POLARIS

ANDY DO • DENNISE MANALO • EMILIO LOZANO • MACKENZIE STICKNEY
PROF. ED SALIKLIS • PROF. ANSGAR KILLING
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First Edition

This project is dedicated to our wonderful professors, Ed Saliklis and Ansgar Killing, who we owe mostly everything to.

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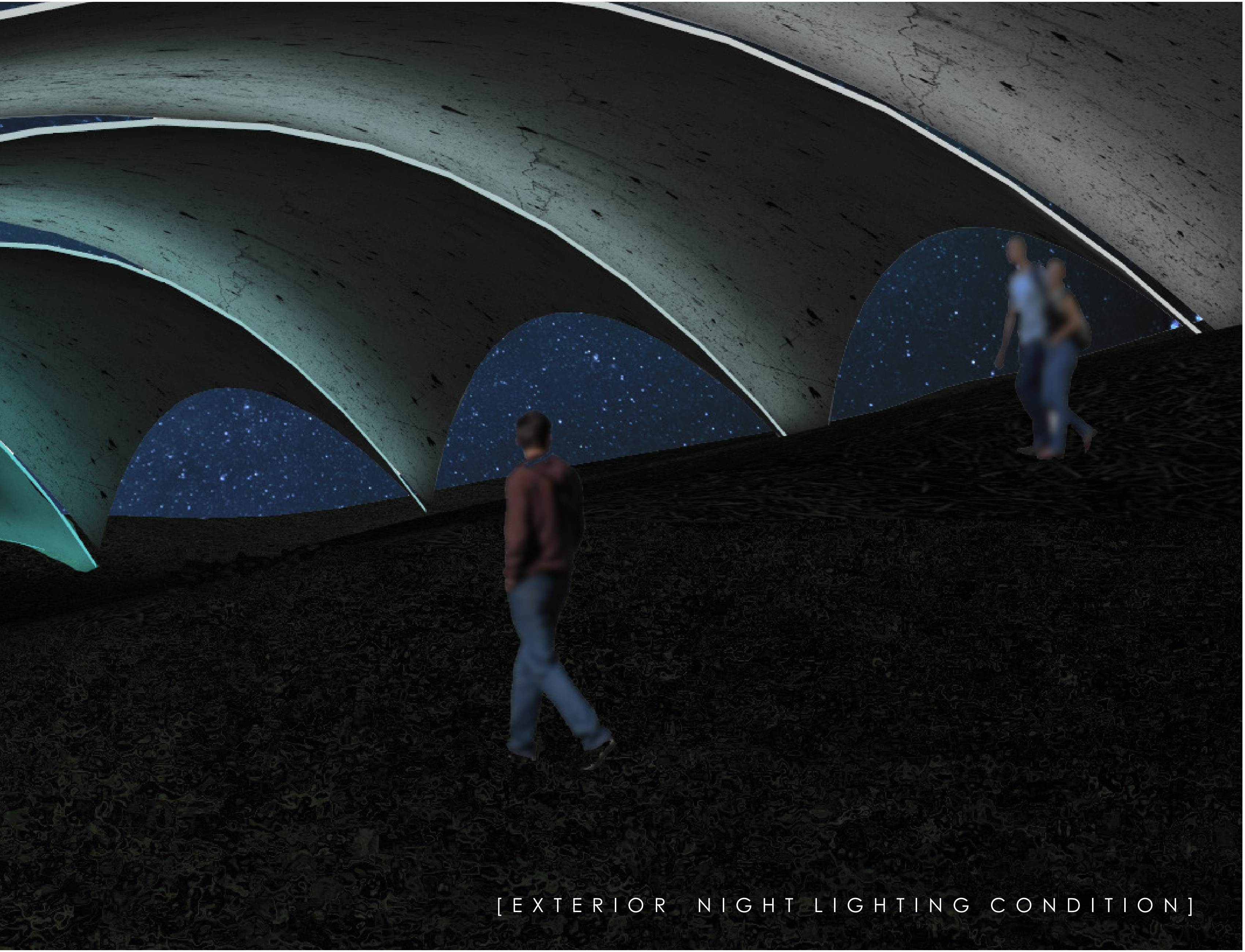
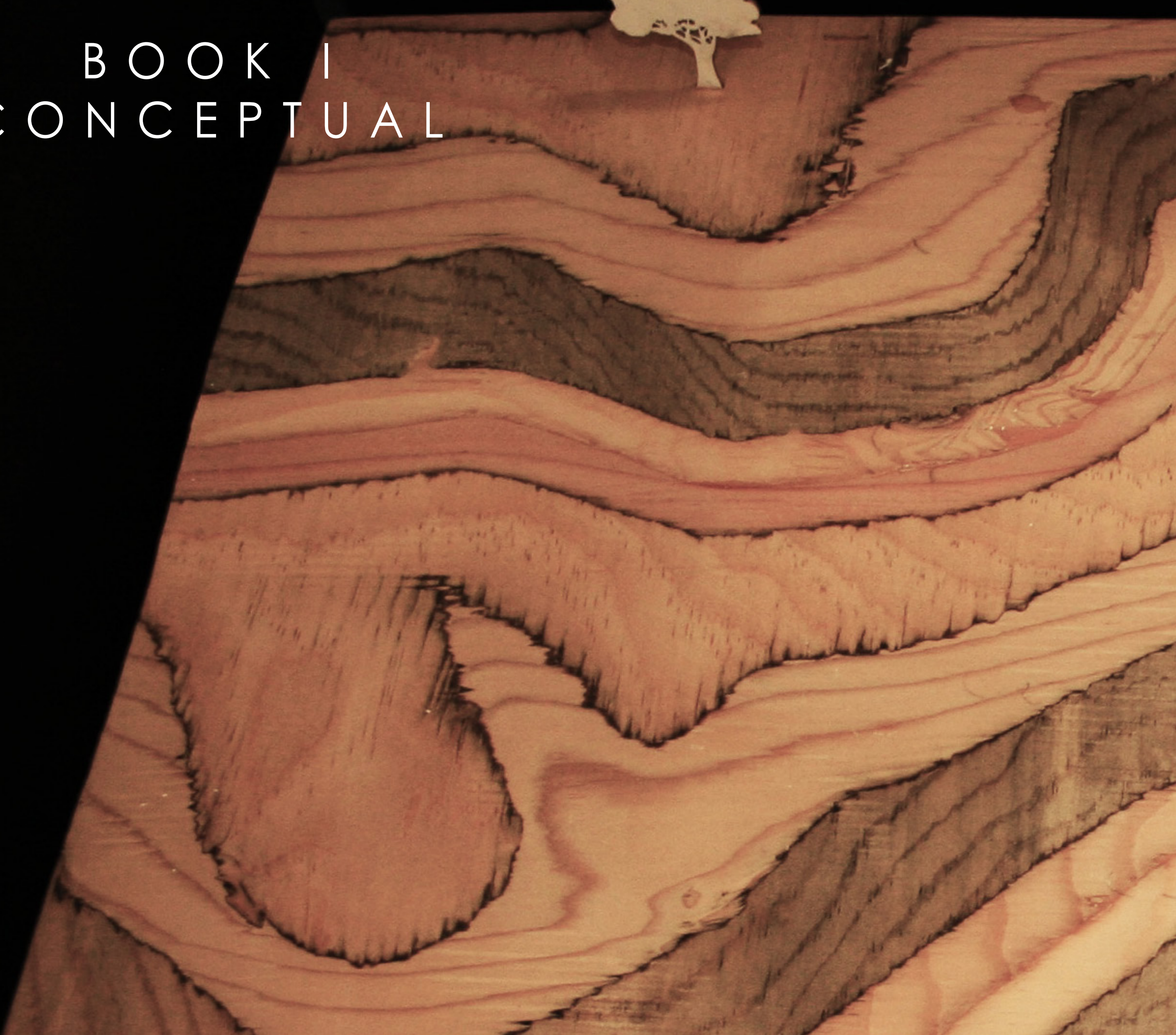
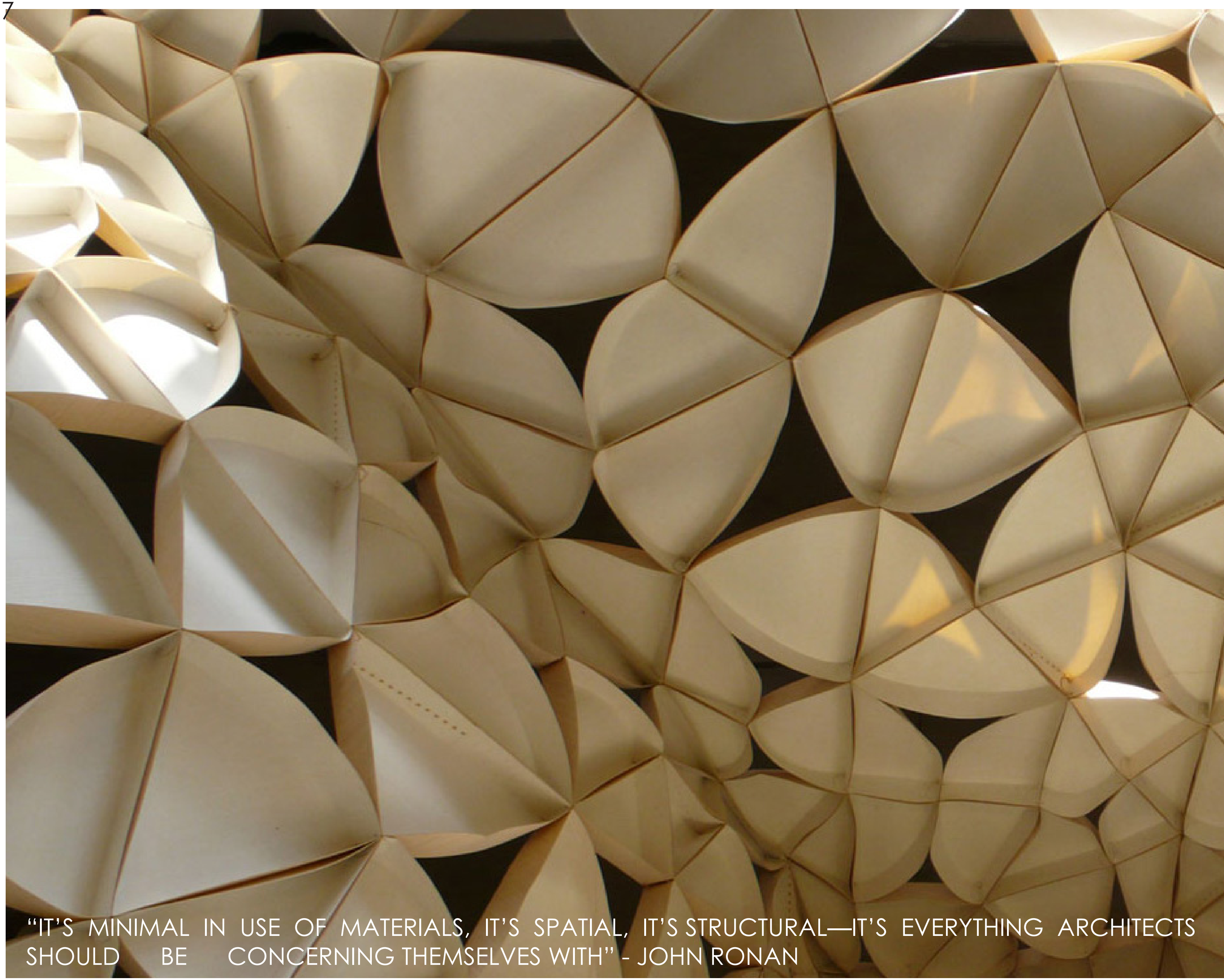


[EXTERIOR NIGHT LIGHTING CONDITION]

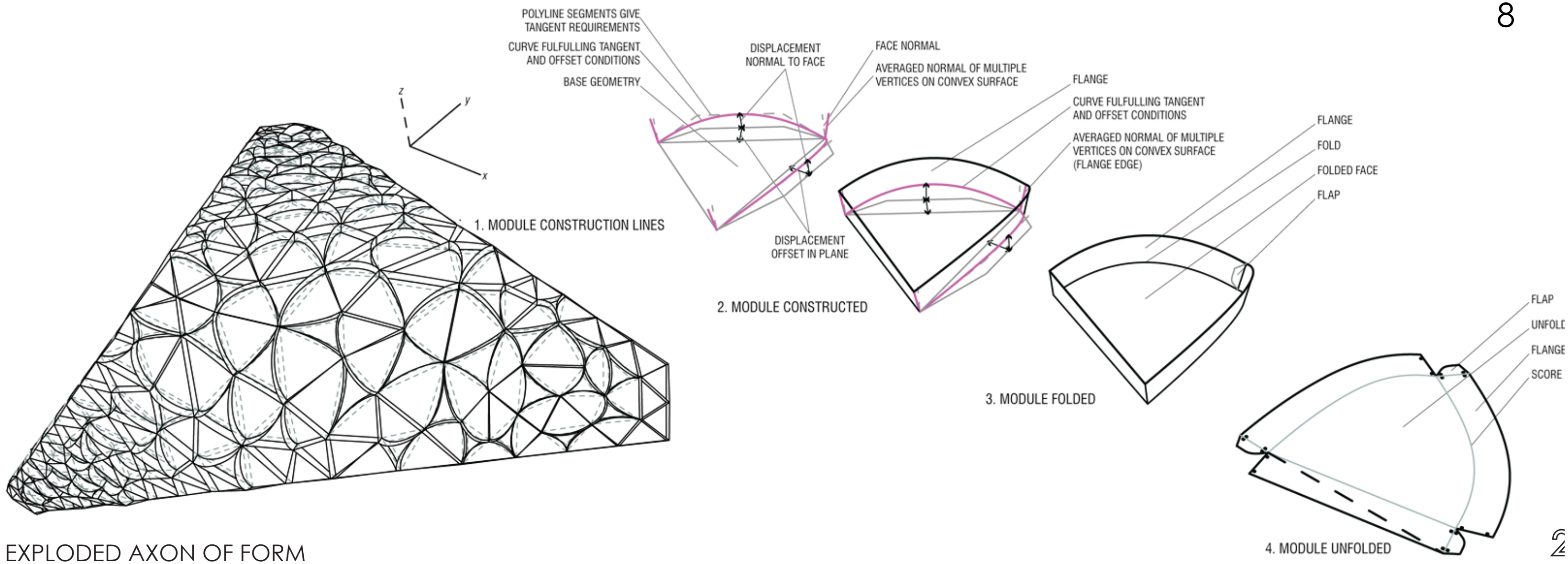
BOOK I
CONCEPTUAL



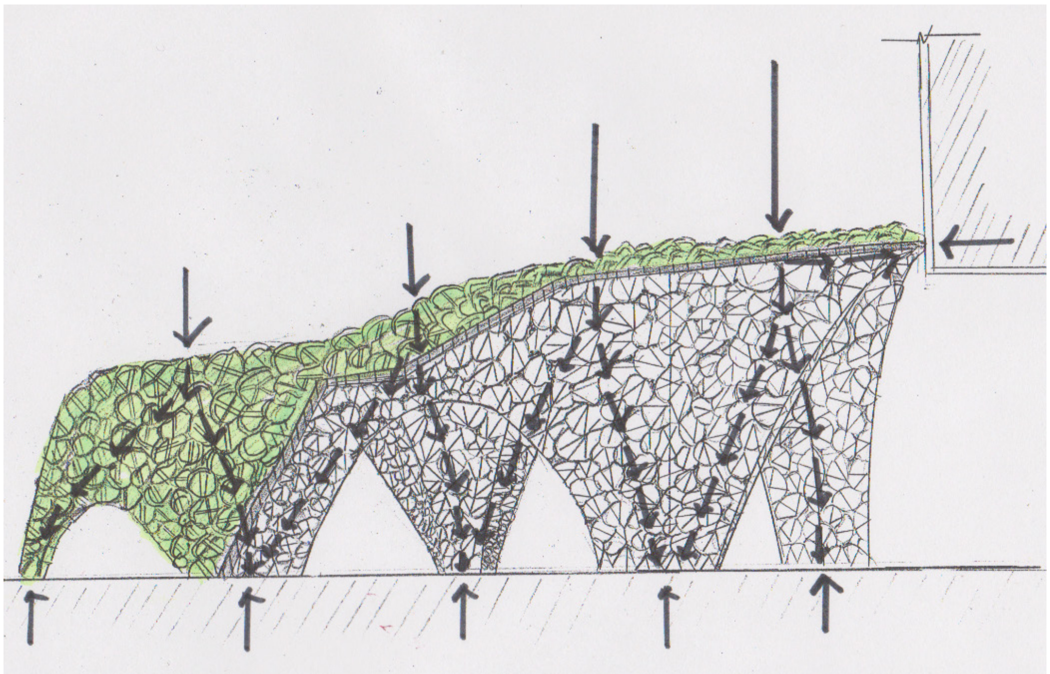
PHYSICAL MODEL PLAN VIEW



"IT'S MINIMAL IN USE OF MATERIALS, IT'S SPATIAL, IT'S STRUCTURAL—IT'S EVERYTHING ARCHITECTS SHOULD BE CONCERNING THEMSELVES WITH" - JOHN RONAN

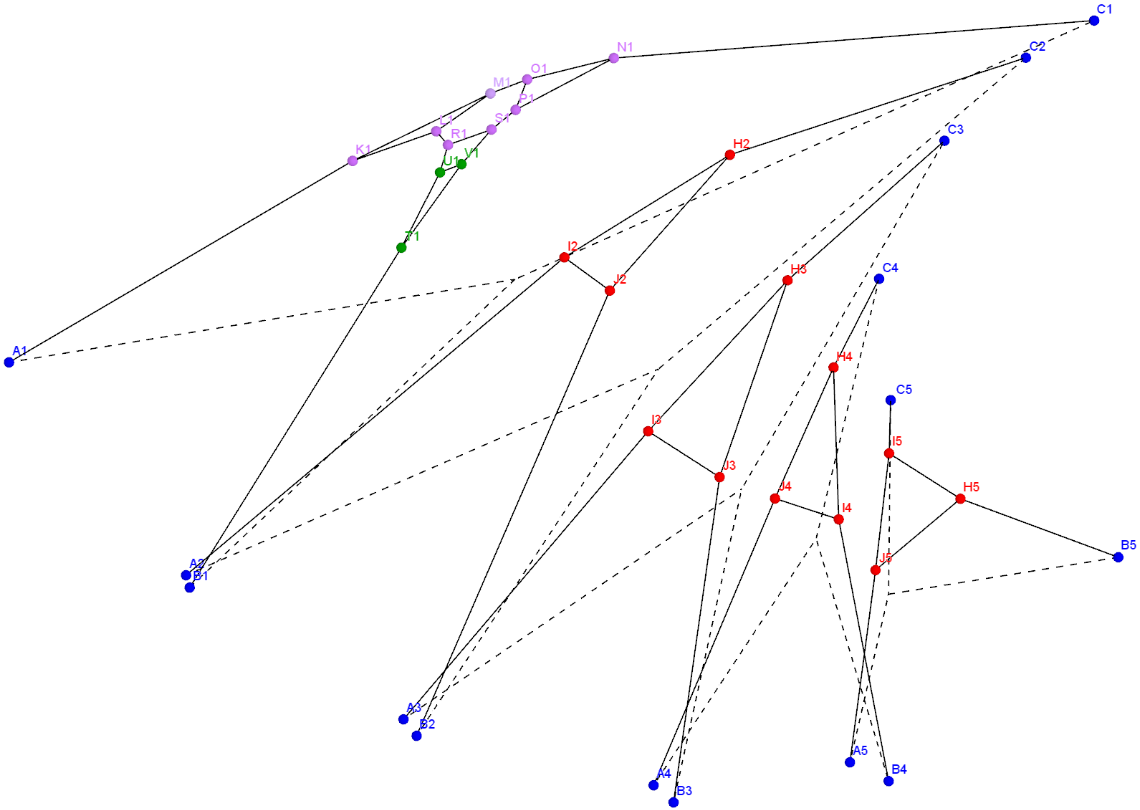


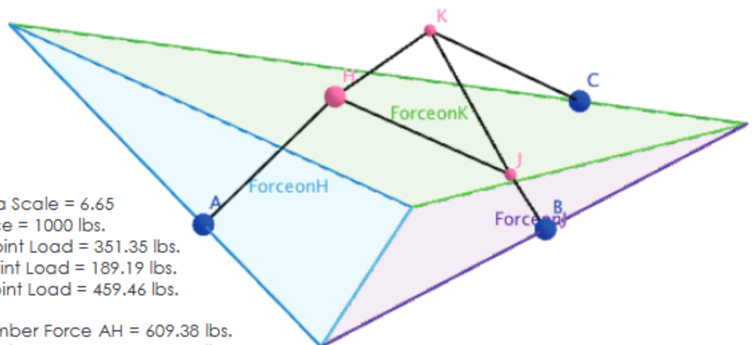
EXPLODED AXON OF FORM



VOUSSOIR CLOUD

This project by Iwamotoscott was deisgned for the SciArc gallery in Los Angeles as a site specific architecural instalation. The design itself sought to combine the contrasting construction logics of pure compression shell structures and thin lightweight sheets. The result was an incredibly light system of wood laminate vaults with a porous shell.





Area Scale = 6.65
Force = 1000 lbs.
H Point Load = 351.35 lbs.
J Point Load = 189.19 lbs.
K Point Load = 459.46 lbs.

Member Force AH = 609.38 lbs.
Member Force BJ = 557.71 lbs.
Member Force CK = 358.01 lbs.
Member Force HJ = 206.95 lbs.
Member Force HK = 323.20 lbs.
Member Force KJ = 244.64 lbs.

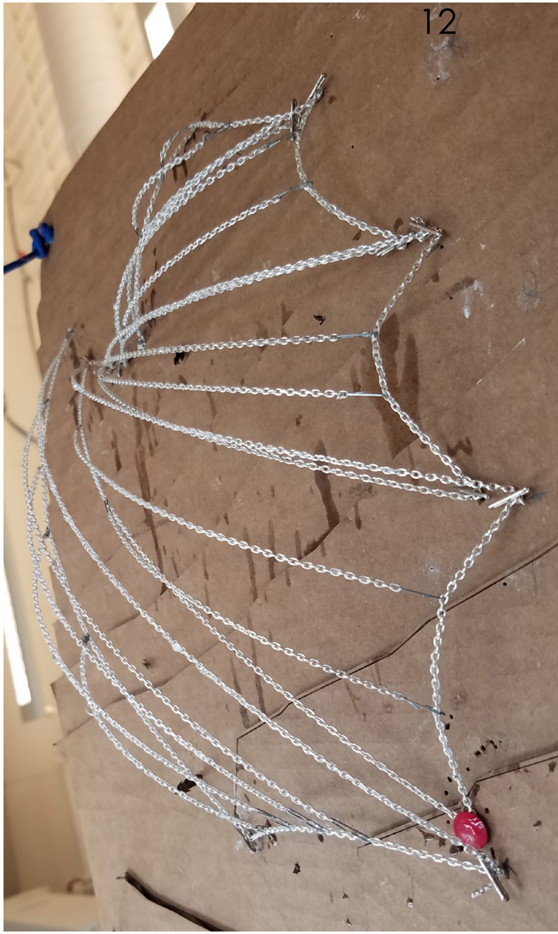
G E O G E B R A

The architectural form was explored with engineering principles in Geogebra. This three strut exploration was critical in understanging the engineering behind a funicular shell as well as options about design

COMPLETED WOODEN STICK MODEL

HANGING CHAIN

Chains were cut to length using Geogebra guidlines, attached by pinchin the chains. Alluminum round bars were cut proportionately to the forces calculated in that strut using Risa and Robot. These bars were attached using rings



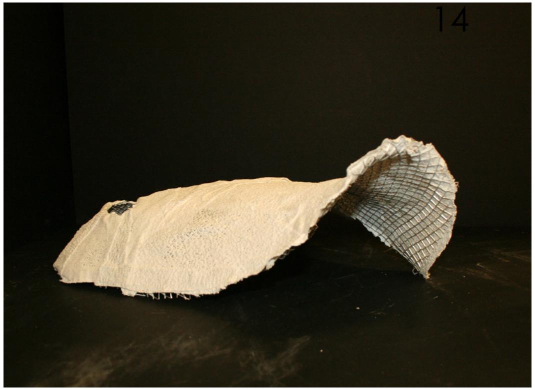
COMPLETED HANGING CHAIN MODEL

FORM FINDING MODEL 1

FORM FOUND

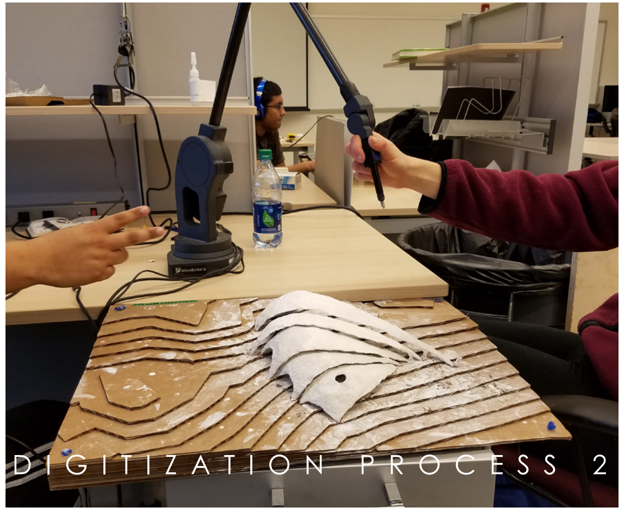
The form was found by taking one funicular shell, replicating and scaling it down four times and, then twisting around an axis. Not only were we inspired by biomimicry, but our shells rotate around an axis as Ursa Minor rotates around Polaris.






F O R M   F I N D I N G   M O D E L   2

DIGITIZATION PROCESS 1



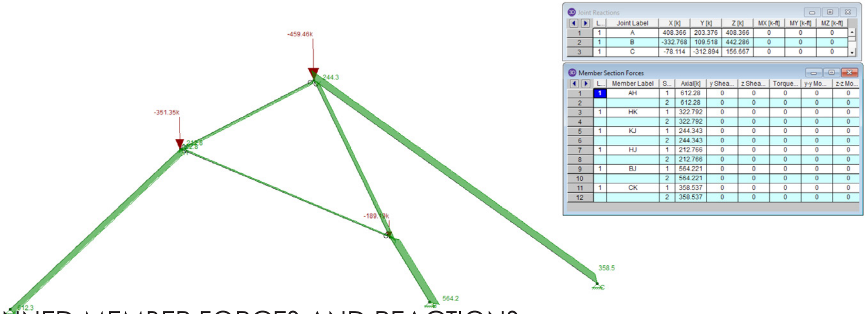
DIGITIZATION PROCESS 2

D I G I T I Z I N G

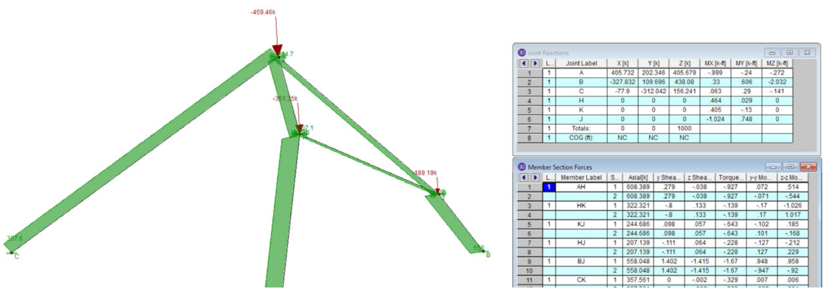
The physical model was digitized twice. The first time, we digitized our hanging chain model. The second time, we digitized our hanging fabric model. The digitizer automatically put our form in Rhino. From Rhino, the model was exported into AutoCad and then to SAP2000.

DIGITIZATION PROCESS 3

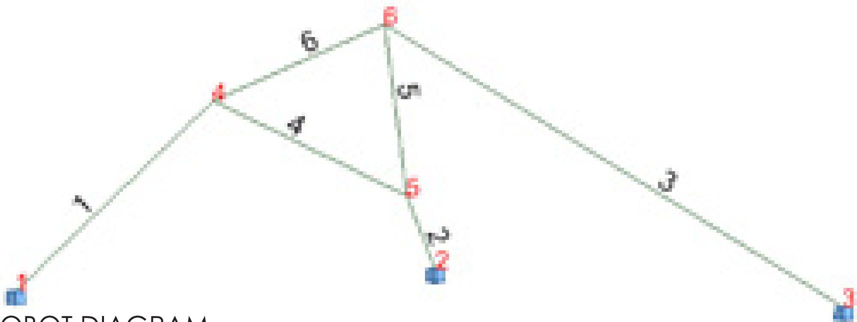
RISA AND ROBOT ANALYSIS - GRAVITY



PINNED MEMBER FORCES AND REACTIONS



MOMENT CARRYING MEMBER FORCES AND REACTIONS

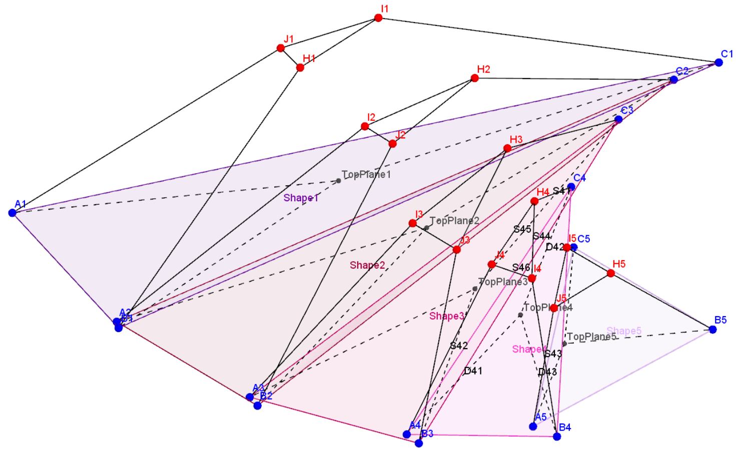


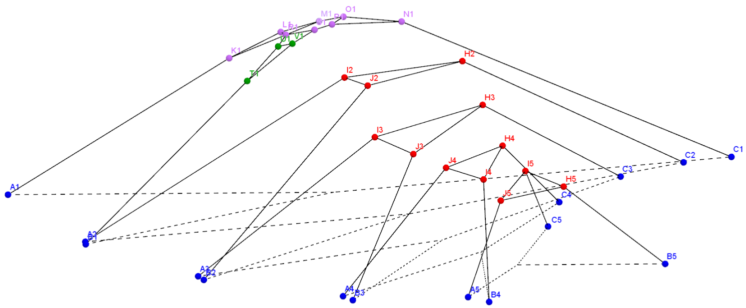
ROBOT DIAGRAM

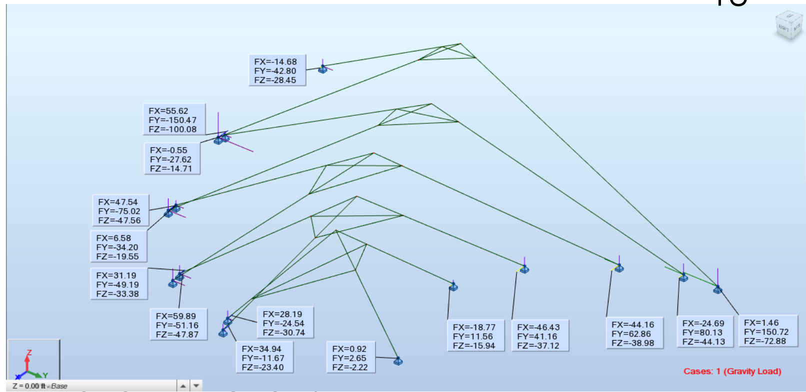
Bar/Node/Case			FX (kip)
1/	1/	1	0.60
1/	1/	2 (C)	0.60
1/	4/	1	0.60
1/	4/	2 (C)	0.60
2/	2/	1	0.56
2/	2/	2 (C)	0.56
2/	5/	1	0.56
2/	5/	2 (C)	0.56
3/	3/	1	0.35
3/	3/	2 (C)	0.35
3/	6/	1	0.35
3/	6/	2 (C)	0.35
4/	4/	1	0.20
4/	4/	2 (C)	0.20
4/	5/	1	0.20
4/	5/	2 (C)	0.20
5/	6/	1	0.25
5/	6/	2 (C)	0.25
5/	5/	1	0.25
5/	5/	2 (C)	0.25
6/	6/	1	0.32
6/	6/	2 (C)	0.32
6/	4/	1	0.32
6/	4/	2 (C)	0.32

Bar/Node/Case			FX (kip)
1/	1/	1	0.60
1/	1/	2 (C)	0.60
1/	4/	1	0.60
1/	4/	2 (C)	0.60
2/	2/	1	0.56
2/	2/	2 (C)	0.56
2/	5/	1	0.56
2/	5/	2 (C)	0.56
3/	3/	1	0.35
3/	3/	2 (C)	0.35
3/	6/	1	0.35
3/	6/	2 (C)	0.35
4/	4/	1	0.20
4/	4/	2 (C)	0.20
4/	5/	1	0.20
4/	5/	2 (C)	0.20
5/	6/	1	0.25
5/	6/	2 (C)	0.25
5/	5/	1	0.25
5/	5/	2 (C)	0.25
6/	6/	1	0.32
6/	6/	2 (C)	0.32
6/	4/	1	0.32
6/	4/	2 (C)	0.32

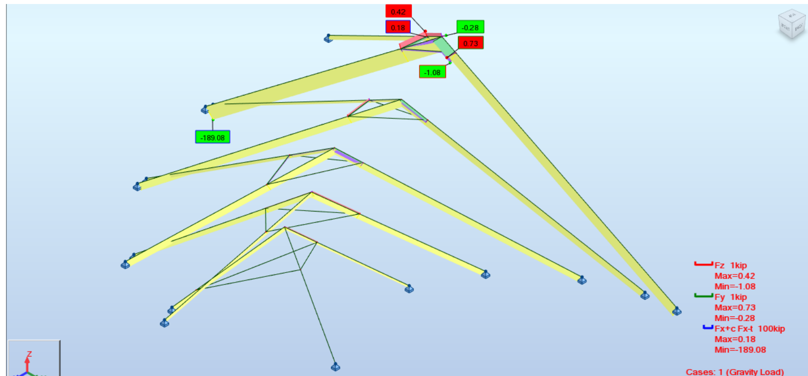
PINNED MEMBER FORCES AND REACTIONS (LEFT)
MOMENT CARRYING MEMBER FORCES AND REAC-
TIONS (RIGHT)





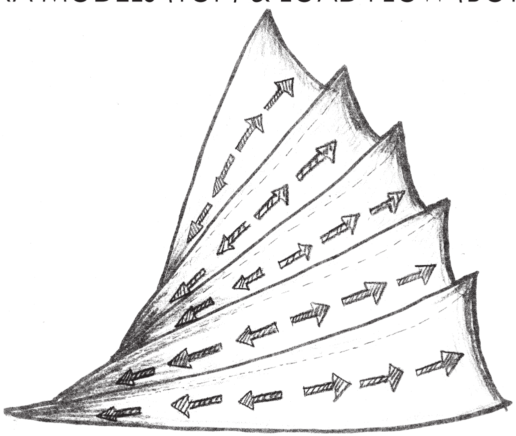


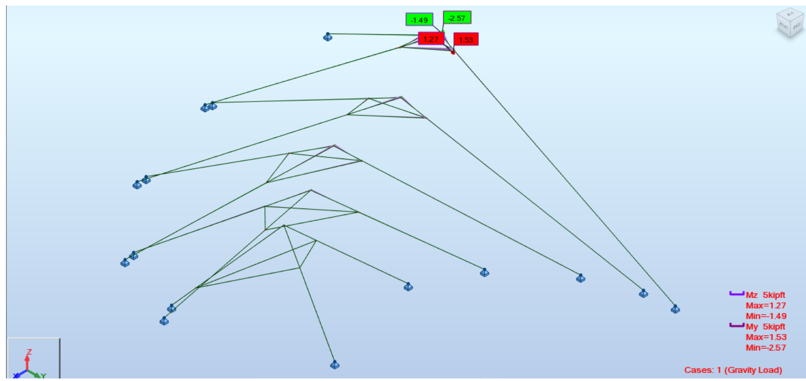
ROBOT: REACTIONS



GEOGEBRA MODELS (TOP) & LOAD FLOW (BOTTOM)

ROBOT: MAX FORCES IN SHELLS

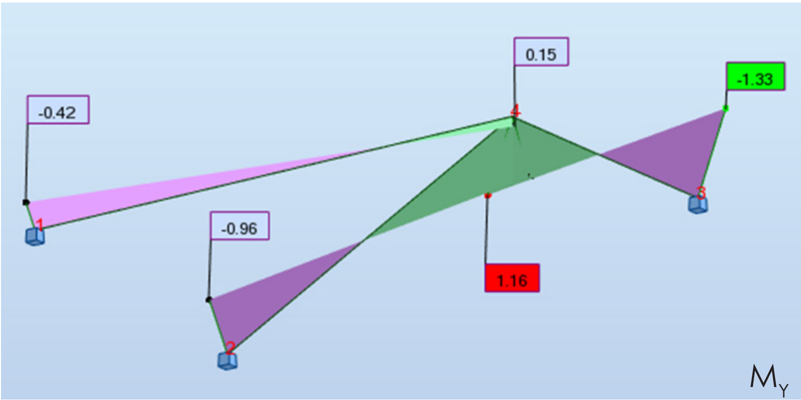


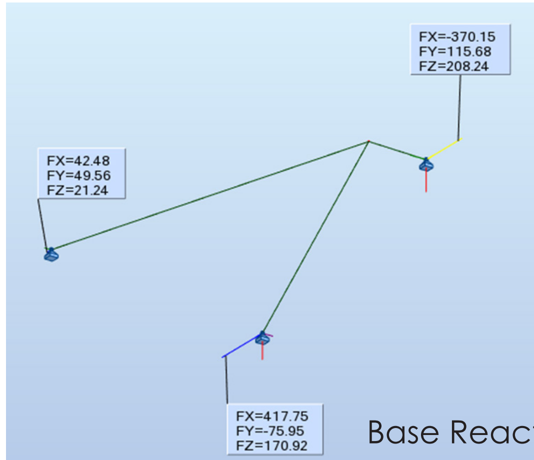


ROBOT: MAX MOMENTS IN SHELLS

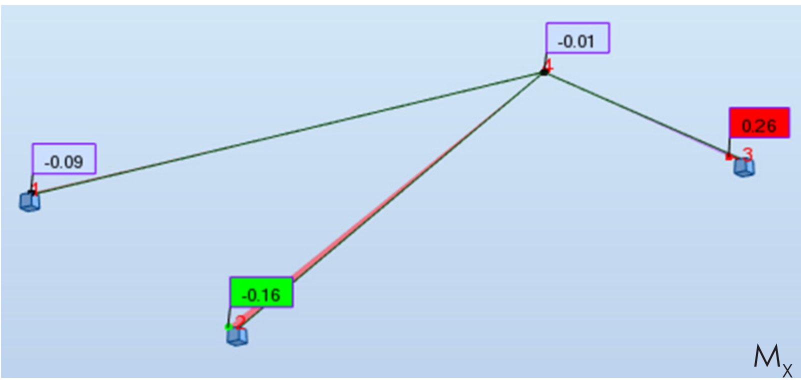
Shell Information:
Surface Area: 7,960 sq. ft.
Uniform Shell Thickness: 4”
Estimate Weight of Shell using Normal Weight Concrete: 400 kips
Lateral Load: 20% of Estimated Weight of Shell

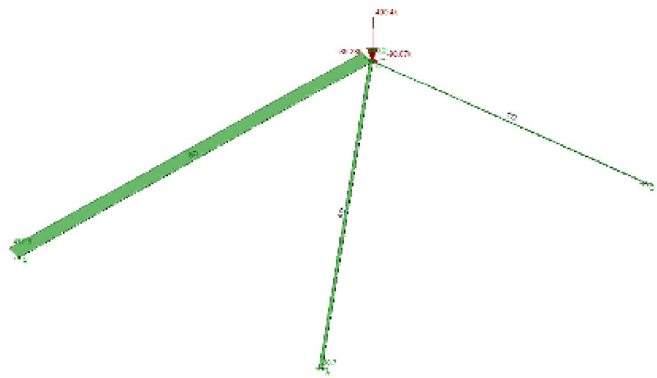
SUMMARY OF RESULTS						
Members	RISA (LBS)			ROBOT (LBS)		
	X	Y	Z	X	Y	Z
A	43	50	22	418	76	171
B	418	-76	171	43	50	22
C	-370	116	209	370	116	209





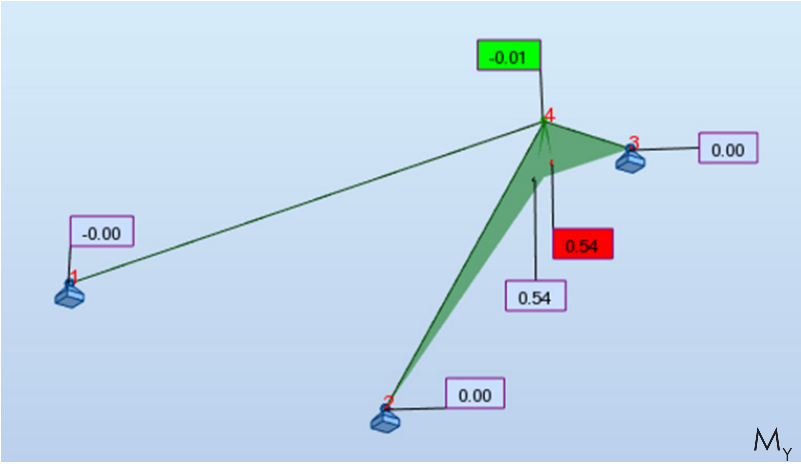
Base Reactions

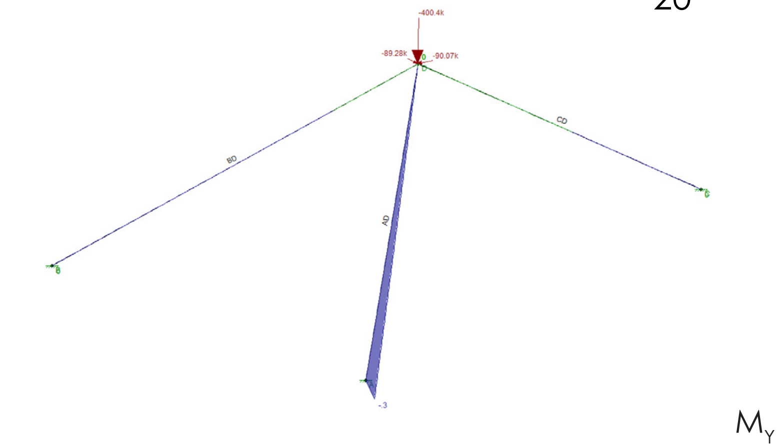


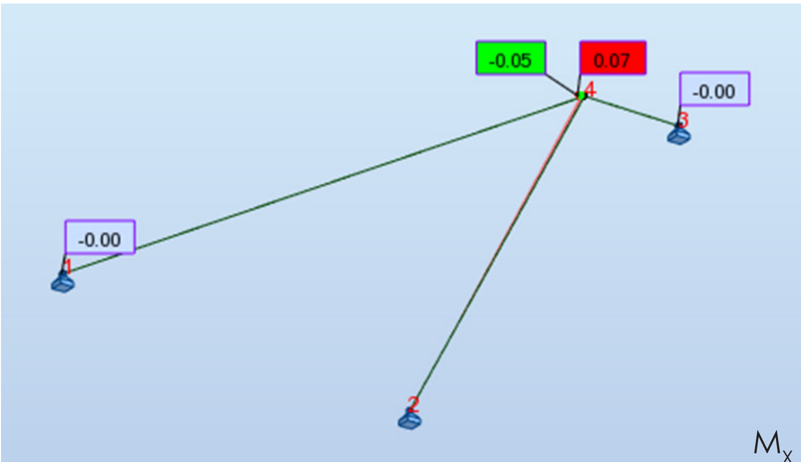


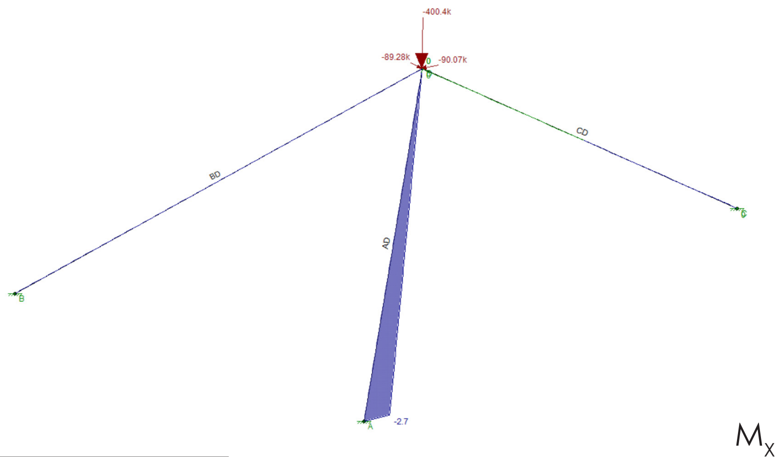
PINNED MEMBER FORCES AND REACTIONS
ROBOT (LEFT) AND RISA (RIGHT)

LATERAL ANALYSIS



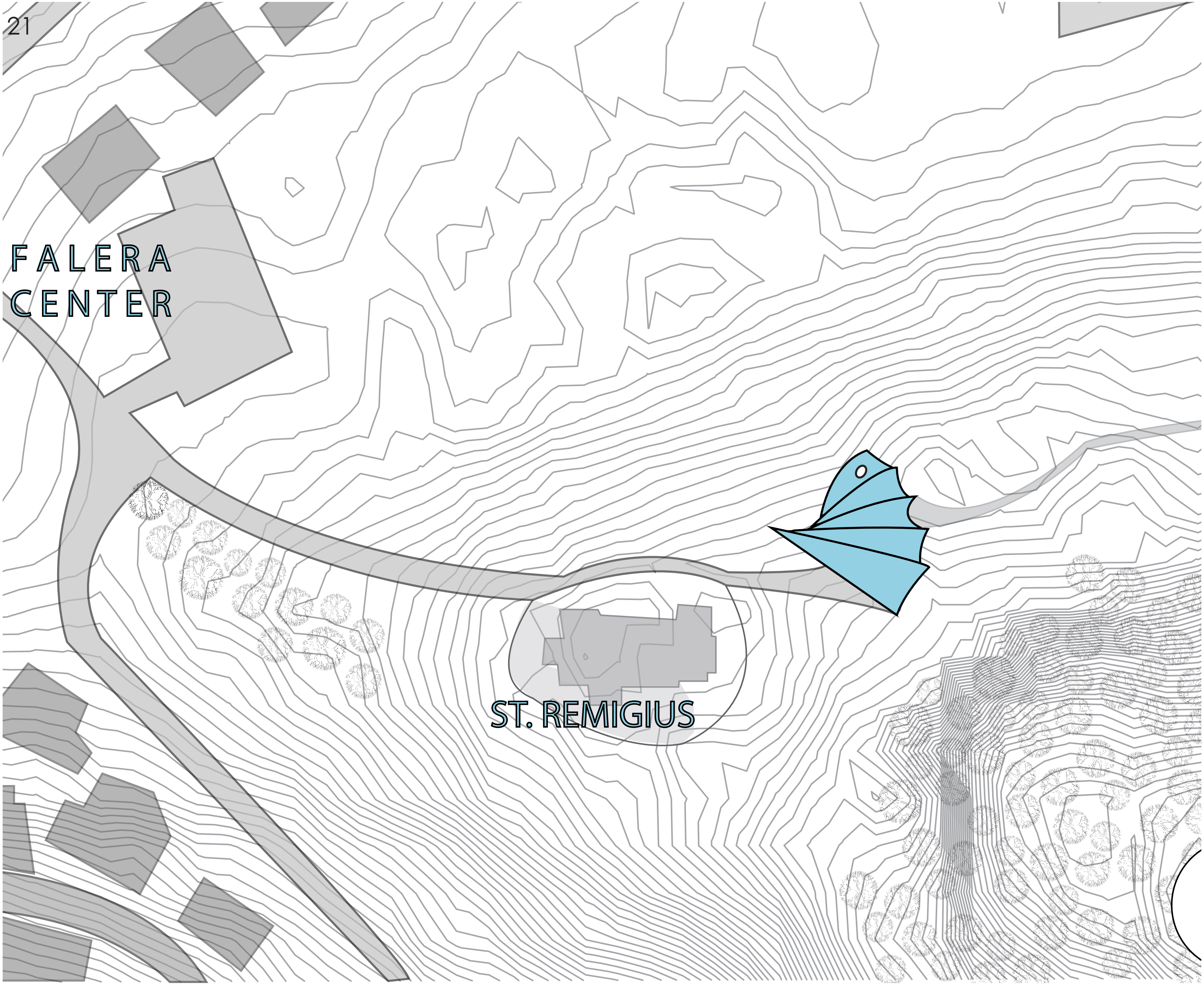






SUMMARY OF RESULTS						
Members	RISA			ROBOT		
	Axial(lbs)	My(lb-ft)	Mz(lb-ft)	Axial (lbs)	My(lb-ft)	Mz(lb-ft)
AD	68.7	-0.28	-2.72	68.6	0.01	0.01
BD	457.6	0	0	457.7	0.54	0.05
CD	440.2	0	0	440.2	0.54	0.07

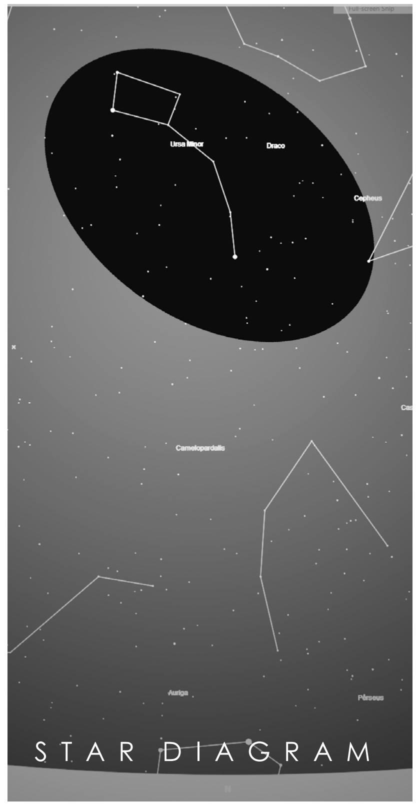
MOMENT CARRYING MEMBER FORCES AND REACTIONS
ROBOT (LEFT) AND RISA (RIGHT)

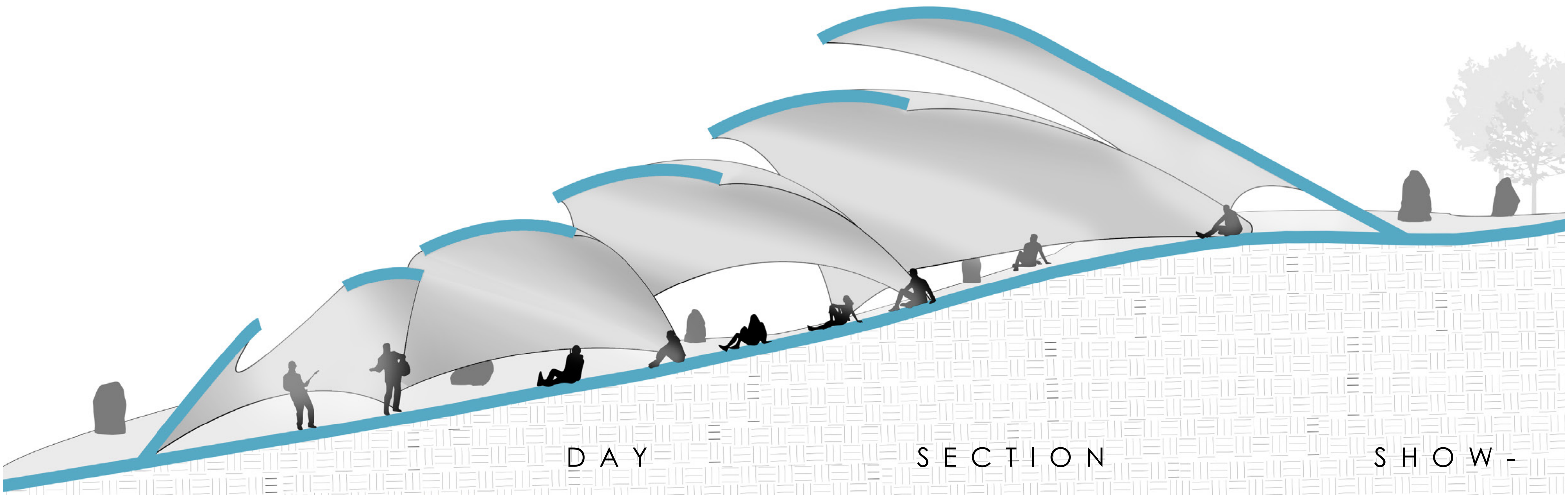

FALERA
CENTER
ST. REMIGIUS

Our site was located in Parc La Mutta, Switzerland, a Celtic astrological viewing site dating back to the Middle Bronze Age. Polaris is an astrological viewing site for the modern era that honors the Celtic standing stones on site. Physically, our shells keep a low profile on the cherished landscape; no shell is over 30’, and our footprint is 6400 ft^2. Our oculus points to the most important Northern constellation to the Celtics, Ursa Minor or “The Lesser Bear”.

Polaris not only accommodates the viewing of the night sky, but also daytime and nighttime live music performances. The curvature and placements of the shells work as an amphitheater, and the ground slopes down to work with the shell for natural seating.

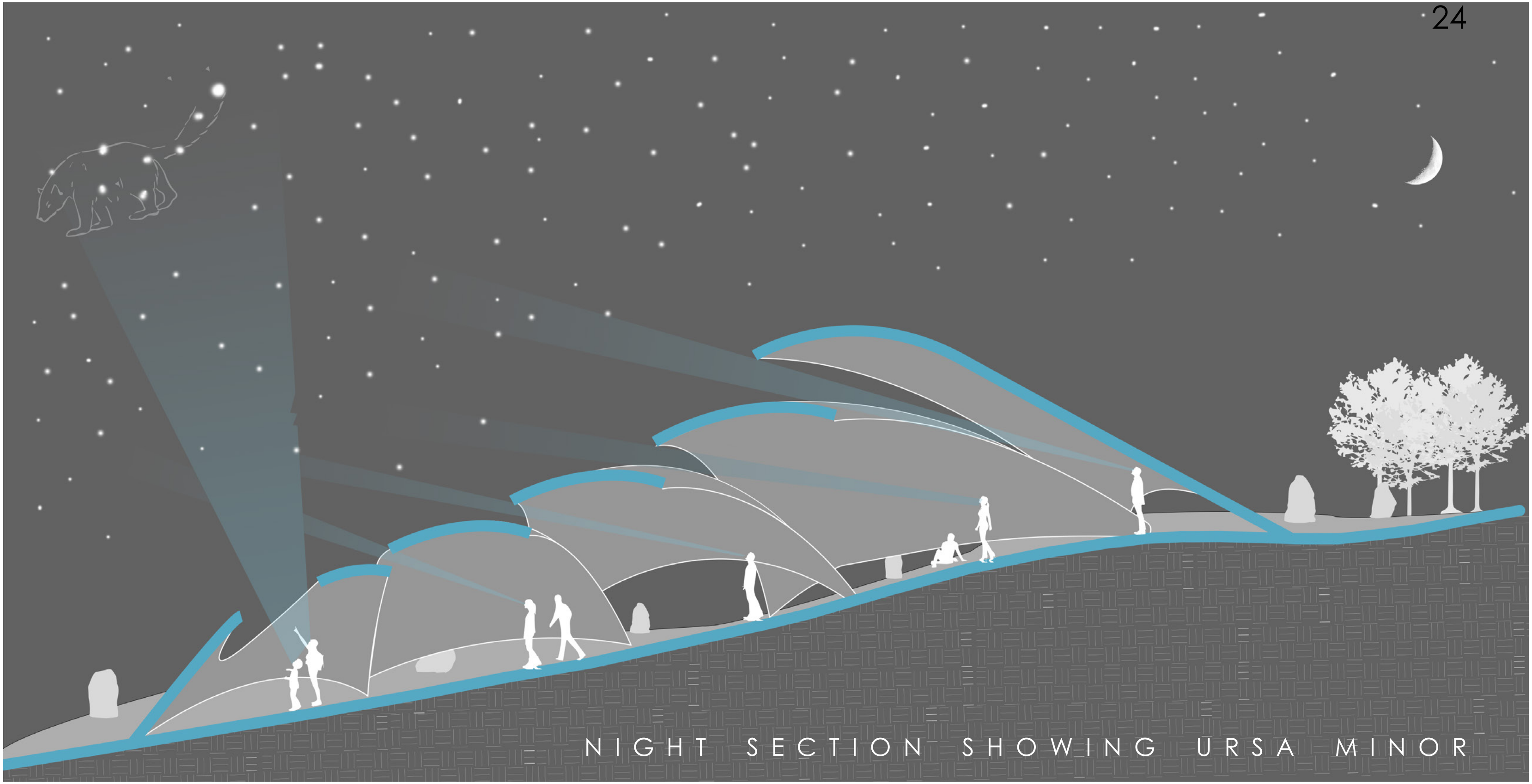
Plan view with site context, access points, functional area and main view axis.

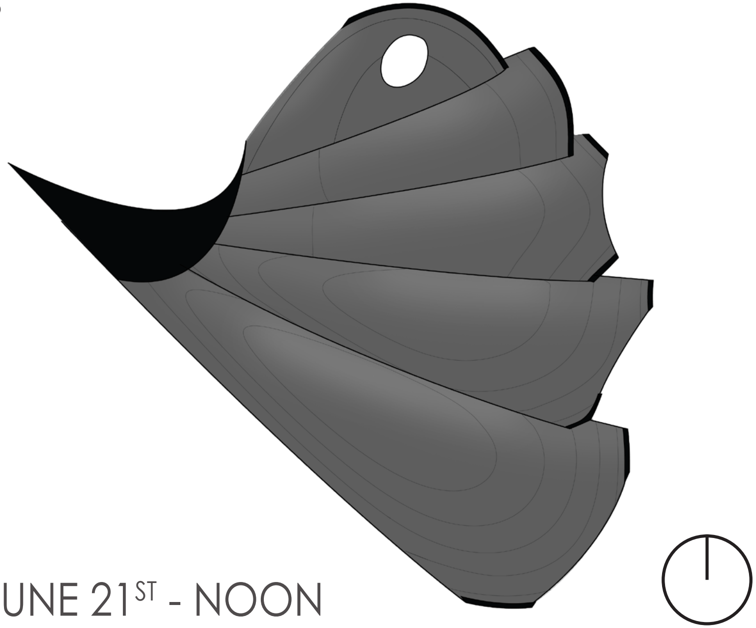




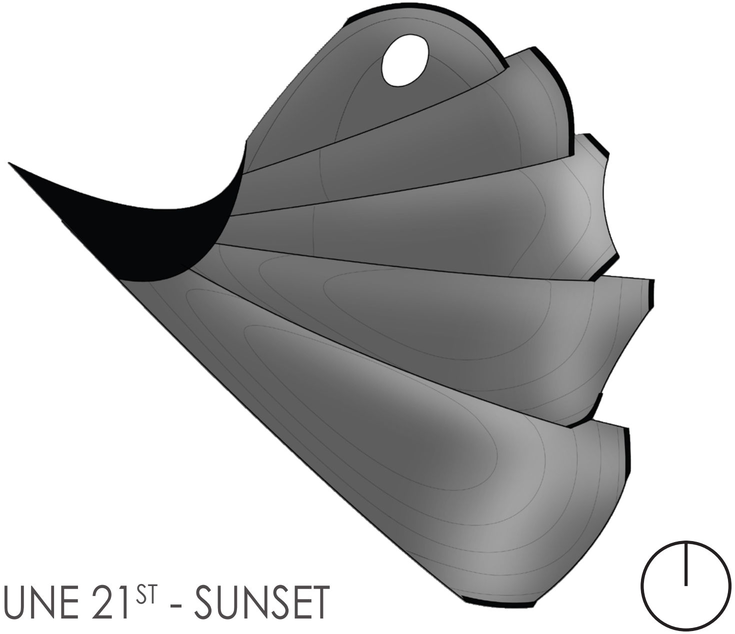
DAY & NIGHT SECTIONS

The daytime section (left) shows how soft ambient Northern light links into the space. It also shows how the curvature of the shells accompanied by the gentle slopping of the hills makes a natrual performance space. Light from the occulus highlights the performers. The nightime section (right) shows views to Ursa minor and glimspses to the stars as you progress through the space

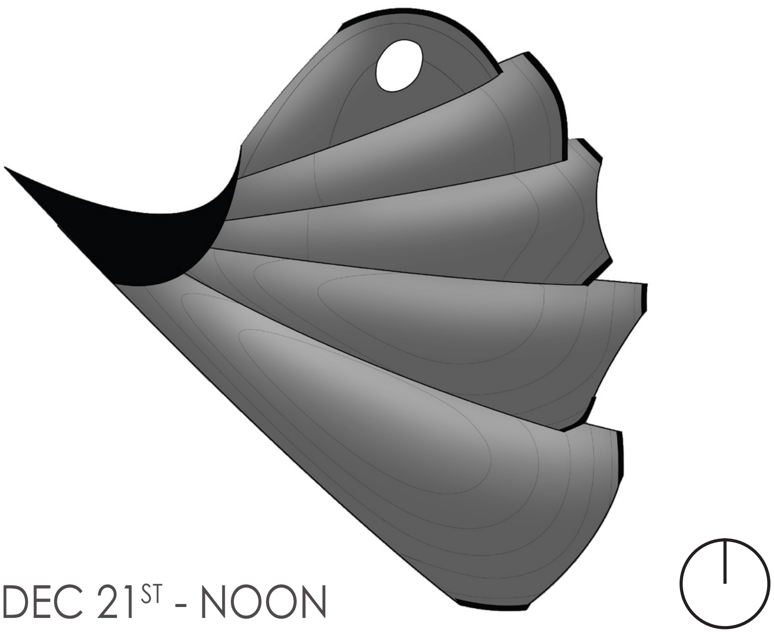

NIGHT SECTION SHOWING URSA MINOR



JUNE 21ST - NOON



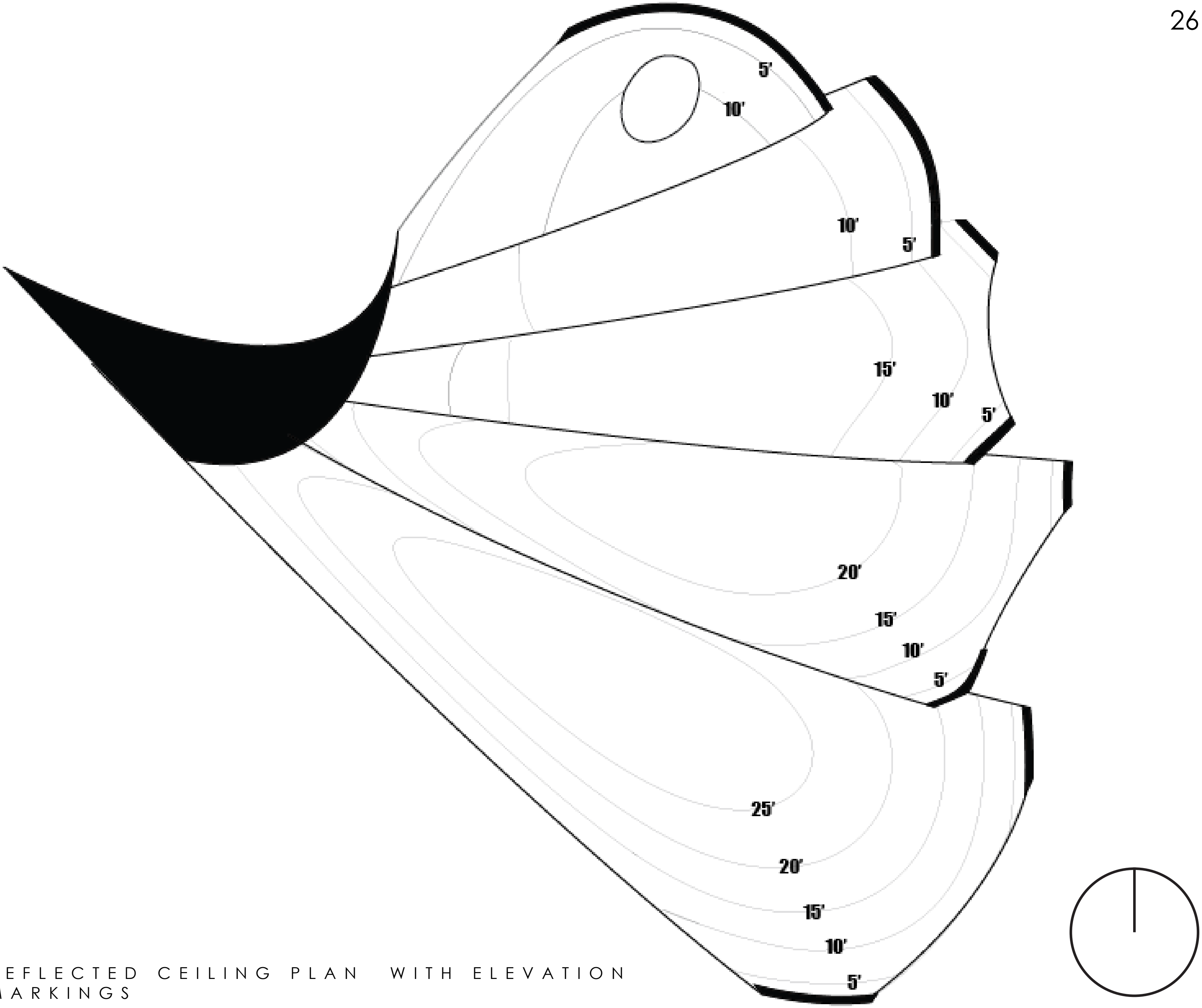
JUNE 21ST - SUNSET



DEC 21ST - NOON

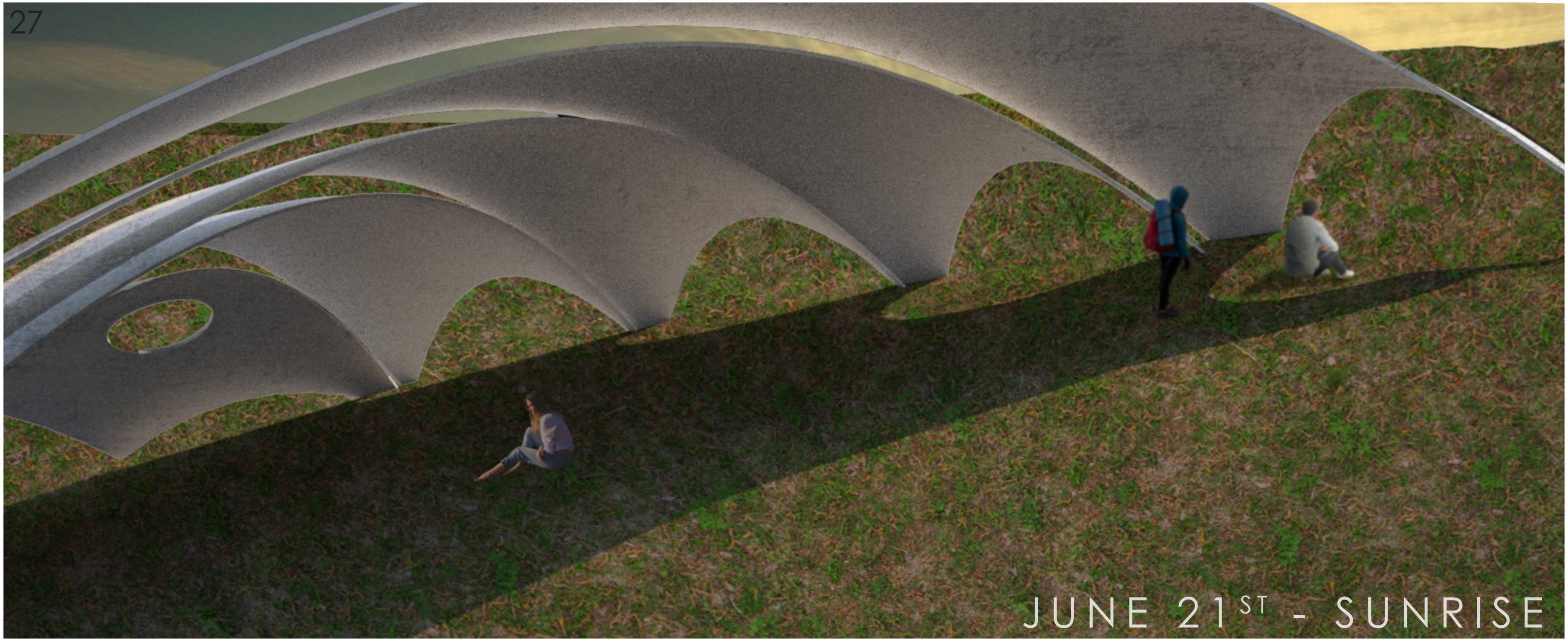
CEILING & LIGHT STUDY

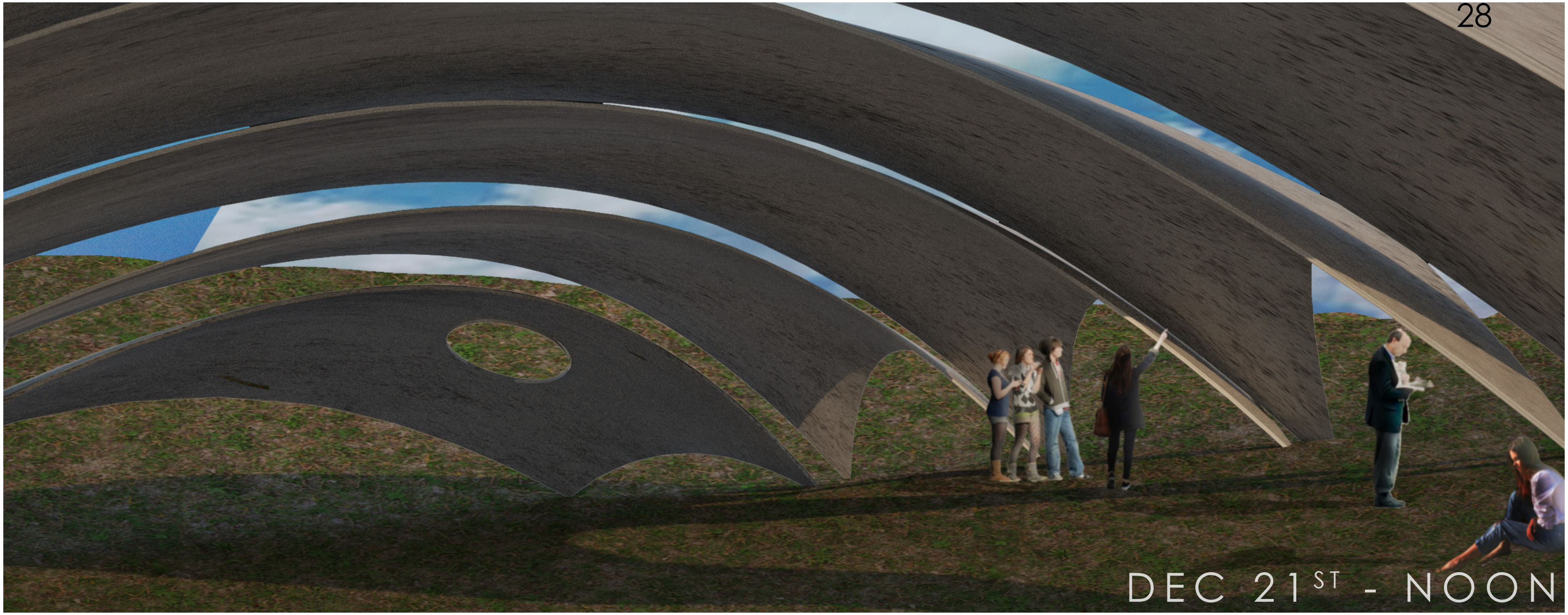
We took a view of our shells from underneath to better represent our shallow ceiling heights (right) and the way light bounces off the interior surfaces of the shell during different times of the year (left.)

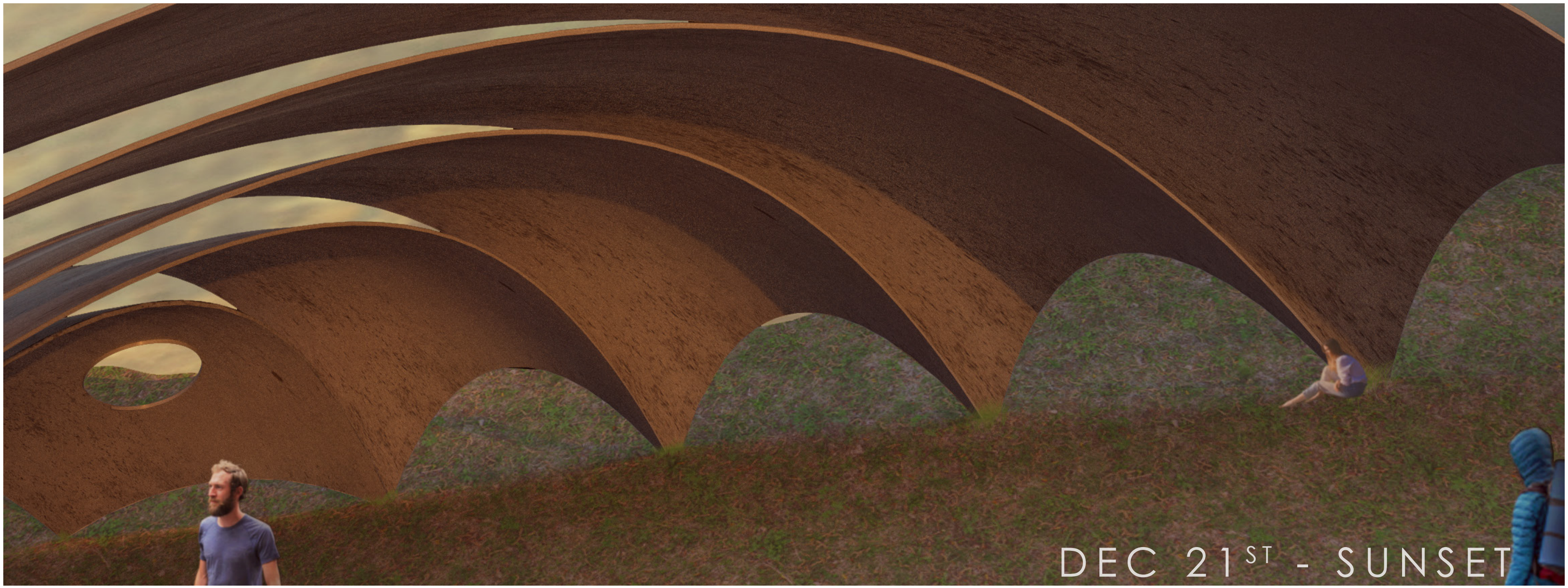


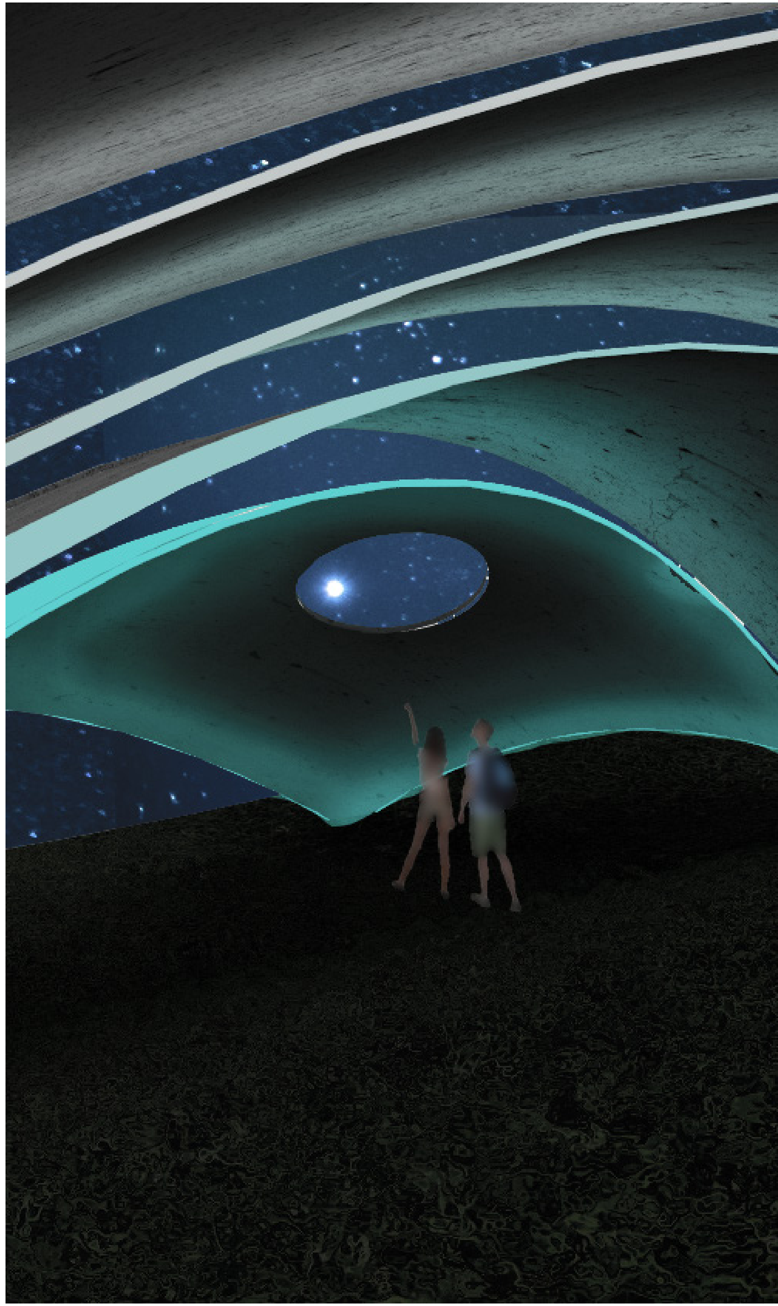
REFLECTED CEILING PLAN WITH ELEVATION MARKINGS

BOOK I : LIGHT STUDY



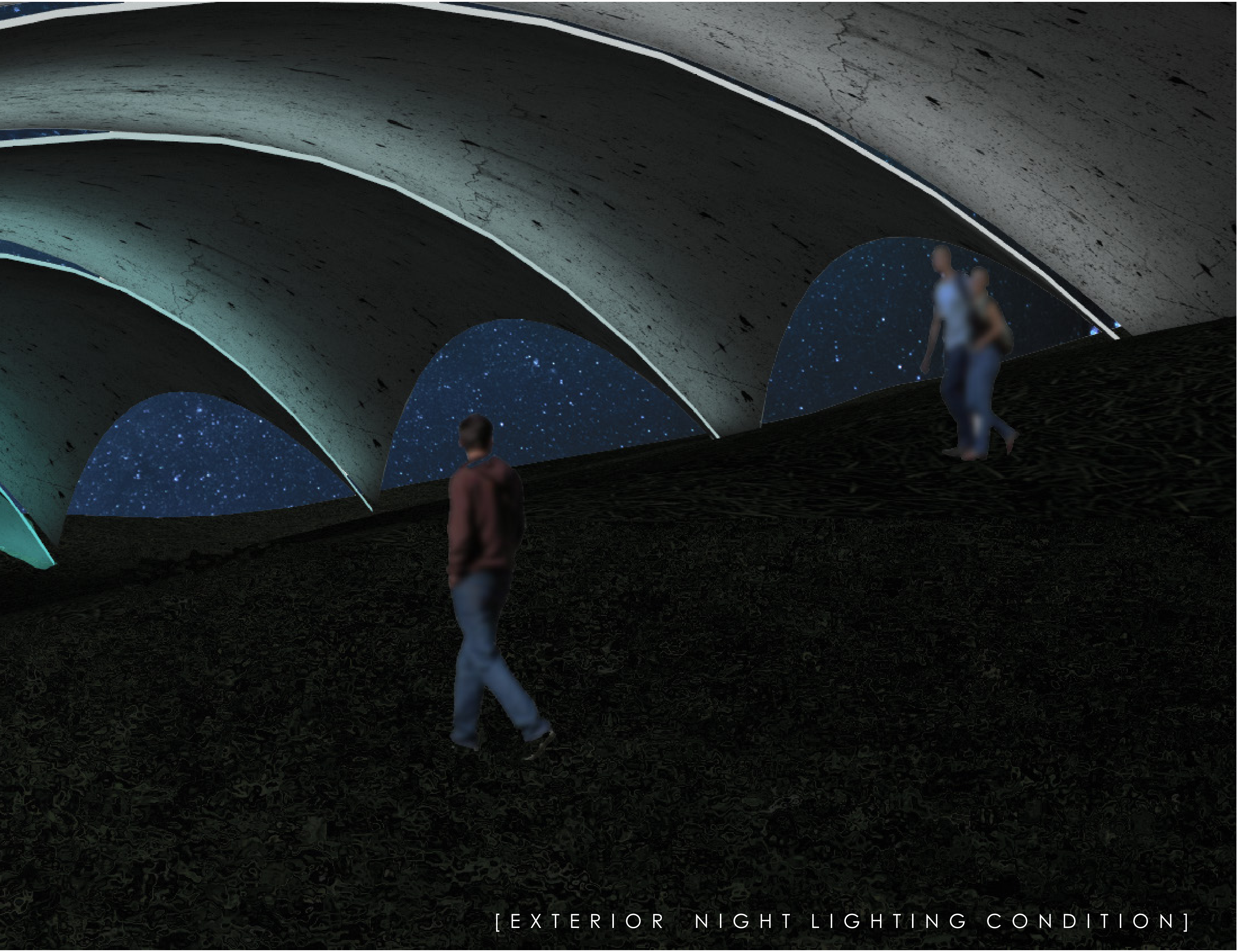

DEC 21ST - NOON


DEC 21ST - SUNSET

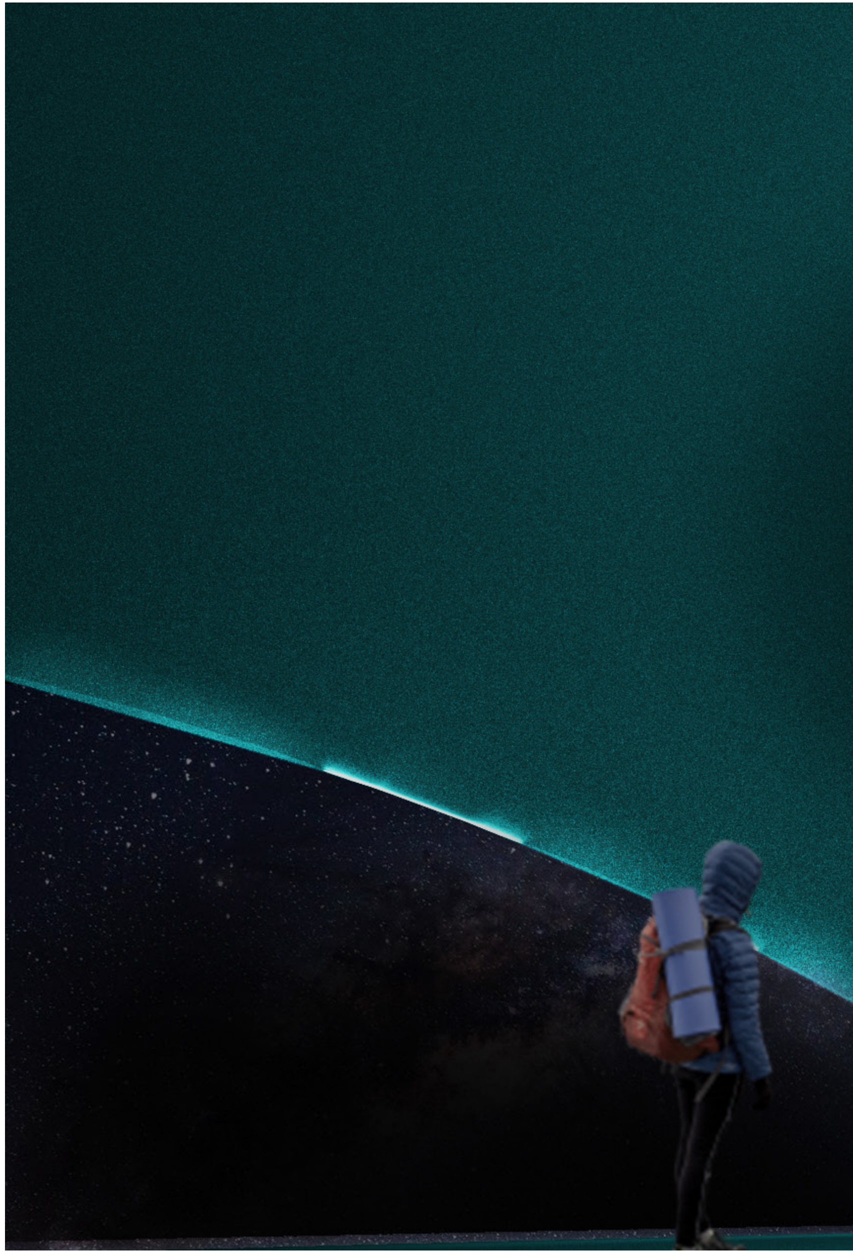


LED PLACEMENT

We drew inspiration for our fading shell from James Turrell's Gugganheim instalment. Upon entering the shell, the lights are white and in high contrast to the night sky. As you move further into the space the colors get more rich and compressive untill the final conclusiona at the last shell occulus.

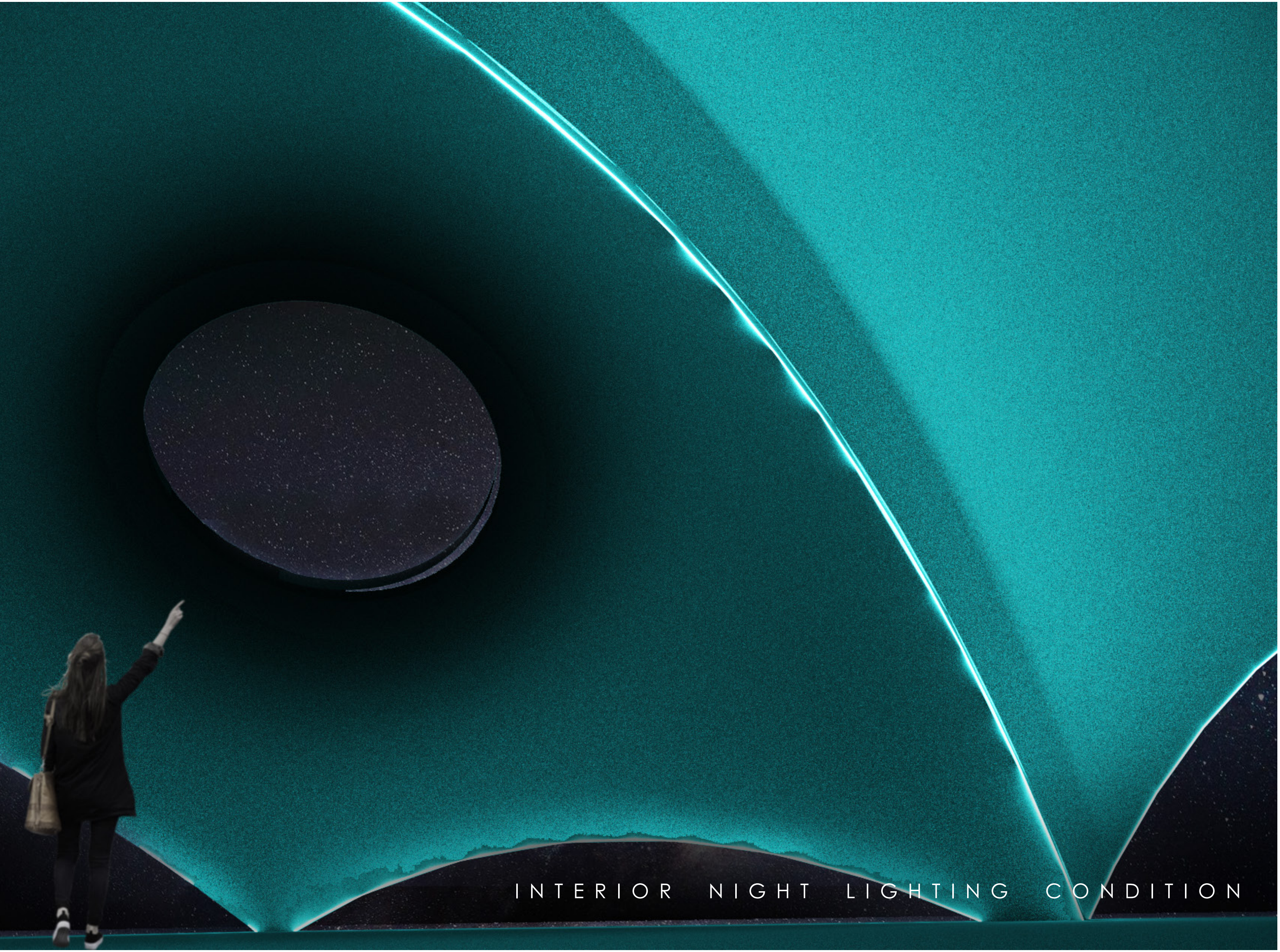


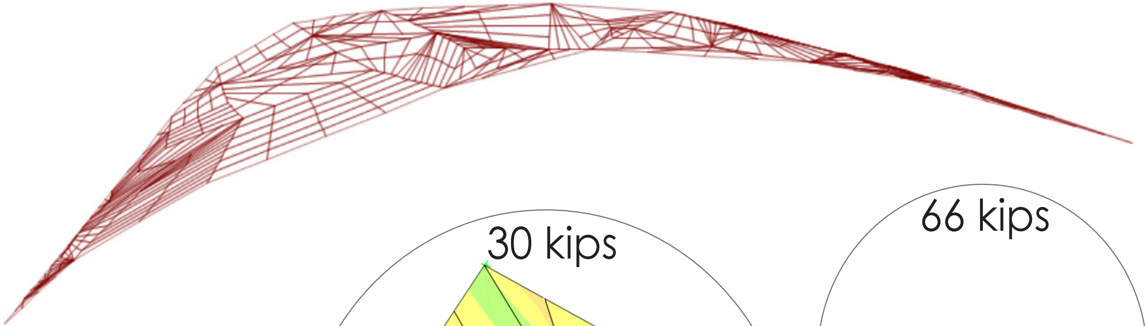
[EXTERIOR NIGHT LIGHTING CONDITION]

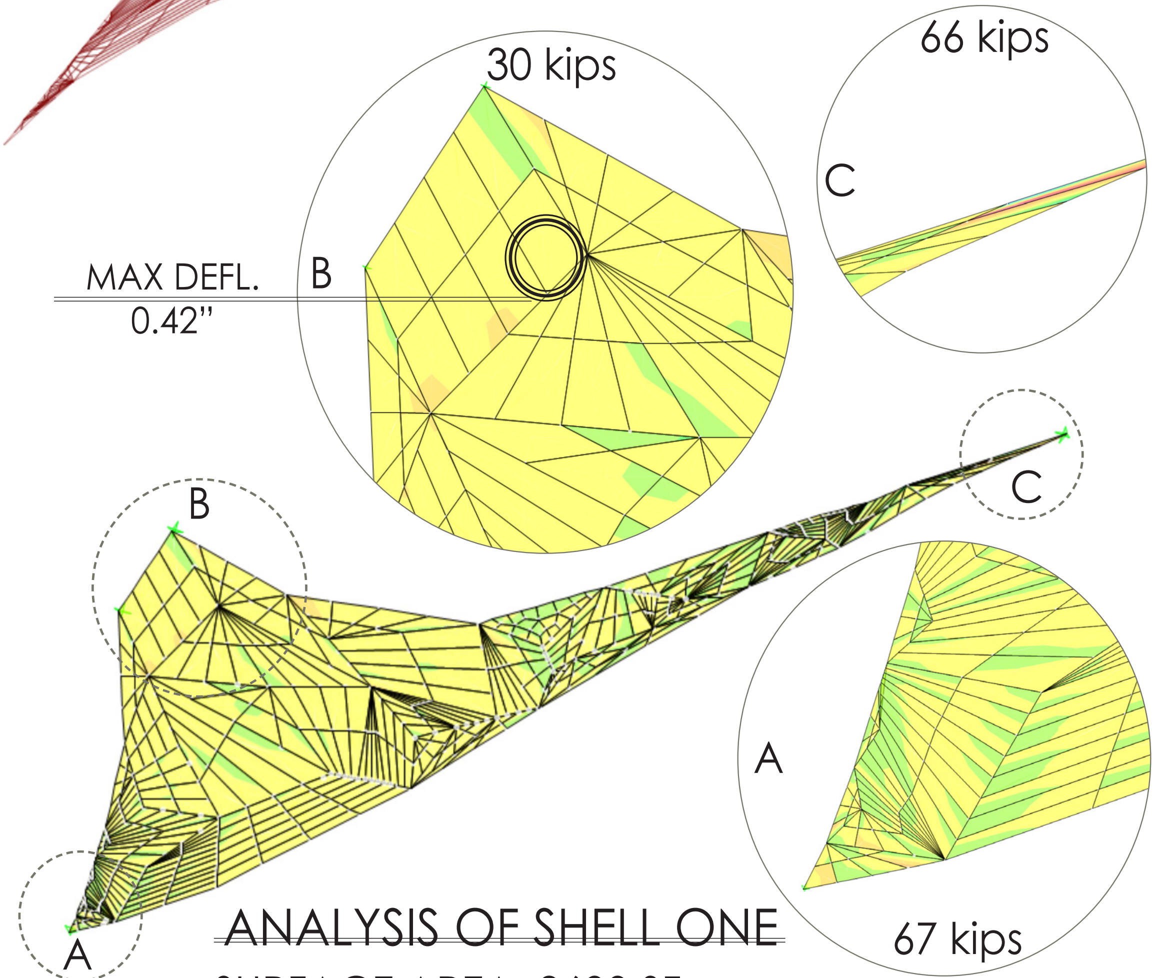


FINAL SHELL

The light placement on the final shell fades into black as it approaches the occulus-- framing the night sky.

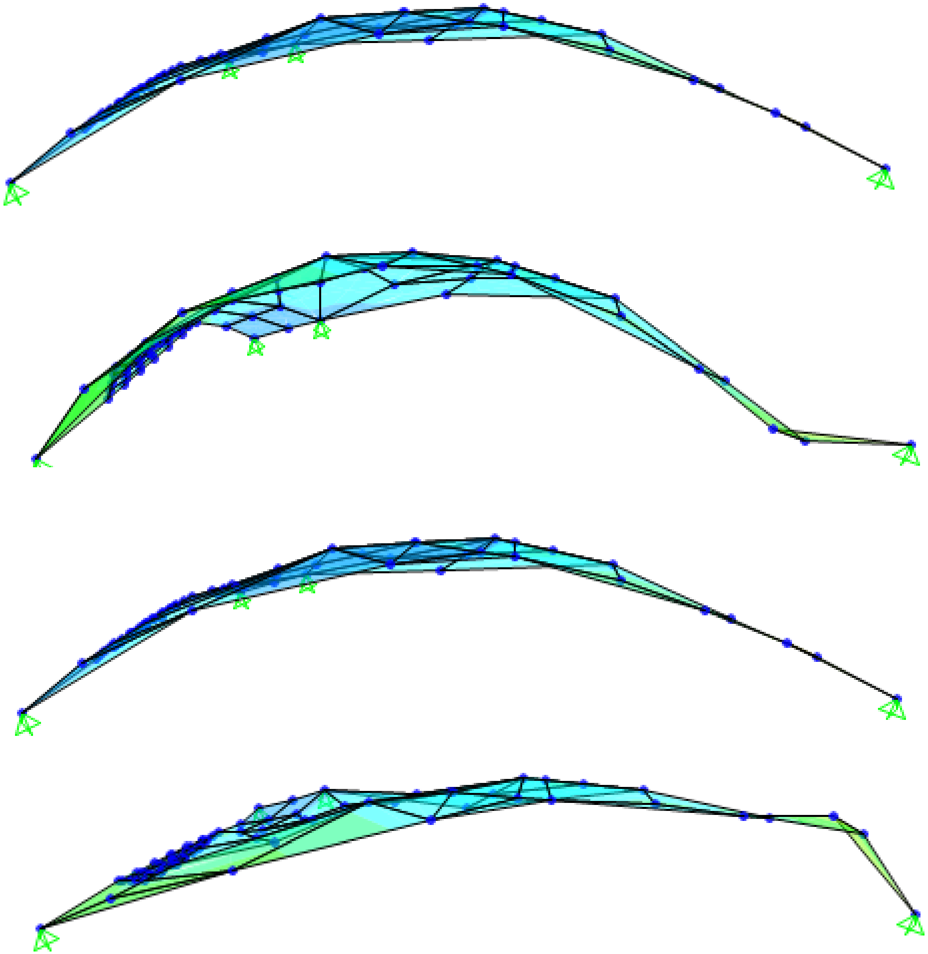

INTERIOR NIGHT LIGHTING CONDITION





ANALYSIS OF SHELL ONE

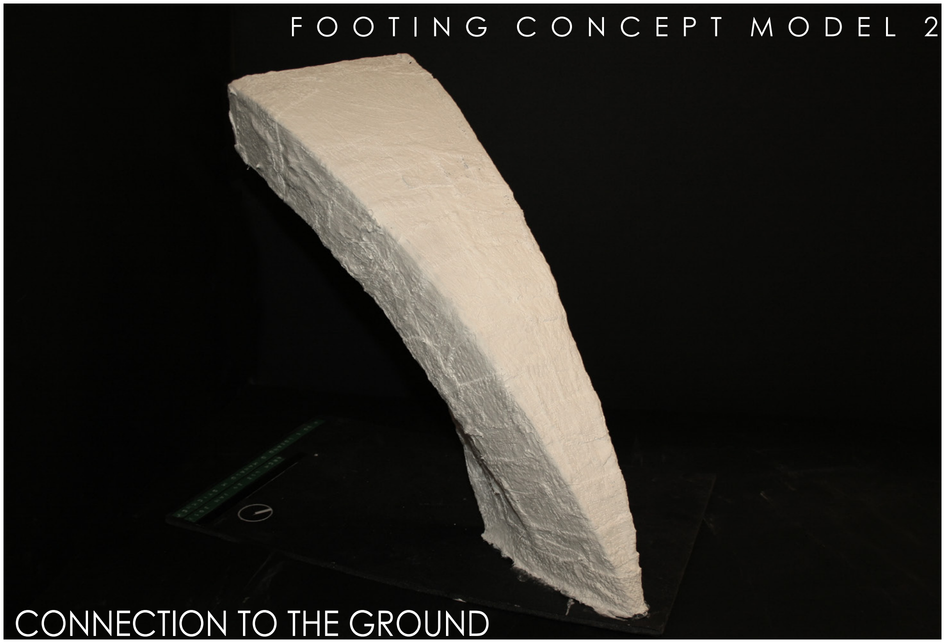
SURFACE AREA: 2600 SF.
CONCRETE THICKNESS: 4"
ESTIMATED WEIGHT: 130 KIPS



A N A L Y S I S

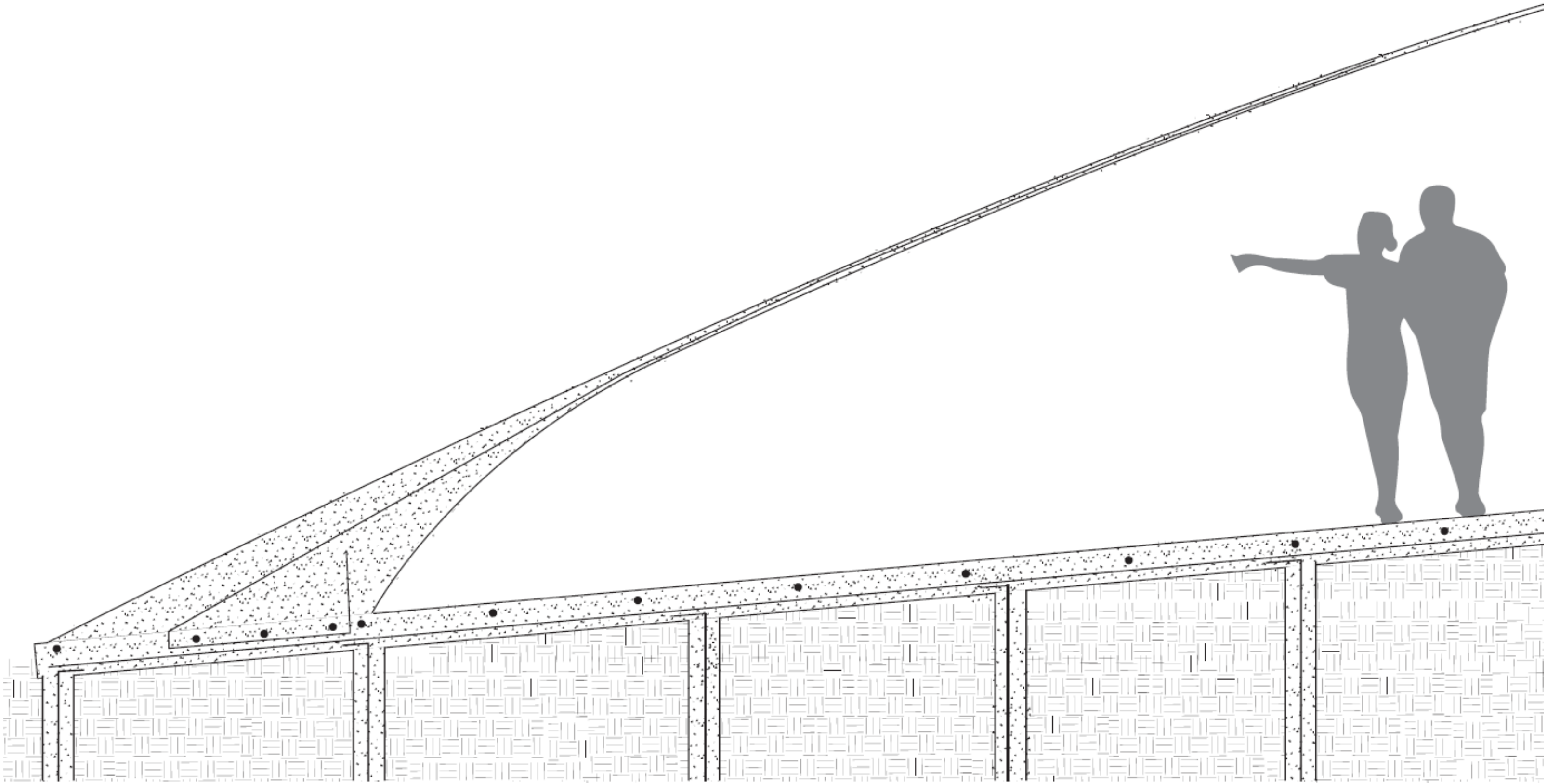
(Left) is the anaylsis of our first largest shell which we anticipated having the largest buckling issues. (Right) is a graphic showing those buckling issues. We added a curved, sculpted wall underneath to prevent buckling.

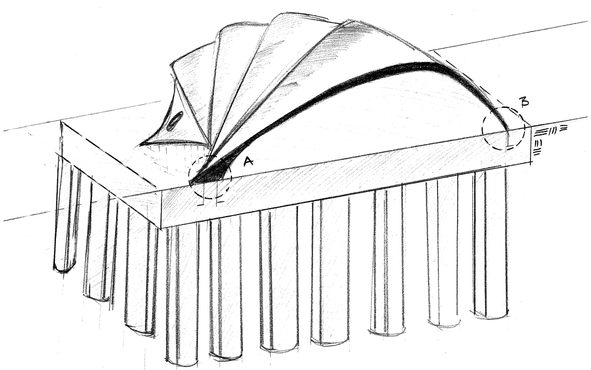
Foundation Forces	
Base Joint	Thrust (Kips)
A1	45
B1	28
C1	151
A2	160
B2	35
C2	84
A3	89
B3	79
C3	77
A4	58
B4	37
C5	62
A5	37
B5	3
C5	22

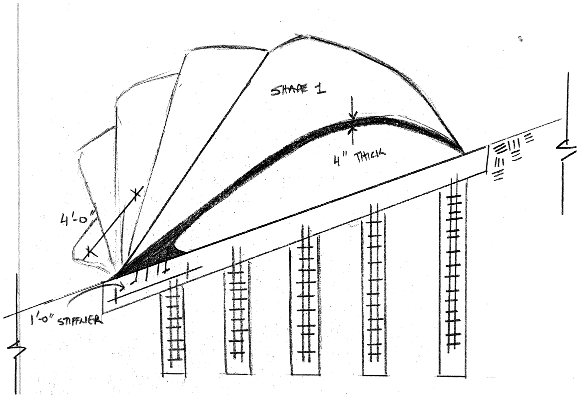


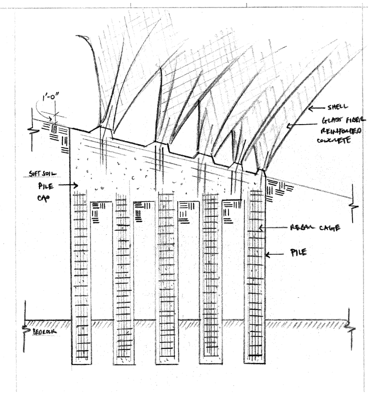
THRUST CONTAINMENT

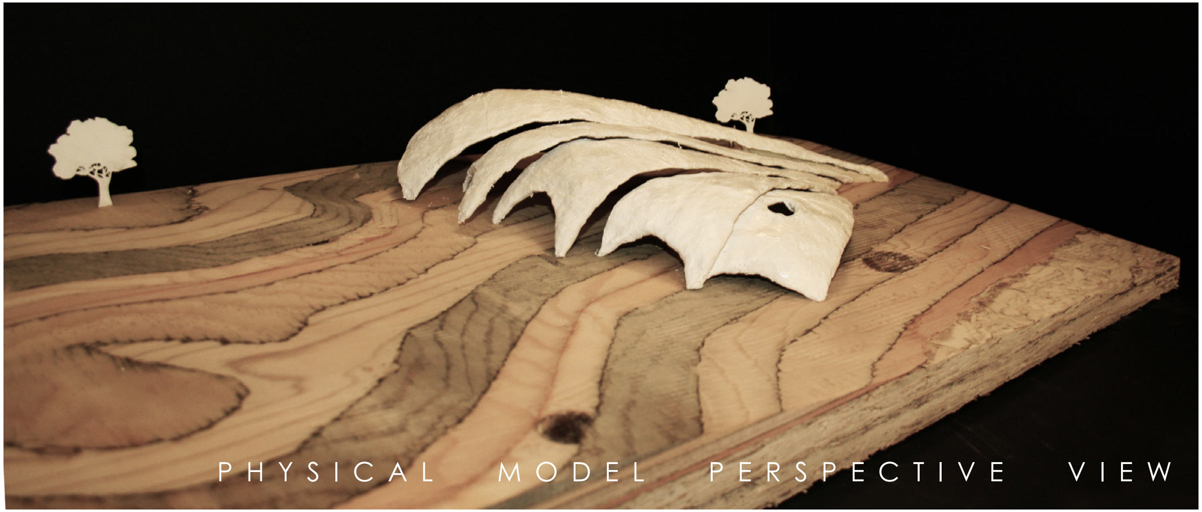
Our thrust containment consisted of a poured concrete foundation platform. We had two different thrust containment conditions. We placed a wall underneath the pointiest side that was at risk for buckling (left top.) We also had a gradual fade connection form the shell to the ground (both on right.)



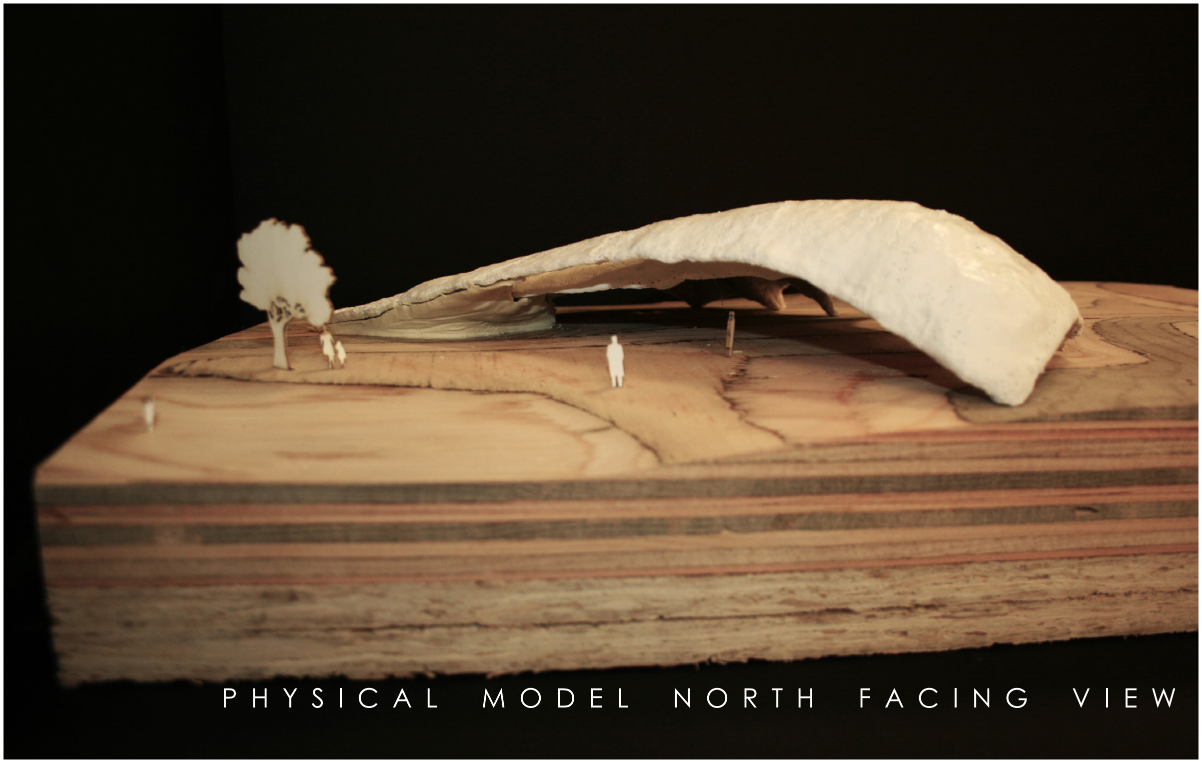

A
B


SHAPE 1
4" THICK
4'-0"
1'-0" STIFFNER


1'-0"
SHELL
GLASS FIBER REINFORCED CONCRETE
SOFT SOIL
PILE CAP
REBAR CAGE
PILE
BEDROCK



P H Y S I C A L M O D E L P E R S P E C T I V E V I E W

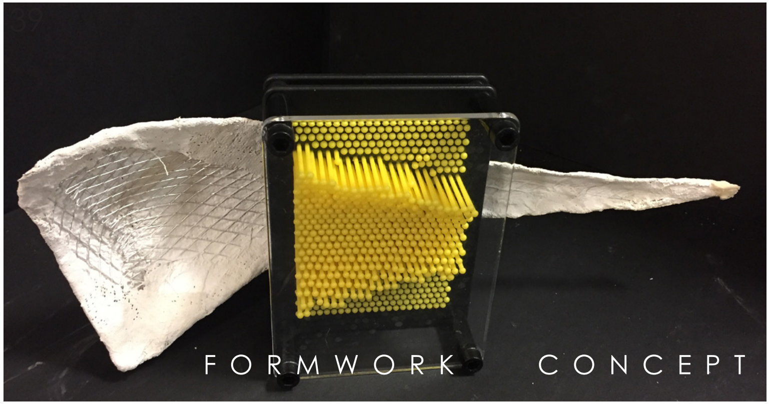


P H Y S I C A L M O D E L N O R T H F A C I N G V I E W

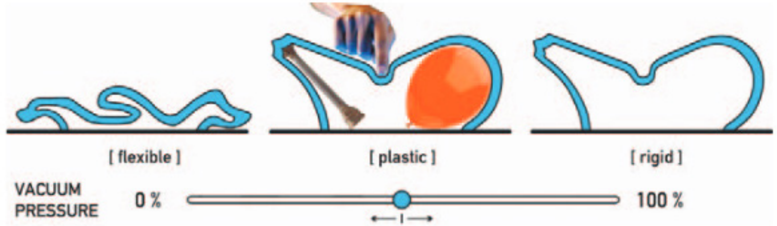
M O D E L

A CNC router was used to create the topo out of laminated ply. The final model was made by hanging fabric and applying plaster sheets.

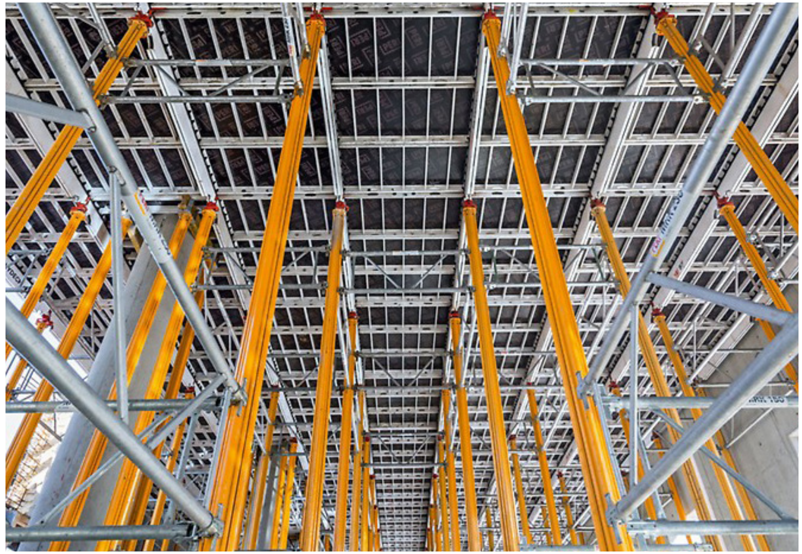
P H Y S I C A L   M O D E L   P L A N   V I E W



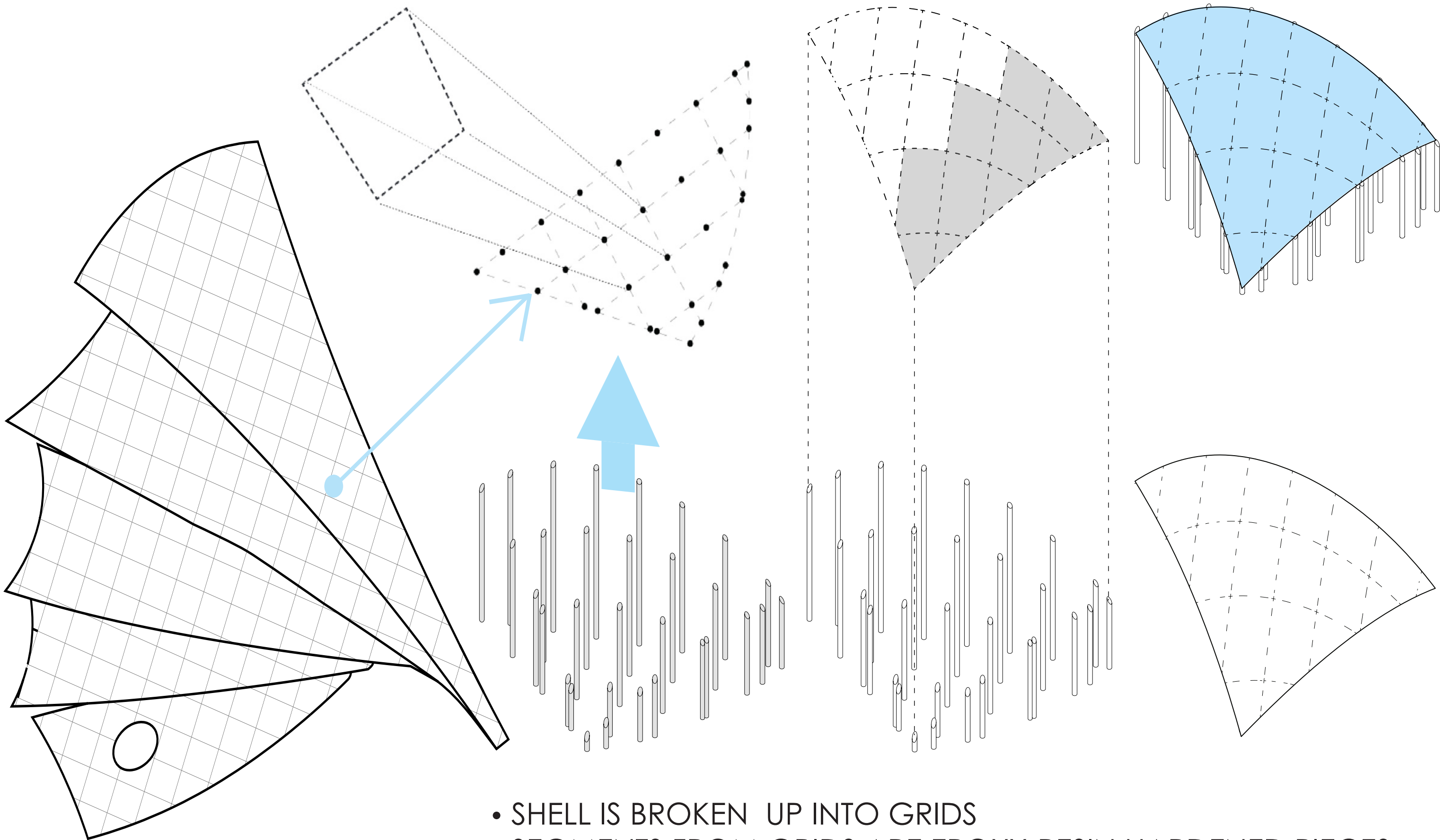
Vacuummatic 3-D Formwork System: flexible plastic formwork molded into the desired shape and then depressurized. Afterwards, all that is left is a rigid form.



Felix Candela's Timber Formwork

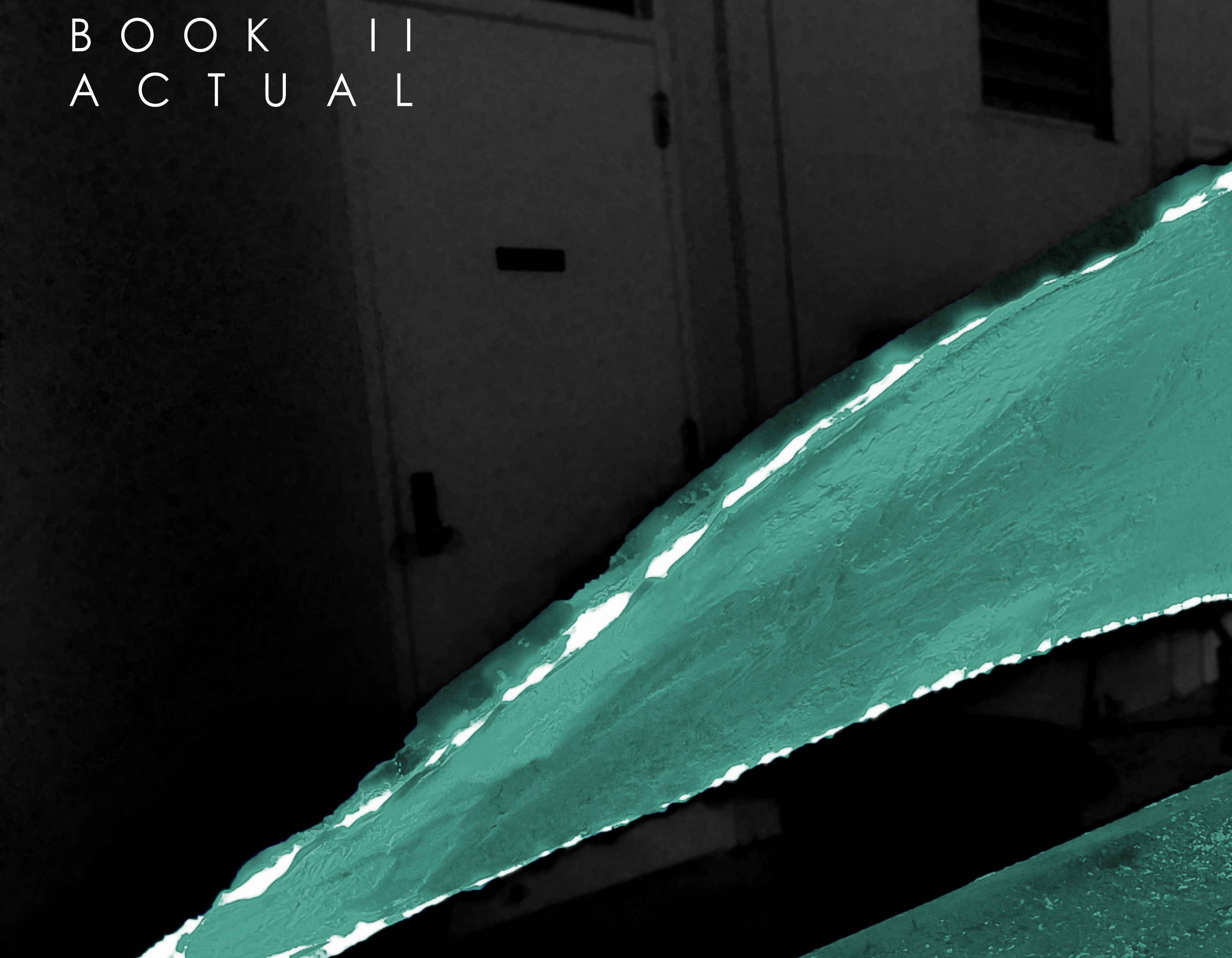


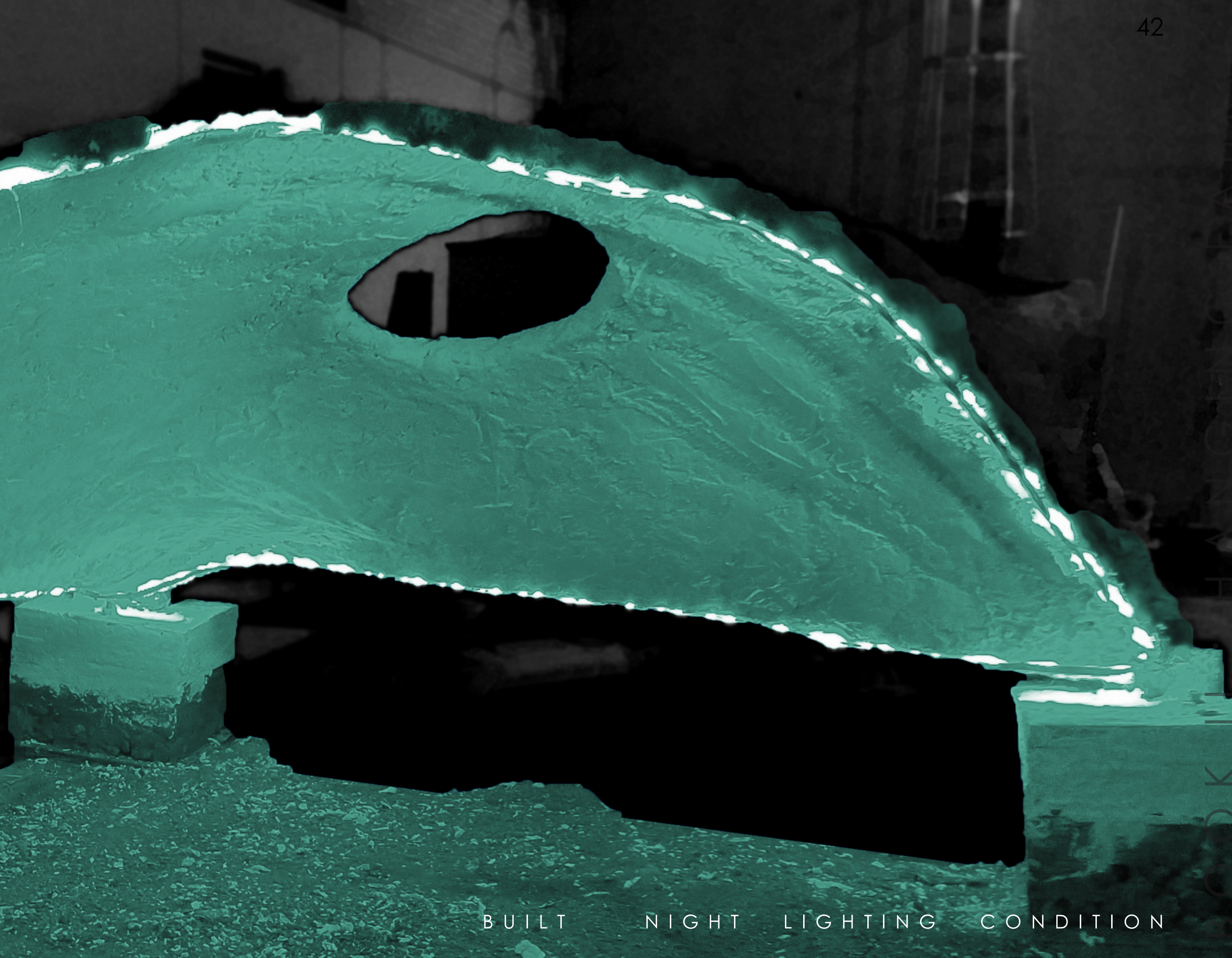
Scaffolding Formwork: adjustable steel tubes



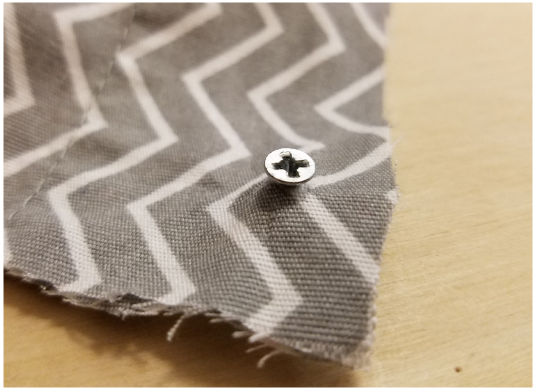
- SHELL IS BROKEN UP INTO GRIDS
- SEGMENTS FROM GRIDS ARE EPOXY-RESIN HARDENED PIECES OF LINEN
- HARDENED FABRIC PIECES ATTACHED TO SCAFFOLDING
- SCAFFOLDING ARRANGED TO SPECIFIED LOCATION USING DIGITIZED MODEL
- CONCRETE POURED OVER HARDENED FABRIC FORMWORK

BOOK II
ACTUAL





BUILT NIGHT LIGHTING CONDITION



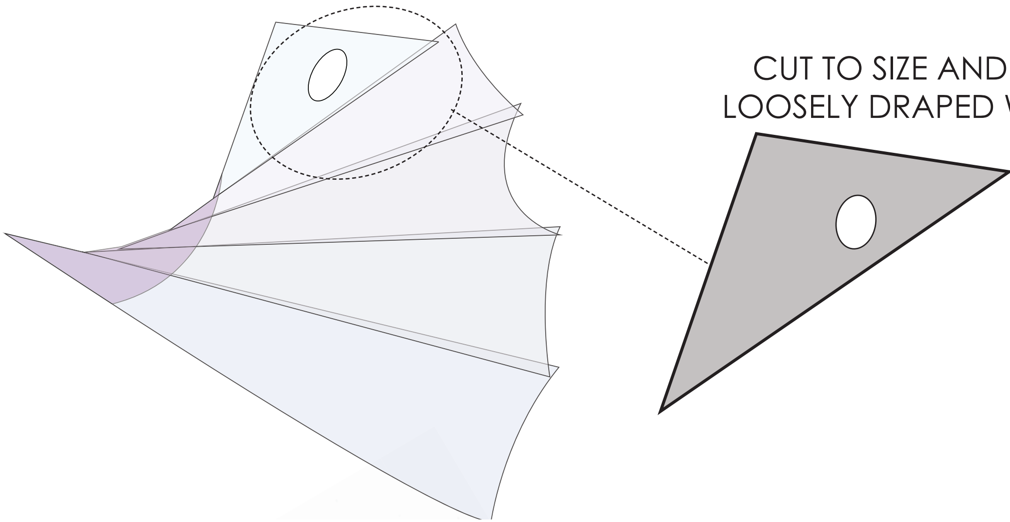
PROCESS

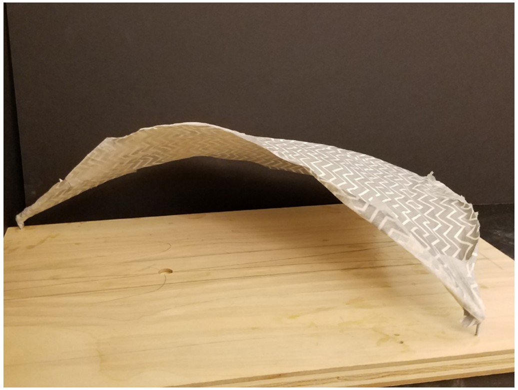
COTTON/NYLON FABRIC

CUT AND SCREWED INTO PLYWOOD
DIPPED IN PAPER -MACHE MIX (ELMERS AND WATER)
DRAPED IN PAPER-MACHE DIPPED PAPER

TARP

CUT TO SIZE AND SCREWED INTO PLYWOOD
LOOSELY DRAPED WITH PAPER-MACHE PAPER





PROGRESS

- COTTON/NYLON FABRIC WAS TOO ELASTIC
- FORM WAS ALTERED BY WEIGHT OF PAPER-MACHE
- FORM WAS INTACT, BUT SAGGED TOO MUCH

- TARP WAS TOO STIFF OF A MATERIAL
- LEARNED FROM FAILURE: PROPER PAPER-MACHE TECHNIQUE

MATERIAL: CLOSE-KNIT LINEN
HARDENING PROCESS: PAPER MÂCHÉ


FORMWORK PROCESS 1


FORMWORK PROCESS 2


FORMWORK PROCESS 3


FORMWORK PROCESS 4

We chose to begin our formwork with paper-mache hardened fabric hanging from a 6' x 4' plywood board marked with a grid. Once the fabric hardened, we flipped it around--what once was in pure tension became pure compression. We measured incremental distances from the plywood to the shell and cut 2x1's to the correct size. We then placed these 2x's on the grid in their proper place. To prevent puncturing, between the plywood 2x's and the paper-mache shell we put cardboard pads to disperse the point load. We attached cardboard lips on the edge to create a clean edge condition. For water-proofing we covered the paper-mache fabric in tin-foil.

FORMWORK PROCESS 5

FORMWORK PROCESS 6

FORMWORK PROCESS 7

FORMWORK PROCESS 8

CONCRETE POUR PROCESS 1

CONCRETE POUR PROCESS 2

POURING

We mixed a low-slump concrete and poured it on top of the formwork. The slow slump allowed us to keep the shell thin and to controll edge conditions

CONCRETE POUR PROCESS 3

CONCRETE POUR PROCESS 4

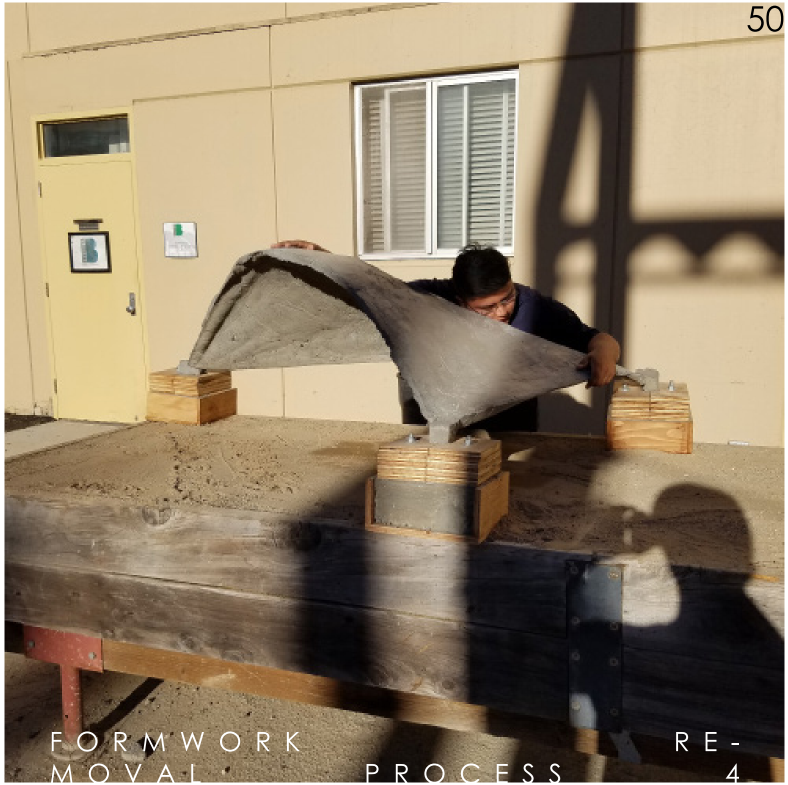
FORMWORK REMOVAL PROCESS 1

FORMWORK REMOVAL PROCESS 2

R E M O V A L

After a week, we removed the formwork by pouring water between the tinfoil covered paper-mache and the cured concrete. We removed the plywood 2x's with a drill.

FORMWORK RE-MOVAL PROCESS 3



FORMWORK RE-MOVAL PROCESS 4

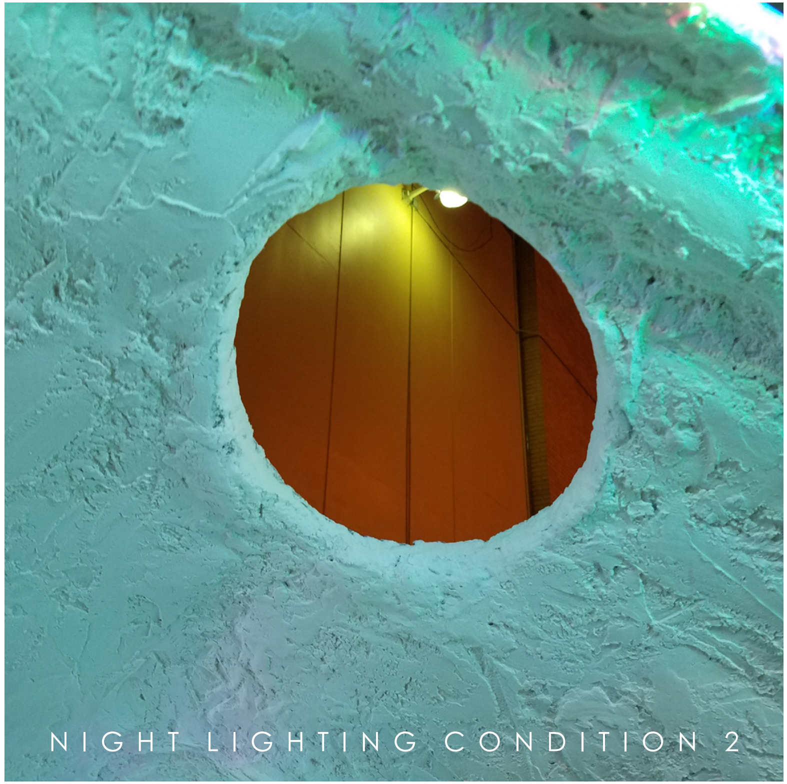
DAY & PLASTER

Once everything was removed we plastered the interior underbelly of the shell and the tippy-tops of our footing. this allows light to bounce into the interior of the shell during the day and night.

DAY LIGHTING CONDITION 3

DAY LIGHTING CONDITION 4

NIGHT LIGHTING CONDITION 1



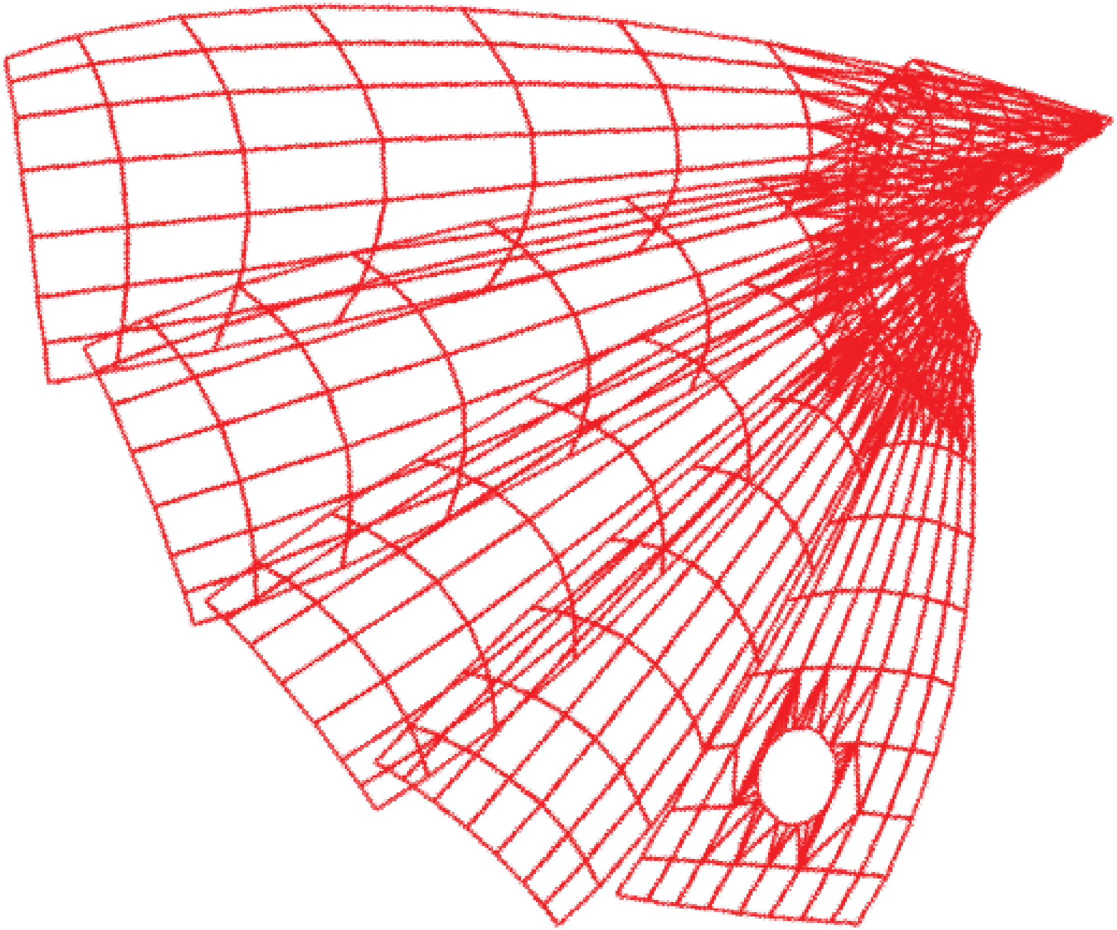
NIGHT LIGHTING CONDITION 2

NIGHT & LED

We attached led lights to the perimiter of our shell. After expiermenting with colors we thought teal looked best.

NIGHT LIGHTING CONDITION 3

NIGHT LIGHTING CONDITION 4



CONCRETE

5" thick shell
4 ksi

STEEL

ASTM A185 WELDED WIRE
(6X6 W5.0XW5.0)
F_Y = 65 ksi
F_U = 75 ksi

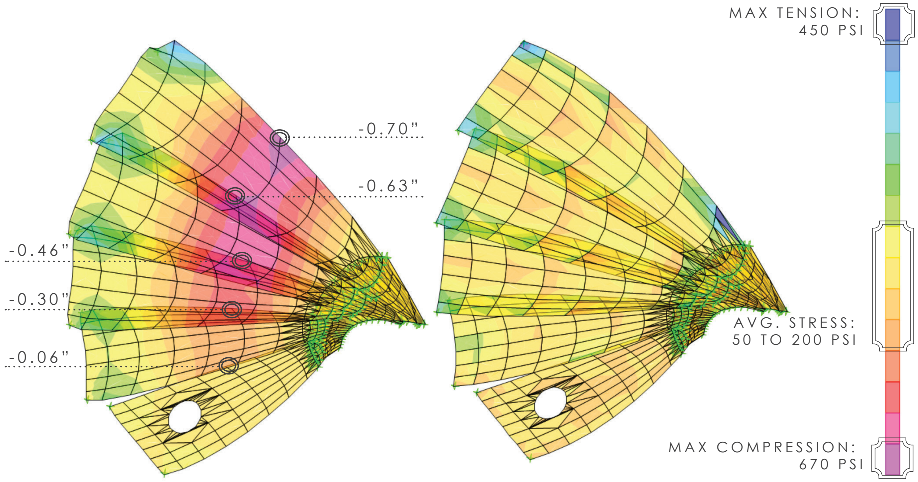
MATERIAL PROPERTIES

From the Deflection Diagram, it becomes evident that the largest deflection occurs at the longest span, or the biggest shell, at 0.70". The deflection at the middle of the span progressively decreases as the shell size decreases.

From the Stress Diagram, it becomes evident that the whole structure is mostly in compression (yellow and orange sections). There are some areas in tension (green and blue sections), which are located in the supports.

The reactions indicate that the largest reaction takes place in the support of the longest-spanning shell. The reaction occurs at the steeper (i.e. more vertical) section of the shell. The reactions at the wall (bottom right image) are minimal, considering that the section has a continuous connection to the ground.

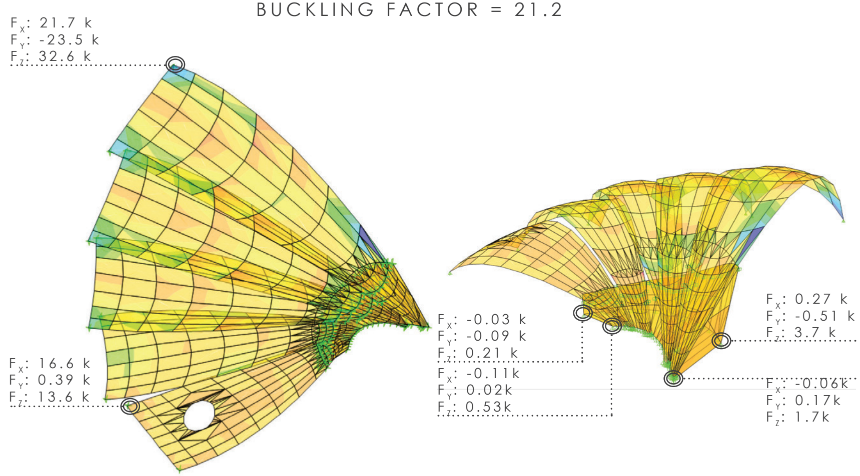
SELF-WEIGHT ONLY
LINEAR ANALYSIS



DEFLECTION

STRESSES

SELF-WEIGHT ONLY
LINEAR ANALYSIS
BUCKLING FACTOR = 21.2



REACTIONS
(MAX AND MIN F_Z)

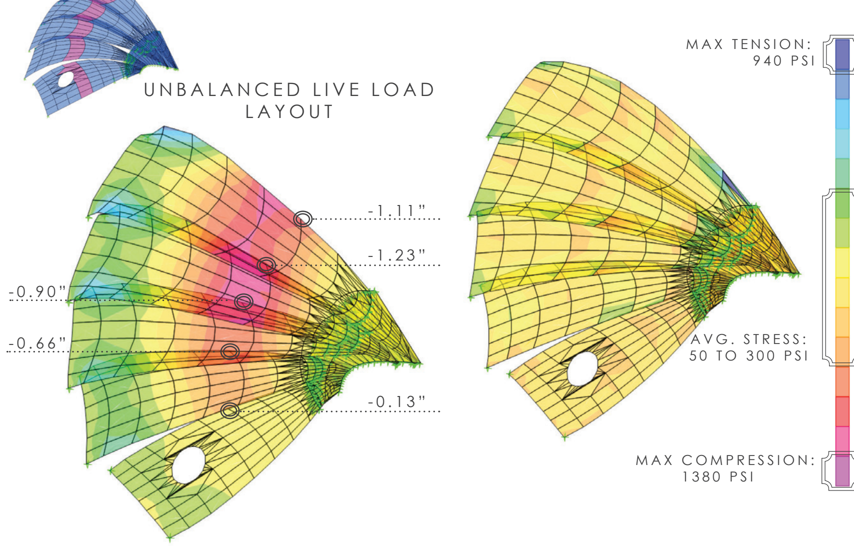
RESULTS

In order to understand the condition of the shell when unbalanced live loads are present, a strip of live load is applied at the middle of the span, where the largest deflection occurs. This unbalanced live load condition can be representative of snow loads that occurs in Switzerland.

From the analysis, it becomes evident that the deflection increases on average, about 100%.

UNBALANCED LIVE LOAD (N-S) + SW

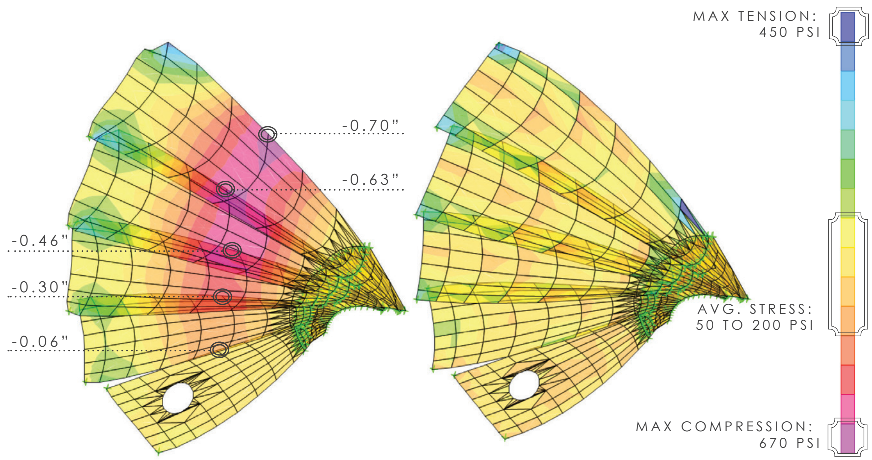
LINEAR ANALYSIS
LIVE LOAD OF 50 PSF



When non-linear concrete and non-linear steel analysis was ran, the deflection came out to be 5 times the value of the linear analysis. After messing around with the different properties in SAP, the conclusion was that concrete went nonlinear under only under its self-weight and had high deflections. This is a problem since the analysis was not supposed converge nonlinearly, so the model needs to have even more meshes to have a more precise values in the nonlinear range from the interaction of the concrete and steel. When running linear concrete and non-linear steel, the results were a lot closer to the expected values from running a nonlinear analysis.

SELF-WEIGHT ONLY

LINEAR CONCRETE
NON-LINEAR STEEL

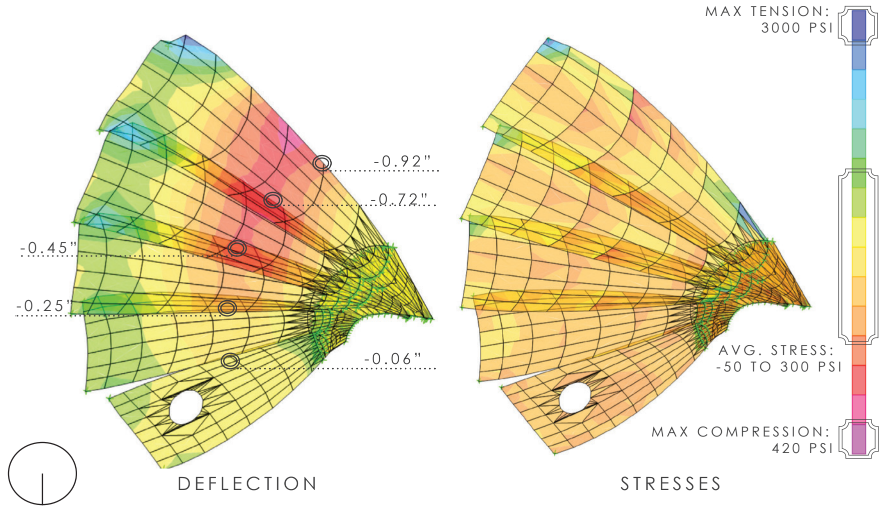


DEFLECTION

STRESSES AND

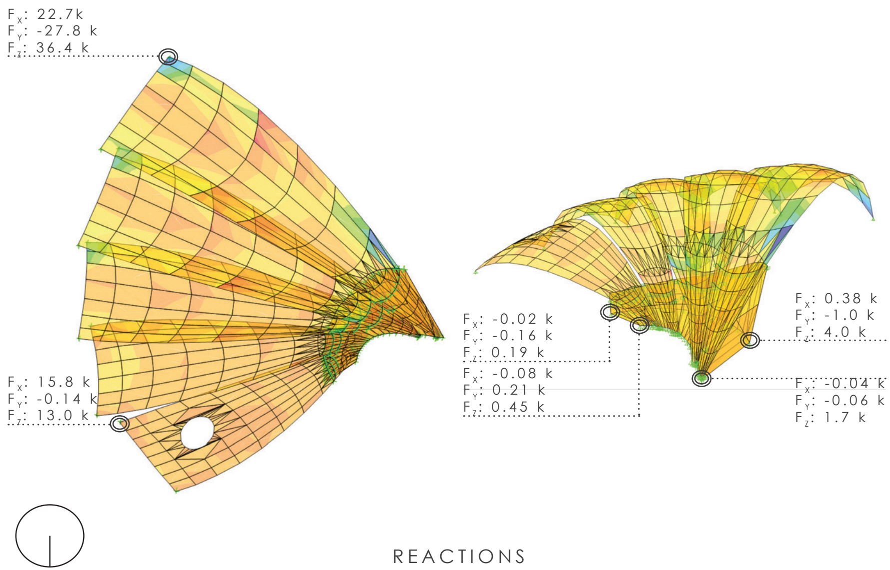
In terms of the lateral analysis, when a lateral load is applied from the north to south direction, the deflections, stresses, and thrusts increases by about 10% from self-weight only. This shows that the structure will perform reasonably well under 20% self-weight lateral load since the structure is a thin shell membrane.

LATERAL ANALYSIS
LINEAR ANALYSIS



DEFLECTION STRESSES

LATERAL ANALYSIS
LINEAR ANALYSIS

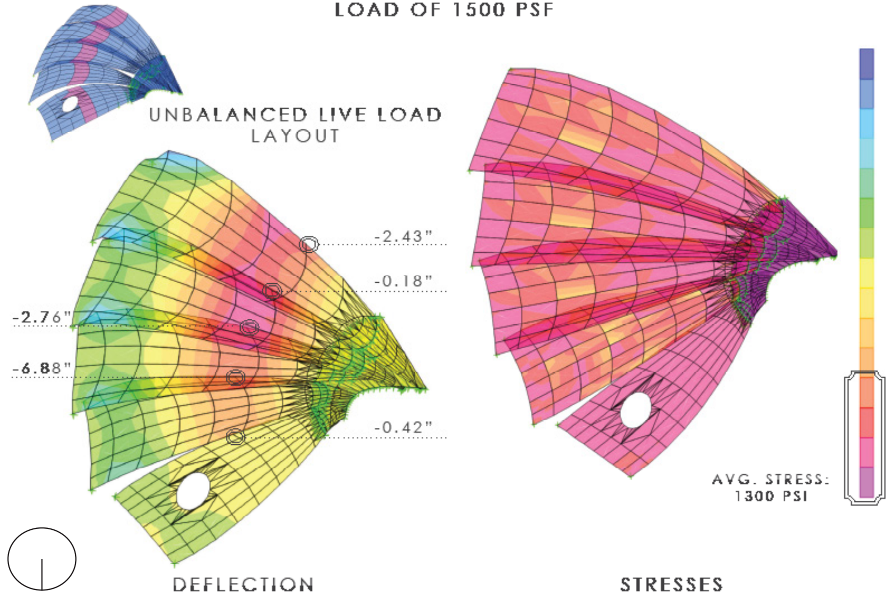


REACTIONS
(MAX AND MIN F_Z)

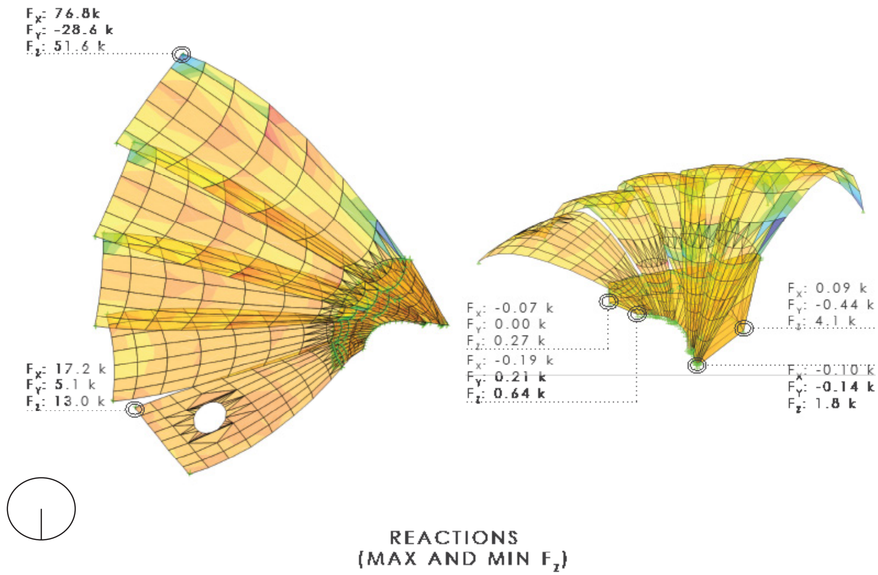
In the non-linear push to fail analysis, there was a 1500 PSF live load applied at a strip on the shell. From the buckling analysis, the dead load was amplified by a factor of 21 to get the live loadings on the strip. Looking at the results, there was major increases in the deflected values at the strips where the point load is applied. The conclusion is that the structure failed due to high deflection and would have trouble with serviceability.

PUSH TO FAIL (N-S)

NON-LINEAR ANALYSIS
LOAD OF 1500 PSF



PUSH TO FAIL (N-S)



FINAL WORDS

Overall, we felt that the simple repetition and rotation, about an axis, of our original shell created an elegant form of cascading shells. We feel that we accomplished the main goal of our design, which was to design a funicular structure that didn't distract or overshadow the church in any way and to pay homage to the Celtic astrological traditions of the site. In terms of constructing the physical shell we felt that the hanging fabric approach that we used was one of the more efficient ideas in terms of actual formwork needed however, one change that we would make to add to the structural stability of the shell would be to cast the concrete foundation into the ground rather than complicate things with a seperate footing detail. All in all we are happy with the results of or project and believe that while there are things we would change, as a group we are content with the way in which we accomplished our design goals and in how we balanced aesthetic and structure.

"James Turrell Exhibition Website." James Turrell Exhibition Website. N.p., n.d. Web. 22 Mar. 2017.
Peri. ""Humboldt Forum" City Palace Berlin." "Humboldt Forum" City Palace Berlin. N.p., n.d. Web. 22 Mar. 2017.
"Posts about Concrete Study / Warming Hut on Kyle Breedlove." Kyle Breedlove. N.p., n.d. Web. 22 Mar. 2017.

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