ARCE 415 Portfolio
June 2023

Green Bird of Paradise

Kristofer Rickansrud
Brendan Peers
Joel Santoyo
Ryan Chan

Bringing the artist back to engineering

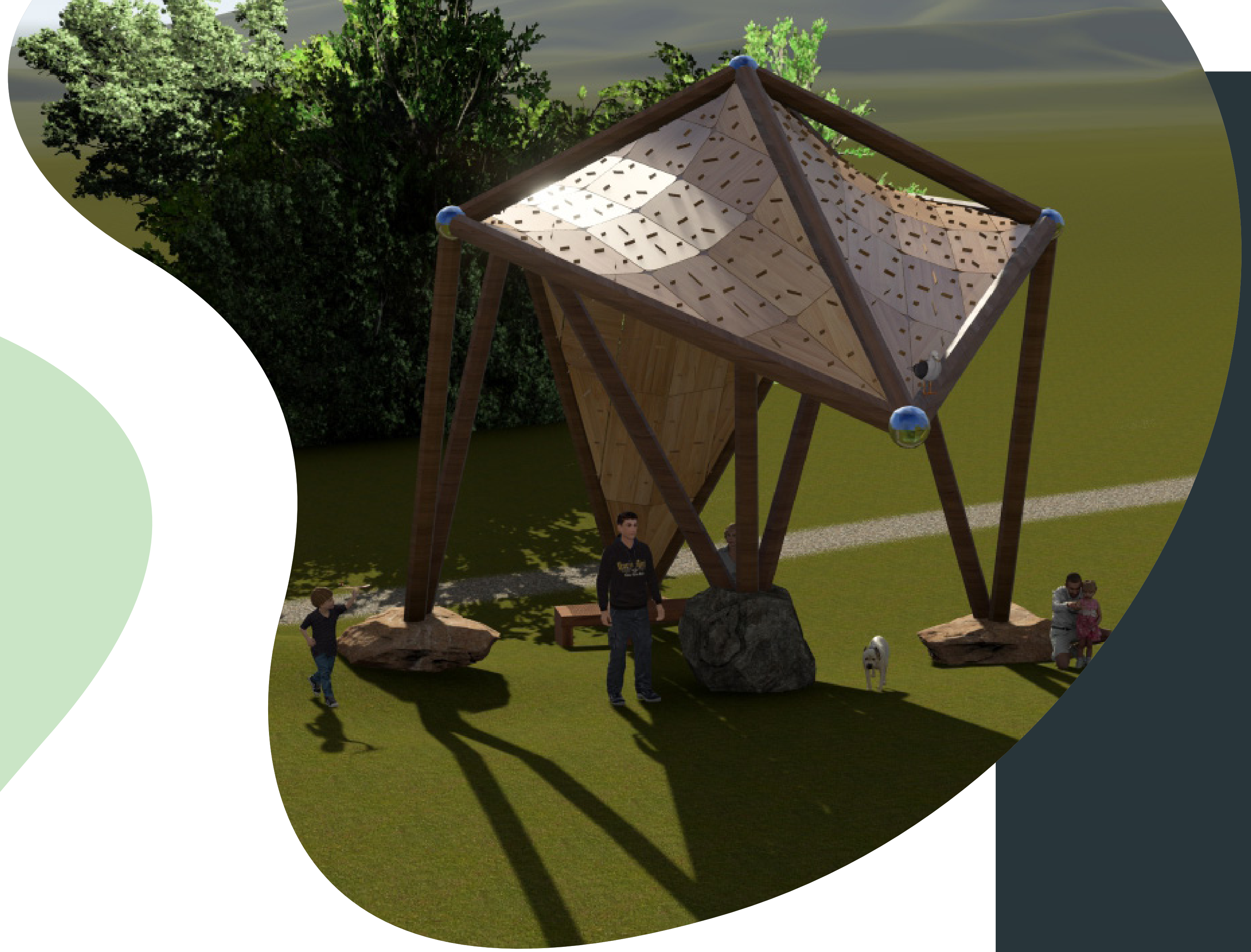


Table of Contents

Introduction

Our senior project team consisted of 4 members who sought to create a dynamic, thought-provoking structure that fulfilled the assigned purpose.
Let's meet the team:

Kristofer Rickansrud (top left)
From Richmond, CA
Has a passion for roller coasters and hopes to design them one day

Brendan Peers (top right)
From Long Beach, NY
Interested in a career in wood frame residential construction engineering

Joel Santoyo (bottom left)
From Los Angeles, CA
Interested in designing modern residential homes

Ryan Chan (bottom right)
From San Diego, CA
Interested in starting a timber single family home engineering firm




Purpose
A desination that highlights the journey

California Polytechnic San Luis Obispo is a campus residing near the coast of central California. With a campus size of approximately 6,000 acres and a student population of 22,400, there are many sites to see and places to explore. One of the most underappreciated and hidden gems residing within Cal Poly SLO is the Leaning Pine Arboretum.

Providing only 5 out of the 6,000 acres to Cal Poly's Campus and positioned far away from the heart of campus, the Leaning Pine Arboretum is one of Cal Poly's most well-kept secrets. For those who know about its existence, the arboretum provides a wonderful and serene environment for students and faculty to relax and get in touch with nature. With many students on campus not knowing about its existence, we wanted to design a structure that would bring attention to the arboretum, while enhancing its natural experience.

Our team sought to create a sunshade that utilizes a dynamic form to create a structure that is both practical and beautiful. The key factors driving our initial design process were all related to the site of the structure, the Leaning Pine Arboretum. We focused on how the structure will interact with the surrounding nature of the sight and how it will affect human interaction with the Leaning Pine Arboretum.

Site
The Leaning Pine Arboretum

The Leaning Pine Arboretum, founded over 50 years ago, is a garden that consists entirely of student work and is managed by students. Our studio embraced this tradition to add another senior project to the site, except as a structure, not a plant. The site has a beautiful view of the adjacent mountain, nicknamed Seesaw Peak, which we wanted to emphasize with our sunshade's design.

The Leaning Pine Arboretum, tucked away at the top of Cal Poly's campus, is home to thousands of beautiful senior projects. The arboretum is divided into several gardens, each highlighting the flora of different geographical regions. The branching paths throughout the multiple gardens create an exciting journey as you explore the beautiful nature of the arboretum.

The spirit of the arboretum was a major factor that drove us to reach our final form. Our team sought to create a form that highlights the experience of the arboretum as visitors travel through it as well as continue the senior project tradition of the arboretum. A driving idea for our design was to create a destination that focuses on the journey. We hope that our structure excites visitors and gives them a reason to journey into the arboretum.

Site Circulation

Our team carefully considered where to place our structure within the Leaning Pine Arboretum to maximize the visitor's experience of the site. The arboretum's layout invites exploration, and with our structure placed in the back of the site, we reinforce this idea.

The image to the left shows the several journeys a visitor may take to reach our sunshade. The visitor experiences the beautiful plants of the arboretum and then reaches the beautiful site where our structure is placed.

Paths of The Arboretum

The Leaning Pine Arboretum offers a variety of paths that visitors can explore. Each path offers a different experience and highlights the horticulture of several regions across the world. The arboretum consists of several explorative experiences which are group wanted to emphasize through the placement of our structure.

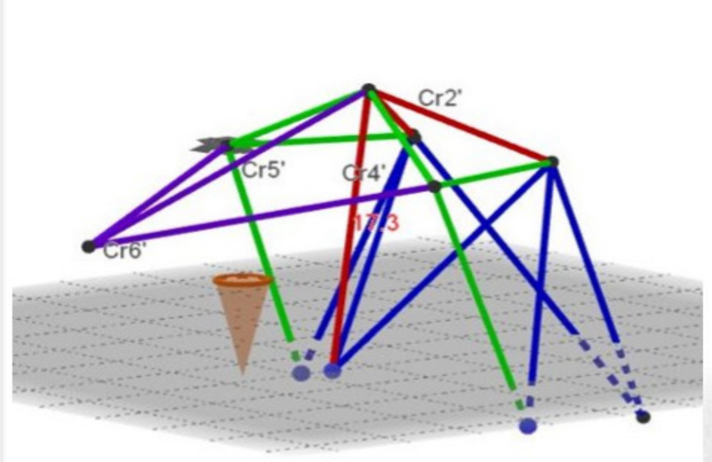
Form Finding

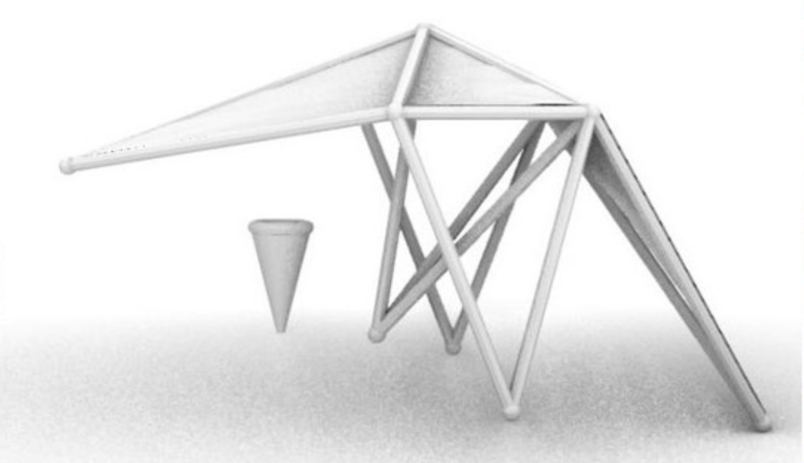
The design process of this studio consisted of a three step cycle:

Form Finding -> Form Testing -> Form Making

We began with form finding which consisted of creating dynamic shapes called Xenaforms, coined by professor Ed Saliklis, which are inspired by Iannis Xenakis' 1958 Phillips pavilion.

Determinant forms were created in Geogebra by forming spheres around base points, creating a point where the spheres intersect (called a crown), and connecting lines from the crown to the base point, ensuring that all 3 degrees of freedom were restricted. A degree of freedom can be analyzed as a spherical movement, therefore if a point has its 3 spherical degrees of freedom supported, it is stable.

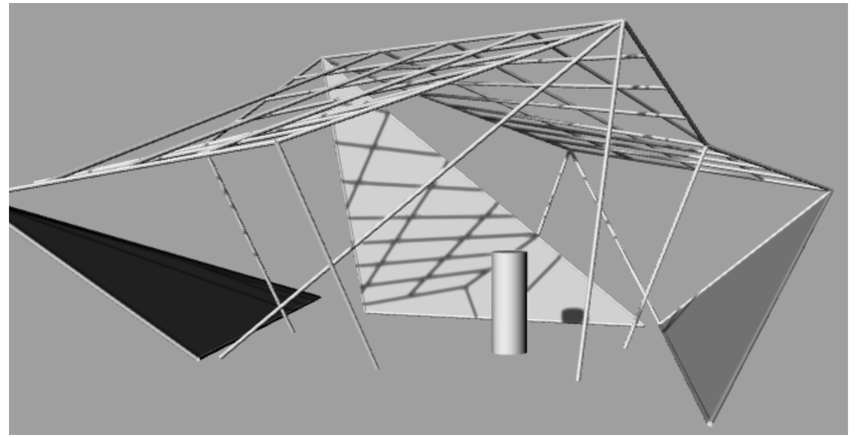


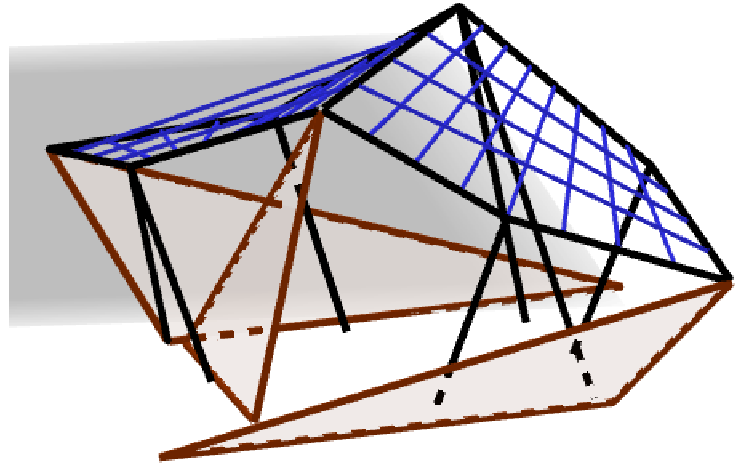


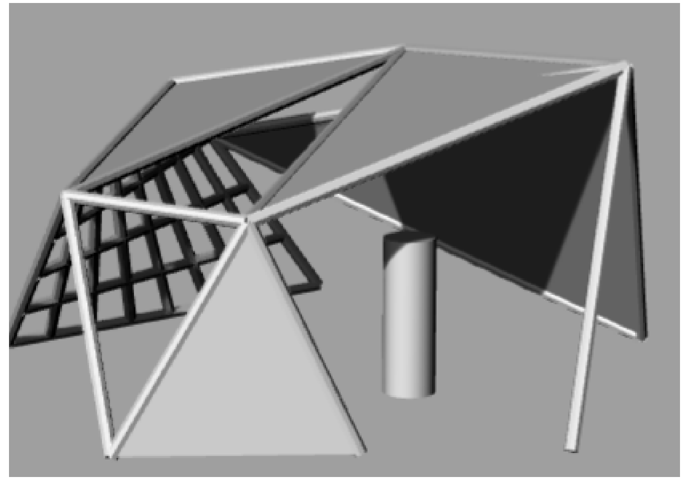
Bad Ideas

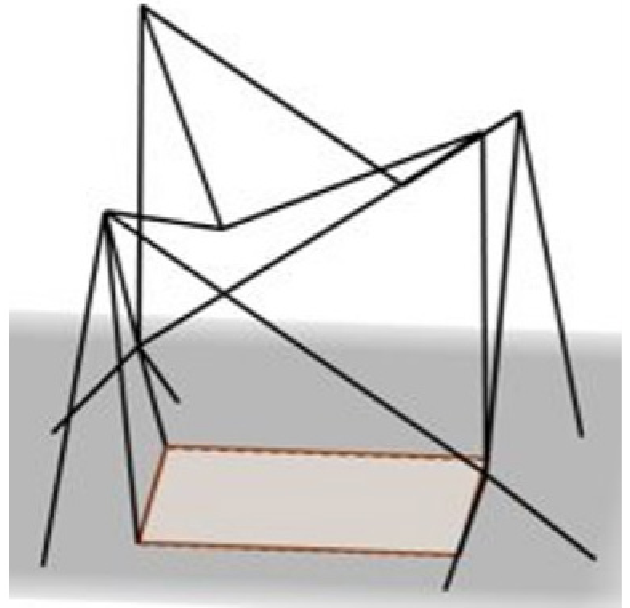
The form finding process began by utilizing bad ideas. Initially, each member of the studio created several designs in geogebra and presented them. Many were bad, but every bad idea has a silver lining. Our studio's design philosophy was to begin with bad ideas that fuel the creative mind and utilize these bad ideas to see what worked and what didn't. This process of creating several bad ideas not only grew our skills in geogebra, but as designers as well. We were able to test out crazy designs without the pressure of needing to create something perfect. Through these bad ideas, our team decided some form ideas and shapes that we wanted to pursue.

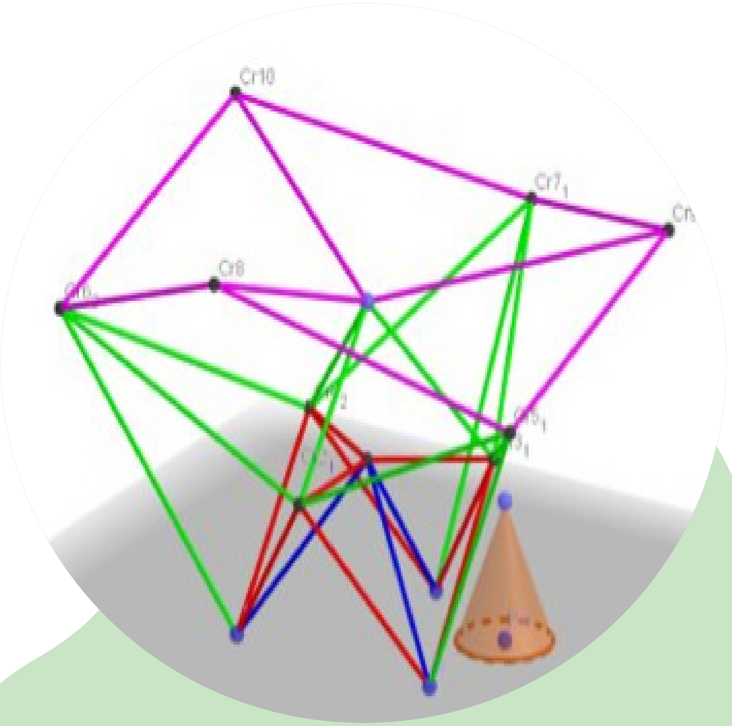
Driven by the purpose of our project, our team decided to pursue a floral shape utilizing multiple crowns, as we agreed that it would best complement the arboretum's natural environment as well as the surrounding mountains. Our team strove to create an attention-grabbing design that draws you into the arboretum, encouraging you to explore the unique beauty it has to offer.





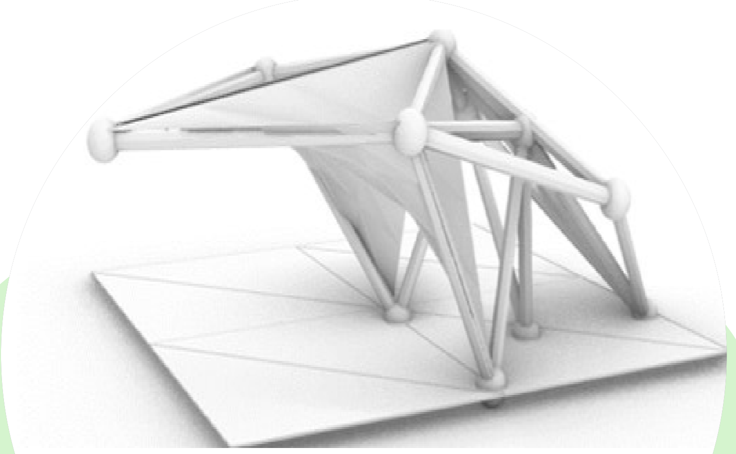






Floral Idea 1

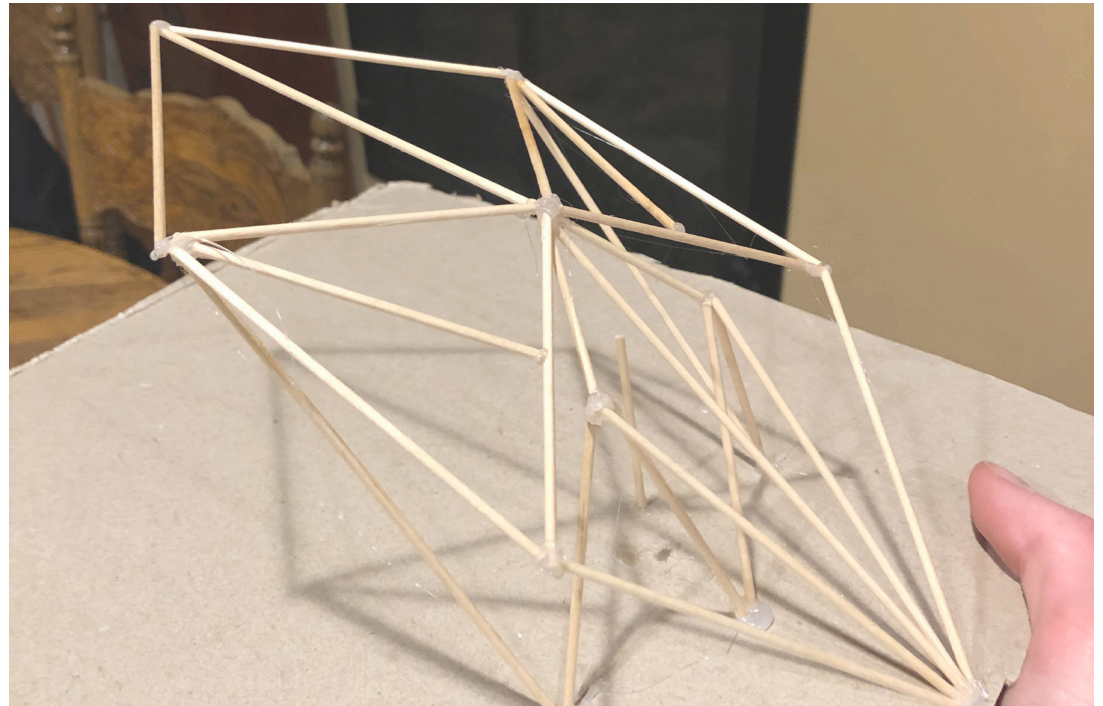
Our team began pursuing a floral/treelike form. This form had the comforting shape of a tree but lacked overall shade. Also, the base of the form was too confined for human access.

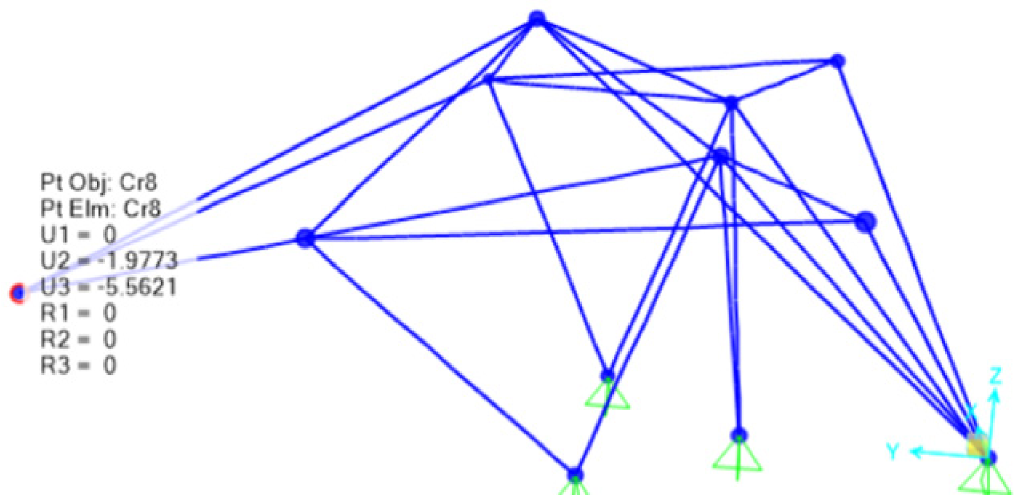


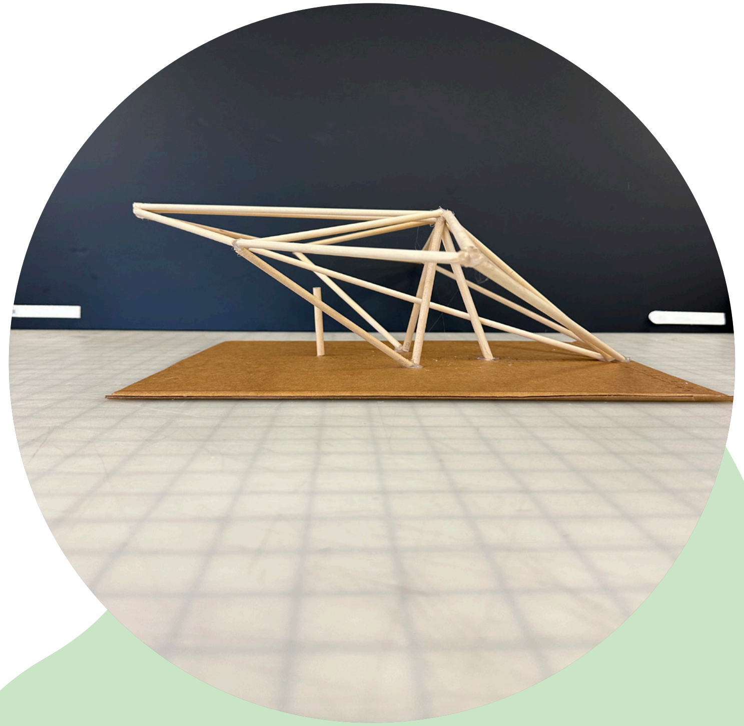
Floral Idea 2

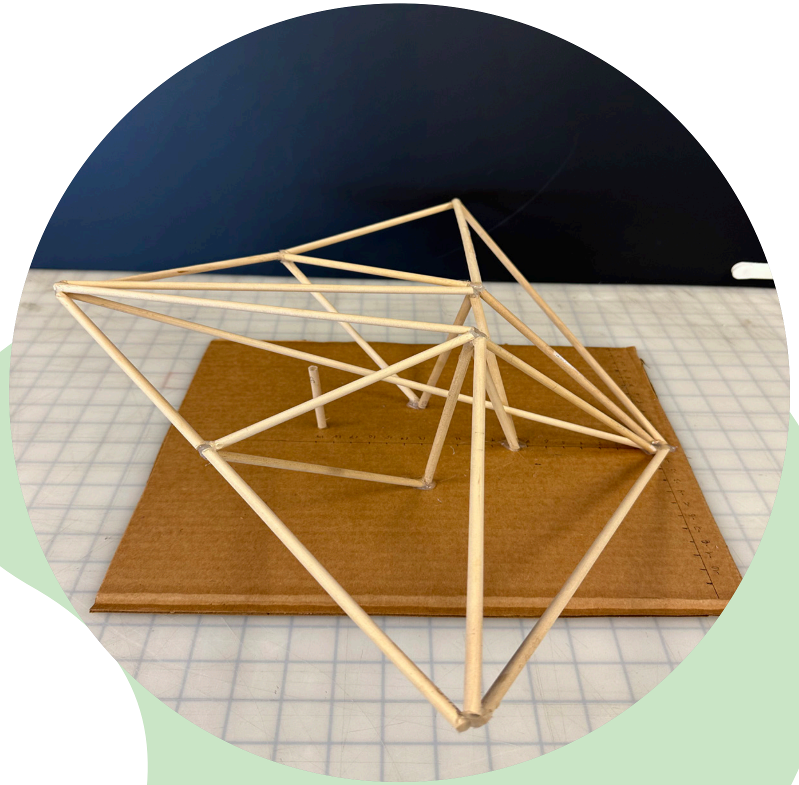
To fix the confinement issues of the first form, our team removed members and pulled the form forward, creating a dynamic cantilever that resembles a bird of paradise. After modeling the form in SAP, some major issues were discovered. The cantilever form was too long and caused a massive 5.5 feet of deflection (shown on the right) and axial forces of 35,800lbs. The dynamic floral form was achieved, but at the cost of structural integrity and safety, therefore, our form had to be redesigned.

Floral Idea 2



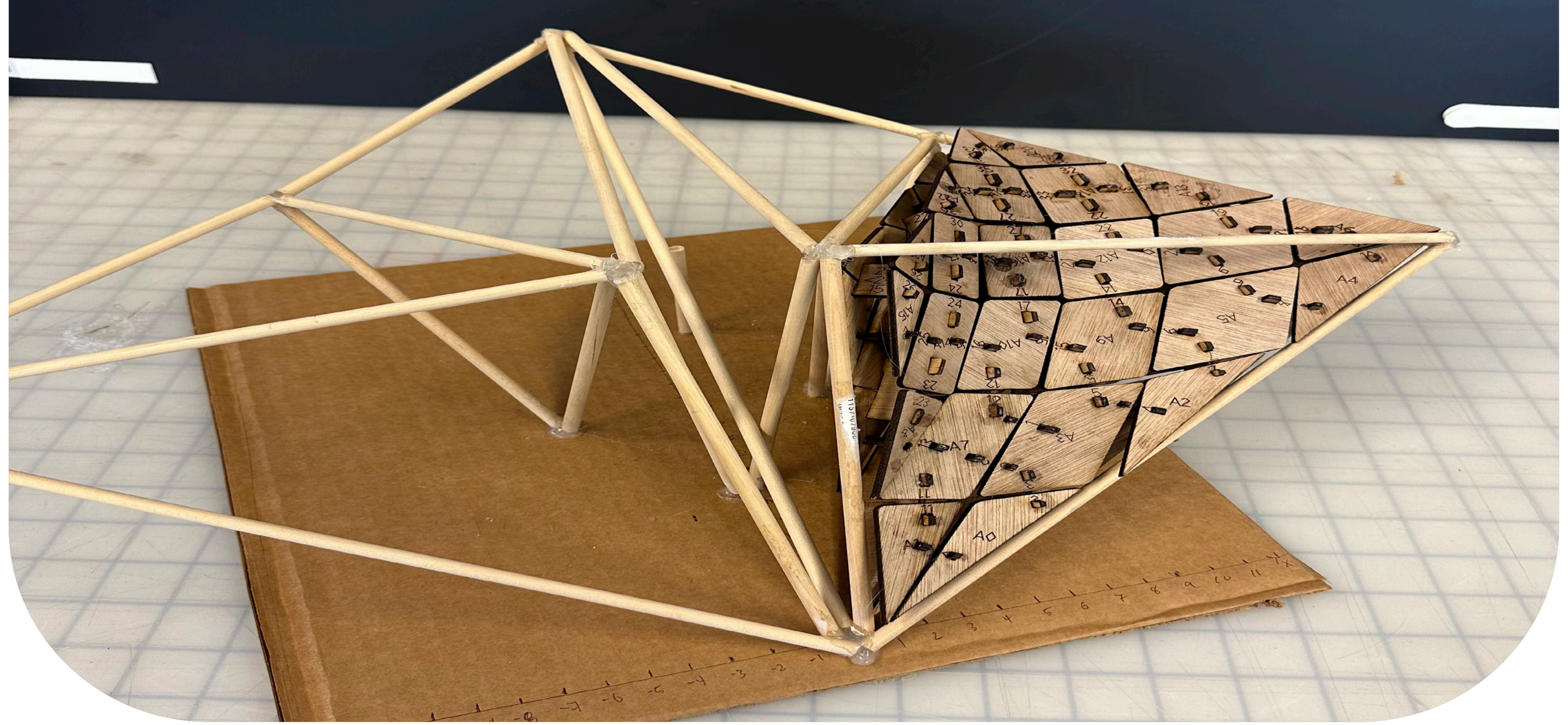


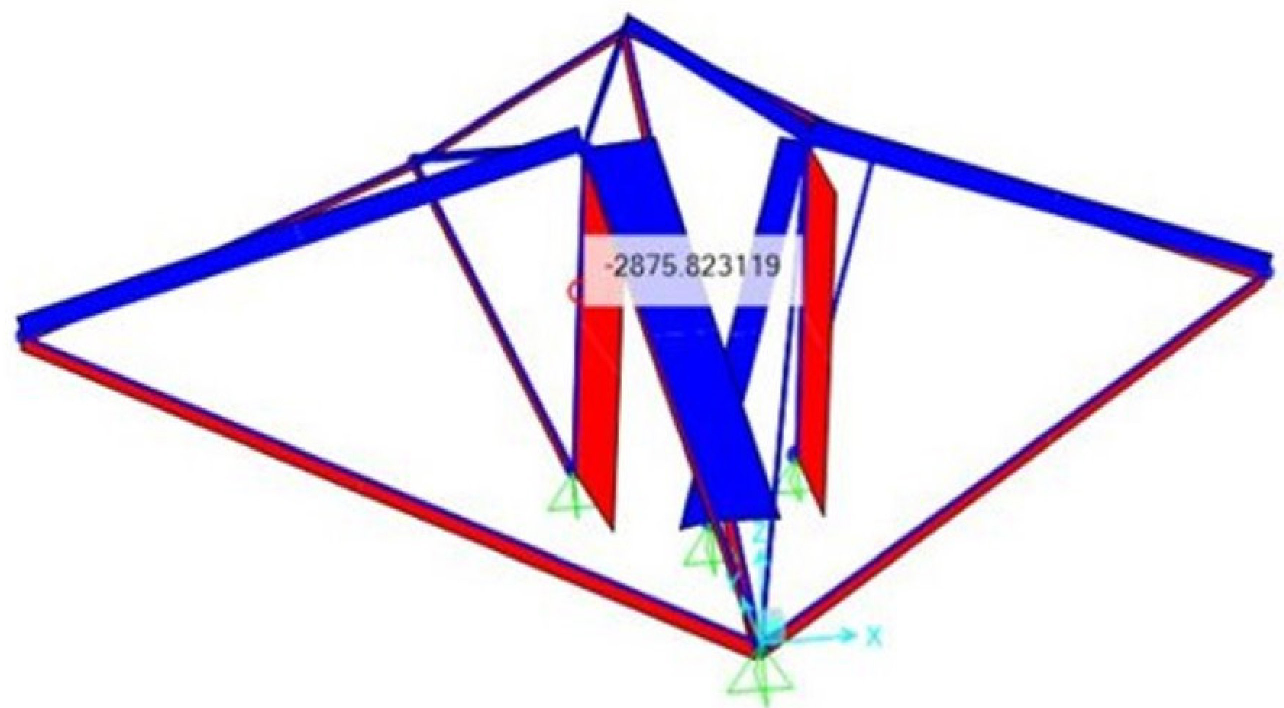




Floral Idea 3

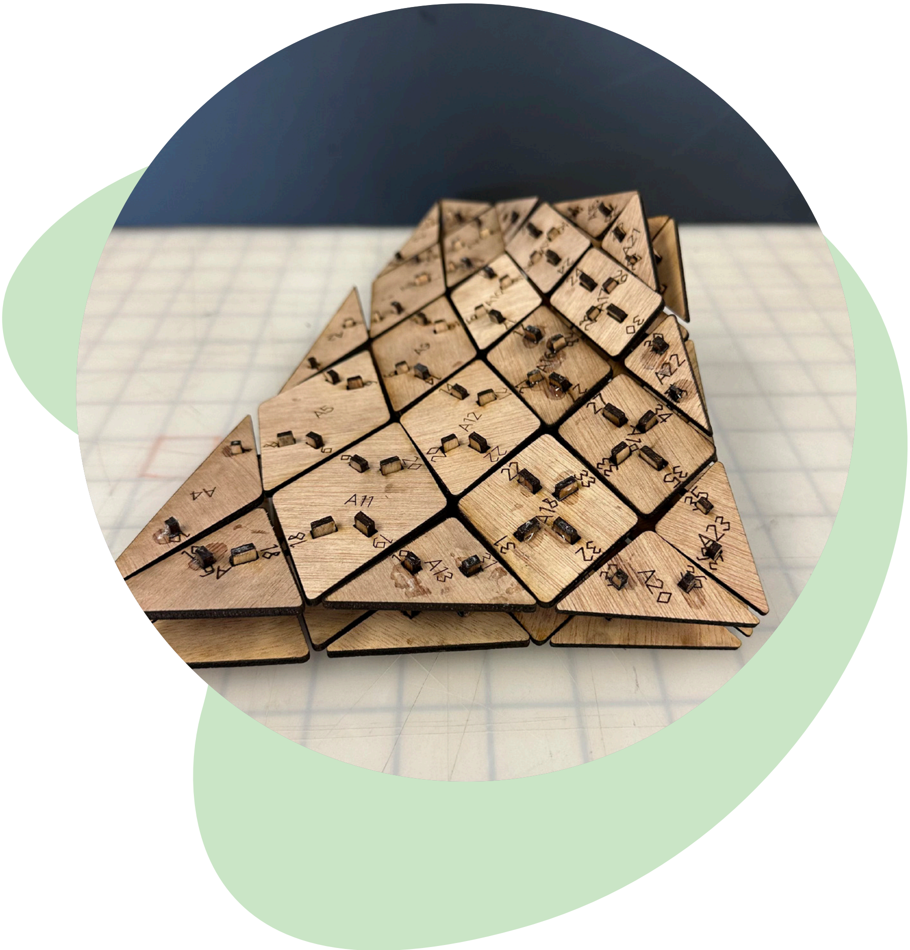
Due to the structural issues of the bird of paradise form, modifications were made to the cantilever. The "beak" was shortened, and the sides were extruded, creating a larger sunshade but removing part of the bird of paradise form, instead creating a more birdlike form.

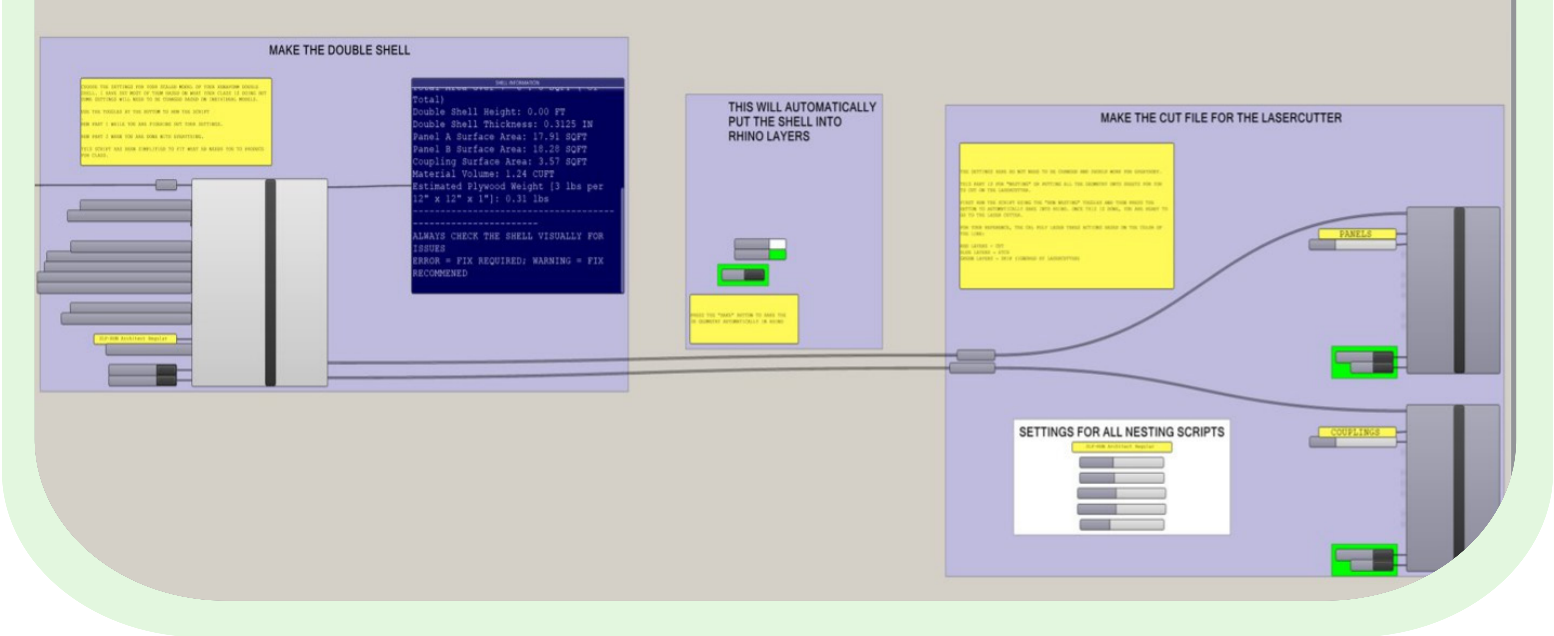




Polyshell

Created in previous iterations of this studio, taught by Edmond Saliklis, the Polyshell is a double skinned plywood shell consisting of polygons that are connected by wooden couplings. For the physical scale model, a grasshopper script created by Nathan Lundberg was used to laser cut the shell, which was then constructed by hand similarly to a puzzle.





Plywood Polyshell made by previous studios

Final Floral Idea
The Green Bird of Paradise

After editing our initial bird of paradise form, we had reached a design that had adequate shade and strength, but our team agreed that our form had strayed from the design we wanted. The new form resembled a plane more than a bird of paradise and it lacked the drama that the cantilever added to our previous design. Therefore, our group decided to revisit our previous design, simplify it, and figure out ways to achieve the dynamic form we desired.

Eventually, after utilizing a rough 2:1 back span calculation, the cantilever was brought back, while maintaining the structural integrity of the design. The floral inspiration was returned to the structure, without the five feet of deflection. The bird of paradise was reborn: a phoenix of paradise.

More than a Structure

The Green Bird of Paradise is a combination of structure and art. The dynamic cantilever form was achieved utilizing engineering knowledge, but the design of the structure was influenced by the natural beauty of the Leaning Pine Arboretum.

The exciting cantilever draws the attention of the visitor and invites them underneath the warm wood canopy. Once underneath, the visitor is surrounded by the views of the arboretum. The beak of the sunshade points to Seesaw Peak, a beautiful view that we wanted to emphasize with our design.

The downward slope of the beak creates a peak at the top of the structure that compliments the peaks of the surrounding mountain ranges.

Our team sought to create a structure that not only offers shade, but also enhances the visitors visual and physical experience of the arboretum.

Influence Views

form emphasizes seesaw peak

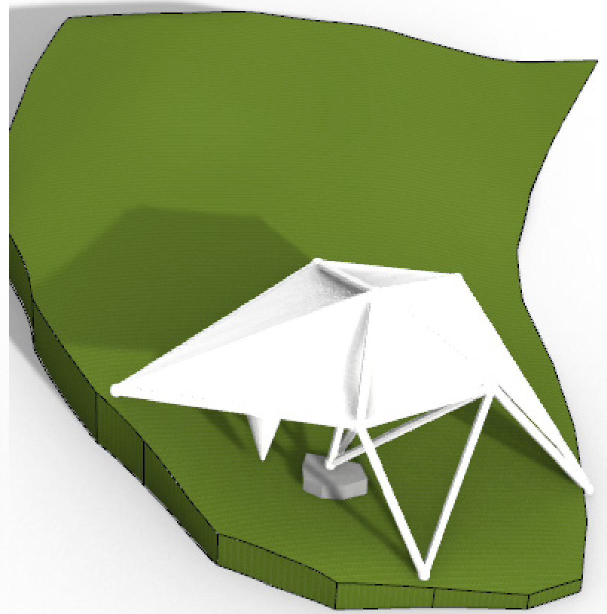
Sun Study

Since shade is one of the main purposes of the structure, a sun study was conducted to observe how the form creates shade during different hours of the day. Hours from 8am-5pm were emphasized as that is when the arboretum is open.

9am

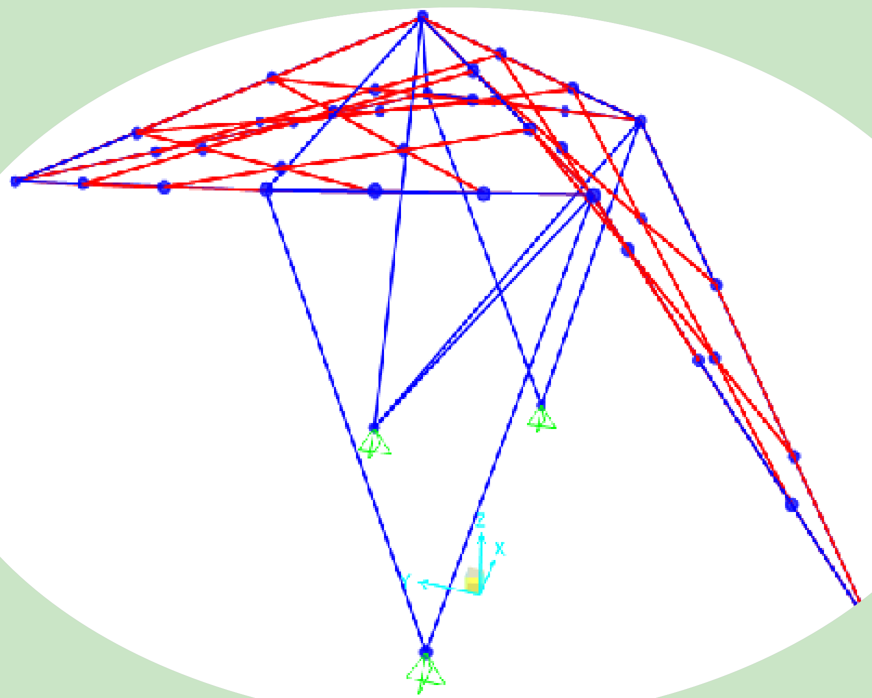
12pm

4pm



Form Testing

Now that our team had decided on a form, it was time to test the form to ensure it was stable and created forces that could be supported by the struts. The structure was analyzed using SAP 2000, paired with a few hand calculations using Geogebra as a calculator. Dead, live, and seismic loading were considered in the analysis of the structure.

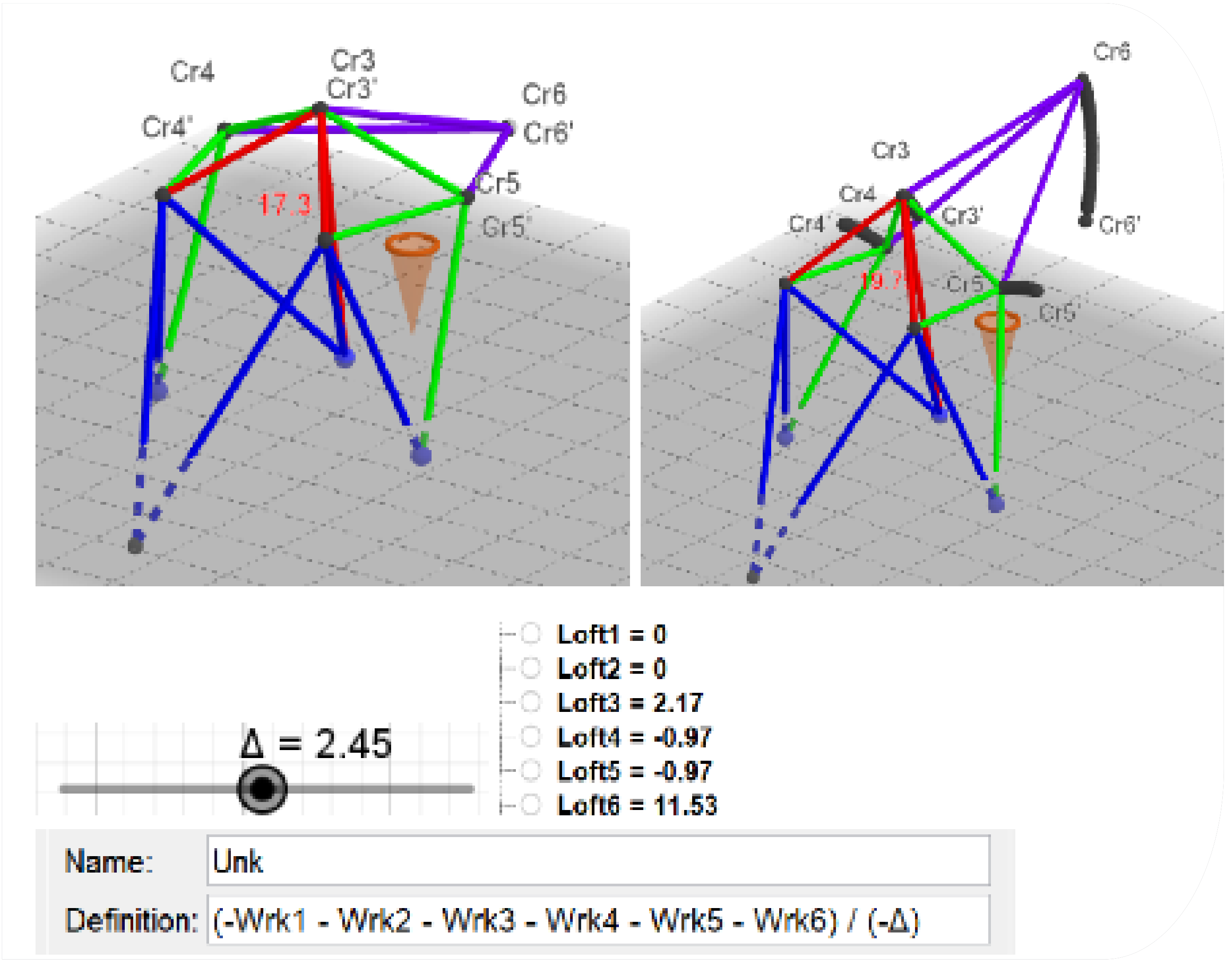


Conservative Analysis Assumptions

For the SAP 2000 and Geogebra analysis, the following assumptions were made:

- 6in x 6in members with a self weight of 40pcf and a modulus of elasticity of 1,000,000psi
- Shell modulus of elasticity of 300,000psi assuming shells are partially structural
- 3in single layer shell, accounting for the double layered 1.5in Polyshell
- Analyzed as a 3D space truss
- All pinned connections

Modern Mueller Breslau Method
hand calculation using Geogebra



The Modern Mueller Breslau method or MMB is an analysis method developed by Cal Poly Professor Ed Saliklis. MMB is a work-based analysis using only one equation and can be used to determine an unknown axial force in a member. The process of MMB begins with finding the self-weight of your structure, and then adding a perturbation to the member you want to solve for. You then measure the lofts (displacement in the applied loading direction) of the surrounding affected nodes. All of these are inputted into the equation:

-Unknown Axial Force * Δ + Σ(Forces * Lofts) = 0

and the unknown axial force can then be solved for. It should be noted that while the surrounding nodes do experience displacements, all the members beside the member you would like to solve for should stay the same length.

Our team utilized Geogebra to calculate the maximum axial force and bending moment with the MMB equation and compared these values to SAP. This hand check served as a way to ensure ourselves that our SAP model and outputs were accurate.

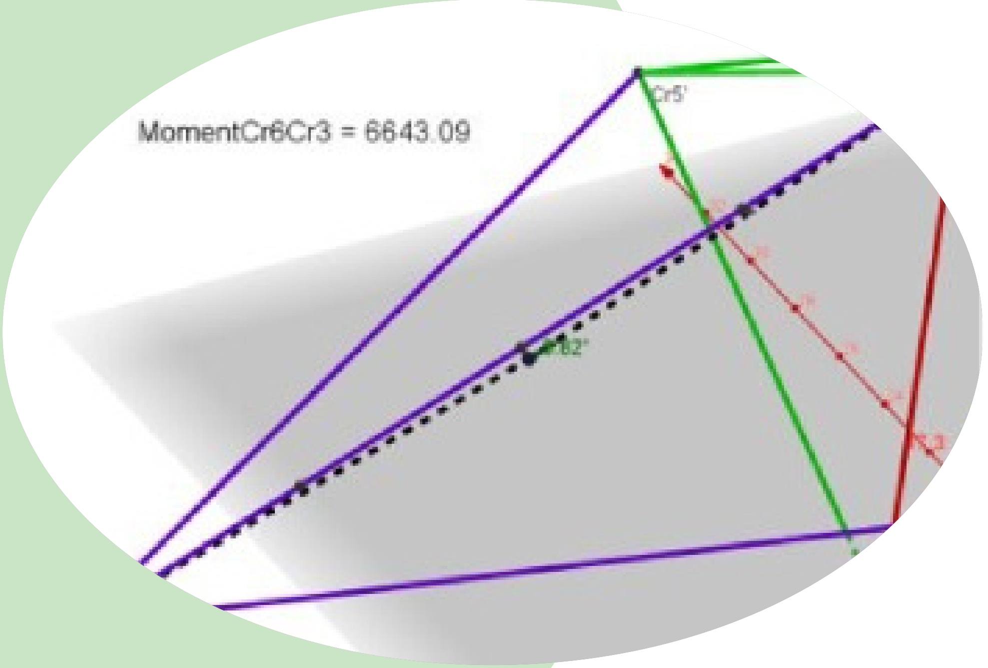
Buckling Analysis

Two methods were used to test the buckling strength of our structure. Method one involved finding the self-weight of each member, and then distributing the weights to the members respective node. Members that were connected to more than one node were distributed equally between the 2 nodes. Method two allowed each member to carry its own self-weight. A handwritten code was then created in Geogebra utilizing the Modern Mueller Breslau method to solve for our worst-case member. The Axial force and safety factor found in Geogebra was then compared to the SAP2000 value to ensure the accuracy and validity of our model. Our worst case member was the central post in the middle of our structure highlighted in red on the Geogebra model.

Applying a Δ of 0.03" to this member, an unknown axial value of 2611.13 pounds in compression was found utilizing MMB. Comparing this to our SAP2000 value of 2625 pounds, we can confirm that both values are correct due to their proximity. These values were also compared to a P critical value that the member will buckle at 24,661 pounds confirming our assumption that our structure will not fail in buckling. Dividing Pcr by the calculated maximum axial gave us a factor of safety of 9.44.

Pcr = 24,661lb

F.S. = 9.44



Bending Analysis

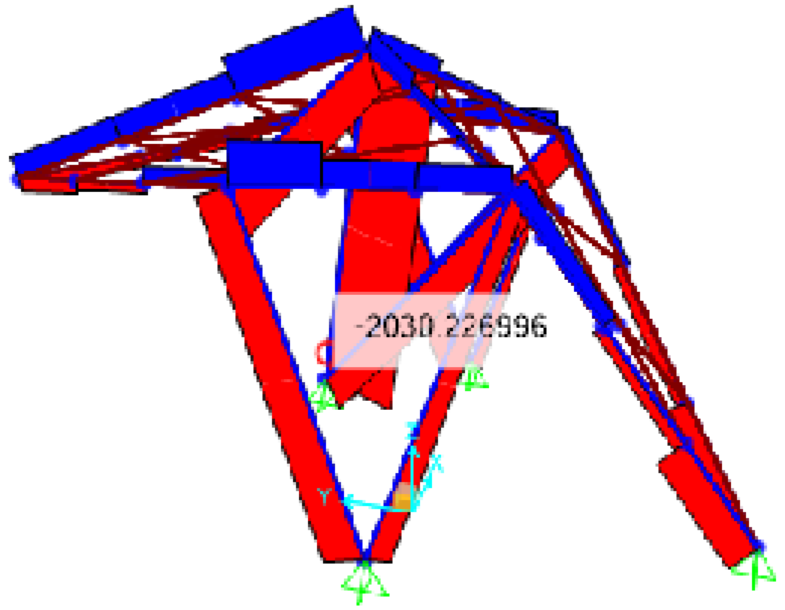
For the bending analysis, we used MMB perturbation to calculate the bending moment under self-weight at our worst-case strut using the unknown moment in Geogebra. We ran through the analysis of our structure in SAP2000 under self-weight to find the bending moment of the same worse case strut. Both results in SAP2000 and Geogebra were extremely close, and we were satisfied with the accuracy of our bending analysis.

MMB: 6643lb-ft
SAP: 6636lb-ft

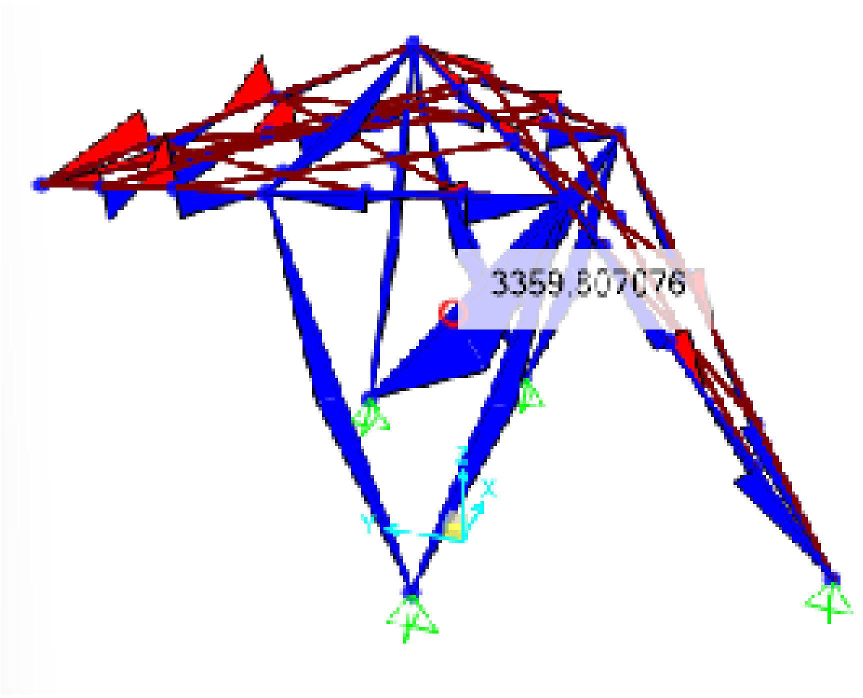
For both the buckling and bending analysis, only dead load was considered, and the shell was excluded in order to accurately compare the MMB and SAP values.

Bending, Axial, and Deflection
with shell and dead + live

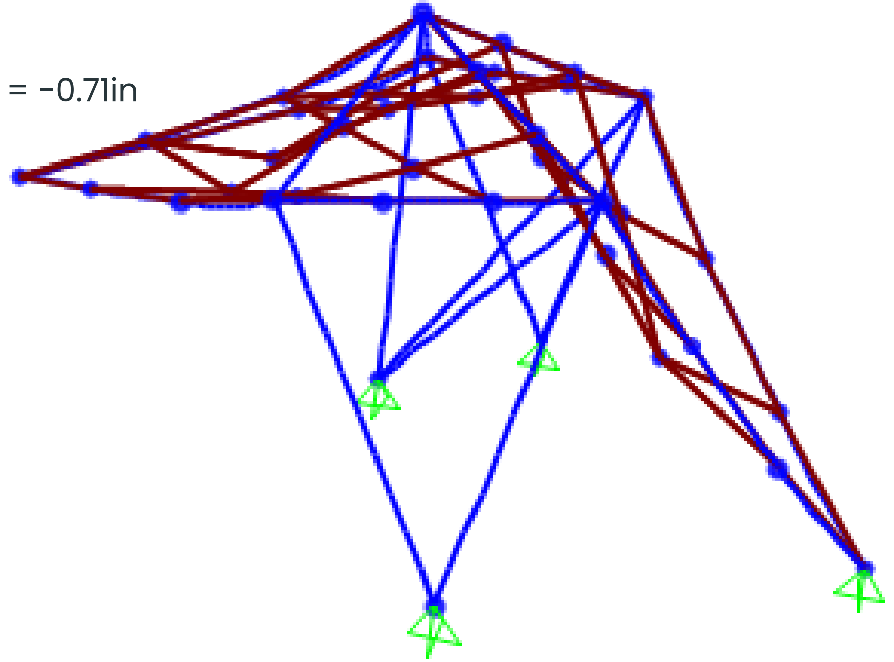
After the SAP outputs were checked using MMB, bending, axial, and deflection was analyzed with the shell added. Also, a 250lb frat boy load was applied at the tip of the cantilever to account for anyone climbing on top of the structure.



Axial Diagram



Bending Diagram



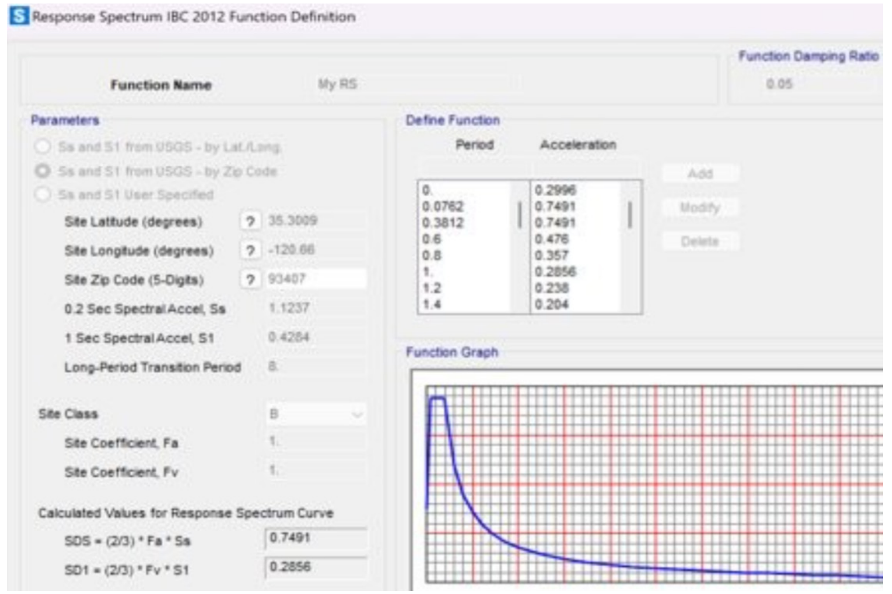
Deflected Shape

Lateral Analysis

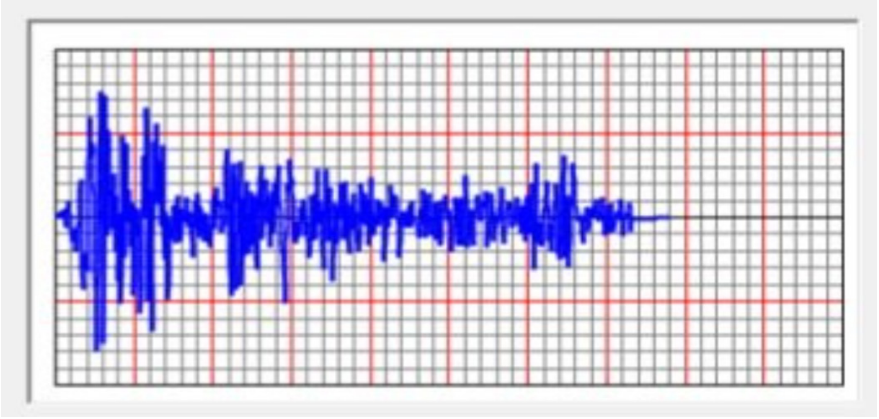
Lateral analysis of the structure was conducted using 3 methods. The first was a static lateral analysis using 0.3*self-weight of the members applied in the positive x direction. 0.3 was used to compare to the maximum force of the EL Centro Earthquake, which was 0.3G. Time history and response spectra analysis in both the global x and y axis were also utilized. The time history analysis was conducted using earthquake data from the El Centro and Northridge earthquakes, and the response spectra used the IBC 2012 function definition.

For all seismic demand values, time history (El Centro and Northridge) governed.

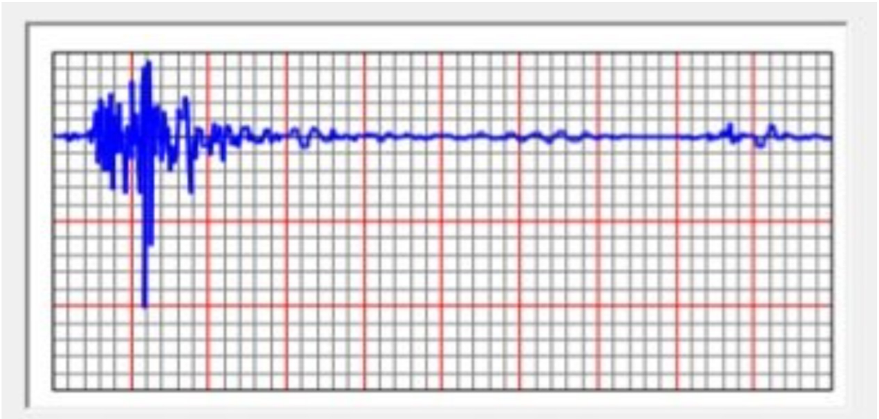
For lateral analysis, wind was neglected. Going forward with this project, wind must be checked because it could govern due to the lightweight nature of this structure.



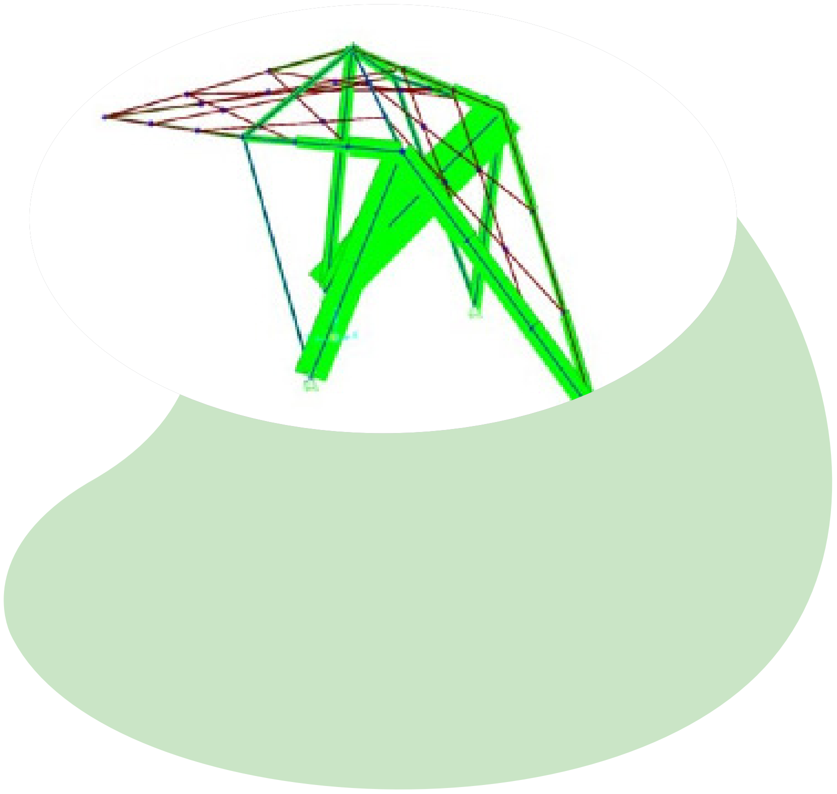
IBC 2012 Response Spectra



El Centro

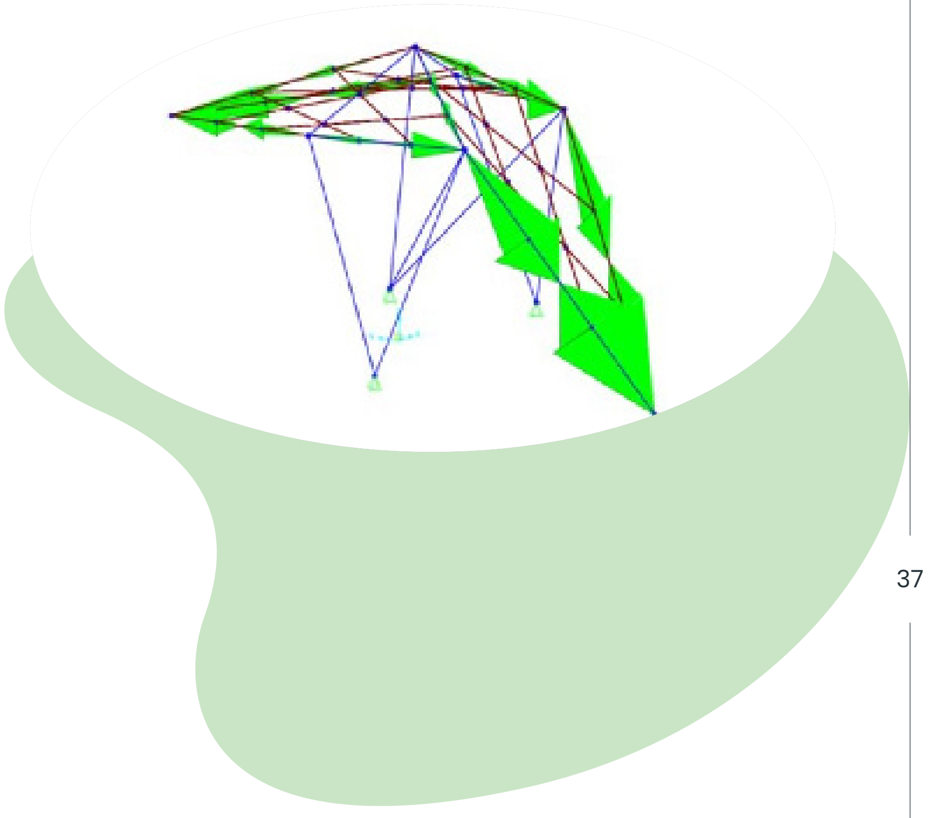


Northridge



Axial Diagram

El Centro created the highest axial force, located in the central diagonal member (shown in the photo above).

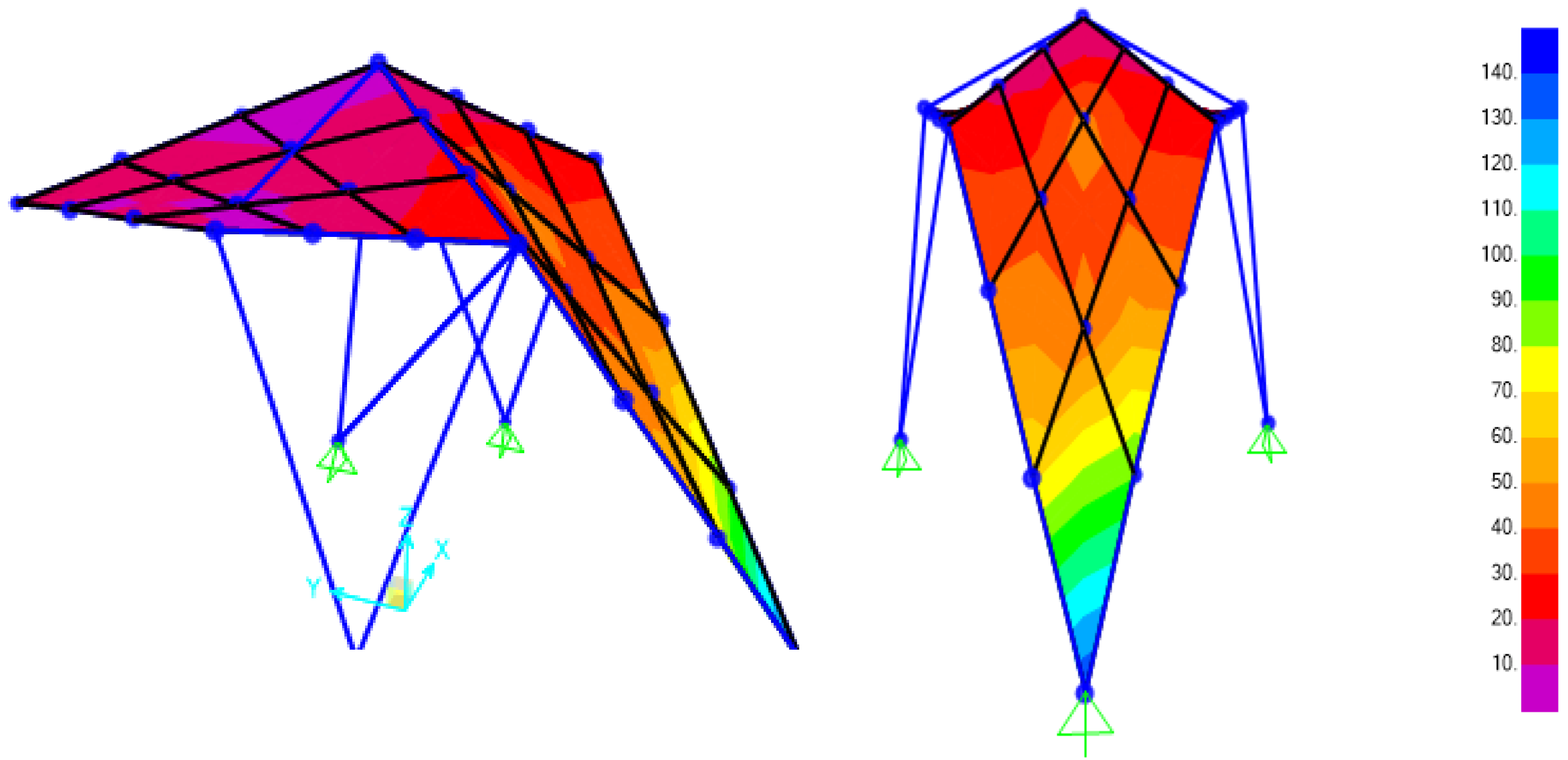


Moment Diagram

Northridge created the highest bending moment, located in the tail end members of the structure (shown in the photo above).

Shell Stresses

Shell stresses were analyzed using all 3 lateral methods in both the global x and y directions. All shell stresses were low, with the highest being 150psi.



Member Design

To check the strength of our members we used ASCE 7-16 ASD load combinations and NDS 2015 capacities. From the start, 6in x 6in DF-L #2 members were assumed. Built into the spreadsheet is the NDS load reduction factor, CD. This is so that the capacity for each load case could be run separately and re used for each load case. Vertical earthquake load is used as 0.2SDS. SDS found using ATC hazards by location.

With a back of the envelope calculation on the cantilevered beak, we found that our initial assumptions were not adequate and decided to change the material to DF-L Select Structural. A fictitious case was analyzed. This fictitious case took the worst bending, shear, and compression from each load case and applied it all to one member with 2 different worst case load combinations. This member was found to only reach about 80% capacity, which tells us that every member is safe. Many of the members will not require the 6x6 section or the DF-L Select Structural material, so these spreadsheets may be used in the future if the client would like to save money on materials.

ASSUMTIONS	REF (NDS 2018)
Sawn lumber analysis, c = 0.8	Table 4.3.1
Moisture Content will exceed 19%, C_M = 0.91 for F_C, 1.0 for F_V, F_t, & F_b	Table 4D
Temperature will not exceed 150°F, C_t = 1.0	4.3.4
Strut will not exceed 12" depth, C_F = 1.0	Table 4D
Strut will not be smaller than 2" X 4", C_T = 1.0	4.4.2
Strut will be square, C_L = 1.0, C_{fu} = 1.0	3.3.3, Table 4D
Strut will not be incised, C_i = 1.0	4.3.8
Strut will be pinned connection, K_e = 1.0	4.3.8

INPUT			
Material Properties		Loading	
F_b [PSI]	1200	C_D	1.6
F_t [PSI]	475	*NOTE : 0.9 for Dead Load, 1.25 for Roof Live	
F_v [PSI]	170	1.6 for Seismic Load	
F_c [PSI]	700	Axial [#]	5062
E_{MIN} [PSI]	470000	*NOTE : Tension (-), Compression (+)	
Length [IN]	252	Bending [#*IN]	9800
Depth [IN]	6	Shear [#]	180

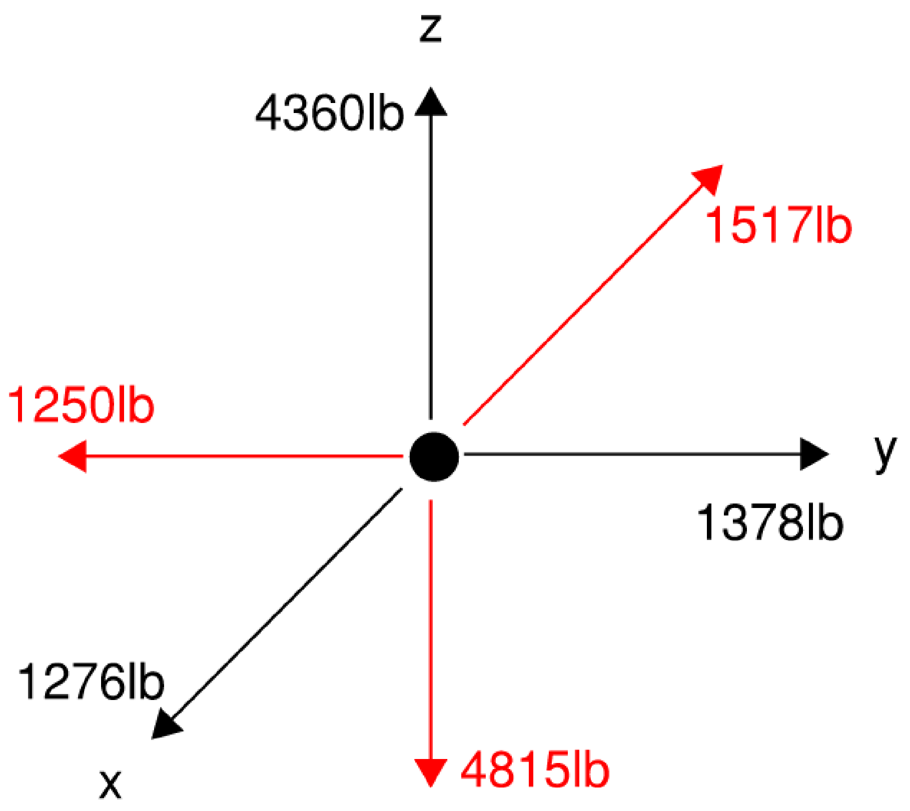
CALCS			
F'_b	1920	f_b	272
F'_t	N/A	f_t	N/A
F'_v	272	f_v	8
F'_c	208	f_c	141
F^*_c	1019	F_{cE}	219
C_P	0.20	F_{bE}	13429

OUTPUT	
DCR Shear	0.03
DCR Bending + Tension	N/A
DCR Bending + Compression	0.81
Are Requirements of 3.9.2 met?	YES
Are Slenderness Requirements of 3.7.1.4 met?	YES

Description			
Maximum load for any 6X6 member is enveloped into 1 analysis			
Stresses from SAP and Excel are matching			
Demand (SAP Output)			
Load	Dead	Roof Live	Earthquake
Compression [#]	1850	218	5062
Tension [#]	870	278	5215
Bending [#*IN]	3340	810	9800
Shear [#]	82	11	180
Unfactored Demand Capacity Ratio (Excel Output)			
Load	Dead	Roof Live	Earthquake
DCR Shear	0.02	0	0.03
DCR Bending + Compressio	0.23	0.03	0.81
DCR Bending + Tension	0.06	0.01	0.19
Worst Case Load Combinations (ASCE 7-16)			
Load	$D + L_r$	$1.2D + 0.7E_h$	
DCR Shear	0.02	0.05	
DCR Bending + Compressio	0.26	0.84	
DCR Bending + Tension	0.07	0.21	

Lateral Base Reactions

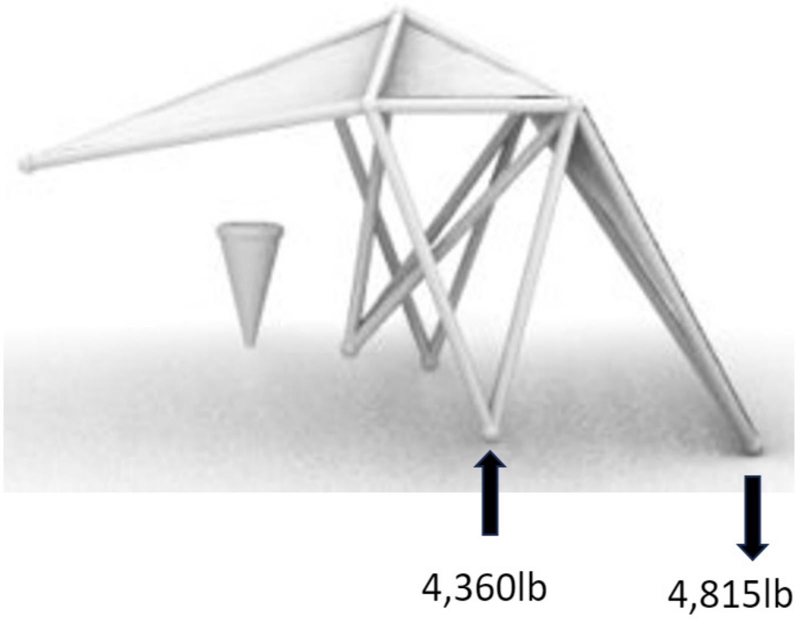
Time analysis governed for the lateral base reaction values. Northridge gave the maximum base reaction in the negative z direction, while El Centro gave the maximum base reaction in the positive z direction. The graphic below shows the maximum base reaction in each direction.



q design = 2,000psf

P/A = 2000psf

A = 4815lb/2000psf = 2.41ft^2

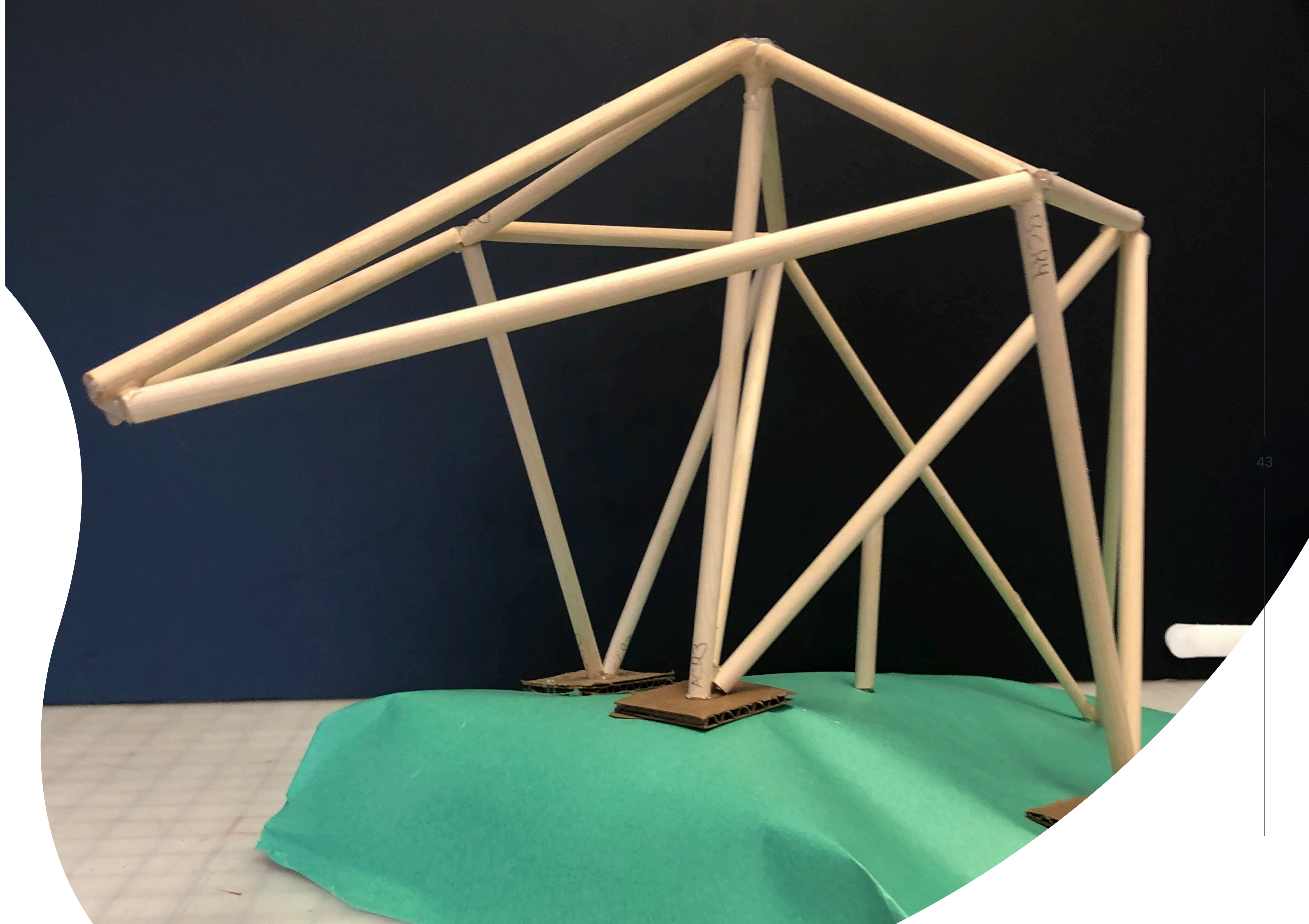


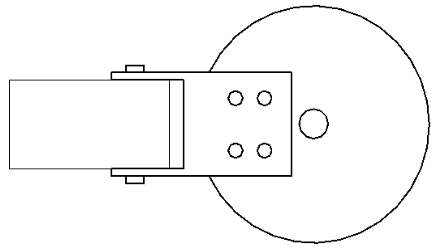
Preliminary Foundation Design

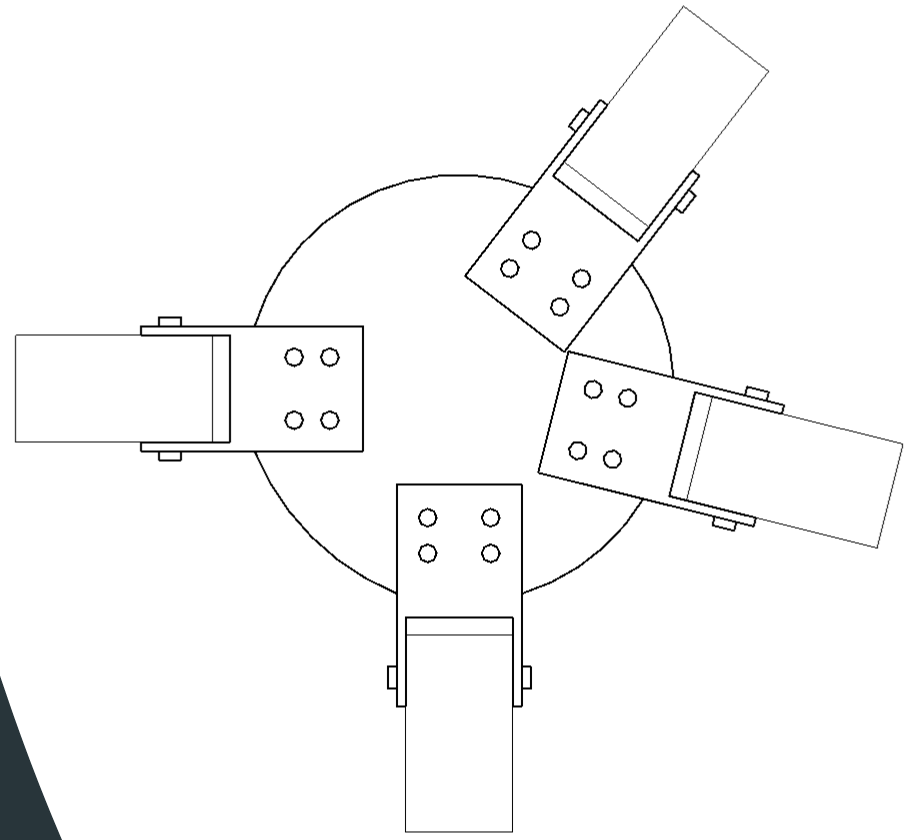
Utilizing the maximum earthquake base reactions in the positive and negative z direction, a preliminary foundation was designed. This design assumes that a boulder is used as the foundation element, to add a natural aesthetic to the foundation, and that the force is applied directly to the top of the boulder. A soil strength of 2,000psf was assumed as a soils report could not be obtained for the site. This design is very rough and ignores possible shearing of the boulder, as well as how the member would connect to the boulder to properly transfer the reaction forces, but gives an estimated size that the boulder may have to be.

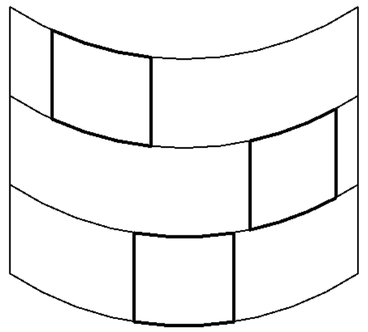
Form Making
Physical Model at 1/2" = 1' scale

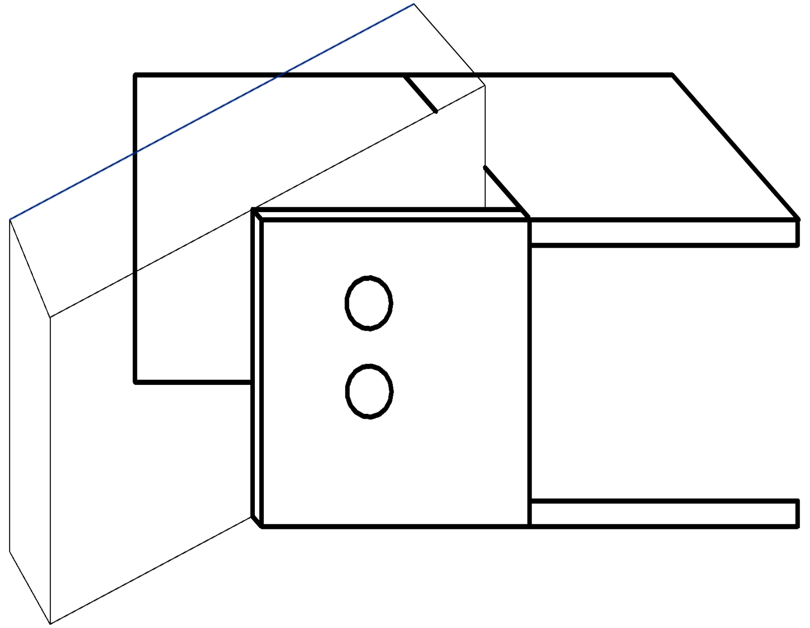
A physical model was created for the final form to help visualize connections and how the structure will look on the sloped site. Unfortunately, our team ran into technical issues trying to print and construct the Polyshell for the scaled physical model, so we were unable to have it in time for this project.





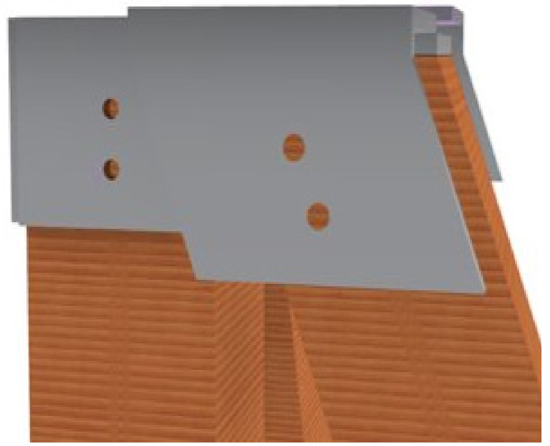


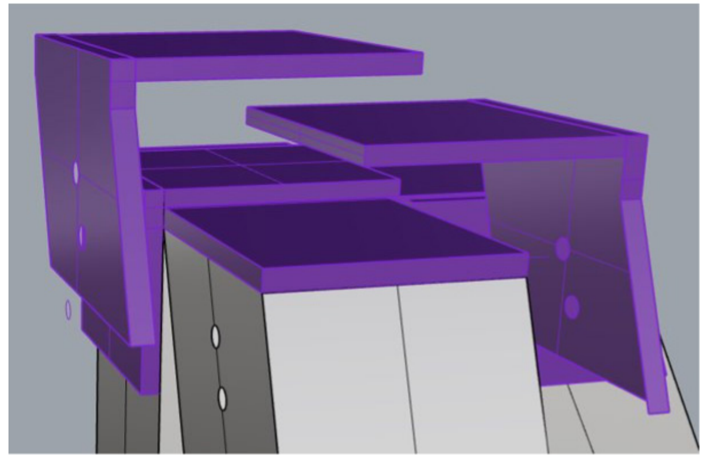




Connection Design

Throughout this studio, the importance of transitions was iterated continuously. Designing a connection that would be able to achieve a smooth transition that would also have enough strength became one of the most difficult aspects in this studio. There were many innovative ideas and many bad ideas for connections, but this was part of the intuitive process that makes a great engineer/designer. The three main connections that we focused on designing were strut to strut, strut to shell, and strut to foundation connections. Unfortunately, our team was unable to create physical models to test our connection ideas, but that would be the next step moving forward in our connection design.





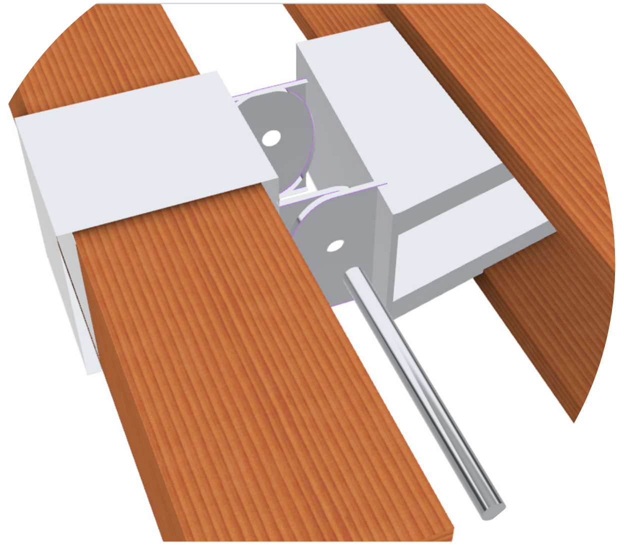
Strut to Strut Connection

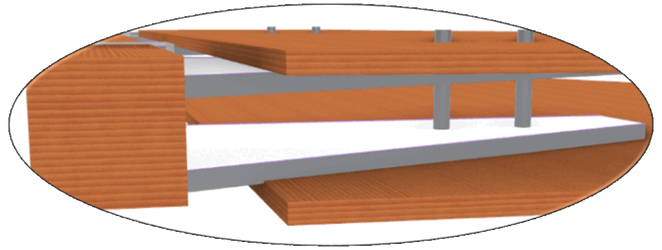
For the strut-to-strut connection, we knew that our connection would require accessibility to at least three struts coming to one single point from different angles. Our initial idea was to have steel plates bolted to the struts and a main steel cylindrical hub that would bolt the plates connected to struts to the main hub. We decided not to pursue this idea because it used an excessive amount of steel, and we were not confident that it would be strong enough in compression.

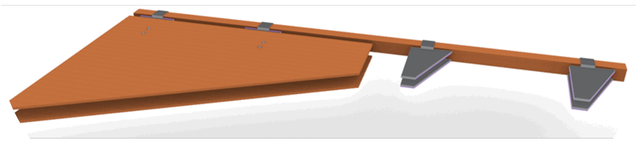
Our final strut to strut design was steel plates that are flush with the sides of the strut and doweled through the side plates and through the strut. Those side plates are then connected to a main top plate which can resist bending.

Shell to Strut Connection

For the strut-to-shell connection, we designed a connection plate that is bolted through the top and bottom skins of the Polyshell. Next, the connection plate is dowelled through a steel sleeve in order to allow rotation for those shells coming in from different angles. Then, the steel sleeve is fixed onto the strut with bolts in order to prevent the sleeve from sliding along strut.

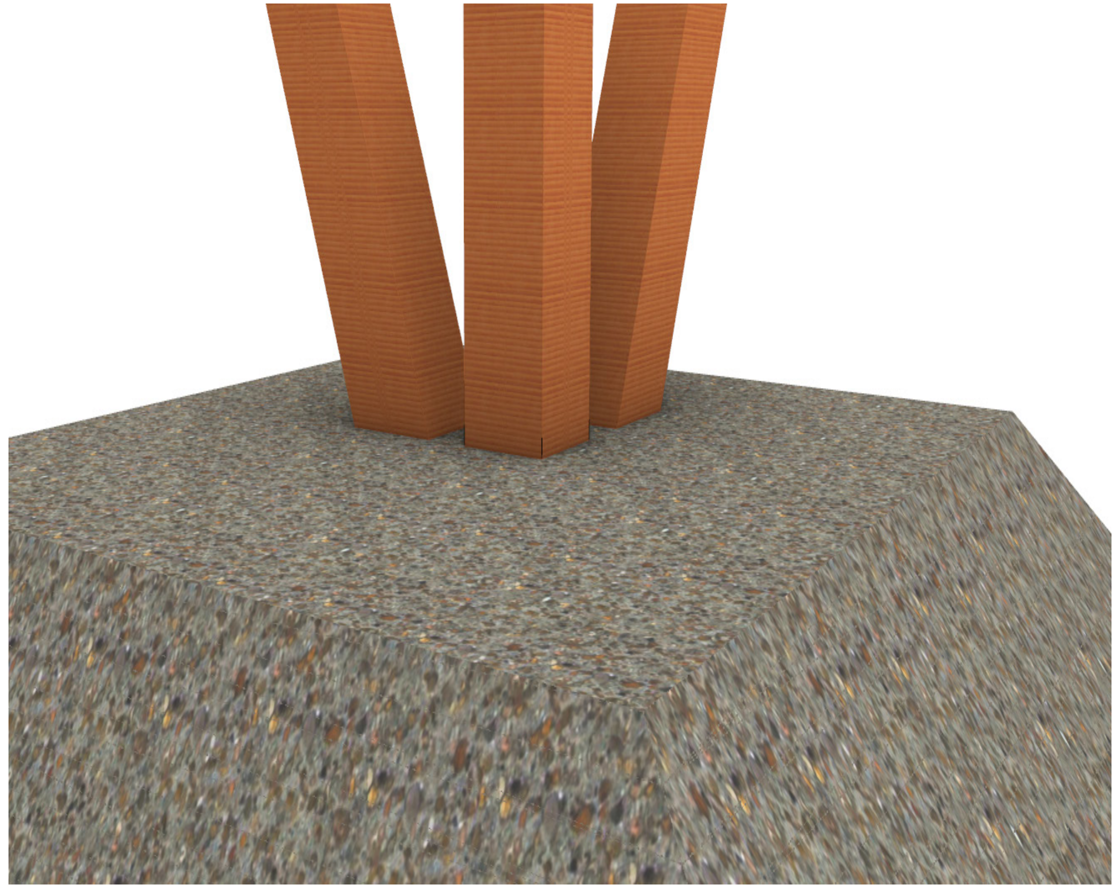


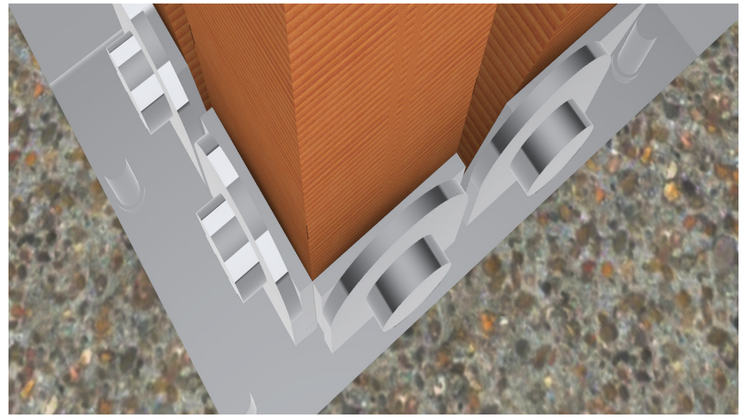


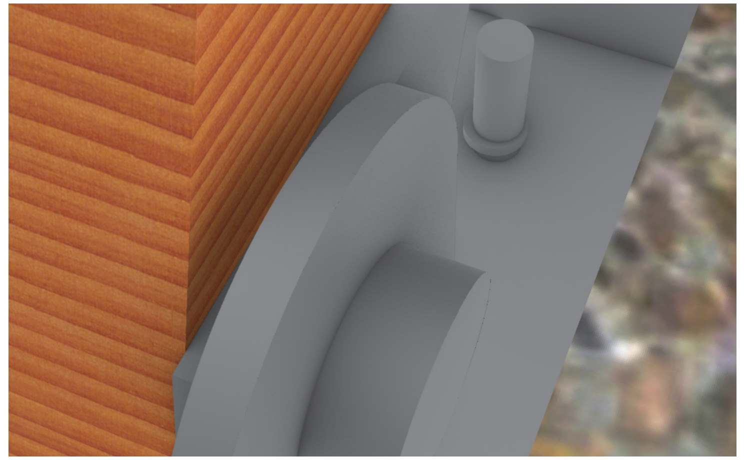


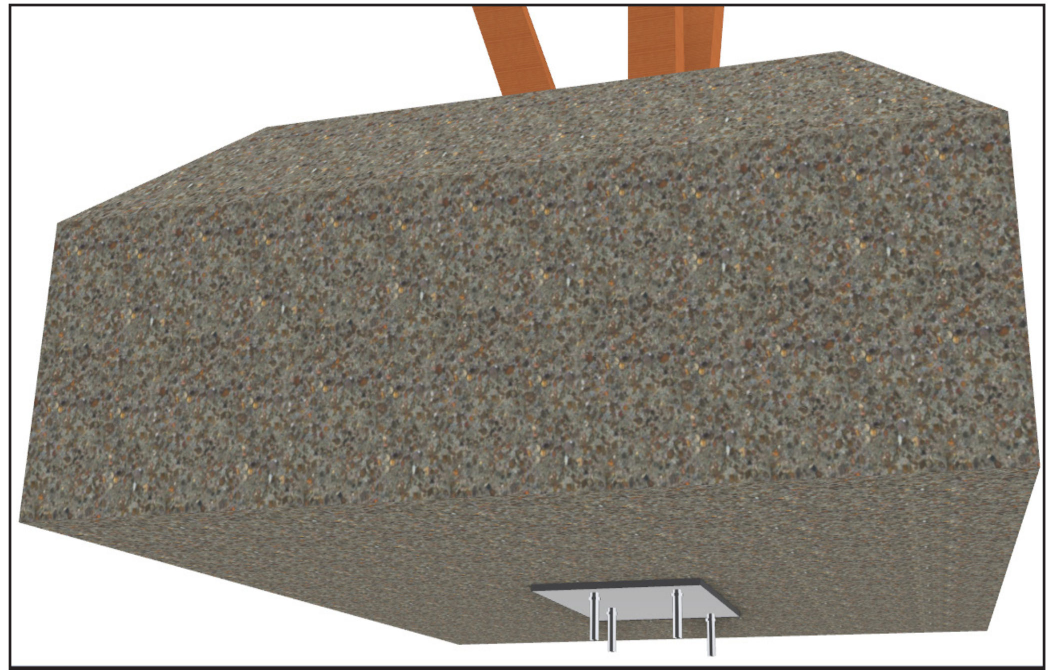
Strut to Foundation Connection

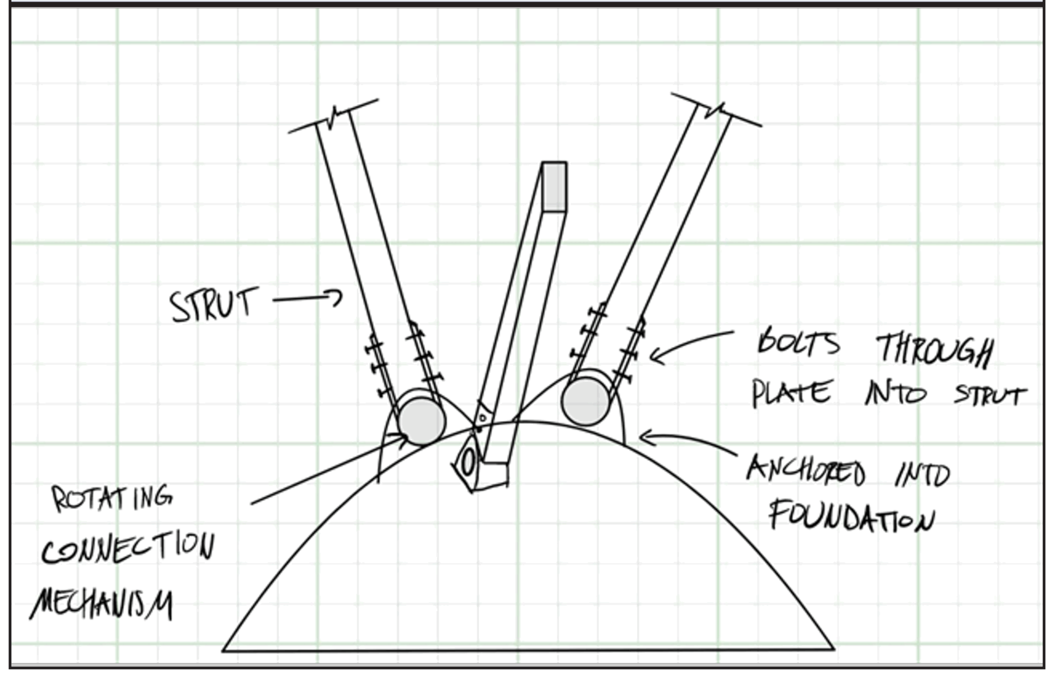
For the strut-to-foundation connection, we wanted to integrate a boulder into the foundation connection. We created this natural façade and transition making it appear that the strut connects through the boulder hiding the true mechanism of the connection. Similar to the strut-to-strut connection, we utilized a main base plate that is then bolted through the boulder and restrained with an underlying plate from pulling through due to uplift.

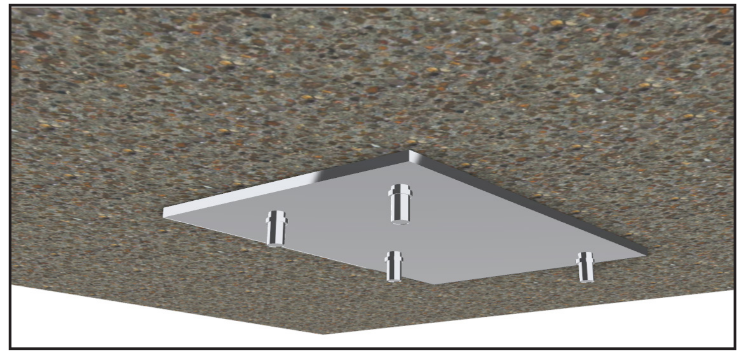


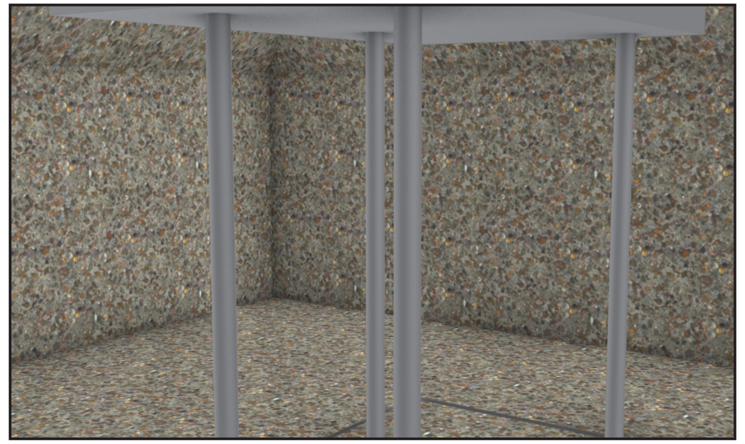












Sustainability and Constructability
utilizing natural materials

Our studio focused on sustainable design and utilizing responsibly sourced natural materials when possible. The Polyshell consists entirely of plywood, even in the connecting pieces. The structure our team designed consists of wood, with small steel plates used for the connections and a mix of steel and a natural boulder used for the foundations.

Another driving aspect in our design was to create a form that could be scaled for a variety of locations and uses, such that it could offer shade to those who desire it across the world, not just at Cal Poly.

Constructability was another key aspect in our design. High tech design, low tech construction was a motto of our studio. Our group implemented this into our connection designs where the connections would be prefabricated beforehand, and then simply nailed in during construction.

Climate needs to be analyzed further in the future, as the wood Polyshells likely need weatherproofing coatings. Further climate protection would be needed if the structure was utilized in other areas of the world with harsher environmental conditions than California.

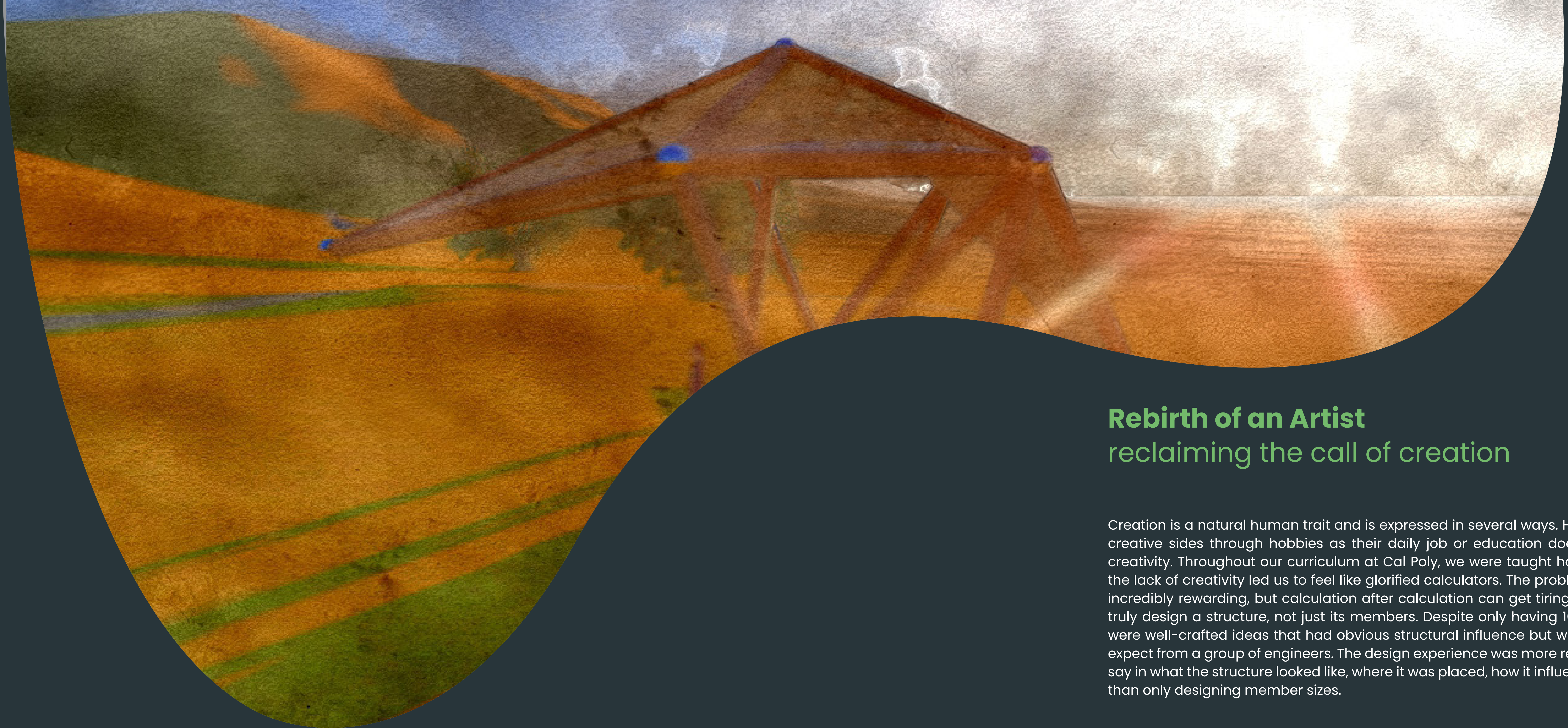
Heal

Reconnect with nature

Mental health is something many people, especially students, struggle with. The pressure of balancing classes, work, and personal life can be too much to handle at times, and occasionally you need a break. Through the design and location of our sunshade, our team sought to create a place where one can take time for themselves and heal their mind.

Lying on the grass or sitting on a bench beneath the beautiful would shell, surrounded by the unique horticultural of the Leaning Pine Arboretum offers a relaxing experience that would be unique to Cal Poly. The natural views and sounds of the arboretum help remind us of the beauty of life and can take our minds off our everyday struggles.

This relaxing experience could be recreated in gardens across the world to help address the increasing global issue of mental health.



Rebirth of an Artist
reclaiming the call of creation

Creation is a natural human trait and is expressed in several ways. However, many are forced to express their creative sides through hobbies as their daily job or education doesn't often offer opportunities to express creativity. Throughout our curriculum at Cal Poly, we were taught how to be great engineers, but sometimes the lack of creativity led us to feel like glorified calculators. The problem-solving aspect of structural design is incredibly rewarding, but calculation after calculation can get tiring. This studio offered us an opportunity to truly design a structure, not just its members. Despite only having 10 weeks, the results created in the studio were well-crafted ideas that had obvious structural influence but were much more beautiful than one might expect from a group of engineers. The design experience was more rewarding as well because our team had a say in what the structure looked like, where it was placed, how it influenced human interaction, and much more than only designing member sizes.

Reflection

The lessons learned in 10 weeks

Our senior project showed us that we are more than human calculators, that being an engineer doesn't mean you can't also be an artist. The question arose if what we were creating was structure or art, our studio answered that it was both. No one in our group considers themselves good artists, but we were able to learn and develop ourselves as creators and pair those skills with our existing structural skills to create a design that was stable and visually appealing. One of the most important lessons we learned through this project, besides the multiple new programs like geogebra, grasshopper, and lumion, was that we are capable of being both artists and engineers.

In 10 weeks, we were able to create something that we as a group are proud of, and that we think properly fulfills the purpose we were given in a unique and thoughtful way. Though there are many more steps before this design can physically be built, we are satisfied with the result we achieved in the time we were given.

As to the future of the xenaform and Polyshells LLC, our team sees the xenaform as an adaptable typography that can fulfill any small-scale design intent while being sustainable and aesthetically pleasing. Xenaforms may be used for large scale structures as well, but this may require the combination of several smaller forms.

Overall, despite the difficulty of this project, the lessons learned, and the results achieved were more than worth it. The work you put in is reflective of what you get out, and we believe that this project clearly reflects that idea. We did the absolute best we could and were able to create something we are proud of, and learned several beneficial lessons we won't soon forget.

Thank You

Please feel free to reach out if you have any questions

krickans@calpoly.edu
josantoy@calpoly.edu
rchan25@calpoly.edu
bpeers@calpoly.edu