MANO DE LA AMISTAD

A THIN SHELL CONCRETE STRUCTURE DESIGNED FOR THE PEOPLE OF HAVANA, CUBA

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DESIGN DEVELOPMENT

INSPIRATION

In designing a thin shell structure to cover the **performance space** on **Tribuna Anti Imperialista Jose Marti**, in **Havana, Cuba,** we developed a heavily symbolic concept and further abstracted it to reach our design. Basing the concept on the quote to the right by Obama about US and Cuba relations, we wanted our design to be **representative of a hand** that works to adjoin the plaza to the US Embassy which is directly west of the site. The "wrist" portion adds an asymmetric element, while the fingers **provide a backdrop** to the performers as well as a view through to the US Embassy and Cuban flag monument behind the space. The **layering of two shell structures** helps to abstract the hand like form, particularly in plan-view, and reinforces the symbolic aspect of the two countries coming together. Interest is also added via an **oculus** in the bottom structure that depending on the viewer's angle, provides images of the sky, upper shell, or both simultaneously.

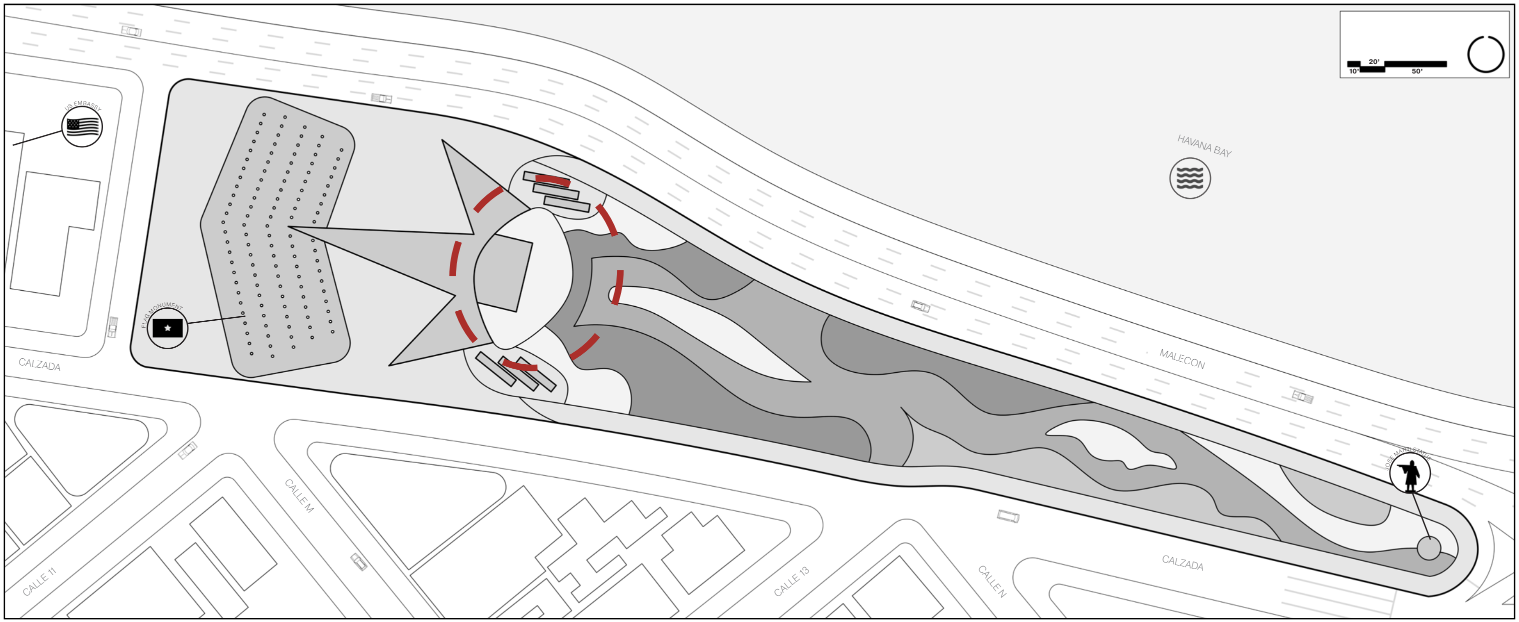
"WE EXTEND A HAND OF FRIENDSHIP TO THE CUBAN PEOPLE… *THE CUBAN PEOPLE MUST KNOW THAT THEY HAVE A FRIEND AND PARTNER IN THE UNITED STATES OF AMERICA"*

-BARACK OBAMA, 2016

THE SITE

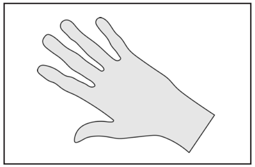
HAVANA, CUBA // TRIBUNA ANTI IMPERIALISTA JOSE MARTI

- To the East of US Embassy
- Directly adjacent to flag memorial for Cuban victims of terrorism
- Activist platform turned concert venue
- Jose Marti statue points directly up the plaza to the stage
- Existing buildings and plaza mosaic limit ground connection around the stage

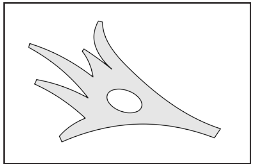


FORM FINDING // 2D

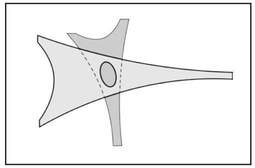
ABSTRACTION PROCESS



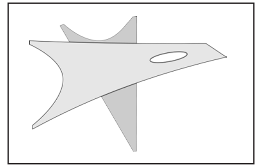
CONCEPT



ABSTRACTION

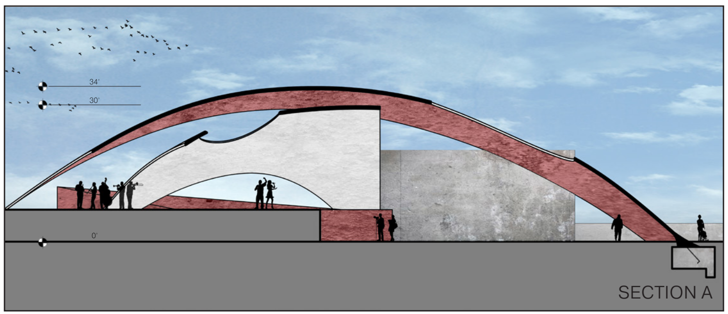


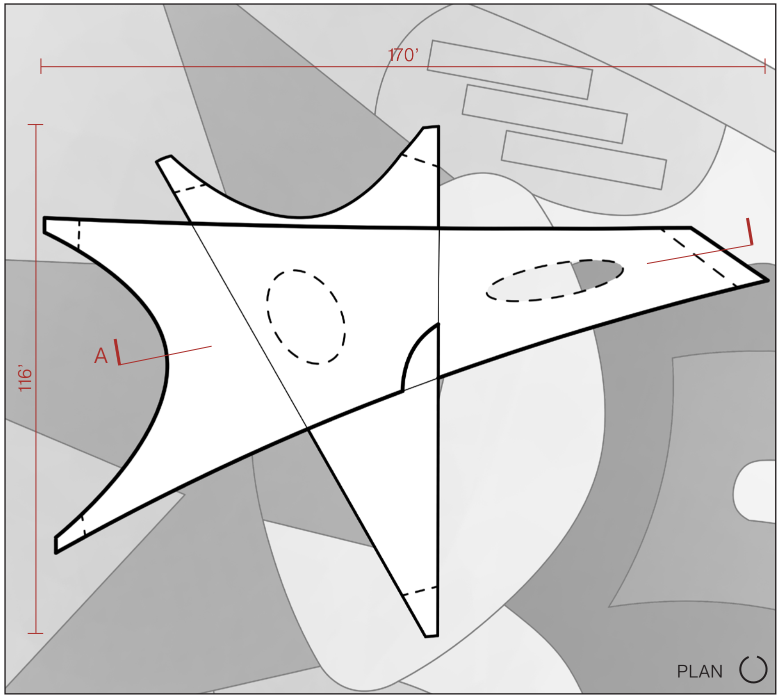
DIVISION



STRUCTURAL EDITS

FINAL PRODUCT

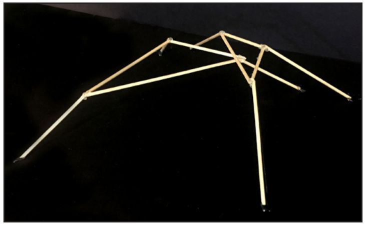




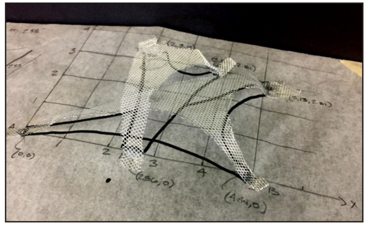
FORM FINDING // 3D

PROCESS MODELS

CONCEPT



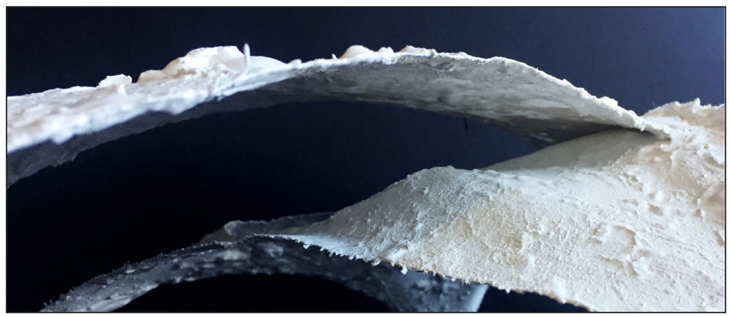
TRIPOD



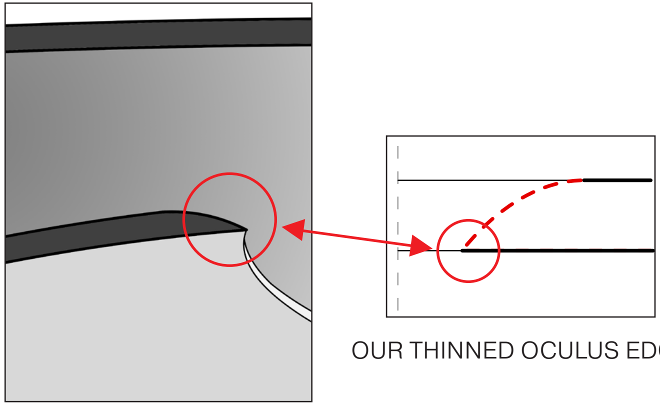
ABSTRACTION

HANGING CHAIN

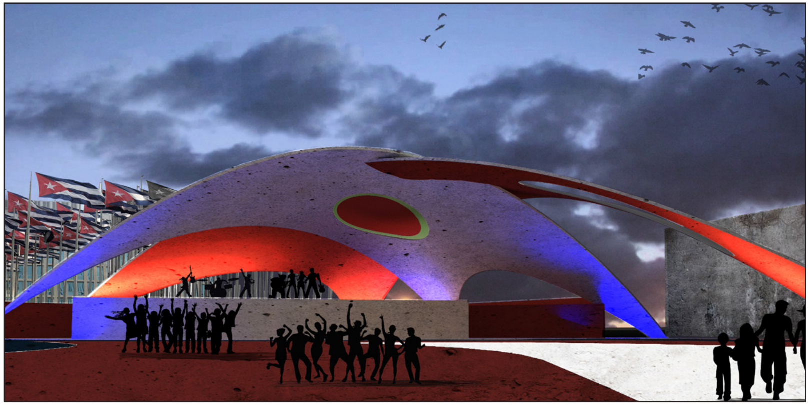
HANGING CLOTH MODEL

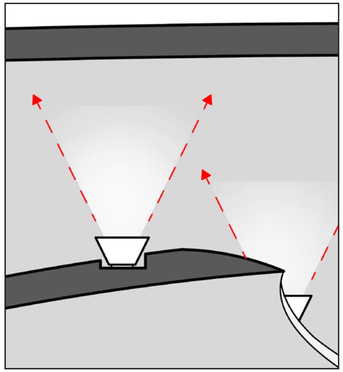


OCULUS AND LIGHTING

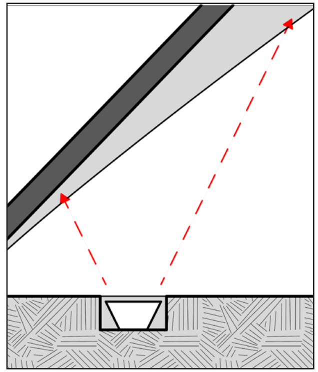


OUR THINNED OCULUS EDGE





OCULUS UPLIGHTING



LEG UPLIGHTING

The inspiration for having one oculus below a solid shell comes from the work of **James Turrell**. By **coloring** the bottom face of the upper shell and **thinning** out the edge conditions on the oculus, it gives the viewer directly under it the **illusion of 2D space** instead of 3D. This intertwines with our design concept of two entities blending harmoniously, as the **flattening** essentially turns the two shells into one. **Lighting around the oculus** on the top of the shell creates the same effect at night if viewed from below, while also emphasizing that the two shells cross through each other.

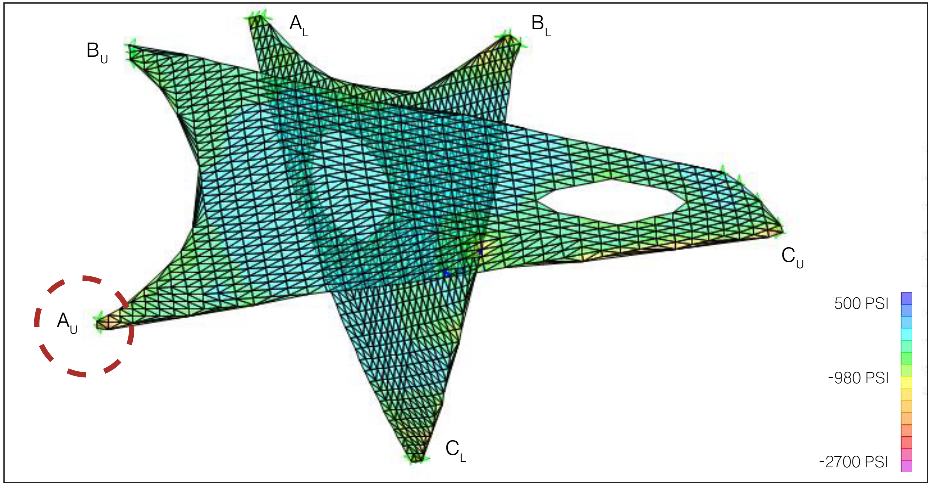
STRUCTURAL CONSIDERATIONS

SAP MODELING

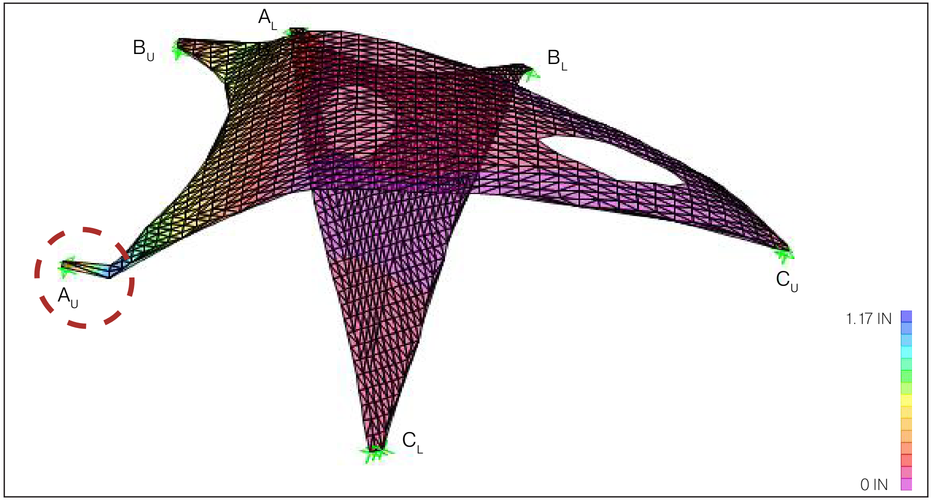
With a shape as complex as this, the best way to analyze was through the use of **SAP**. SAP allowed us to **iterate** until we found the **optimal shell thickness of four inches.** With the upper shell measuring 76'x 170', and the lower shell measuring 66' x 116', the shell's **surface area equals roughly 9155 square feet**. Using this information we concluded our shell **weighs around 440 kips**. The maximum stress values and the maximum thrust values were both found in the upper shell, which makes sense as it spans further than the lower shell. More specific stress analysis results include:

- Max stress (leg $a_{u)}$ = -2843 psi
- Max thrust (leg a_u) = 100 kips
- Max deflection = 1.24"

A **buckling analysis** was also done, and revealed a buckling factor of 3.236, meaning the **shell would have to be over 3 times its existing weight** before buckling anywhere.

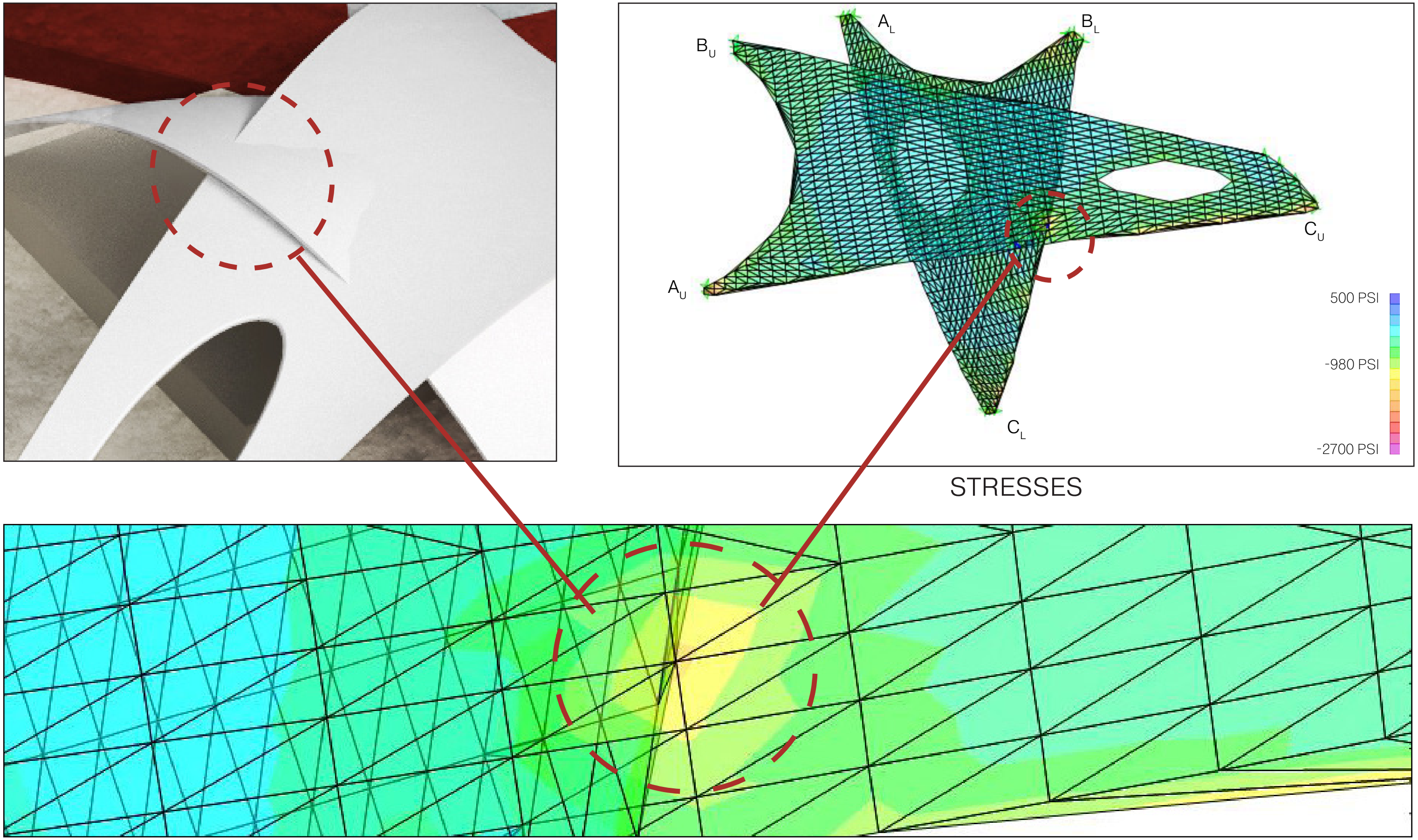


STRESSES



BUCKLING

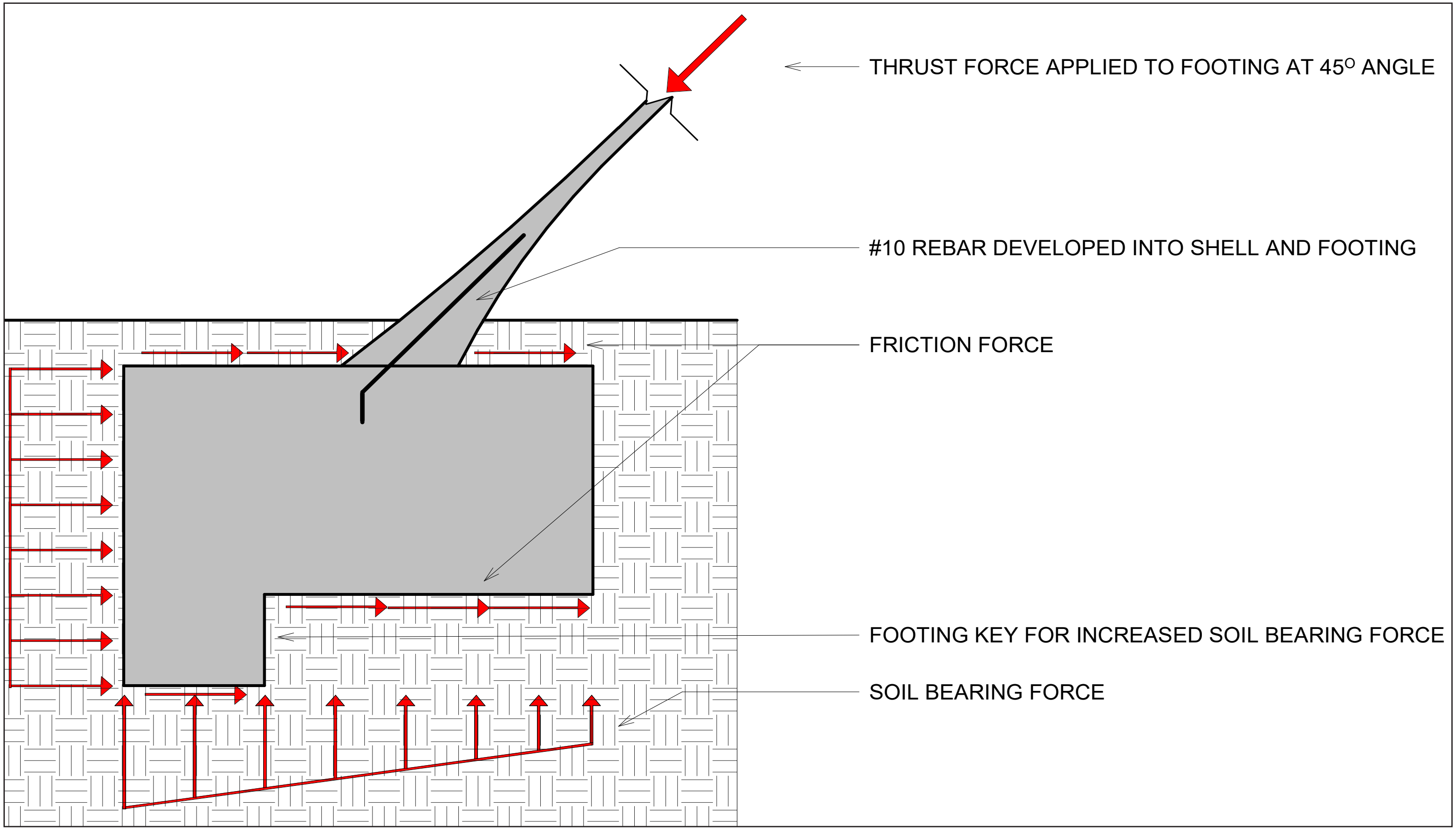
SAP MODELING // INTERSECTION



STRESSES

One obvious **spot of interest** in our design is the point where the two shells **overlap and cross through one another**. SAP was especially helpful in proving that this design choice was not too much of a structural issue. There was an inherent **stress “hot spot” of -1319 psi** at this location, and the **compressive force at this point was 11.5 kips**, but neither of these numbers were large enough to denote structural failure, and thus we were confident in our decision to overlap the shells.

THRUST CONTAINMENT

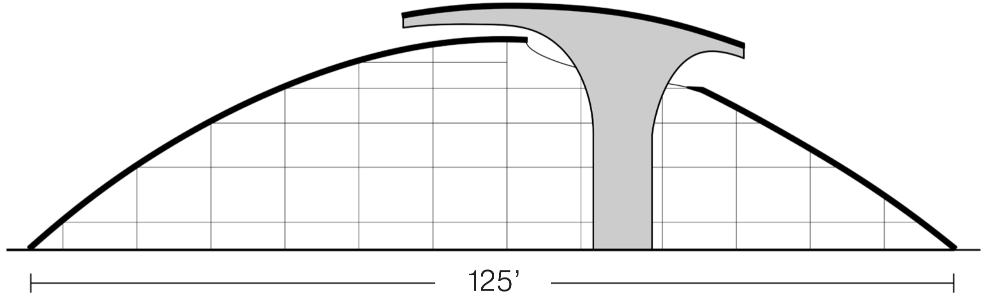


Our structure has **up to 100 kips of thrust** forces coming down at a forty-five degree angle into the ground. To contain these forces, **individual foundations are needed**, as they will be **minimally invasive** in order to preserve the existing ground pattern. They will have **keys** at varying depths to **increase the soil bearing force** in the direction against the thrust forces. The shell will elegantly widen from four inches to two feet thick near the footing and connect to the foundation with **steel reinforcing**. Each leg will be buried one foot under the soil before tying into the poured in place foundation.

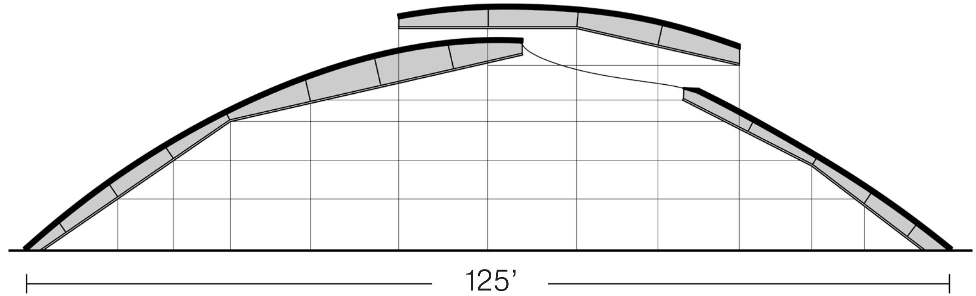
LARGE SCALE CONSTRUCTIBILITY

LARGE SCALE CONSTRUCTION

With the addition of the second shell, more emphasis had to be put on how construction would be possible. We started with two options feasible on their own, but in the end decided on a hybrid between the two that could easily translate into small scale construction as well. Our concept combines a typical and more creative strategy that somewhat **resembles standard construction methods for multilevel concrete elevated decks**. First, we will **form and shore** the underside of the lower shell, using typical curved wooden formwork and metal scaffolding for support. This shell will be **poured**. While the concrete is in the process of curing, we will construct the **formwork for the upper shell** out of scaffolding and custom cut foam blocks, resting the upper formwork on the lower shell when necessary. We will **not remove any shoring until both shells have cured** and the concrete has reached design strength. Once cured, all shoring and formwork can be removed, beginning with the top shell.

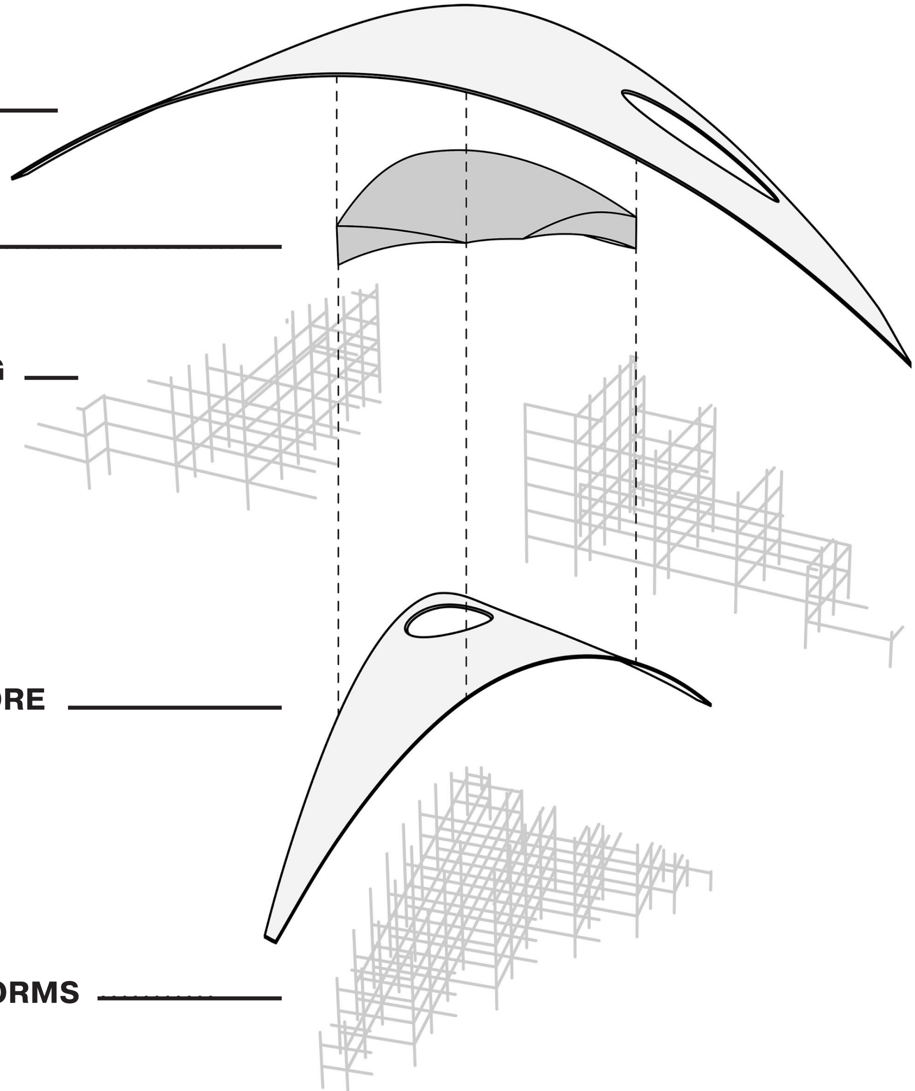


OPTION 1: CURVED WOOD BOARDS WITH CANTILEVERED SYSTEM FOR CROSS-OVER AREA



OPTION 2: CUSTOM CUT FOAM BLOCKS AND METAL SCAFFOLDING THROUGH LOWER SHELL

LARGE SCALE CONSTRUCTION



POUR TOP SHELL
(OPTION TWO)

PLACE CUSTOM FOAM FORMS
(OPTION TWO)

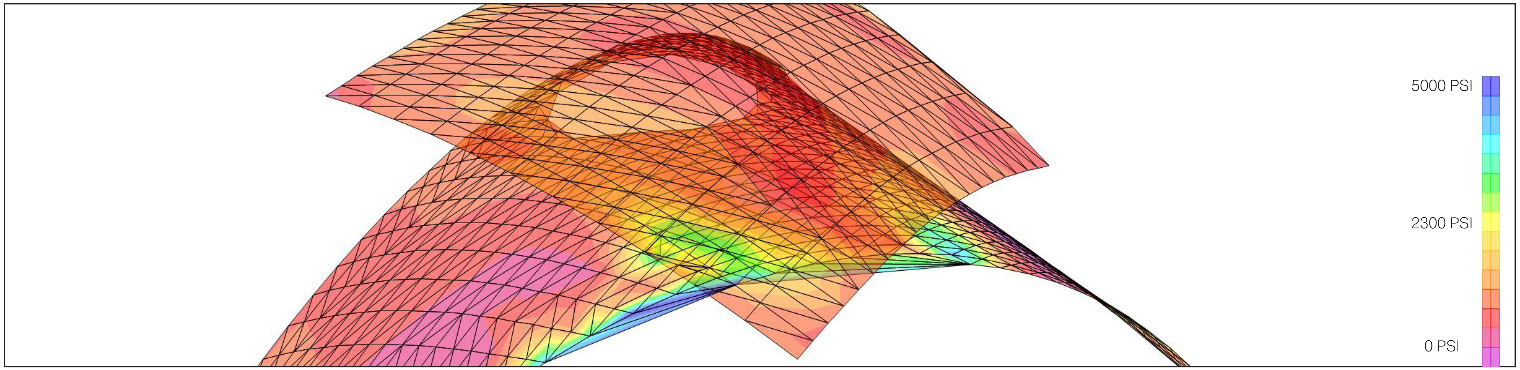
CONSTRUCT TOP SHELL SCAFFOLDING
(OPTION TWO)

POUR BOTTOM SHELL, LET CURE, SHORE
(OPTION ONE)

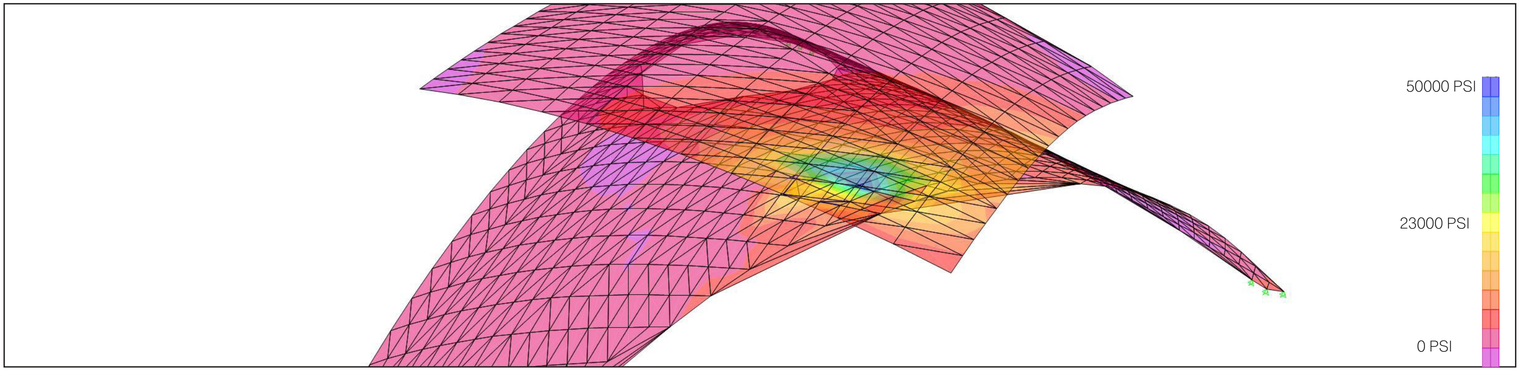
CONSTRUCT BOTTOM SHELL WOOD FORMS AND SCAFFOLDING
(OPTION ONE)

SMALL SCALE REALIZATION

POTENTIAL MODEL ANALYSIS



MODEL WITH SUPPORT

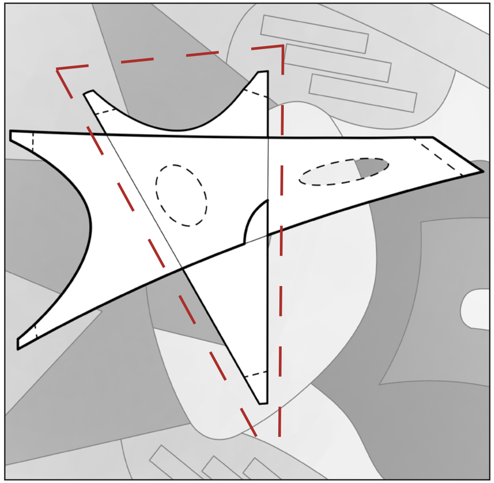


MODEL WITH CANTILEVER

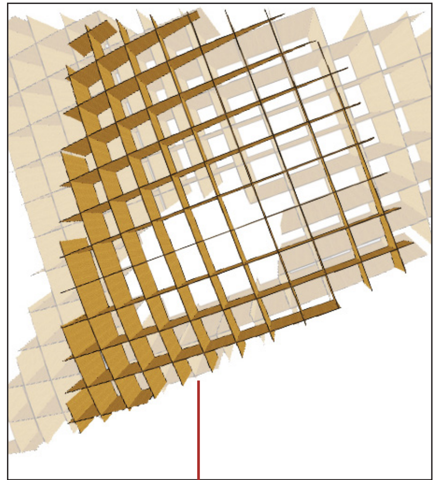
Our original idea was to construct the entirety of our design on our 9’ x 5’ frame, however it was encouraged that we only **construct a section**, as building the entire design would be beneficial to our understanding of the project, but it would be an inefficient use of the frame. Knowing that meant **part of our design would have to cantilever** and **introduce tension into a compression only structure**, we decided to **test** the portion we wanted to build **at full scale in SAP**. The shell was tested to see force intensities both **with and without a shoring support** in order to determine how to treat the upper cantilevered portion after pouring.

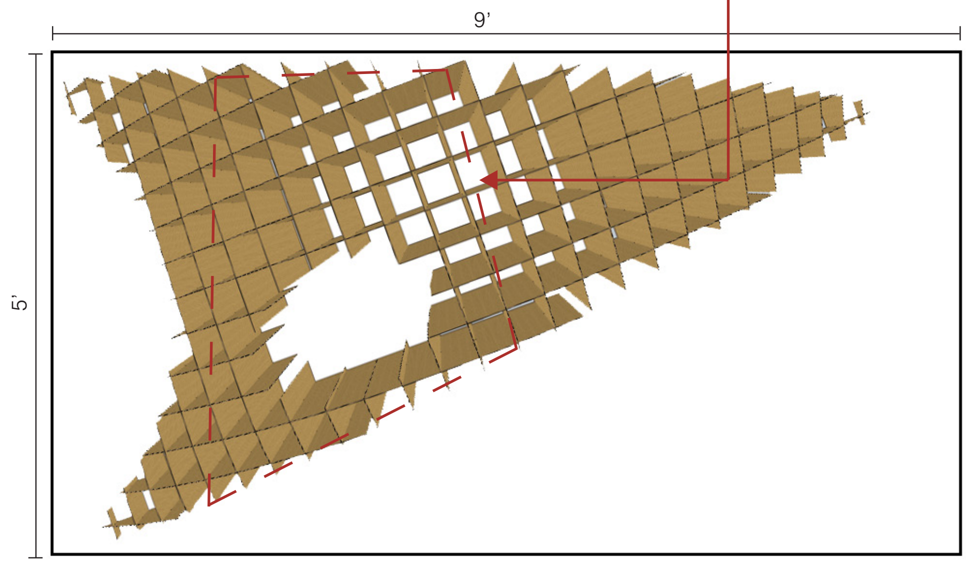
FORMWORK CONSTRUCTION

Modeling our project proved to be quite the task. Our **first challenge** was providing a **smooth doubly curved surface** on both shells. We accomplished this with a **waffle grid formwork,** developed by putting our Rhino model into Autodesk Slicer for Fusion 360. In order to make this rigid enough and solid enough to pour concrete on, **newspaper and spray insulation** were used to fill the voids. After cutting enough foam off to get down to the cardboard and get the curved shape of our shell, we were still left with a very porous surface, and therefore ended up putting a layer of **plaster** over the whole form. This was repeated for the upper shell's formwork. Once the first shell was poured, we excavated part of its formwork to get the cross-through effect we wanted. **Foam blocks and curved rebar** were employed to help reinforce and **ensure a continuous pour** through the bottom shell. Even though the design was challenging in form, the meticulous thought that went into the formwork ensured our success.



MODELED PORTION





LOWER SHELL CONSTRUCTION

ASSEMBLE WAFFLE

SPRAY FOAM AND CUT SMOOTH

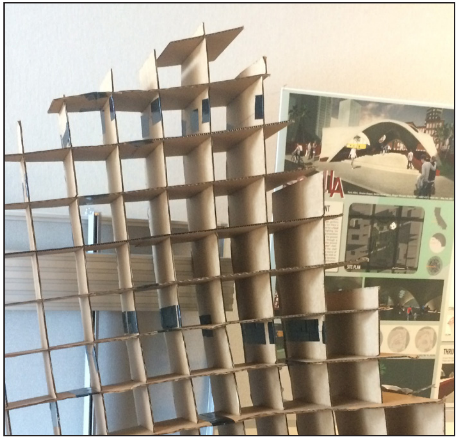
PLASTER LAYER OVER FOAM

SECURE FORMWORK

CUT AND LAY WIRE MESH

POUR AND SMOOTH CONCRETE

UPPER SHELL CONSTRUCTION



ASSEMBLE WAFFLE

SPRAY FOAM AND CUT SMOOTH

PLASTER LAYER OVER FOAM

BUILD BOTTOM FORMWORK

BEND AND LAY REBAR

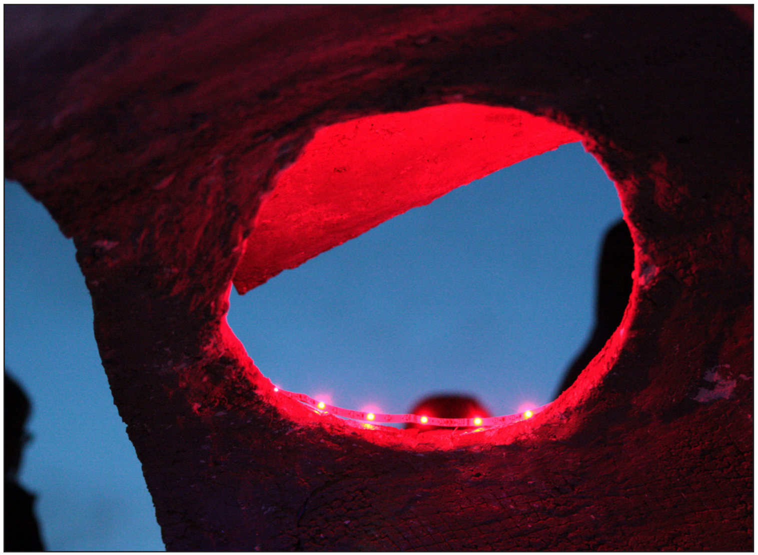
POUR AND SMOOTH CONCRETE

FINAL PRODUCT // DAY

FINAL PRODUCT // DAY

FINAL PRODUCT // NIGHT

FINAL PRODUCT // NIGHT



REFLECTION

Despite being different majors, our whole group certainly found this studio a unique, but worthwhile experience. We definitely believe that Ed's mantra of "you can't tell who's an architect and who's an ARCE" was especially applicable to our team, as we balanced all responsibilities between the two disciplines, and never found ourselves having a disconnect between the design and its structural feasibility or placing more importance on one discipline's contribution than the other like is typical of the professional world.

Some of our biggest challenges this quarter did not come from our team dynamic, which was essentially perfect as far as team projects go, but from multiple outside influences that were skeptical of our design choices and worried for our success later on in the quarter. In retrospect, we are extremely happy of our choice to stick by our design and see it through until the end despite the possibilities of failure, because it shows just how much can be accomplished when different fields work together. That being said, I think this was also a valuable experience for each discipline to see what skills the other uses on a regular basis and how to combine them into a successful project, since we're usually only exposed to the other group's curriculum once or twice throughout our education.

With how complicated our design was, looking back there are definitely some things we would have done differently, despite how successful we were in designing and constructing our double shell structure. The first thing we would have done differently was to start with a hanging cloth model, or multiple, instead of relying on tripods and Rhino's patching tool to give us our vertical form. This would streamline our design process, and work as a more convincing visual aid for critiques. Additionally, digitizing the cloth model we ended up with ensured our success when modeling with SAP - if we had relied solely on tripods and Rhino, our shape would probably not have been completely funicular. The next learning curve we had was while constructing our formwork, but wasn't so much a problem as a means to be efficient and save materials. If we were to do the project again, we would minimize spray foam infill in the waffle by adding square supports close to the top of the waffle, much like we tried to do with the upper shell's waffle. The place we learned the most though, was after the actual construction in the revealing of the shell, since none of us had worked with concrete in this manner before. While our formwork slipped out nearly effortlessly, all of us were a little shocked with the surface quality on the inside. Given how many spots had air pockets that showed part of the reinforcing mesh, we deducted that in the future, a concrete with an even lower slump should be mixed in order to get through to the formwork's surface. To further perfect the surface quality, we should have used a plastic tarp over our plaster layer to get the extremely smooth surface other groups had. Even with these all these things we would change for next time, we still feel this was an extremely successful project and something we can be proud of!