cresent

by Hayle Jones, Ian Kelly, Emilie Phuong, and Brooke Heitman

bios

Hayle Jones

I'm a 4th year architectural engineering students from Elk Grove, CA and my favorite food is my Dad's Gumbo.

Ian Kelly

I'm a 5th year architectural engineering student from Fresno, CA and my favorite food is my grandmother's Cuban dishes.

Emilie Phuong

I'm a 4th year architectural engineering student from Los Angeles, CA and my favorite foods are noodle dishes.

Brooke Heitman

I'm a 4th year architectural engineering student from Utah and my favorite food is Italian.

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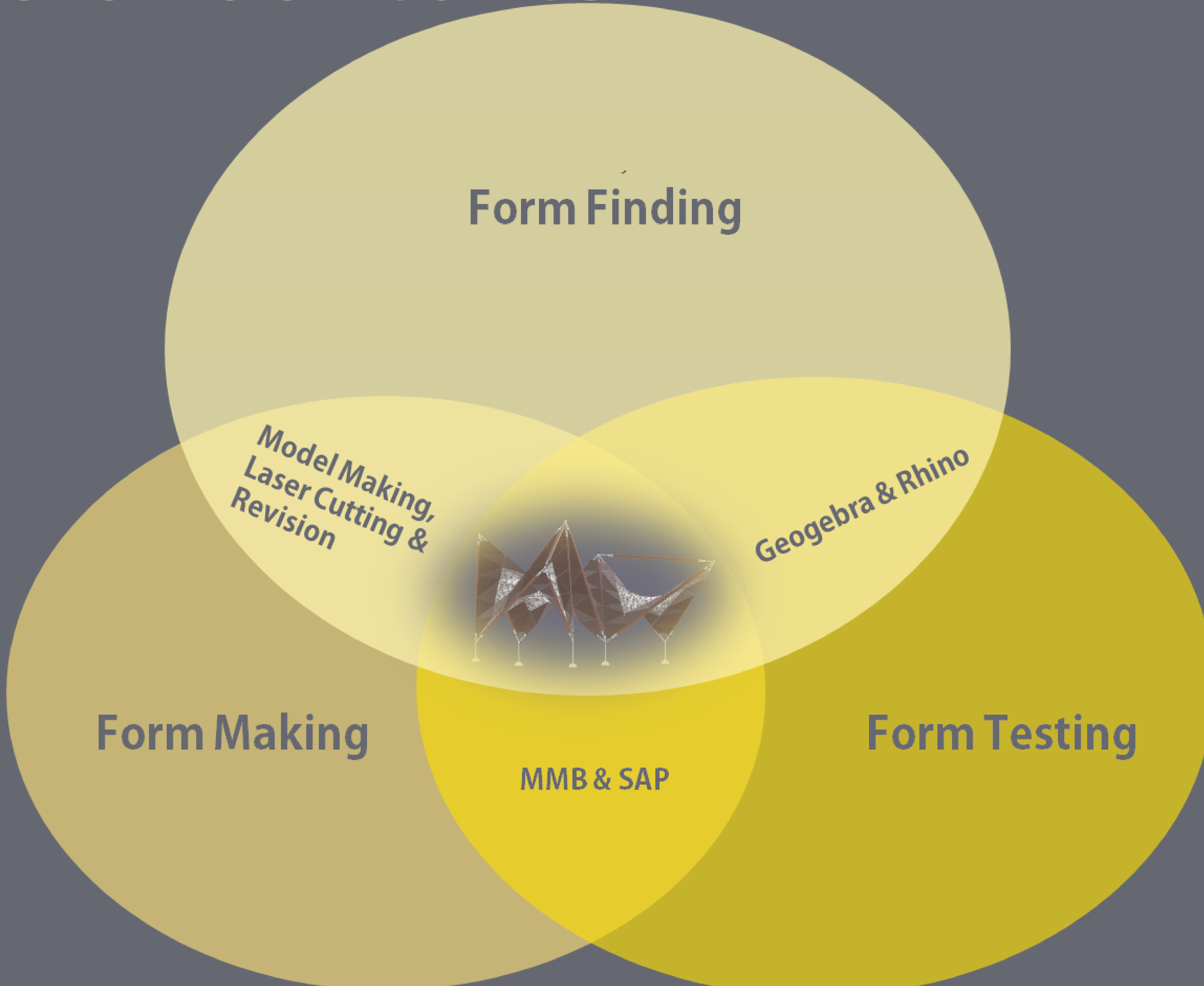
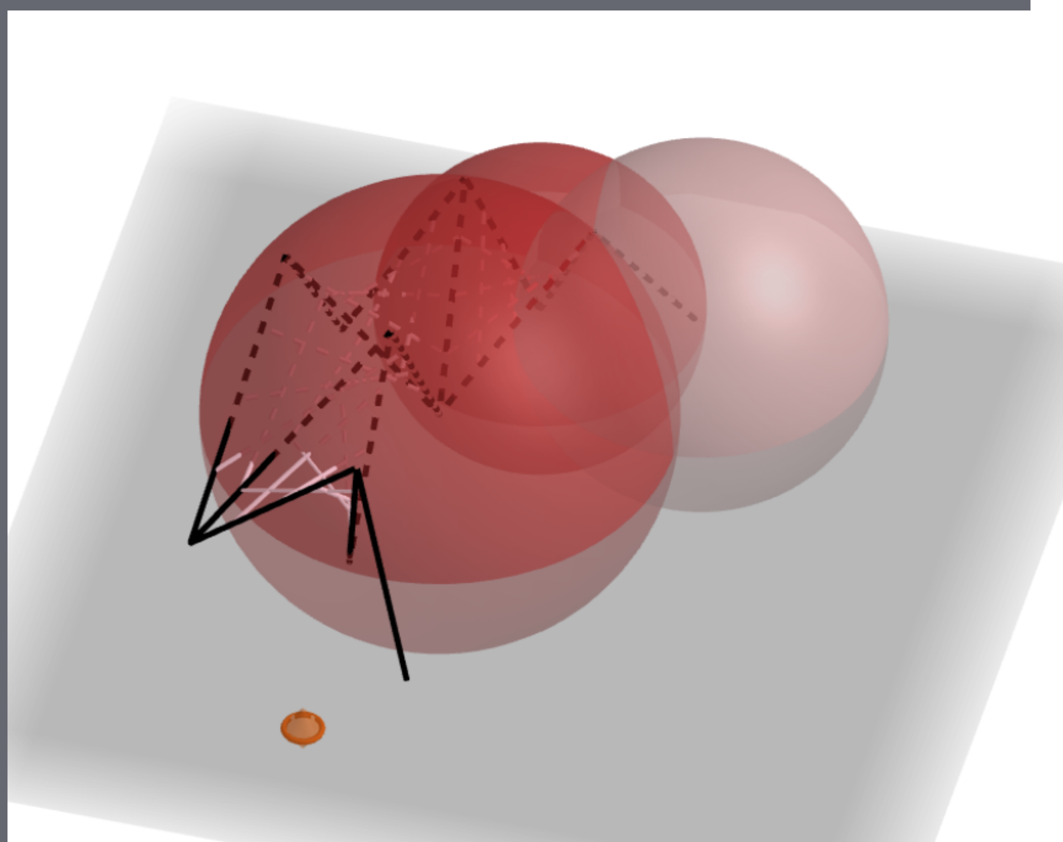
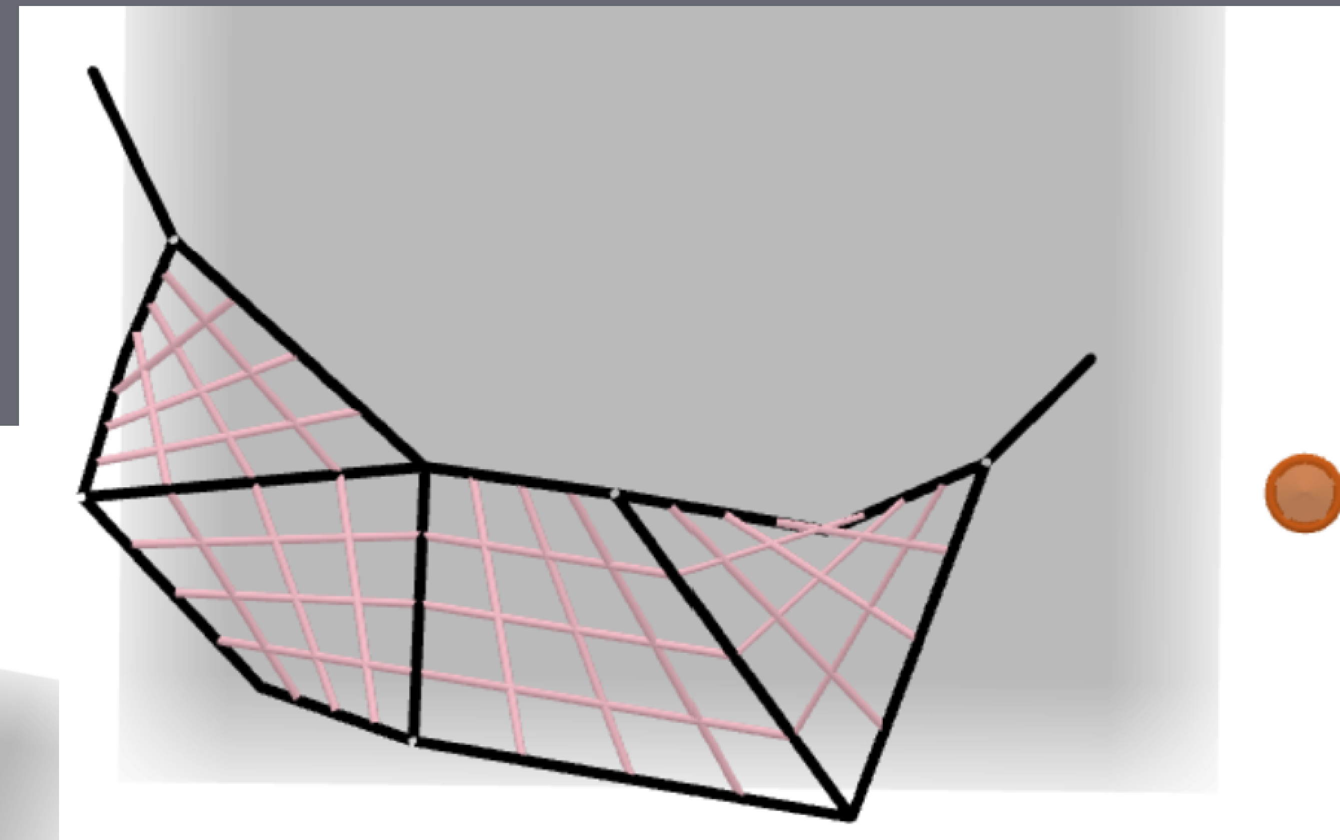
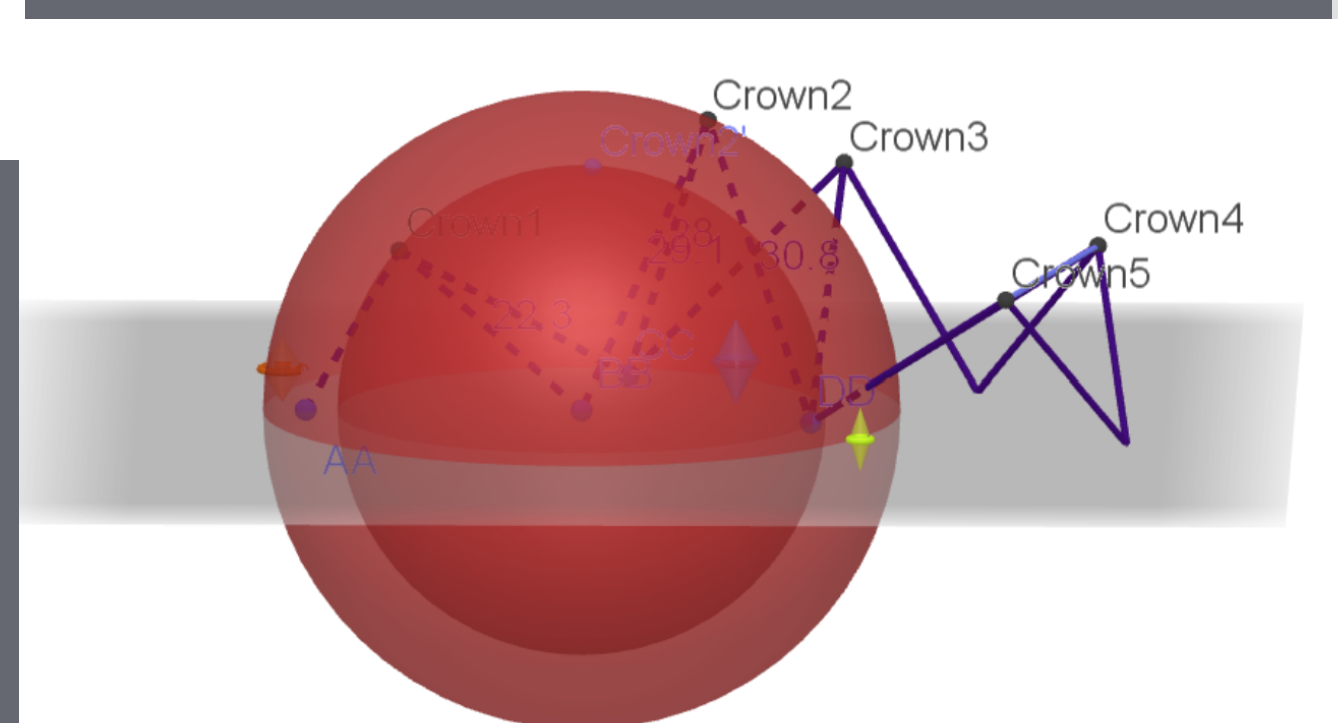


form finding

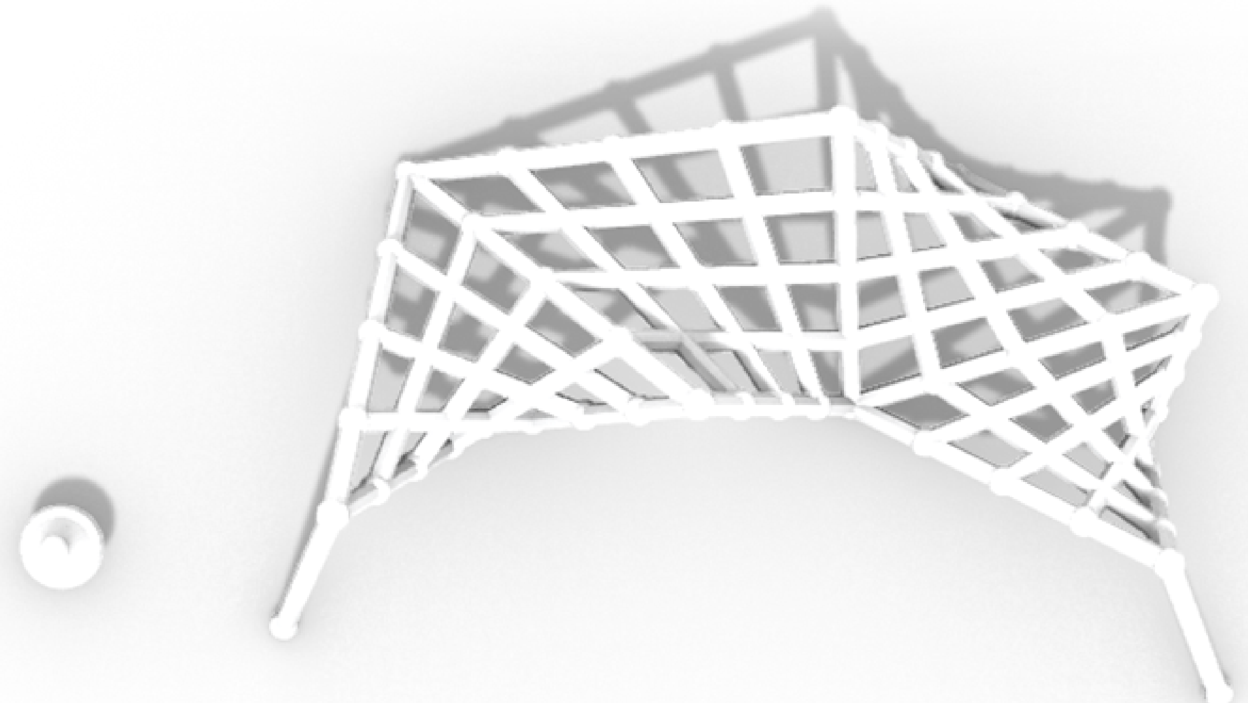
form

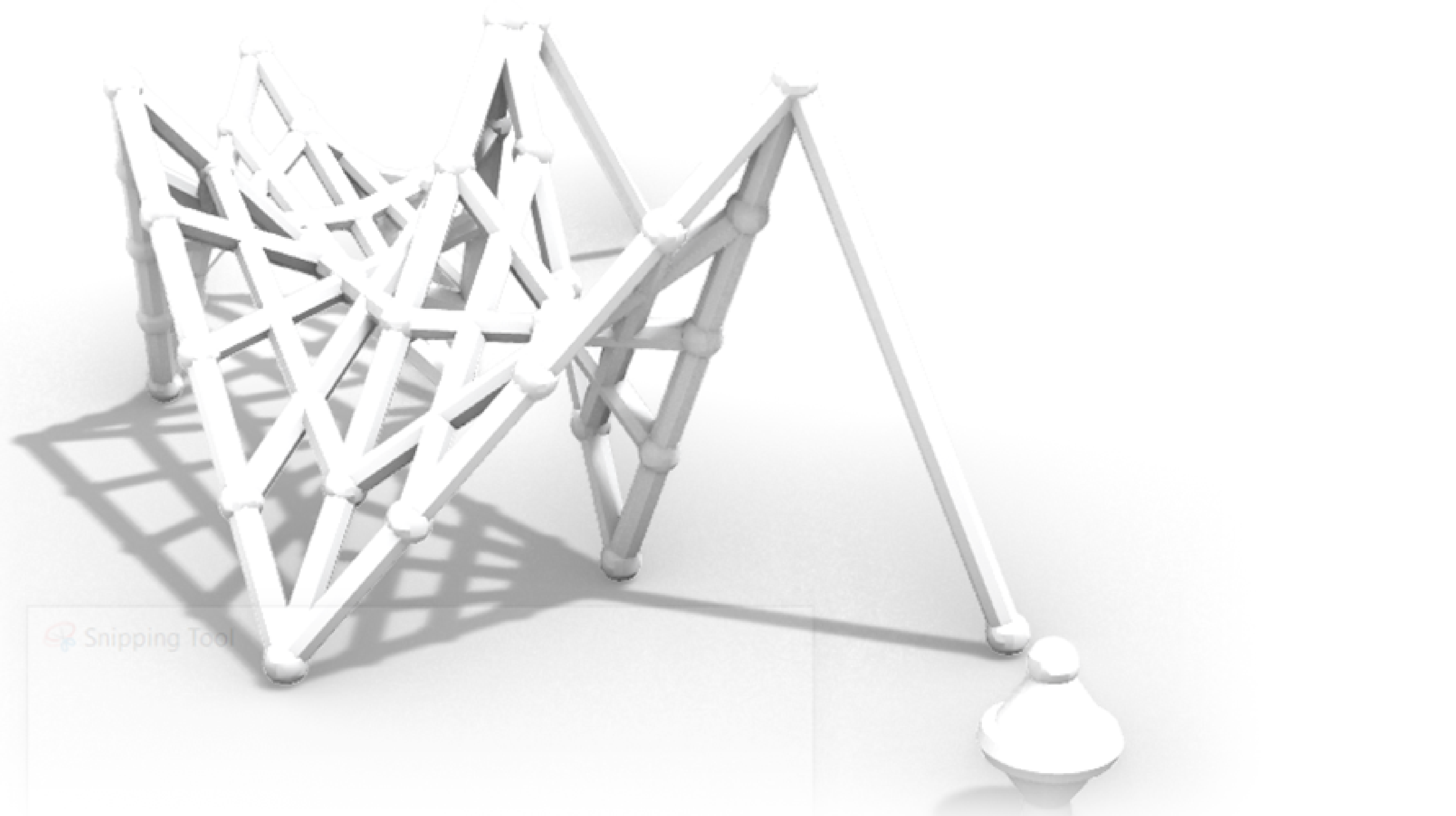


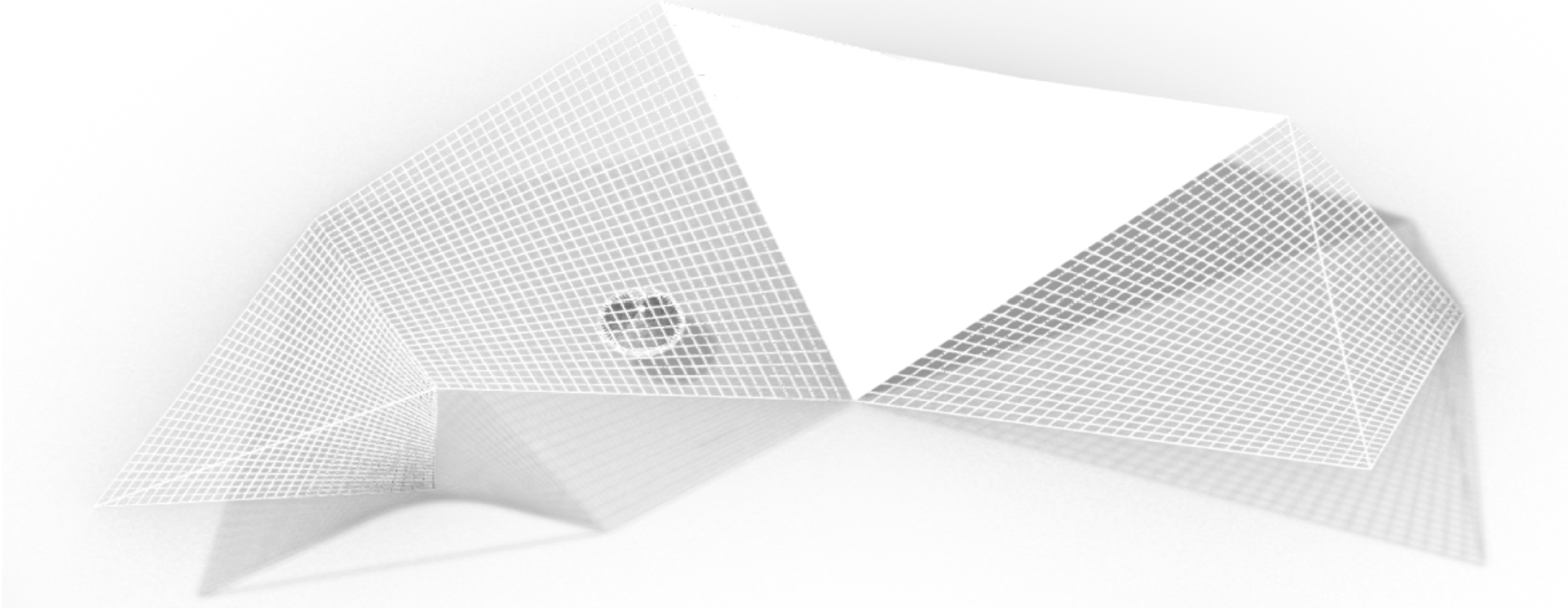
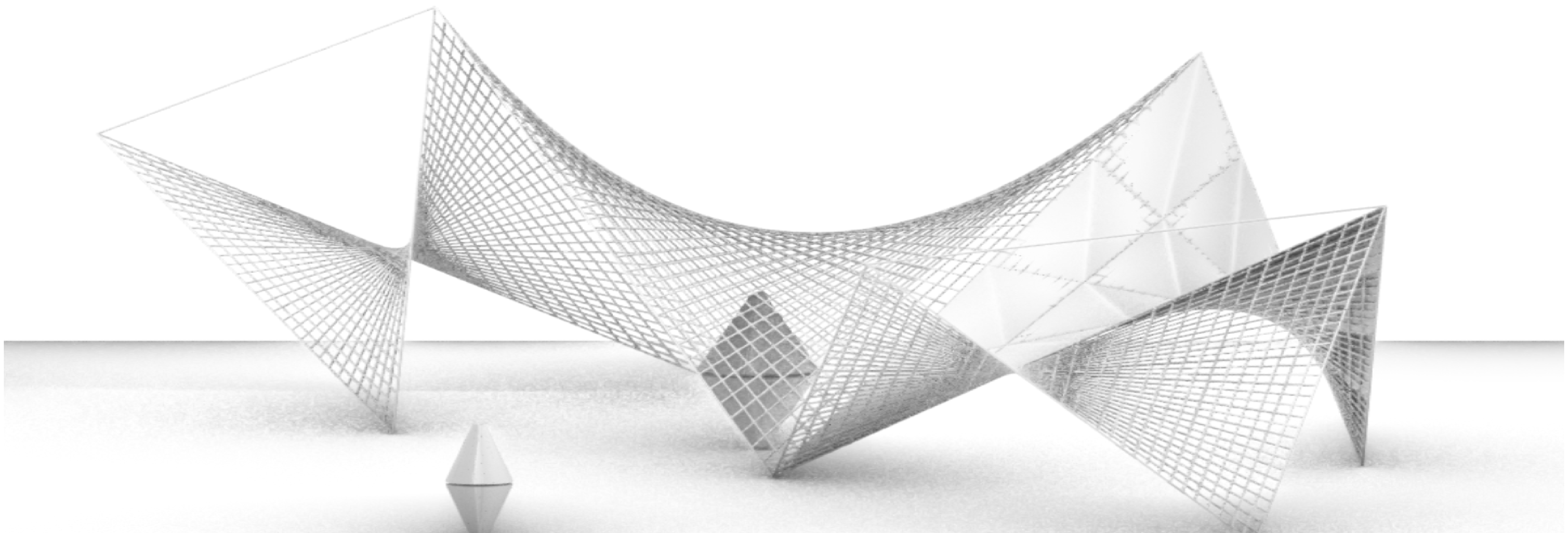


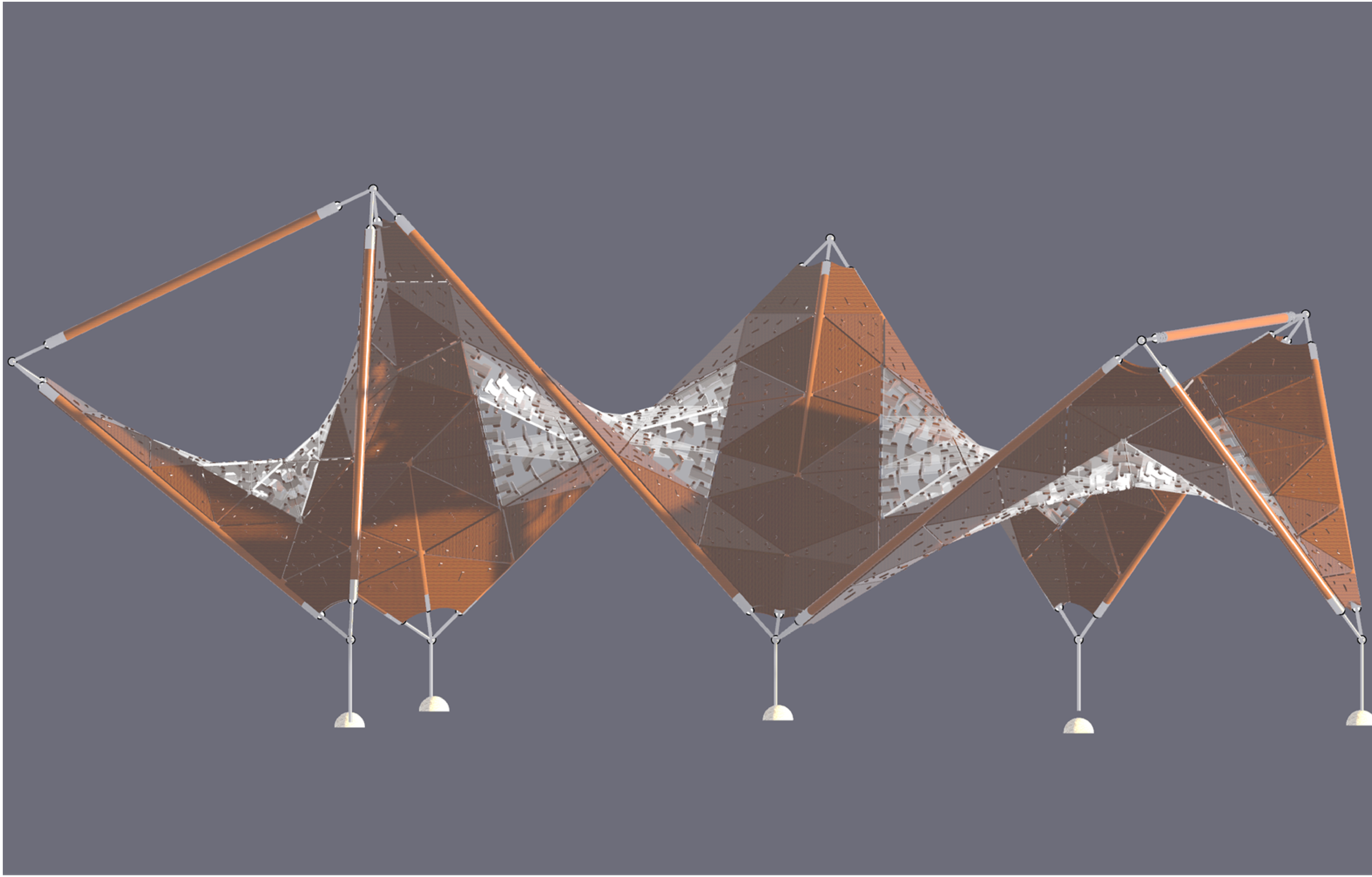


In finding the final form, the shape went through multiple iterations to perfect the final piece. The first step in form finding is to consult the drawing board. In doing so the form progressed from the idea of a curvilinear shape that would guide to new places. Sticking to the idea of wanting to provide shade from the sun and elements. The structure would curve like a crescent along a beautiful path. The projects of Iannis Xenakis was a major draw of inspiration for the shade structure. Geogebra was were the preliminary model was created as you can see to the left. On the next pages you will see the form develop even further by using Rhino and Lumion.



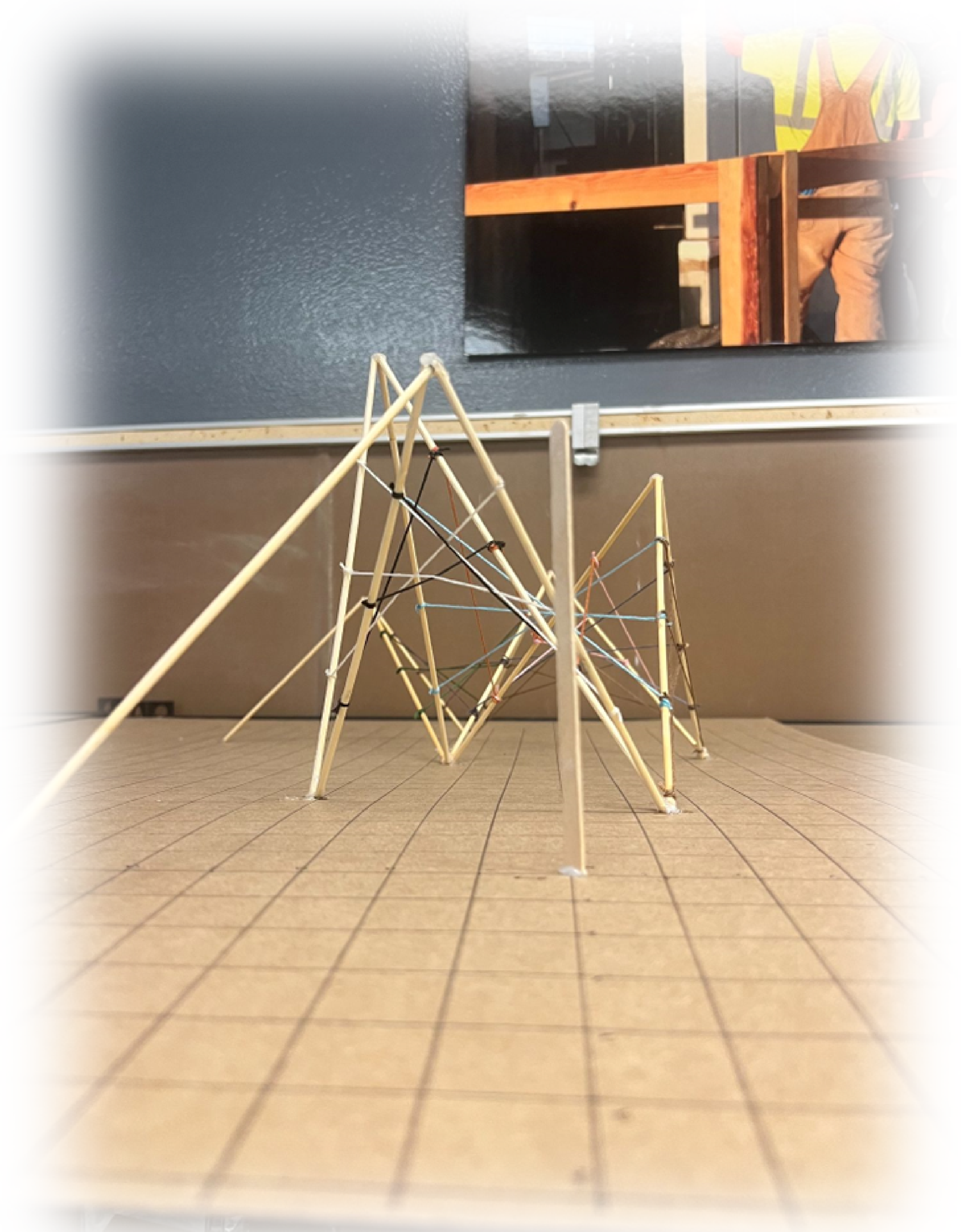

Snipping Tool

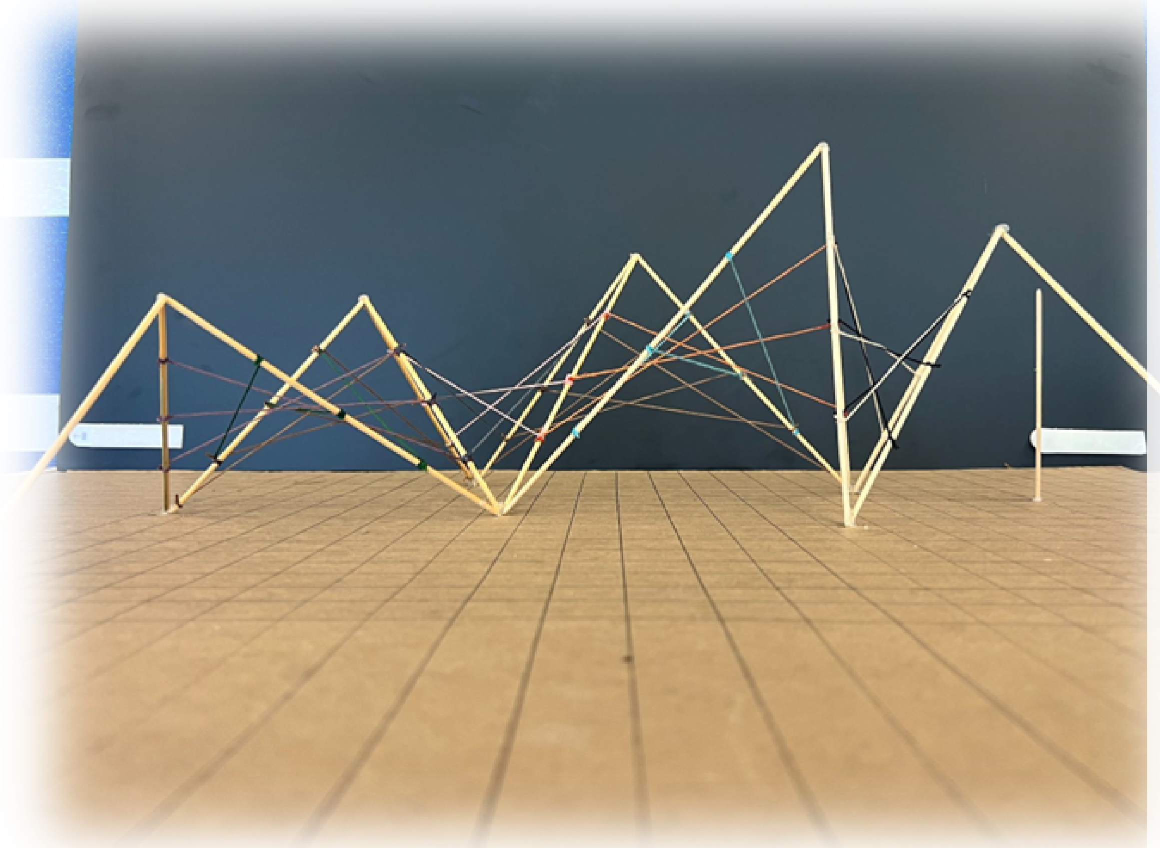



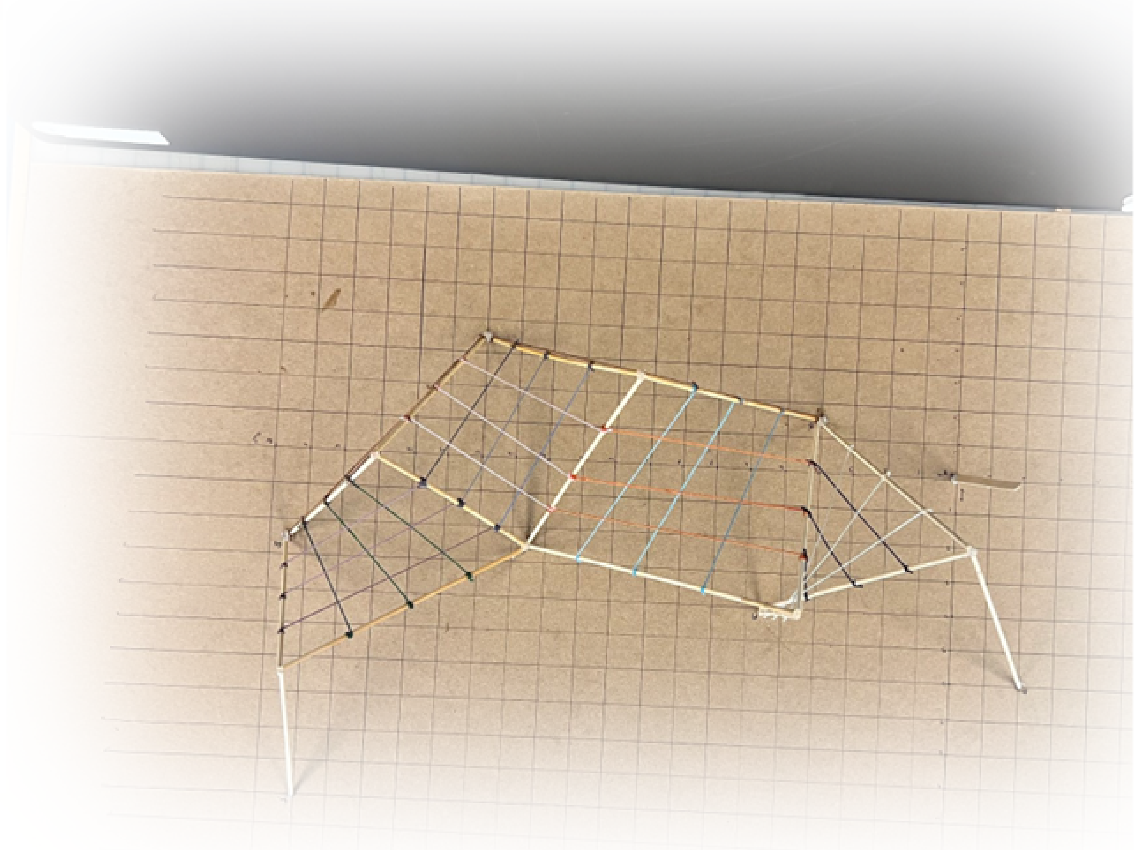


form making

form

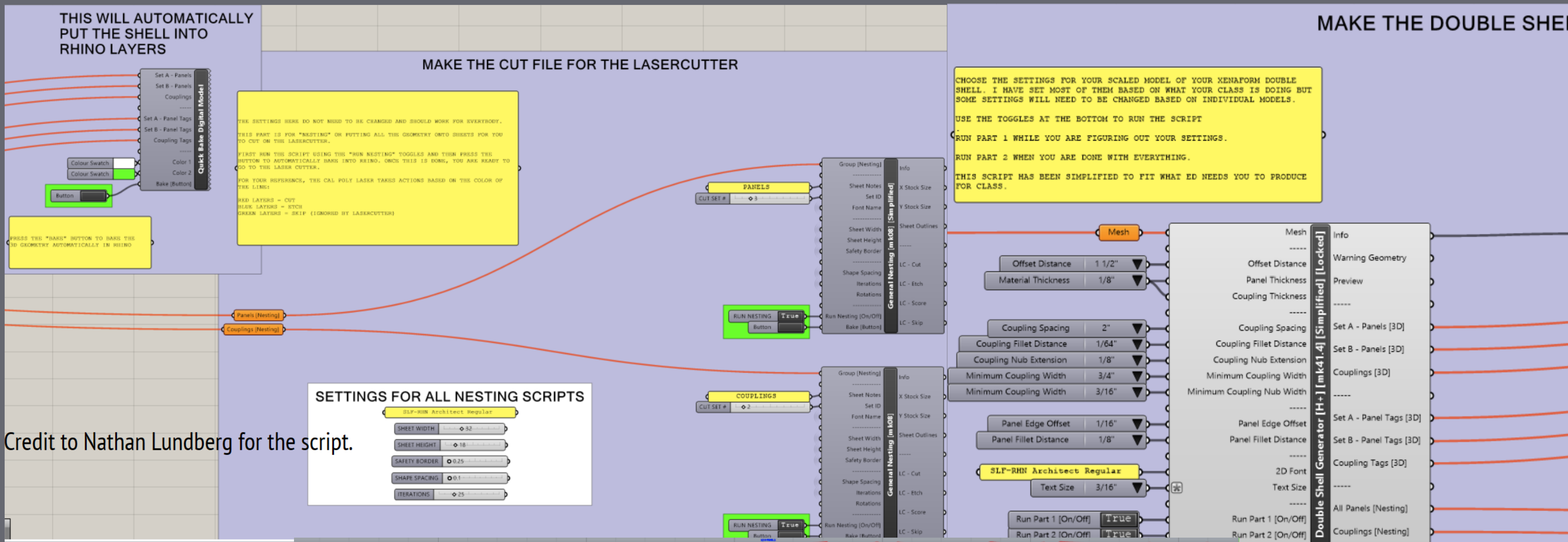




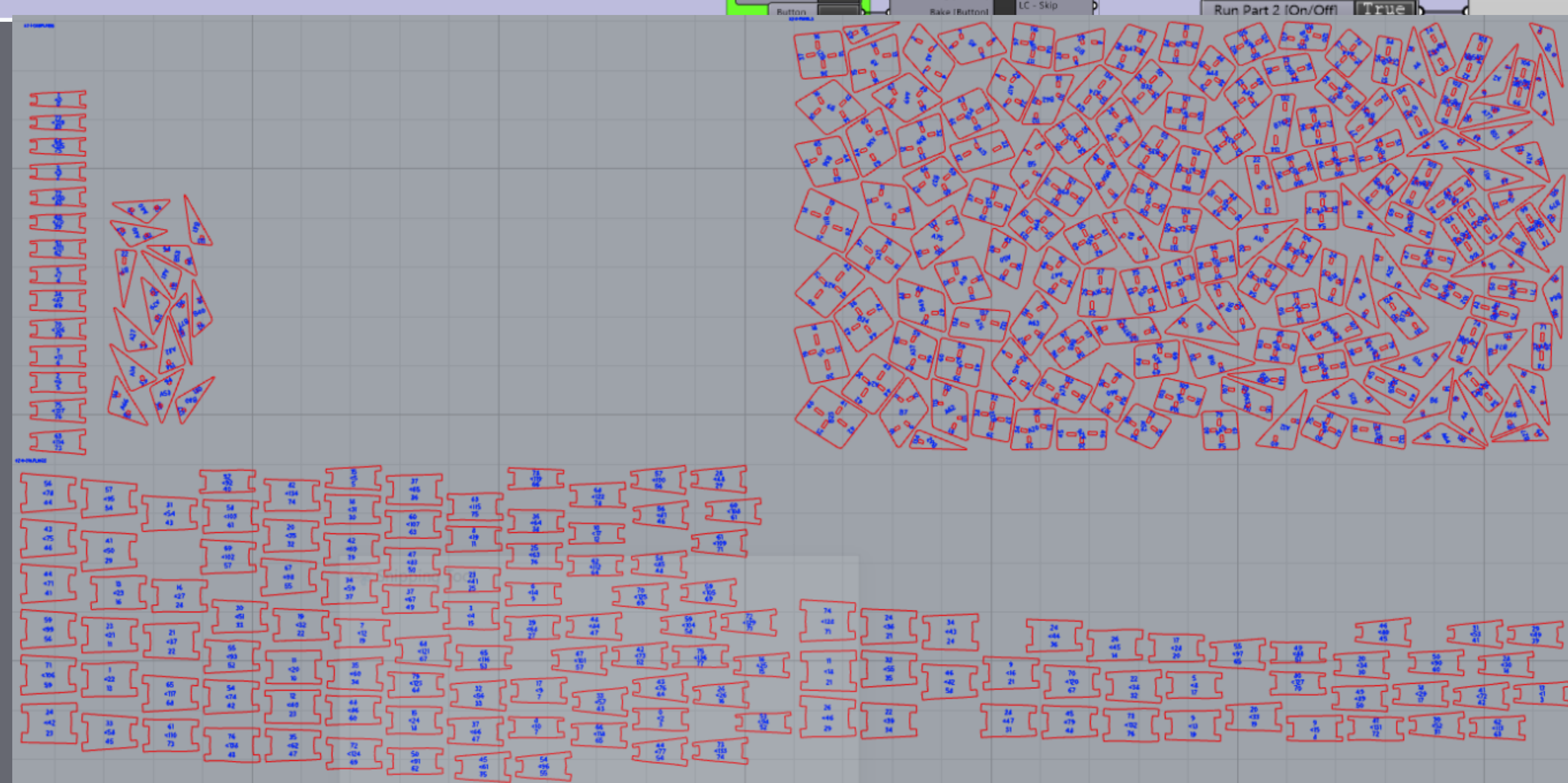


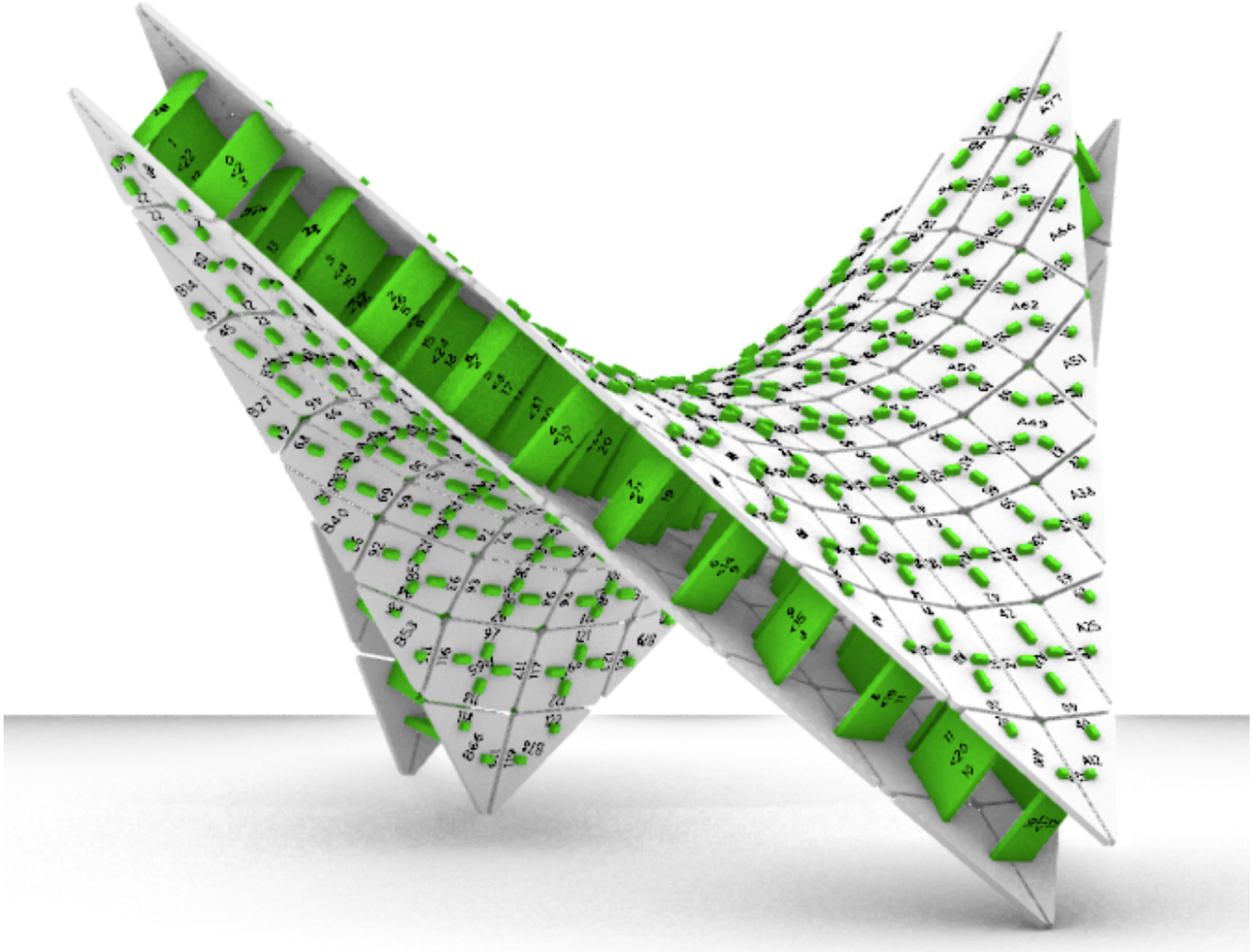
In making the final form the shape underwent a few revolutions in the case of sizing and other small tweaks to perfect the form. the preliminary model shown to the left provided valuable insight to the experience of the structure. Many iterations of material models showed the real value of the piece in terms of shadows and grandeur. The final model was made possible by a Grasshopper script which created the shells. On the next pages the script is shown, as well as a blown up view of the complex puzzle the shell was constructed by on Rhino and eventually created for the final model. The grasshopper script will be touched on more later. Ultimately, a final model with one of the shells was assembled.

form

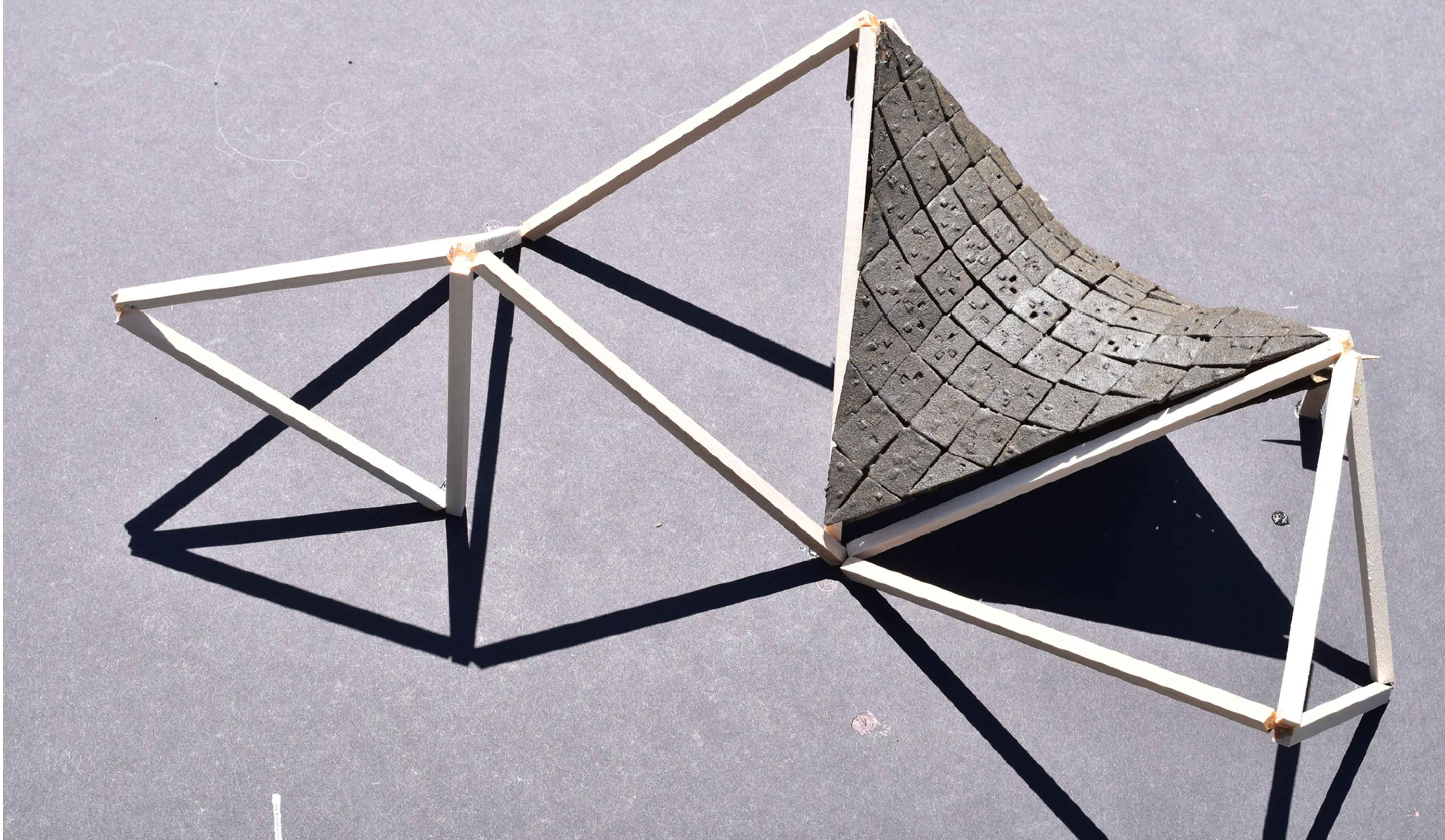


Credit to Nathan Lundberg for the script.



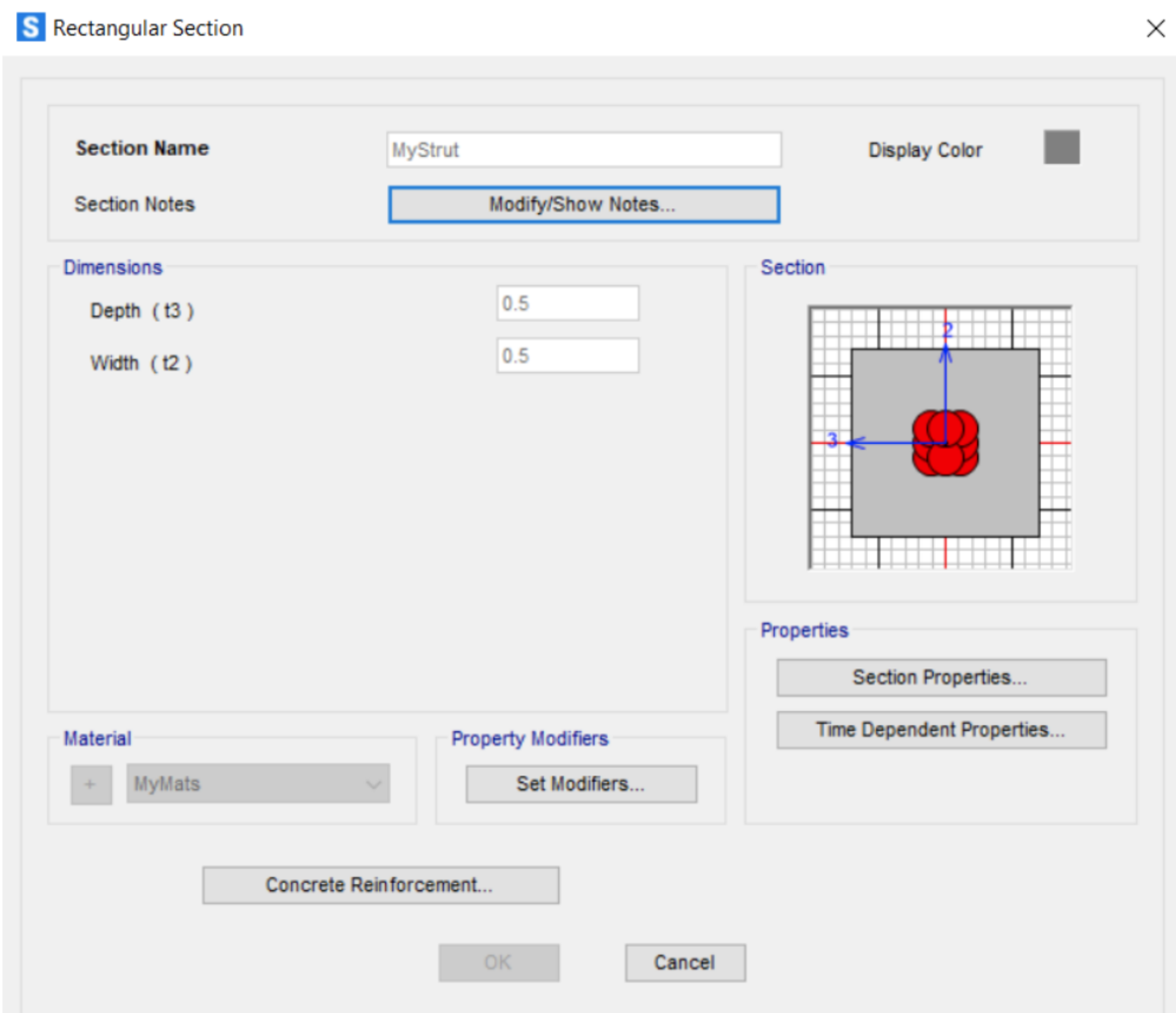


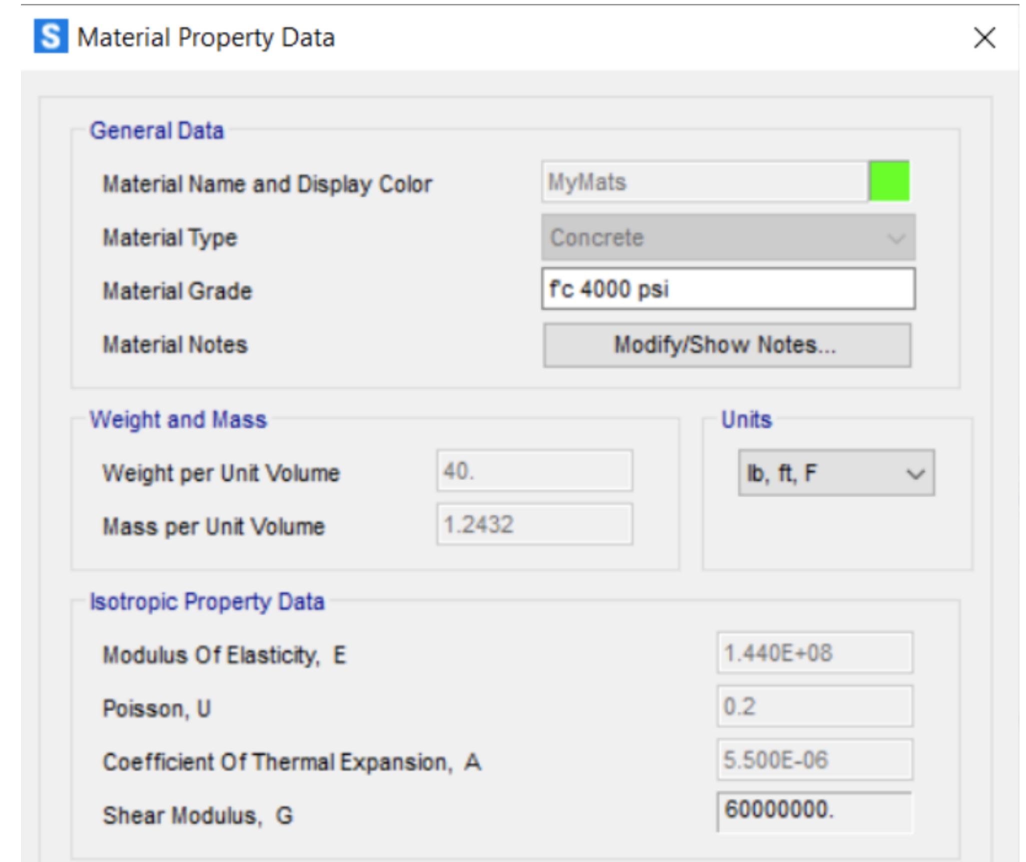
final form



form testing

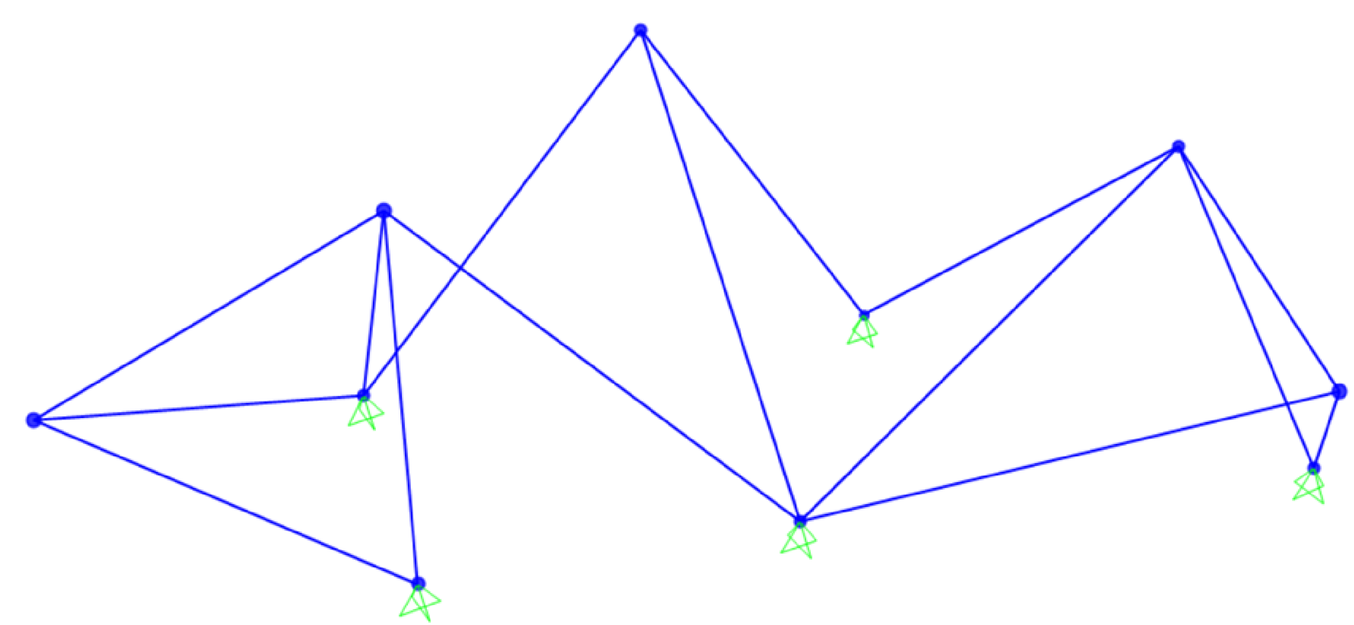
sap inputs





Inputs for the SAP model to fully replicate the crescent into its full glory.

Joint Text	CoordSys Text	CoordType Text	XorR ft	Y ft	Z ft
A	GLOBAL	Cartesian	10.84	-12.84	0
C	GLOBAL	Cartesian	-8.82	35.27	0
D	GLOBAL	Cartesian	4.12	25.85	0
E	GLOBAL	Cartesian	-16.06	0.85	0
G	GLOBAL	Cartesian	10.23	43.52	0
L	GLOBAL	Cartesian	27.04	45.48	0
M	GLOBAL	Cartesian	0.64	2.41	0
Crown1	GLOBAL	Cartesian	3.88	-6.79	23.56
Crown2	GLOBAL	Cartesian	1.87	14.75	22.29
Crown3	GLOBAL	Cartesian	-12.51	26.36	18.65
Crown4	GLOBAL	Cartesian	1.64	45.81	14.84
Crown5	GLOBAL	Cartesian	16.68	40.62	15.79



What is Modern Muller Breslau theory?

Modern Muller Breslau theory or MMB is an evolved form of the classic Muller Breslau theory which was originally using influence lines to accurately determine the shear, moment and reaction of said beam[1]. The new version (MMB) uses the principle of loft and perturbation. In theory the Unknown force is perturbed a "delta" amount, when this occurs all of the external forces are then lofted. Using similar triangles the lofts are found, if the lofts are in the same direction of the force then will exhibit positive force and if opposite then negative. The only equation of MMB is shown here.

$$Unknown * \Delta + \Sigma(Force_i * Loft_i) = 0$$

[1] Claire Ballard, Edmond Saliklis PhD: "Equilibrium Without Statics: The Modern Muller Breslau Method"

geogebra and MMB

Geogebra FbarB = 633.95 lbs
SAP2000 FbarB = 637.86 lbs

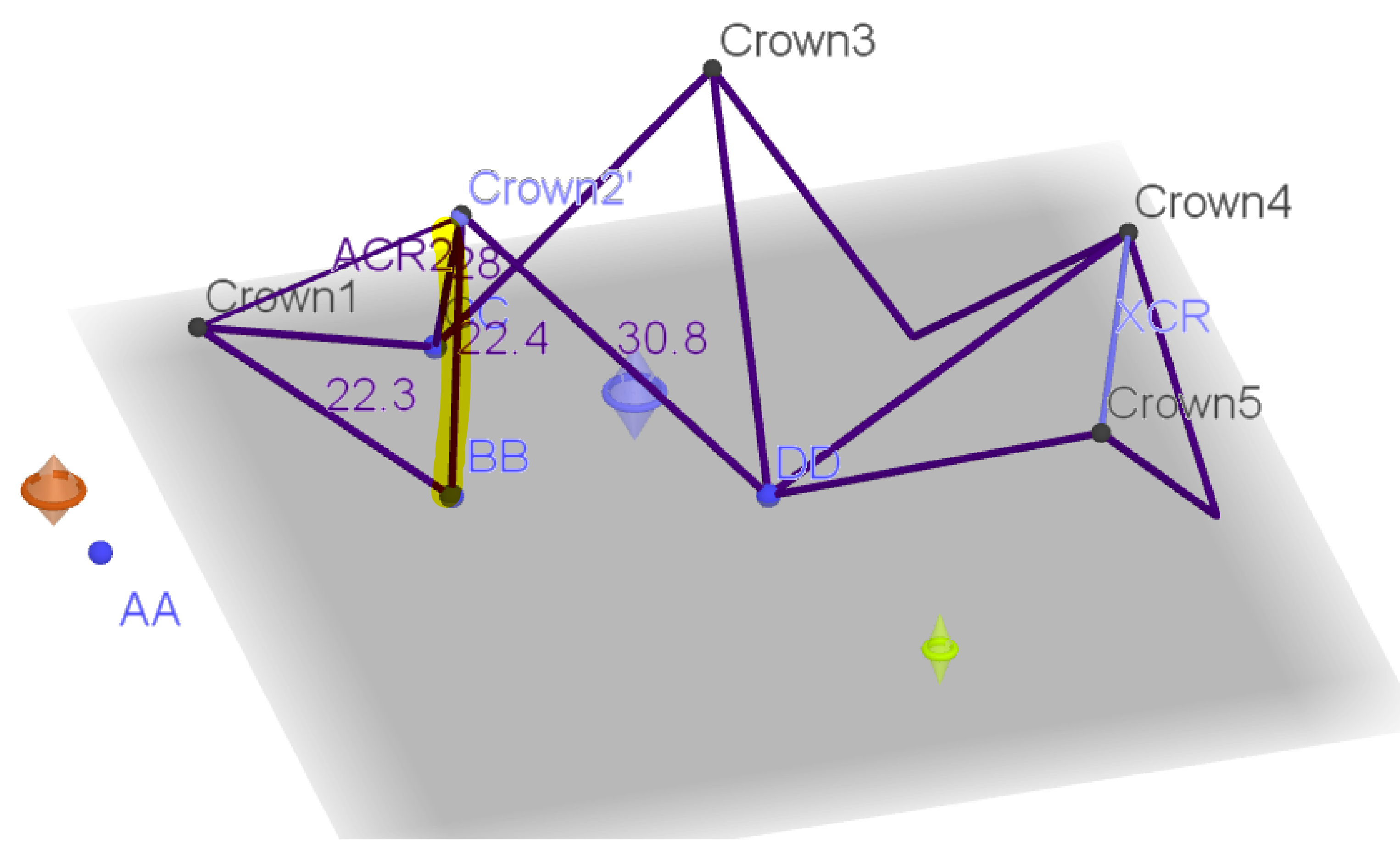
Density of Wood = *40pcf*

Modulus of Elasticity = *1,000,000 psi*

Cross-Sectional Area = *0.196 ft^2*

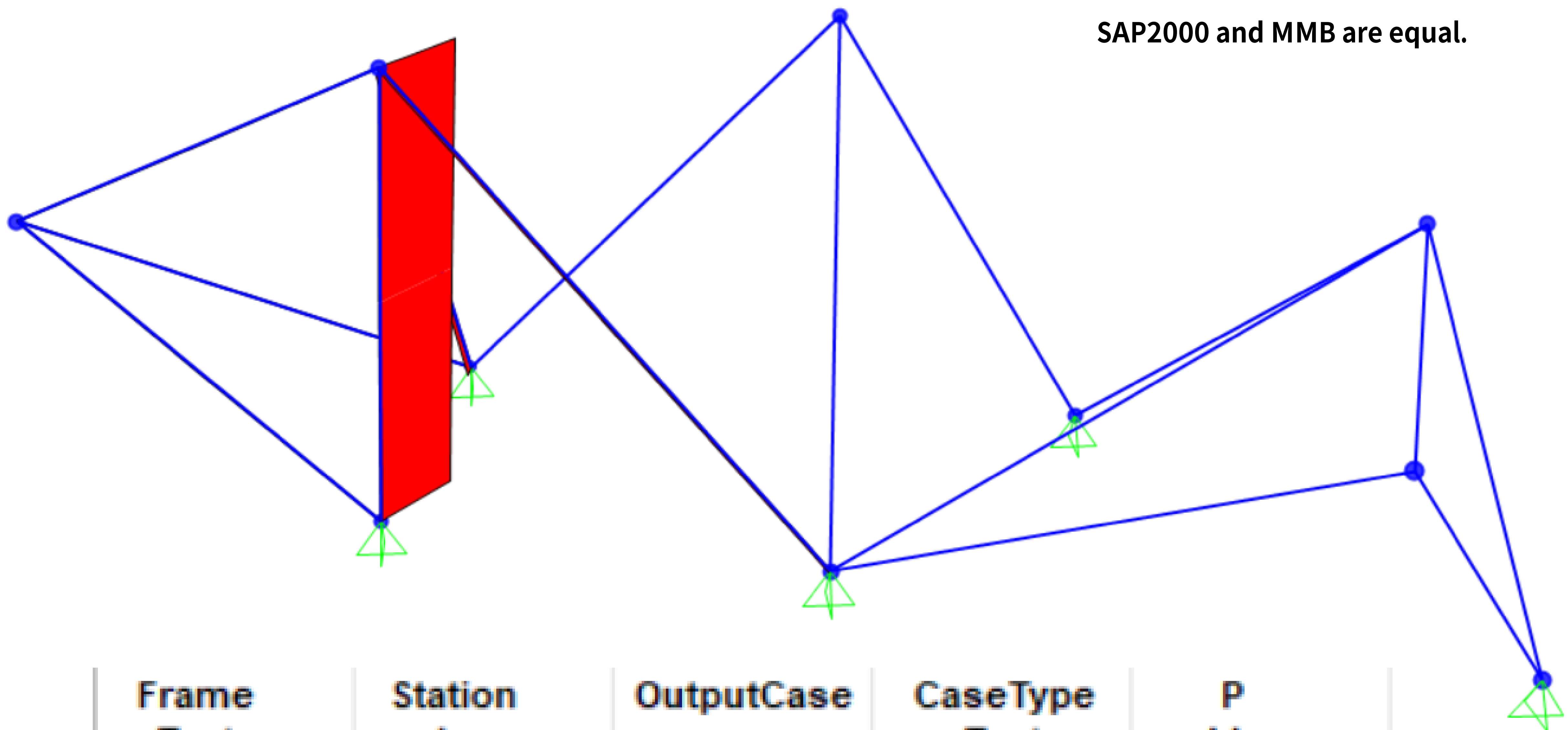
Moment of Inertia = *0.01 ft^4*

Thickness of Shell = *0.25 ft or 3 inches*



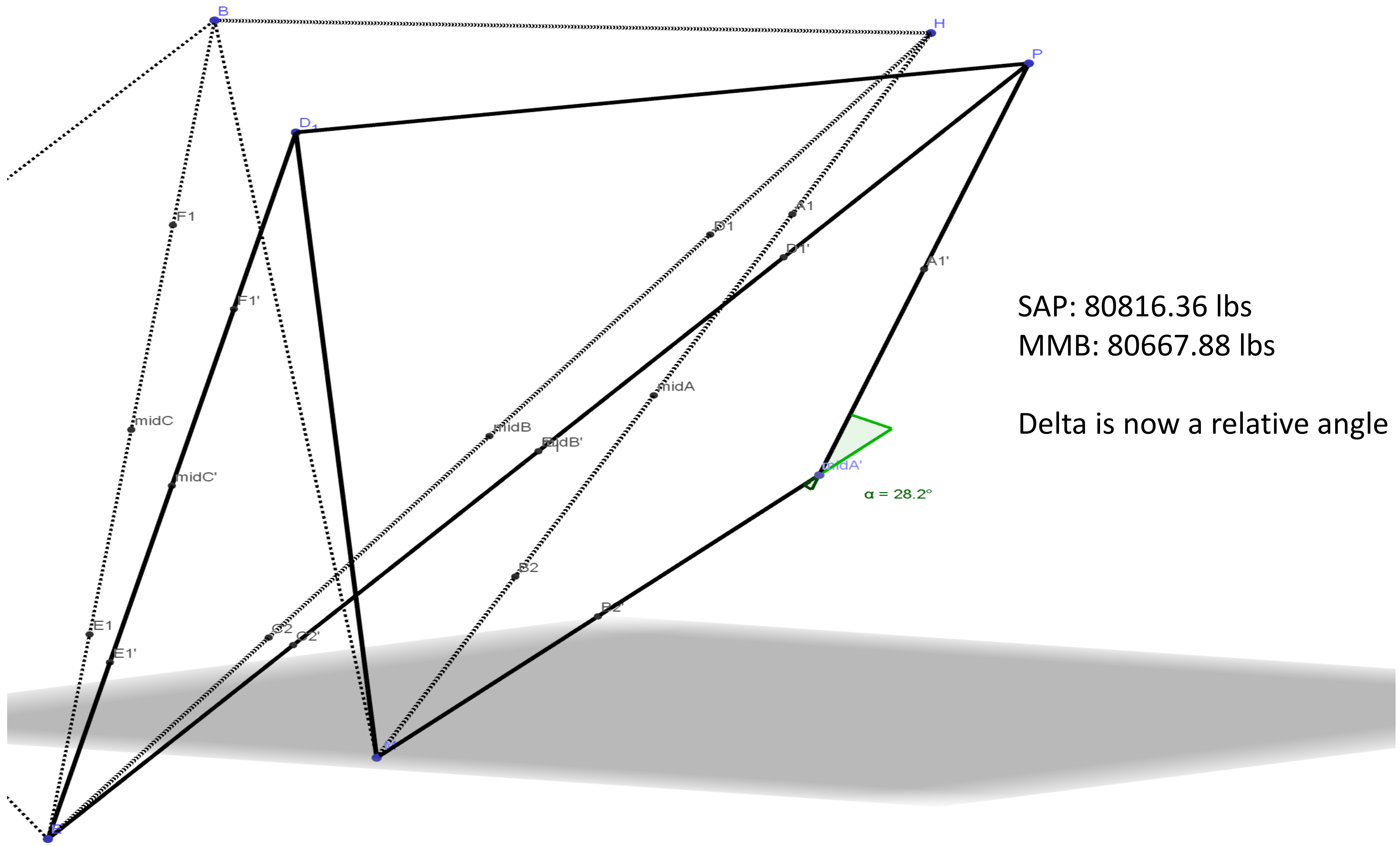
point load

Point load of 716.31 lbs (total weight of members to CROWN B) applied to CROWN B in order to replicate the MMB hand-calculation and to confirm that both SAP2000 and MMB are equal.



Frame Text	Station in	OutputCase	CaseType Text	P Lb
91	0	MyPTLoad	LinStatic	-637.86
91	133.781	MyPTLoad	LinStatic	-637.86
91	267.561	MyPTLoad	LinStatic	-637.86

bending



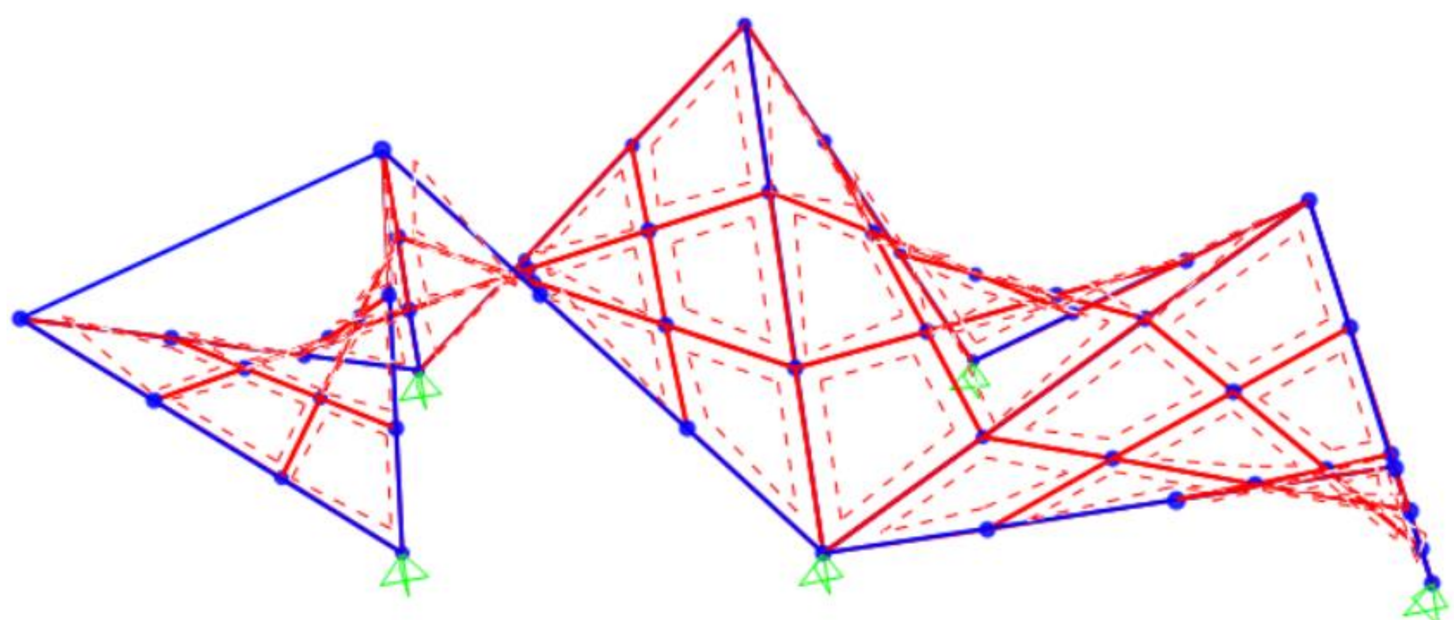
SAP: 80816.36 lbs
MMB: 80667.88 lbs

Delta is now a relative angle

Same iterative process as perturbing the CROWN to get a load on a Frame but now perturbing the midpoint to accurately get the bending moment. Delta as stated is now a relative angle.

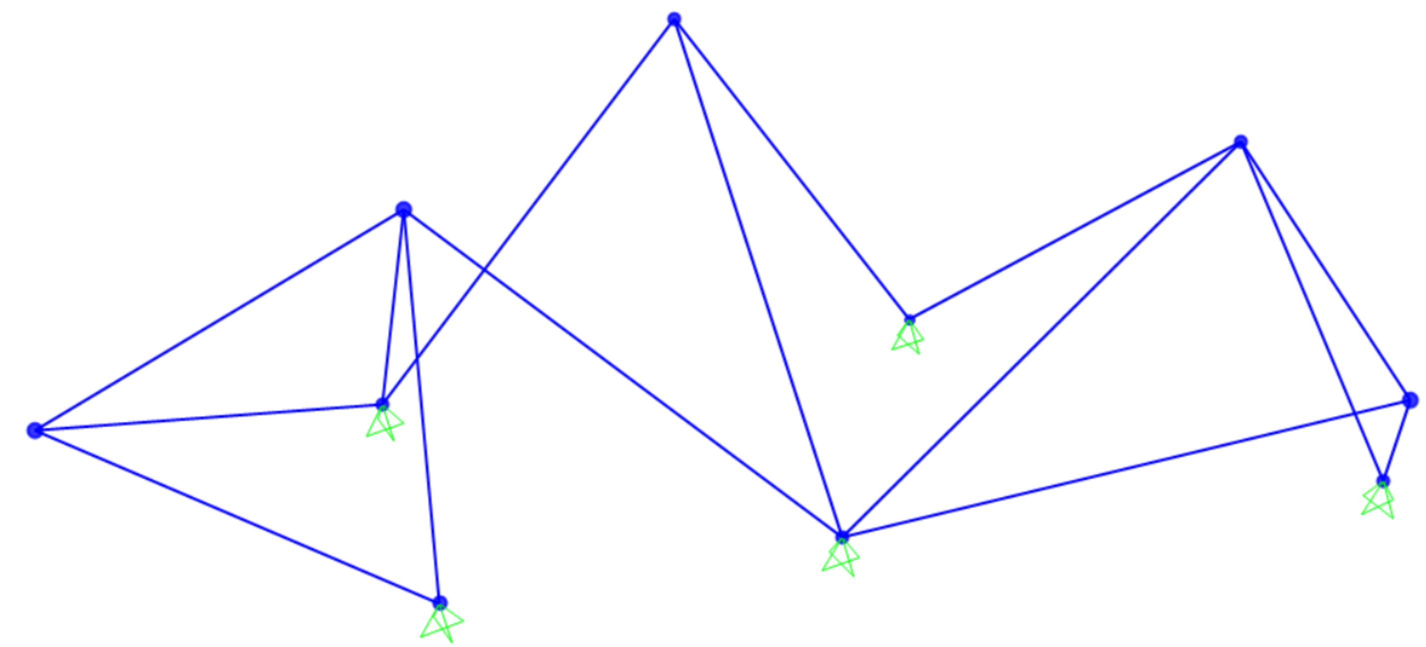
how heavy?

with the shell



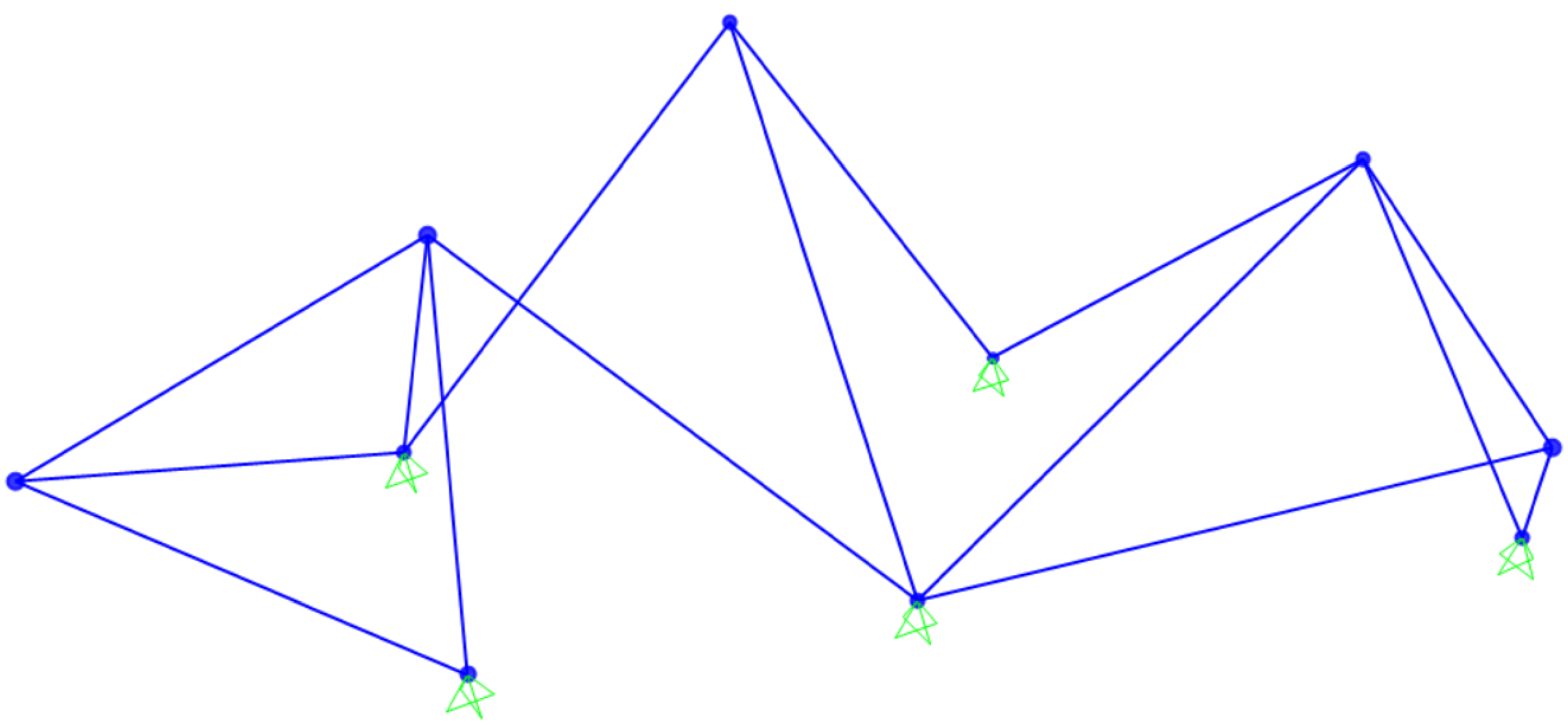
	OutputCase	CaseType Text	GlobalFX Lb	GlobalFY Lb	GlobalFZ Lb
▶	DEAD	LinStatic	-9.322E-12	1.228E-11	19792.97

without the shell



	OutputCase	CaseType Text	GlobalFX Lb	GlobalFY Lb	GlobalFZ Lb
▶	DEAD	LinStatic	1.137E-13	-5.684E-13	3021.27

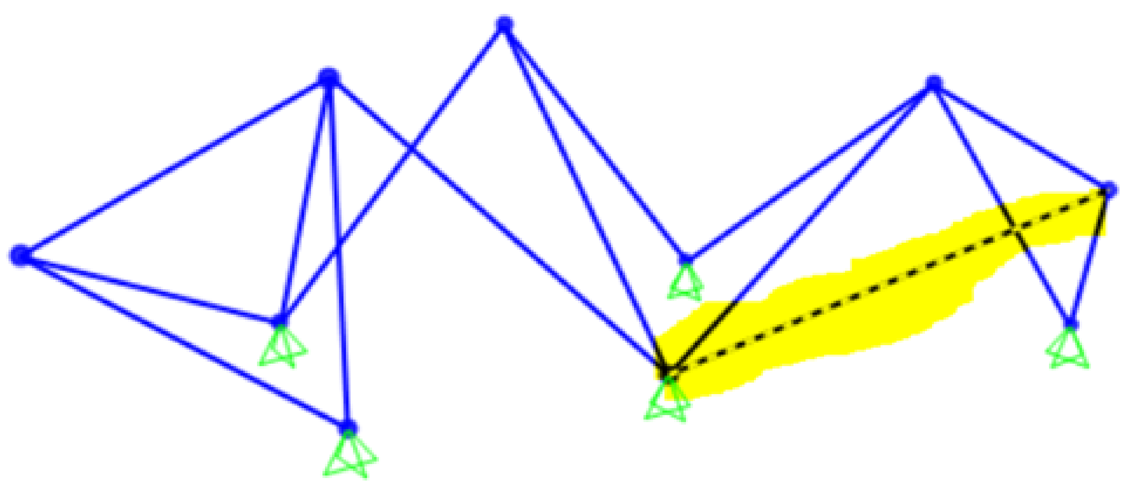
buckling



The buckling was not a major concern due to the shell no being of any structural benefit. The buckling case shown was that of pure dead load across the entirety of the structure.

	OutputCase	StepType Text	StepNum Unitless	ScaleFactor Unitless
▶	MyBuckle	Mode	1	91.81845
	MyBuckle	Mode	2	91.833738
	MyBuckle	Mode	3	-121.925119
	MyBuckle	Mode	4	-121.98513
	MyBuckle	Mode	5	163.918944
	MyBuckle	Mode	6	164.084574

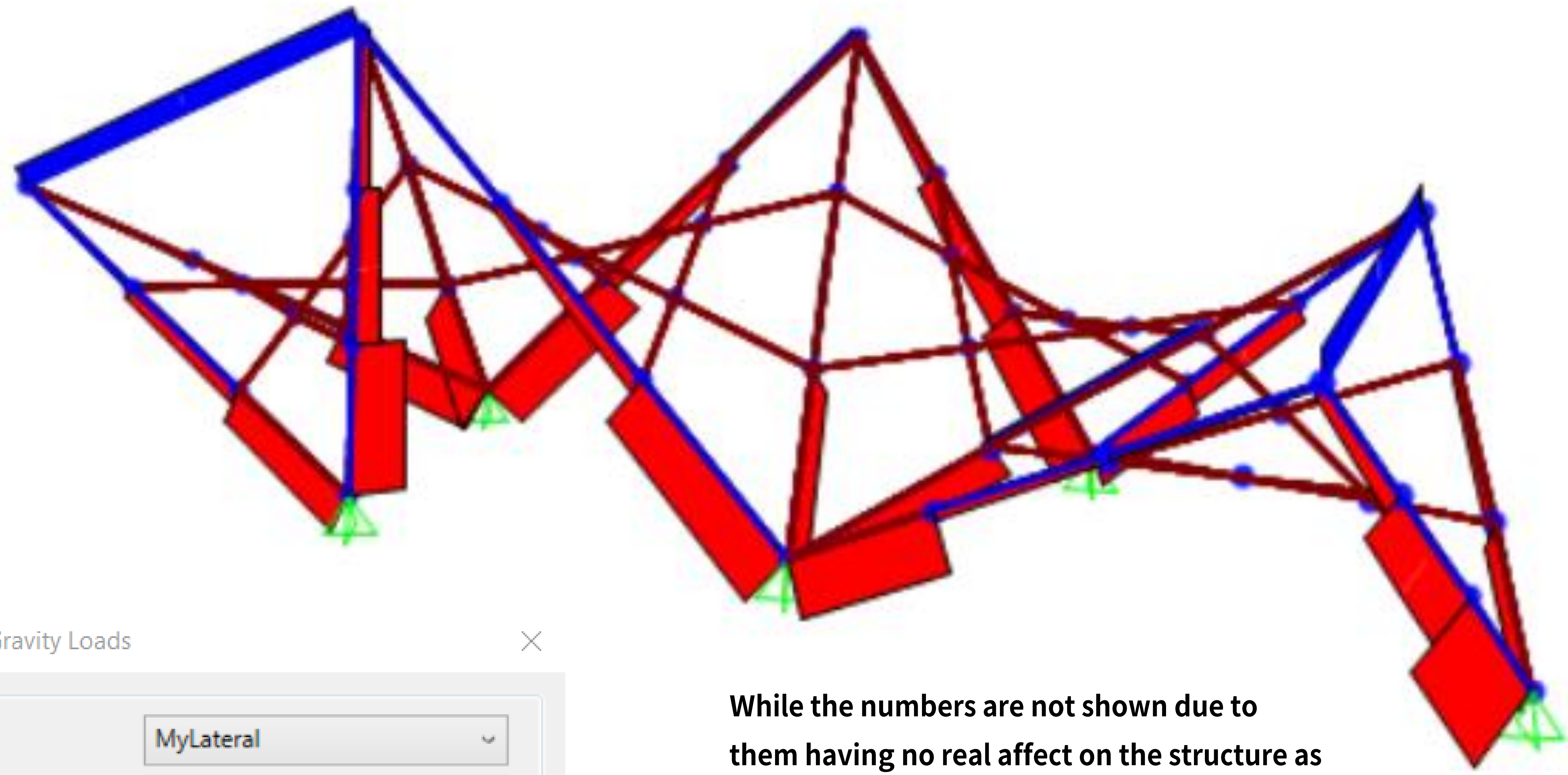
beam outputs

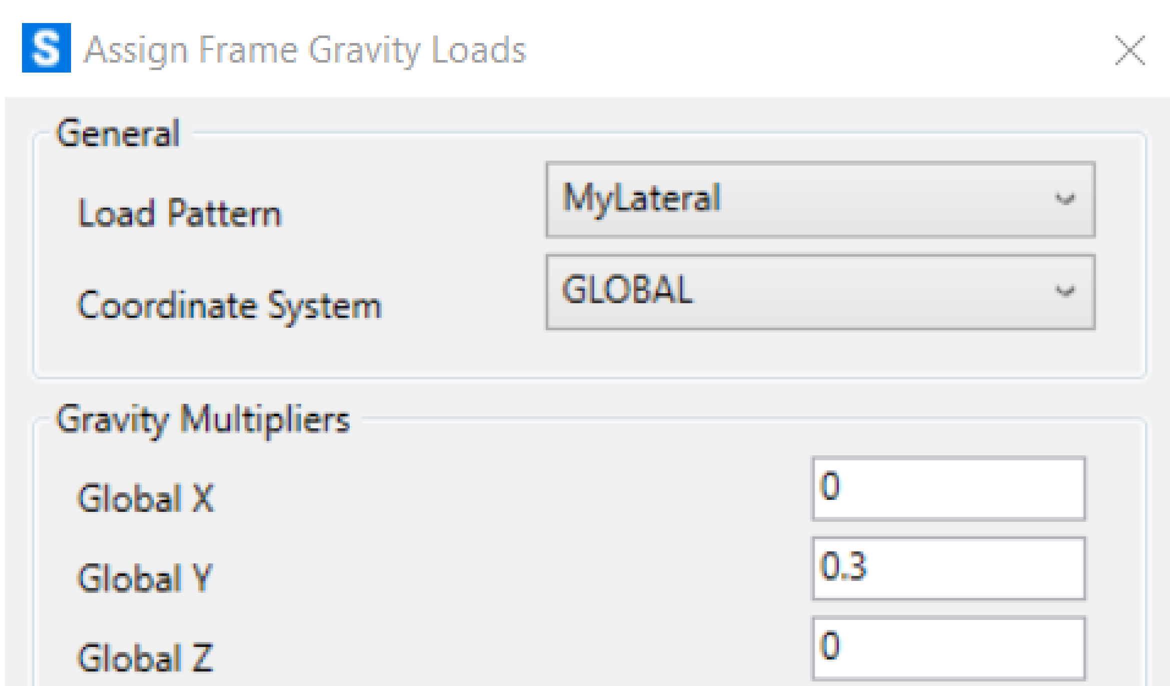


Brendan Peers			5/17/2023
ASSUMTIONS			**REF (NDS 2018)**
Sawn lumber analysis, c = 0.8			Table 4.3.1
Moisture Content will exceed 19%, C_M = 0.91 for F_c, 1.0 for F_V , F_t, & F_b			Table 4D
Temperature will not exceed 150°F, C_t = 1.0			4.3.4
Strut will not exceed 12" depth, C_F = 1.0			Table 4D
Strut 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]	775	C_D	0.9
F_t [PSI]	350	*NOTE : 0.9 for Dead Load	
F_v [PSI]	135	1.6 for Seismic Load	
F_c [PSI]	1000	Axial [#]	770
E_{MIN} [PSI]	400000	*NOTE : Tension (-), Compression (+)	
Length [IN]	369.72	Bending [#*IN]	9796.3
Depth [IN]	8	Shear [#]	107
CALCS			
F'_b	698	f_b	115
F'_t	N/A	f_t	N/A
F'_v	122	f_v	3
F'_c	147	f_c	12
F^*_c	819	F_{cE}	154
C_P	0.18	F_{bE}	10386
OUTPUT			
DCR Shear			**0.02**
DCR Bending + Tension			**N/A**
DCR Bending + Compression			**0.36**
Are Requirements of 3.9.2 met?			**YES**
Are Slenderness Requirements of 3.7.1.4 met?			**YES**

The beam chosen was subjected to the worst effects during the Northridge Earthquake. Shown via the table, we would have to increase the member size due to slenderness and loading requirements.

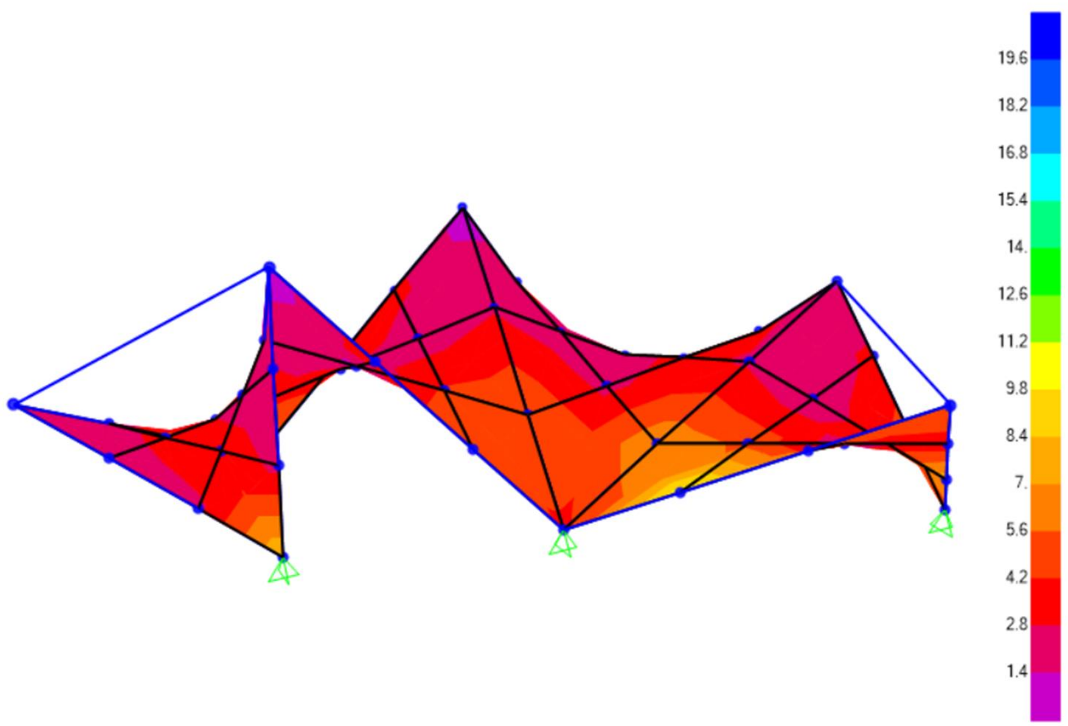
seismic output (0.3D)



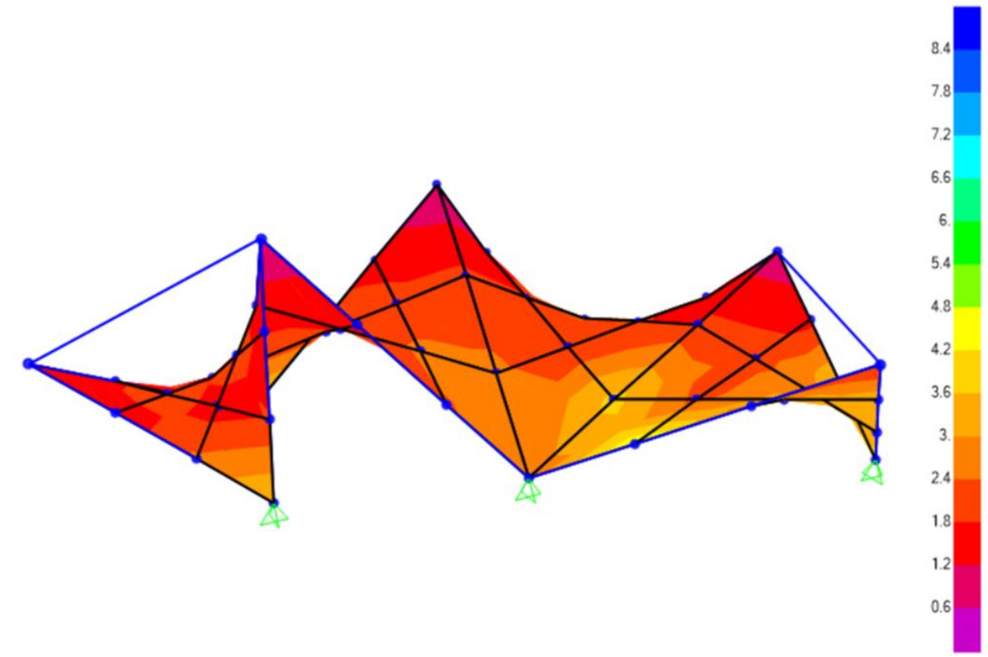


While the numbers are not shown due to them having no real affect on the structure as the other earthquakes do, the purpose of the 0.3D was to simulate what the load flow would look like under an earthquake like El Centro. This is due to El Centro having a ground acceleration of 0.33G which is near the 0.3D applied in the Y direction.

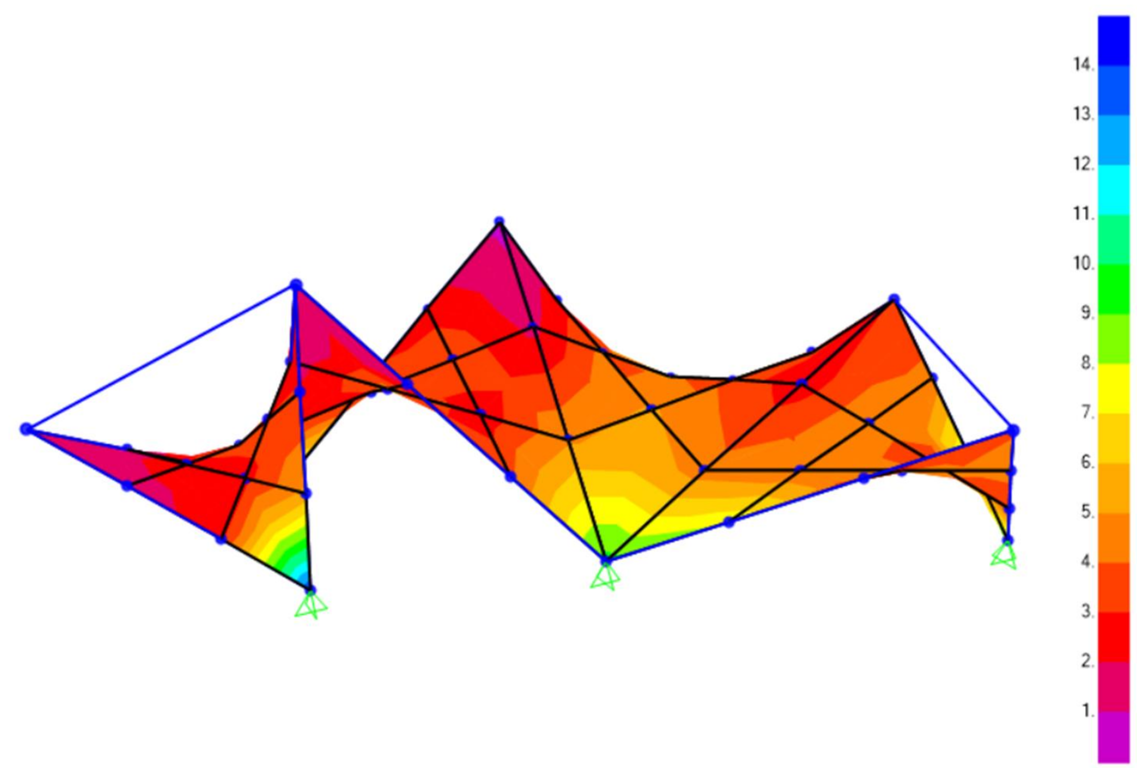
el centro earthquake



SHELL STRESS S11 MAX ENVELOPE = 19.6 PSI

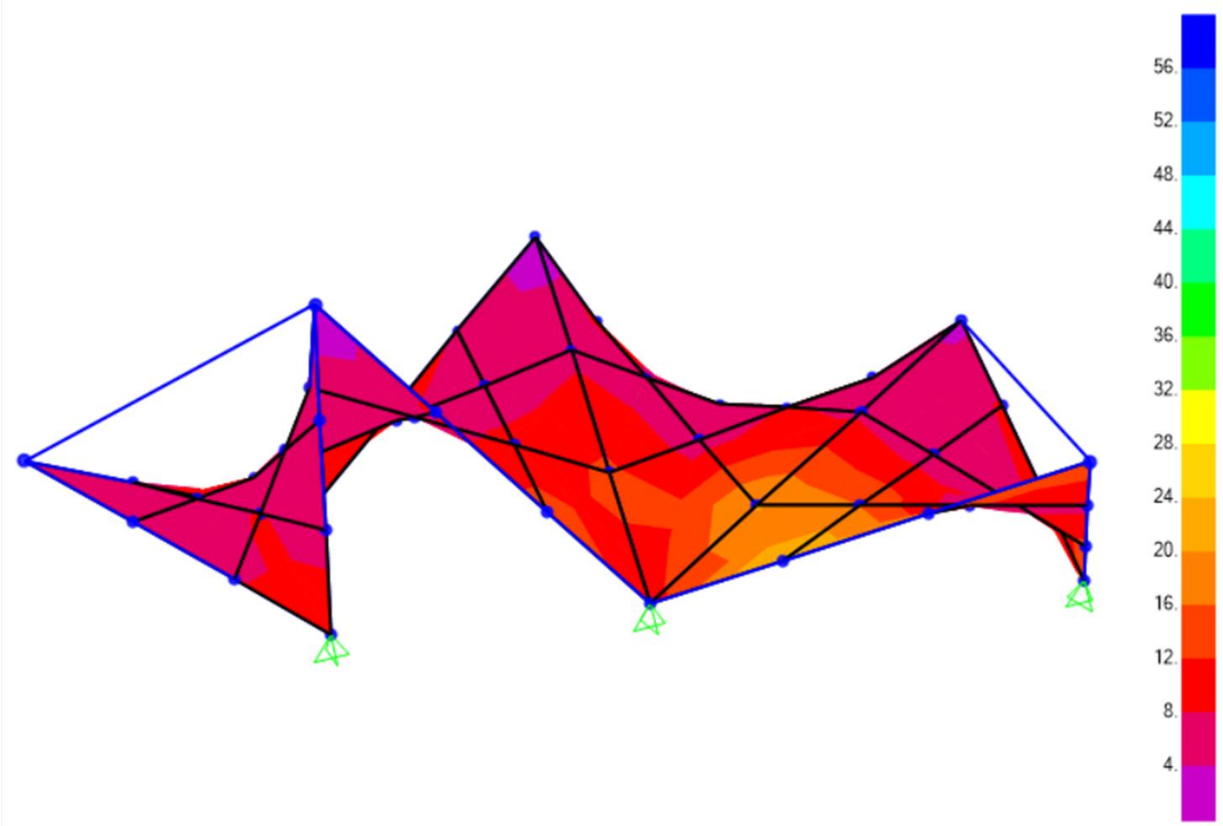


SHELL STRESS S12 MAX ENVELOPE = 8.4 PSI

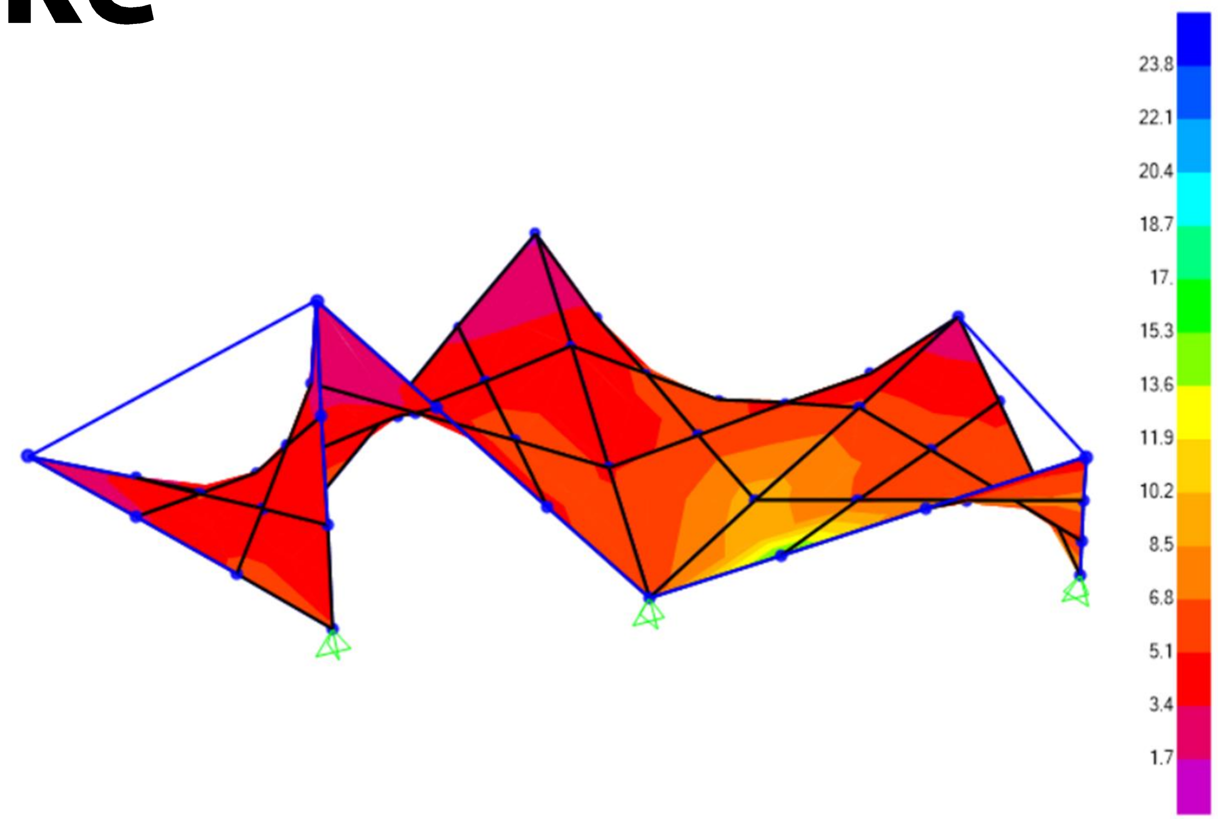


SHELL STRESS S22 MAX ENVELOPE = 14 PSI

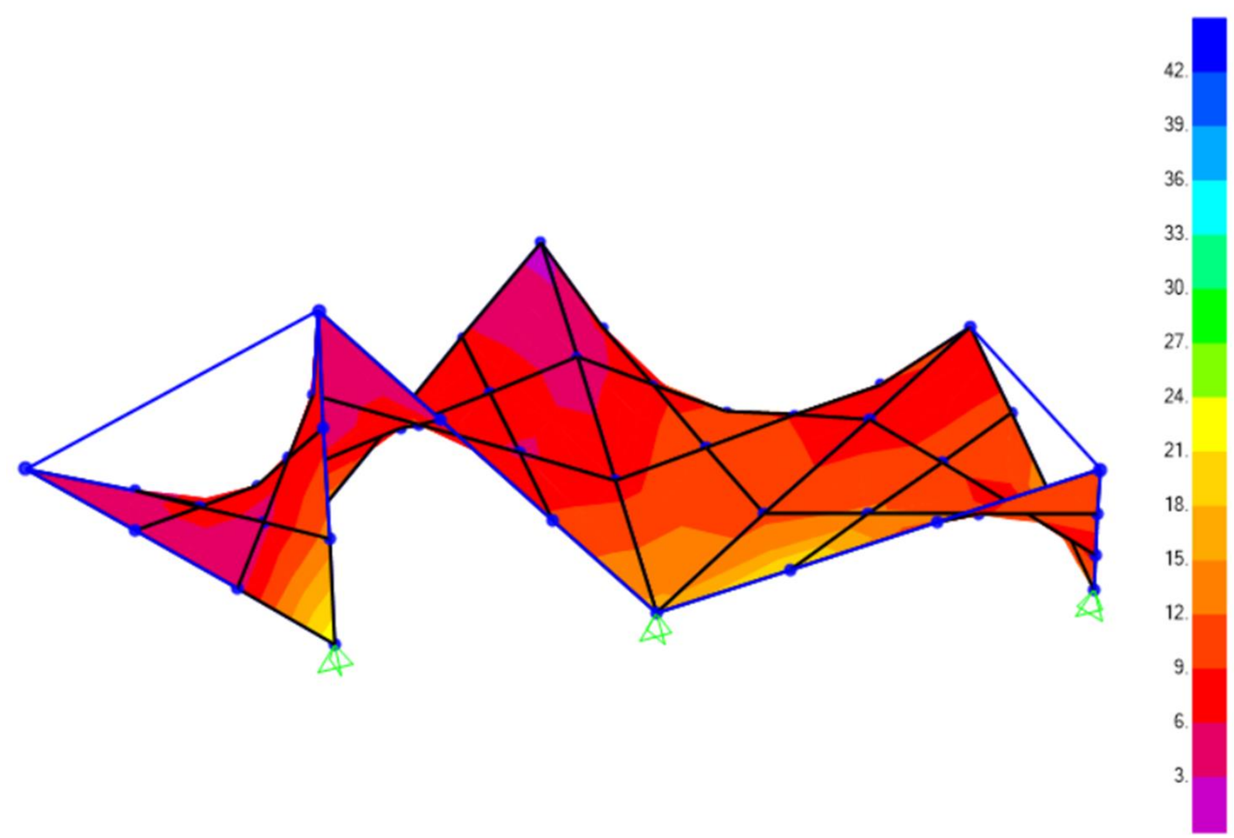
northridge earthquake



SHELL STRESS S11 MAX ENVELOPE = 96 PSI

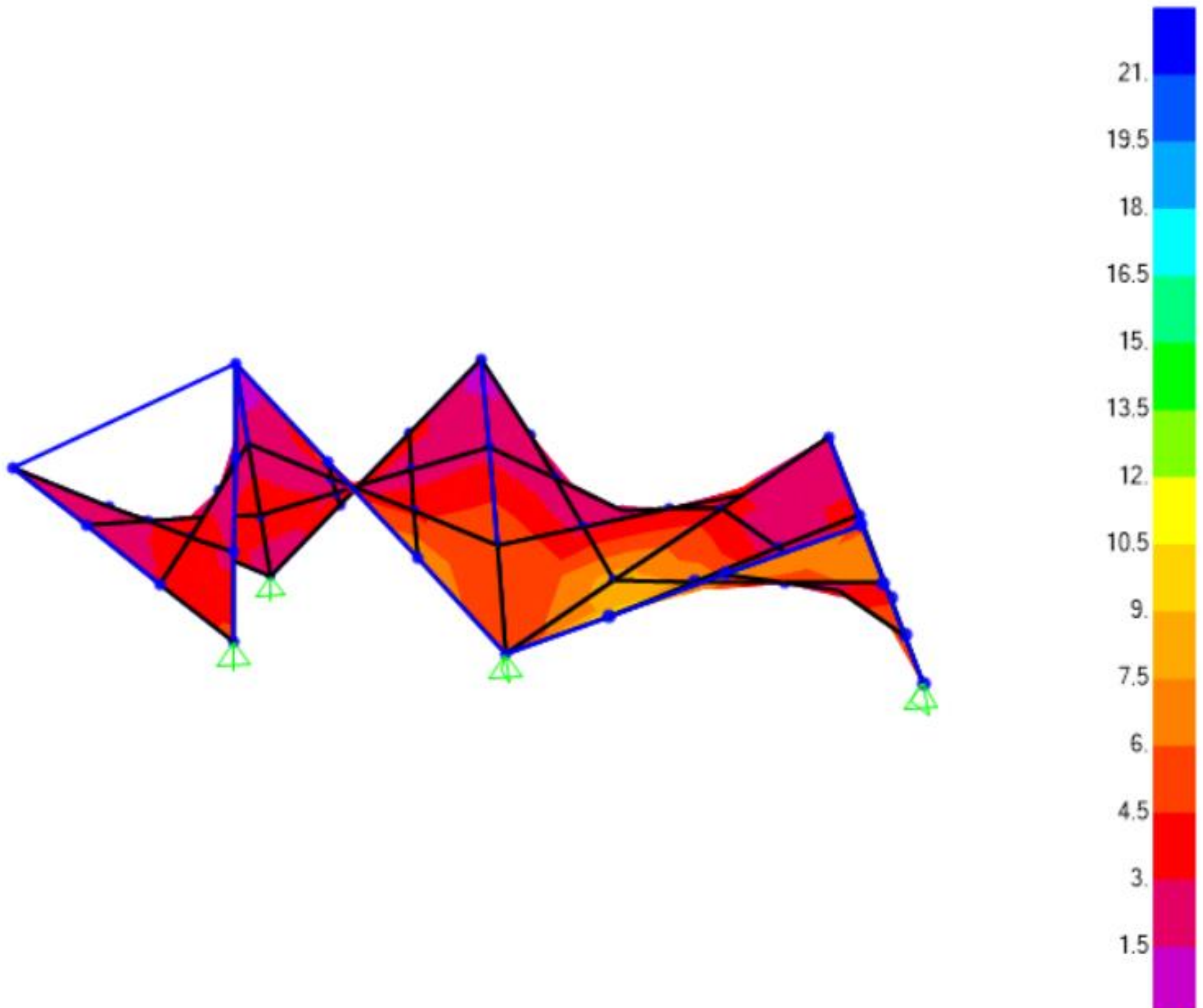


SHELL STRESS S12 MAX ENVELOPE = 23.8 PSI

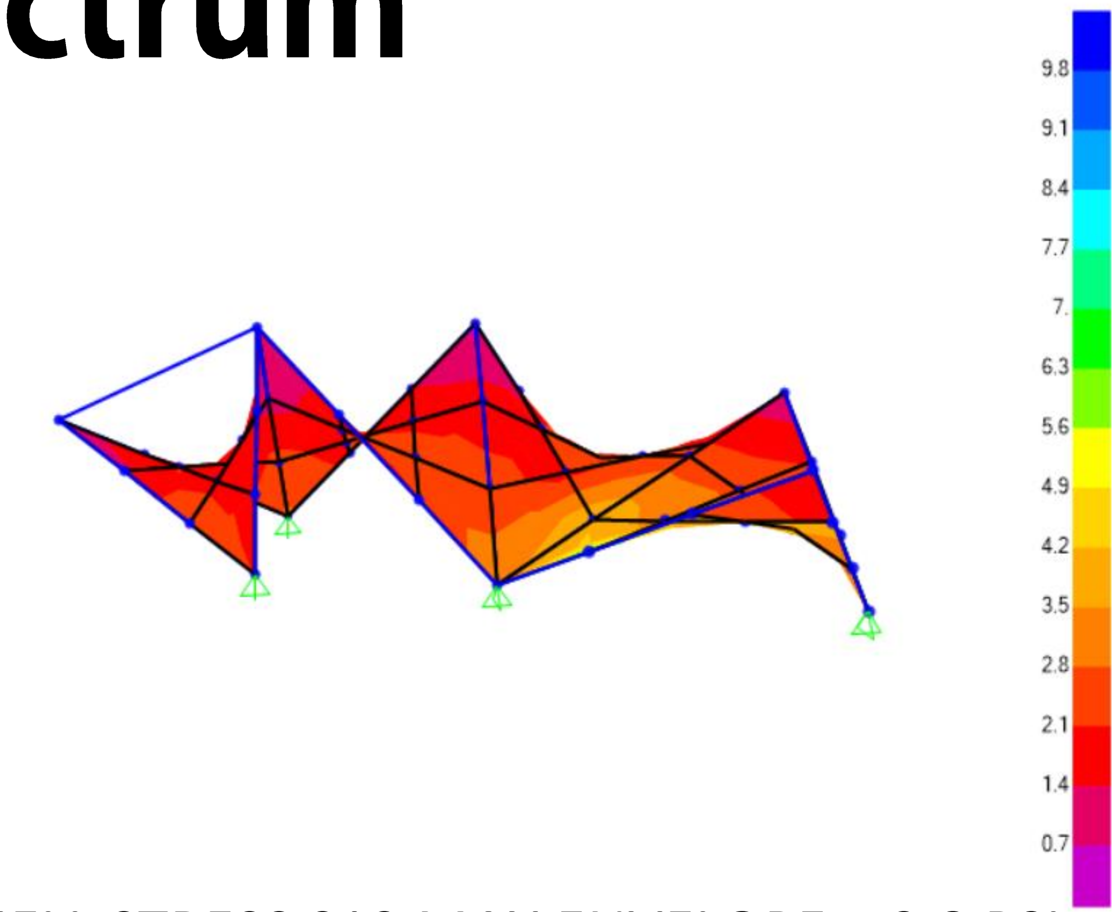


SHELL STRESS S22 MAX ENVELOPE = 42 PSI

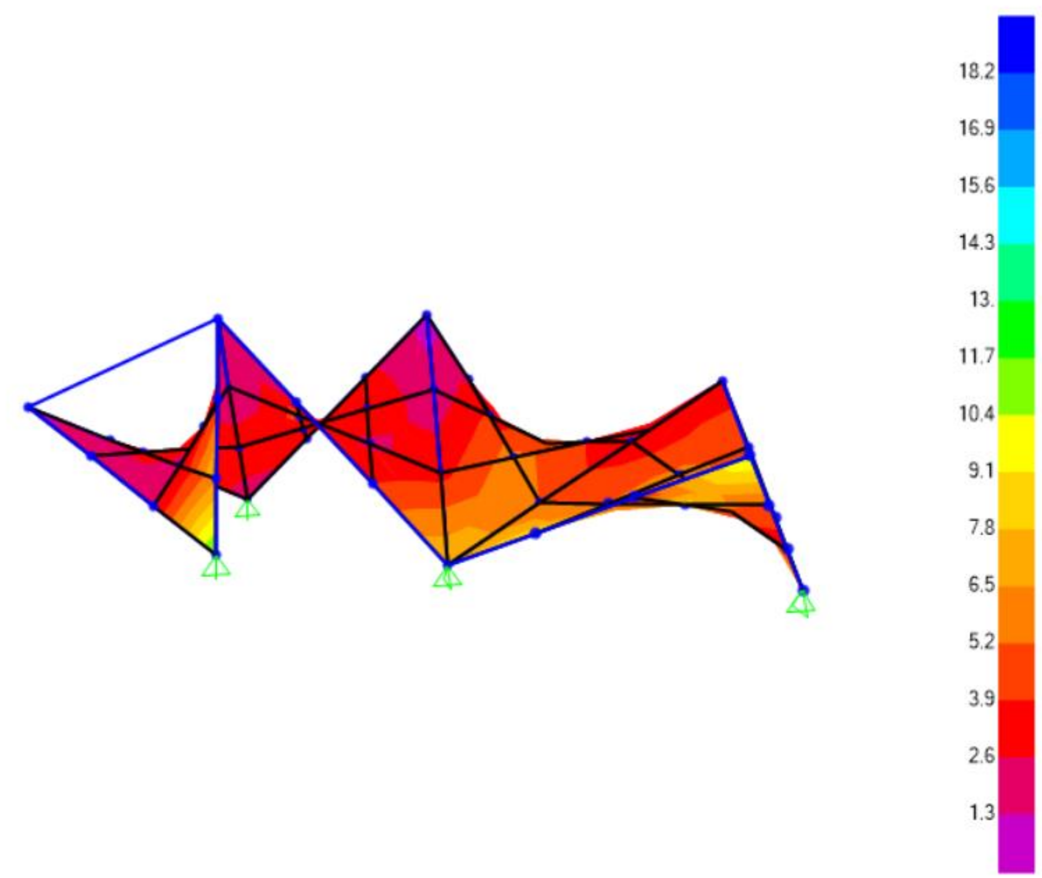
IBC 2012 response spectrum



SHELL STRESS S11 MAX ENVELOPE = 21 PSI



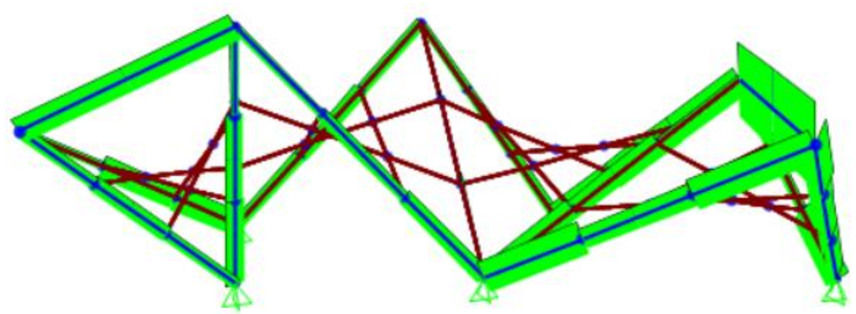
SHELL STRESS S12 MAX ENVELOPE = 9.8 PSI



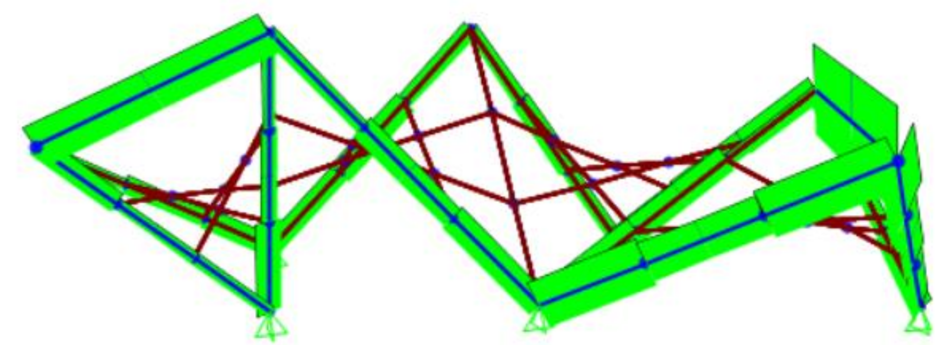
SHELL STRESS S22 MAX ENVELOPE = 18.2 PSI

seismic analysis

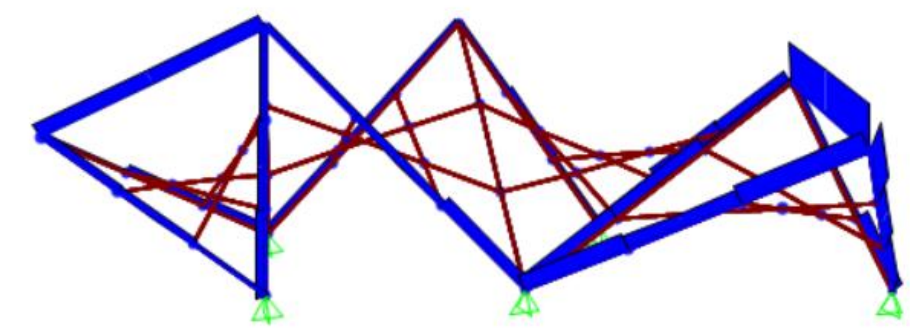
Axial



El Centro

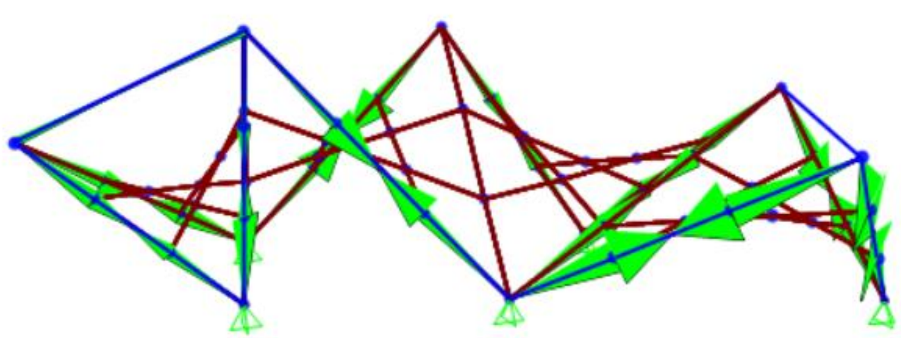


Northridge

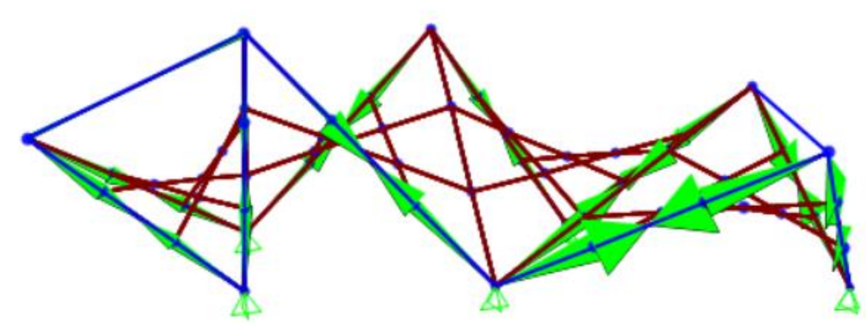


IBC 2012

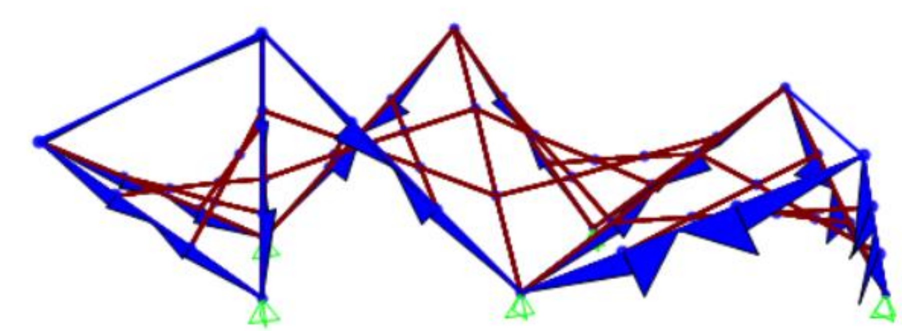
Bending



El Centro



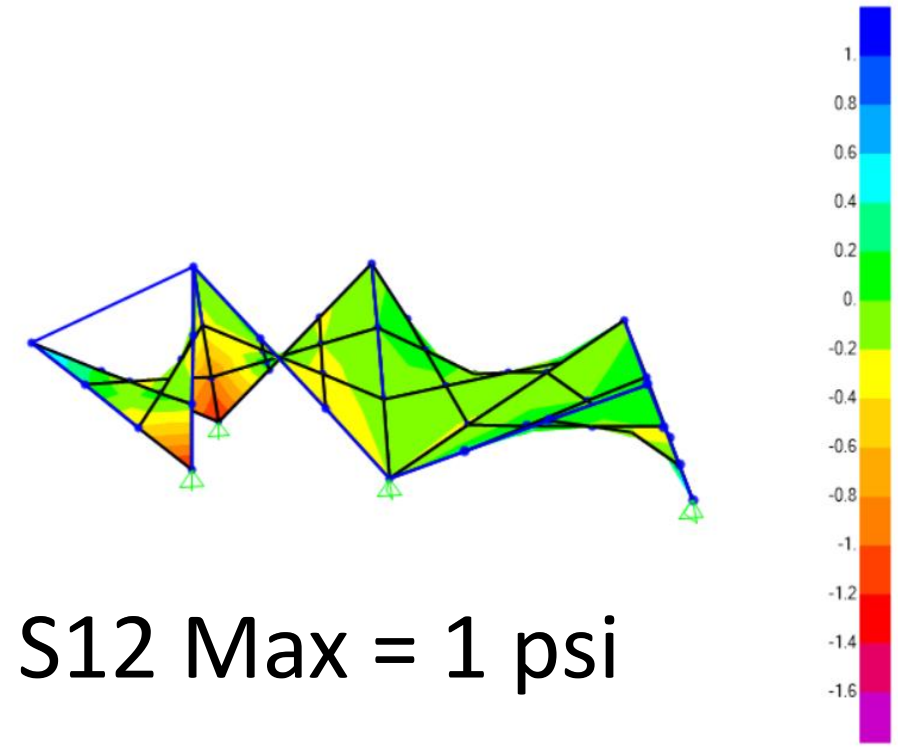
Northridge



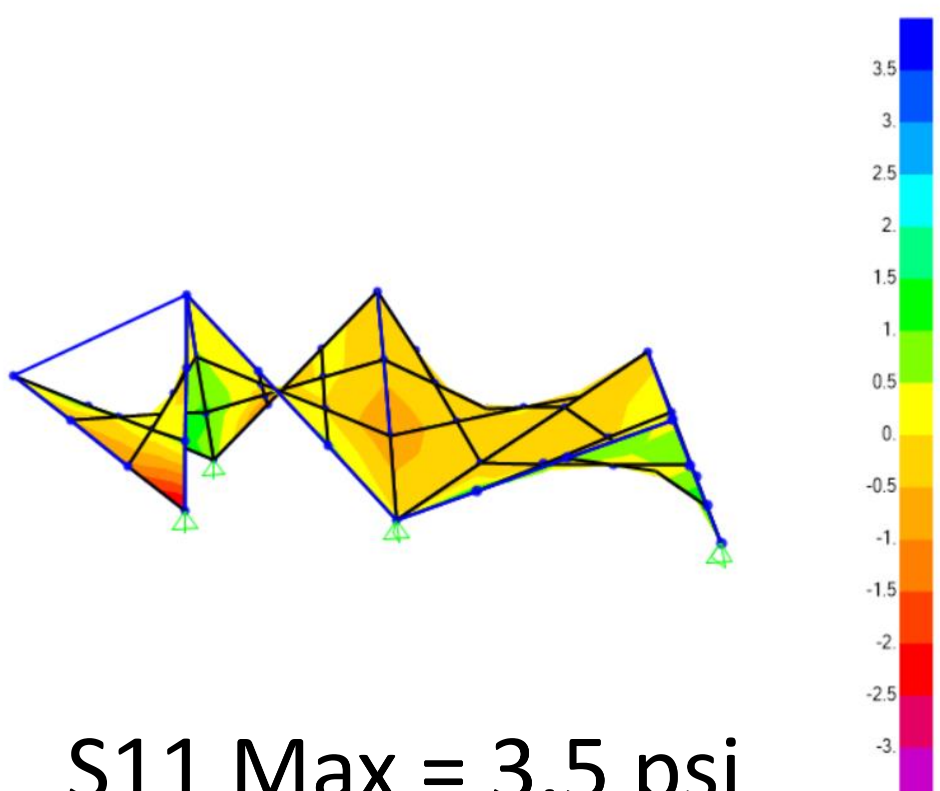
IBC 2012

wind

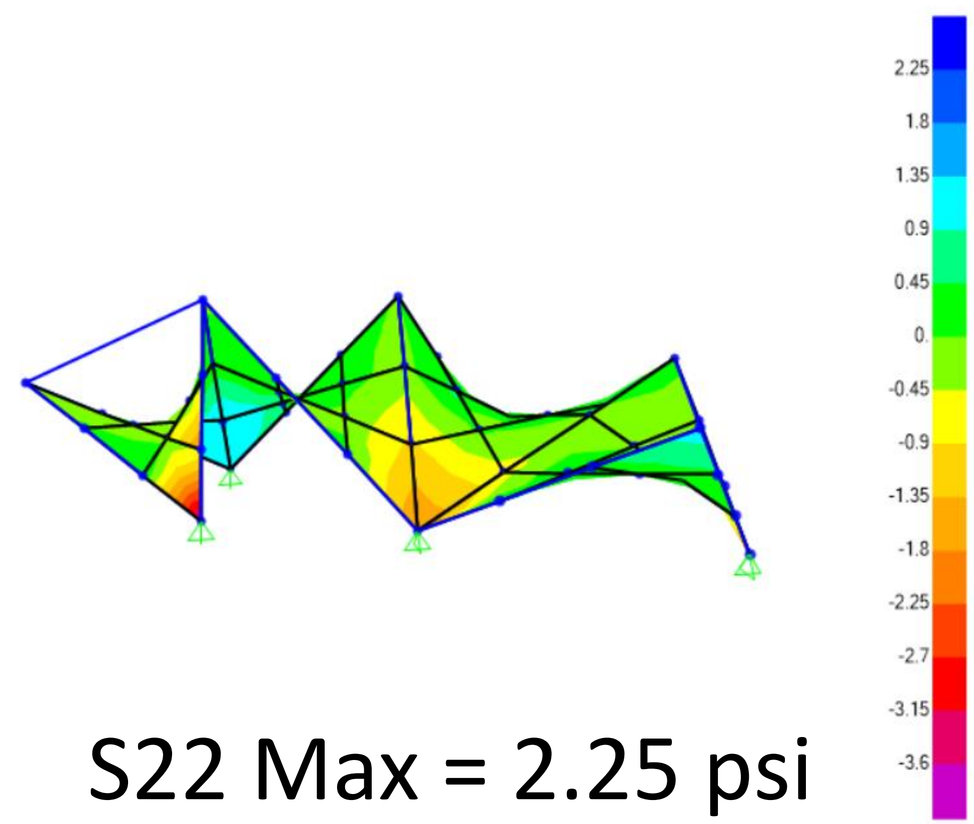
ASCE 7-16 Chapter 26
Wind Speed = 87 mph
Wind Pressure = 19.37 psf



S12 Max = 1 psi



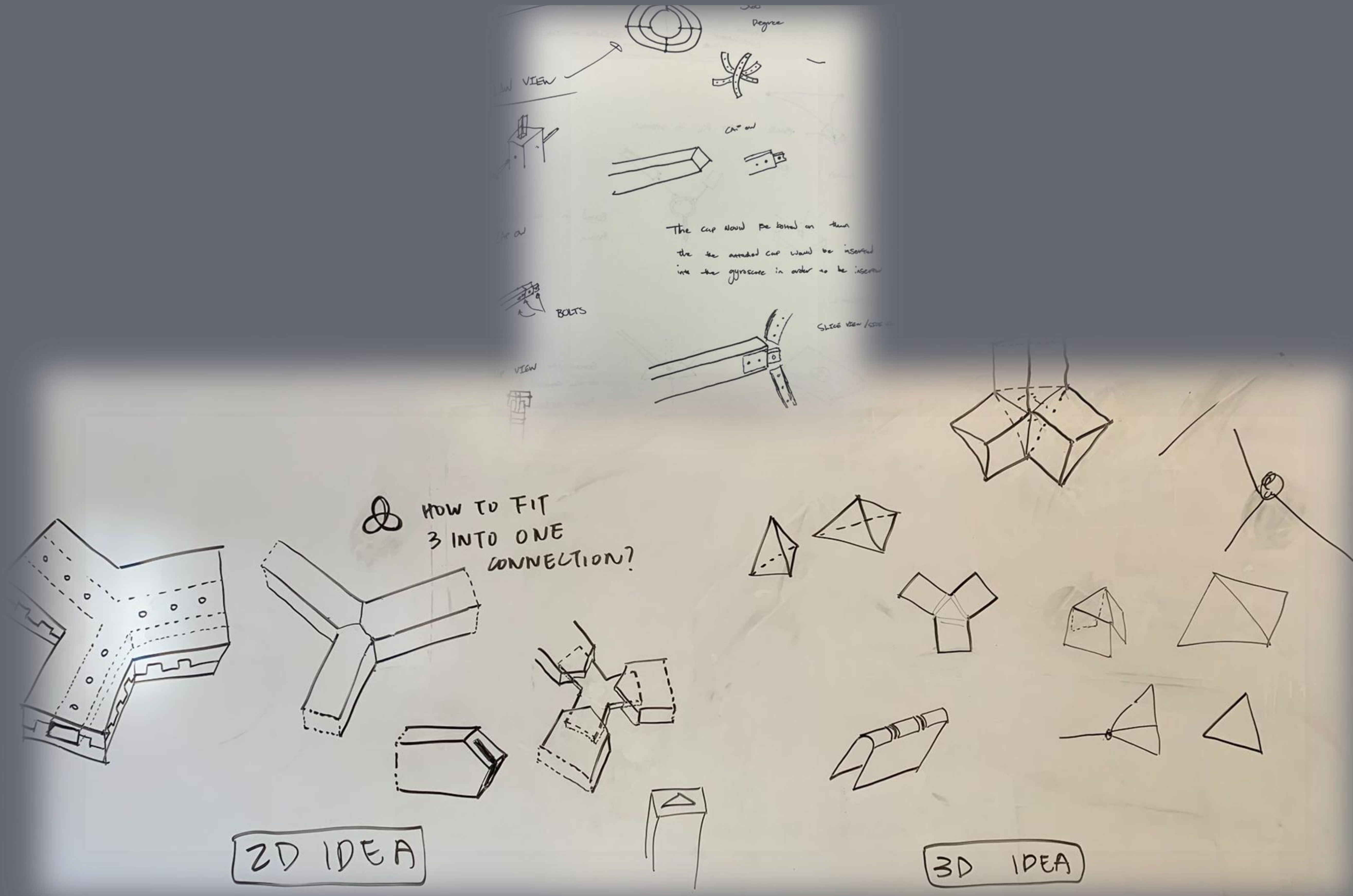
S11 Max = 3.5 psi



S22 Max = 2.25 psi

connections

initial connection ideas

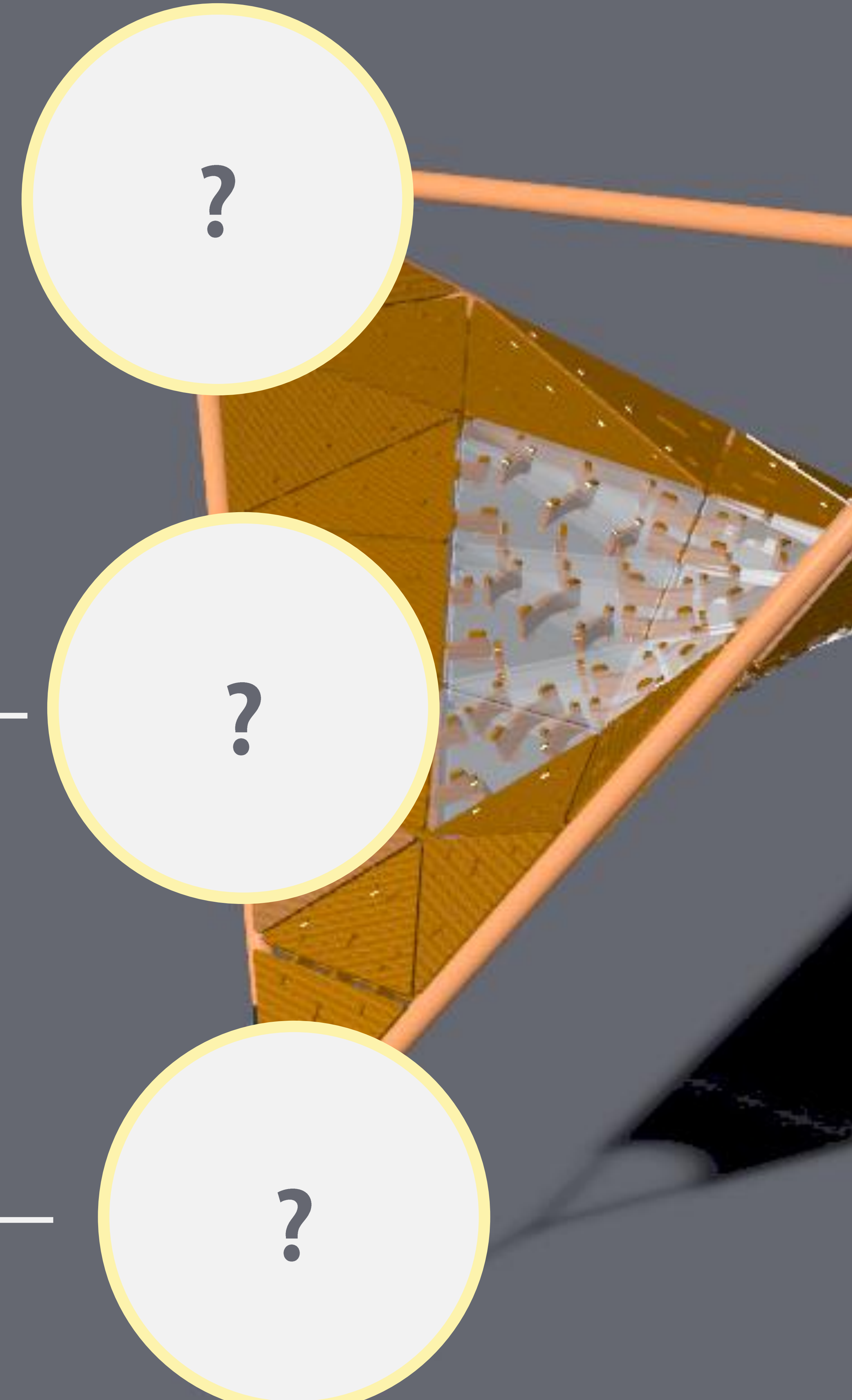


connections

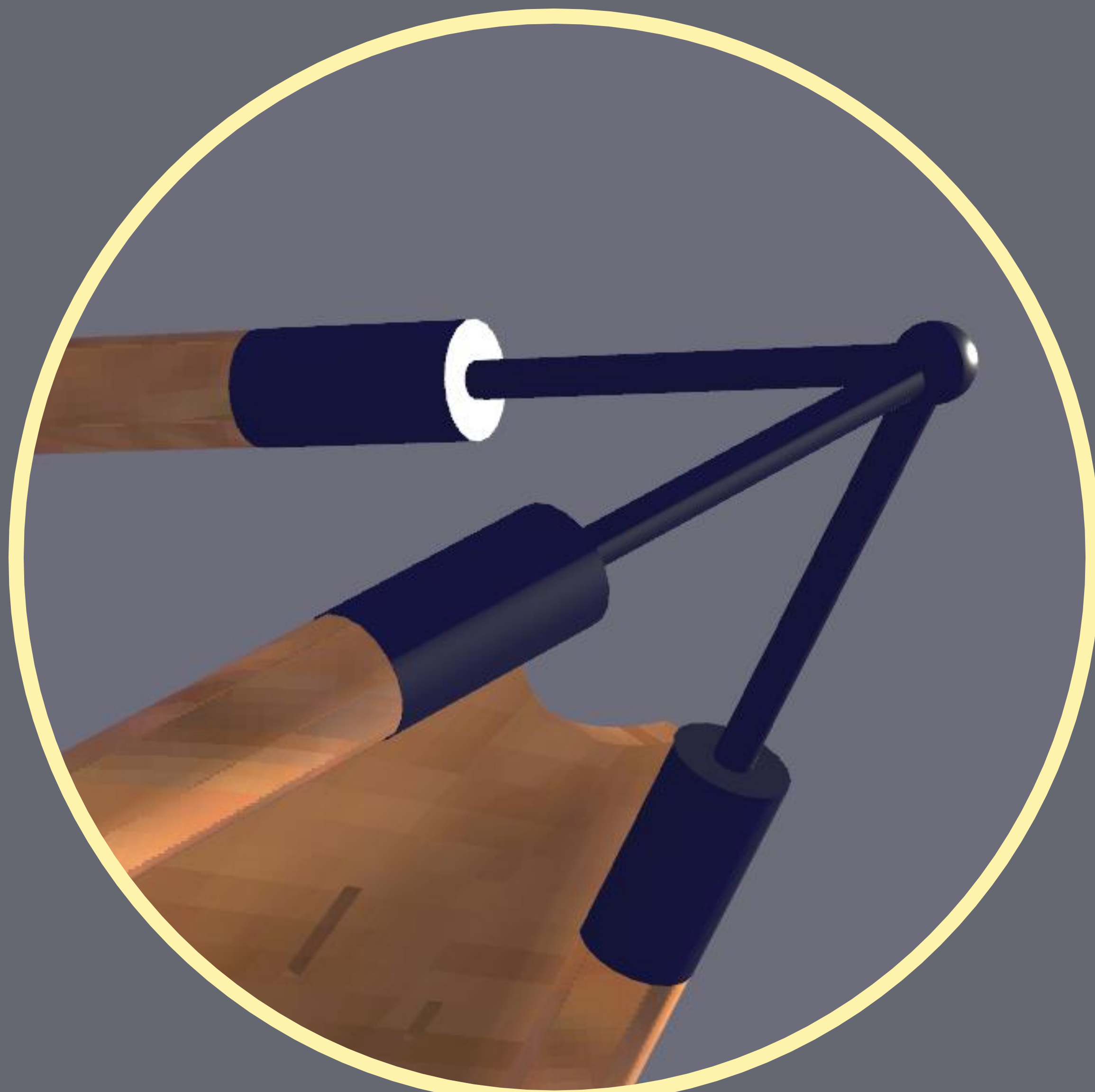
strut to strut

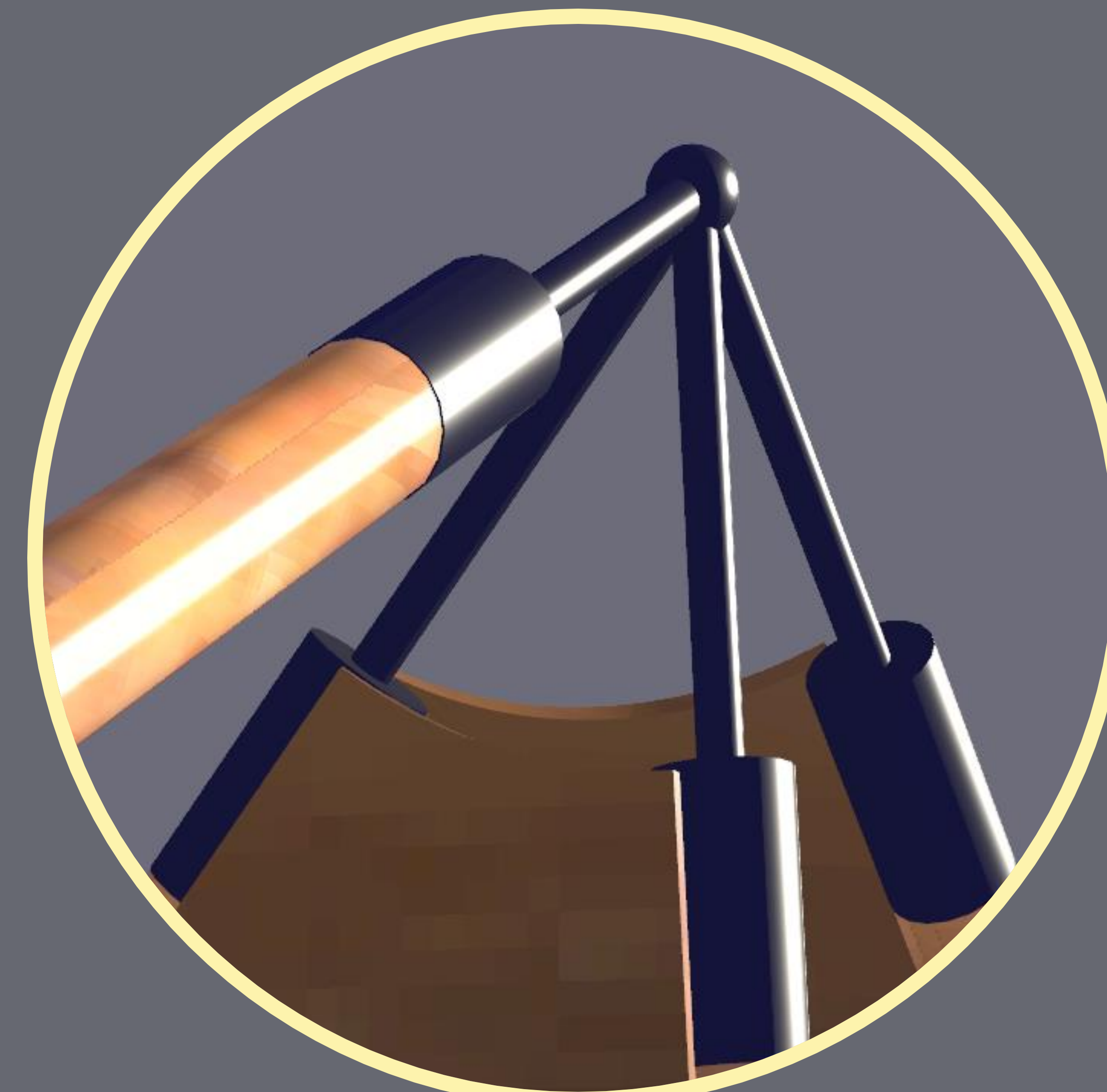
shell to strut

strut to foundation



strut to strut connection





strut to strut connection

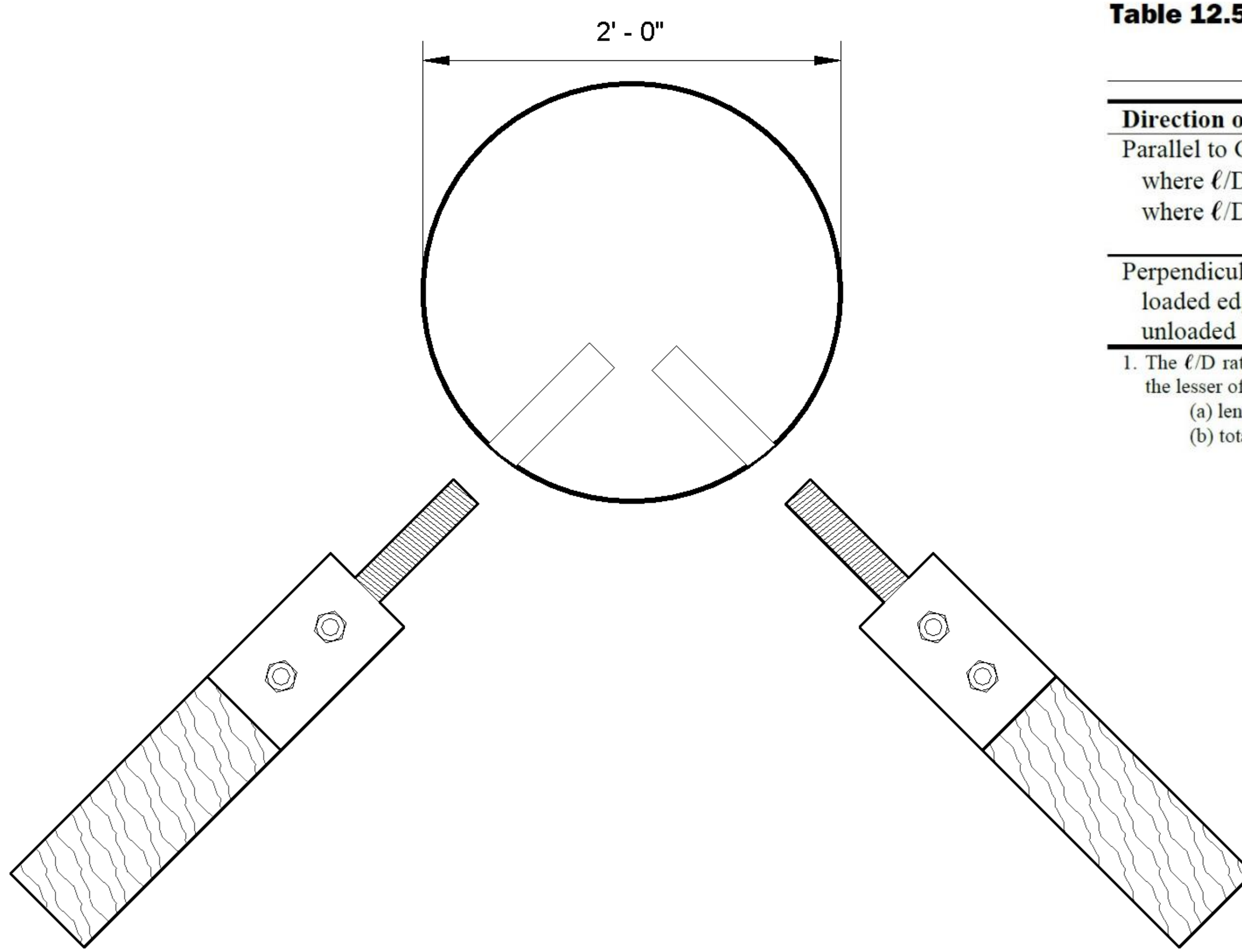
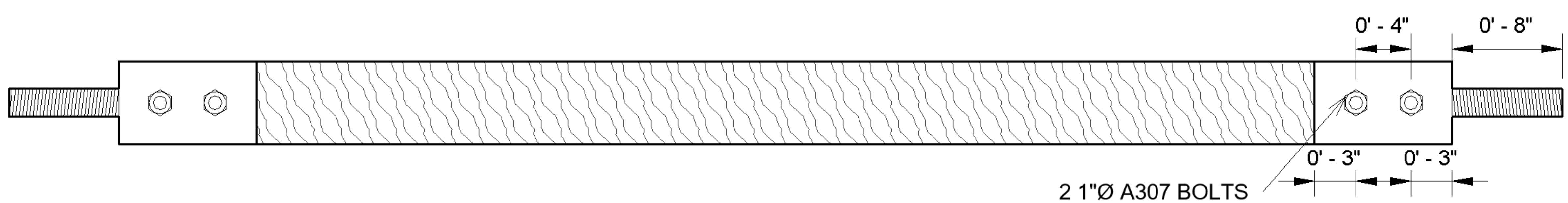


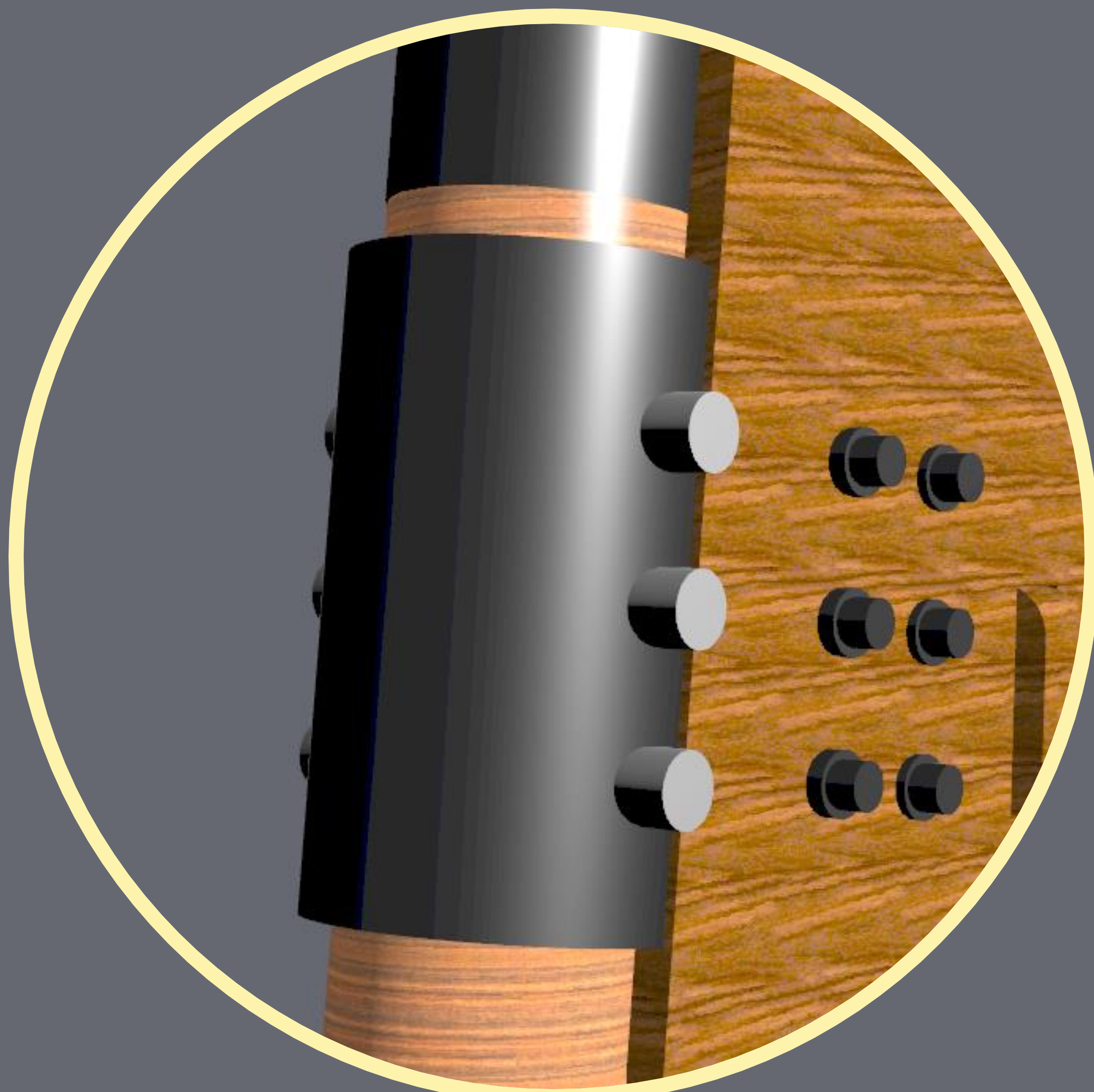
Table 12.5.1C Edge Distance Requirements[1,2]

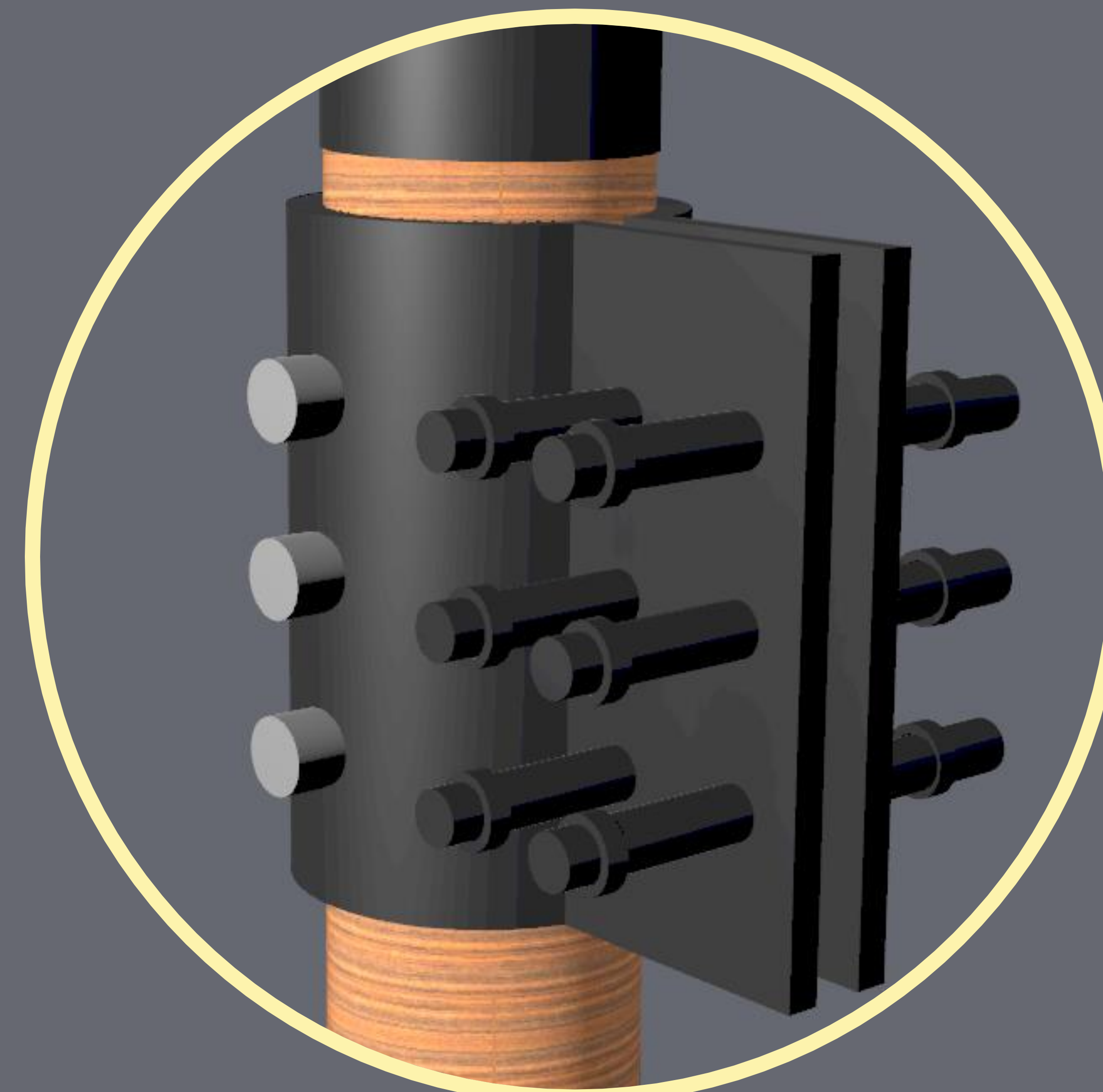
Direction of Loading	Minimum Edge Distance
Parallel to Grain:	
where $\ell/D \leq 6$	1.5D
where $\ell/D > 6$	1.5D or ½ the spacing between rows, whichever is greater
Perpendicular to Grain:[2]	
loaded edge	4D
unloaded edge	1.5D

1. The ℓ/D ratio used to determine the minimum edge distance shall be the lesser of:
   (a) length of fastener in wood main member/D = ℓ_m/D
   (b) total length of fastener in wood side member(s)/D = ℓ_s/D



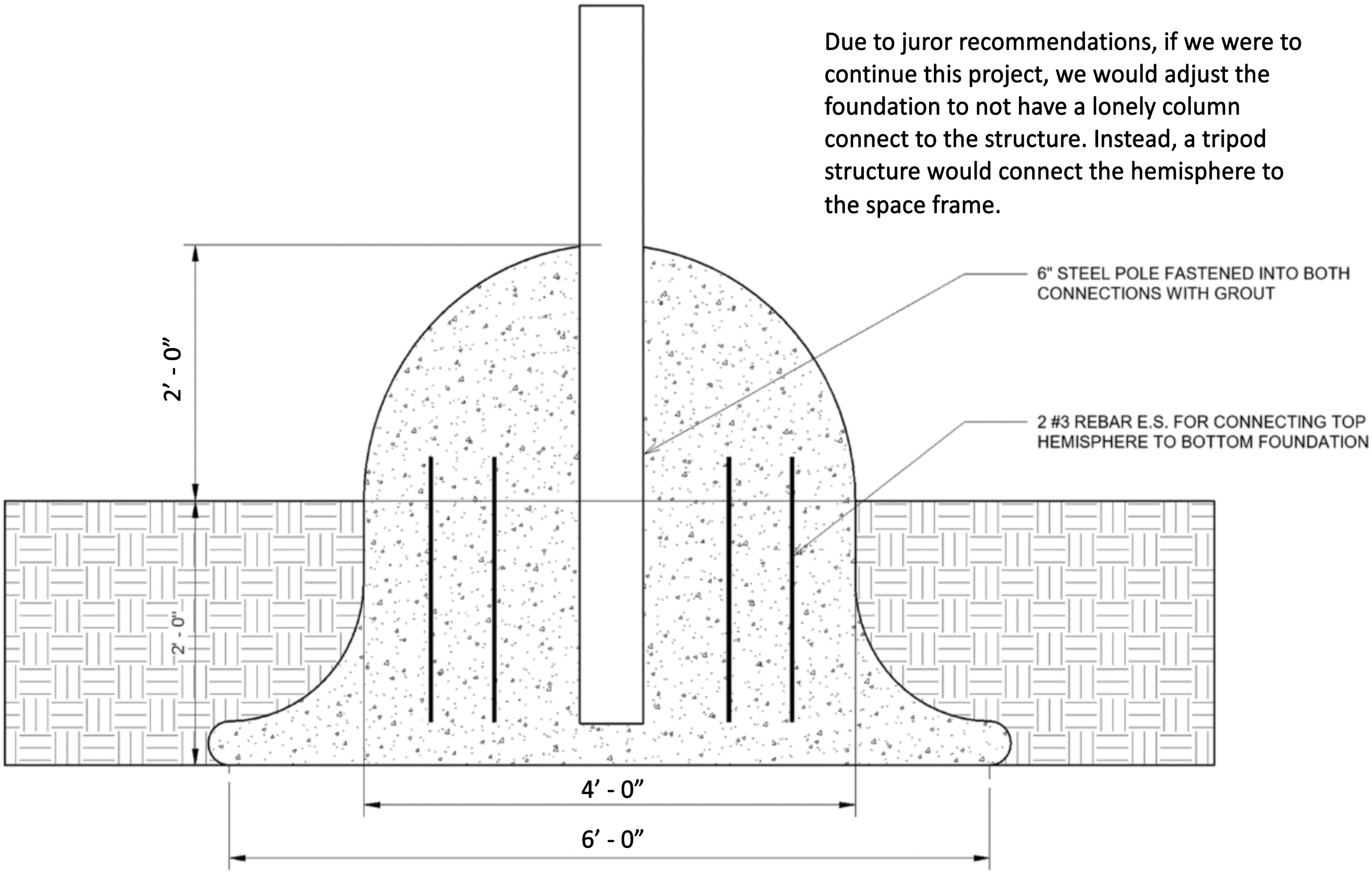
shell to strut connection





strut to foundation connection

foundation



Due to juror recommendations, if we were to continue this project, we would adjust the foundation to not have a lonely column connect to the structure. Instead, a tripod structure would connect the hemisphere to the space frame.

constructibility

The goal for the construction of this structure is high tech design, low tech construction. The aim was to find innovative designs to fit the structure. For strut to strut connections each piece would be prefabricated producing an all steel connection. The metal end caps would be connected the timber poles using bolts, then the pieces would all be welded to a central metal sphere. An issue that arose was trying to get concentric connections, and the proposed solution was to go back to the design and look at the original placement of the members. For the foundation design, it was decided to take the same strut connection idea and inverse it. To connect into the ground, our design uses concrete "boulder like" foundations. The steel ball connection would be bolted through the outside and anchored into the ground. For the shell connection, the idea is to clamp the connection around the timber poles, and bolt the shell layers over the top.

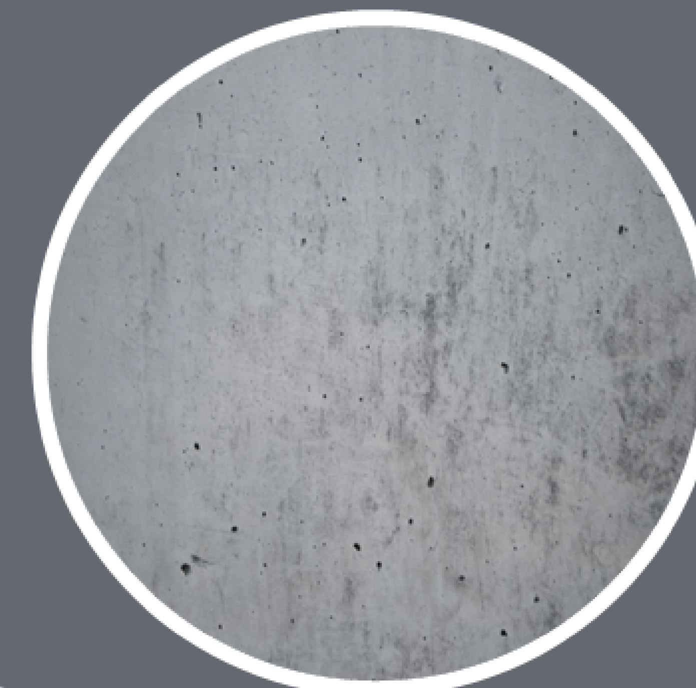
experience

materials

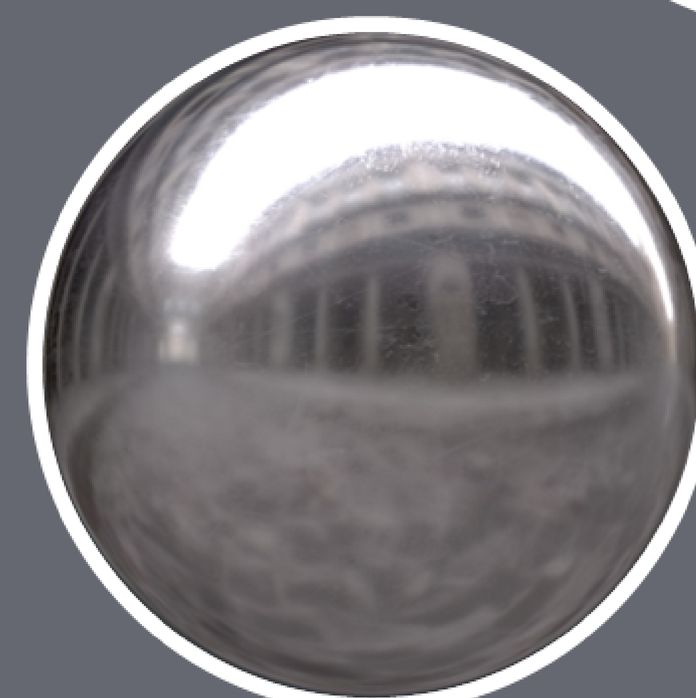
lodgepole pine.

plexiglass.

concrete.

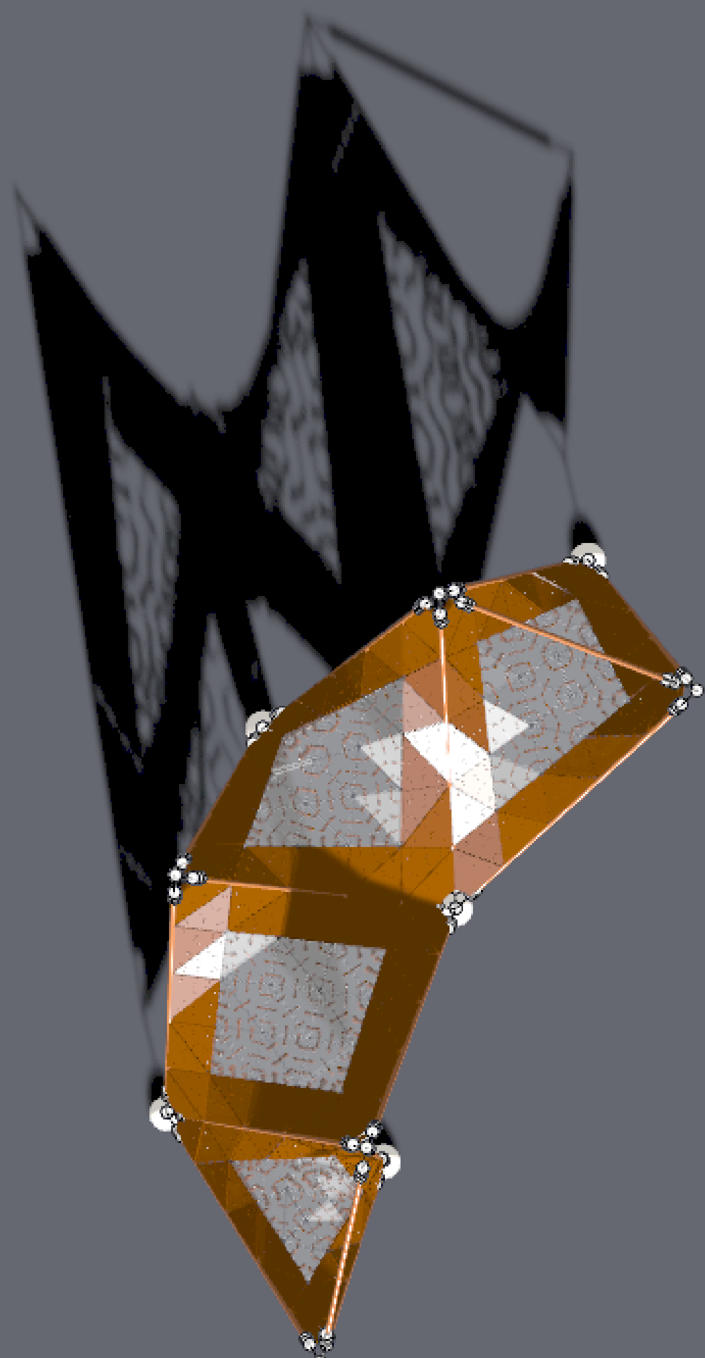


plywood.



steel.

sun study



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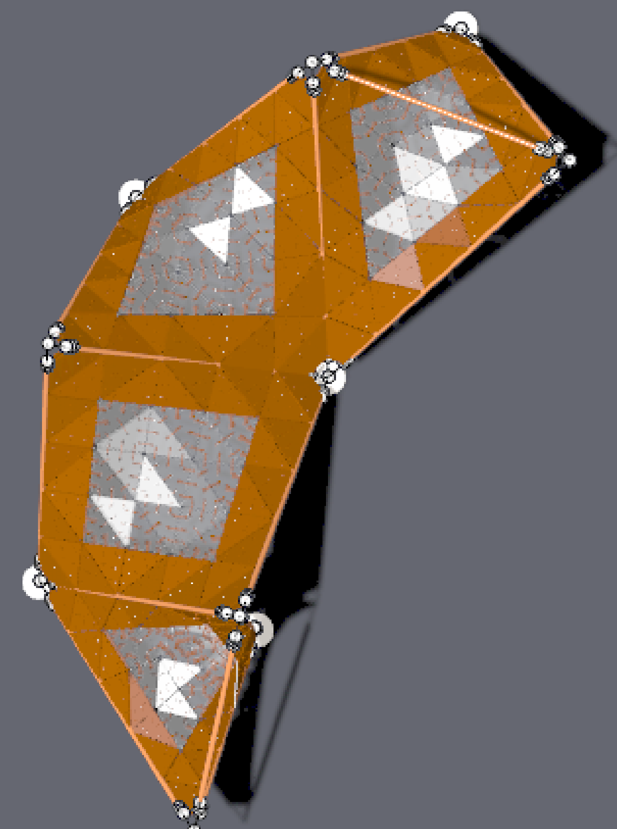

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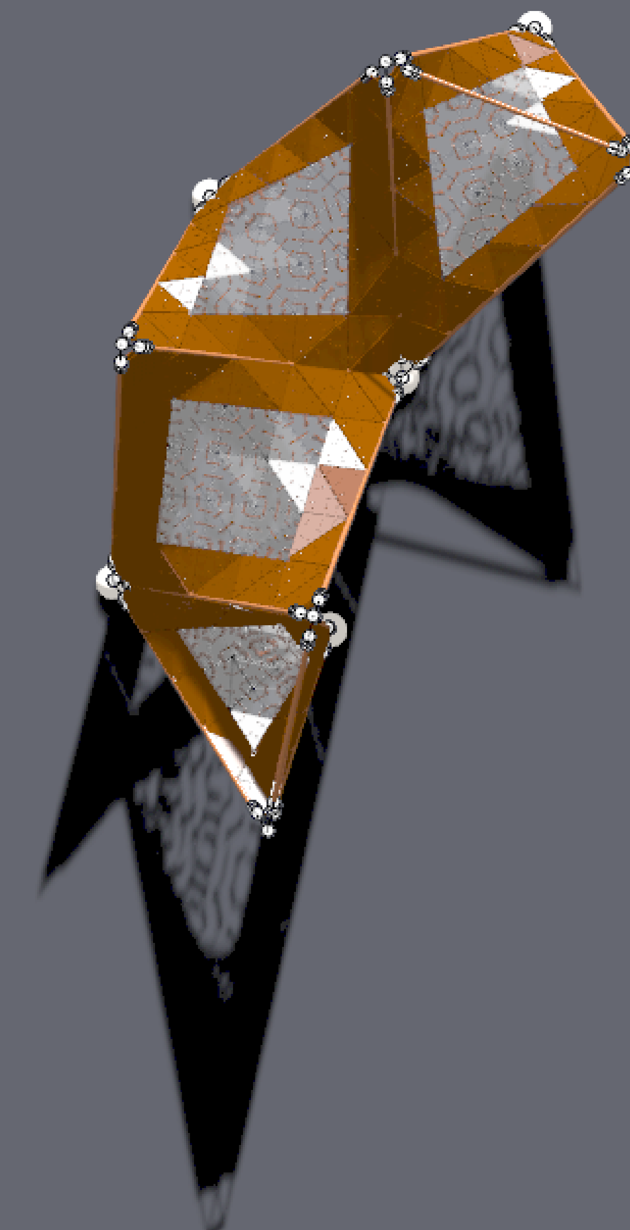
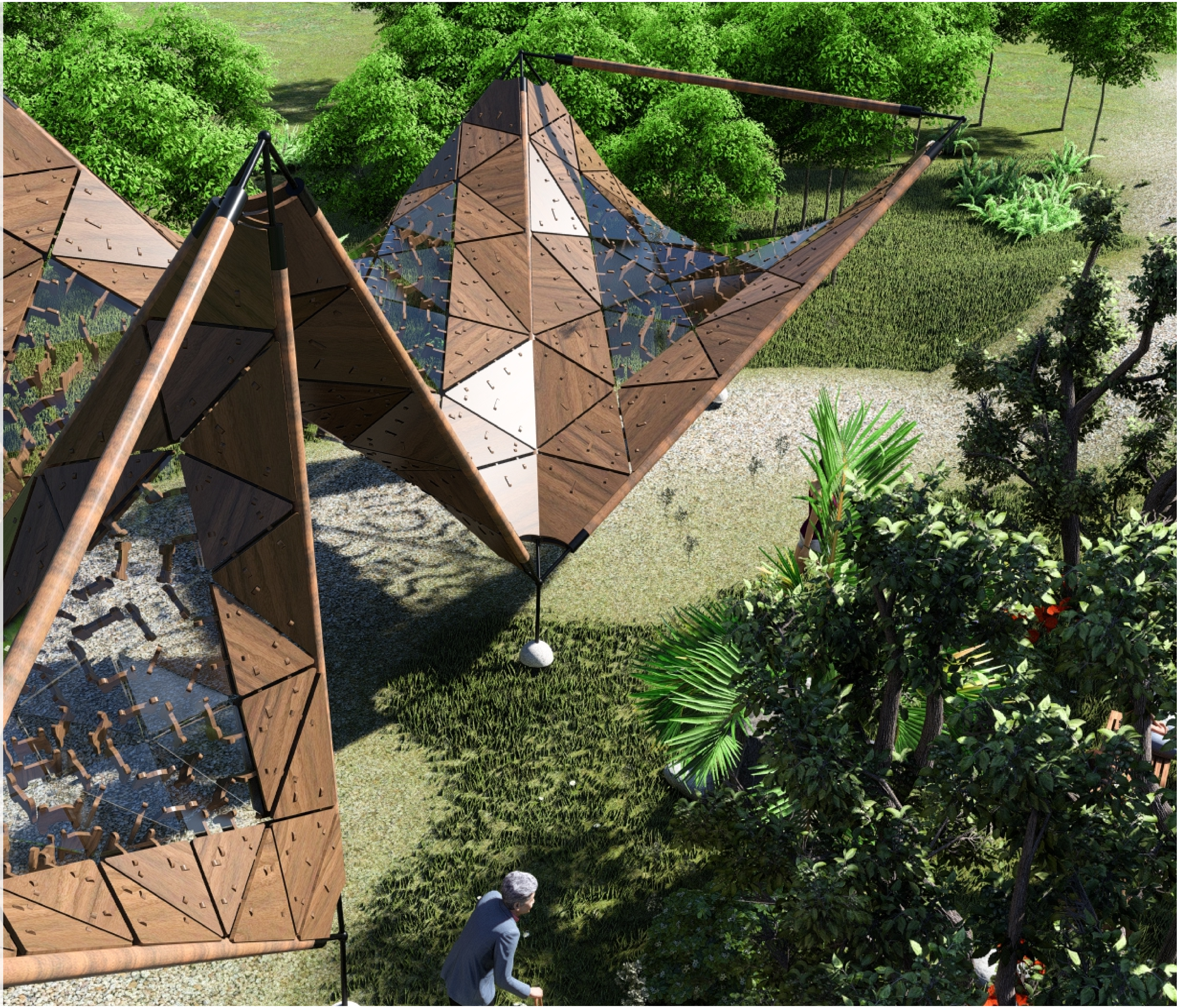
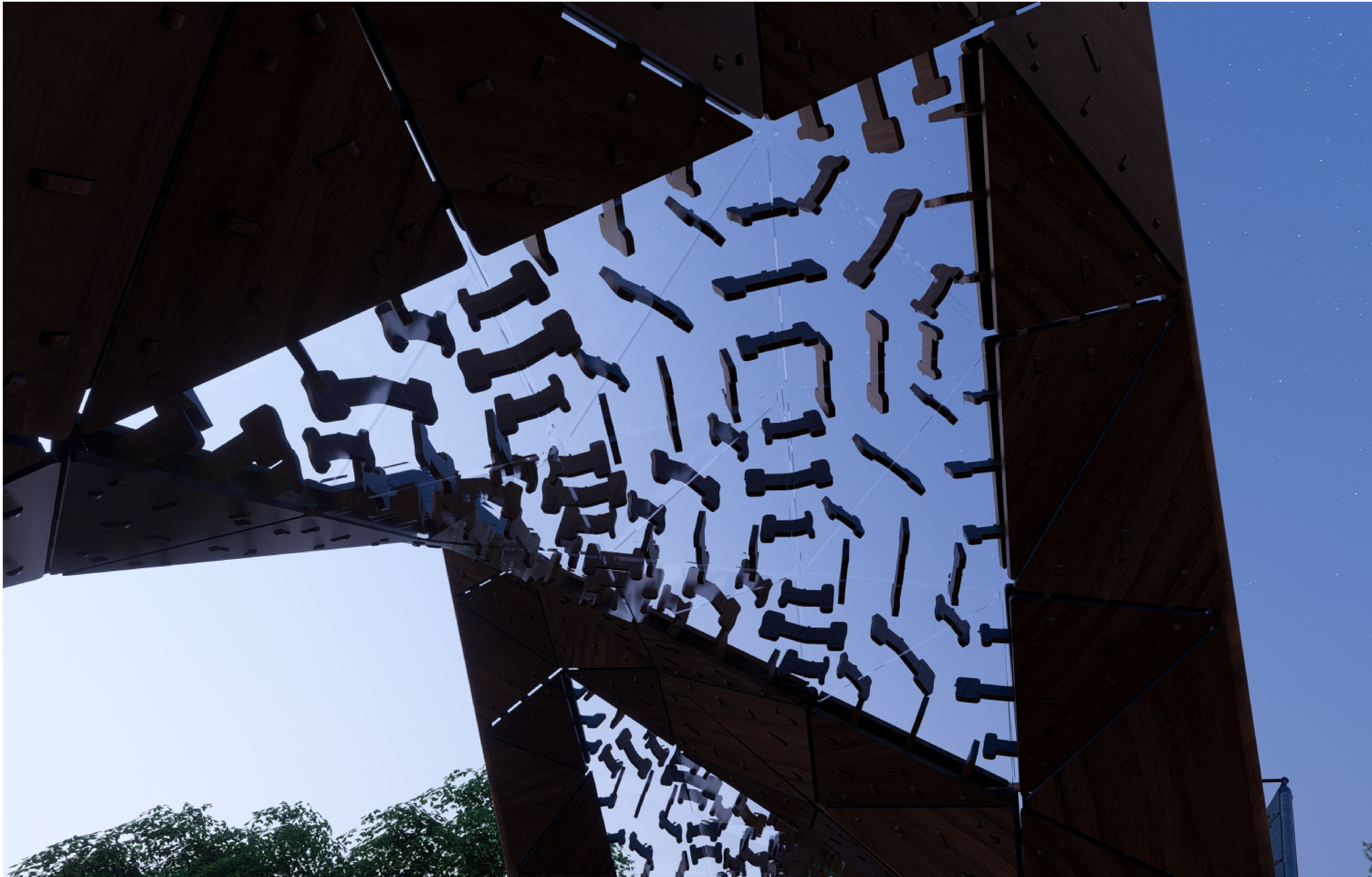


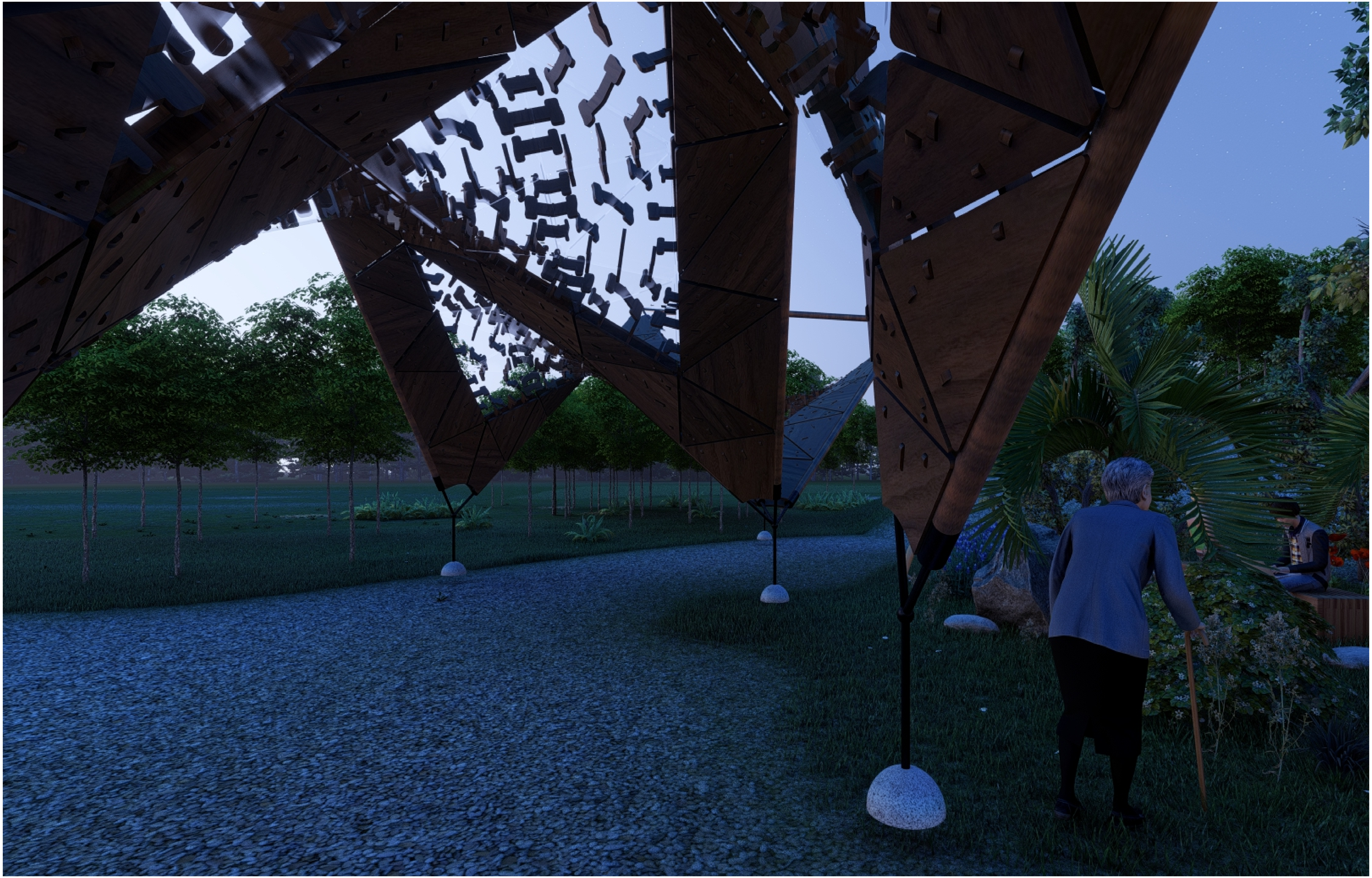
5 PM

The experience of the structure is centered around the location: the arboretum, where hundreds of native Californian species of plants are in full display. The arboretum is filled to the brim with student curated landscaping, which is the main focus of the location. Although novelty drives interest, the structure's purpose is to introduce students, family and friends alike to a hidden gem on Cal Poly campus. This is largely why the center of the roof is clear, to keep the surrounding environment on display. Additionally, a clear roof will exhibit the engineering of the double skinned shell (two layers of plexi-glass, separated by a wooden coupling).

Without the clear roof, the experience would be less powerful. A completely wooden roof creates shade in an area that does not require anymore shade. It cuts the view of the engineering along with the sky views. It also creates a division in the location where there should be easier flow. On a path, the wooden structure would create a blockage of flow since it's no longer open and clear. While there are some logistical concerns with a clear roof, the design intent behind the plexi-glass prevails against the alternative. Here are some logistical concerns: Maintenance is possible considering the gaps between panels and polarization to protect from UV.

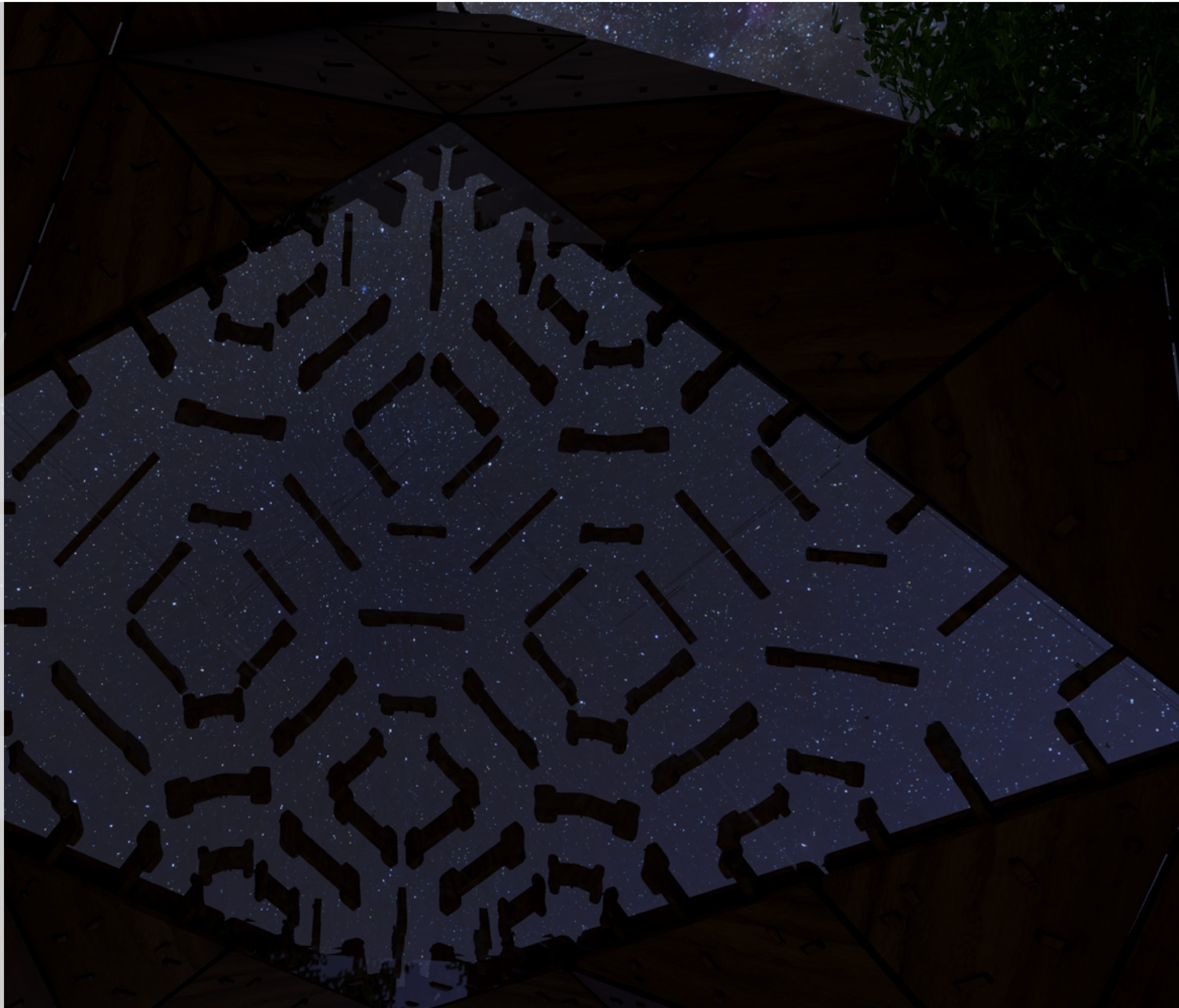




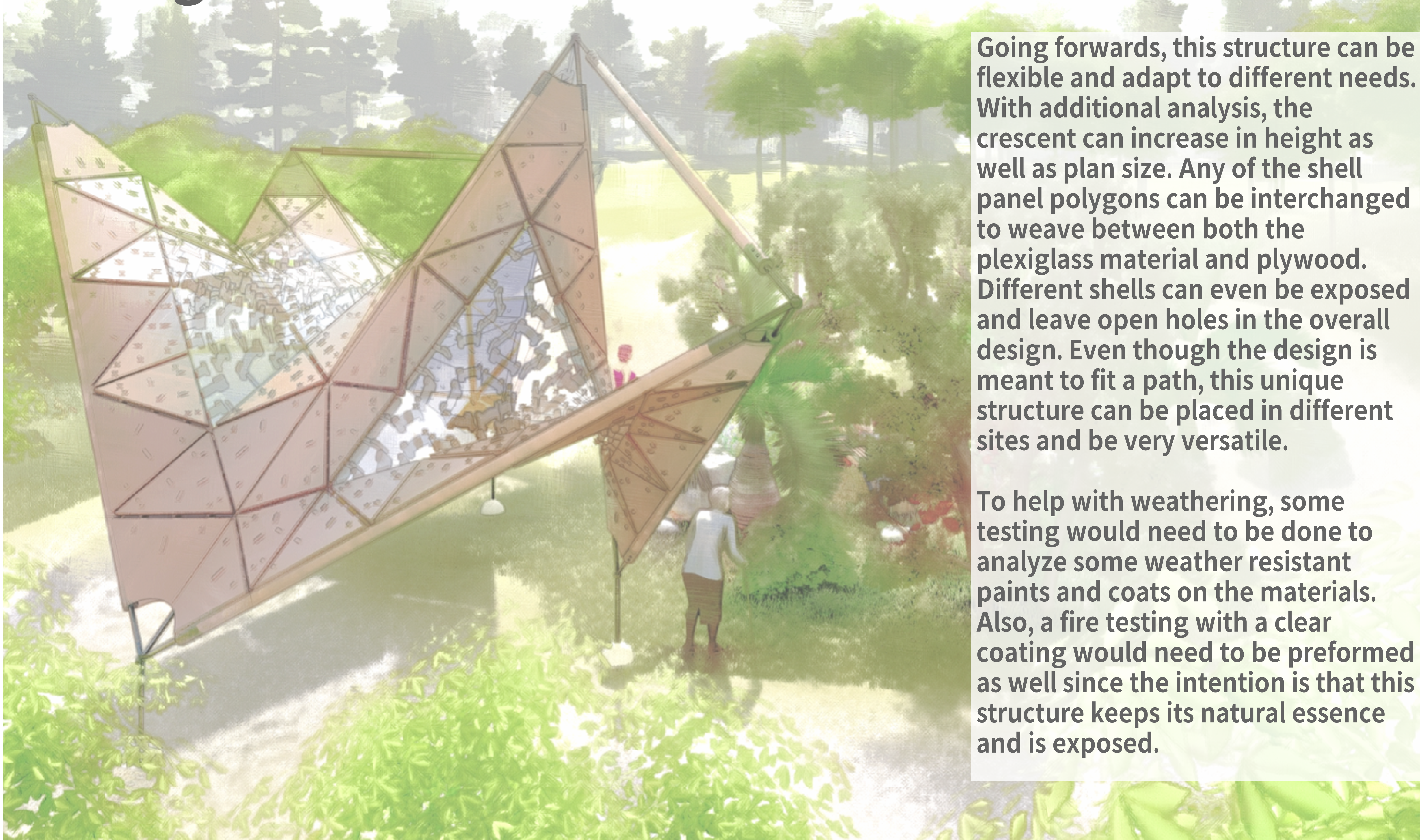


Over the course of the quarter, the design of the structure has had many variations, as seen in the design process. Through sun studies, site research and form making, our team settled on a more controversial idea. Although there are some concerns with a clear sun shade, there are also many benefits that swayed us towards the design we have today. Without the clear roof, the key component of the entire course would be hidden from view. The double shell is not just a means of constructibility, it's an engineering feat. Although our team did not code the Grasshopper script that made it possible to turn out hypars into tangible pieces of architecture, Nathan

Lundberg of Polyshell, LLC walked so that we could run. Using his script, it was the truly the main component of the entire project. Without it, realistic renders would not be possible. Having to figure out constructibility would also be another problem to tackle. All this to say that the clear roof is really a tribute to all the hard work that went into the previous renditions of the project. Is it the most practical of materials and the most useful of designs? No, but it does give credit where credit is due. It showcases the engineering in architectural engineering. Despite all the problems our team had to troubleshoot, the result has been fulfilling the proportional to the work.



looking towards the future



Going forwards, this structure can be flexible and adapt to different needs. With additional analysis, the crescent can increase in height as well as plan size. Any of the shell panel polygons can be interchanged to weave between both the plexiglass material and plywood. Different shells can even be exposed and leave open holes in the overall design. Even though the design is meant to fit a path, this unique structure can be placed in different sites and be very versatile.

To help with weathering, some testing would need to be done to analyze some weather resistant paints and coats on the materials. Also, a fire testing with a clear coating would need to be preformed as well since the intention is that this structure keeps its natural essence and is exposed.

broad view

Structures whether no one inhabits them, or a lot of people pass by them all are in contact with some part of the world. Every structure has been interacted with and the goal of this structure is to force this natural interaction. Using a design that curates an interactive experience addresses global concerns of a lack of cohesiveness which is present all around.

Surrounding and affecting every person are environmental concerns. There is a huge switch over to sustainable structures and everyone needs to hop on board. Creating more carbon-conscious structures is ideal and that what we have done. The crescent design promotes sustainable ingenuity by using mostly sustainable methods. This structure aims to intentionally source materials from companies that are apart of the initiative to get down to net zero. Infrastructure is the largest carbon emitting sector and it is our goal as future structural engineers to mitigate this and start learning about it early on.

reflection

Throughout the trials and tribulations associated with such a momentous task, we have all grown emotionally, physically and mentally. From the inception of “Le Croissant” to the moonlight gleam of “Crescent,” the studio was our playground where we practiced the prophesied, “Discipline and Play.” With our engineering prowess and our lowercase “a” architecture, we were able to create something truly remarkable, enough so to even show our progeny. No wind, no earthquake, no rain, and even no frat boy can topple this xenaform, the only thing to stand against it was our own ambitions. To be a part of this glimpse in the ARCE time line was not only a joy but a pleasure, to see such great creations spawn out of thin air in a little studio was nothing but awe-inspiring and it is this creative mindset that will shape our very future in this world. There is no doubt that this studio will go down as one of the most revolutionary studios in ARCE 415 history and to put a stamp on it is enough…even for Crescent.

cresent