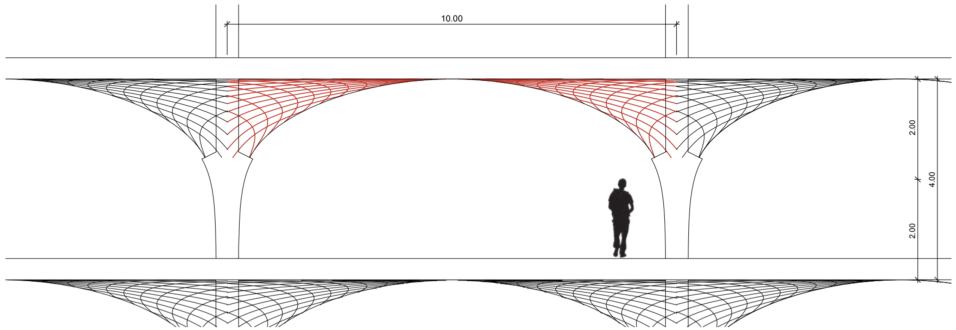


Fig. 31: Elevation of office building type

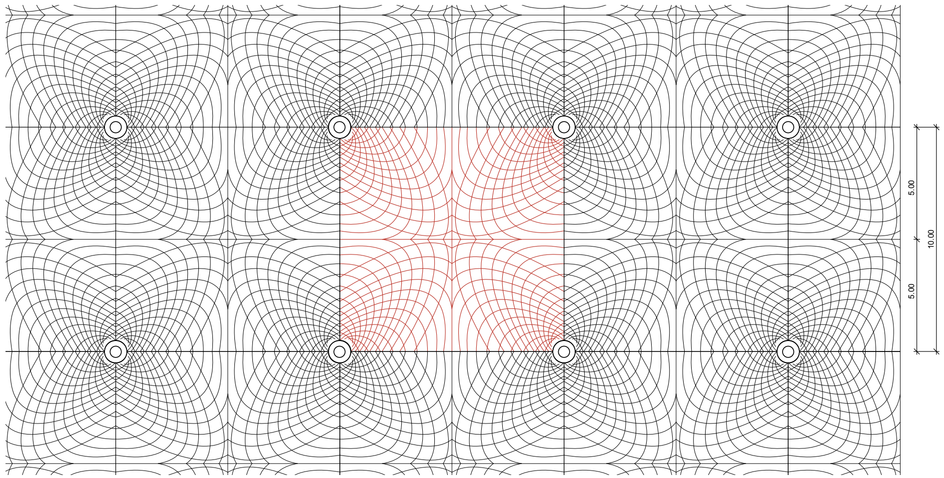


Fig. 32: Plan of office building type

Architectural Concept

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Fig. 33: Axonometric of residential building type

Fig. 34: Interior rendering of residential building type

Fig. 35: Interior rendering of office building type

Fig. 36: Pattern on ceiling

Fig. 37: Exterior rendering of residential type

Fig. 38: New structural skeleton for concrete jungle

Summary

The new possible structural skeleton for concrete structure can allow increased efficiency in construction, while also imposing strong gesture to the interior of the building. The gridshell takes its structural advantage of easy and fast assembly, minimal formwork, stability and strength. The gridshell formwork could allow stronger structural system, fasten on-site construction, while minimizing the use of resources.

Bibliography

[1] Edward M. Segal. Final Report: 2008 SOM Structural Engineering Travel Fellowship. 2010. 28-31. https://somfoundation.som.com/repository/files/submissions/ted.segal_.final_.report.pdf

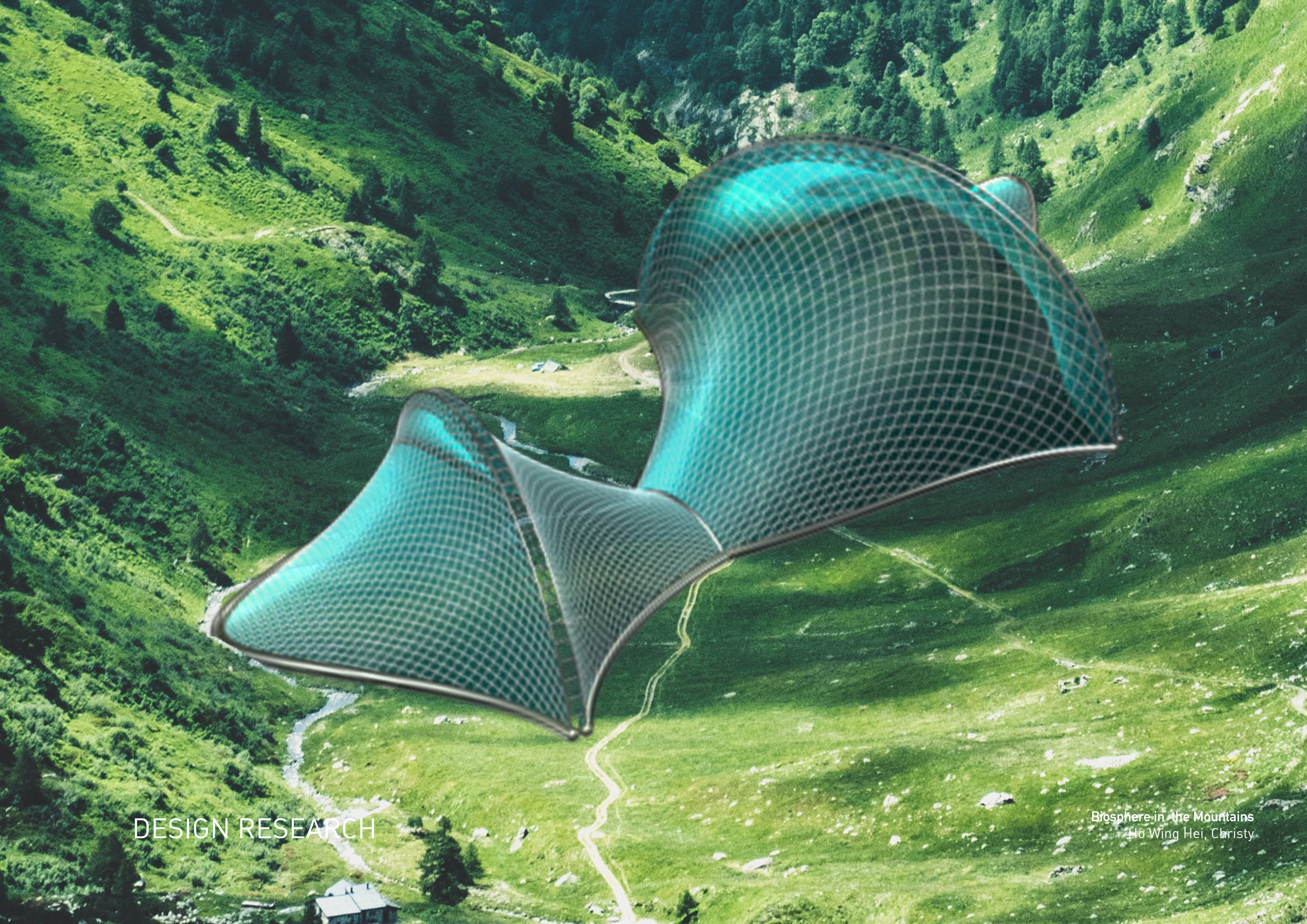
[2] ETH Zürich. NEST HiLo. https://systems.arch.ethz.ch/research/synergistic-buildings/nest-hilo.html

[3] Block, P. & Schlueter, Arno & Veenendaal, Diederik & Bakker, J. & Begle, M. & Hischier, Illias & Hofer, Johannes & Jayathissa, Prageeth & Maxwell, Iain & Echenagucia, Tomás & Nagy, Zoltán & Pigram, Dave & Svetozarevic, Bratislav & Torsing, R. & Verbeek, J. & Willmann, Anja & Lydon, Gearoid. (2017). NEST HiLo: Investigating lightweight construction and adaptive energy systems. Journal of Building Engineering. 12. 10.1016/j.jobe.2017.06.013.

[4] Block Research Group. Full-scale construction prototype of the NEST HiLo shell roof, 2017. https://block.arch.ethz.ch/brg/project/full-scale-construction-prototype-nest-hilo-shell-roof

[5] Lionel Du Peloux, Pierre Cuvilliers, Cyril Douthe, Robert Le Roy. Hybrid structural skin: prototype of an elastic gridshell in composite material, braced by a thin fiber-reinforced concrete envelope. 2017. https://edisciplinas.usp.br/pluginfile.php/3490160/mod_resource/content/1/Jiass_2017_vol58_no1_11_Cuvilliers_Hybrid-structural-skin-elastic-gridshell-fiber-reinforced-concrete.pdf

List of Figures



DESIGN RESEARCH

Biosphere in the Mountains
Ho Wing Hei, Christy

SCENARIO PROPOSAL

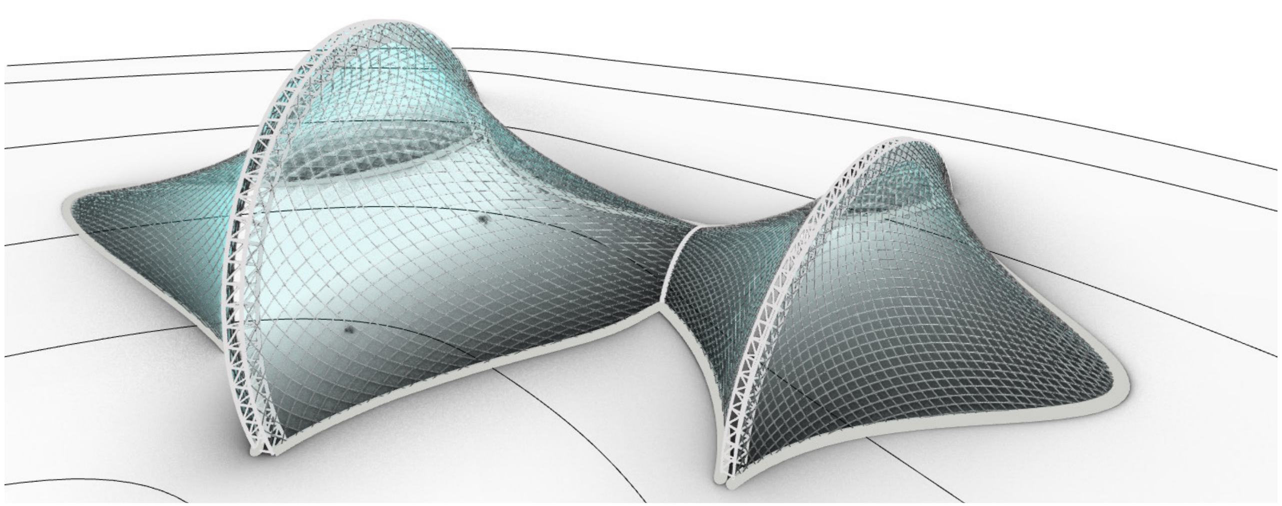


Fig. 1: Glass roof structure

Span
200 m

Material
Steel and plexiglass

Construction Method
Joint System

Target Group
General Public

KEY CONCEPT

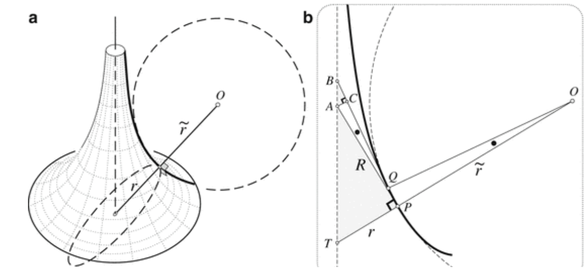


Fig. 2: Graph that psedosphere is derived from

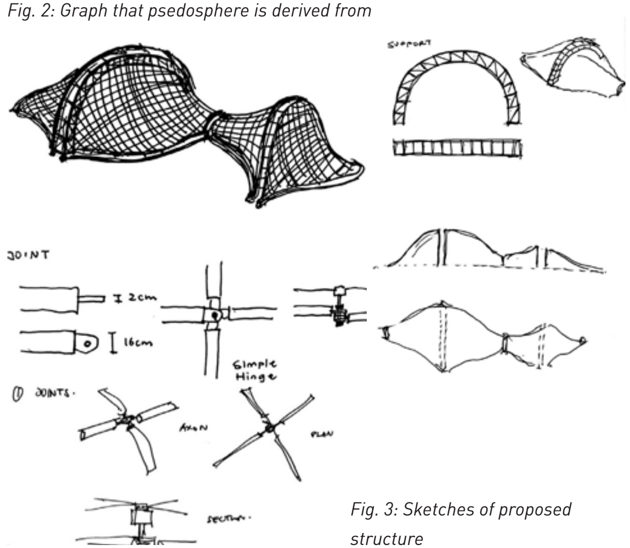


Fig. 3: Sketches of proposed structure

Introduction

After learning from the Munich Olympic stadium, I have decided to design a new roof structure that is beneficial for the construction process and fabrication process. In the design of the Munich stadium, they utilised a tensile structure with a layer of plexiglass on the top as the way of designing the roof. In my design

I want to design a large biosphere that is located on the mountains that utilises the shape of a pseudosphere to design a roof, and apply a layer of plexiglass on top to stop wind and rain from entering the structure. It will use a joint system that connects the 4 members.

It will be a public structure for anyone to enter and exit, and will act more as a spectacle on site due to its size. The material used will be steel since it is stronger and rigid in extreme weather conditions.

Challenges

A pseudosphere is a surface generated by constant negative Gaussian curvature and it revolves around an axis. It is generated by tractrix that is rotated along one axis, forming rings three dimensionally. The asymptotic curves of a pseudosphere has constant edge length, constant geodesic torsion, constant negative double curvature and zero normal curvature.

The challenge would be how to play with the restrictions given by a pseudosphere to construct a new roof that would be easier for construction of the roof.

Potentials

In terms of potentials of architectural construction, the line work of a pseudosphere can be constructed from straight tubes with joints that connect at the node. Each of the straight tubes are of the same length which allows for simplified fabrication of each of these steel tubes.

The shape restriction of a pseudosphere is not that much of an disadvantage since the quality of constant length makes the fabrication and constriction process much easier.

Network and Geometric Properties

A pseudosphere is formed by revolving a tractix of a certain radius around an axis to generate a surface. The structural network follows the asymptotic lines on this surface. These asymptotic curves. These are the curves that are traced on the surface that are tangent at each point to one of the asymptotic directions.

Modelling Process

1. 2 pseudospheres are placed adjacent to each other so they connect at the centre.

2. Instead of using the tractrix and its rings, the asymptotic lines of the pseudosphere are used to create a gridshell.

3. Since the site is slanted, half of the pseudosphere rotational surface will be beneath the site. This will be trimmed away.

4. The remaining part of the pseudosphere's network is used as a basis for structural design.

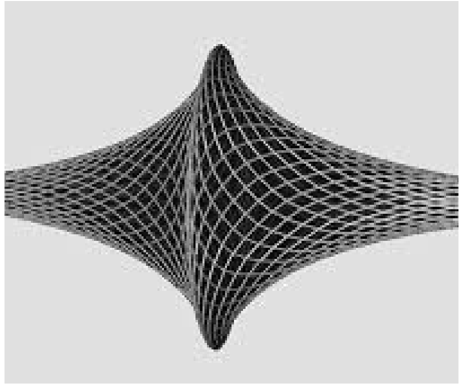


Fig. 4: Pseudosphere with asymptotic lines

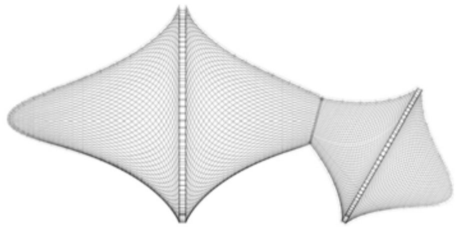


Fig. 5: Pseudosphere network

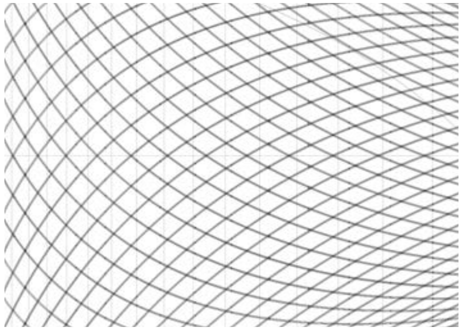
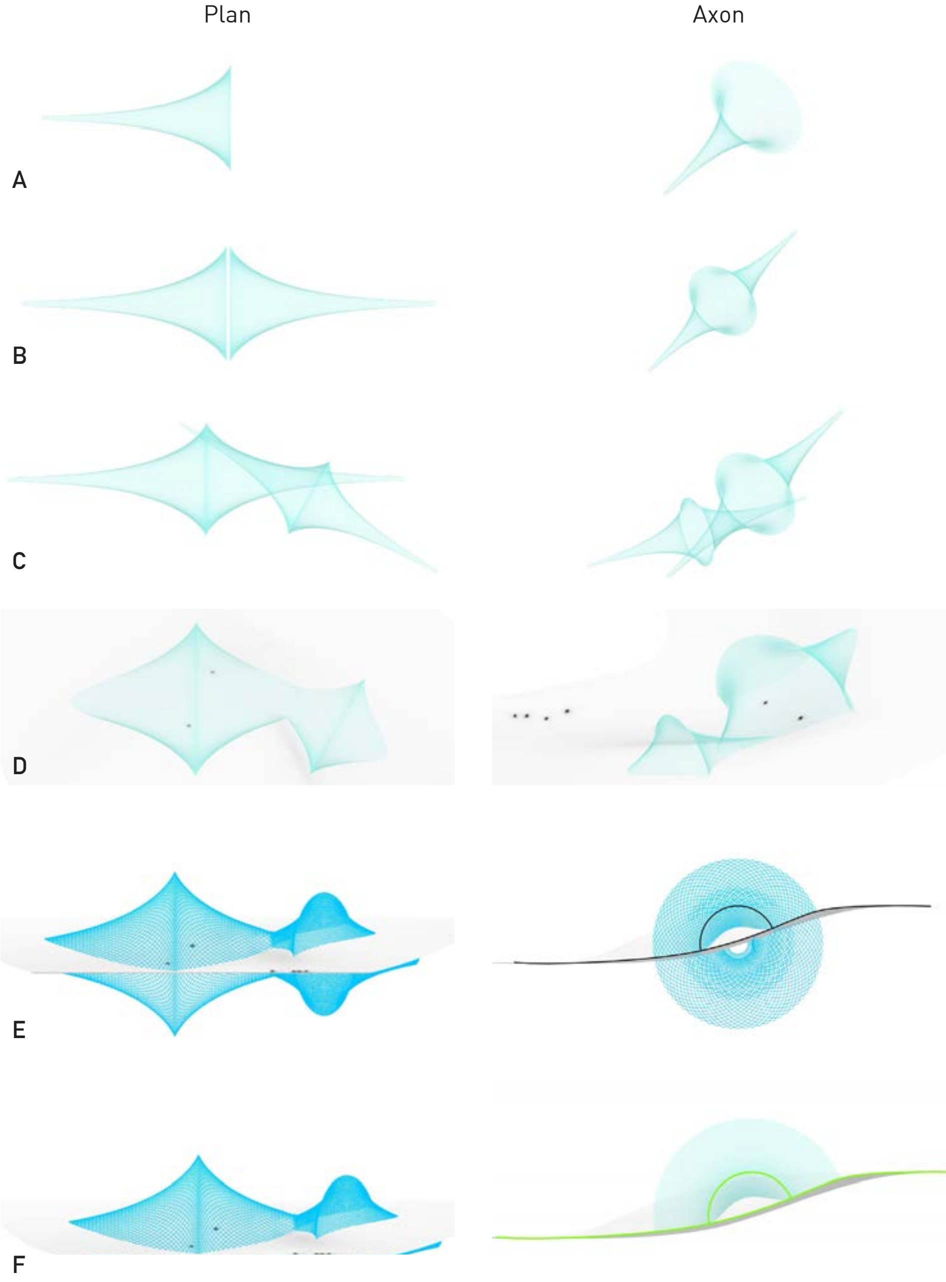


Fig. 6: Network detail



Case Study 1: Eden Project

Details

The eden project functions as the world largest greenhouse with plant species from all around the world. Its spherical space frame is designed from a hexagonal grid and the overall weight of the structure is extremely light.

Construction + Erection

The structure is more than 120 meters long. The structure itself is lightweight and rigid and it is constructed with a prefabricated joint system that allows for easier and precise fabrication process. All the parts can be delivered to the construction site piece by piece.

Joint details

The joint system is designed so that ETFE cushions can be plugged in easily. The joints are made of steel tubes, which are light, relatively small and easily transportable.

Facade

Aluminium clamps on its cladding panels clamps down ETFE cushions (a material that is environmentally efficient and extremely lightweight)

Site

The site is also quite unstable and uneven (like my chosen site at the foot of the mountain), and this biodome structure offers a stable and sustainable structural solution.

Fig. 7: Photograph of membrane

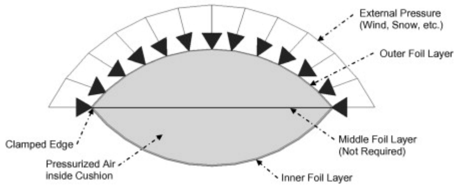


Fig. 8: ETFE "Tefzel"

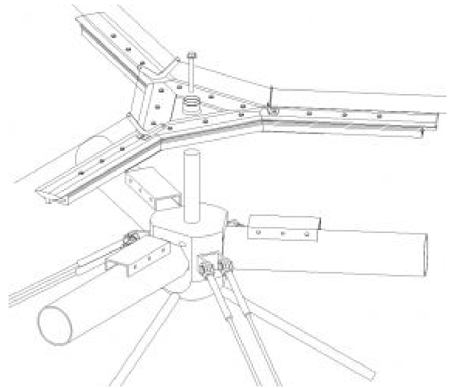


Fig. 9: Joint detail

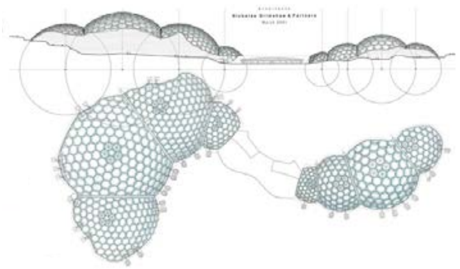


Fig. 10: Design of The Eden project

Case Study 2: Shukhov Rotunda

Details

The Shukhov Rotunda has a diagram having cover and utilises the tensile gridshell structure which is patented on 1894. The structure itself has a diameter of 68 meters and is 16 meters high. It was also deemed the first hyperboloid structure.

Functions

The Rotunda functioned as a exhibition pavilion for the All-Russia Exhibition. Shukhov uses mathematics to derive the design of the structure with the minimum materials, time and labour.

Truss support

The centre of the roof is supported by 14 vertical steel truss that holds up the circular top ring of the roof. They are joined together with bracing at the top.

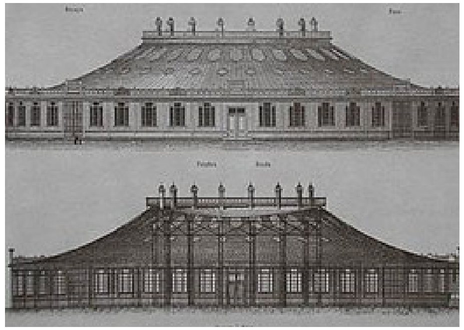


Fig. 11: Sections of Shukhov Rotunda

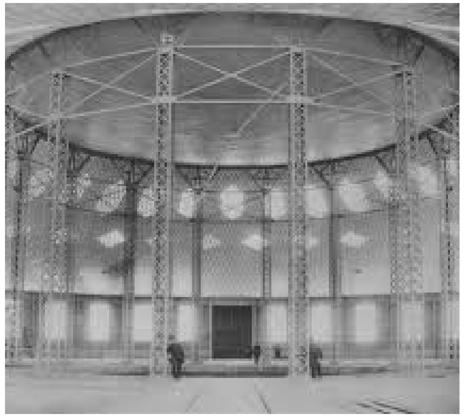


Fig. 12: Interior view

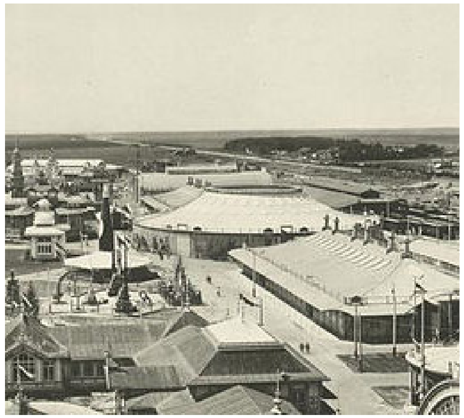


Fig. 13: Exterior view

Case Study 3: Munich Olympic Stadium

Facade - The roof is made from plexiglass panels suspended in a web formed into a tent by huge ‚tent poles'. It is made of acrylic sheet for the semi transparent cover plexiglass. This tent-like theme threads across all the other buildings of the Olympic Park. On top of each joint, there are pins that pins the plexiglass material down at its corners.

Construction - The roof is made of cable net structures that consists of saddle shaped surfaces. The entire framed by edge cables and suspended by masks.

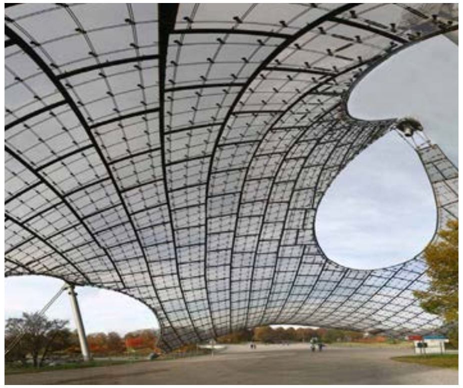


Fig. 14: Roof of Munich Olympic Stadium

Fig. 15: Typical support

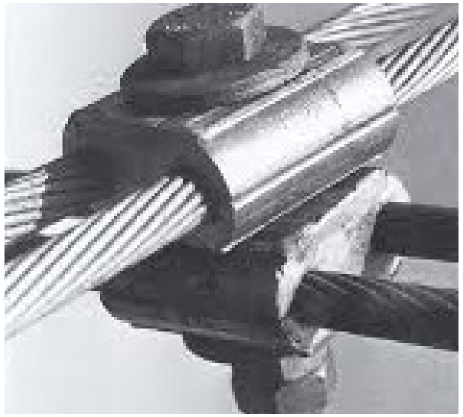


Fig. 16: Typical joint

Typical Joint

All the joint pieces have a constant length and they are straight pipes that are made of steel, with a diameter of 16mm. They have a simple hinge system to accommodate for the geodesic angle of the pseudosphere. The hinge system is advantageous when the structure expands and contracts slightly (when there are changes in temperature on site).The entire structure is able to shift slightly and the plexiglass material can bend accordingly

1. Aluminium clamping strip
2. Three layer inflated ETFE cushion
3. 4cm diameter steel tube
4,5. Metal bolt
6. 16cm diameter steel tube

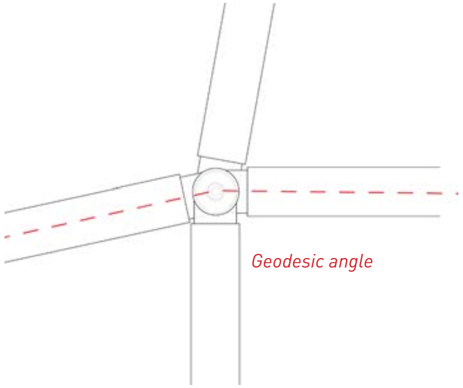


Fig. 17: Geodesic torsion of typical joint

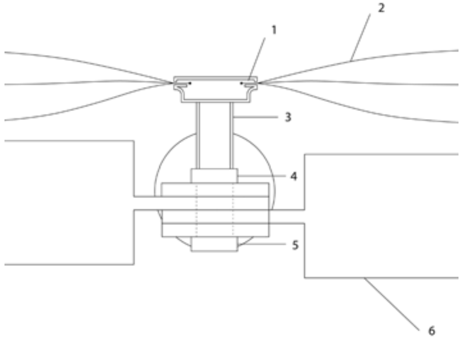


Fig. 18: Detail of typical joint

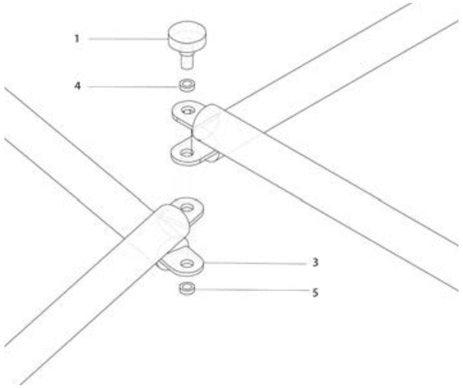


Fig. 19: Axonometric of typical joint

Typical Support

This support is inspired by the Munich Olympic stadium´s anchorage. It allows the steel metal tubes to rotate freely to fit the asymptopic curves of the structure.

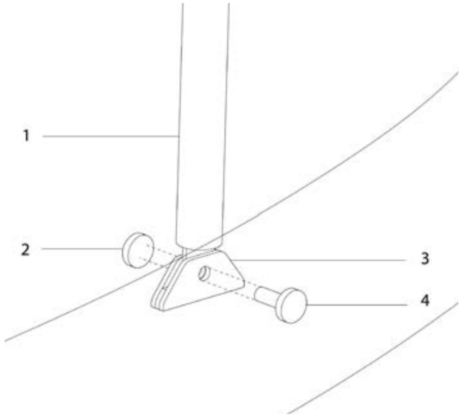


Fig. 20: Axonometric of typical support

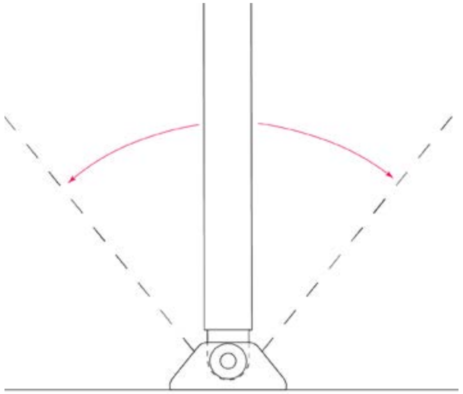


Fig. 22: Rotation for typical support

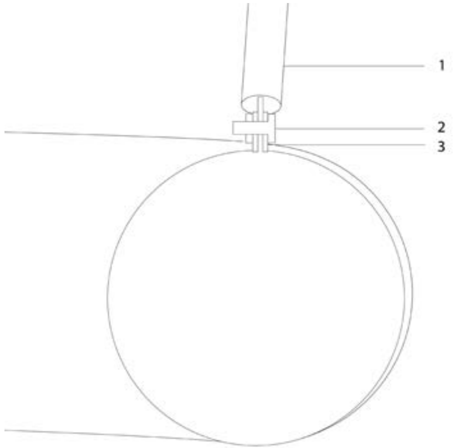


Fig. 21: Section of typical support

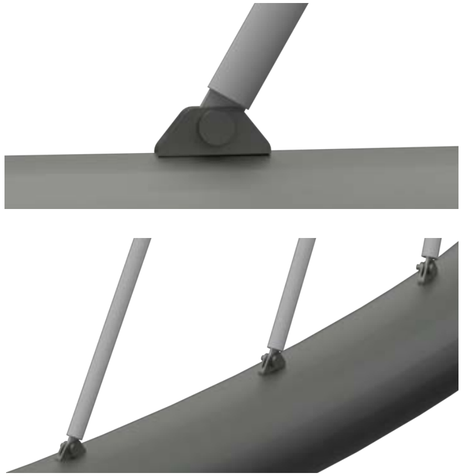
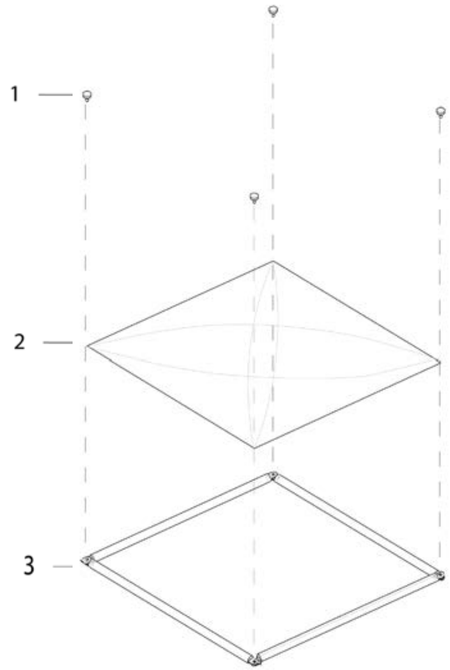


Fig. 23: Renders of typical support

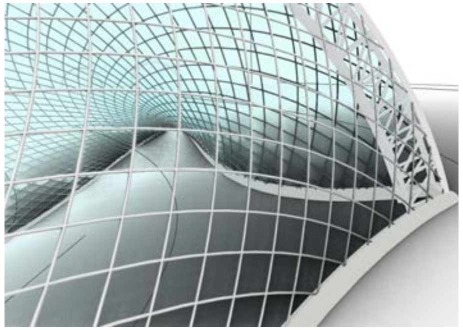
Facade - Bent plexiglass

Aluminum clamping pins are secured at the top of where 4 joints meet. Inspired by the Munich Olympic stadium as, we, plexiglass panels are used as the exterior facade since it can bend and move accordingly to the shifts of the joints since it is an elastic material that repels rain and wind (even under extreme weather conditions).



1. Aluminium clamping pin
2. Plexiglass
3. 4 m steel tube

Fig. 24: Axonometric of facade



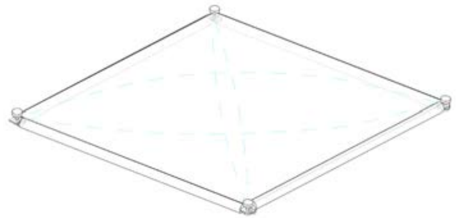


Fig. 25: Facade detail

Fig. 26: Construction process

Arch truss and bracing

The entire structure is supported by 2 arch trusses that span 95 meters and 70 meters long. the bracing itself has a cross section of 3 meters by 5 meters.

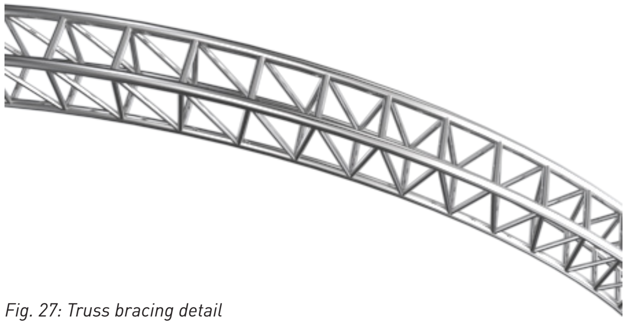


Fig. 27: Truss bracing detail

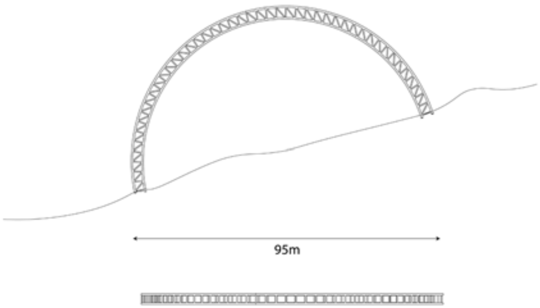


Fig. 28: Plan of arch truss

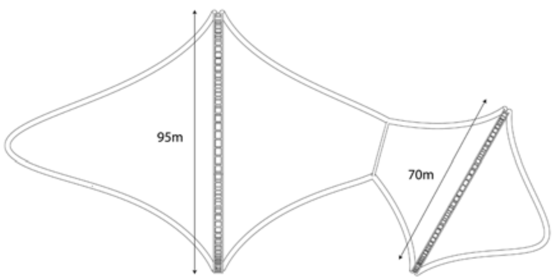


Fig. 29: Detail of arch truss

Site

The structure is located at the mountain terrains, it is wedged between the foot of 2 mountains. The shape of the large Biosphere is designed to adjust to the terrain.

Design Concept

The concept is to use a pseudosphere to build biosphere within the mountain terrains. The structure will create a grand space by suspending an asymptotic grid-shell from two large trussed arches. In this project, two pseudospheres are joint together as the design shape.

A pseudosphere constant edge length, which means each of the steel tubes will be of equal length. The shape also has constant geodesic torsion, and this will be solved by the hinge system at the joints which allows each of the bars to rotate and move accordingly. Other qualities of a pseudosphere are that is has a constant negative double curvature and zero normal curvature, which allows rain, snow etc to flow off the glass roof easily.

Functions

The structure functions as large-scale modular grid-shell and offers a space as a biodome in extreme weathers. Since it is such a huge mega structure, the geometry of a pseudosphere is very convenient for fabrication. The structure creates a column-free space below which allows people to roam around freely. dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est.

Fig. 30: Site map

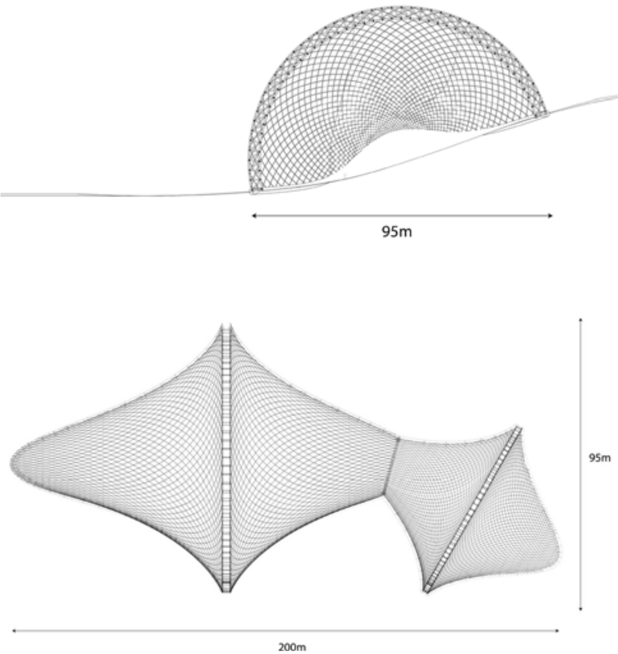


Fig. 31: Dimensions of structure

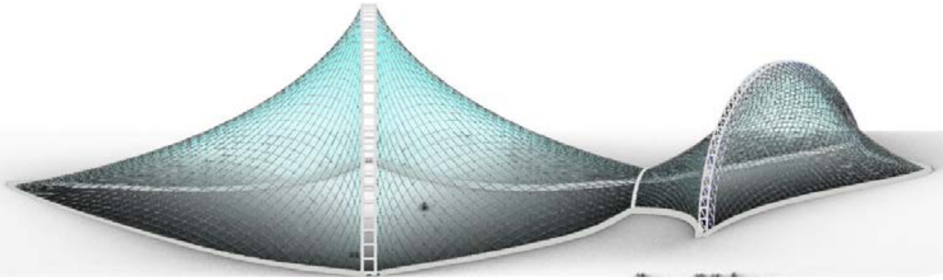


Fig. 32: Plan/top view

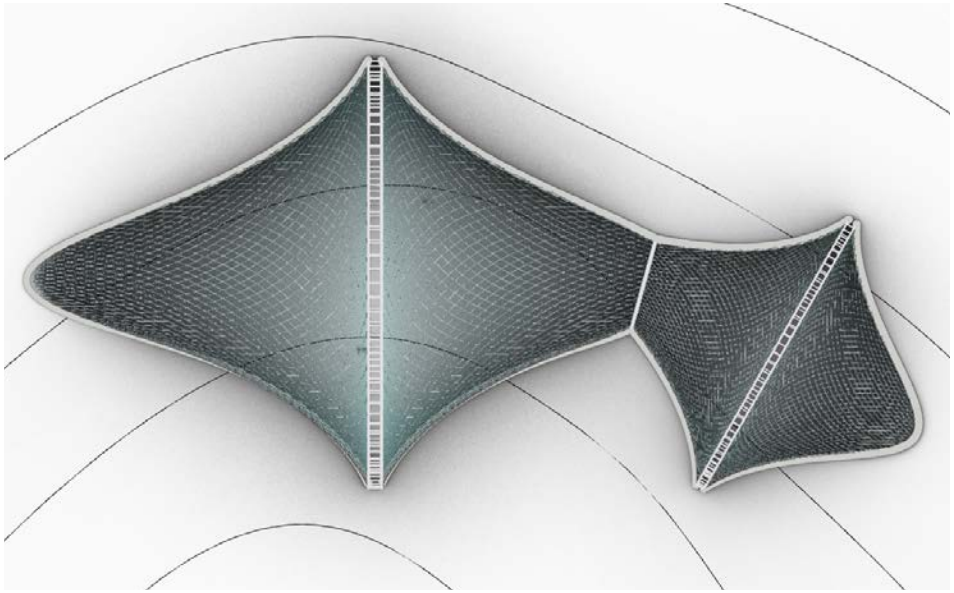


Fig. 33: Plan

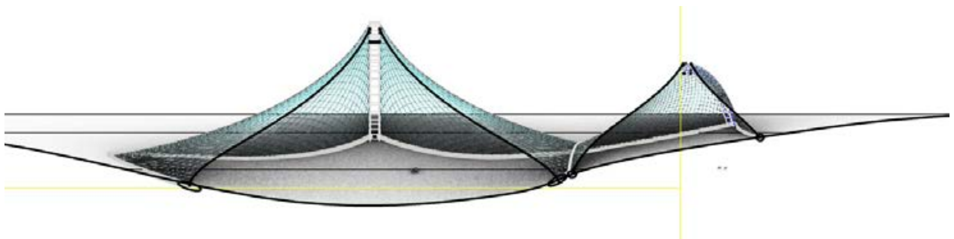


Fig. 34: Short sections

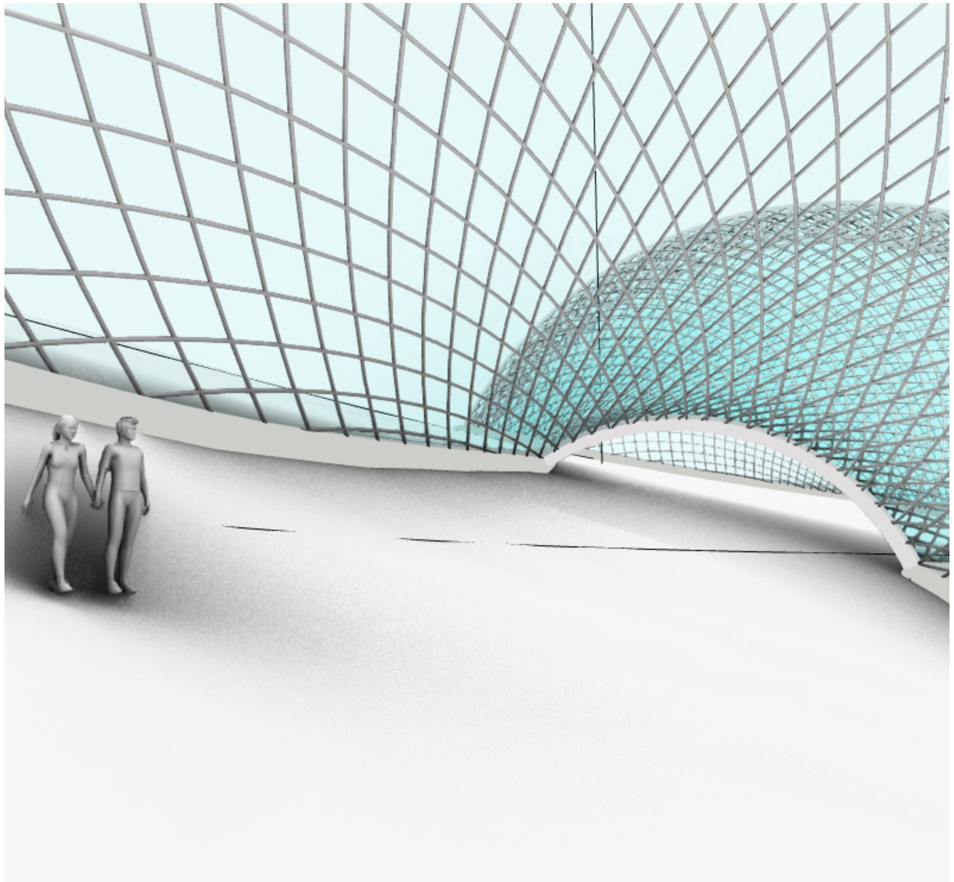


Fig. 35: Interior rendering

DESIGN RESEARCH

Asymptotic Highrise in Hong Kong
Mirae Nam

SCENARIO PROPOSAL

Fig. 1: Site context

Span
100 m

Material
Steel

Construction Method
Prefabricate, Discrete

Target Group
HongKong Company

Introduction

Hong Kong is a place with of lot of highrise buildings, and a beautiful skyline for each side of the lands. However, it seems like most of the buildings are restricted to the rectangular footprint of the land and extruded out all the way up to the top. As a result, this pile of buildings is blocking the views and taking away space for the ground. People feel stiff and confined when they walk through these buildings.

This project will suggest a highly flexible design method to resolve this problem with a negative surface. The negative surface can provide more freedom to design the building with curvature also can achieve spatial efficiency at the same time. In addition, the main concern about designing a building with curvature is cost and efficiency, and asymptotic curves created from the negative surface can minimize the structure need for the construction.

Challanges

To generate the asymptotic curves, the surface needs to be negative curvature, which means curved in two different directions. For the joint, we need to think about how to accomodate geodesic curvature and geodesic torsion. We need to think about different layering system, for function of each layers and how the structure, facade, and shading work together.

KEY CONCEPT

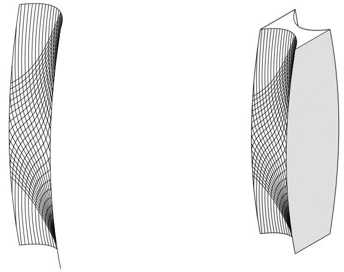


Fig. 2: Concept sketches

Fig. 3: Modular surfaces

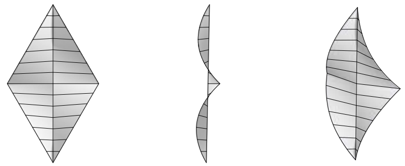


Fig. 4: Ruled surfaces

Potentials

This layering system can be highly flexible to any negative surface, therefore, it provides much freedom to design the shape of a highrise building. For the structure, we can produce planar joint, as the asymptotic curve does not have any normal curvature. Moreover, the asymptotic can easily transform the straight stips of steel into double curved facade.

Case Study 1: Canton Tower, Guangzhou

IBA

Architectural Concept

The Canton Tower is a 604 meter tall multipurpose observation tower in Guangzhou, China. The Canton tower's twisted shape or c structure. In combination with parametric design methods and applied a simple structure concept of three elements, columns rings and braces, to this more complex geometry. The form, volumen and structure of the towers is generated by two ellipses, one at foundation level and the other at a horizontal plane at 450 m. These two ellipses are rotated relative to another [1].

This is an example of highrise building with asymptotic structure system. It is referencing how this simple method can creat a doubly curved surface with straight lines.

Fig. 5: Outside view

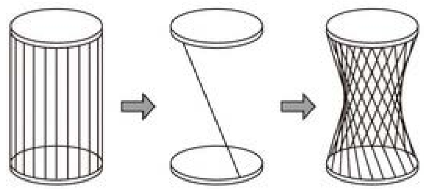


Fig. 6: Form finding process

Fig. 7: Facade of the building

Case Study 2: 30 St Mary Axe (The Gherkin), London

Foster + Partners

Architectural Concept

The Gherkin building is a commercial skyscraper in London's primary financial district, the City of London.It is 180 meters tall and stands on the former sites of the Baltic Exchange and Chamber of Shipping. The building was constructed by Skanska, completed in December 2003. The building uses energy saving methods which allow it to use only half the power that a similar tower would typically consume.Gaps in each floor create six shafts that serve as a natural ventialtion system for the entire building [2].

This project is a well-know example of diagrid building with doubly curved shape. From this, we can understand the primary structure of diagrid building, and the detials of different part of specific structure such as joints, glazing, and diagonal elements.

Fig. 8: Outside view

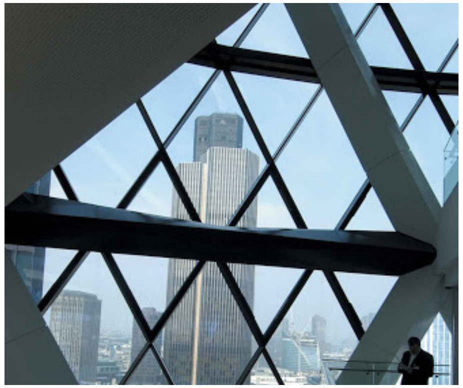


Fig. 9: Inside view

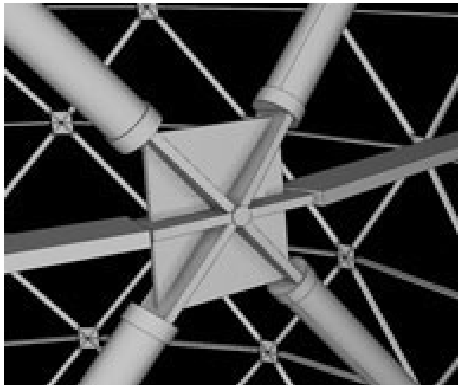


Fig. 10.Typical joint and support

Case Study 3: XXCQ Tower, New Zealand

Studio Pacific Architecture

Architectural Concept

XXCQ Tower is a landmark building on Wellington's waterfront. This building is one of the saftest structures to be standing in during an earthquake. It has been designed to minimise structural damage in a 1 in 500 year earthquake and is estimated to meet up to 180 percent of the building code. It features a diagonally-braced steel diagrid perimeter structure with base isolation, representing a new generation of safety and resilience. The base isolation system also reduces the likelihood of structural damage, increasing the building's lifecycle and reducing its environmental cost [3].

This reference provides knowledge about different layers of facade system, and how the diagrid buildng can construct step by step.

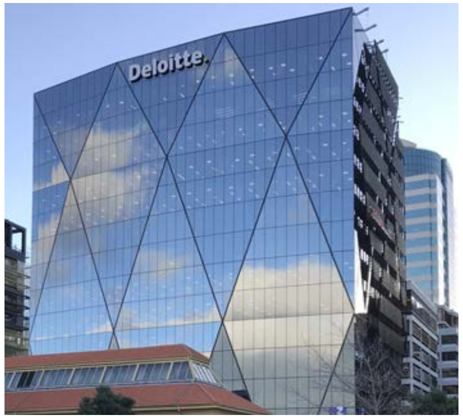


Fig. 11: Outside view

Fig. 12.Construction process

Form Finding

A. Generate a negative surface

B. Substract two sides of the building of rectangle extrusion

C. Connect two negative surface into one continuous surface, and naturally makes curved edges for two different sides.

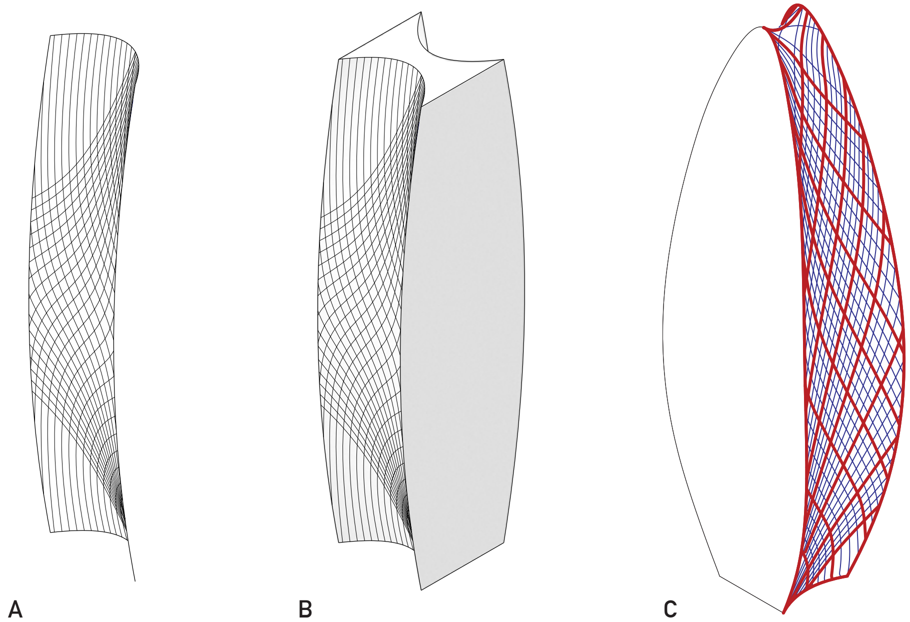


Fig. 13: Form finding process A, B, C

Prototypes

These are different prototypes, shows the possiblity for more options with any negtively curved surface building.

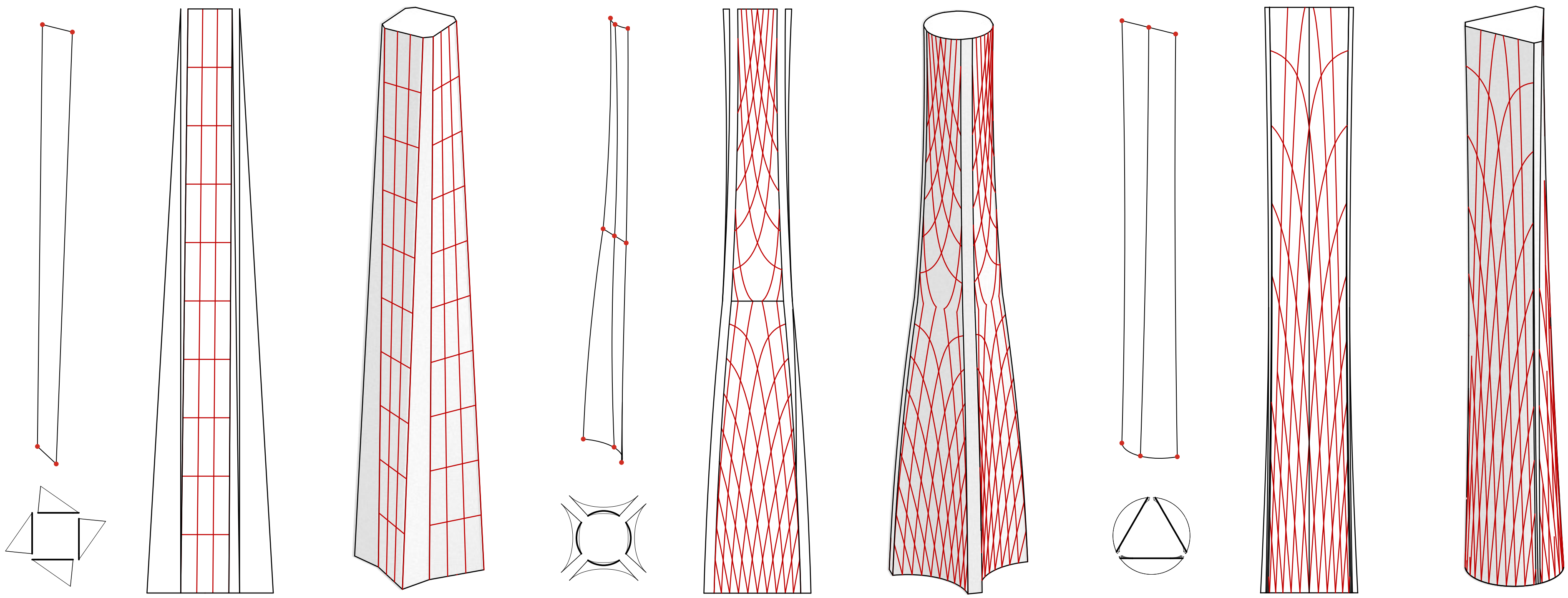


Fig. 14: Prototype

Main Structure Joint

The main diagrid structure are mainly divided into two parts, a node and diagonals. Nodes will align on the floor slab, and connected with horizontal members. The diagonal members are constructed with round steel rod that could resist the geodesic torsion. And, flat metal piece attached on the end will joined with node with screws. The diagonals could move side to side to adapt the geodesic curvature.

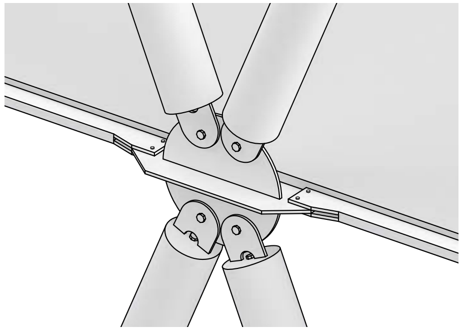


Fig. 17: Joint

Sub-Structure

Sub-diagonal structure is 4 times denser than main structure it is a floor height of the building. This structure will prefabricaed into a segment of smooth structure, and hold the window panels. The structure will be 1cm thick and 20cm wide. There will be 2 triangular glass panels will fit into one diagrid. To fill in the tolerance between glass panel and steel lamella, added sillicone sealanct in between.

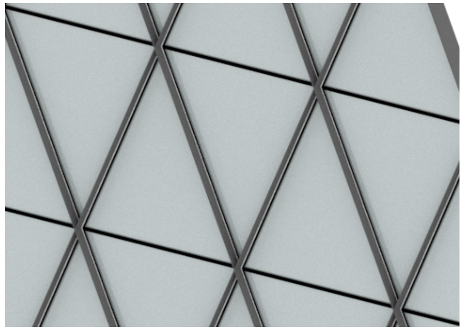


Fig. 20: Sub-diagonal structure

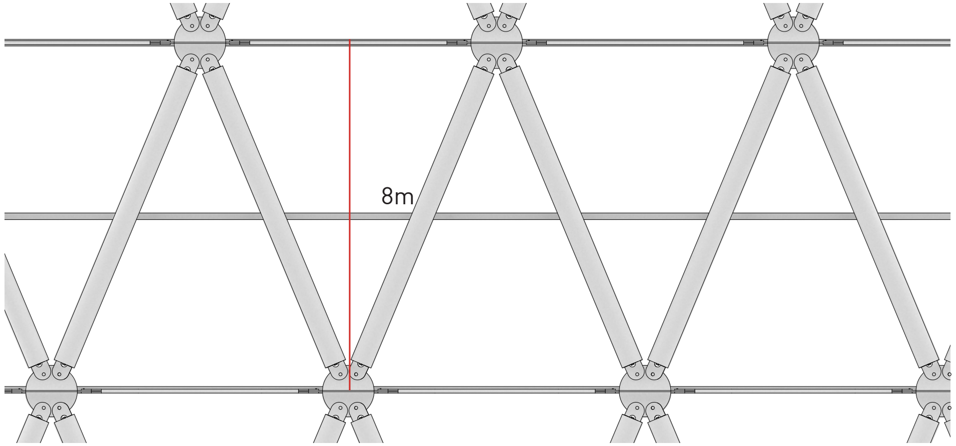


Fig. 15: Elevation of nain structure

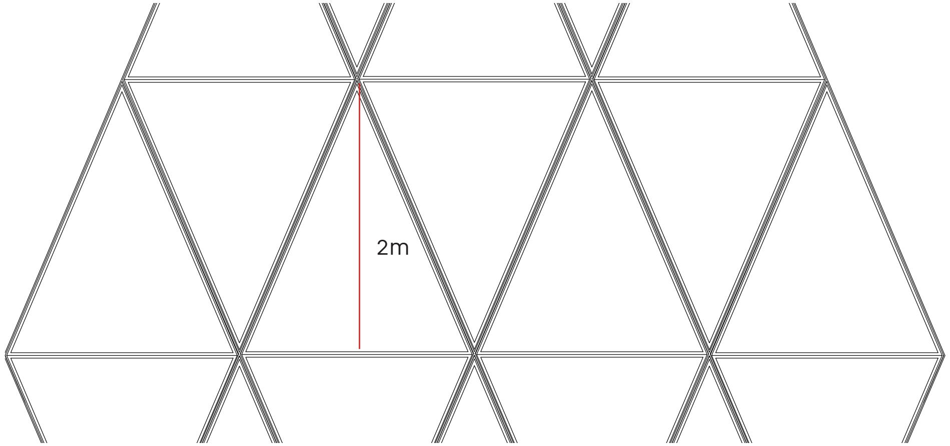


Fig. 18: Axonometric of sub-structure

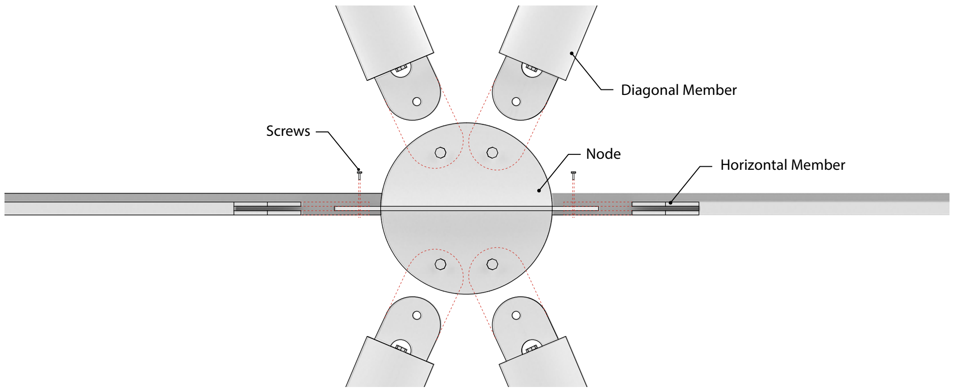


Fig. 16: Detail of main structure

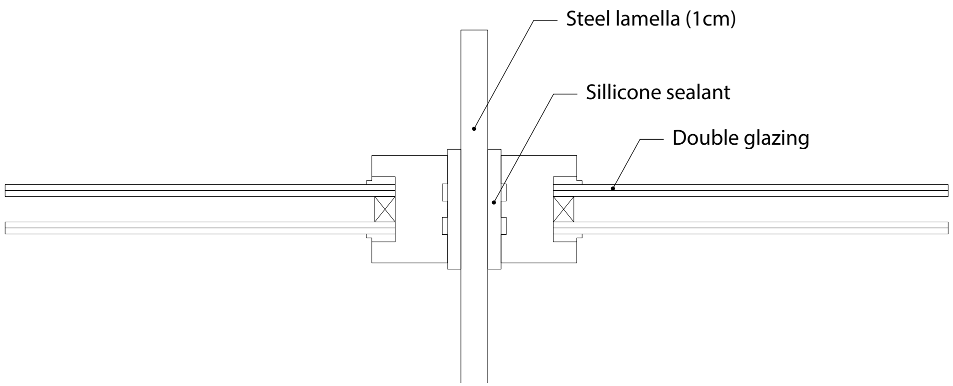
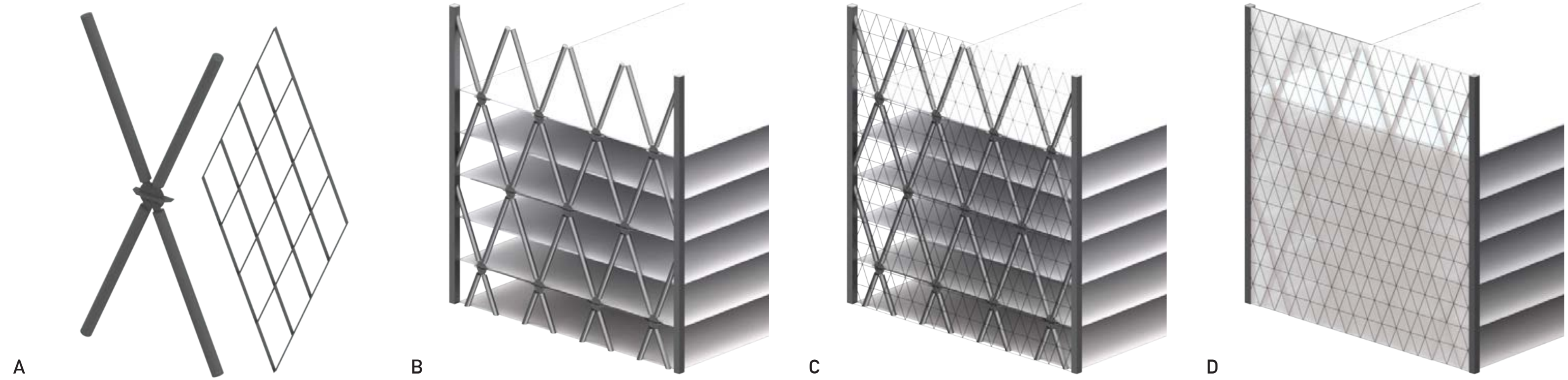


Fig. 19: Detail of typical sub-structure



Construction

A. Prefabricate Main Joints, diagonal members, and segements of sub-diagonal structure.

B. Assemble joints and the diagonal members and attach to the floor slabs.

C. Add sub-diagonal layer to the main structure, the edge need to be aligned with the main joints and connected to it.

D. Insert the triangular glass panel onto the sub-diagonal structure.

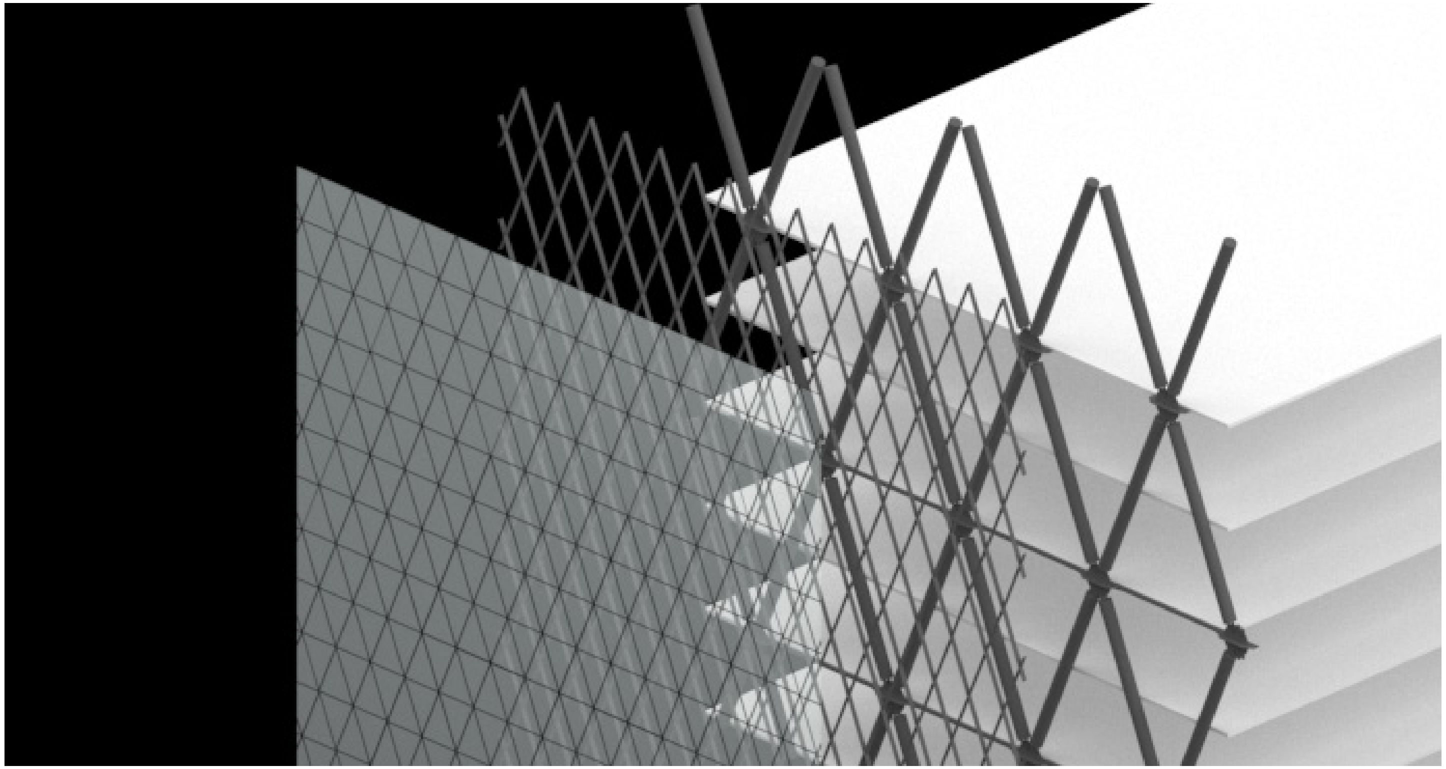


Fig. 21: Exploded axonometric

Site

This is site of Central,Hong Kong, with lot of highrise buildings and it seems like most of the buildings are restricted to the rectangular footprint of the land and extruded out all the way up to the top. As a result, this pile of buildings is blocking the views and taking away space for the ground. People feel stiff and confined when they walk through these buildings.

Design Concept

Design concept of this project is avoid homogenous extrusion of building, and use curves to overcome spatial deficit, which is usual situation in Hong Kong. By using negative surface and extract asymptotic curves from it, can easily generate a layering facade system for highrise building.

Functions

This highrise building is suitable for office building. The shape of the building is iconic from the outside, and can provide optimized working area for internal space.

Architectural Concept

Most beneficial part of asympotic curve is the efficiency of building structure. This drives to various layering system for facade. Each layer has different structural function, and it needs to be co-works together. First layer of asymptotic curves will become main diagrid structure to support whole builing with a core structure located on the center of the building. The second grid is sub-diagonal structure that will holding up the glazing panel. Third layer is divsion of diagrid into triangle, so the glass panel can be flat and insert into the grid.

Fig. 23: Site

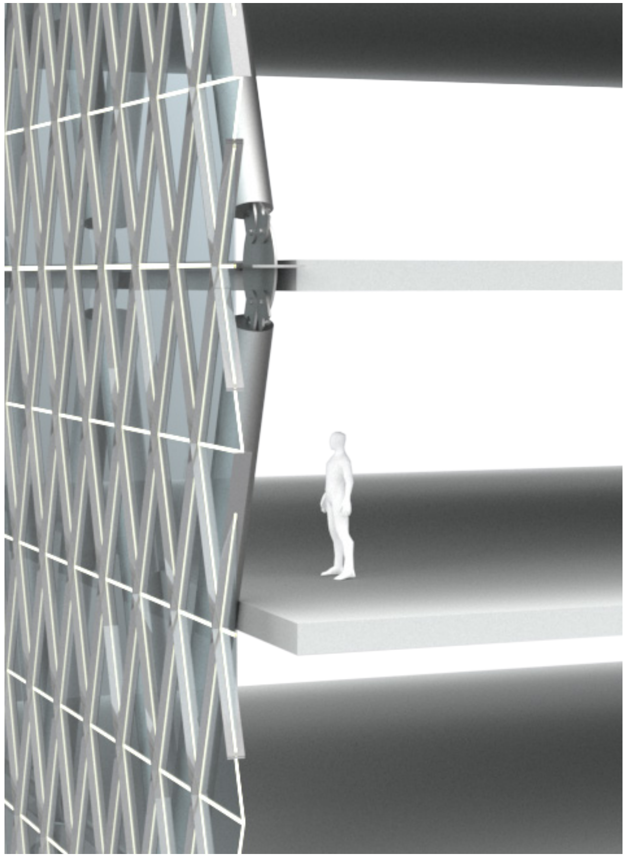


Fig. 24: Section

Fig. 25: Exterior view

Fig. 26: Street view

Fig. 27: Inside view

Bibliography

[1] "Canton Tower." Wikipedia. Wikimedia Foundation, May 11, 2020. https://en.wikipedia.org/wiki/Canton_Tower.

[2] "30 St Mary Axe." Wikipedia. Wikimedia Foundation, May 11, 2020. https://en.wikipedia.org/wiki/30_St_Mary_Axe.

[3] NZ Institute of Architects. "XXCQ." NZ Institute of Architects (www.nzia.co.nz). Accessed May 17, 2020. https://www.nzia.co.nz/awards/local/award-detail/8301.

List of Figures

1 "Hong Kong Skyline - 2020 All You Need to Know BEFORE You Go (with Photos)." Tripadvisor. Accessed April 17, 2020. *https://en.tripadvisor.com.hk/Attraction_Review-g294217-d2482919-Reviews-Hong_Kong_Skyline-Hong_Kong.html.*

5 "Canton Tower." Wikipedia. Wikimedia Foundation, May 11, 2020. *https://en.wikipedia.org/wiki/Canton_Tower.*

6 Museum, Nagoya City Science. "Nagoya City Science Museum." Nagoya City Science Museum Website | Exhibition Guide | Keyword Search | H | hyperboloid | Ruled Surface. Accessed April 17, 2020. *http://www.ncsm.city.nagoya.jp/cgi-bin/en/exhibition_guide/exhibit.cgi?id=S427&key=H&keyword=hyperboloid.*

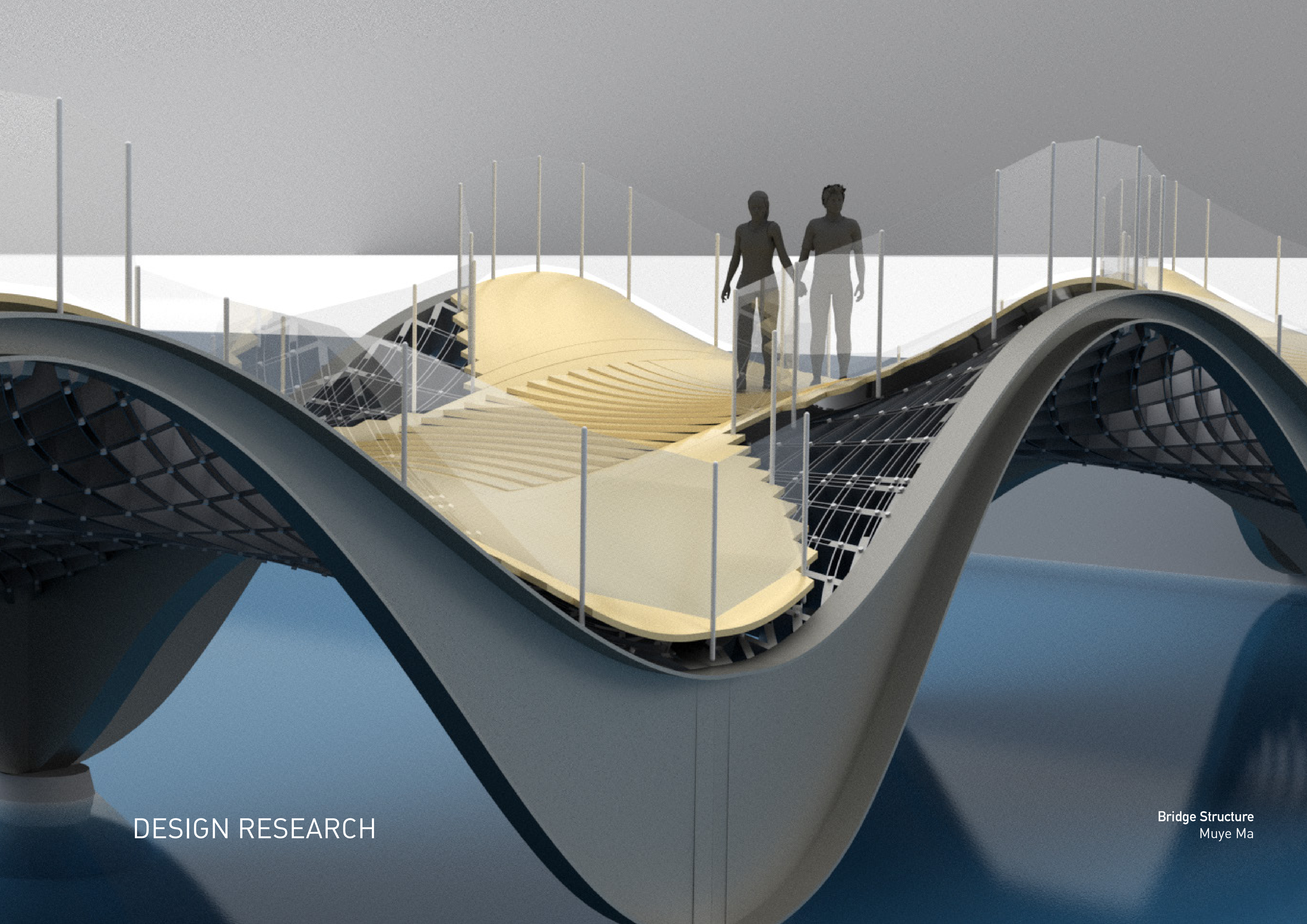
7 "Canton Tower." Wikipedia. Wikimedia Foundation, May 11, 2020. *https://en.wikipedia.org/wiki/Canton_Tower.*

8 "The Gherkin, London." The Gherkin, London. Accessed April 17, 2020. *https://www.thegherkinlondon.com/.*

9 Harvard Design Magazine: 30 St. Mary Axe. Accessed May 17, 2020. *http://www.harvarddesignmagazine.org/issues/35/30-st-mary-axe.*

11 "Deloitte New Office - Talk and Tour (Wellington)." New Zealand. Accessed April 17, 2020. *https://network.corenetglobal.org/newzealand/events/eventdescription?CalendarEventKey=77bd2dd1-2cda-4410-9fa5-725d6603062b&CommunityKey=b4a89342-a671-4f82-9010-35d8c7032e4d&Home=/newzealand/home.*

12 "20 Customhouse Quay: MJH Engineering LTD." 20 Customhouse Quay | MJH Engineering LTD. Accessed April 17, 2020. *https://www.mjh.co.nz/projects/mit-auckland-3/.*



DESIGN RESEARCH

Bridge Structure
Muye Ma

SCENARIO PROPOSAL

Fig. 1: Lam Tsuen River near Kwong Fuk

Span
30 meters
10 meters per unit

Material
Reinforced steel

Construction Method
Prefabricated unit, On-stie Assembly

Target Group
Hong Kong

KEY CONCEPT

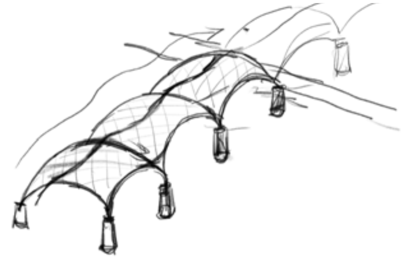


Fig. 2: Concept sketch perspective

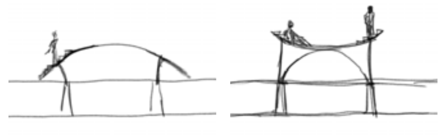


Fig. 3: Concept sketch sections

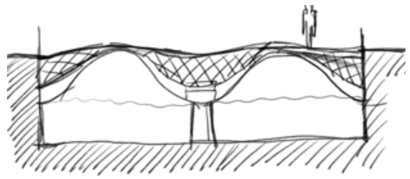


Fig. 4: Concept sketch elevation

Introduction

We often use gridshell structure to build a building facade or a dome, but can we use this strategy to build a bridge? If so, what are the benefits and the limitations of using gridshell? Besides, how can we enlarge the benefits and avoid the limitations? In my opinion, the gridshell structure has the benefits of creating a longer span, which fits the need of the bridge? How many loads are you able to apply on top of the gridshell? What kind of joint suits the bridge better? Is the bridge site-specific, or can it be a prototype that can be applied anywhere in the world? And what´s the experience to walk on a gridshell bridge? Is the gridshell making the construction easier? We have to keep asking these questions when we are designing the structure, so it explores the maximum potential of the bridge.

Challanges

There are several challenges when designing the bridge. The first one is that most bridge has a relatively flat surface, so it is more comfortable to walk on it. However, the gridshell structure often deals with a curved surface, which could be a downside of the structural design. The second one is that a typical bridge only has several points that have an equal length in between, which allows the piloti to touch the ground. Therefore, the gridshell surface has to be lifted the edges to create the points that gently touch the ground. The third one is the joints of the gridshell has to be strong enough to support the weight. In this case, I am using the asymptotic curvature network to create the grid. This network allows each piece to be a straight member. However, the grid has to be equally distributed on the surface so that the weight is able to transfer to the structure evenly.

Potentials

The negatively curved surface can be modified in a way to have a relatively flat path in the middle so that it is easier to walk on. The up and down surface creates an extraordinary experience of this pedestrian bridge to make it fun to walk on. Besides, there is an intimacy between the user and the structure, the user is able to feel the curvature of the gridshell. When the bridge is reaching to the edge where it is close to the water, the surface is relatively more curved, so it is higher or lower than the middle. Therefore, we can use this area to be a place for fishing or sightseeing. The bridge is more than the function of bridging but also provide other experiences.

Case Study 1: Bending Bridges

Architectural Concept

Bending Bridges focuses on the development of a double-layered construction system for a free-standing load bearing lightweight wooden structure, through global double curvature, and local active bending principle. The project aim is the design and construction of a pedestrian bridge exploiting the elastic bending capacity of standard thin plywood.[1]

Functions

I was inspired by the negatively curved surface of this bridge, and I believed that this curvature could give me a nicer asymptotic curvature network.

Fig.5 & 6: Bending bridge photos

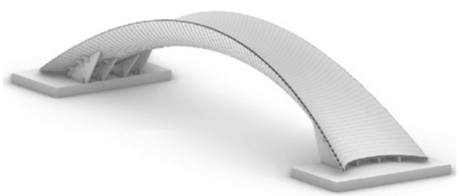


Fig. 7: Typical joints and supports

Case Study 2: Footbridge in Maribor

Architectural Concept

The architects felt the bridge's proximity of the existing bridges over Drava along Lent Tabor embankment provided an opportunity for the new bridge to become more of landmark and a vibrant urban surface engage with the water's edge. The 15m wide undulating surface creates a variety of experiential conditions and provides the structural stability for the project.[2]

Functions

This pedestrian bridge has a unique experience that allows people to walk up and down to interact with the bridge, which is a very interesting feature that I want to introduce into my design.

Fig. 8: Photo of bridge

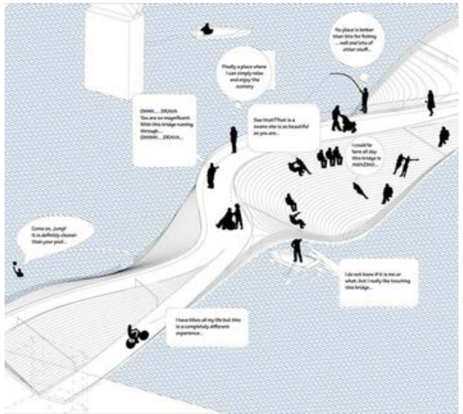


Fig.9: Diagram of bridge

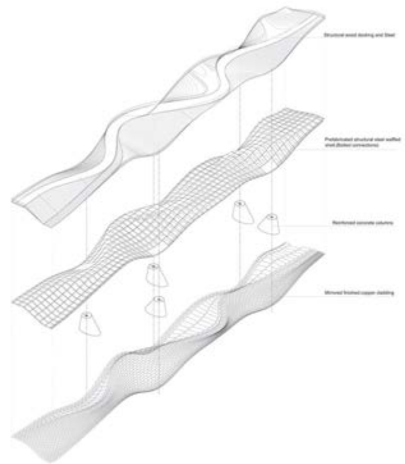


Fig 10: Typical joints and supports

Case Study 3: Footbridge Over the Railways

Architectural Concept

The long-awaited Villetaneuse Université interchange is now taking shape. Although this is a good thing in terms of urban development, it also exacerbates the division between north and south due to the ensuing concentration of networks and traffic lanes.[3]

Functions

The structure of this bridge brings the cover and the desk together, it might not be able to directly related to the asymptotic gridshell, but I would like to test the potential of the gridshell in this direction.

Fig. 11 & 12: Photos of footbridge

Fig. 13: Photo of footbridge

Typical Joint

There are four typical joints on this structure; the first one is the connection between the asymptotic members. Two pieces of metal strips are used on one asymptotic curved member, and they have prefabricated slots so that they can be intersected into each other. Therefore, there will be a whole in the middle to allow a bolt insert into it. Two extra pieces are also inserted into each side of the joint to reinforce the slot of the connection. The second one is between the asymptotic members and the metal frame. Precisely calculated angled metal pieces are welded on the frame to allow the asymptotic pieces to connect on the frame. The third one is the wooden deck connected to the gridshell by grabbing by clamps to the I beam, and the wooden deck is drilled onto the I beam. The last one is the handrail connected on the wooden deck. And it is connected to the glazing fence.

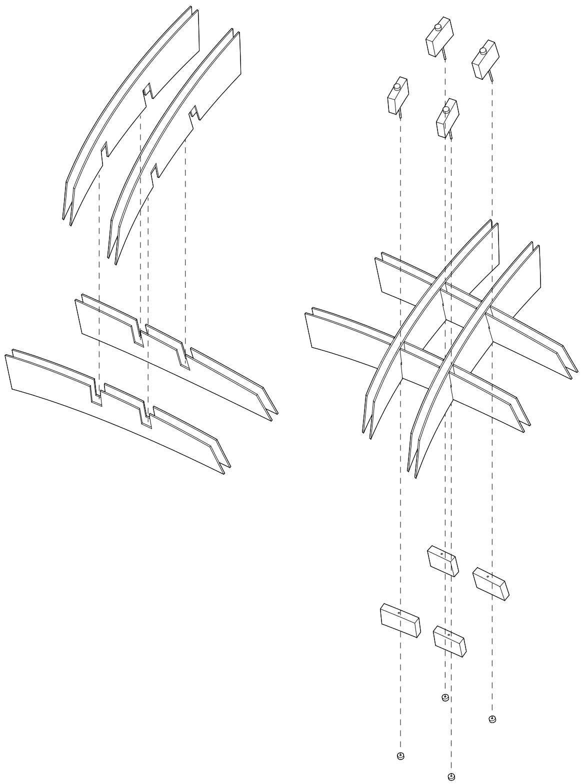


Fig. 14: Axonometric of typical joint 1

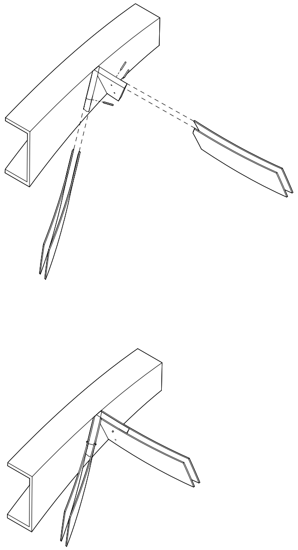
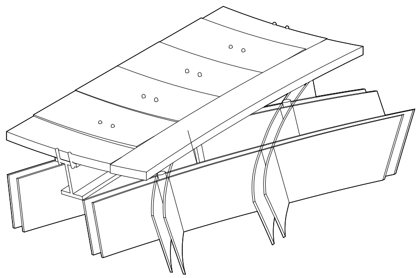


Fig. 15: Axonometric of typical joint 2

Typical Support

There are two main typical supports. The first one is the primary structure, which is a C-section symmetrical metal frame, which can be divided into two parts and prefabricated. And the second one is the secondary structure, the asymptotic metal pieces, which are straight flat metal longitudinal planes, and they can be folded to create the gridshell network.



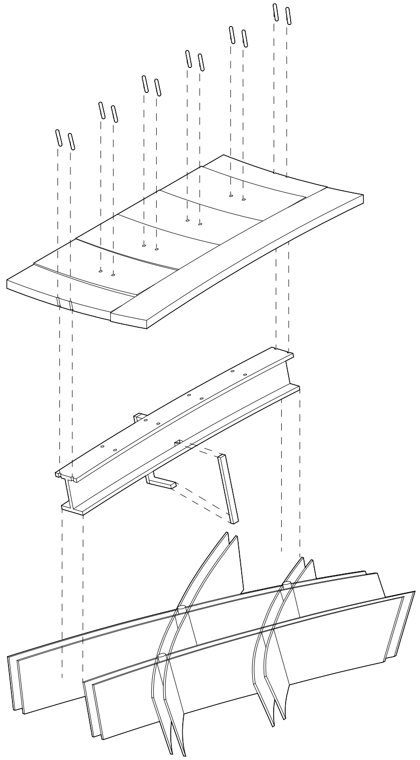


Fig. 16: Axonometric of typical joint 3

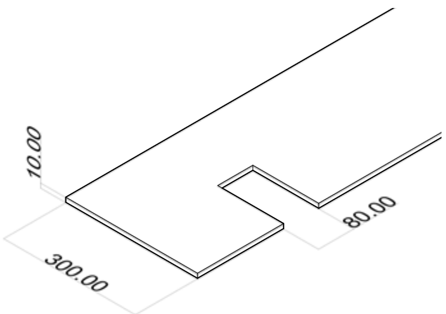


Fig. 18: Secondary structure

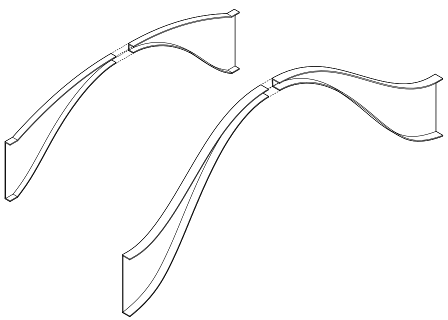


Fig. 19: Primary structure

Construction Process

The construction process can be divided into two parts; the first one is the prefabrication of the frame and the asymptotic gridshell of each module. The second one is the on-site assembly to connect each module and put the wooden deck and handrail on them. The prefabrication of each module needs the frame to be assembled first to define the boundary of the gridshell. Then the joints are welded on the metal frame to allow the asymptotic to be attached to it. Since the curved members are following the asymptotic network, the curved surface is automatically generated.

The on-site assembly is happening because each module is relatively small, so you can easily put the gridshell on the top of each piloti. The I beam connecting the wooden deck for pedestrians is later assembled with the handrails.

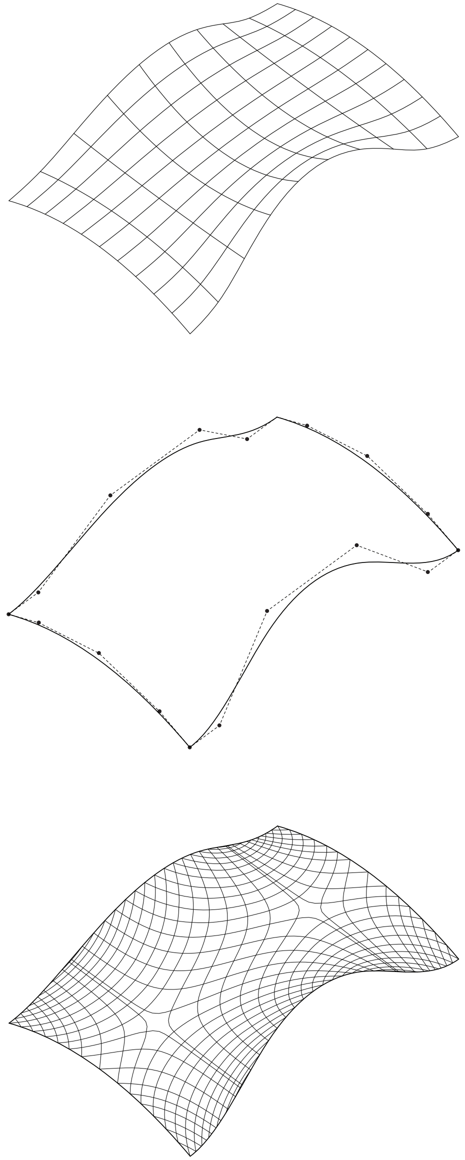


Fig. 20: Surface and asymptotic network

CONSTRUCTION DEVELOPMENT

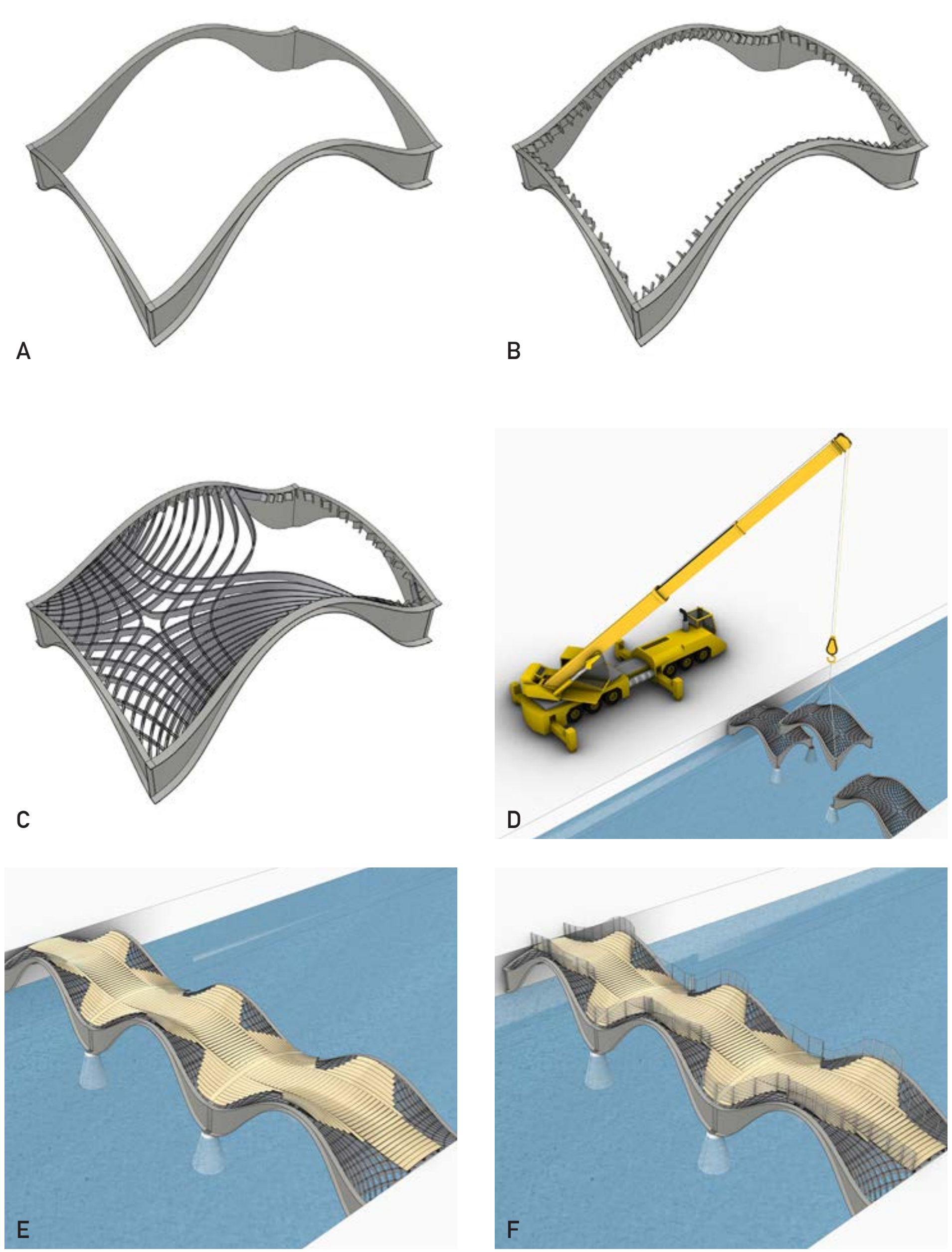


Fig. 21: Construction process A, B, C, D, E, F

SCENARIO DESIGN

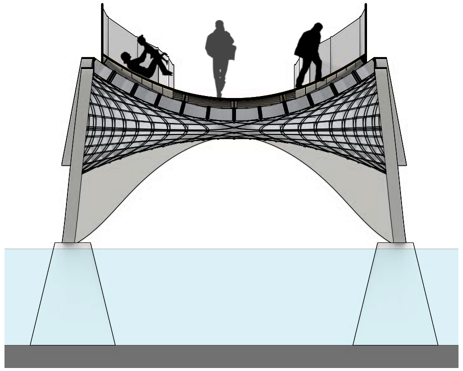


Fig. 22: Cross section

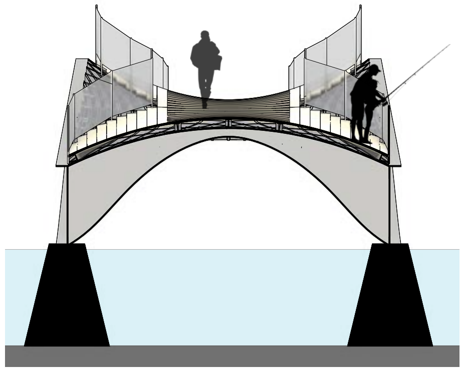


Fig. 23: Cross section

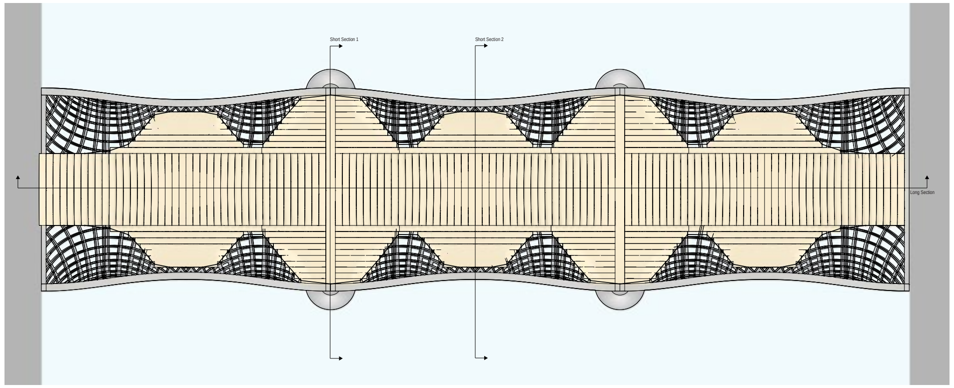


Fig. 25: Bridge plan

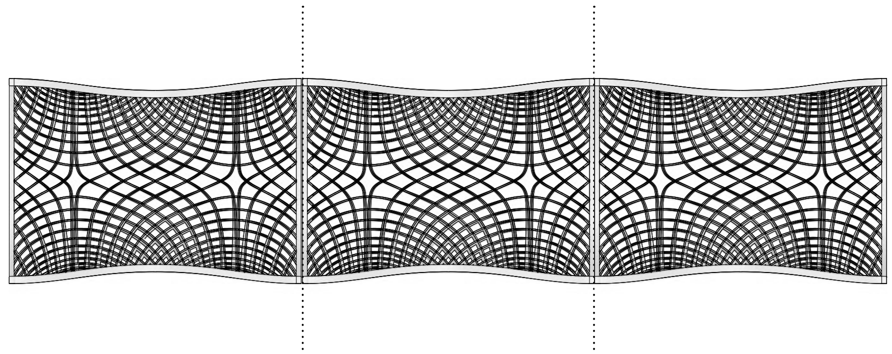


Fig. 26: Module plan

Architectural Concept

The curved surface of the bridge gives opportunities to create multiple interesting moments for people to interact. From the section of the bridge, we can see that the curve on each part of the section can be curved up and down. When it is curving up, it has a slop to bring people in a higher position for sightseeing. When it is curving down, it brings people to the level that is adjacent to the water.

Therefore, the bridge is not only performing as a connector between A to B but also a space to have potentials for users to explore. And the gridshell structure really brings everything together as a whole system to make this possible.

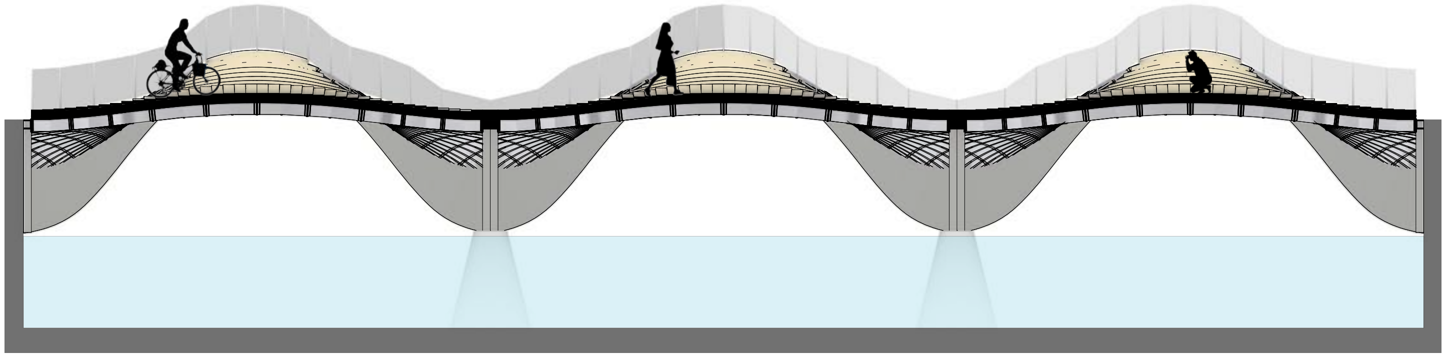


Fig. 24: Long section

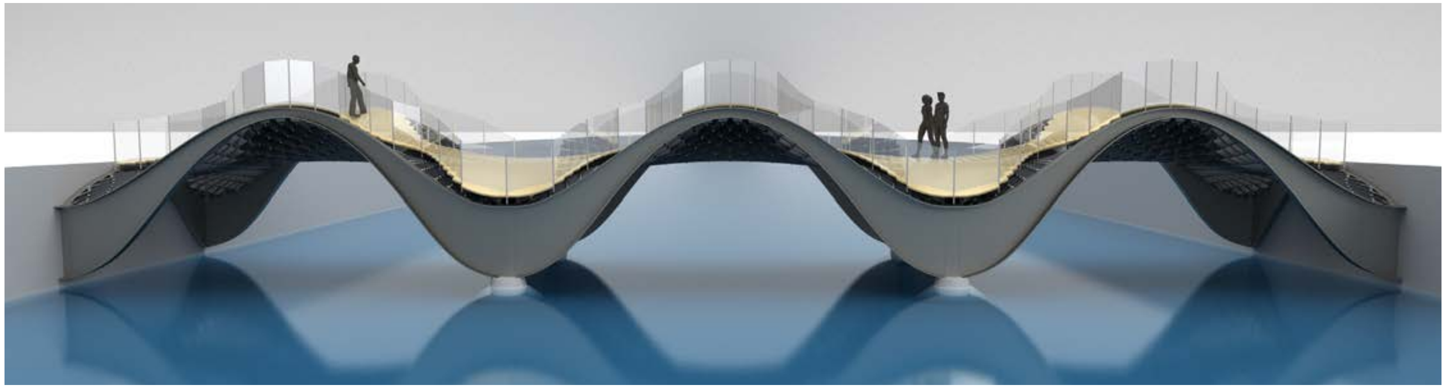


Fig. 28: Elevation

Fig. 29: Central perspective view

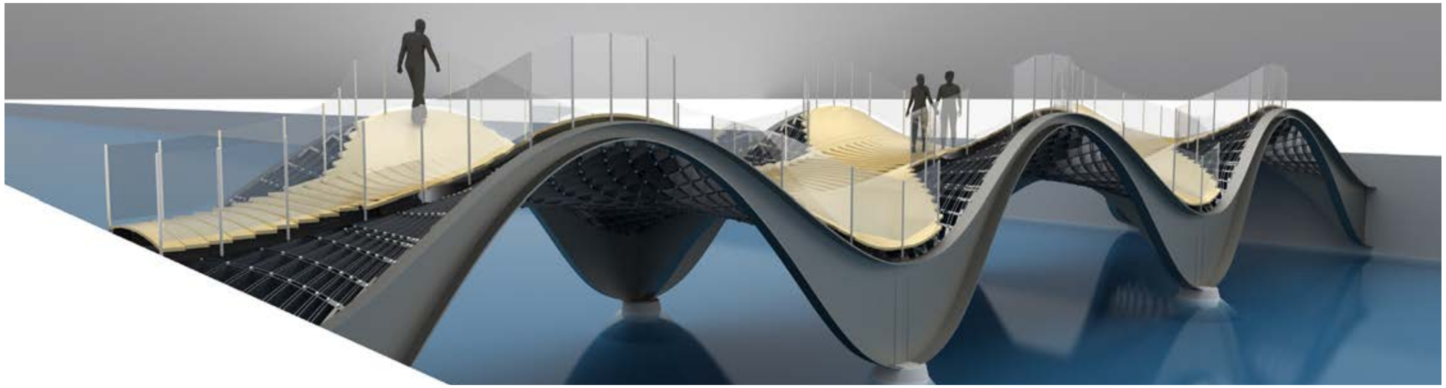


Fig. 30: Perspective view

Site

This bridge is not site-specific, but it is more like a prototype that suits multiple sites. In Hong Kong, there are many rivers or canals that are reinforced by the concrete embankment. The weight of the rivers and canals is relatively uniform, and the water flow is not intensive. I believe that this prototype can be applied to multiple sites with the same condition. The repeatable modular design allows the bridge to be very flexible in most conditions. And it is able to bring the surrounded neighbourhood a space with good atmosphere.

a. Kwong Fuk Bridge

b. Shatin Central Park Bridge

c. Shing Mun River Bridge

d. Lam Tsuen River Near Kwong Fuk

Fig. 32: Site Picture a, b, c, d

Fig. 33: Render on Staunton Creek, between Wong Chuk Hang Station and Ap Lei Chau Bridge

Summary

This bridge is using a negative curvature surface to create an asymptotic gridshell by playing the negative surface. It creates the area with a gentle slopping for pedestrians versus a step slopping for the footings. Moreover, the asymptotic gridshell is duplicable, and it can be placed at the end of each one so that it is creating a longer span. The construction is a combination of pre-fabrication and on-site installation. The prefabricating part is to assemble the gridshell, so that the on-site installation is easier and quicker. The curved surface of the bridge brings a very interesting space for going up and down, which is mimicking the slopping landscape in Hong Kong. Therefore, the bridge becomes a space not only to commute but also to gather.

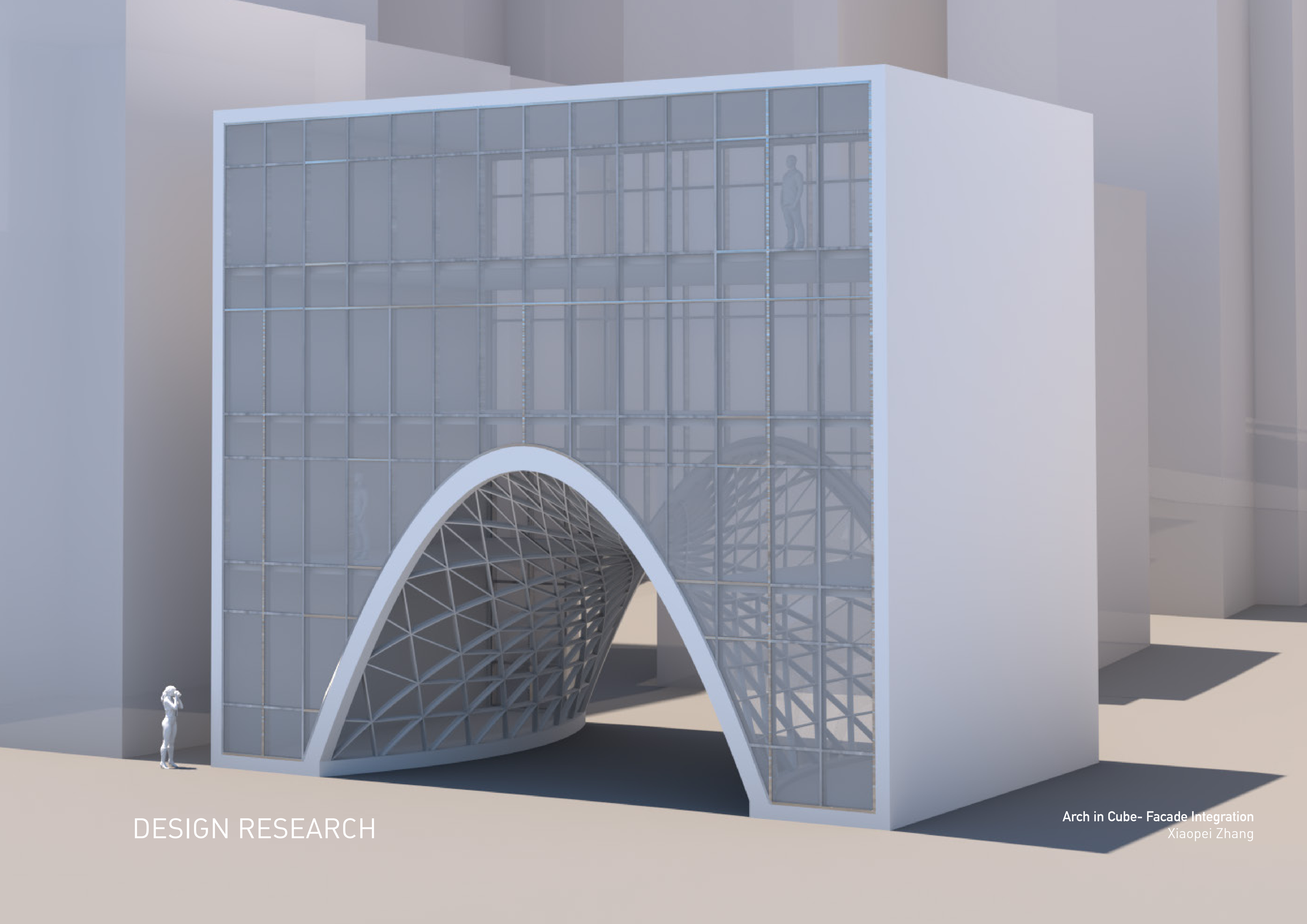
Bibliography

Caballero, Pilar. "Bending Bridges / Centro De Estudios Superiores De Diseño De Monterrey, CEDIM." ArchDaily. ArchDaily, July 16, 2019. https://www.archdaily.com/920941/bending-bridges-centro-de-estudios-superiores-de-diseno-de-monterrey-cedim?ad_source=-search&ad_medium=search_result_projects.

Cilento, Karen. "Footbridge in Maribor / Ja Studio Tadj-Farzin Studio." ArchDaily. ArchDaily, April 11, 2010. https://www.archdaily.com/55957/footbridge-in-maribor-ja-studio-tadj-farzin-studio.

Gaete, Javier. "Footbridge Over the Railways / DVVD: Architectes - Designers." ArchDaily. ArchDaily, December 19, 2012. https://www.archdaily.com/308723/footbridge-over-the-railways-dvvd-architectes-designers.

List of Figures


DESIGN RESEARCH
Arch in Cube- Facade Integration
Xiaopei Zhang

SCENARIO PROPOSAL

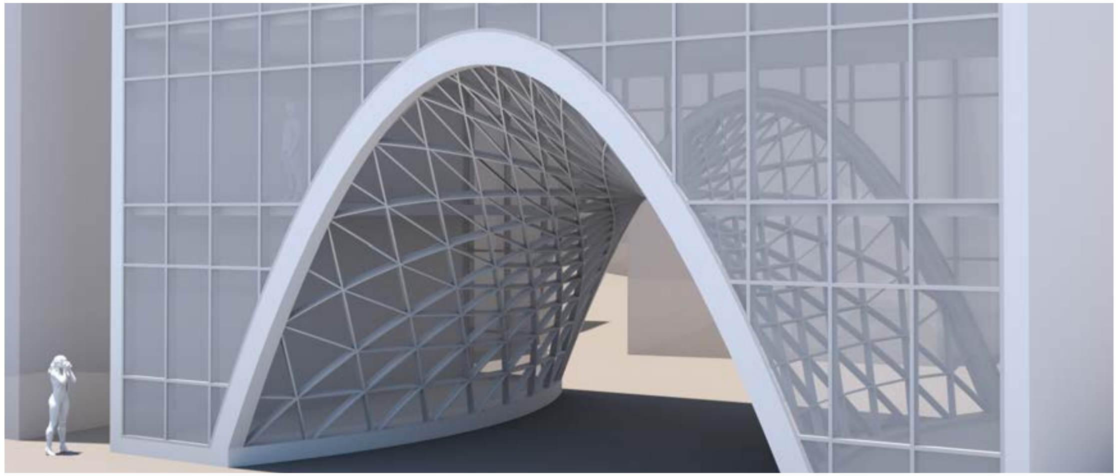


Fig. 1: Arch in Cube- Facade Integration

Span
5 - 12 m

Material
Steel

Construction Method
Prefabricate

Target Group
Urban Inhabitants

Introduction

The course introduces the functions, methods and application of structure gridshell in different aspects of architectural designs. My proposal is .to design a facade that integrate into an middle-height building. The facade can be a glimpse, that supply a lightweight visual perception in Hong Kong´s heavy urban context.

Gridshell Structure benefits structural stiffness, behaves well on carrying the load and bearing the wind. The organic form activate the interior and exterior context. People can efficiently walk under the building, and being attracted by the inside exhibition and outside context of the gridshell structure.

The arch-like facade idea was inspired by Effel Tower, supplying a shading path and observation square.

KEY CONCEPT

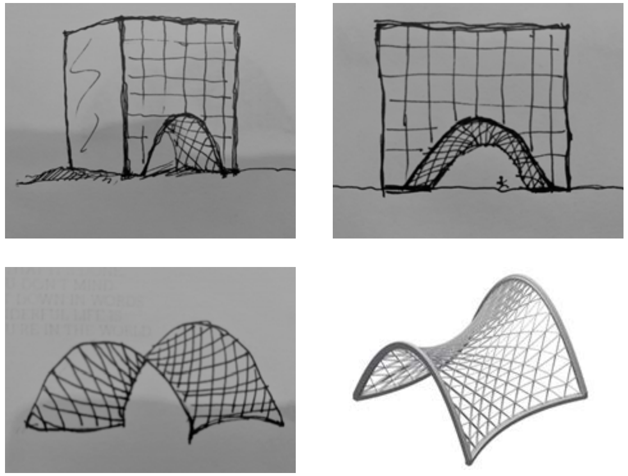


Fig. 2: Concept sketches

Challanges

The scale of the facade needs to be controlled in a small size but well integrated into a normal building.

The facade supports, joints and construction need to be well chosen and designed. The glass should not be twisted. The supports need to be prefabricated and assembled on site.

Potentials

The gridshell structure is material economic and environmental friendly. double curved surface and multiple layers of mullion provide a visual and structural benefits. Smooth steel strips can be prefabricated and discrete strips can be assembled on site by well numbered and ordered. The triangular repetitive pattern makes material efficiently ,avoiding twisted glass technique.

Case Study 1: Busan Opera House

Location:
Busan, South Korea

Time:
2012-2020

Architectural Concept

The form is derived from Busan's context and culture. The layout refers to Kun (Heaven) meeting Kon (Earth) which again meet Kam (Water). The classical trigrams of these elements describe this site exceptionally well, whilst also referring to the historical and philosophical relationships of great importance to Korean culture.

Functions

The Busan opera house is located on a waterfront reclaimed land, converting a passive playground into a interactive, democratic space, responding to the public's ambitions and interests.

It uses the triangle glass and opaque panels enveloping the public functions in a soft flowing skin, offering protection and transparency to the foyer within and linking the ground plane to the roof plane in an unbroken movement.

Source:
https://snohetta.com/project/12-busan-opera-house

Fig. 3: Outside view

Fig. 4: Inside view

Fig. 5: Typical joints and supports

Case Study 2: Schubert Club Band Shell

Location:
Raspberry Island, Mississippi River, U.S

Time:
2002

Span: 15.2 m
Width: 7.6m
Rise: 3.4 m
Mesh: Quadrangular mesh (0.8*0.8m / 0.8*1m)
Grid bars: Tubes (d=40mm)
Glass: Single glazing laminated safety glass (2*6mm)
Diagonal Rods: High-strength (d=8mm)
Bolted node

Architectural Concept

The band shell is an outdoor venue for concerts and performing arts. The island with scenic vistas in a central location had been neglected for many years but now offers the Band Shell and pedestrian walkways.

Functions

The double curved glass roof has a saddle-shaped surface and consists of a grid of stainless steel pipes with quadrangular meshes.

The free-standing, self-supporting shell is designed bear high snow loads, temperature fluctuations of up to 50 Kelvin and floods without damage.

The design is a stable, yet delicate, anticlastic shell structure. Both at day and at night, when the shell can be illumintated, it serves as a new landmark. The innovative steel and glass structure has helped to reincorporate the island into the surrounding urban fabric.

Source:
https://www.sbp.de/en/project/schubert-club-band-shell/

Fig. 6: Outside view

Fig. 7: Typical joints and supports

Case Study 3: Facts Emporia

Location:
Malmo, Sweden

Time:
2012

Architectural Concept

Emporia is a first urban planning project that offices, housing, and retail coming together in a mixed-use development. The main idea of this complex entry was to hide inward-looking retail. The whole shopping complex would integrate into the fabric of the city.

Functions

Double-bent glass encloses the diagonal slit that cuts through the building.

The shell in the building seems like being made up by thousands of discrete pipes that connected by cross joints.

Source:
https://www.archdaily.com/386107/facts-emporia-wingardhs

Fig. 9: Outside view

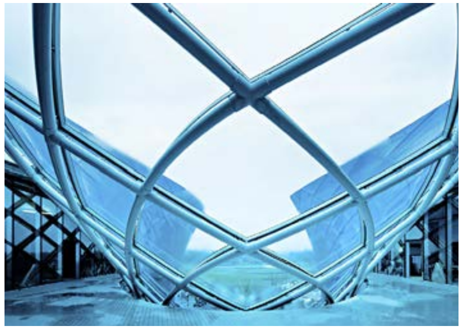


Fig. 10: Inside view

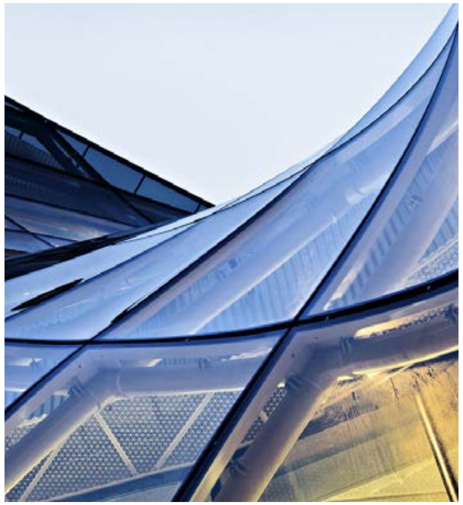


Fig. 11: Typical joints and supports

Design Process

The design process started from three curved lines. They form a saddle-like double curved surface. And the grid shell organic cover the whole surface with quadrangular grids. In order to avoid creating twisted glass. The glass seal will cut diagonally in each quadrangular grid.

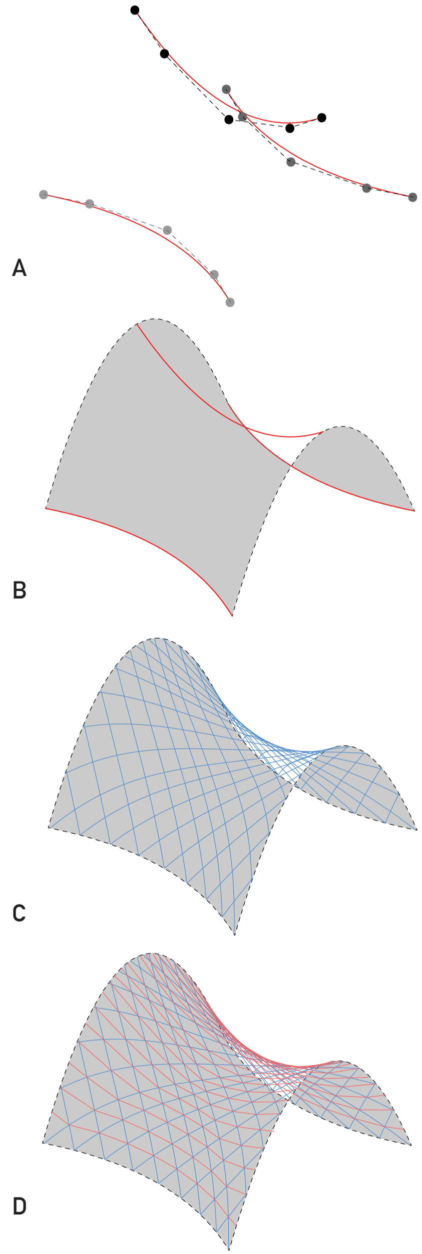


Fig. 12: Design process

Typical Support

The detailed construction system learned from the Effel tower pavilion. There are two directions of lamellas. One direction is smooth and one direction is discrete. There are four layers in this façade. Glass, and smooth steel lamellas and the discrete curved pipe support, and the grey seal avoiding twisted glasses. The whole construction can be prefabricated and assembled on site. They have a coding system for the engineers to figure out each assemblage position.

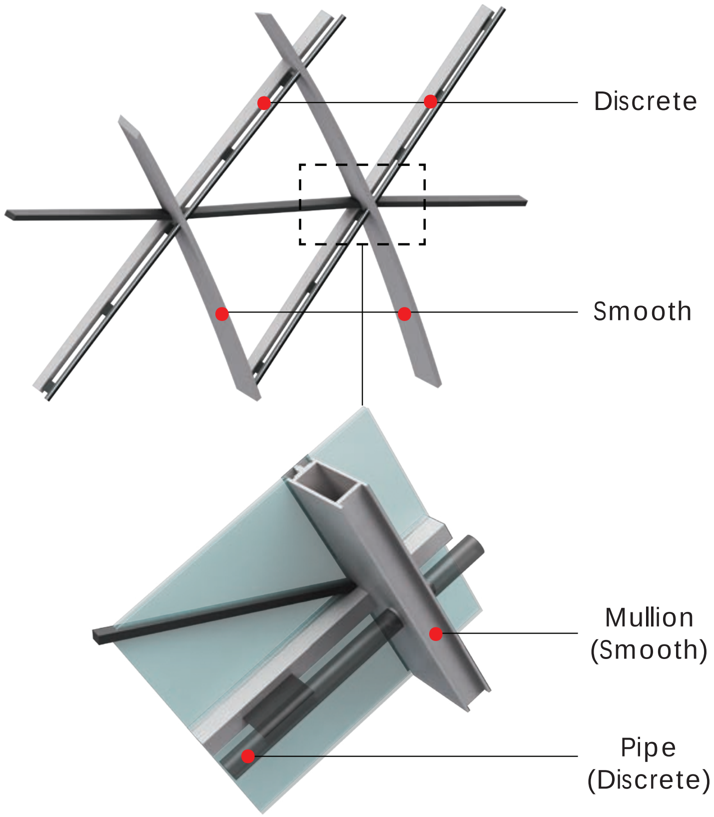


Fig. 13: Joints / Support Details

Fig. 14: Render

Fig. 15: Construction process A, B, C, D

Site

The facade design is integrated into a small gallery building. And the building sits in the surrounding small scale commercial shops and art complex facing to the Hong Kong seaside.

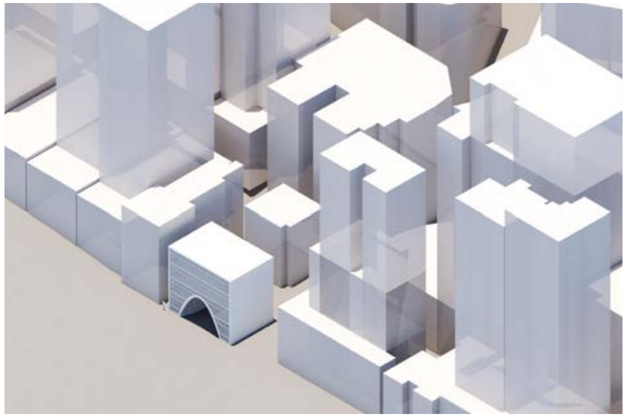


Fig. 16: Site perspective

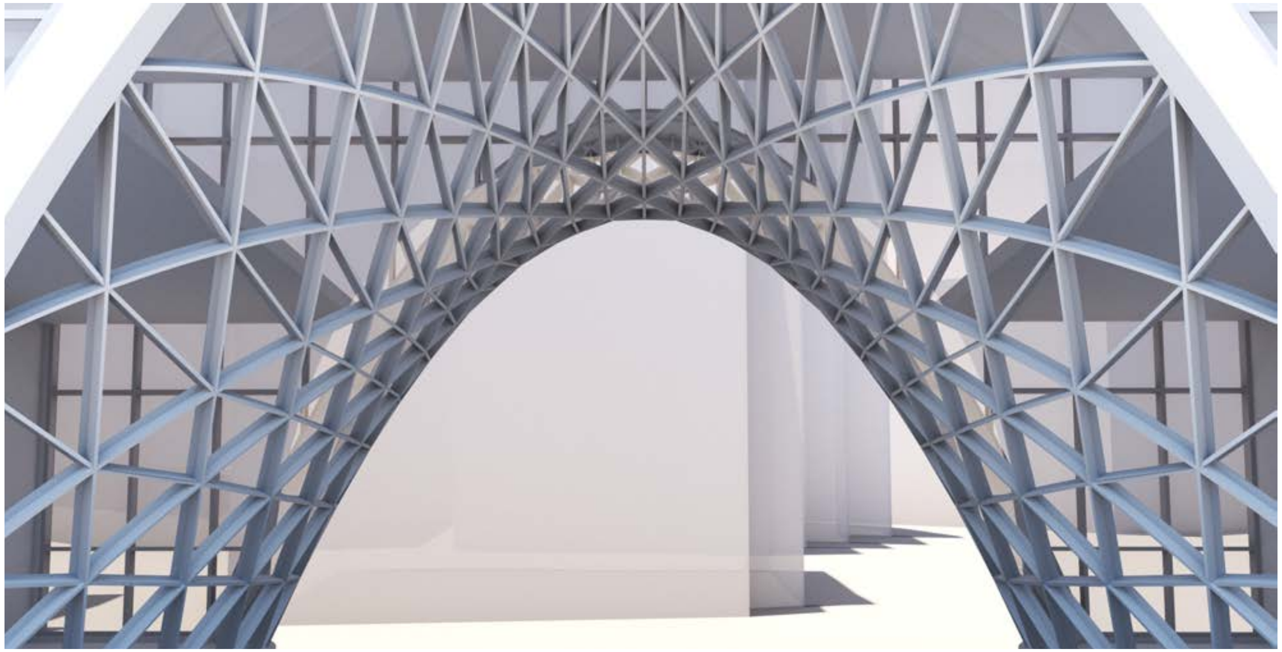


Fig. 18: Structural grid and envelope

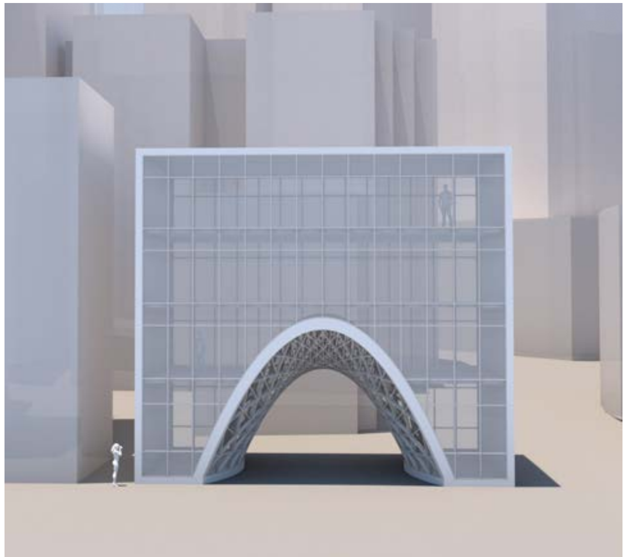


Fig. 17: front elevation

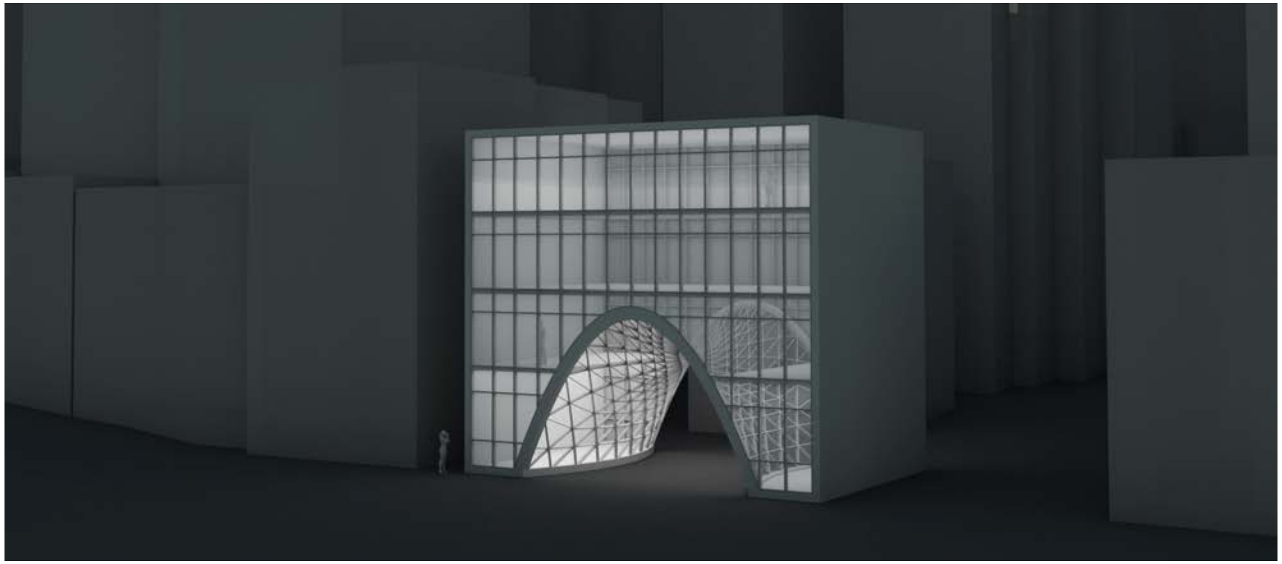


Fig. 19: Night render

Architectural Concept & Functions

The arch double curved facade was built in the middle of the lobby, like a transparent bridge connected two sides of the building.

The arch-like facade idea was inspired by Effel Tower, supplying a shading path and observation square.

Gridshell Structure benefits structural stiffness, behaves well on carrying the load and bearing the wind. The organic form activate the interior and exterior context. People can efficiently walk under the building, and being attracted by the inside exhibition and outside context of the gridshell structure.

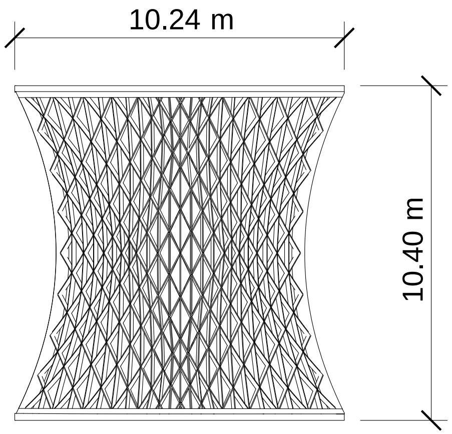


Fig. 20: Top view

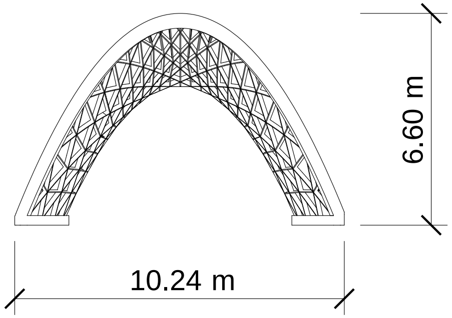


Fig. 21: Front elevation

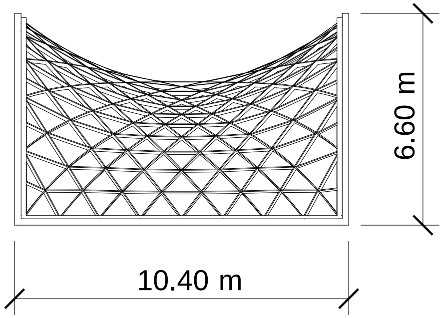


Fig. 22: Left / Right elevation

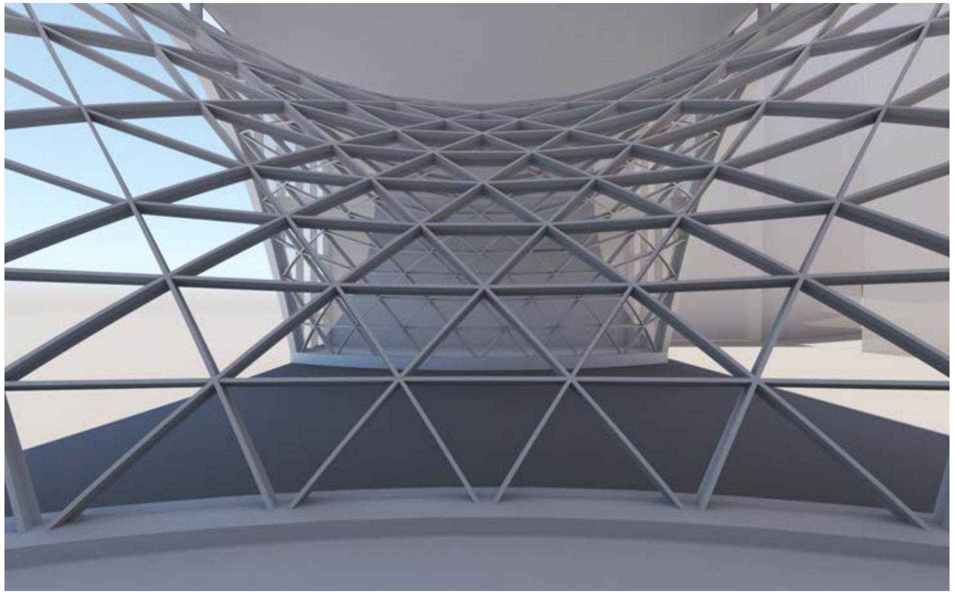
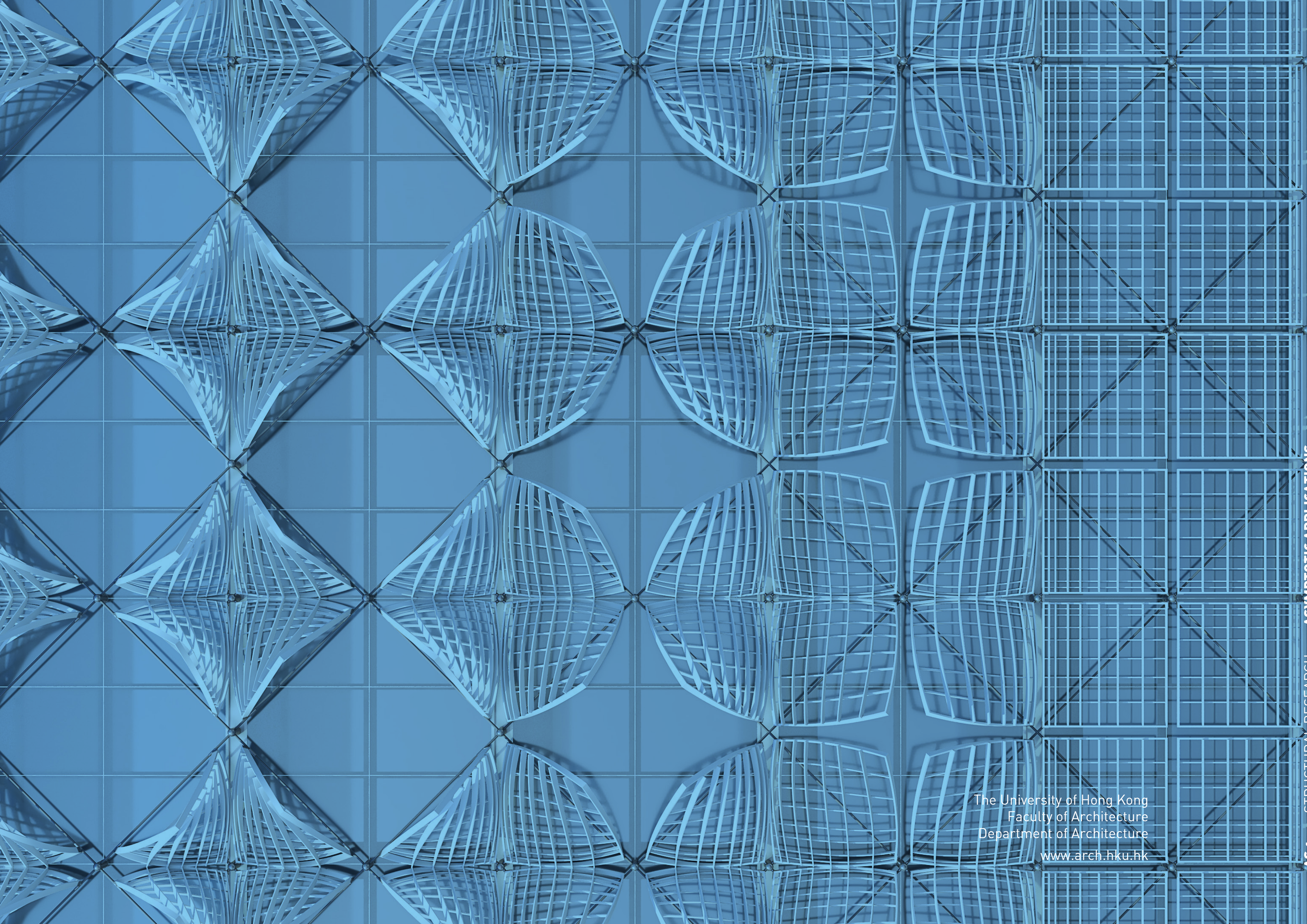


Fig. 23: Interior render

Fig. 24: Interior render



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STRUCTURAL RESEARCH ASYMPTOTIC APPLICATIONS