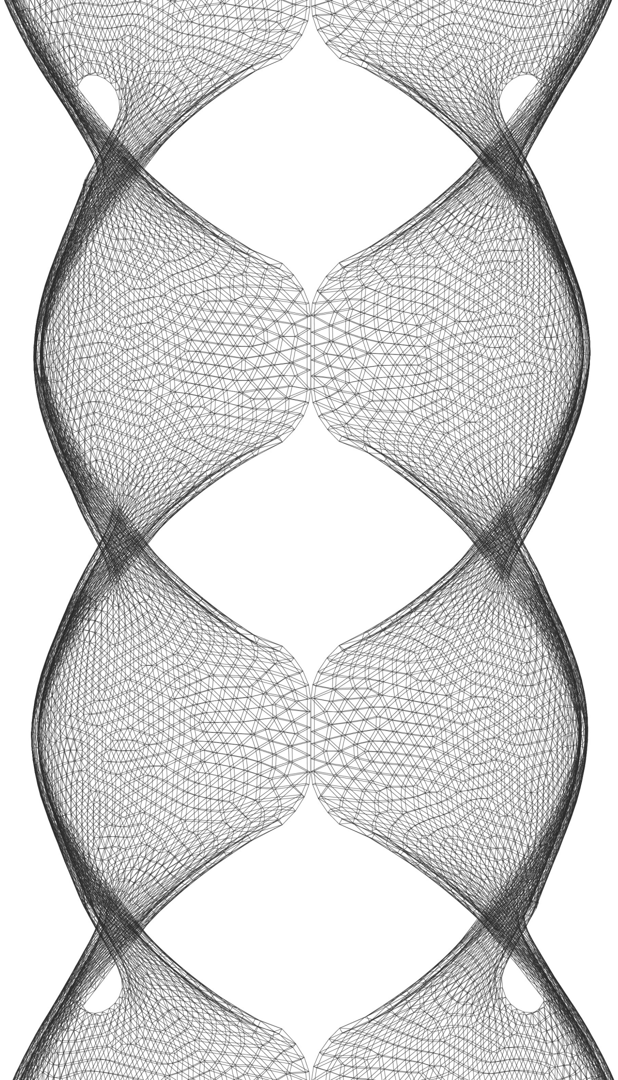
SAGE GARDEN PAVILLION SHADE STRUCTURE

ARCE 415 | ARCH 453 | SPRING 2022 | INTERDISCIPLINARY SENIOR PROJECT

PROJECT INTRODUCTION



TEAM HADID

Sarah Holt | *Architecture*

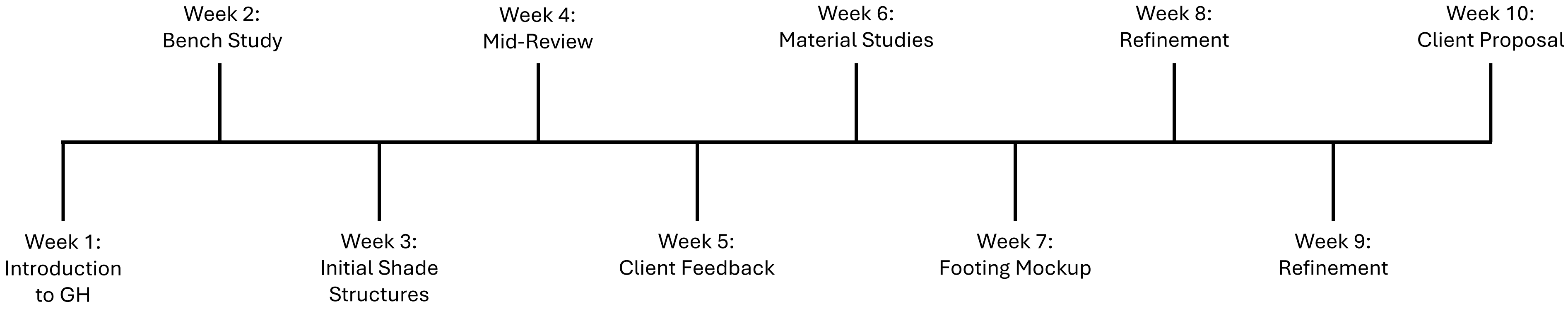
Marisa Martineau | *Architecture & Psychology*

Matthew Kilbride | *Liberal Arts and Engineering Studies*

Manny Bermudez | *Architectural Engineering*

Anthony Karroum | *Architectural Engineering*

TIMELINE


Week 1:
Introduction to GH
Week 2:
Bench Study
Week 3:
Initial Shade Structures
Week 4:
Mid-Review
Week 5:
Client Feedback
Week 6:
Material Studies
Week 7:
Footing Mockup
Week 8:
Refinement
Week 9:
Refinement
Week 10:
Client Proposal

CLIENT AND TERRITORY

San Luis Obispo Botanical Garden requested that we design a shade structure for the Sage Meadow in the Children's Garden. This project should facilitate the meetings of their outdoor children's classes and honors the values and goals of the San Luis Obispo Botanical Garden.

This project will serve as a test for a larger scale, and more permanent Instructional pavilion for the future.

The project, and the entirety of the garden, is located on land original to the Chumash people. We want to take a moment to recognize the significance and historic ownership of the land.

San Luis Obispo
BOTANICAL
GARDEN

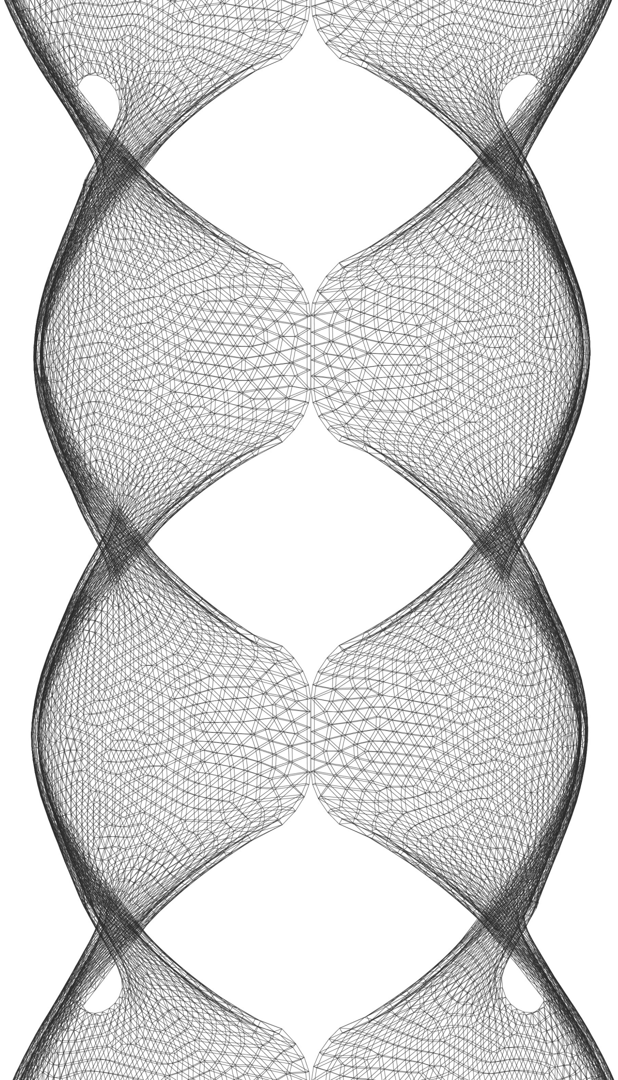
PROJECT SCOPE

FORM FINDING | *Form Finding was conducted though Grasshopper and Rhino 7. Initially, our group explored form through the bench shelter warm up project, and finally came together and began ideating towards a suitable form for the Sage Garden Pavilion. The form finding process was guided by site analysis, cultural considerations, and function of the pavilion.*

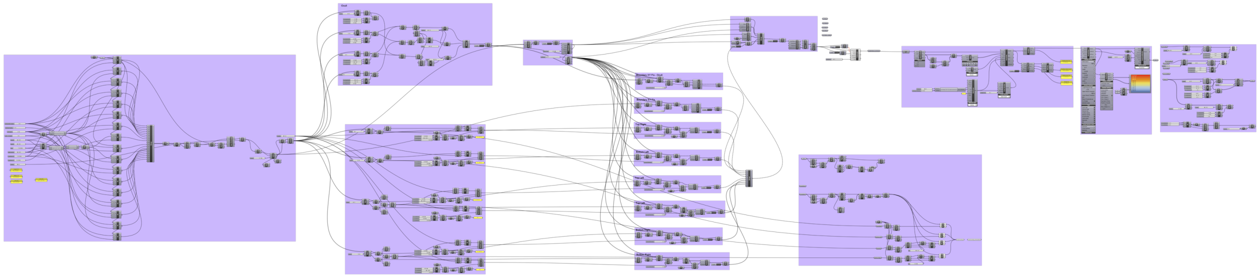
FORM TESTING | *Form Testing included in depth structural analysis of many of the forms that we had made. Form Testing also included the construction and analysis of multiple material tests. During this phase an iterative design process was used to find the ideal system to anchor the shell to the ground.*

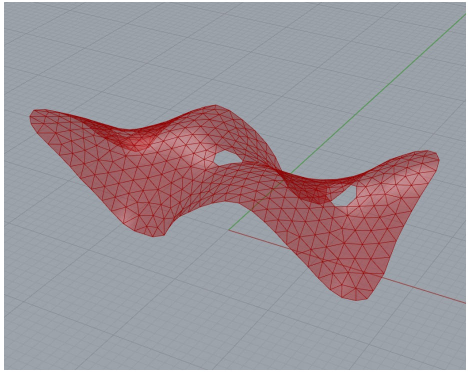
FORM BUILDING | *To test the feasibility of construction, and to gain a better understanding of the construction process, we built a portion of our shell at full scale. This exploration allowed us to confirm that the construction process was simple and moved quickly. This also allowed us to see the anchor detail in the real world, and to better understand it's strengths and limitations.*

PROCESS WORK: FORM FINDING



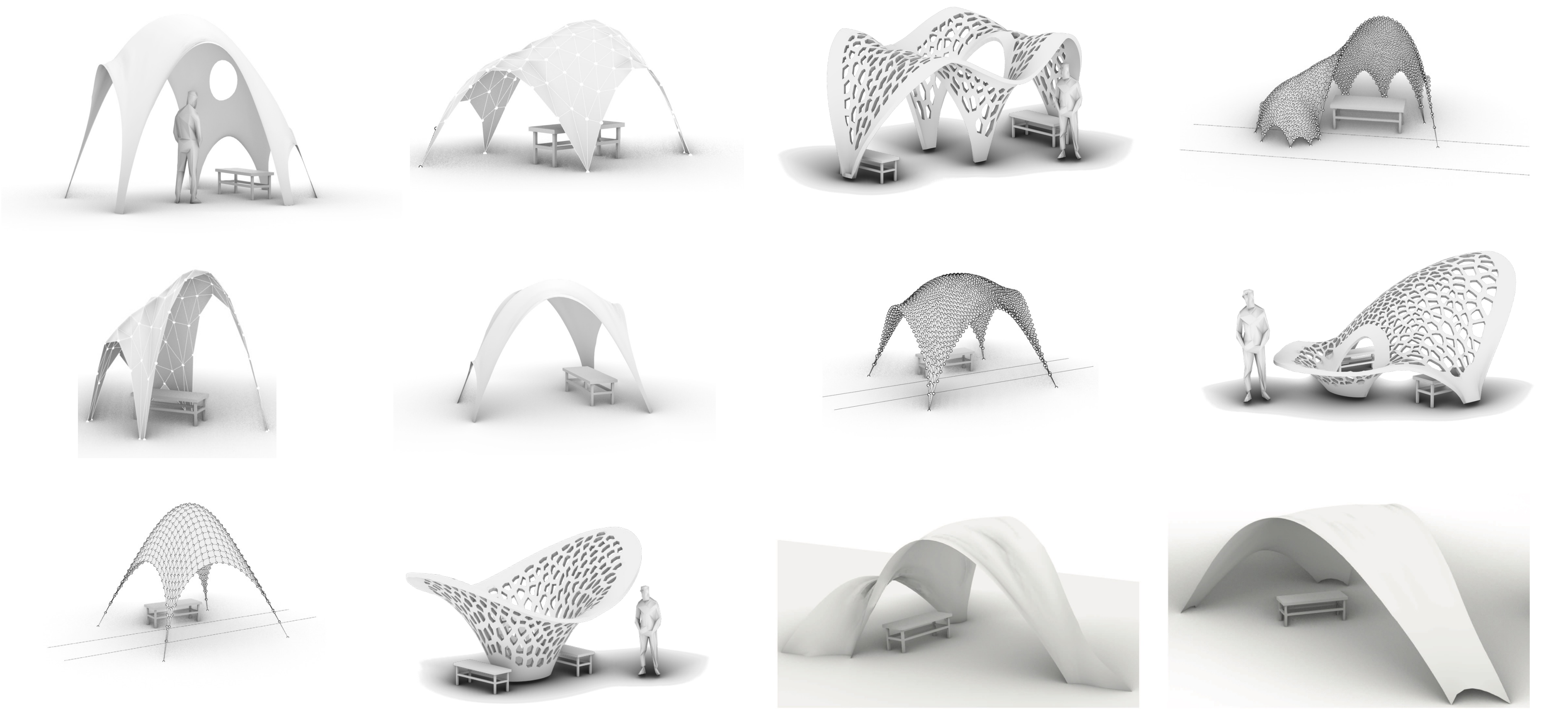
GRASSHOPPER



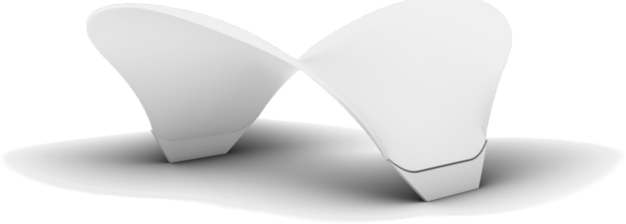
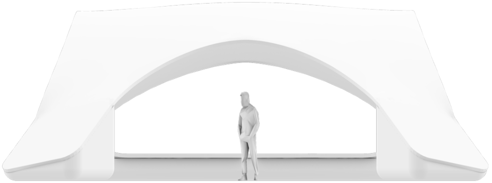


Grasshopper, a visual programming language within Rhino, was used to generate funicular shell designs. Kangaroo, a GH plugin with the capability of simulating fabric-like meshes, and Karamba, a structural analysis plugin, allowed us to explore designs parametrically and iteratively while considering both aesthetics and structural feasibility.

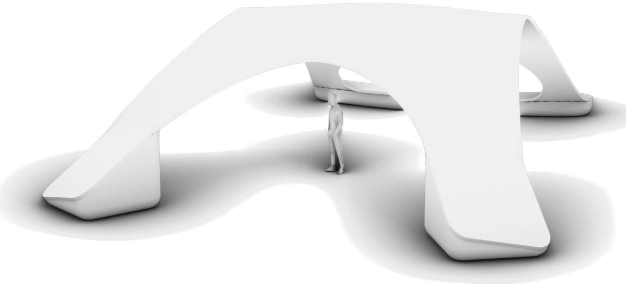
PROCESS WORK- WARM UP PROJECT



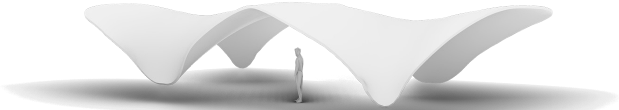
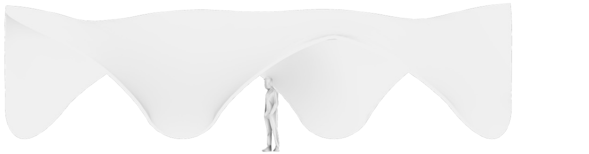
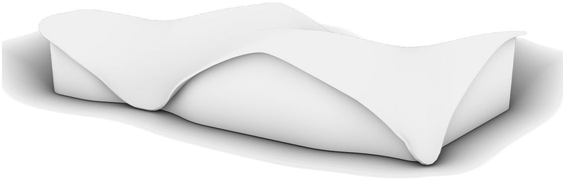
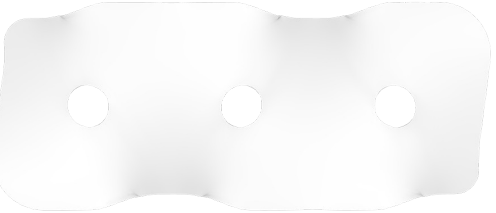
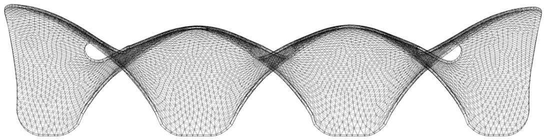
PROCESS WORK- PAVILION GENERATION

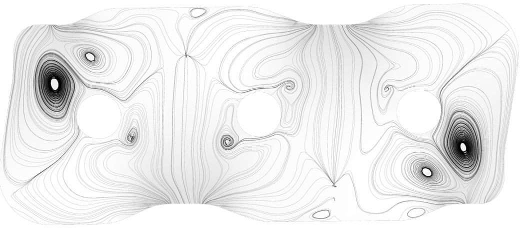



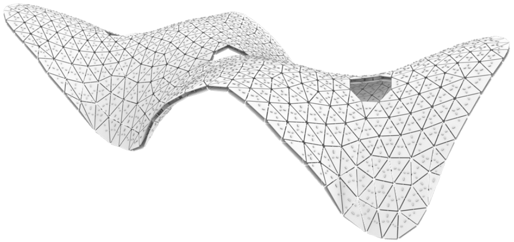


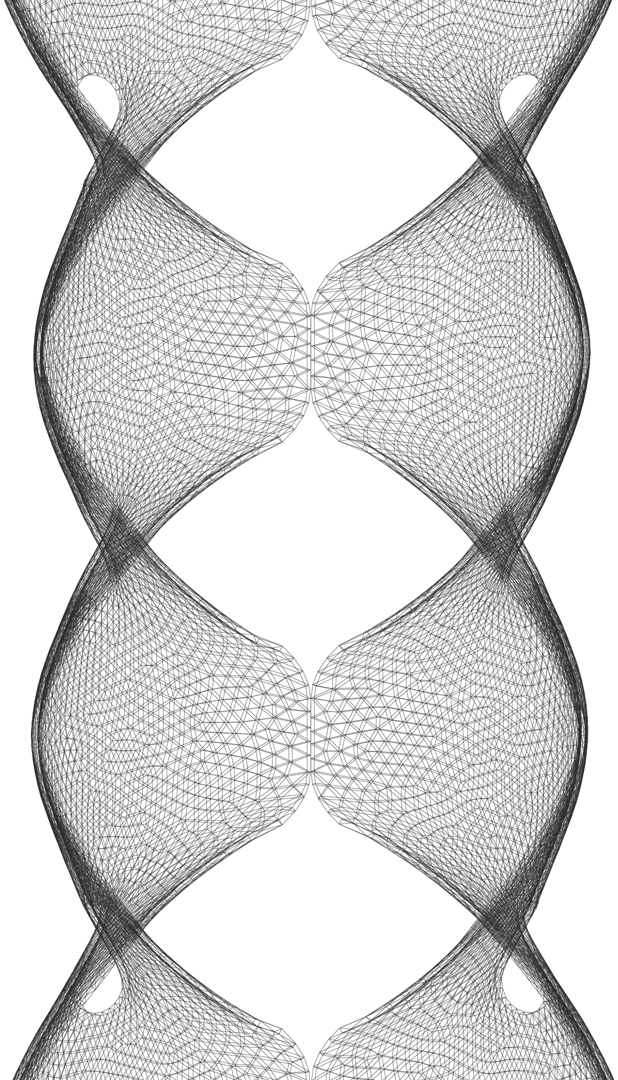

PROCESS WORK- FINAL PAVILION FORM





SAGE MEADOW PAVILION PROPOSAL



SITE PLAN

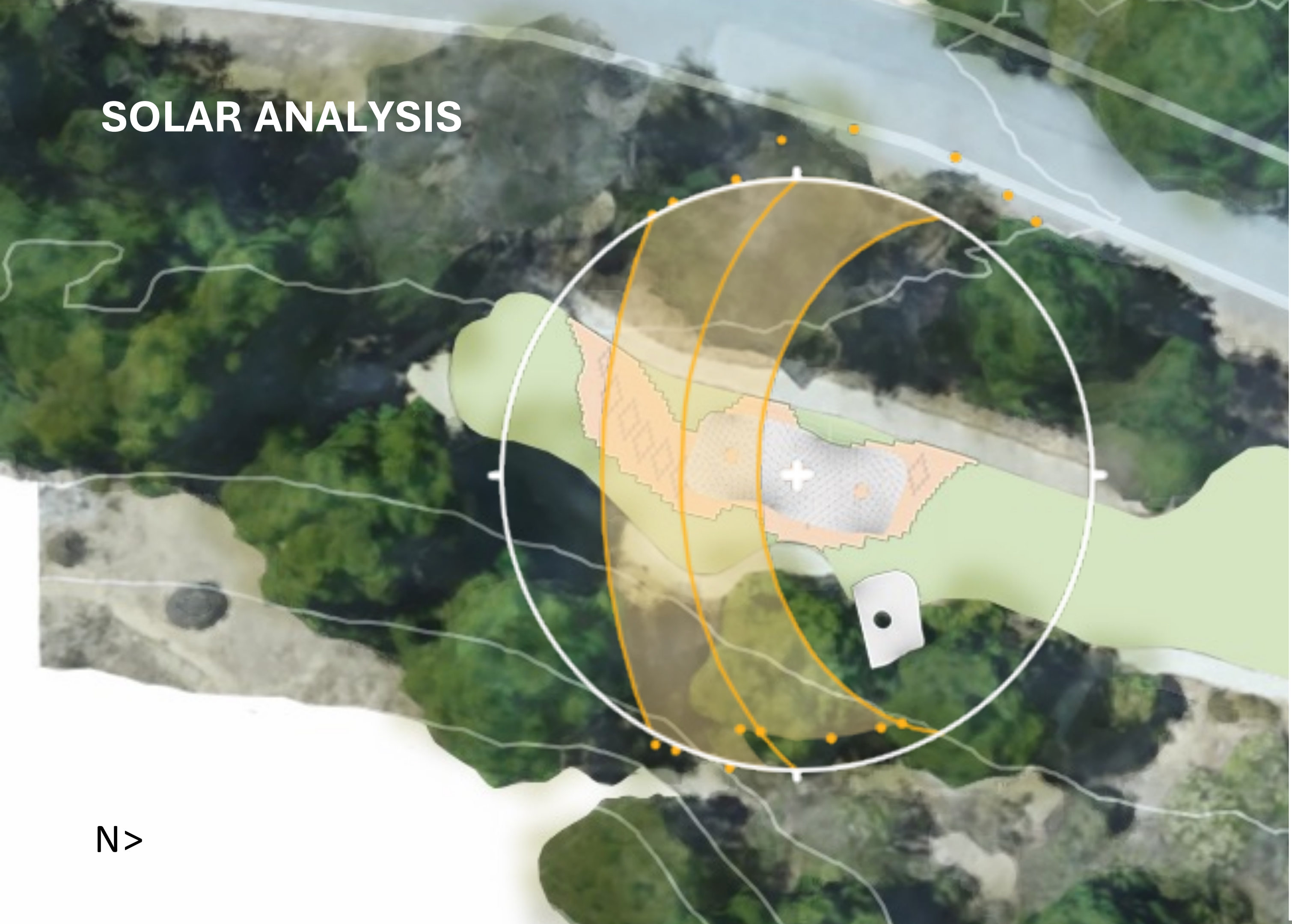
Located around 200ft from the SLO Botanical main building, the Children's Garden is host to many school activities. Without disrupting existing features of the space, our shell structure creates a more versatile space in the garden.

CLIMATE ANALYSIS

In terms of climate, SLO experiences very mild climate. Rarely seeing temperatures below the 40s, and occasionally getting temperatures above the high 80s. Rain is scare, but more common in the winter.

In our location, the tree structures guarded the garden from coastal winds and valley winds.

SOLAR ANALYSIS



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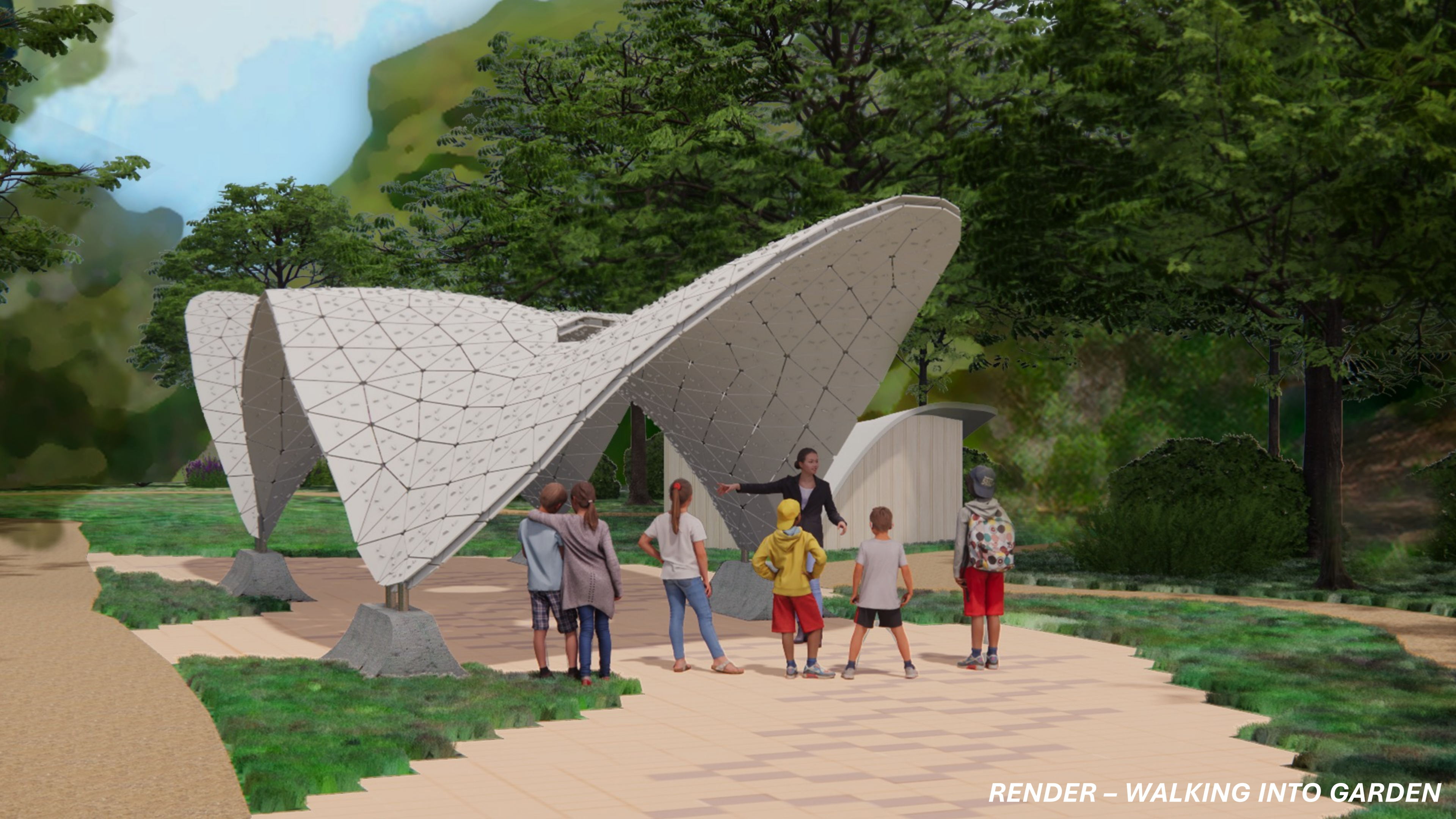
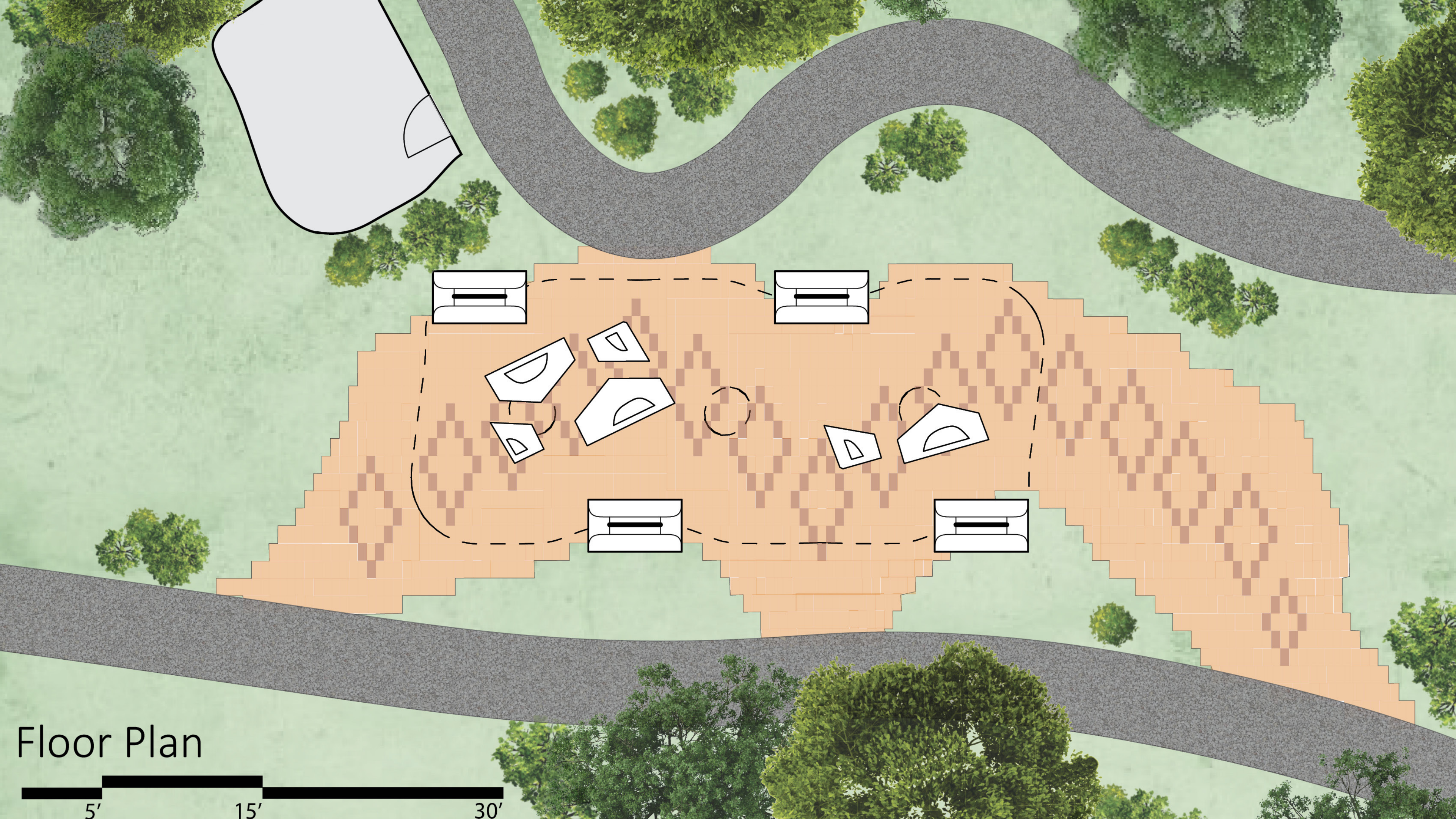
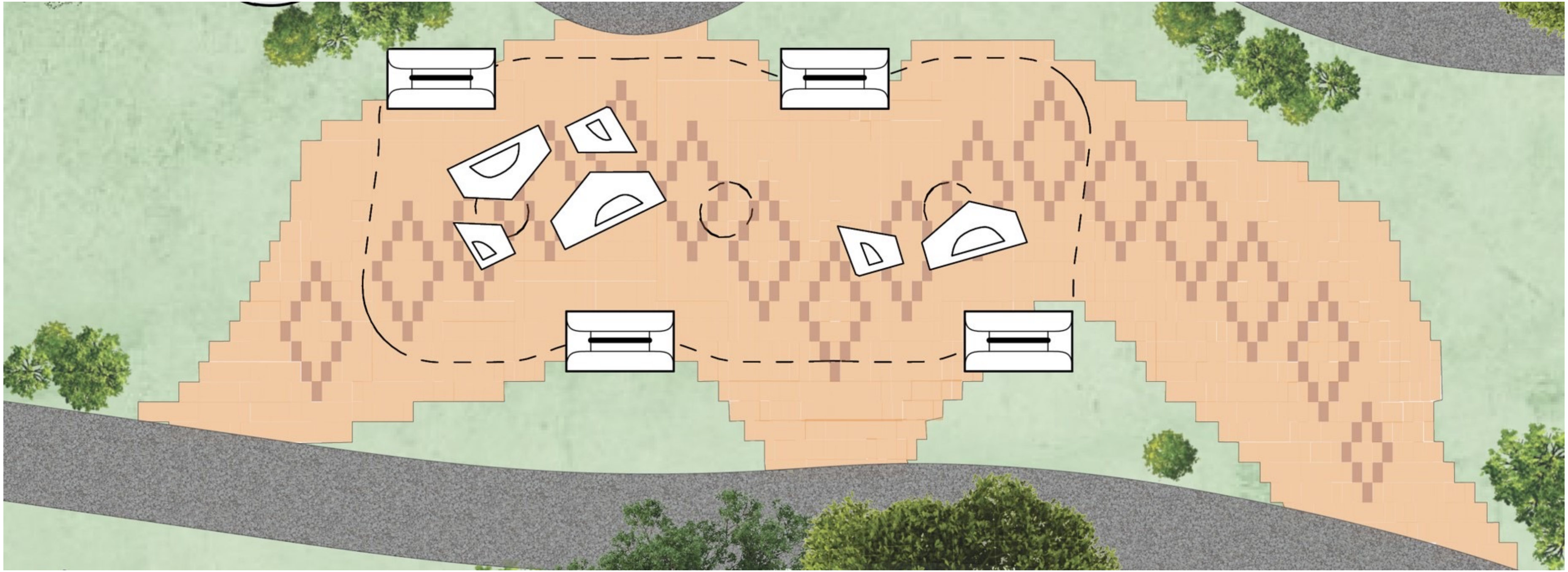
Although the canopy offers extensive shade, it doesn't from the hours 11-3pm, which is when classes use the space. Our aim was to extend the tree canopy to offer a shaded space during the hours of 11-3pm.



RENDER – WALKING INTO GARDEN

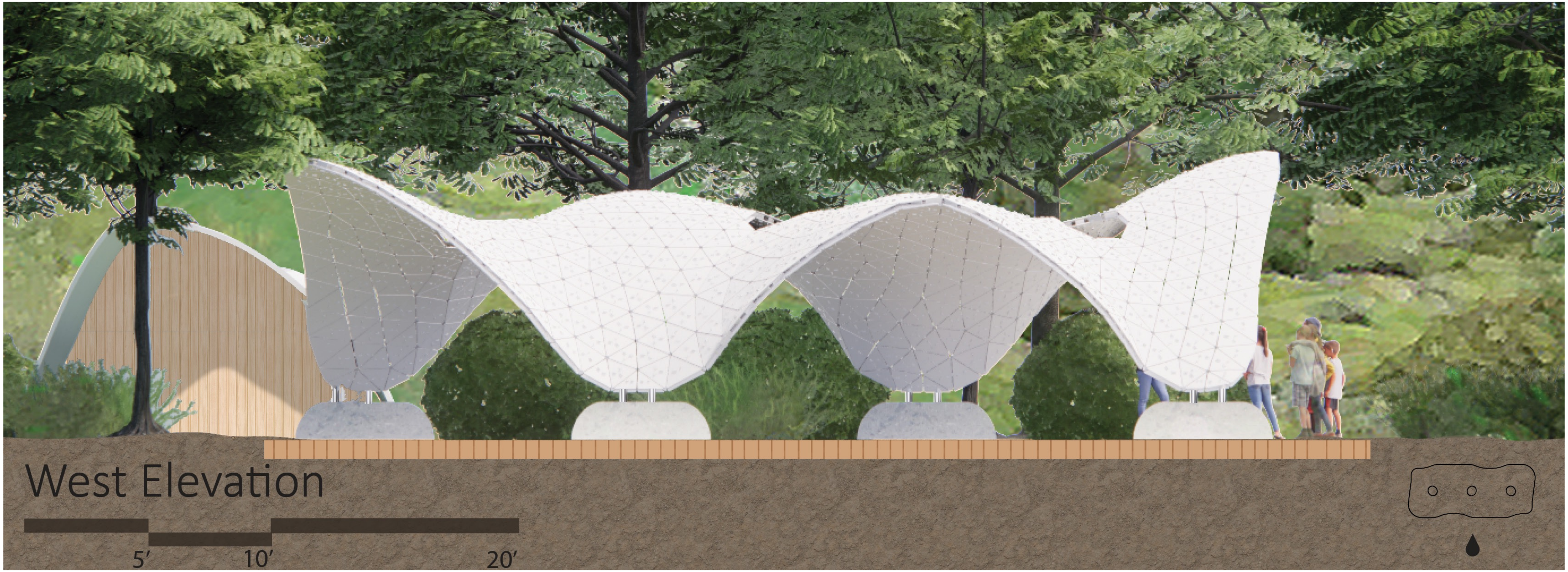


Floor Plan



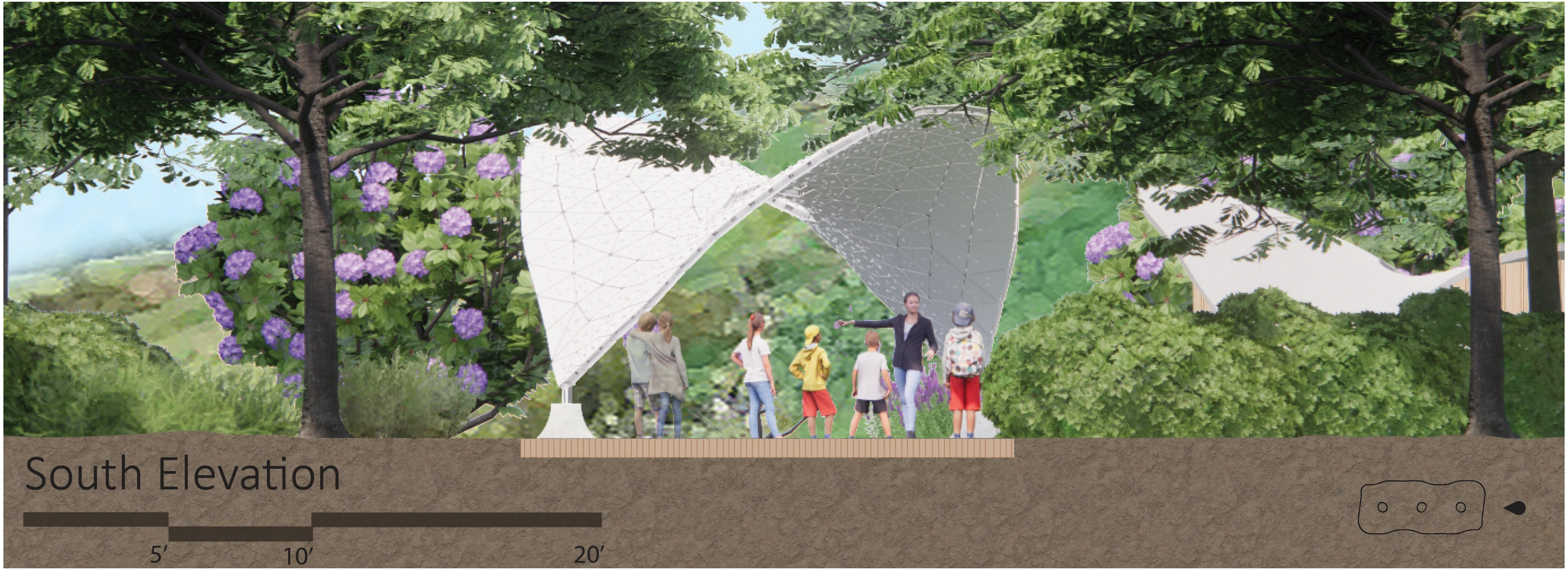
The open floor plan of the Pavilion creates a unique multifunctional space. The pavillion will support classes taking place in the Children’s garden, guided tours walking throughout the botanical garden, and a place to play and explore.

One goal of the project was to create accessible connections across the garden. The pavers, which slither under the canopy, add four key connections between the exsisting main paths.



The Sage Meadow is surrounded by beautiful mature trees that offer an organic sense of enclosure and ample shading during the morning and evening hours.

Our Team was inspired by these trees and sought to create a structure that extended their canopy over the meadow, with a light simple touch to the ground.



The airiness feeling of the overall structure helped us to maintain a sense of openness, lightness, and joy. These are attributes that are well suited for a meadow pavilion.

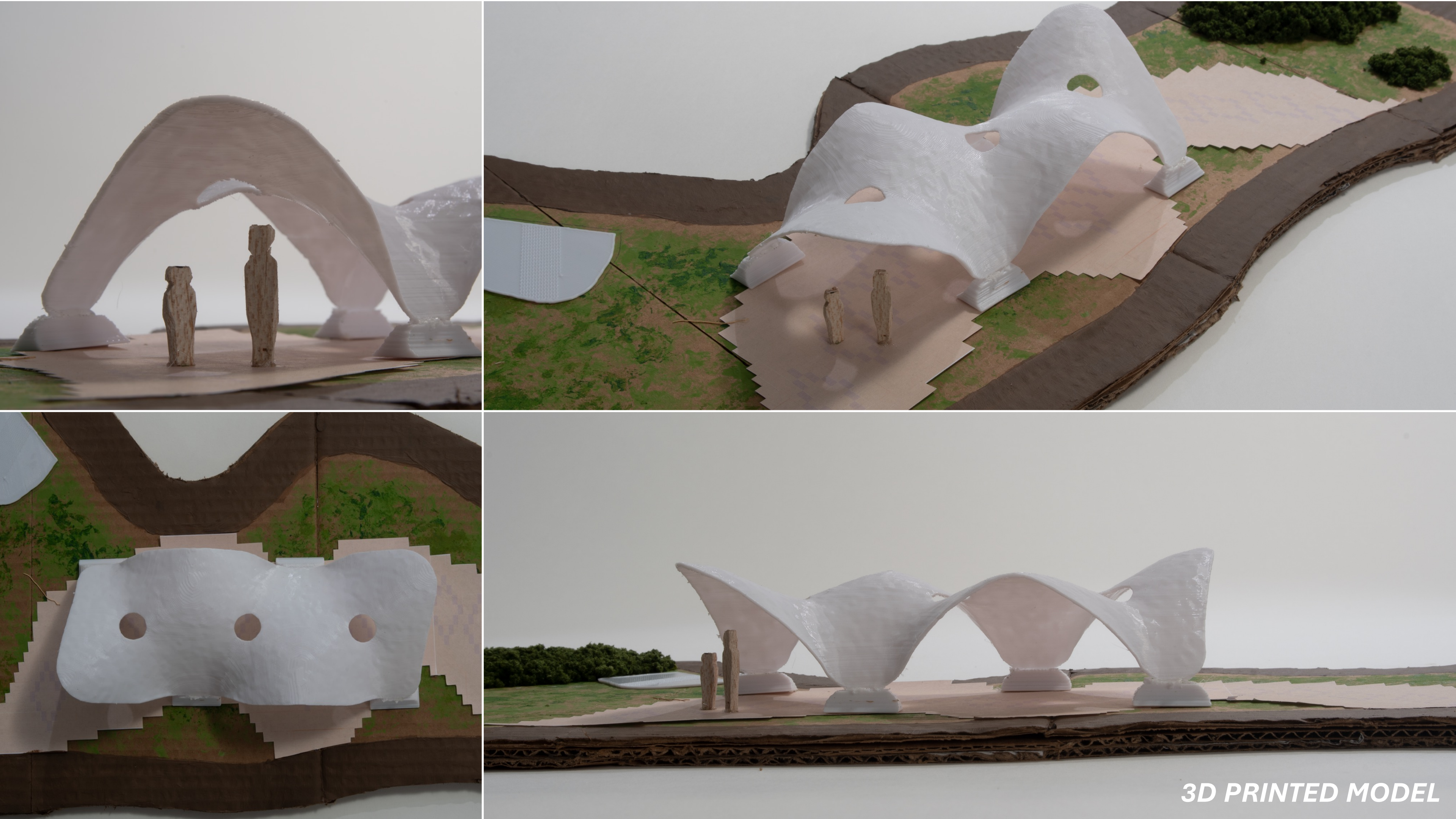
Another goal of the design was to limit visual interruptions across the meadow. In this elevation, at the entrance of the meadow, the entire length of the meadow is visible, curating an inviting space.

This cross section reveals the spatial quality of the center of the pavilion. From inside, a high level of visual connectivity is maintained with the rest of the garden.

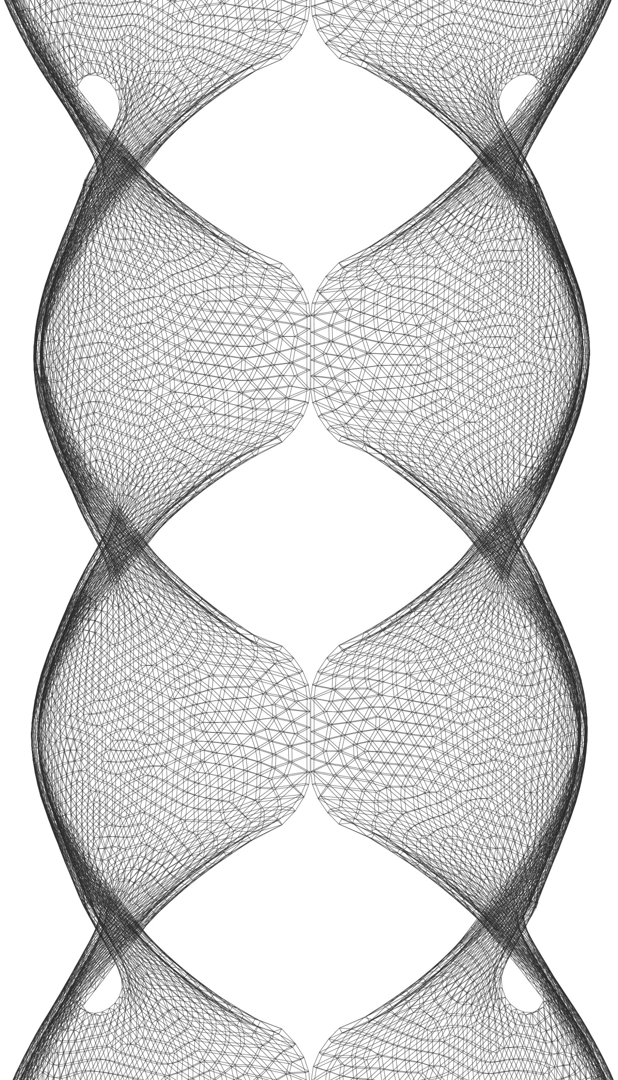
One of the benefits of the exposed double skin panelized construction is the dappled light effect that it has inside the shell. This dappled light, along with the stronger light coming from the oculi, will create a bright and cheery environment, similar to being under the natural canopy of the surrounding trees.

The pavilion is designed to integrate into the existing, thriving classroom of the garden. Rather than being a building in a meadow, the pavilion is meant to become one of the many rooms of the garden.

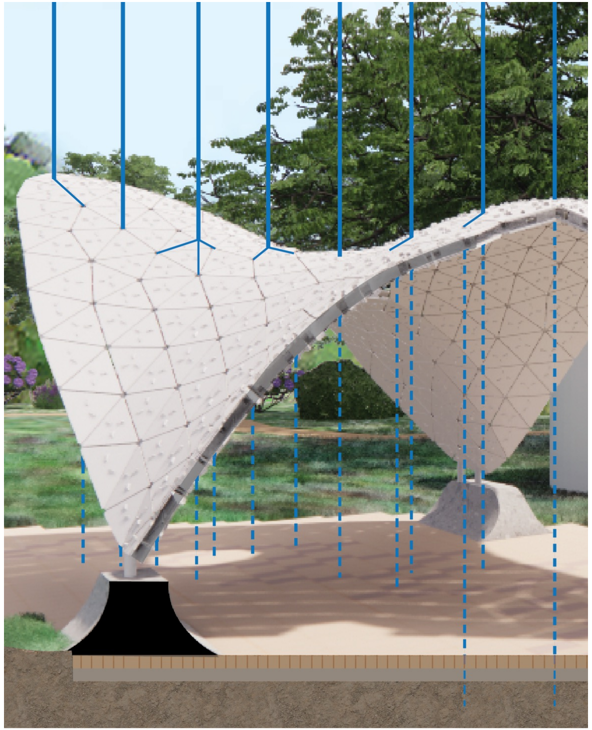
RENDER – INTERIOR PERSPECTIVE


3D PRINTED MODEL

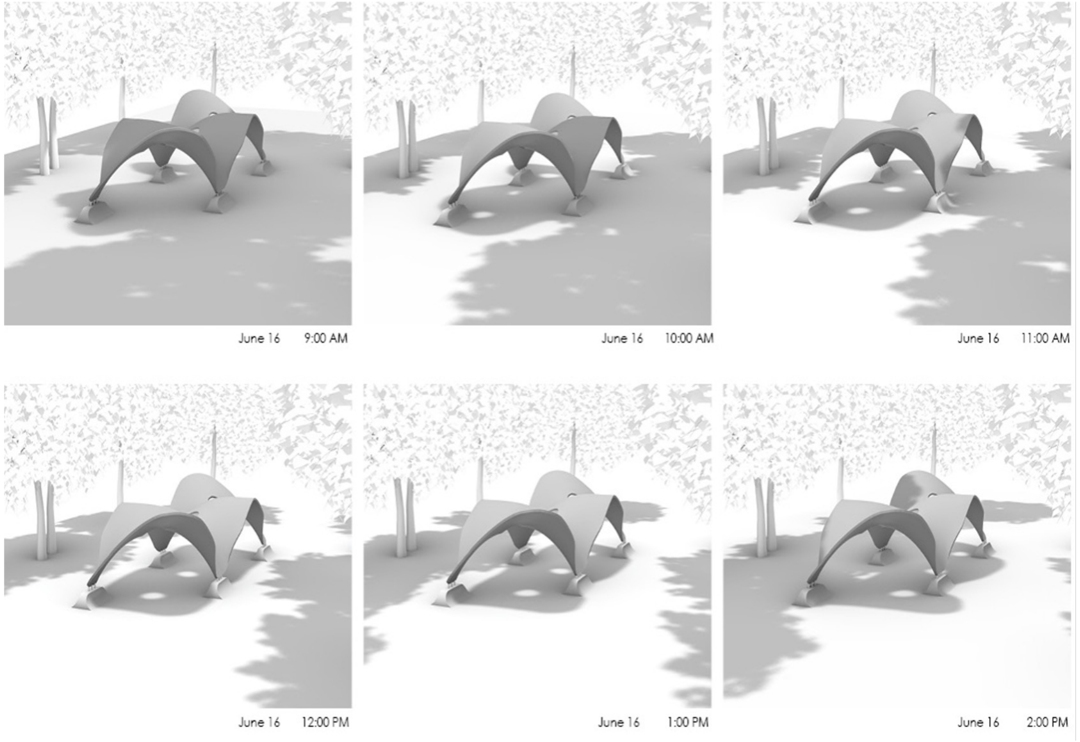
DIAGRAMS AND DETAILS



WATER DIAGRAM

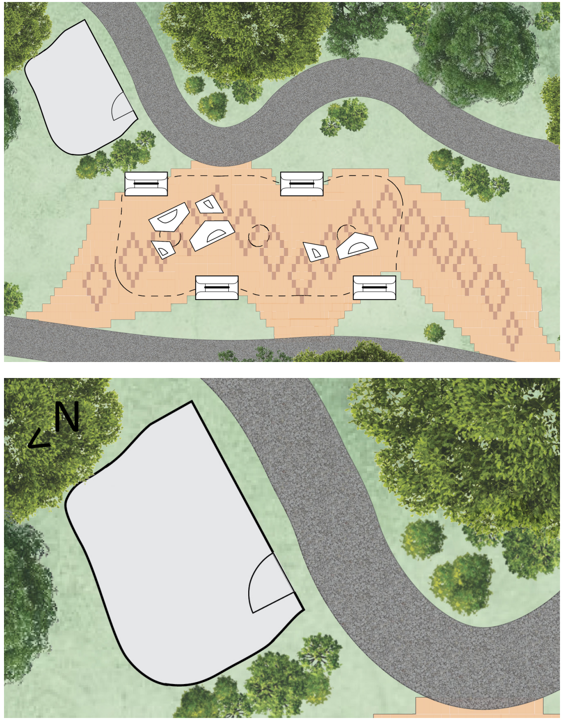


SHADING DIAGRAM

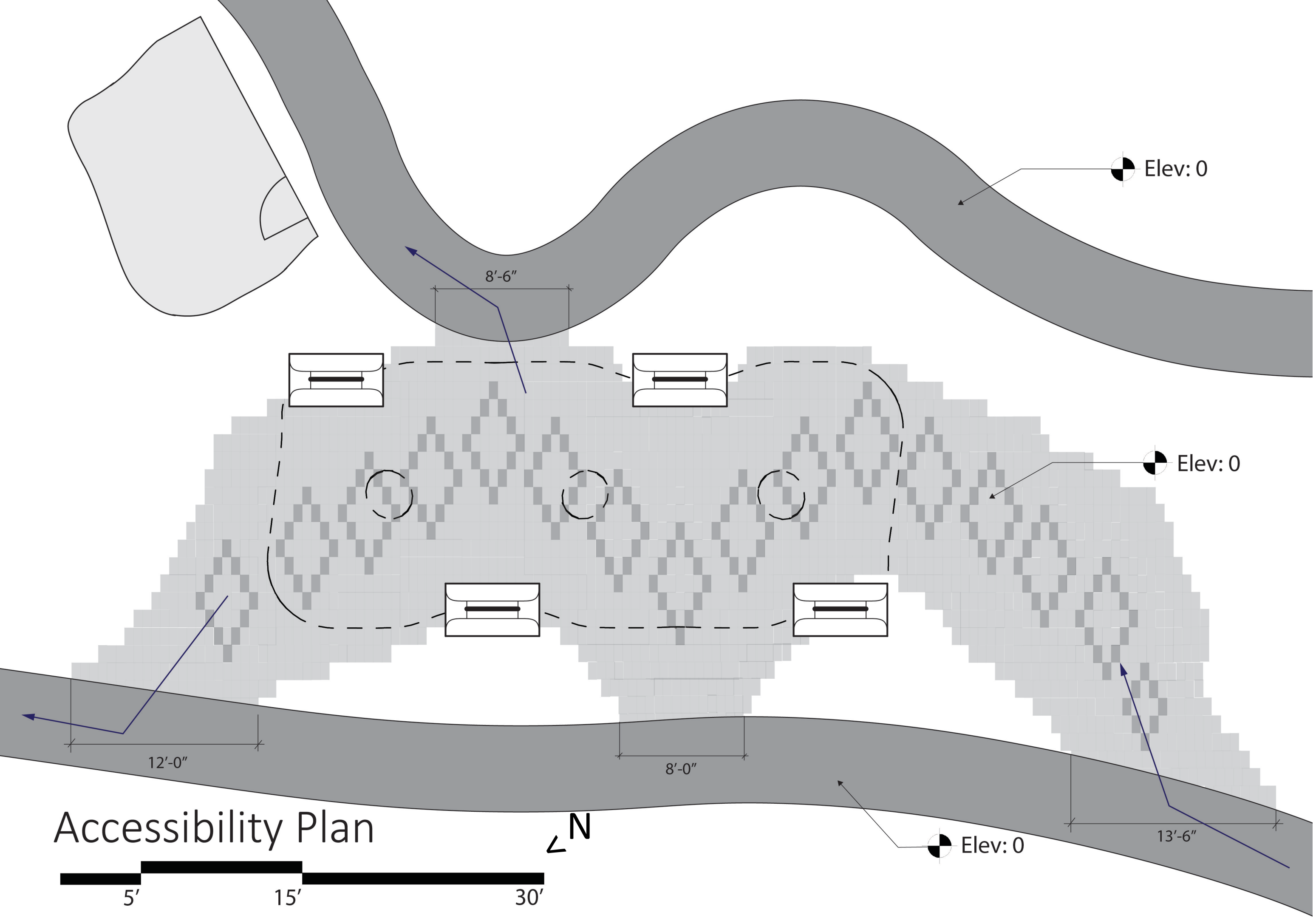


Rain and sunlight were determining factors for form as well as finish. Rainwater is filtered through the structure in a dappled manner, mimicking the surrounding tree canopies. Natural runoff is returned to the ground with minimal disruption. As seen in the shading diagram to the right, the structure provides shade during peak sunlight hours in the meadow.

DETACHED STORAGE MODULE



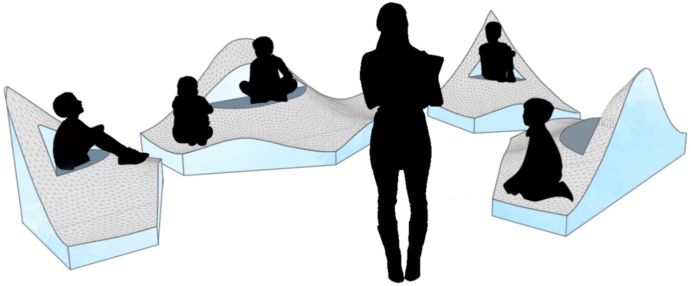
A section of the larger shell was used as a detached storage module for garden tools and teaching materials. This was done as an exercise in constructability for the larger shell. The storage module is easily accessible thanks to the paver connection to the existing path

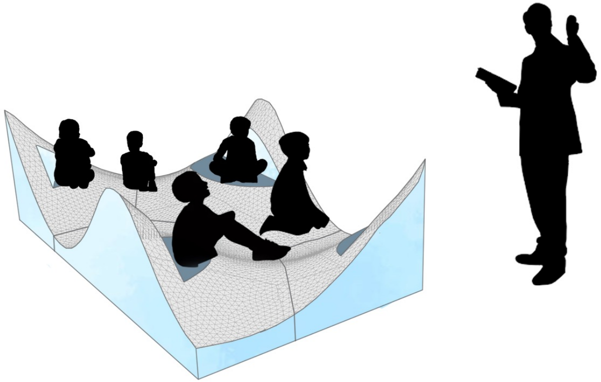


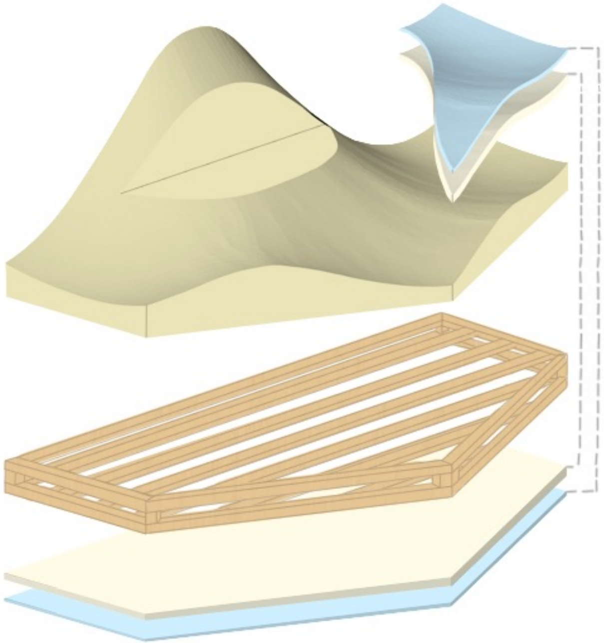
Accessibility Plan

In order to offer equal experience to all users, we prioritized accessibility. Ensuring all pathways and spaces are usable for all modes of mobility.

FURNITURE DESIGN







To create an outlet for children's playful energy, we decided to flip the shell upside-down and create interactive furniture. They can all be assembled together, or be moved around as desired.

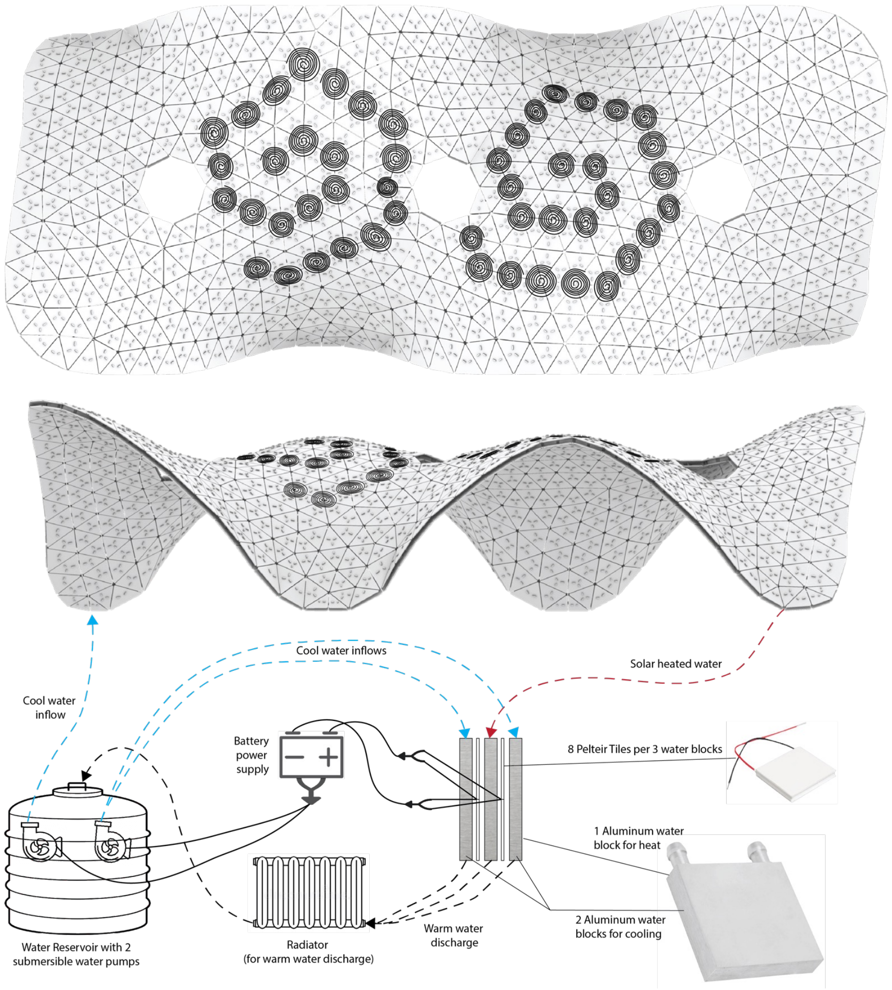
The material consists of a wood base, hard foam for the structure, encased in soft foam and outdoor fabric.

SOLAR THERMOELECTRIC POWER

***Example of accompanying didactic panel**

Using solar heat, Peltier devices, and the Seebeck Effect to produce clean electricity.

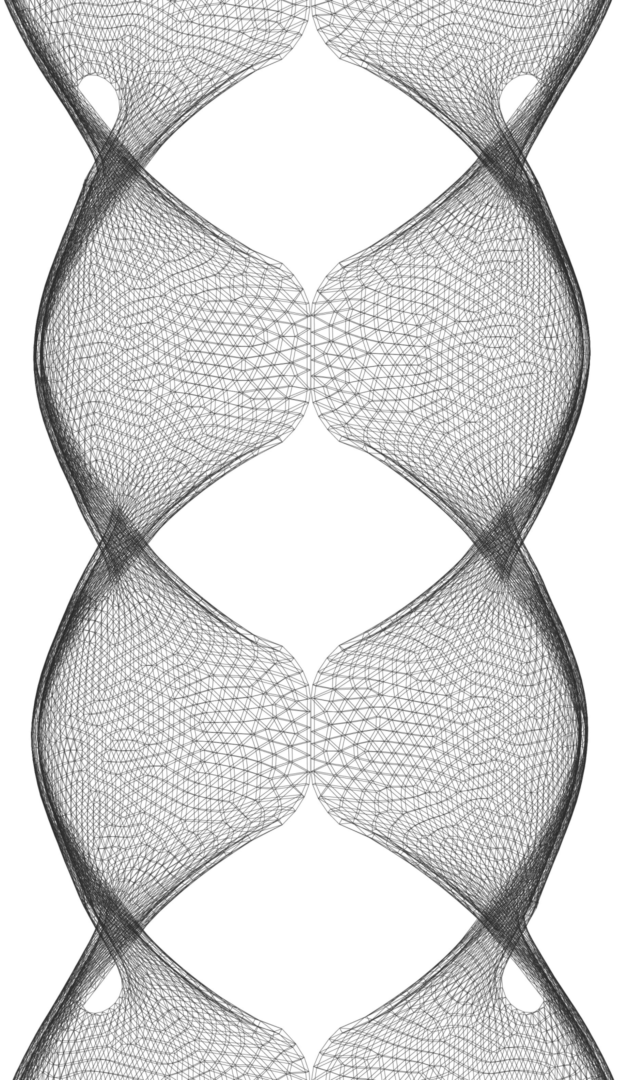
This system you see here takes advantage of the sun's heat and widely available thermoelectric devices to create energy. Unlike solar photovoltaics, which use the visible light and some infrared light of the sun to convert photons into electricity, this thermoelectric system takes advantage of all the infrared light radiation (heat from the sun) which is converted into energy through the Peltier devices. Each Peltier consist of small thermoelectric diodes that according to the Seebeck Effect, create a current when introduced to a temperature difference. There have been many applications of these devices, most notably on Mars missions as a a fuel source for the Curiosity Rover. Our implementation of Peltier devices allows for a simple and low-cost energy system that can be used independently or integrated as part of a larger structure.



4 hours of sun/day = 96W of energy to fully charge one 12V, 8Ah Battery

Battery can supply **20 LED light bulbs for approximately 5 hours**

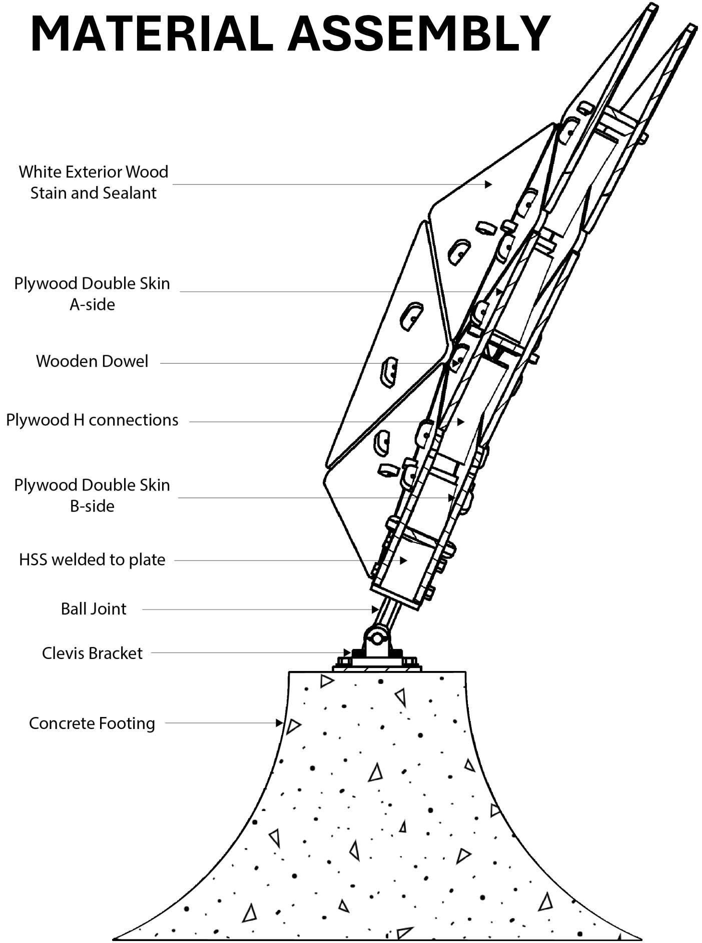
MATERIAL DESIGN AND TESTING

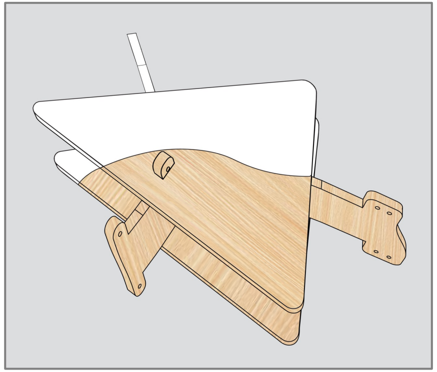


MATERIAL TESTING

Initial material exploration began with white plaster, fabrics, limewashing, and linseed oil. Ultimately a white wood stain and sealant was chosen for its ease of application and water resistance.

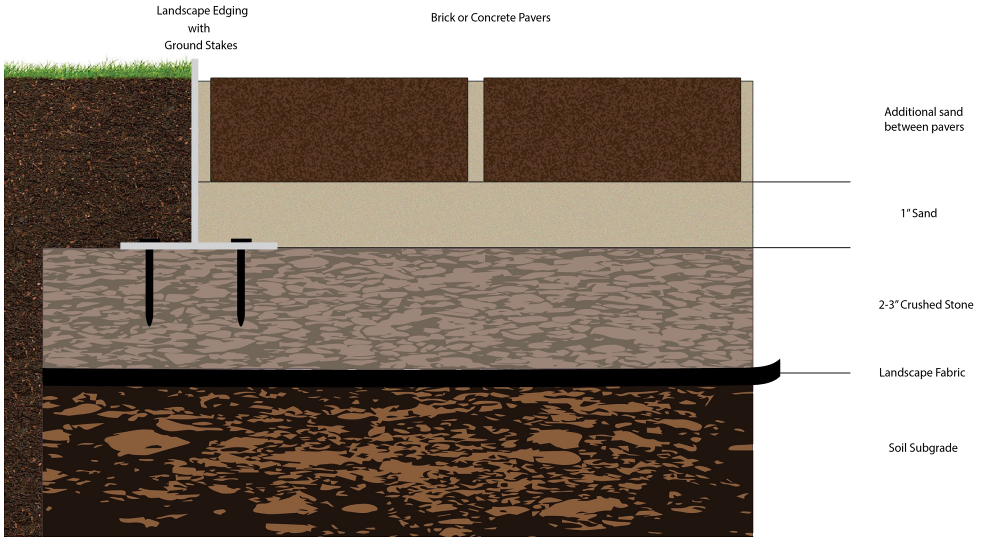
MATERIAL ASSEMBLY



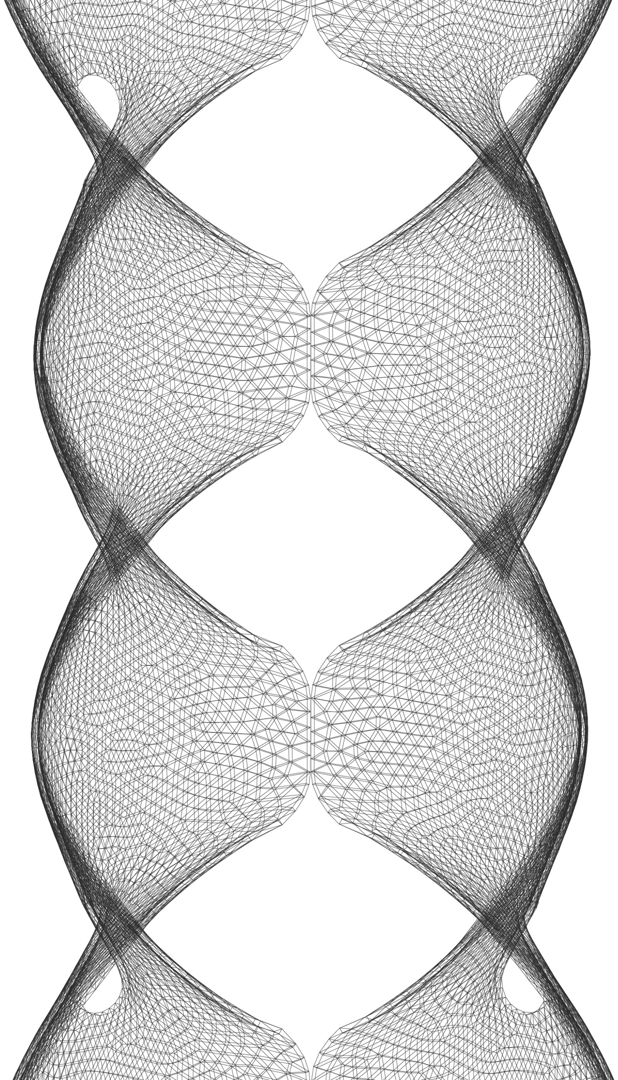


White exterior wood stain and sealant provides UV defense and water/mildew resistance.

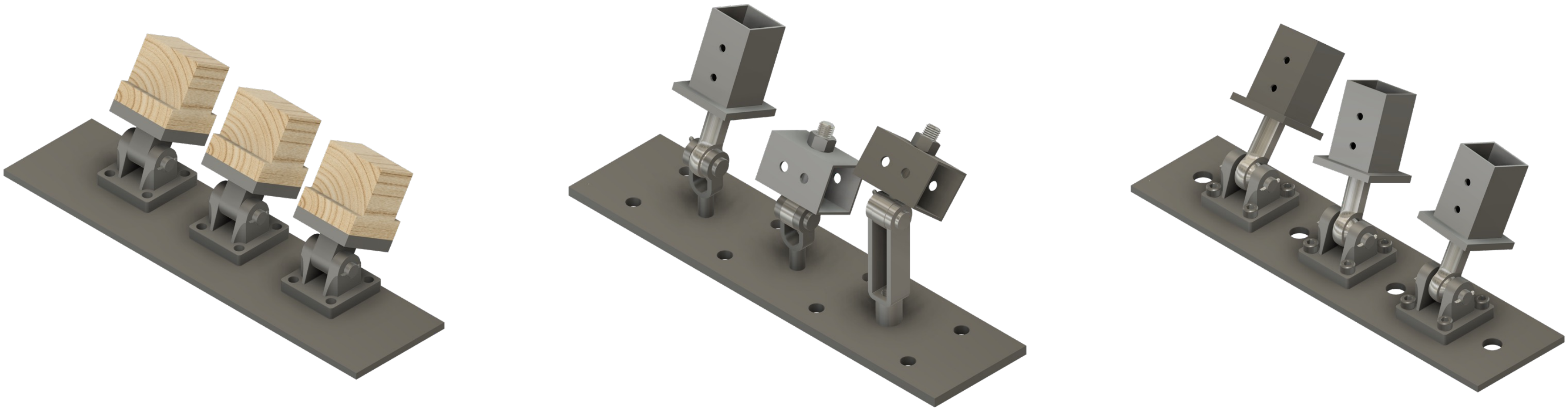
The ground condition is permeable to water and can be sourced with local materials.



ANCHOR DESIGN AND CONSTRUCTION

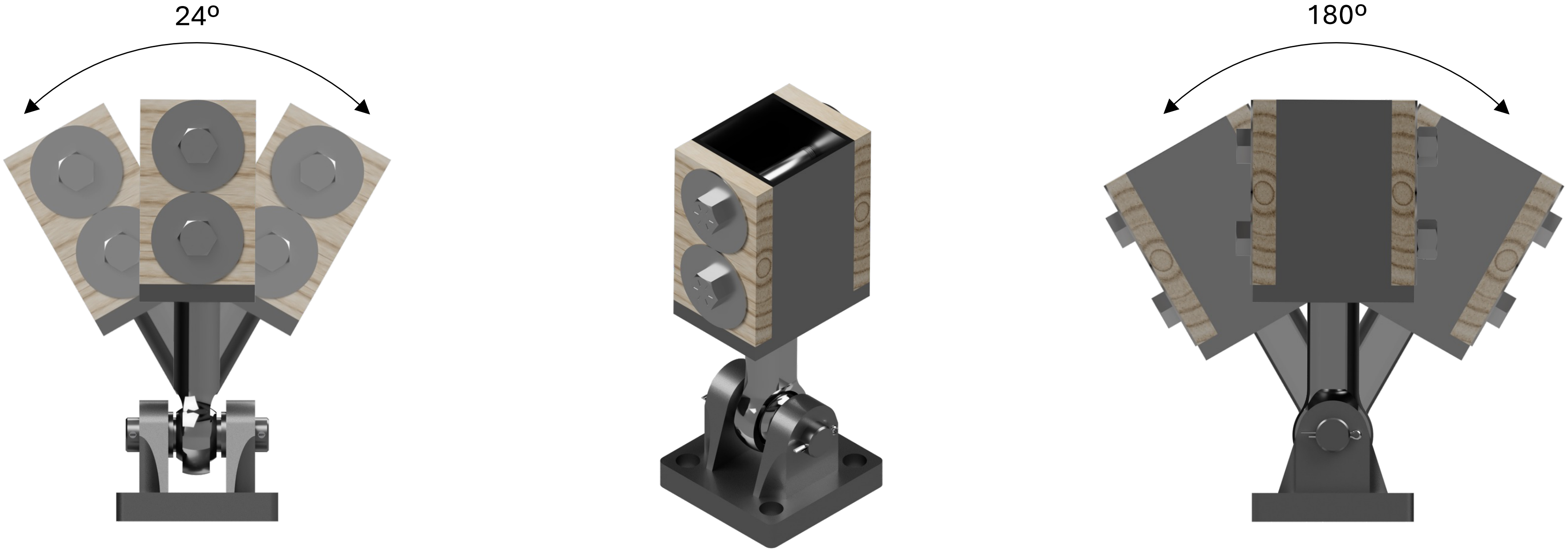


ANCHOR CONSIDERATIONS

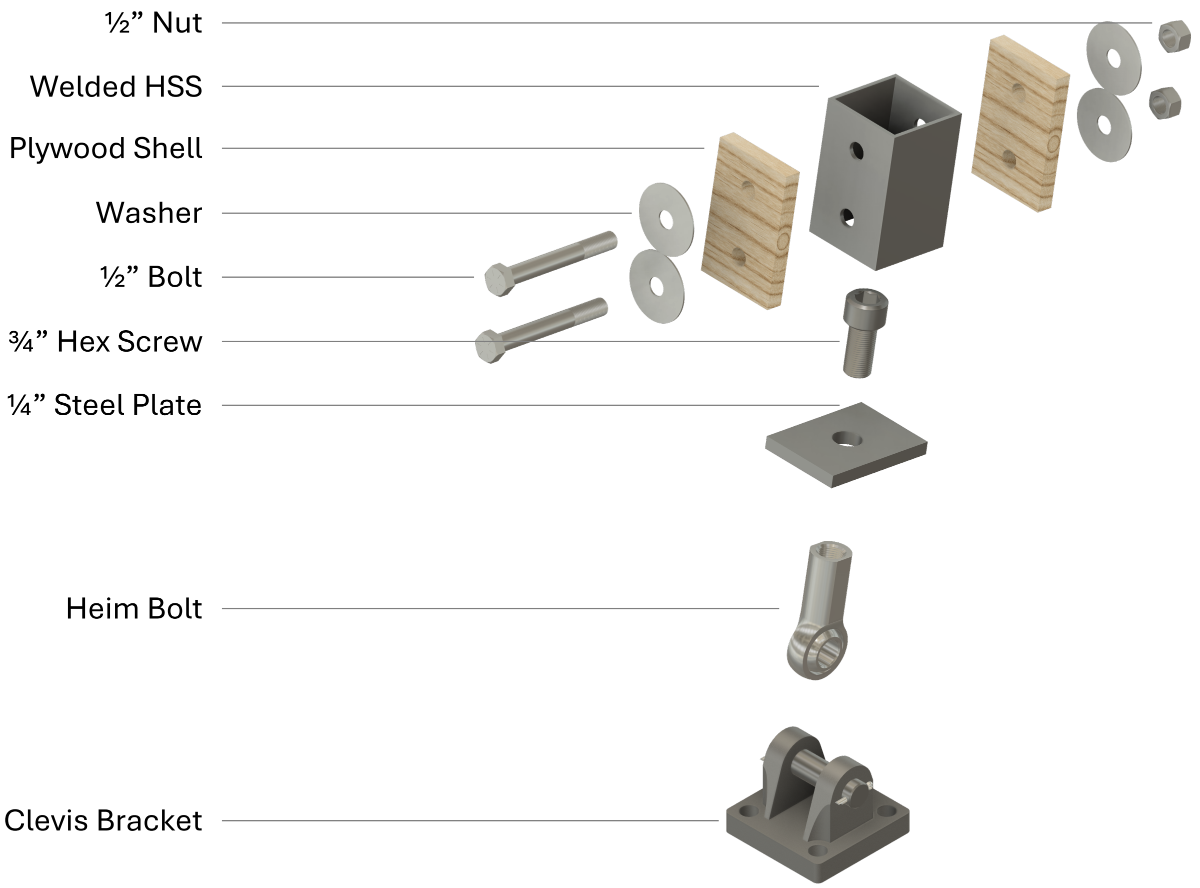


Constructability was one of our primary design considerations from the start and one of our biggest challenges. We knew the design had to be easy to assemble, perform well, and compliment the look of any shell. Through many iterations, we were able to converge on an anchor design that met our goals.

ANCHOR DESIGN



The anchor design utilizes a clevis bracket and heim bolt to allow for the most flexibility in positioning during construction of the shell. With the freedom to rotate in almost any direction and the use of a modular tube, the same anchor design can be used at any point on any shell with little modification. In other words, the anchor is project agnostic.

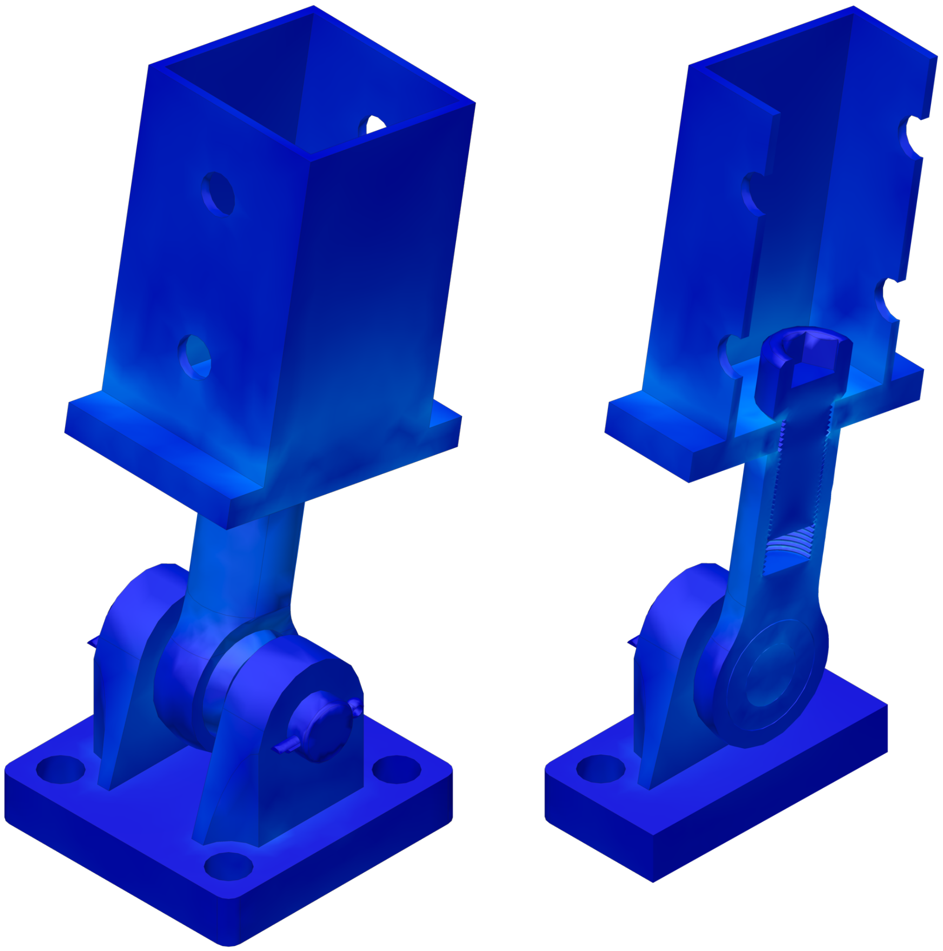


ANCHOR ASSEMBLY

ANCHOR ANALYSIS

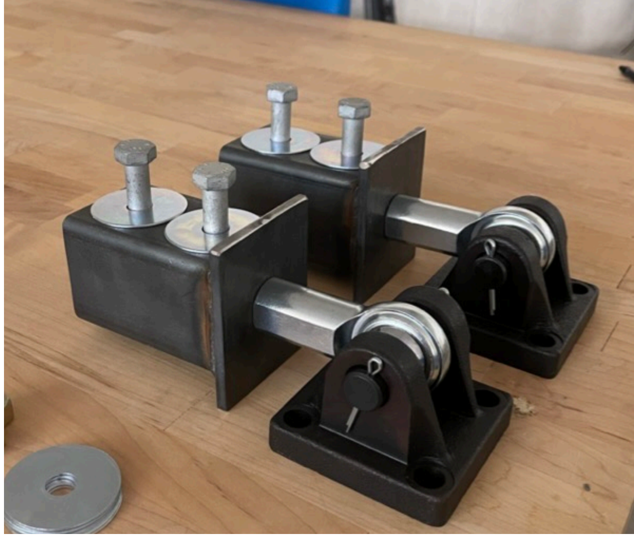
We ran a limited finite element analysis using Fusion 360 to determine if the anchor met design criteria. Stress concentrations are visible in the lighter portions of the cross section when a 2000 # gravity load is applied to the bolt holes and plate flange. Since the anchor design is primarily steel and the overall shell does not weigh

Moving forward, a more thorough analysis using a more capable finite element program, like ANSYS, should be done to better understand loading of the shell at the footing. The new model would include plywood panel elements, as the most likely point of failure would be the plywood connection itself.



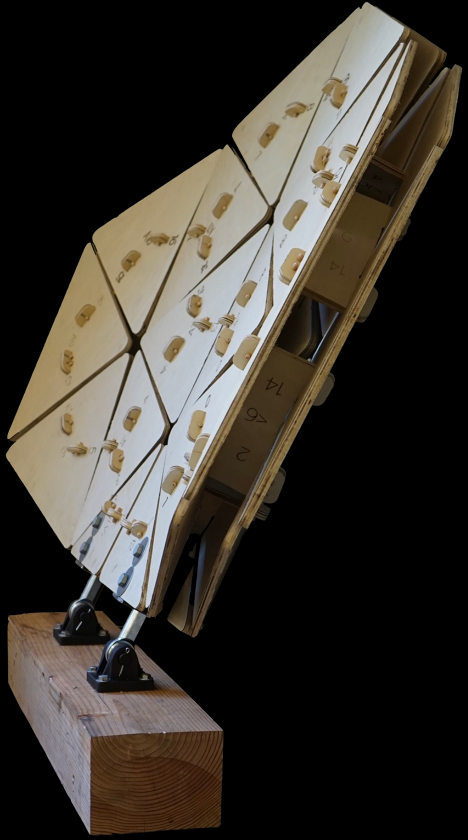
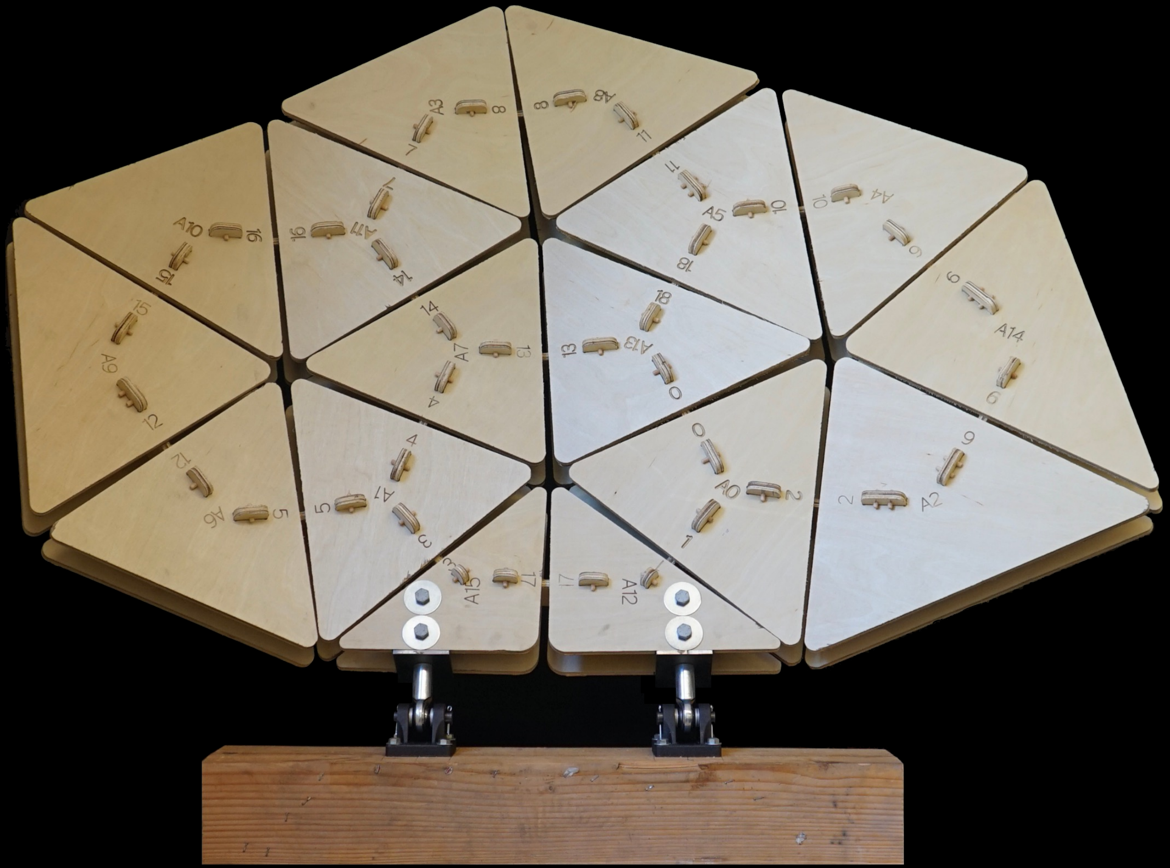
FOOTING DESIGN & MOCKUP

A curved concrete foundation was created for the shell to reflect the design and could be prefabricated off-site. A steel base plate with a modular hole pattern would be bolted to the concrete and the shell anchors would be screwed on to the plate. The double-skin shell itself only requires wooden dowels and a hammer to assemble. We built a mockup to test the the anchor design for ease of assembly and construction. Manufacturing of parts took a total of 10 hours, while assembly only took 2 hours.



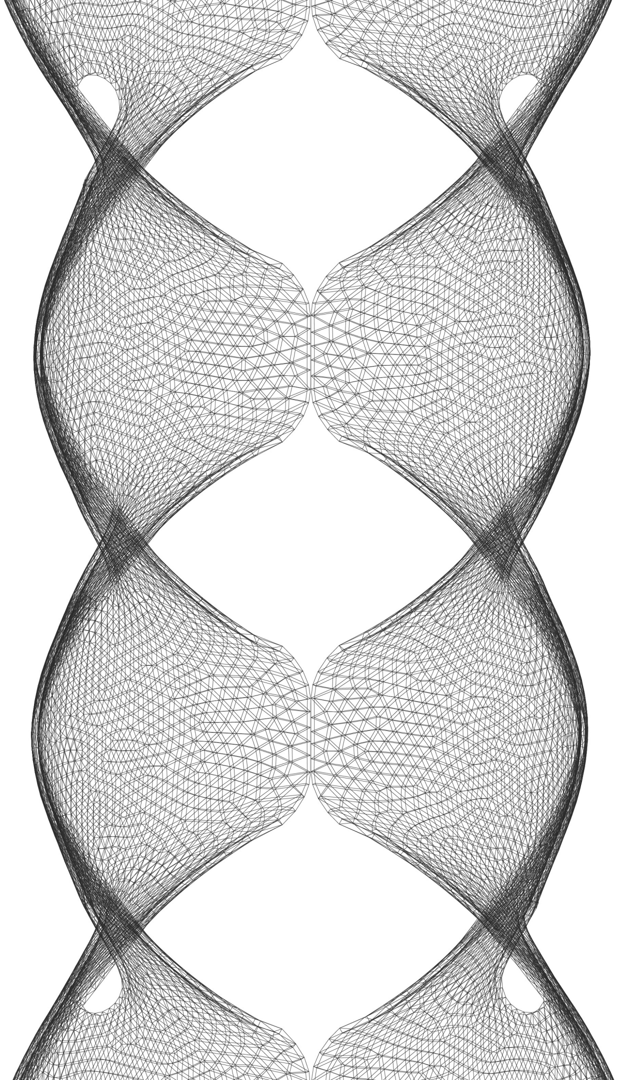

SLOW DOWN
DORINGER
ANCHOR MANUFACTURING


FOOTING ASSEMBLY

FOOTING MOCKUP

STRUCTURAL ANALYSIS

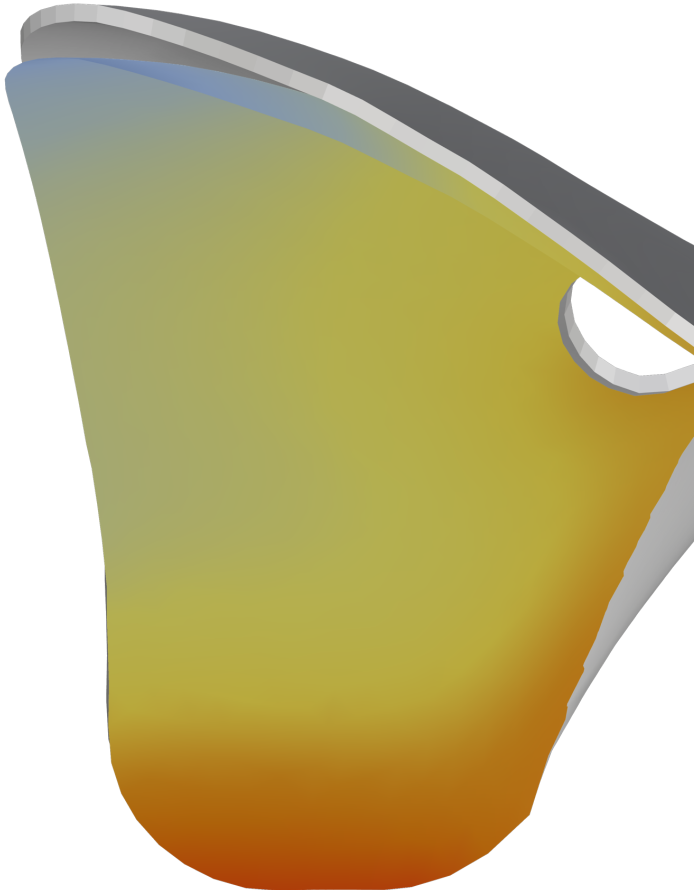


STRUCTURAL ANALYSIS

With any funicular shell, structural analysis and design begins right from the start.

Karamba | Within Grasshopper, Karamba was used with each shell iteration to test buckling capacity, view possible tension zones, and inspect areas with the greatest deflection. The shell was assumed to be concrete within Karamba, though numerical results were ignored in favor of deflection and load flow heat maps of the shell, such as the deflection map to the right.

SAP2000 | In order to understand shell demands and loading more thoroughly, we created an idealized single-layer model in SAP2000, assuming a one-inch-thick concrete shell. By doing this, we could look at shell reactions, buckling capacities, and seismic response. Within each analysis, we looked at cases where material thickness and weight were changed in order to simulate a more conservative response for our shell. Note overall shell deflections were negligible for this analysis.



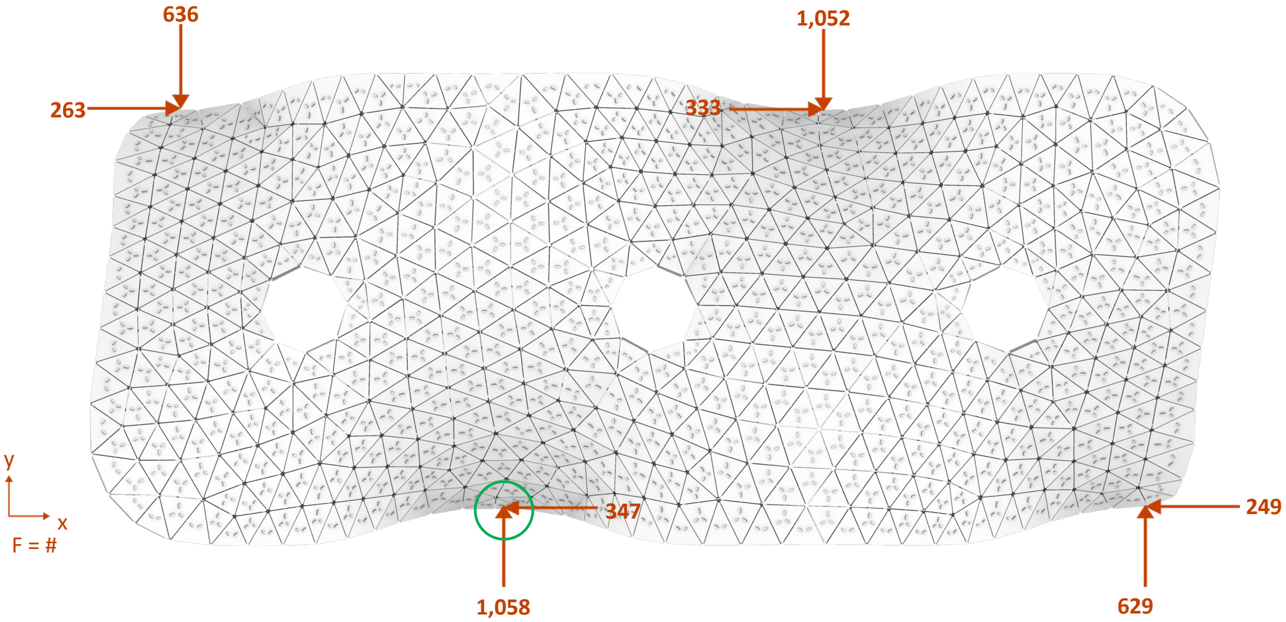
GRAVITY

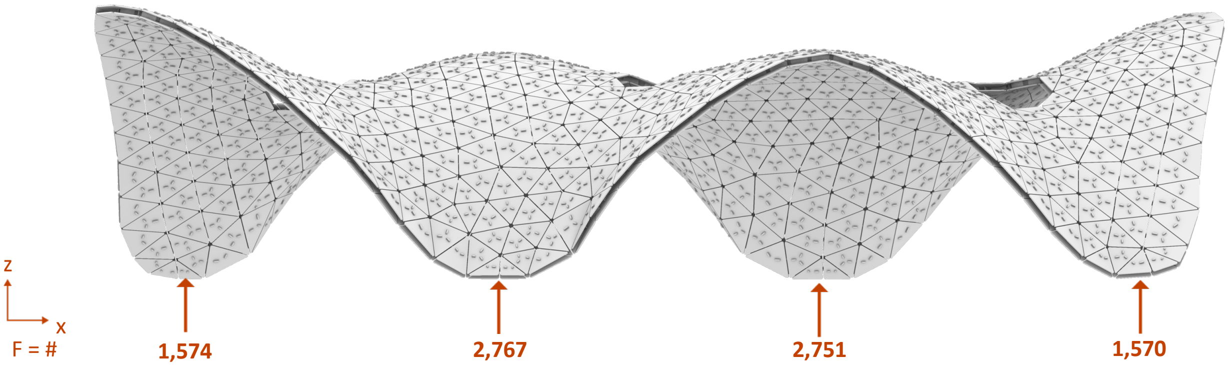
REACTIONS

R_{max} = 1,113 #
Weight = 8,662 #

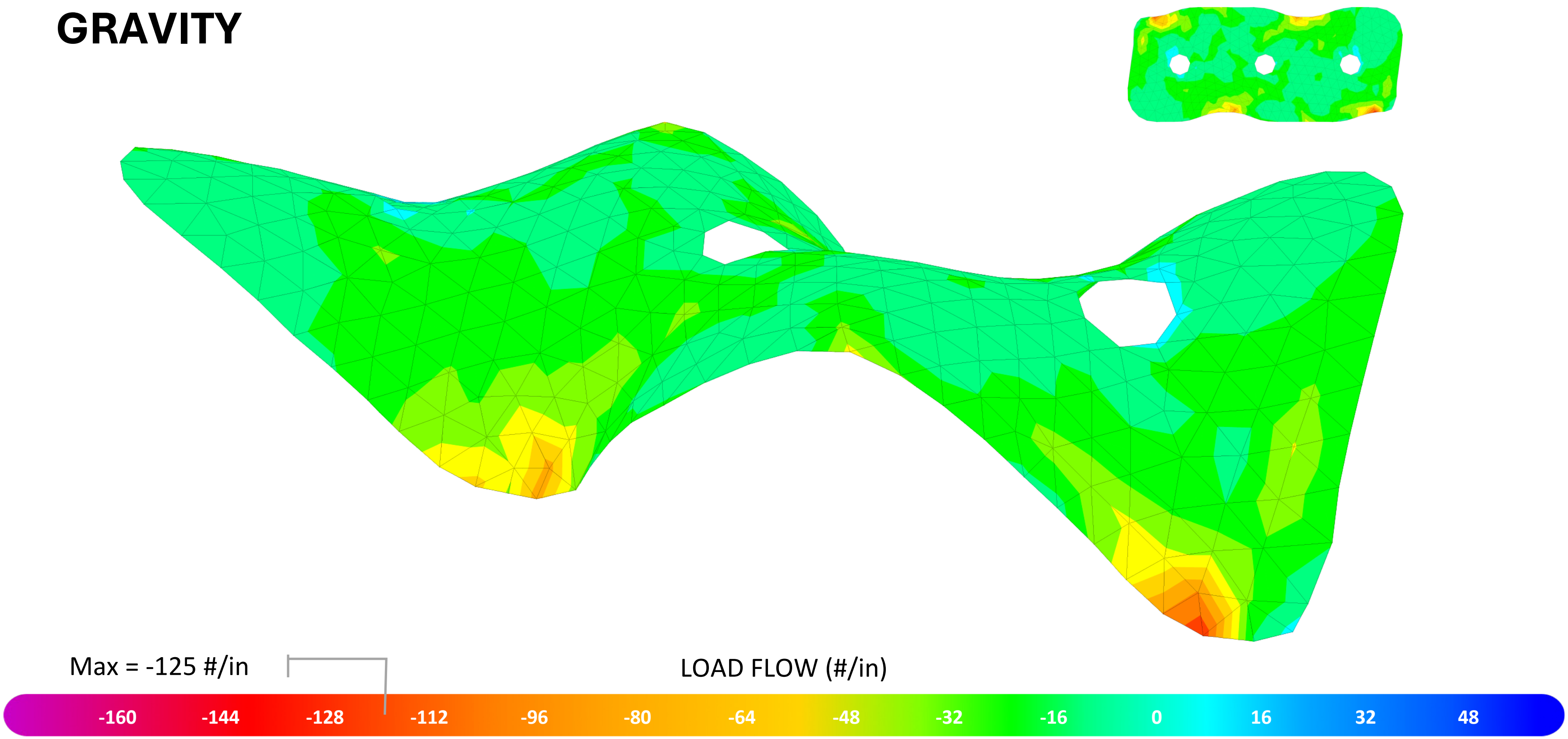
NOTES

Reactions are symmetrical across axes due to design symmetry. Outer footings can be smaller than inner due to those locations only experiencing half the reaction force. Largest reaction occurs at green mark.



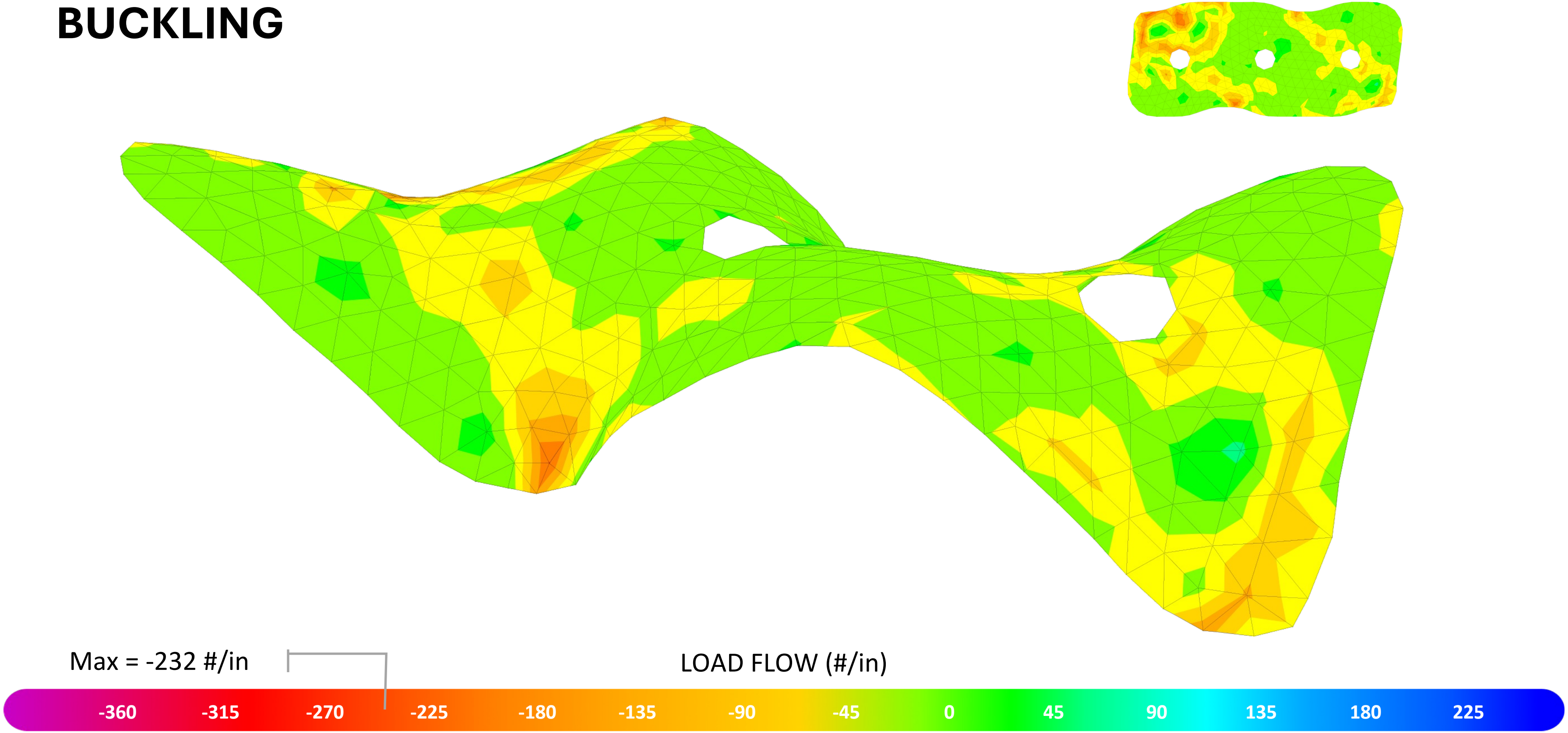


GRAVITY



The shell is almost in full compression under its own self weight, except for minimal tension around the oculi. Footing locations are areas of concern as the load concentration is much higher, though this was expected.

BUCKLING



The shell has a buckling factor of safety of 72, meaning it can experience 72 times its self weight before collapsing. Like the gravity case, load concentrates around the footings, meaning we should try to incorporate redundancy in those areas.

TIME HISTORY

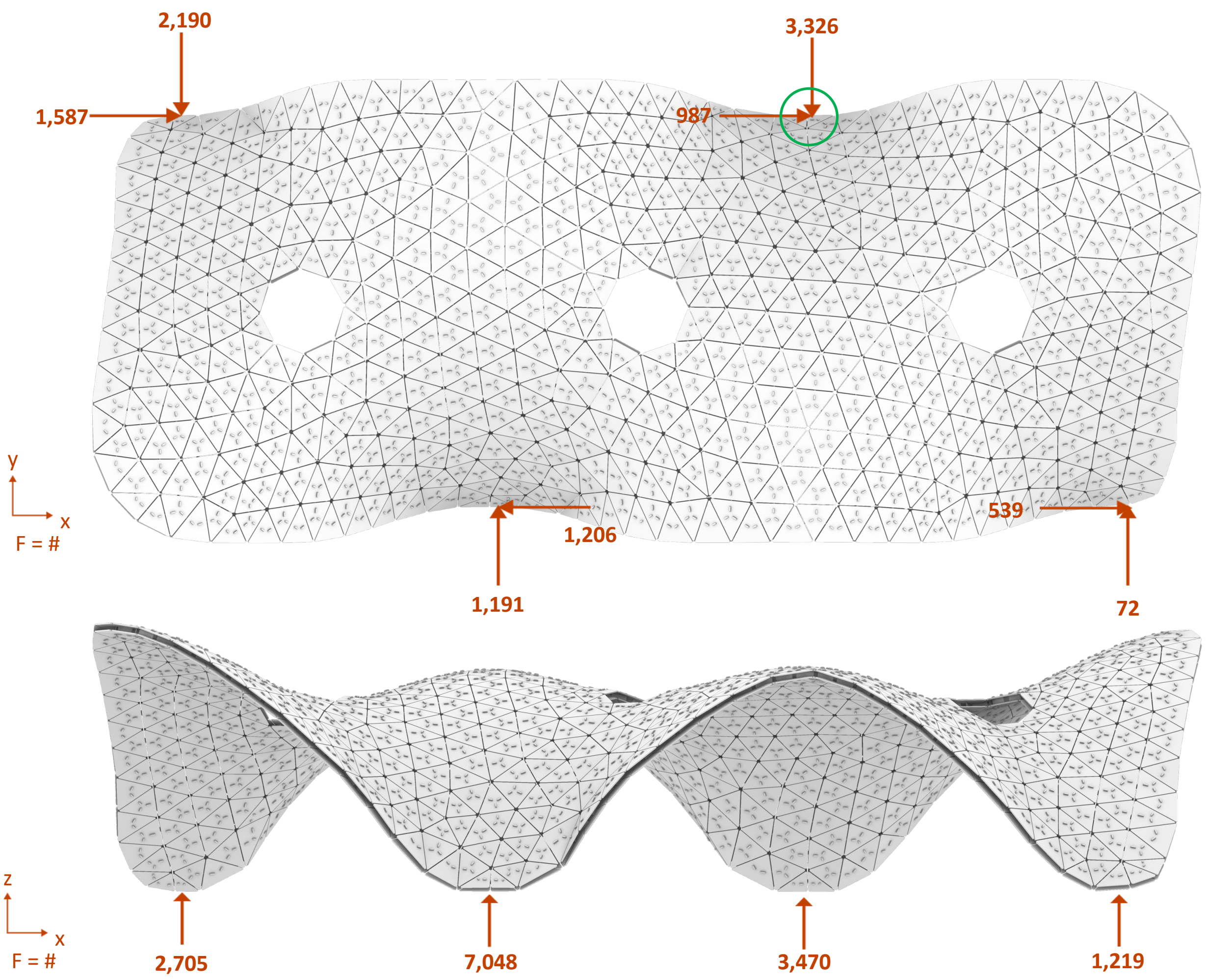
NORTHRIDGE – X Acceleration

<u>REACTIONS</u>

R_{max} = 3,470 #

<u>NOTES</u>

Model is locked in the Y & Z. Results are max envelope reactions. Largest reaction occurs at green mark.



TIME HISTORY

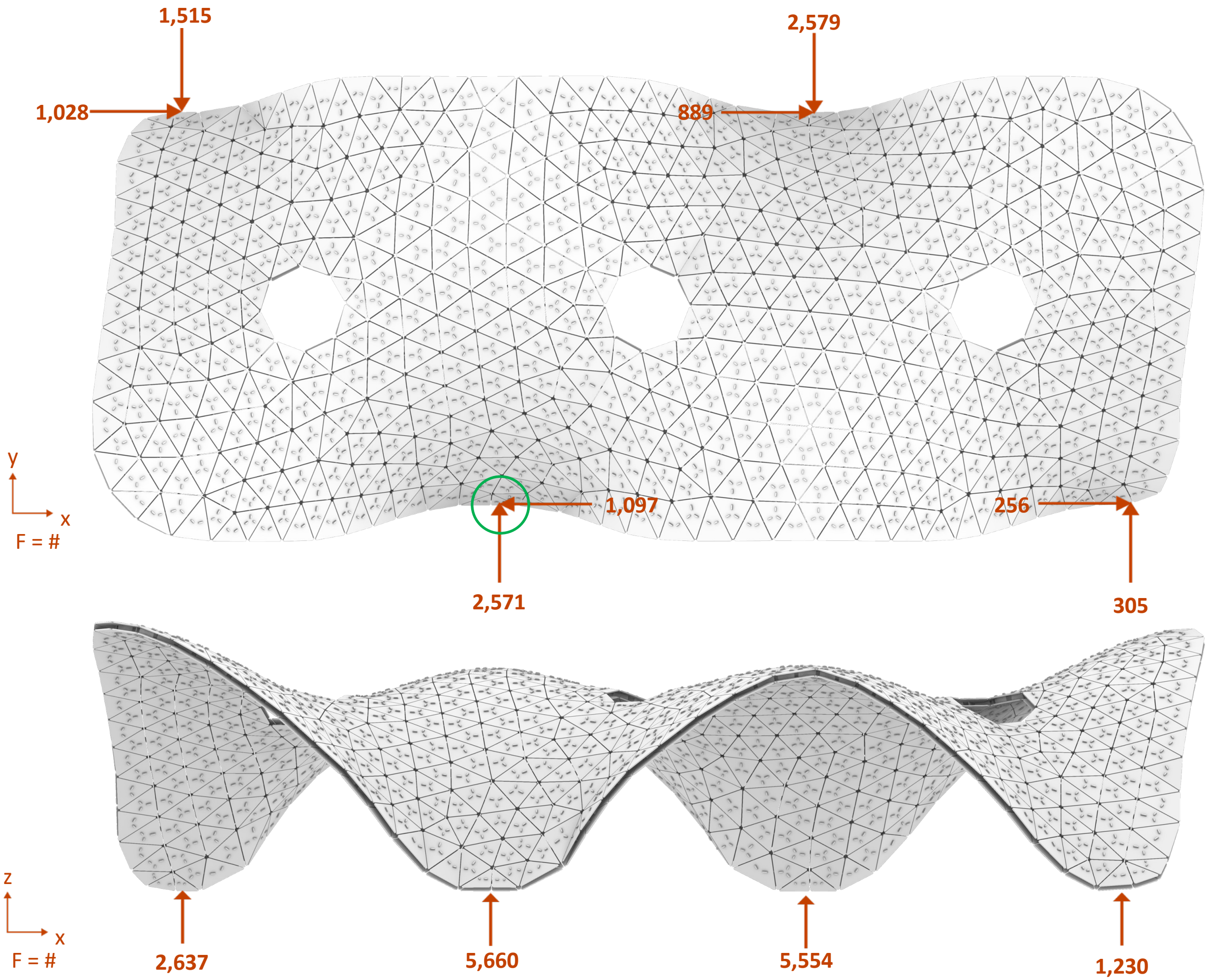
NORTHRIDGE – Y Acceleration

<u>REACTIONS</u>

R_{max} = 2,795 #

<u>NOTES</u>

Model is locked in the X & Z. Results are max envelope reactions. Largest reaction occurs at green mark.



TIME HISTORY

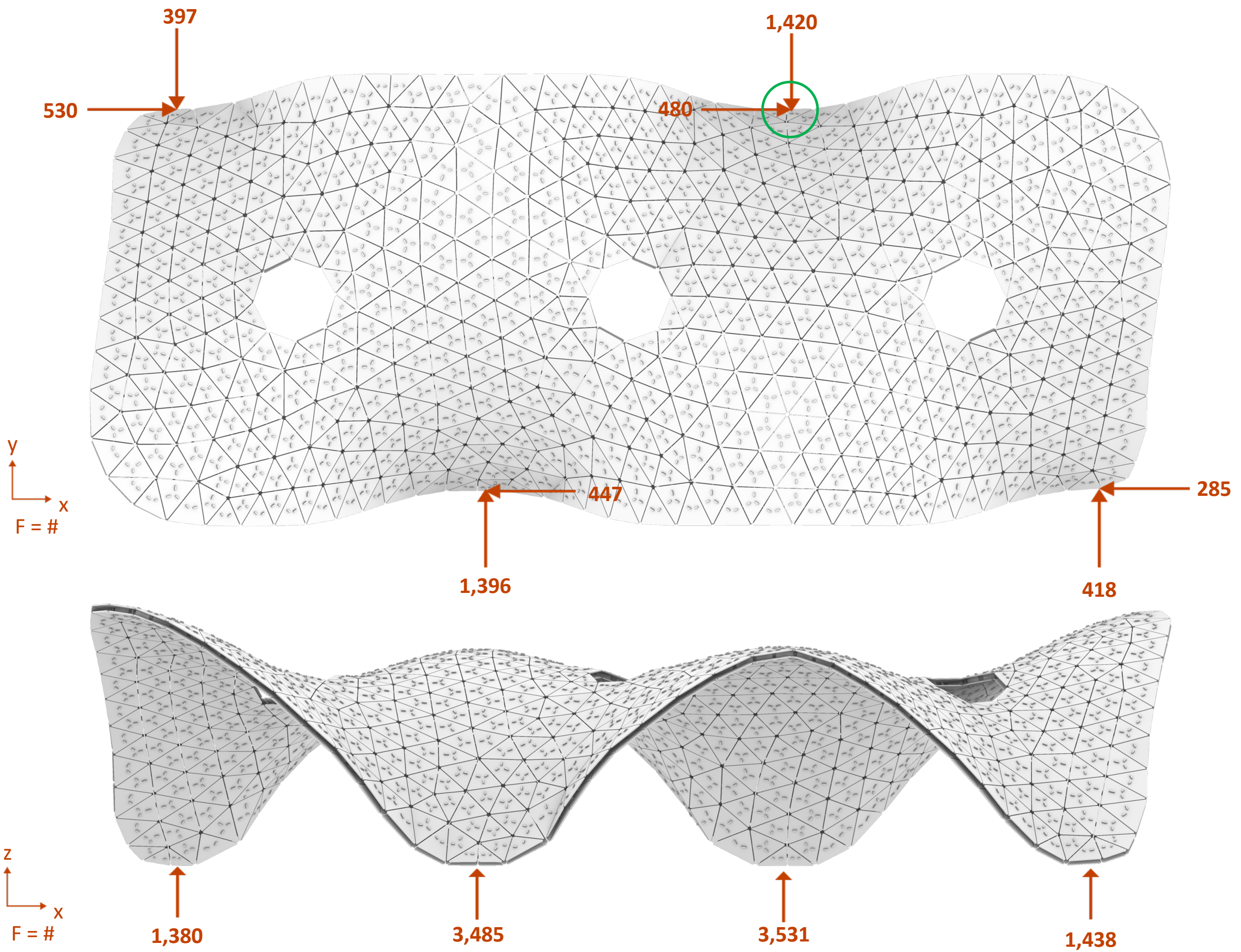
NORTHRIDGE – Z Acceleration

<u>REACTIONS</u>

R_{max} = 1,499 #

<u>NOTES</u>

Model is locked in the X & Y. Results are max envelope reactions. Largest reaction occurs at green mark.



TIME HISTORY

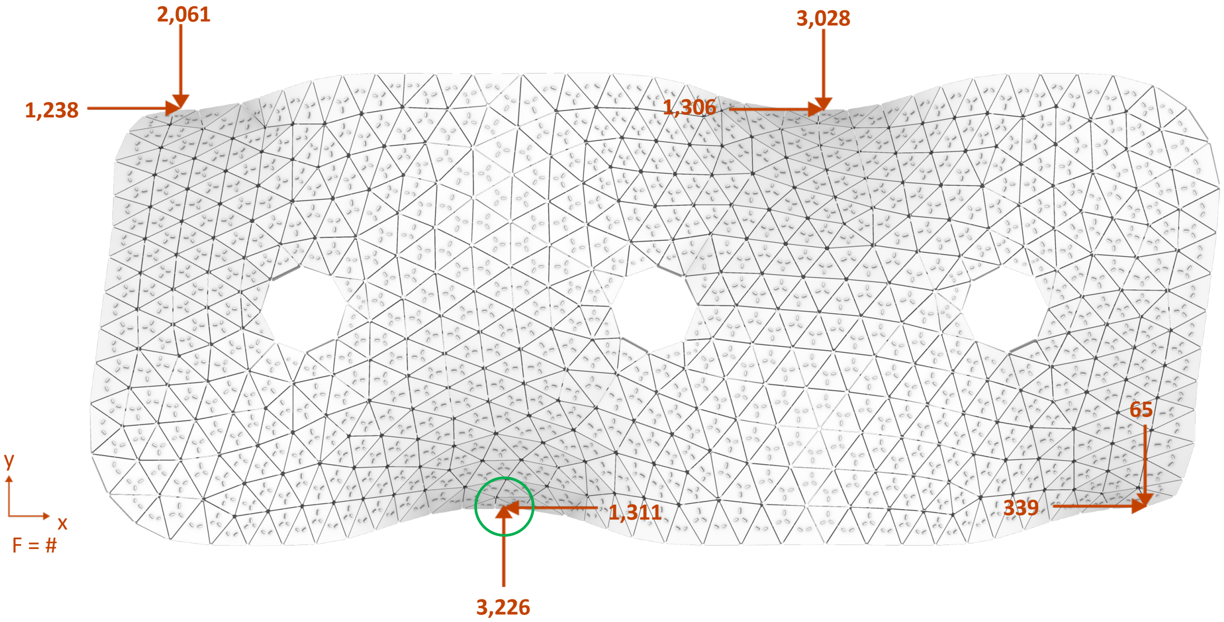
EL CENTRO – X Acceleration

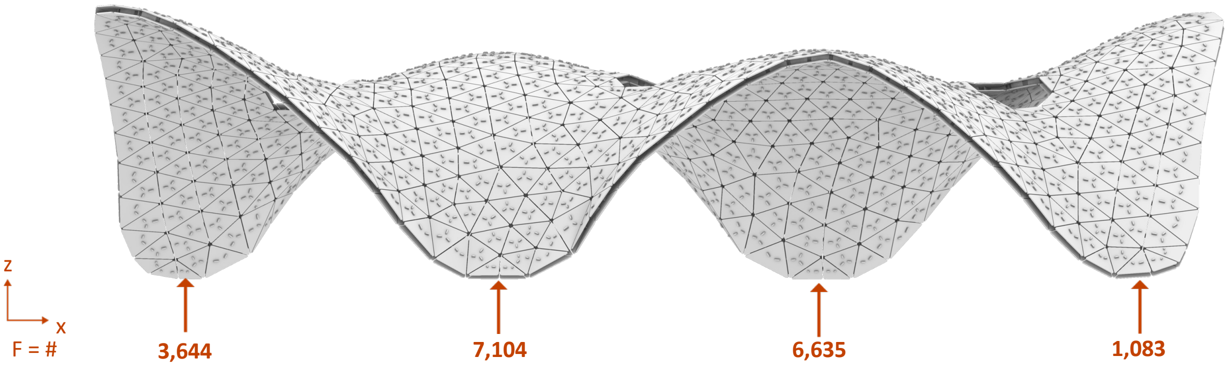
REACTIONS

R_{max} = 3,482 #

NOTES

EL Centro reactions are substantially larger than Northridge. Model is locked in the Y & Z. Results are max envelope reactions. Largest reaction occurs at green mark.





TIME HISTORY

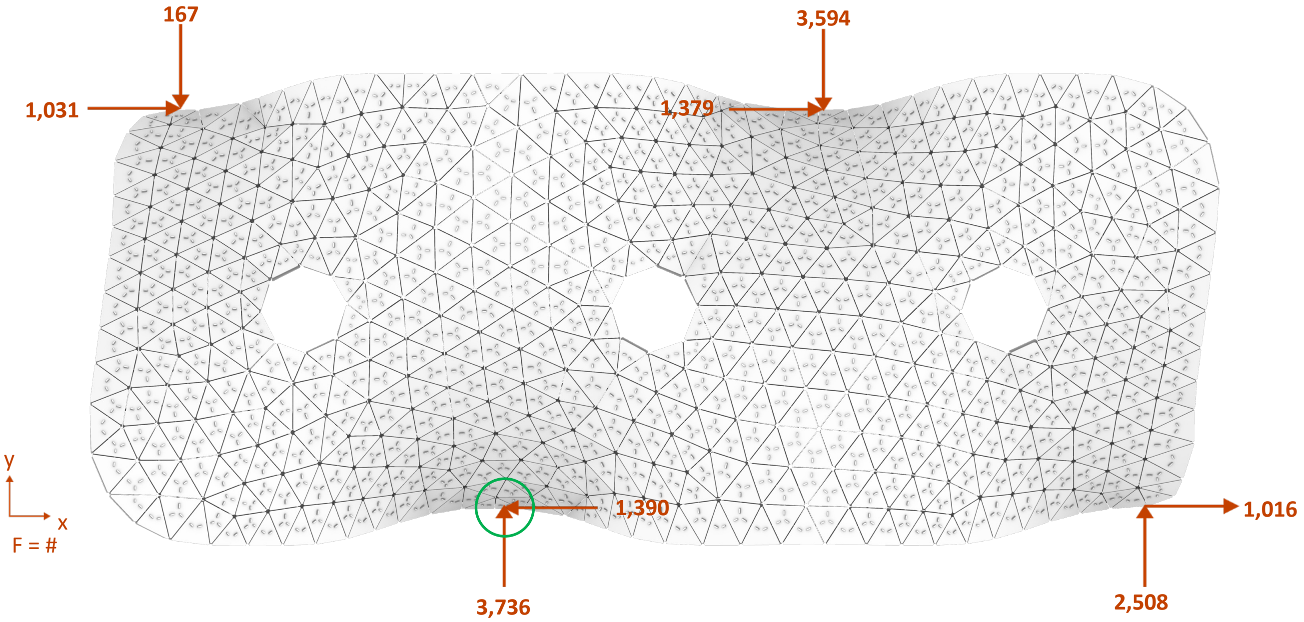
EL CENTRO – Y Acceleration

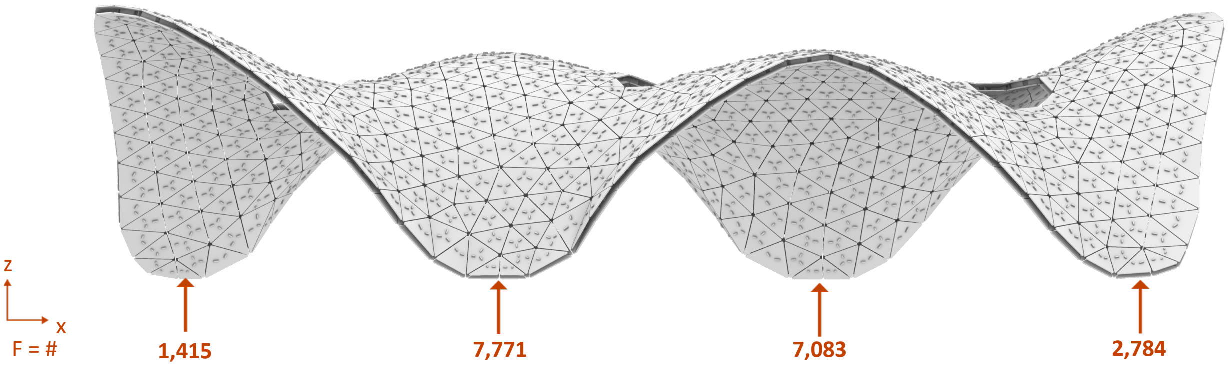
REACTIONS

R_{max} = 3,987 #

NOTES

EL Centro reactions are substantially larger than Northridge. Model is locked in the X & Z. Results are max envelope reactions. Largest reaction occurs at green mark.





TIME HISTORY

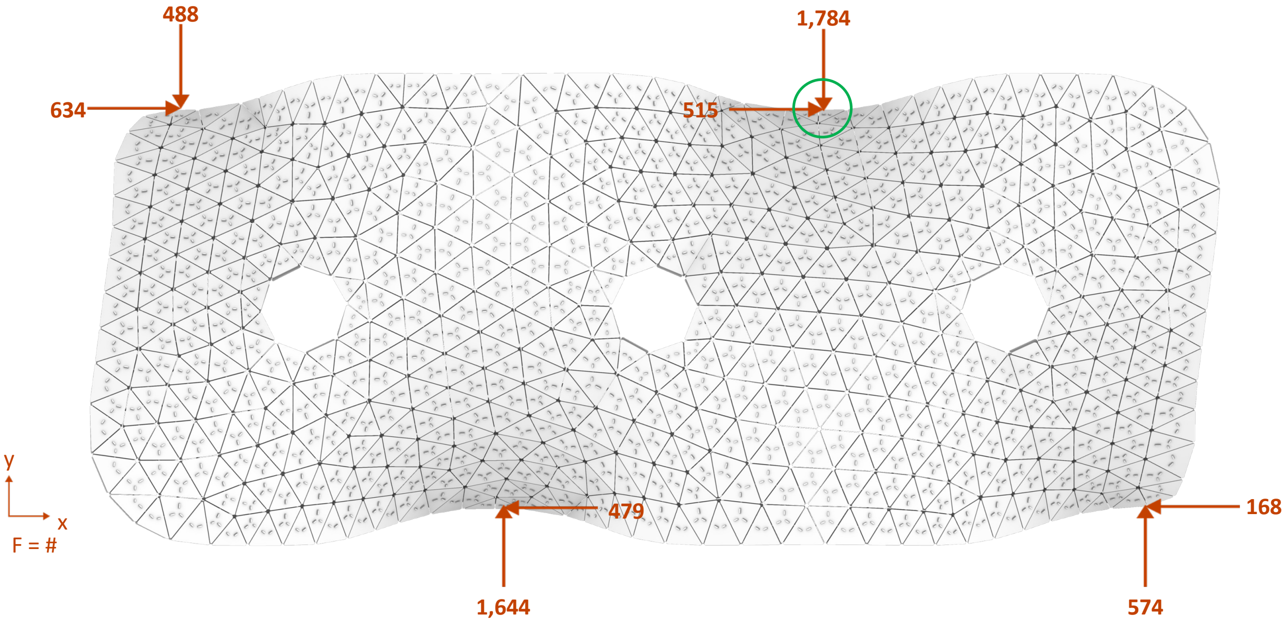
EL CENTRO – Z Acceleration

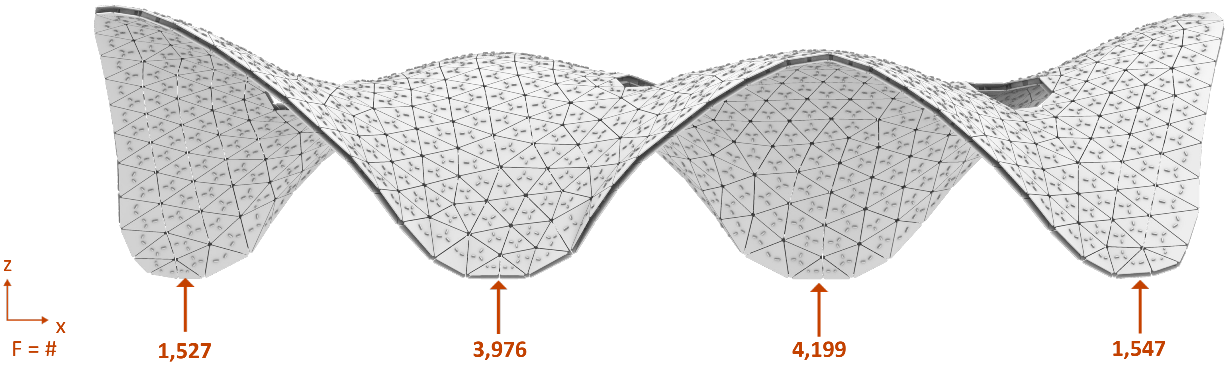
<u>REACTIONS</u>

R_{max} = 1,857 #

<u>NOTES</u>

EL Centro reactions are substantially larger than Northridge. Model is locked in the X & Y. Results are max envelope reactions. Largest reaction occurs at green mark.





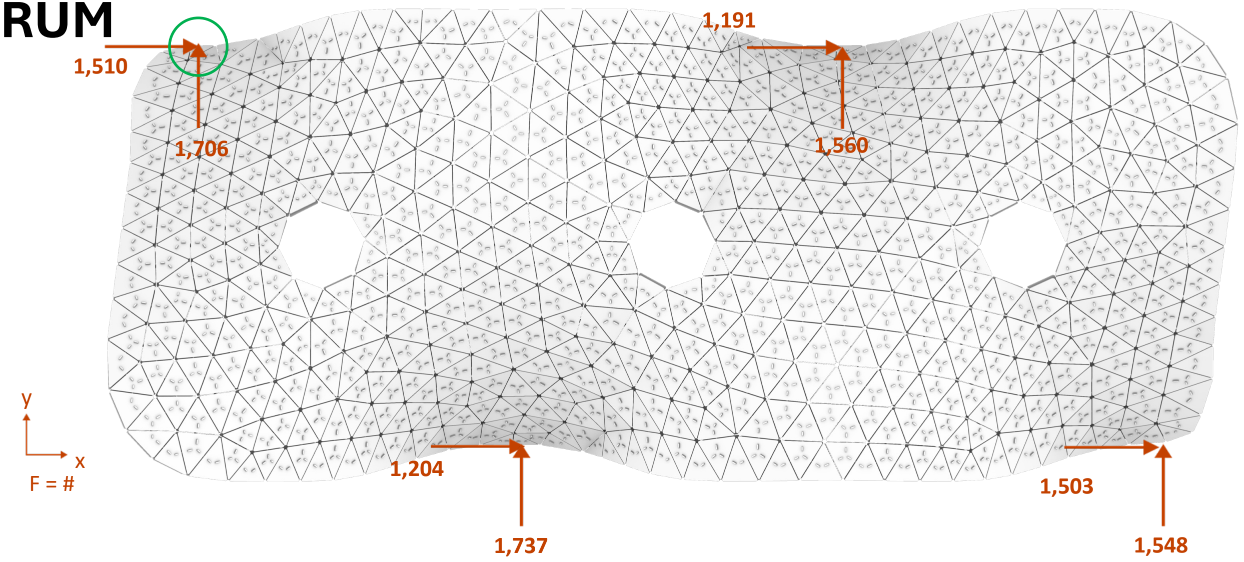
RESPONSE SPECTRUM

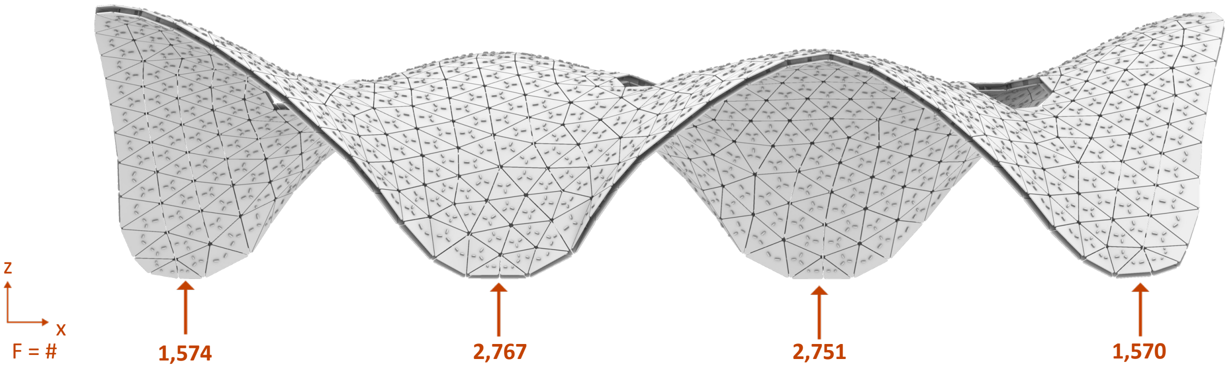
SPECTRUM INFORMATION

CODE: IBC 2012
ZIP CODE: 93405
SITE CLASS: D

REACTIONS

R_{max} = 2,278 #





OUTCOMES & MOVING FORWARD

Team Hadid found the double skin model to be a clever system with unique challenges that required a hands-on and interdisciplinary approach to solving. Luckily, this was well provided to us in the form-finding, testing, and making process.

Moving forward, more thorough work needs to be done to refine the footings, storage, and finishes. These design decisions would be made in accordance with the structures' permanence and client needs.