The Ginkgo Shell

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Dieses Baums Blatt, der von Osten
Meinem Garten anvertraut,
Giebt geheimen Sinn zu kosten,
Wie's den Wissenden erbaut,

Ist es Ein lebendig Wesen,
Das sich in sich selbst getrennt?
Sind es zwei, die sich erlesen,
Daß man sie als Eines kennt?

Solche Frage zu erwidern,
Fand ich wohl den rechten Sinn,
Fühlst du nicht an meinen Liedern,
Daß ich Eins und doppelt bin?

In my garden's care and favour
From the East this tree's leaf shows
Secret sense for us to savour
And uplifts the one who knows.

Is it but one being single
Which as same itself divides?
Are there two which choose to mingle
So that each as one now hides?

As the answer to such question
I have found a sense that's true:
Is it not my songs' suggestion
That I'm one and also two?

Gingo Biloba
Johann Wolfgan von Goethe

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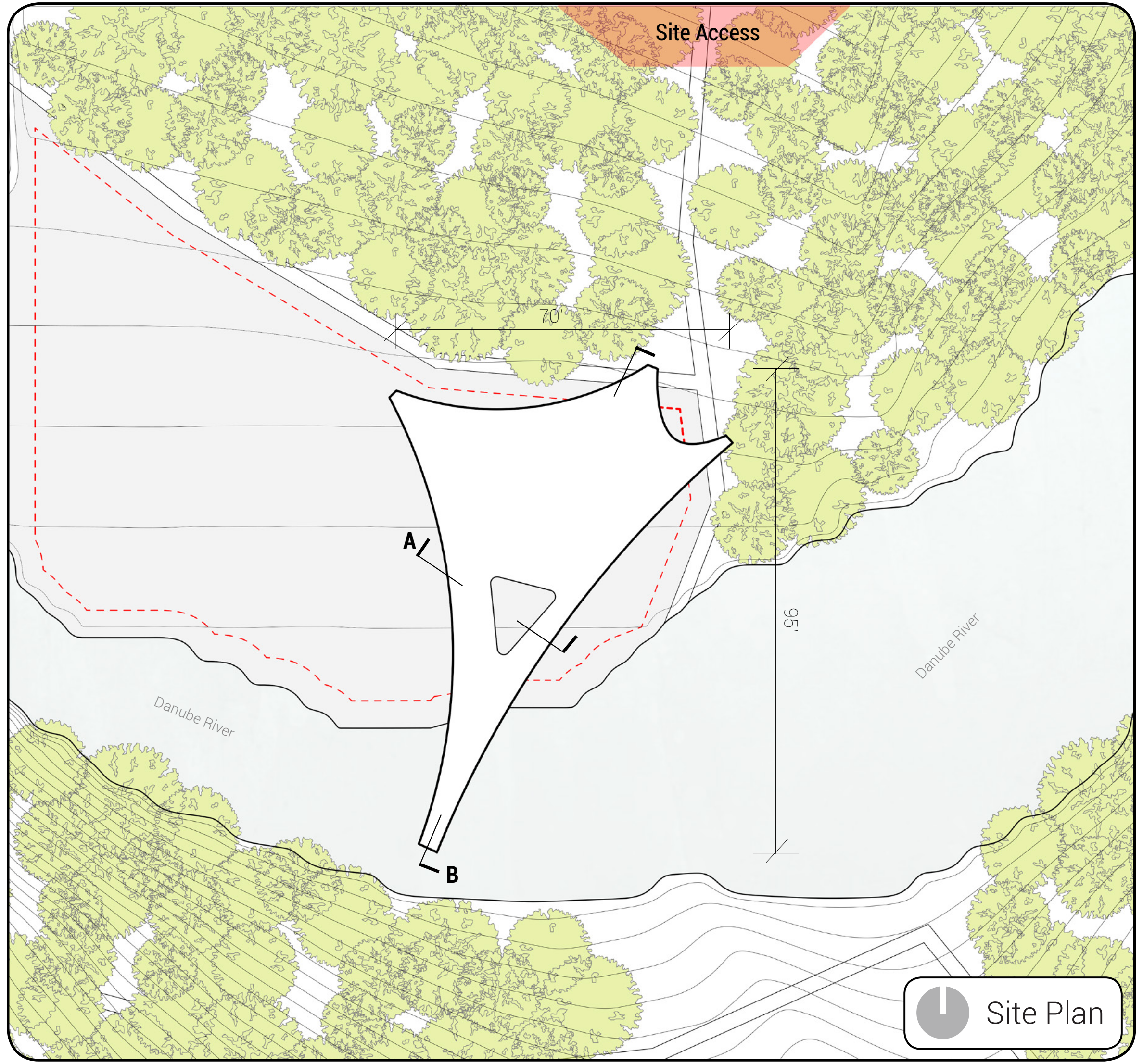
Shell Design

Overall Design

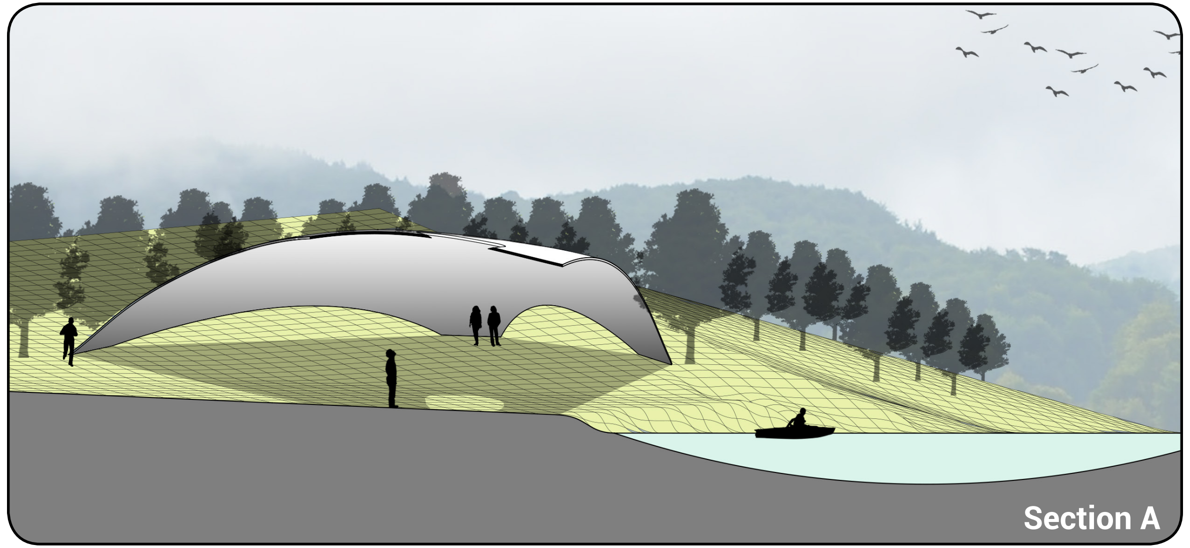
The overall concept for this outdoor concrete shell structure, located in Furstliche Park in Inzigkofen, Germany, is derived from an **abstracted ginkgo leaf.** Drawing on inspiration from a poem about the two parts of the ginkgo leaf becoming one, we took the approach of **combining both the natural and built environment** into one cohesive piece.

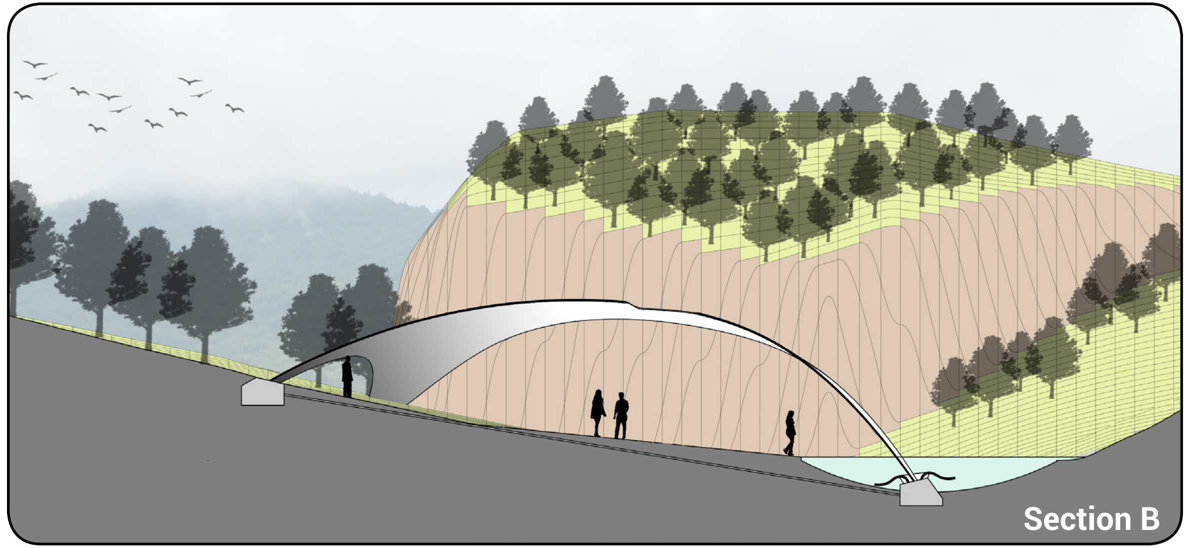
To connect the two, it was imperative that we place the shell on the site as to have the **smallest impact.** With a small portion of the overall site used, the unoccupied space further enhances the natural environment. Creating a literal design **connection between the land and water**, one of the four allowed legs falls within the Danube River.



Site Plan

Design Considerations


Section A


Section B

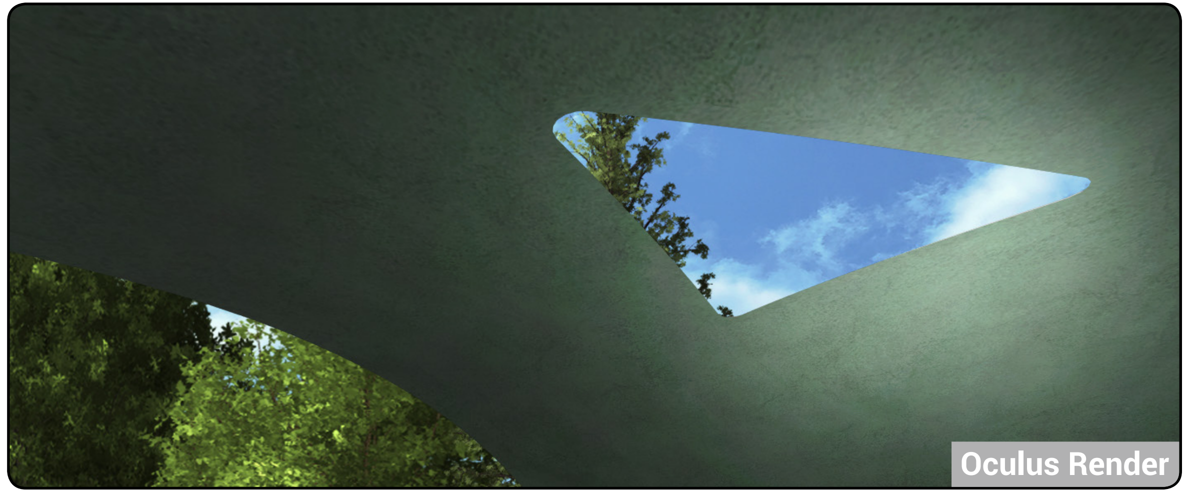
The purpose of the structure is to highlight the **surrounding views** and landscape through the use of large openings. Providing direct sight lines to both the forest and a historical carving, each side of the shell provides a **frame to the outside world**. To further this experience, the entrance of the structure is low, blocking one's line of sight until they enter the space.

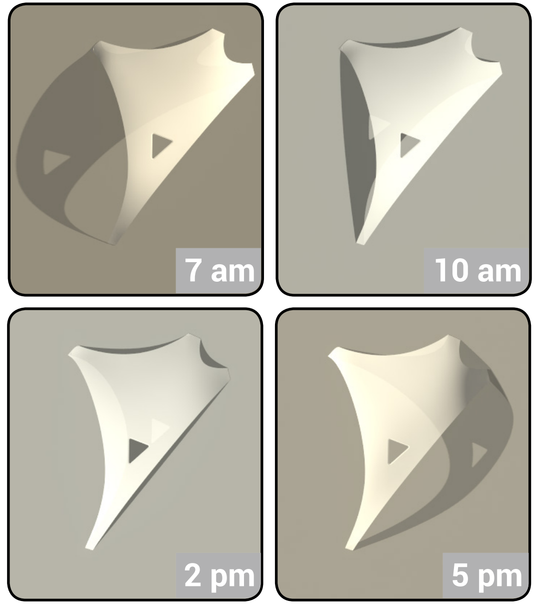
Choosing to design the structure with an overall max height close to the river, visitors transition from nature to the built environment while also experiencing the "lifting" of the shell, contributing to a **lightweight feel**. The oculus is also placed at the peak of the structure to further **minimize the presence** of the shell, opening it up to the sky.

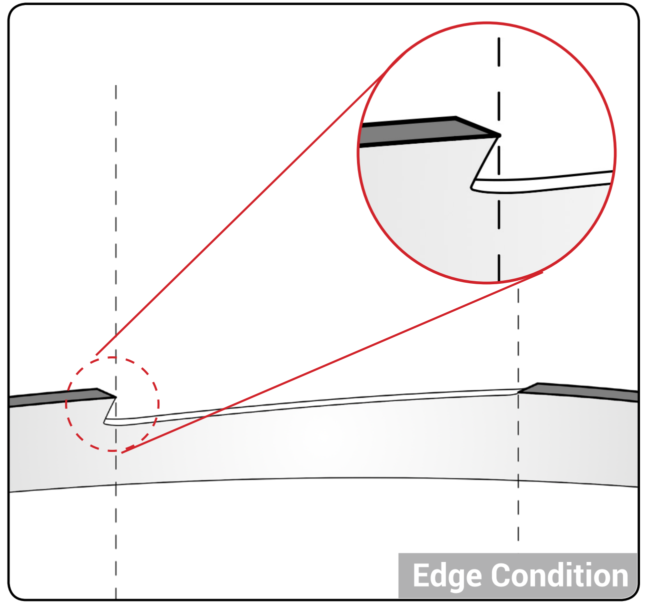
Detail | Oculus

The oculus design for the structure is a **further abstraction** of the overall form. Taking into consideration the large openings on the sides of the shell, the oculus is meant to act as a way point, **drawing the viewer into the space** and towards the river. Along with this, the oculus shadow moves throughout the day, **highlighting the views** of the site as they become illuminated.

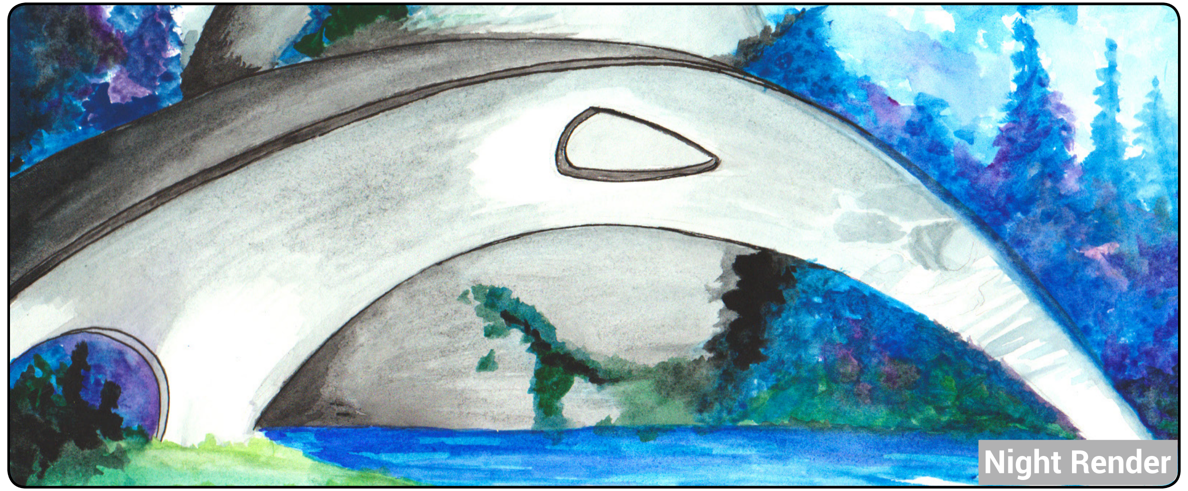
In an attempt to **link the ground and the sky**, the edge of the oculus is chamfered, creating a **sharp edge frame**. This edge condition blurs the distance between the built structure and what is in view, flattening the sense of space. The top edge is offset as to hide the connection and provide a smooth corner.

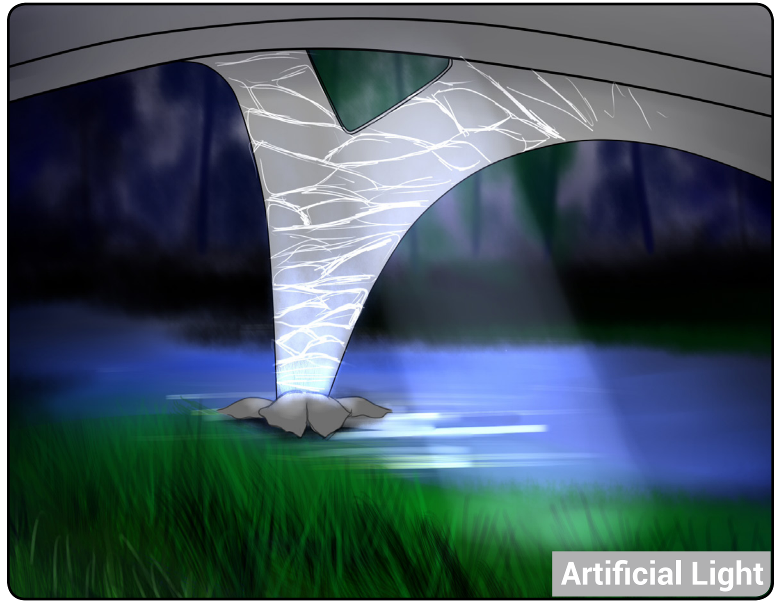

Oculus Render

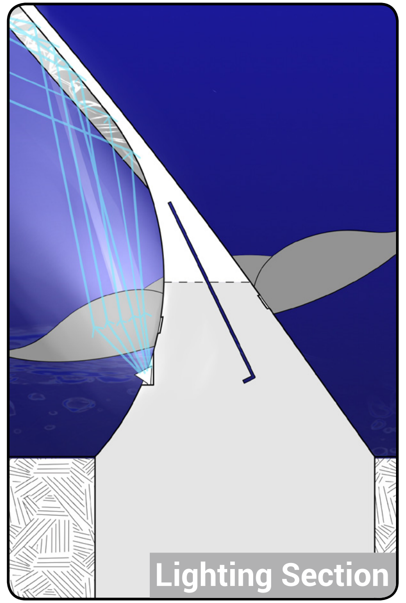



Edge Condition

Detail | Lighting


Night Render


Artificial Light

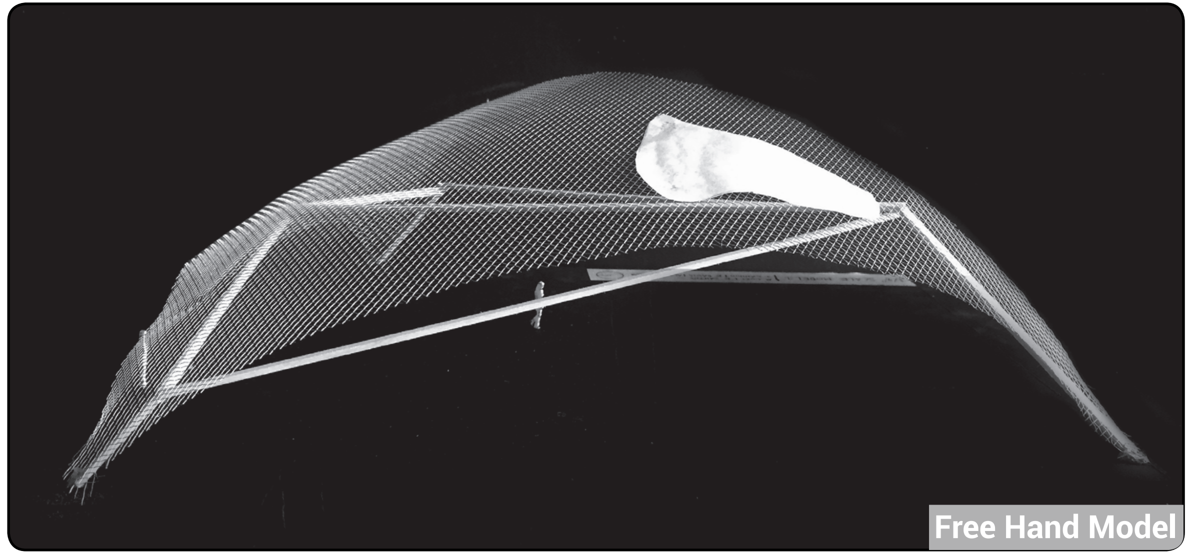

Lighting Section

During the day, the main light source is the sun. Asides from being lit throughout most of the day, the oculus, as mentioned before, creates an experience for the visitors as the light moves through the space.

At night, the main light source exists **under the river**, shining up through the water and onto the surface of the structure. This lighting technique will **project the water's movement and shadow** onto the concrete. Casting a texture onto an otherwise smooth surface will create a dynamic relationship between the structure and its surroundings. With the use of only one light source, users will be **drawn to the water's edge** and away from the dark.

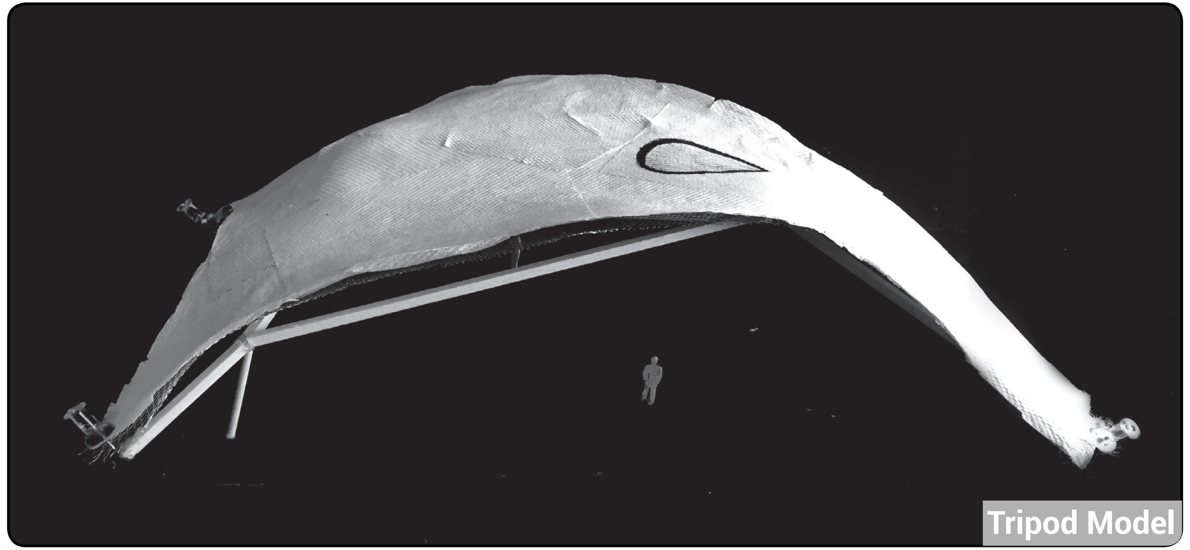
Study Model Process

To begin modeling the shell structure, we used two tripods (an exercise done with **GeoGebra**) with one similar strut, creating a four-legged funicular structure. With the computer program at our disposal, we attempted to create a "quadpod", however the method was not working and this model demonstrates a **free hand** attempt.



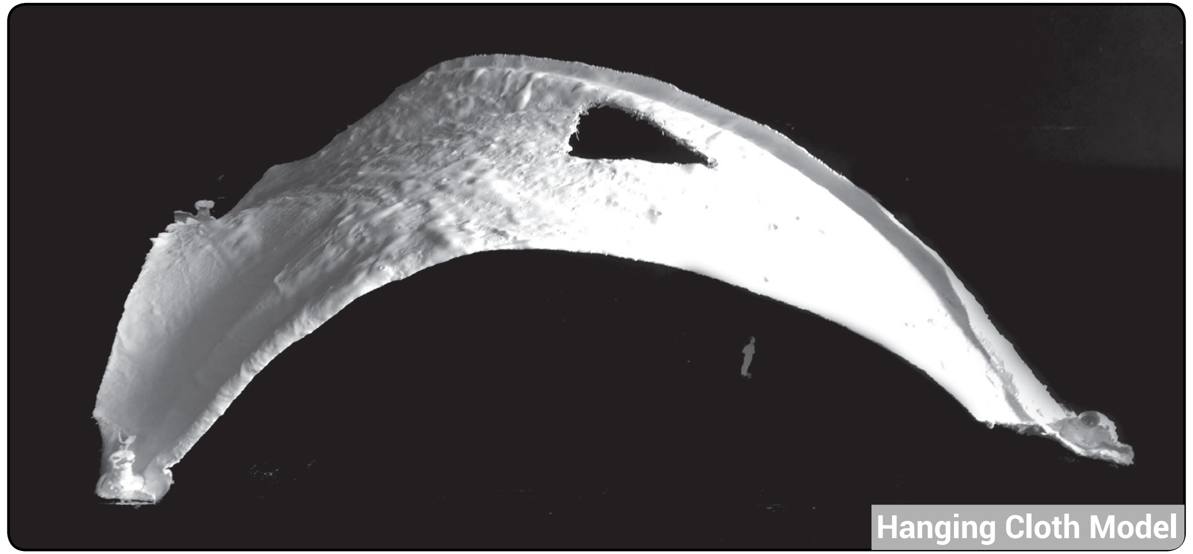
Free Hand Model

The second model was created with the idea of two tripods combined. Using the computer model, analyzed to be **funicular,** we were able to measure the length of each segment and assemble using basswood. We then **paper-mached** a wire mesh form on top of the tripods, however it was hard to match the supporting structure.



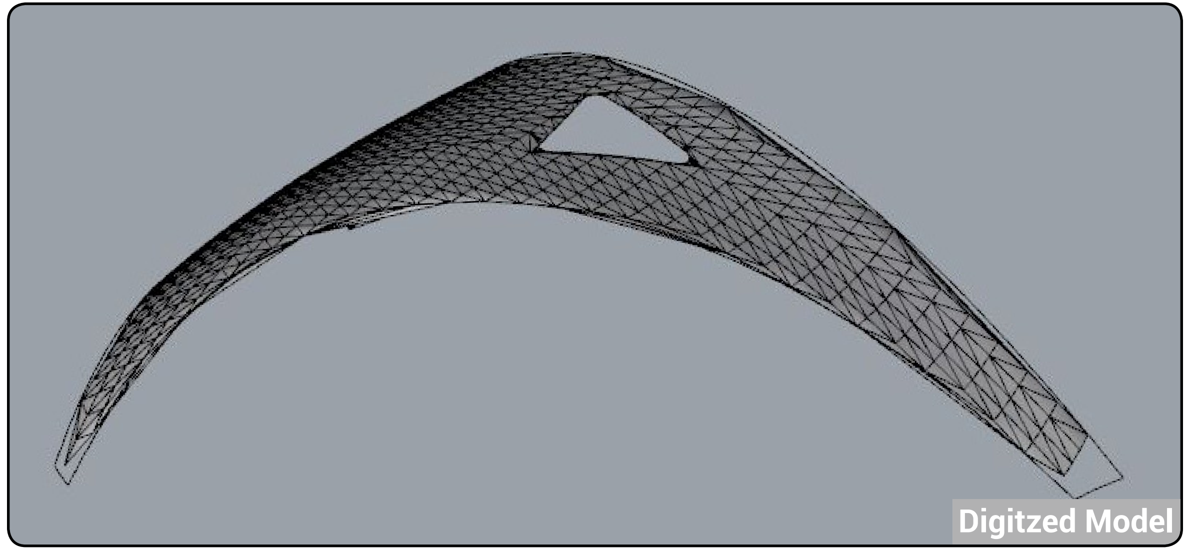
Tripod Model

Digitizing



Hanging Cloth Model

Moving away from the tripod analysis, we chose to create a **hanging cloth model** instead. The concept behind this model is that a cloth, when hung, is experiencing only tensile forces. When "frozen" in place and flipped, the fabric becomes a **compression only** structure. To achieve this, we dipped the cloth in **plaster** as it was hung.



Digitzed Model

Once we had a working model, the challenge became transitioning from a physical to a digital model. It was important to carry over the exact model as we proved it was funicular in its physical form. To do so, we used a **3d digitizer** tool, which creates a **series of points** along the surface of the physical model and imports them to rhino.

Shell Analysis

SAP Analysis

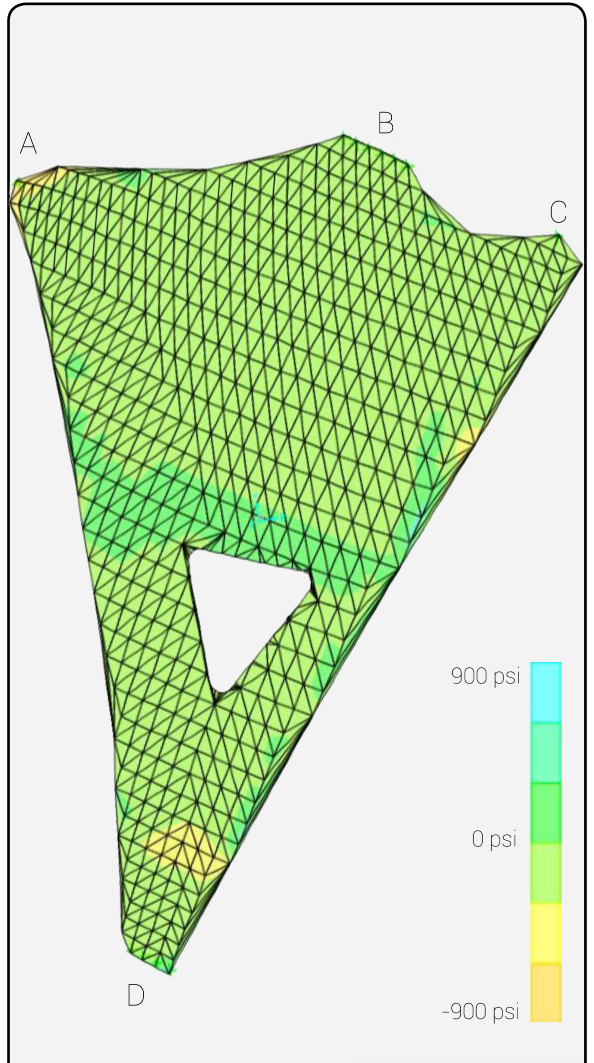
Transitioning from the hanging cloth model to a rhino model, SAP was used to confirm that the shell was both funicular **(compression only)** and capable of withstanding forces. Upon analysis, the shell was found to have an area of **tensile forces,** however this is due to **inaccuracies** in the digitizing process and was not seen as an issue.

Shell Span = 95' x 70'
Overall Thickness = 2 in.
Surface Area = 2328 ft^2
Overall Weight = 68 k
Shell Deflection = 0.65 in

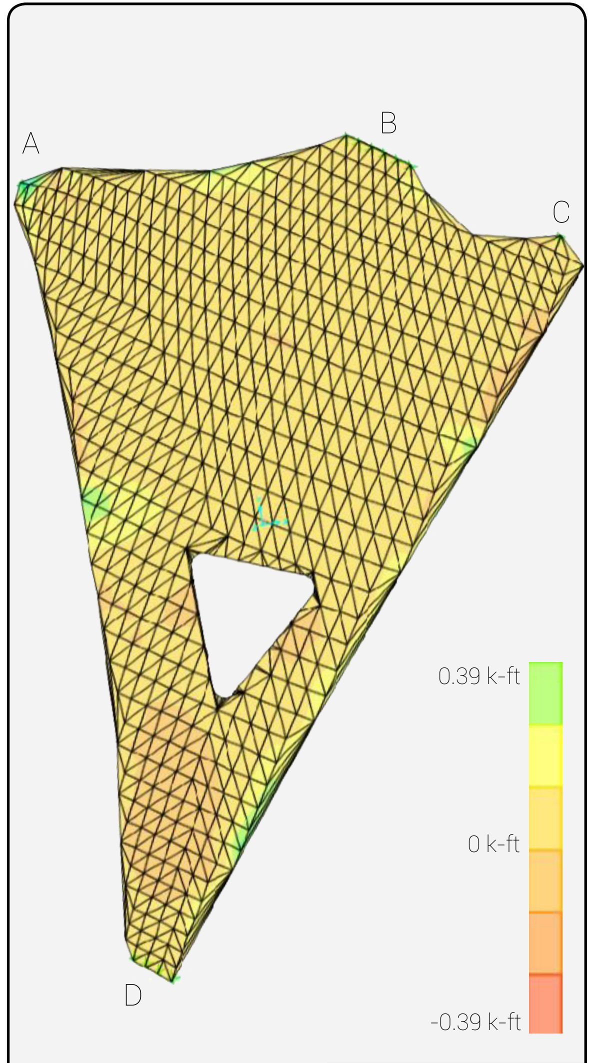
Worst Stresses = 650 psi
Average Stress = 60 psi

Worst Bending = 0.7 k-ft

Thrust at A = 17k
Thrust at B = 17 k
Thrust at C = 17 k
Thrust at D = 37 k

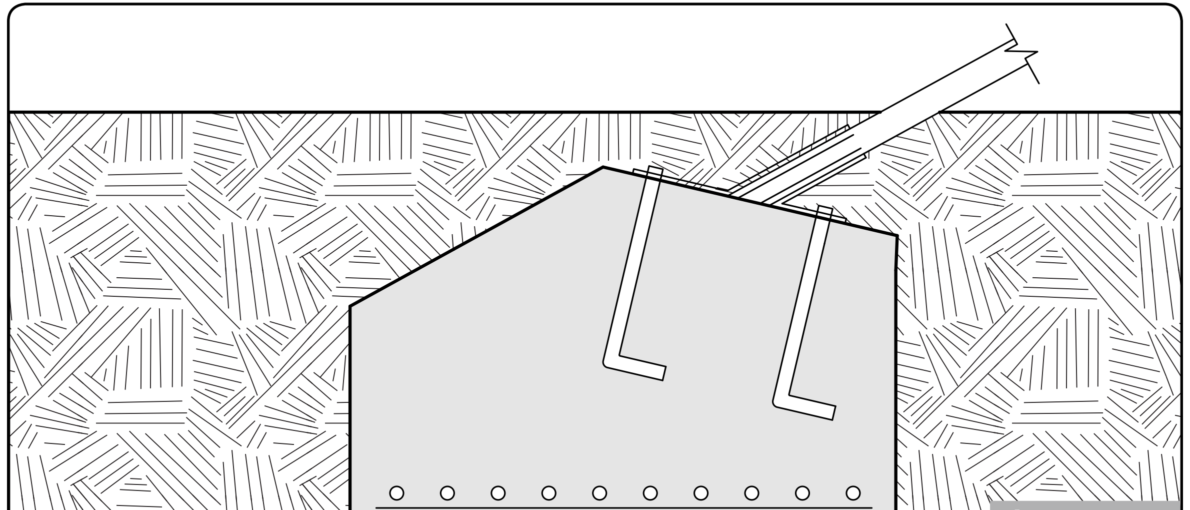


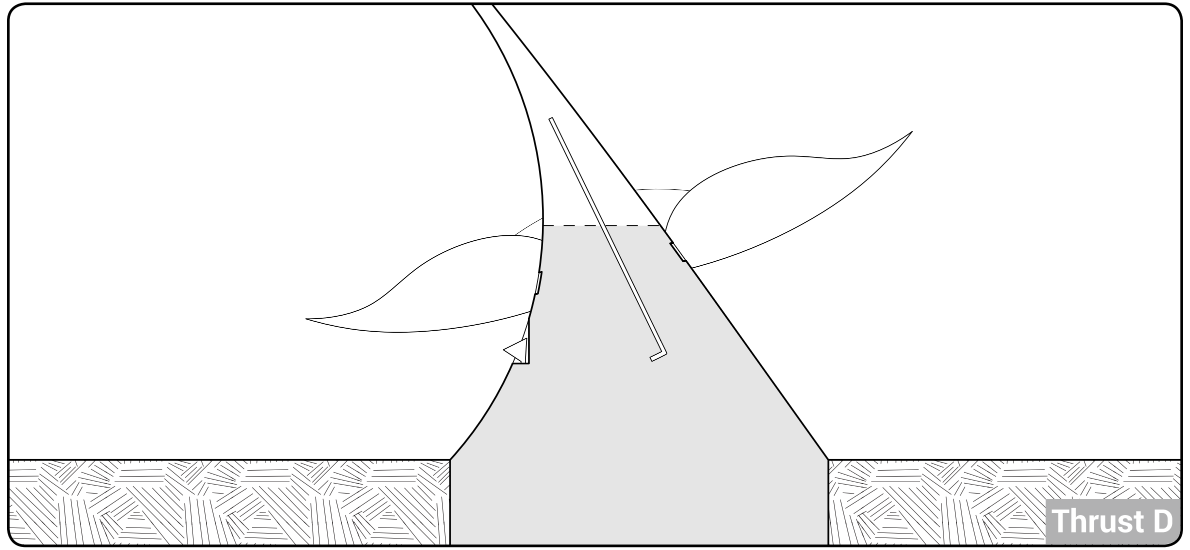
Stress Analysis



Bending Analysis

Thrust Containment


Thrust A,B,C


Thrust D

The primary method of thrust containment for all three land connections is a **spread footing** with an angled top surface at each point on contact. This slope will allow the foundation to better receive the struts coming in at an angle. The blocks on land are hidden **underground** as to not disturb the simplistic and natural feel of the shell.

The foundation in the river will be visible as the **water level fluctuates**. With this in mind, the connection between the shell and footing is made seamless, following the curve of the shell. This sculptural footing **blurs the line between support and structure**, however it is designed to become a **pile** once it hits the riverbed, counteracting the poor soil conditions of the river.

Construction Precedents

The first precedent study done to legitimize the full scale construction process was the **LAM Pavilion** in Lille, France. Although this structure is not a concrete shell, this project was chosen to demonstrate the amount of **customization** within inflatable structures. This structure in particular spans about 100 feet and the interior of the material is inflated.

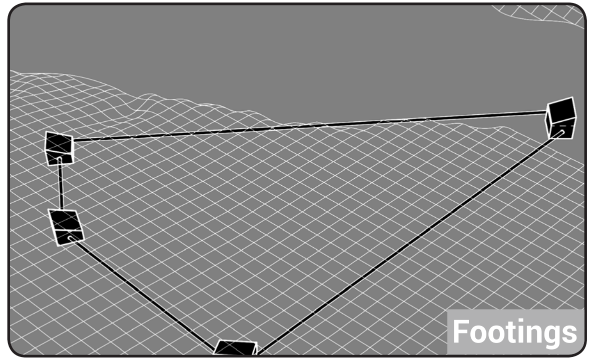
The second precedent study was focused on finding a real life example of inflatable formwork. **Binishells** is a company which specializes in custom **inflatables** used in creating formwork. With a variety of systems used for construction, this method allows for **unique concrete forms** with minimal overall material needed to form the structure.

LAM Pavilion

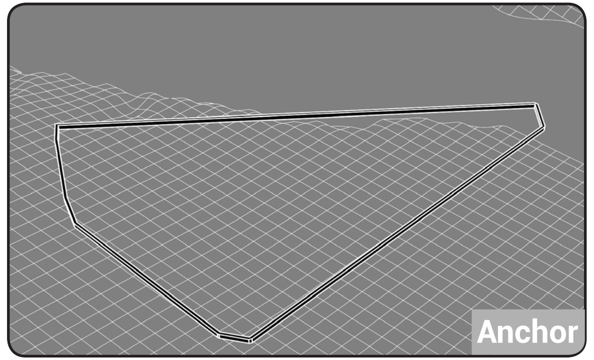
Shell Construction

Binishell System 4

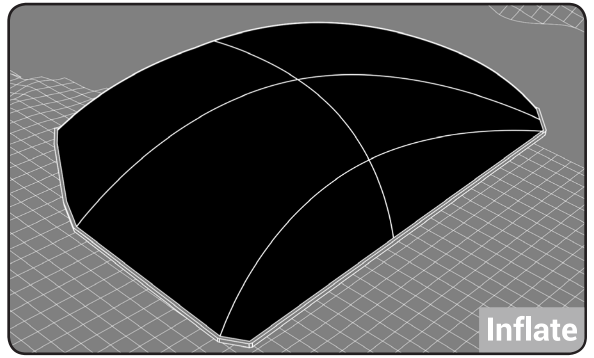
Large Scale Construction



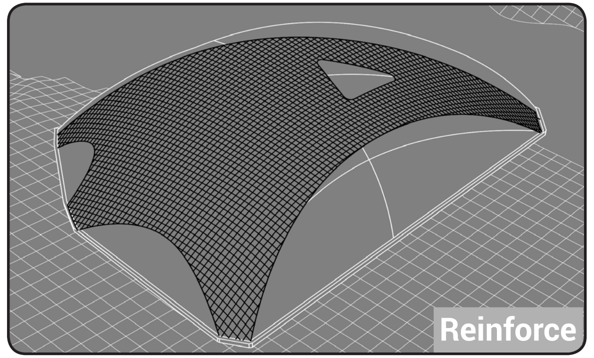
Footings



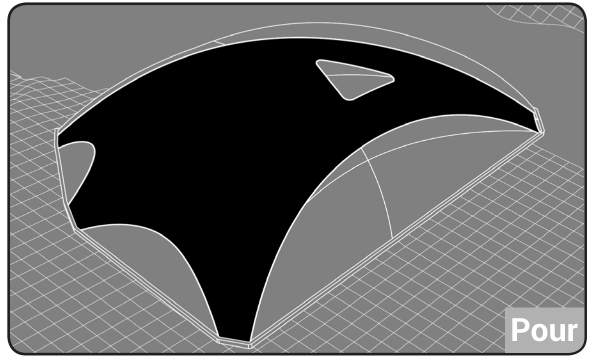
Anchor



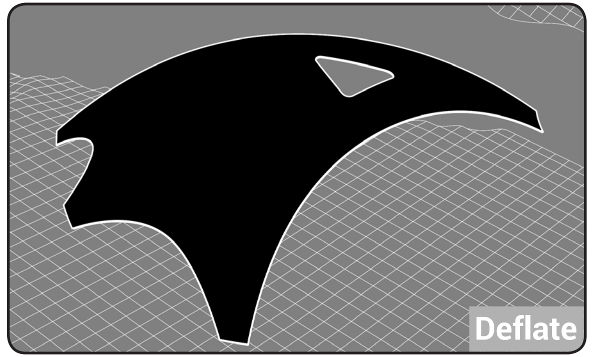
Inflate



Reinforce



Pour



Deflate

Given the isolated and dense nature of the project's site, the ability to transport standard construction materials is limited. With an access point located 400 feet way, it is important to consider the **feasibility of construction**. With an emphasis on **low impact** and material usage, the decision to use inflatable formwork was made.

In terms of large scale construction process, the formwork for the footings would be built first, with an edge beam placed between. This beam would serve an anchoring point for the inflatable form. Once sealed and connected, the form would be inflated, making sure to keep a **constant air pressure**. Once inflated, the desired form is made using **Shotcrete.**

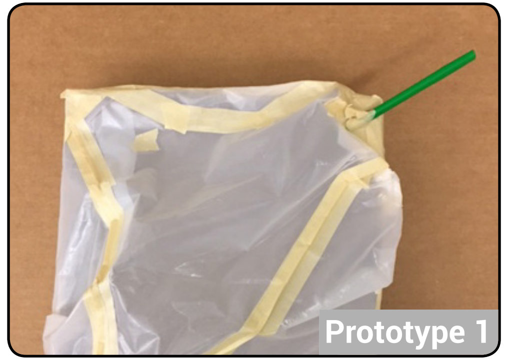
Shell Realization

Prototyping

The main goal of the prototyping process was to create quick and simple models that highlighted the positive and negative effects of using certain **materials and methods** to create an inflatable. Listed below are the take-aways from the series of models which led to the final construction.

- ✔ Plastic base cover seals the frame.
- ✘ Straw fails to hold air pressure.
- ✘ Taped seams create air leaks.

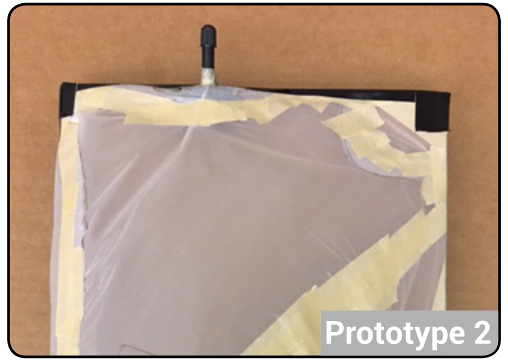
- ✔ Bike wheel nozzle holds air pressure.
- ✔ Ironing the seams creates air tight seal.
- ✘ Connection of side pieces affects form.


Prototype 1


Opening


Seam

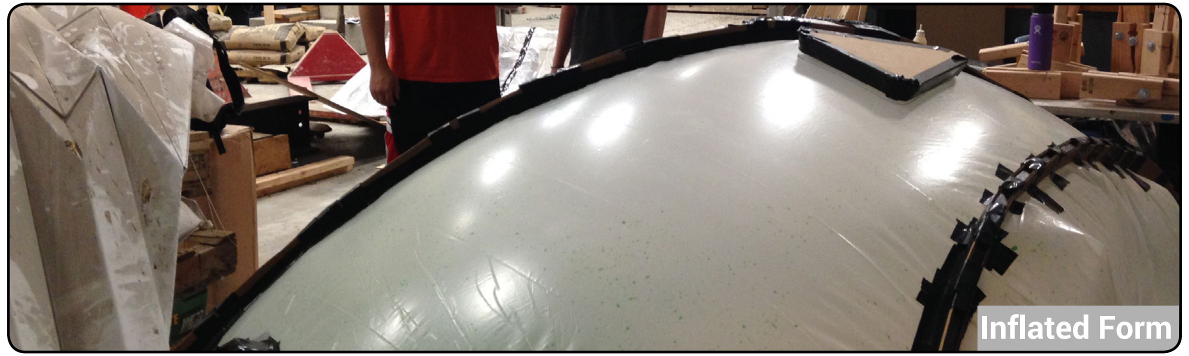

Edge


Prototype 2


Opening


Seam


Edge


Inflated Form

Unroll

In order to ensure that the inflatable takes the desired shape of our shell, we needed to cut a piece of plastic to the exact **flattened shape of the form**. To do this, we used a tool in Rhino called **UnrollSrf** which takes a 3d form and instead of projecting it onto a flat surface, it "unrolls" the surface into a flat 3d shape, taking into account the length needed for curvature.

Process (double curved)

[1] 3d surface

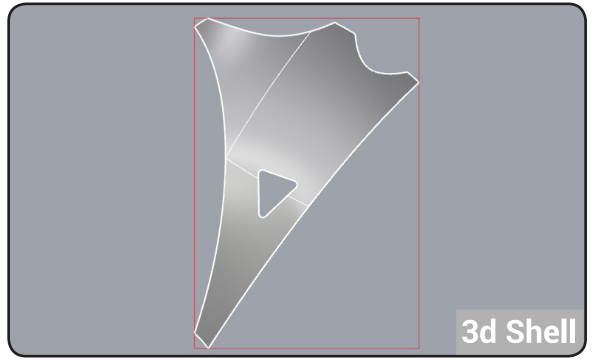
[2] Surface to Mesh

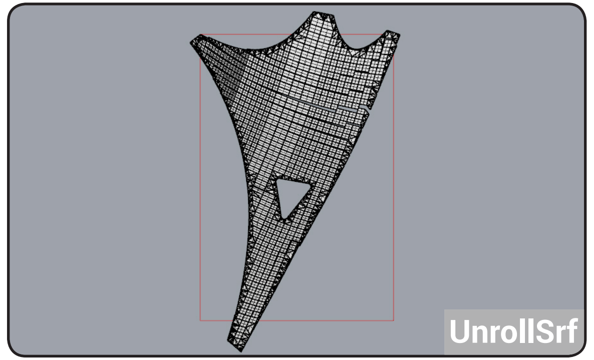
[3] Mesh to NURBS

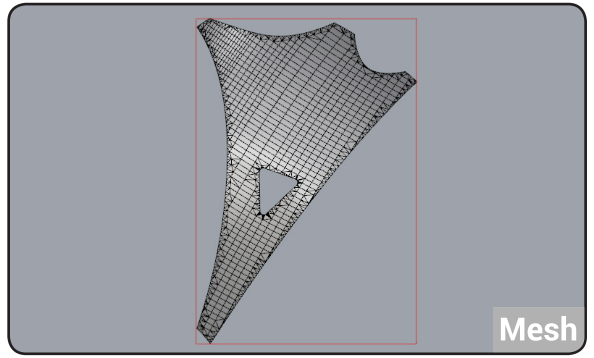
[4] UnrollSrf

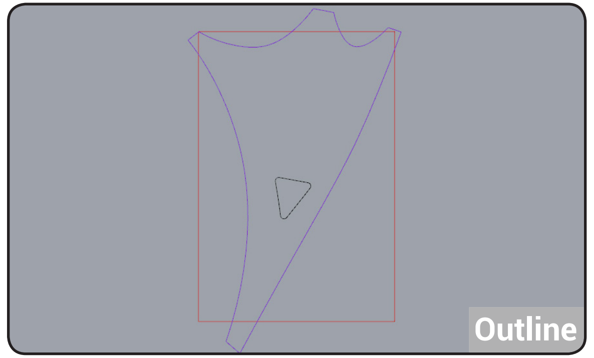
[5] Polyline

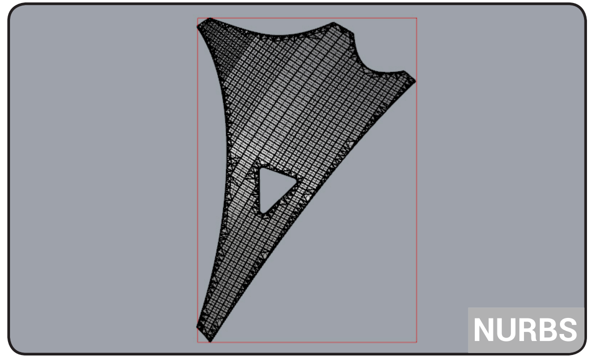
[6] Print File

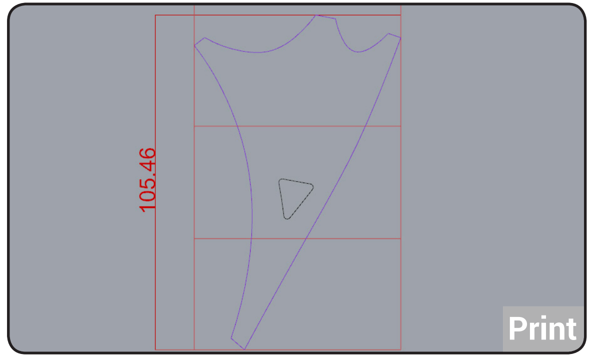

3d Shell


UnrollSrf


Mesh

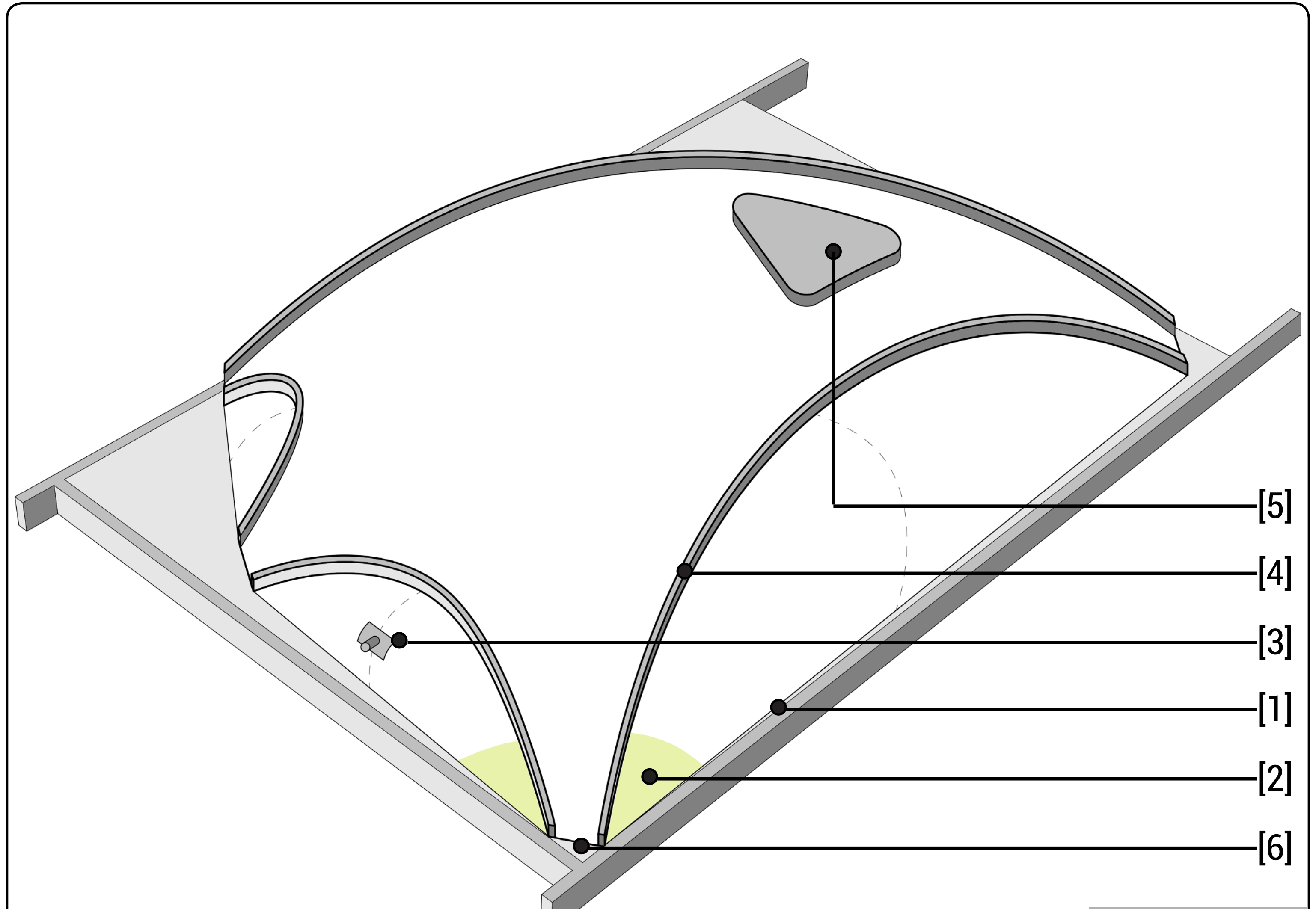

Outline


NURBS



Print

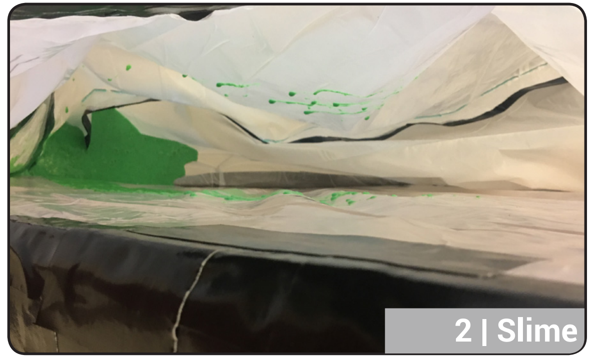
Formwork Process



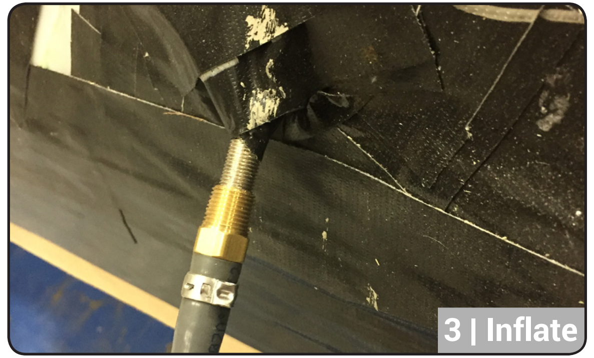
Process Diagram

Formwork Photos

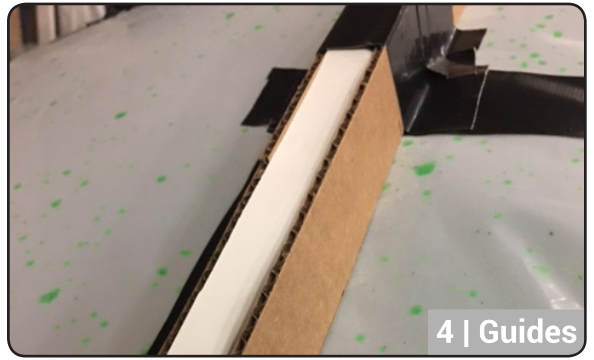
1 | Iron



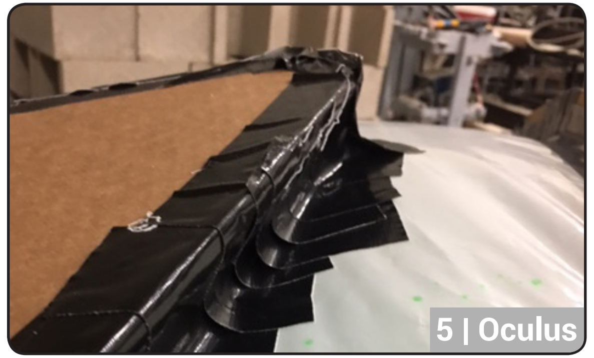
2 | Slime



3 | Inflate



4 | Guides



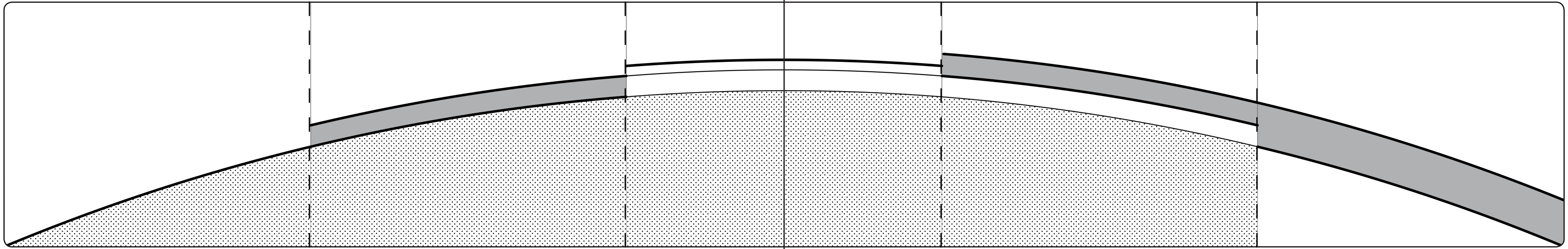
5 | Oculus

6 | Thrust

Once the unrolled surface was printed, traced, and cut out of **painters tarp,** the next step was to create the side pieces. For an easier attachment, although the overall shape of the side pieces has no real effect on the final form, the side curves were traced from the top form and extended. With the pieces cut, the top form was then **ironed to the base** at all 4 legs. From there the side pieces were ironed to the main form. To create an air tight system, we poured **Slime** into the form to plug any holes.

Once inflated, using the bike nozzle and an air compressor, we were able to attach "guides" made of **weatherstripping** and cardboard. To attach the shell to the frame we created **2x4 supports.**

Pouring Process



Inflated structure @30 psi

First layer of concrete

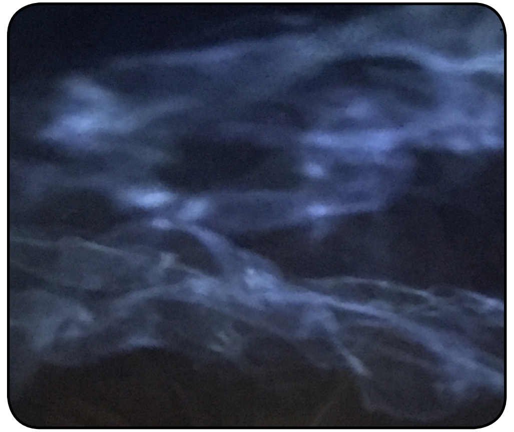
Reinforcement layer | stucco mesh

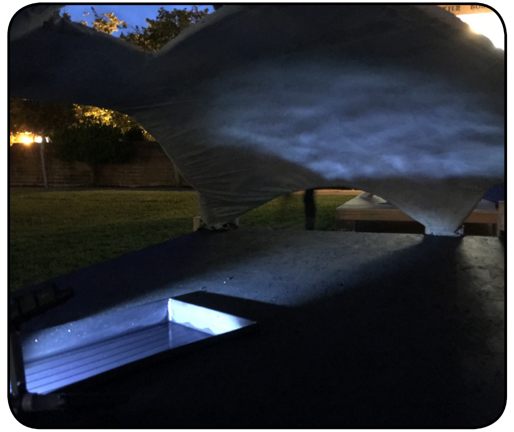
Second layer of concrete

Decentering process | deflation

Final Product

Shell Lighting





Reflection

This quarter introduced us to different ways of designing and analyzing a compressive, funicular, thin shell concrete structure. Our project brief asked for a low impact concrete shell structure located in a natural area in Germany that limited our design to four points of contact to the ground, a challenge that differed from our peers. We began with mathematical models, which served as an initial design method, but through different study models found that the hanging cloth model produced the best design and the most funicular shape as well. It produced the best results in terms of form, as well as structural analysis while consistent with our initial design concept. Our challenge came when it came time to decide the best method to construct the shell. There were arguments between the group between a common construction method and a construction method that was unknown and lacked enough precedents, but proven to be feasible. Ultimately, we decided on pursuing the challenge of creating an inflatable formwork with the risk that it may fail. We had one week to research and create the formwork. After multiple prototypes and models, we successfully ironed together painter's tarp with tape and cardboard reinforcement to create our custom inflatable formwork. We were able to maintain a constant air pressure to keep the formwork inflated, poured the concrete, and removed the formwork after seven days of curing. The project proved to have been worth the hard work and effort in the end. Our group was able to demonstrate that inflatable formwork was more than achievable, it was efficient in the time it took to construct and remove the formwork, and also produced a smooth interior surface in our shell.

Although there were challenges in our design and construction process within the group, as well as outside the group, the final results proved the obstacles to have been worth the effort. We were able to produce results that most of our peers did not expect and rid them of their skepticism. Looking back, there were a few things we could have done that may have helped us in this project. If we had decided earlier in the quarter to build an inflatable formwork, we might have had more research, time, and practice to produce better results. We might also have been better prepared with the supplies and tools we needed, as we constantly improvised on what materials might have worked best. We hope that challenging ourselves to pursue something outside of our comfort zone will serve as an example to future students who wish to explore inflatable formworks or those who wish to approach a problem different from everyone else.