CAST COLUMNAR BRANCHING

ERIC ENRIQUEZ | CHRIS LASKOSKI | BERNABE LONGORIA

Cast Columnar Branching is a process used to create asymmetrical columns, without any re-bar reinforcement, using Ultra High Performance Reinforced Fiber Concrete (UHP-FRC). With the latest technology today we are able to design non-euclidian geometry using computationally controlled parametric functions that allow us to determine, with precise accuracy, the optimal structural performance criteria. With the help of more affordable material for formwork, the process for developing concrete columns becomes much more desirable. Branching concrete columnar structures offer a unique opportunity to merge biomimetic form with structural geometry by implementing computationally controlled performance criteria.Because of advancements in the software used in the design and development process, precision of geometry or the ability to understand forces associated with asymmetrical loading, are no longer limited.

COST

Typical costs of formwork construction of concrete are 50% of the total costs. Utilizing an affordable and efficient formwork will allow for expedited production and construction.

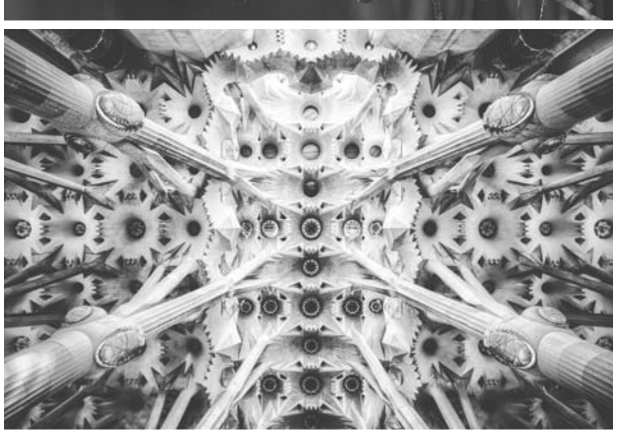
SAVING SPACE

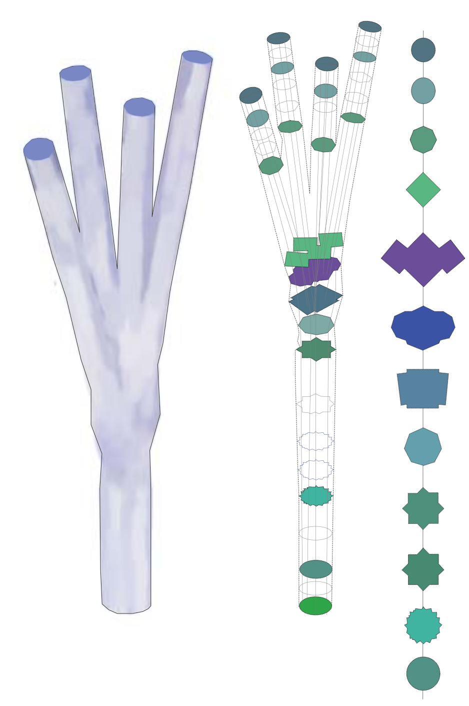
With the help of Ultra High Performance Fiber Reinforced Concrete (UHP-FRC), the amount of formwork and structural elements is reduced to maximize on space.

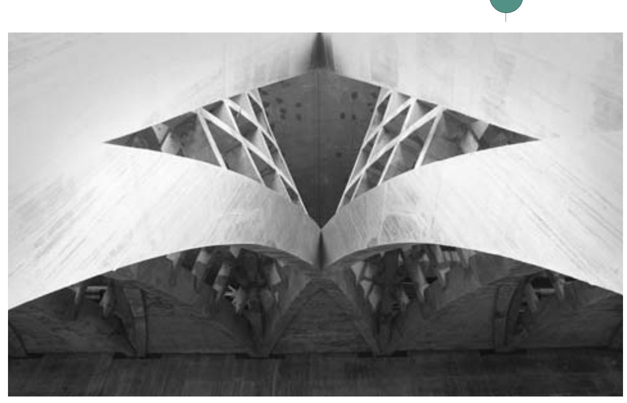
DESIGN

With the development of digitally fabricated formwork, the precision of current technology can allow for creative design in architectural and structural elements.

PRECEDENCE







One of the biggest influence to our research would be Antoni Gaudi's Sagrada Familia temple. In his desire to overcome the defects he saw in Gothic structural systems, Gaudi aimed to create a new architecture with balanced and self supporting structures.

In order to do, so he spent 10 years constructing a 1:10 scaled "hanging chain" model consisting of weights on strings that would serve as an upside down version of the arched forms he sought. Through his studies of the inverted model and graphical calculations, he arrived at the revolutionary idea of columnar branching to reach his goal of optimal support.

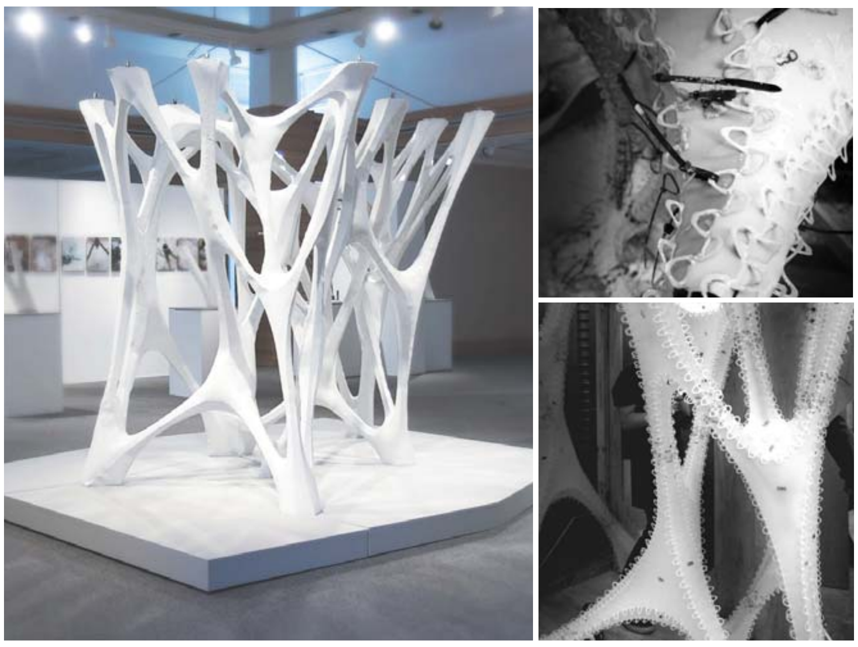
Gaudi designed all the branching columns as double twisted columns formed by two helicoidal columns. The base of each column has a cross section that is a polygon or star which twists up and the right and the left branches transform into a circular cross-section higher up.

Past explorations of non-euclidic geometries have yielded cast columnar structures using polypropylene plastic as a semi-rigid formwork. UHP-FRC is then poured into the formwork and set to cure for 28 days before structural testing is done to determine the performance of the geometry. The use of UHP-FRC is used to eliminate internal steel reinforcement.

Some of the issues that arose from the polypropylene formwork were the weak points in the zipping; due to a high amount of hydro static pressure towards the base of the formwork. Zip ties were used to tighten the seam but became an expensive solution to the problem.

PREVIOUS RESEARCH

REINFORCEMENT



CAST THICKET

Josh Hallette | Austin Ede | Adam Heisserer

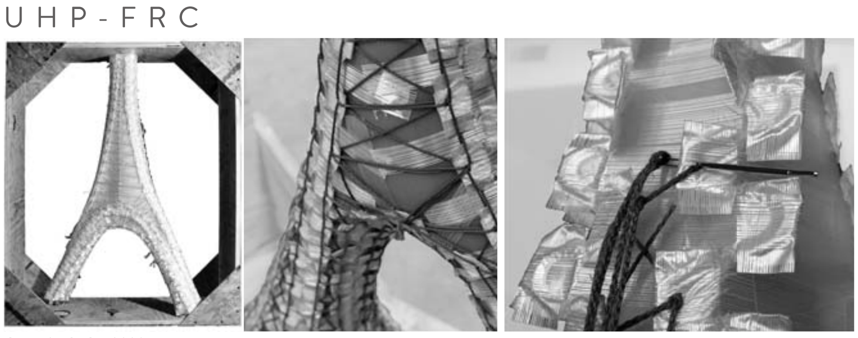
3D PRINTED NODES

LASER CUT STEEL

FALL 2015

Miriela Rico | Rene French | Cameron Martin

UHP-FRC



SPRING/SUMMER 2015

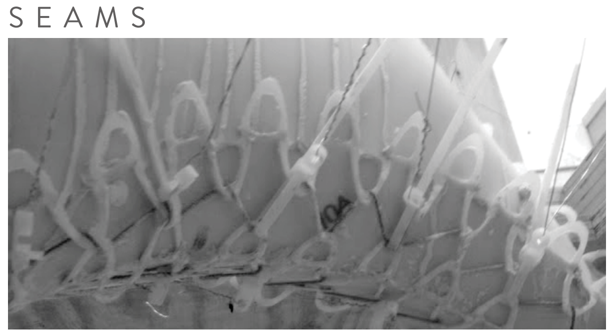
Ikram Eloualid | Elizabeth Hurtado | Hoang Le | Crystal Portillo | Victor Vielma

ISSUES

REINFORCEMENT

Initial designs incorporated concrete which required steel reinforcement. Standard reinforcement was not applicable in this situations. Custom reinforcement was nessecary. Flat steel was cut specificaly to length then custom cut down to match to the specific geometry of the formwork. Which also required custom compression rings.

SEAMS



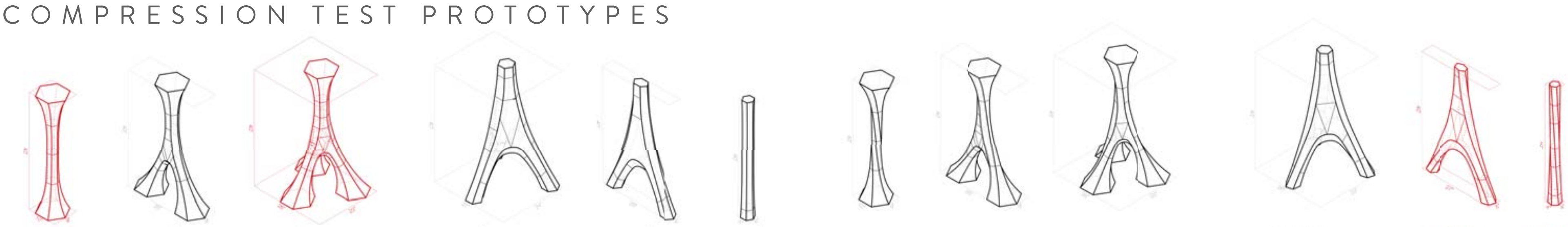
Design of the semi rigid formwork, the cutting, began with the cncing and this initial approach is very difficult to manuver. This does not result in an accurate cut formwork that is completly closes and creates a tight seal. The previous attempts at creating this formwork with the CNC machine did not result in a perfect profile regardless of material and tab profile was an issue.

BLOWOUT

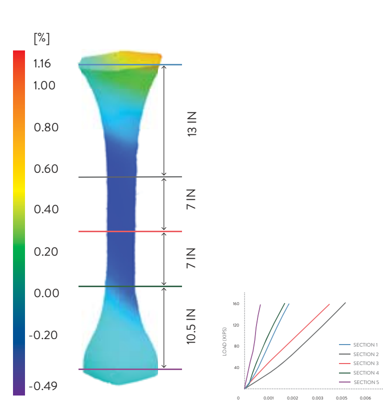
Fabricated formwork elements whose tolerences were not taking into strict consideration are prone to leaking and complete structural failure. Casting material with increasingly high amounts of hydrostatic pressure places an even greater burdon on this formwork.

MATERIAL DATA

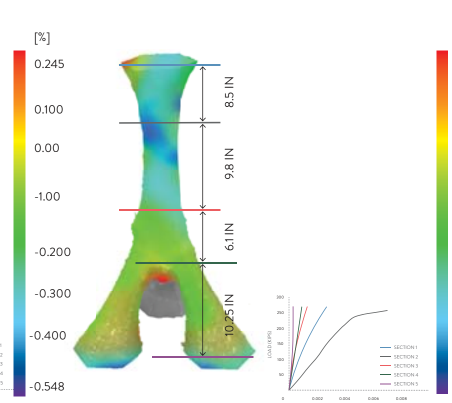
COMPRESSION TEST PROTOTYPES



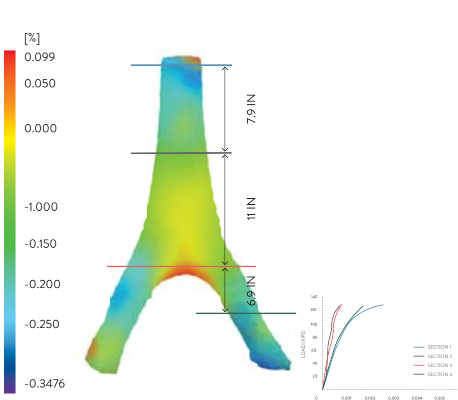
CONCRETE STRAIN DIAGRAMS



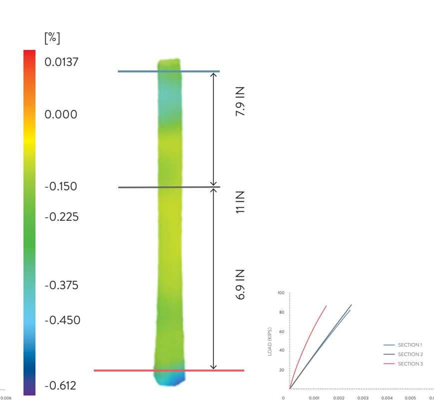
COLUMN **0**



COLUMN **2**



COLUMN **10**



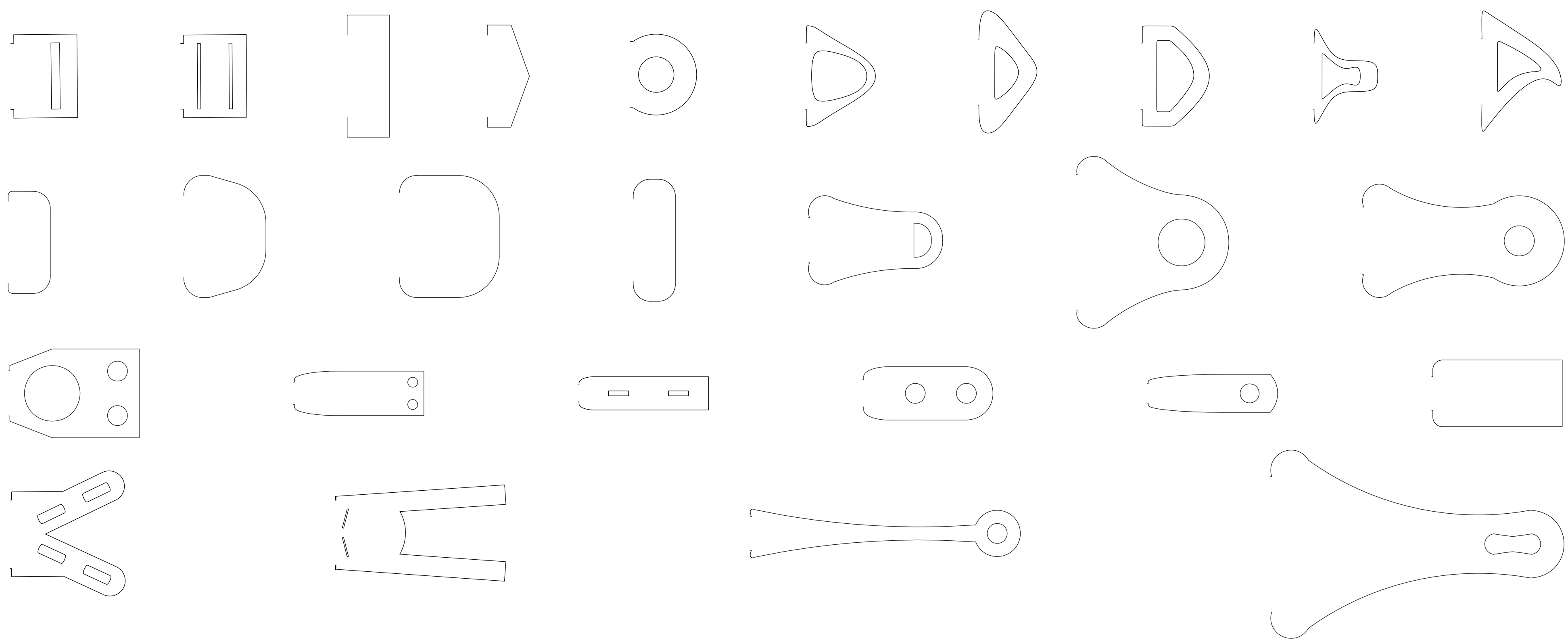
COLUMN **11**

MYLAR

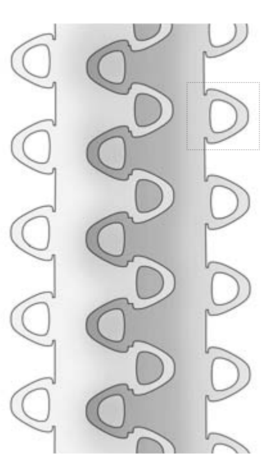
Mylar is a polyester film made from stretched polyethylene terephthalate that was developed in the mid 1950s, originally by DuPont Imperial Chemical Industries. Also known as BoPET (Biaxially-oriented polyethylene terephthalate), mylar is used for many reasons due to its high tensile strength, chemical and dimensional stability, transparency, reflectivity, gas and aroma barrier properties, and electrical insulation. With a tensile strength of 38,000 PSI it is very strong. Other materials that we tested, such was polypropylene, were thicker and became very brittle once any cutting was done to the material. While the texture and transparency were desirable to see the casting as it is poured and being cured, the benefits of Mylar's tensile strength are more ideal for the casting of high amounts of concrete.

SEAM CONNECTIONS

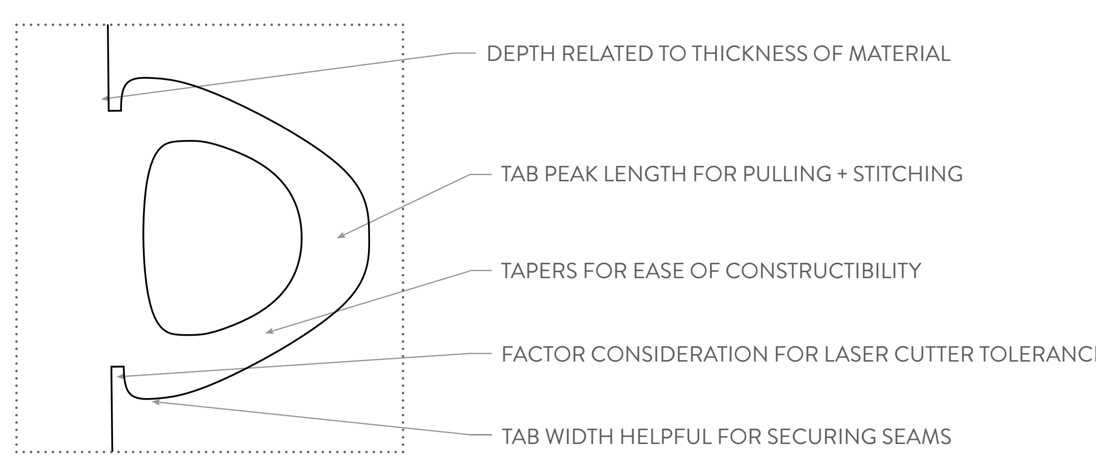
NEW TAB ITERATIONS



Due to the high amount of hydro static pressure, tab design on the formwork needs to be altered to counteract the forces acting upon it. Several iterations have arose that attempt to solve this issue. By following the force lines at the weakness, the new tabs aim to give a tighter seal at the point of two seams coming together. Previous semester research would tighten these tabs by lacing the two adjacent sections together creating tension reinforcement. The goal in the current research is to minimize the amount of labor required to lace the seams together and create a self supporting structure; similar to how a buckle works.



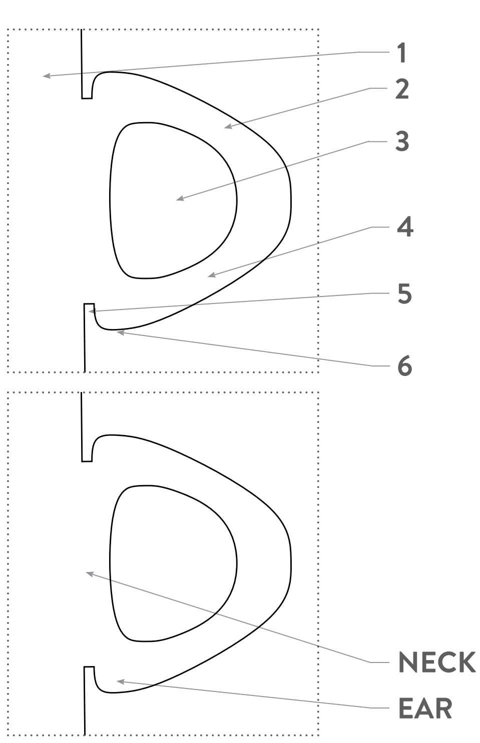
TAB CONNECTION



TAB ANALYSIS

SEAM CONNECTIONS - ANALYSIS

Our first phase of testing centered on developing a more efficient tab design. Aside from our assumptions that we could develop a better tab for a tighter seal, a self supporting structure design, and ease of constructibility, we came across several new issues that required us to alter our later iterations. Over the course of the design, we as a group, had started to gravitate to a common language when referring to elements of the tab.



1 Current material thickness is 0.014in Mylar.

2 Tab is more desirable if lengthened to a minimum 1/2in. This makes the zipping of crossing tabs easier to join.

3 Punch out design allowed for easier grip and also as a way to lace in previous forwork. In our current testing we have removed the punch-out design to decrease laser cutting time and this has little effect on being able to grasp the tab.

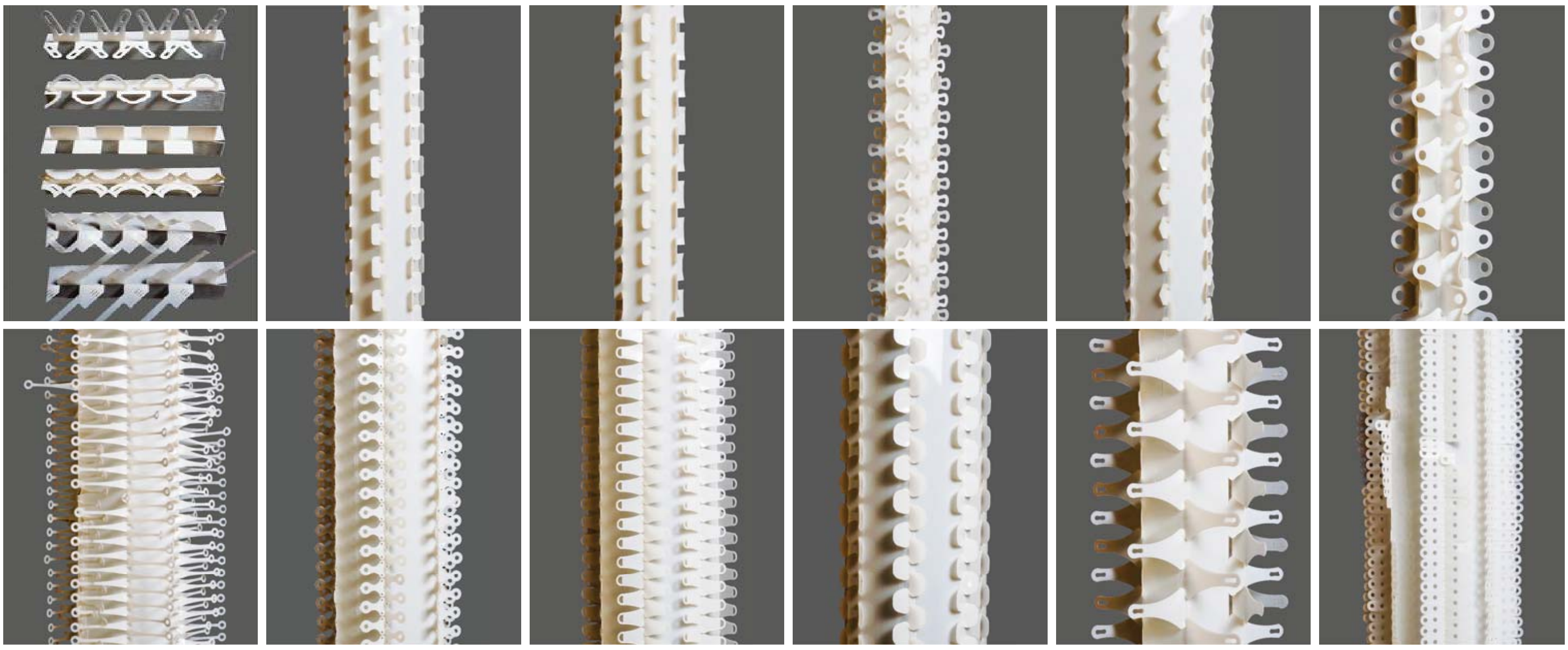
4 Rectilinear tab shapes were very difficult of assemble in comparison to curved tab geometry.

5 Width of the laser was determined to be approximately 0.014in. Therefore, the file for lasering must have the fabricated section offset by 0.007. This allows for a precise fit (Tolerance = 0).

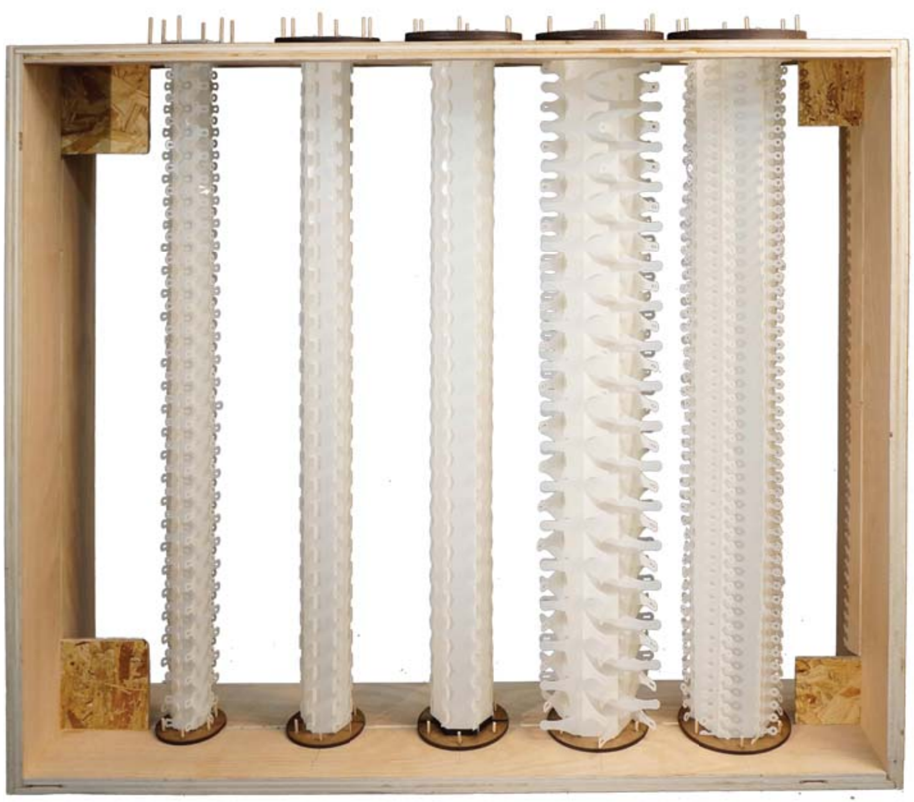
6 The curvature of the ears allowed for easier assembly of adjoining sections and may work better for curving geometry. However, for linear geometry a squared ear design creates a tighter seal and rigid structure. Constructibility is more difficult with this design method.

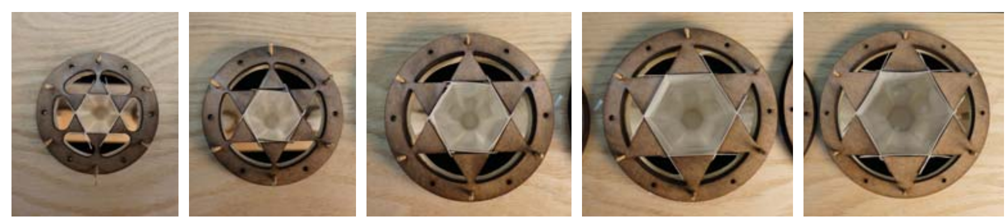
PHASE 01

FORMWORK TAB ITERATIONS



SCAFFOLDING ASSEMBLY

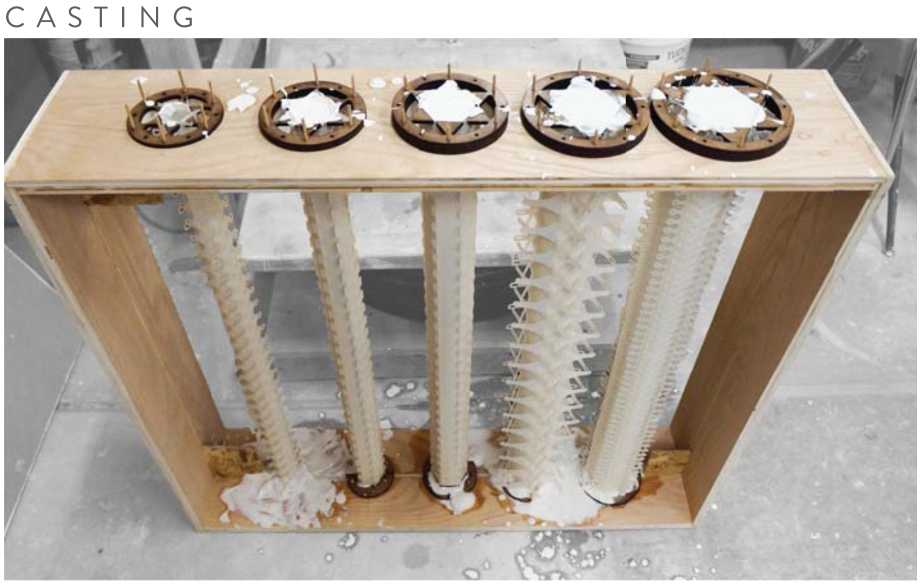




Assembly of the placement rings allowed the formwork to remain static while pouring the Hydro-Stone and for the remaining time of curing. These rings are designed to allow the tabs to slide easily through openings at adjoining angles. One visible defect in the formwork at the top of the ring was the torquing it displayed. This is due to the zero tolerance of the neck gap size. One-Eighth dowels were used to hold the rings together.

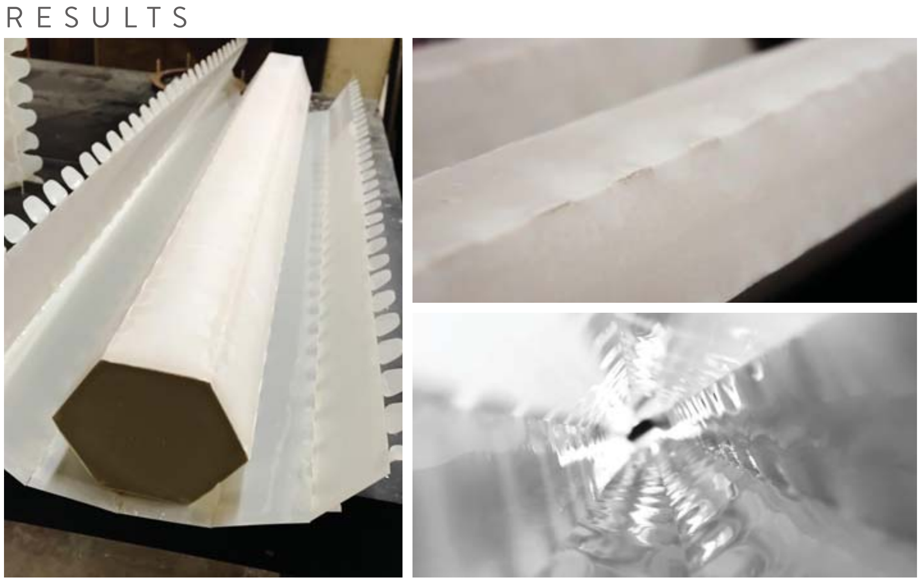
The bottom compression rings were designed to hold the base of the formwork and create a seal so that the Hydro-Stone will not leak. Some formwork needed tape at the bottom due to minor seam miscalculations. One-eighth inch dowels were also used to hold these rings in place.

CASTING



Most of the leaks at the base of the formwork were due to a failure in either the compression ring or design of the formwork in CAD. There were no “blowouts” due to a high amount of hydrostatic pressure. The Hydro-Stone casting material was purposefully mixed as a more runny mixture to really test the tightness and seal of the seam-work. The end results were a success in that there were no significant leaks along the tabs and the leaks that did occur happened at the base which is fixable by a more thorough investigation at this area.

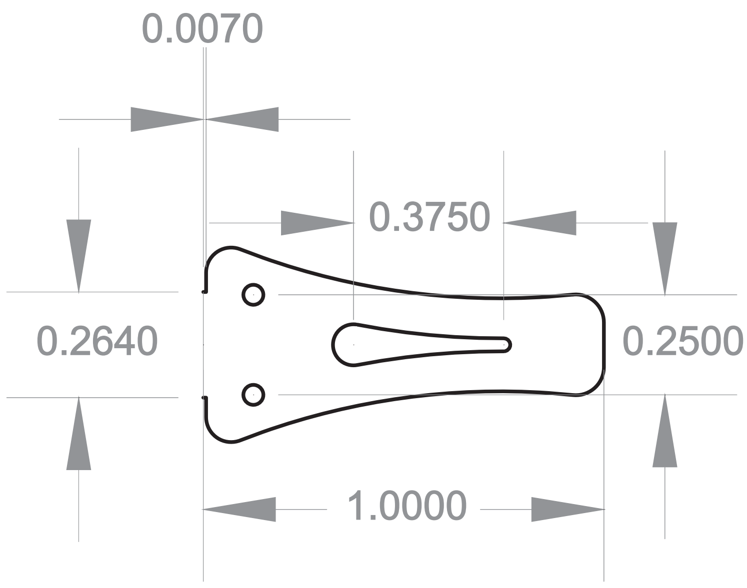
RESULTS

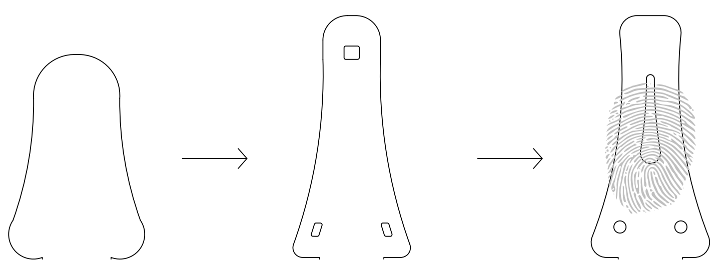


The Hydro-Stone casts were a great success. The surface of the casts resembled that of the mylar’s smoothness. One particularly interesting note was that on the iteration with zero tolerance in neck size, the inside formwork showed a rippling pattern. Our hypothesis of this discovery became that the mylar formwork would expand due to the pressure of the casting material and smooth out these ripples. However, this was not the case. Whatever the formwork pattern was, the cast would resemble this defect. On the 3.5in cross-section columns they began to show signs of bulging towards the base of the column. This was due to the high pressure of the casting material. The seam detail of the columns displayed the imprint of the tab connections. This was less apparent in columns who’s formwork neck gap was designed with a tolerance level of 0.005in-0.007in.

PHASE 02

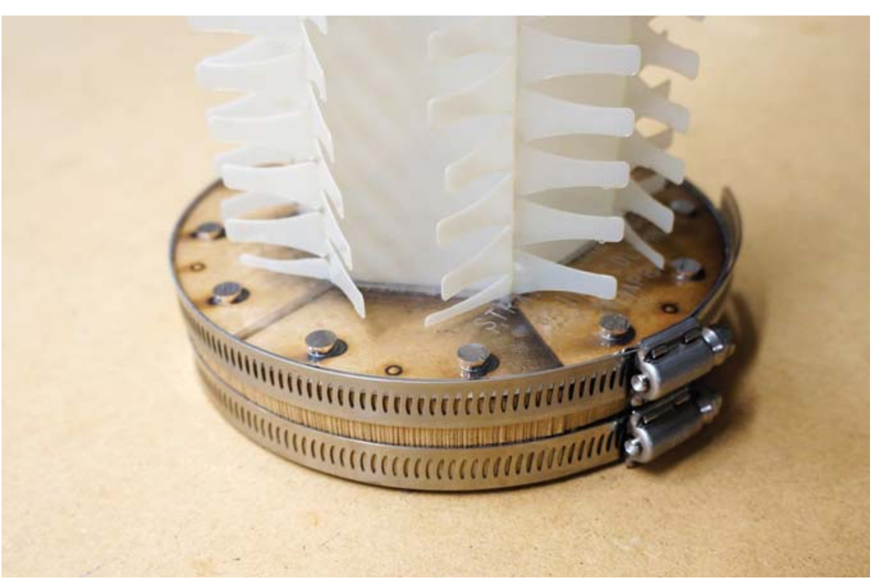
FINAL TAB DESIGN

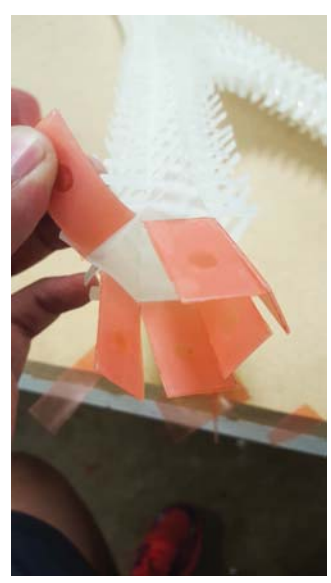


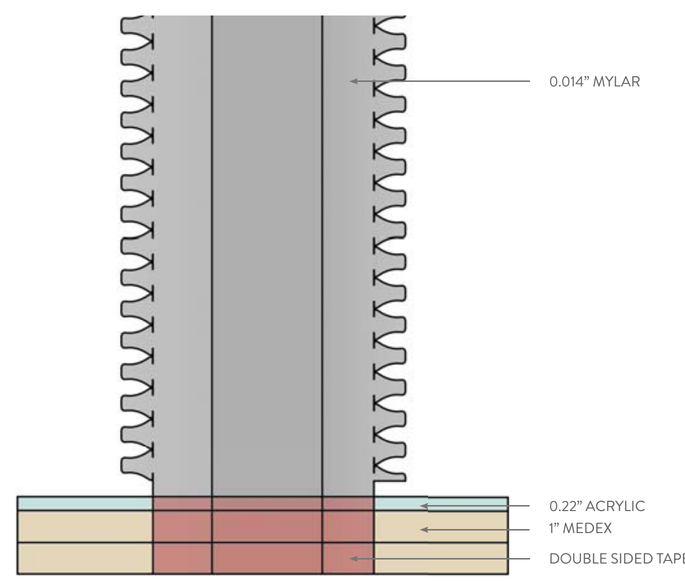


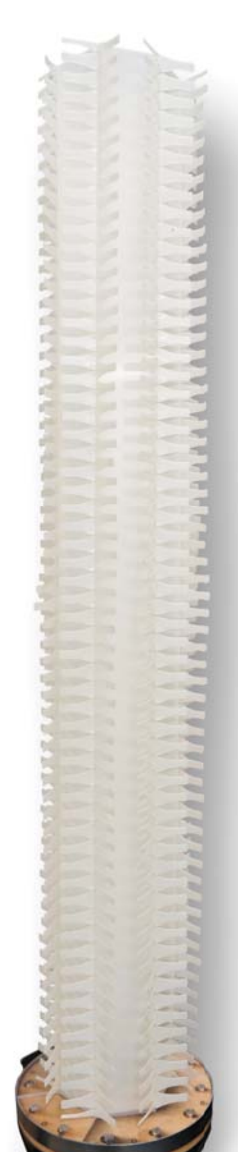
After multiple tests with different tab designs, it became clear of what the final tab design needed to be. The overall length had to be just long enough so that grasping with the fingers would be comfortable. After contact with YO-CY we learned that this ideal length would not be suitable for the moment the tabs came about a large curvature in geometry. Therefore, it was decided that the length be reduced to no less than a half-inch. As for the width of the tab, this remained constant and true to all test subjects. This width size allowed for the casted specimen to reveal much smaller seam compared to a larger width. Gap size remained a constant half thickness of the Mylar (0.014) at 0.007 to maintain the tightest seal allowable due to the material. While this seemed to have caused a rippling effect on the formwork, it was a very small detail. Time became a precious resource for this project and there were many variables we had to take into consideration. The cuttout holes on the tab were there as a precautionary means of constructing a secondary reinforcement incase there was moment of blowout. Ultimately our hypothesis became that early testing of the Mylar material showed great signs of tesnsil strength and resistance due to hydrostatic pressure. Therefore, in order to cut laser cutting time and costs down these interior cutouts were removed.

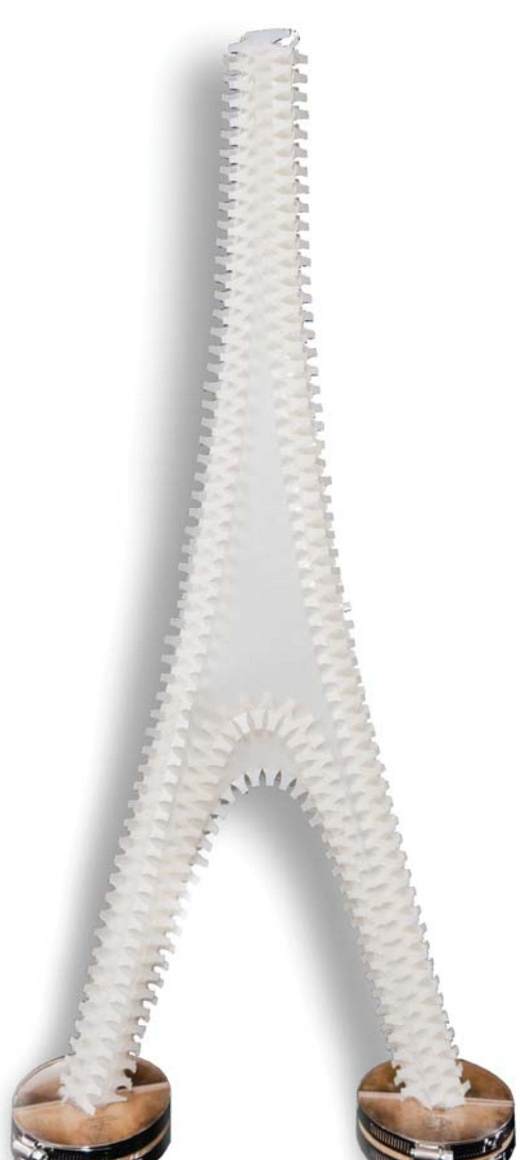
COMPRESSION RING RE-DESIGN

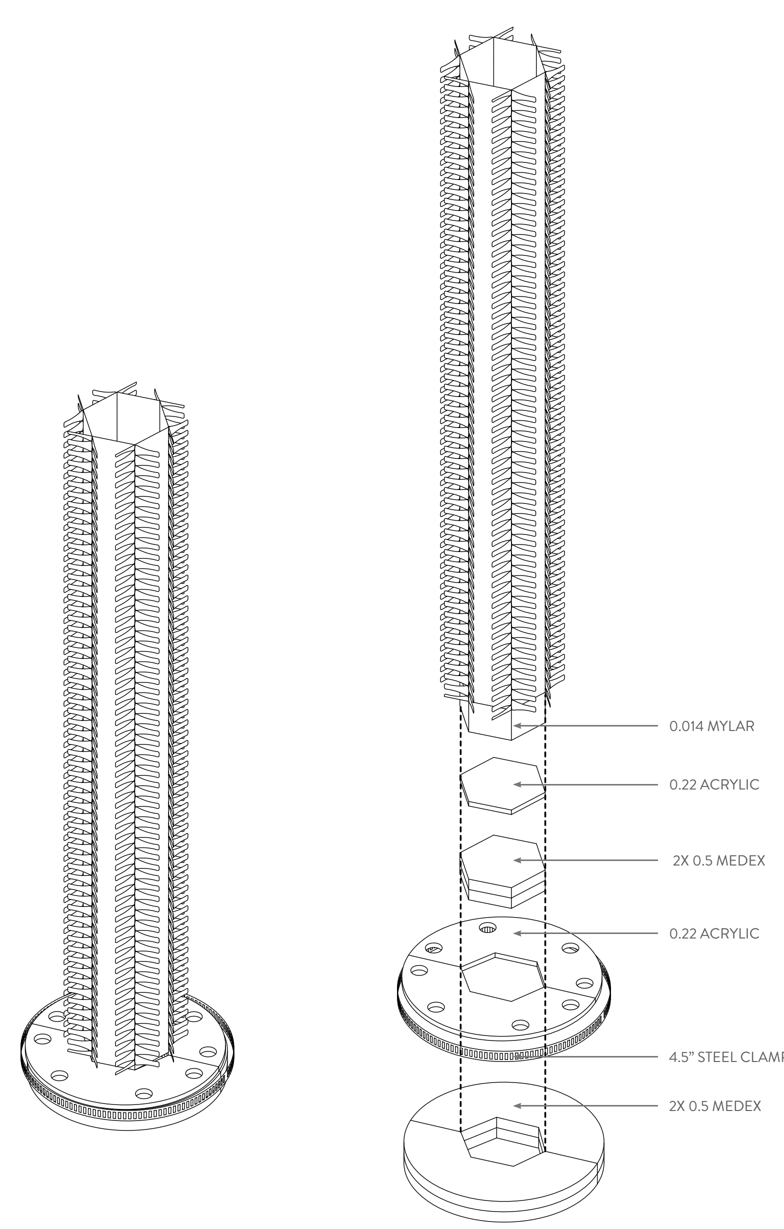












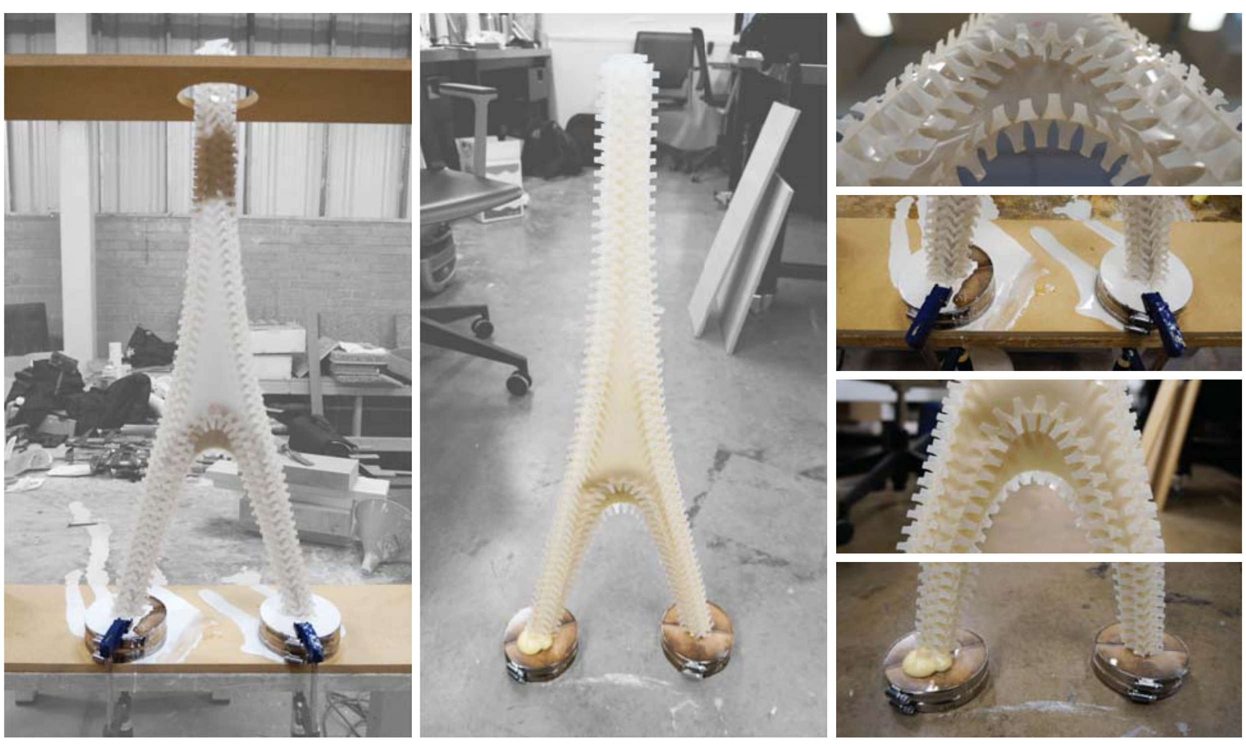
PHASE 03

STRAIGHT COLUMN - HYDRO-STONE/FOAM

Tests with the straight column at 30 inches in height went very well. The goal of this test was to look for any leakage at the compression ring. While there was some leakage this was mainly due to the termination of tabs at the base, resulting in a weak point in the formwork allowing Hydro-Stone to leak. Although, this should not be considered a failure.

In previous tests with foam and the older compression ring design, the result was that the formwork removed it self due to the high amount of pressure of the faom. The new design was successful in keeping the foam static. As with the Hydro-Stone test there was a small amount of leakage at the base but this was expected as a result of testing the Hydro-Stone. Our conclusion to this test was that both were succesfull and the same results were to be expected with casting UHP-FRC.

SADDLE COLUMN - HYDRO-STONE/FOAM



One of the greatest unkowns about the geometry from Yo-Cy was the point at it's greatest curvature, or as we called it the "saddle". To test this area, a section of the 60 inch geometry was taken to test in Hydro-Stone and expanding foam.

Initial thoughts on the Hydro-Stone were that the low viscosity of the plaster would be great enough to leak at the curvature. After testing, there was absolutley zero leakage to our suprise. However, again, due to the termination of the tabs at the base of the formwork there was a great amount of leakage.

Foam testing on the saddle proved to be a great success in that the compression ring did it's job of holding the formwork down to a static position. The point of greatest curvature was also unaffected by the high expansion of the foam. Although, a moment of bending in the formwork was discovered.

RESULTS

Hydro-Stone Column

Hydro-Stone Saddle

Foam-iT! Column

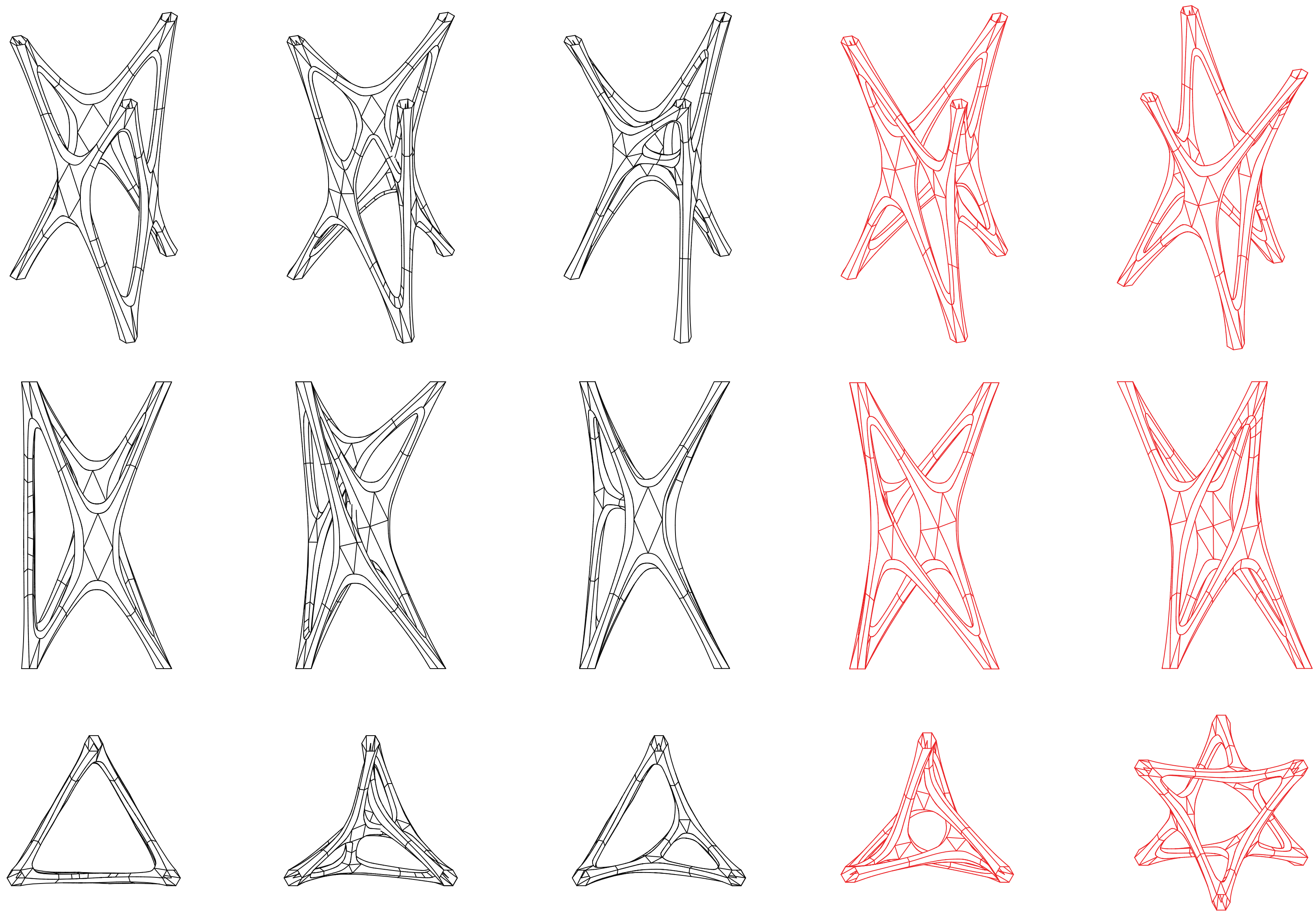
Foam-iT! Saddle

These two column tests were very important in our first steps to see if our overall final tab design for the project would really work. The Hydro-Stone casts differed in ways we did not see coming. On the left we have the simple column solely testing the tab on a curved form, what we know as the "saddle", which turned out completely different. Although no plaster escaped from the saddle's seam, proving the design of the tab could hold in any poured substance, plaster escaped through our compression assembly. With such a small diameter, we felt no matter how much compression we added, possible other reinforcement to the mylar on the inside such as screwing into the wood could possibly aid this better.

The Foam tests were completely new to us. The expansion rate of this substance was so great the first test it pulled our compression assembly completely out of the scaffolding and ripped our seam apart. These two being more advanced in design, the expansion rate escaped minimum amounts through the seams but did not decimate our compression assembly. Towards the end of both tests we could hear the foam trying to tear the seam apart, almost like popping and cracking sound, but overall did not tear anything apart.

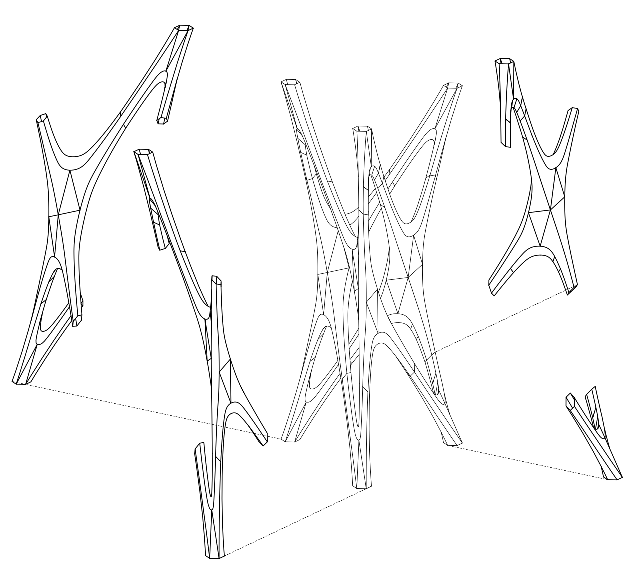
GEOMETRY

MASSING 1-5



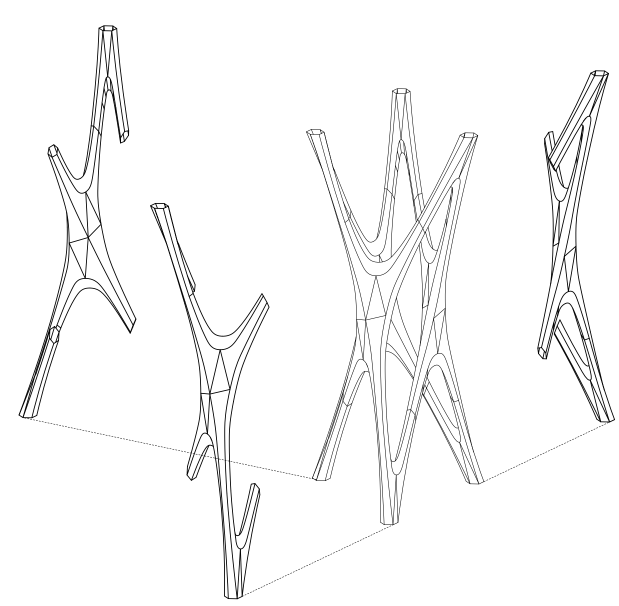
1 2 3 4 5

MASSING 4



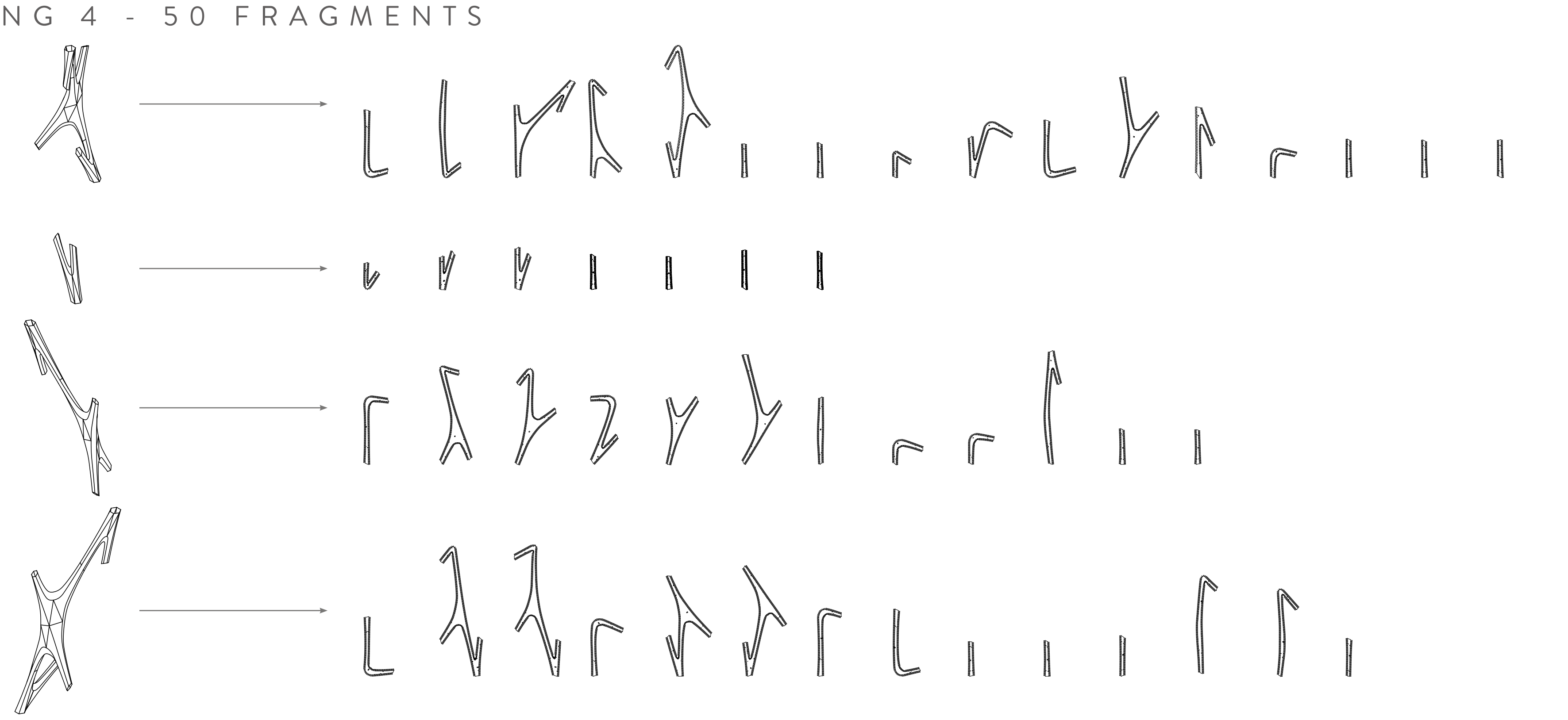
Exploded Isometric

MASSING 5



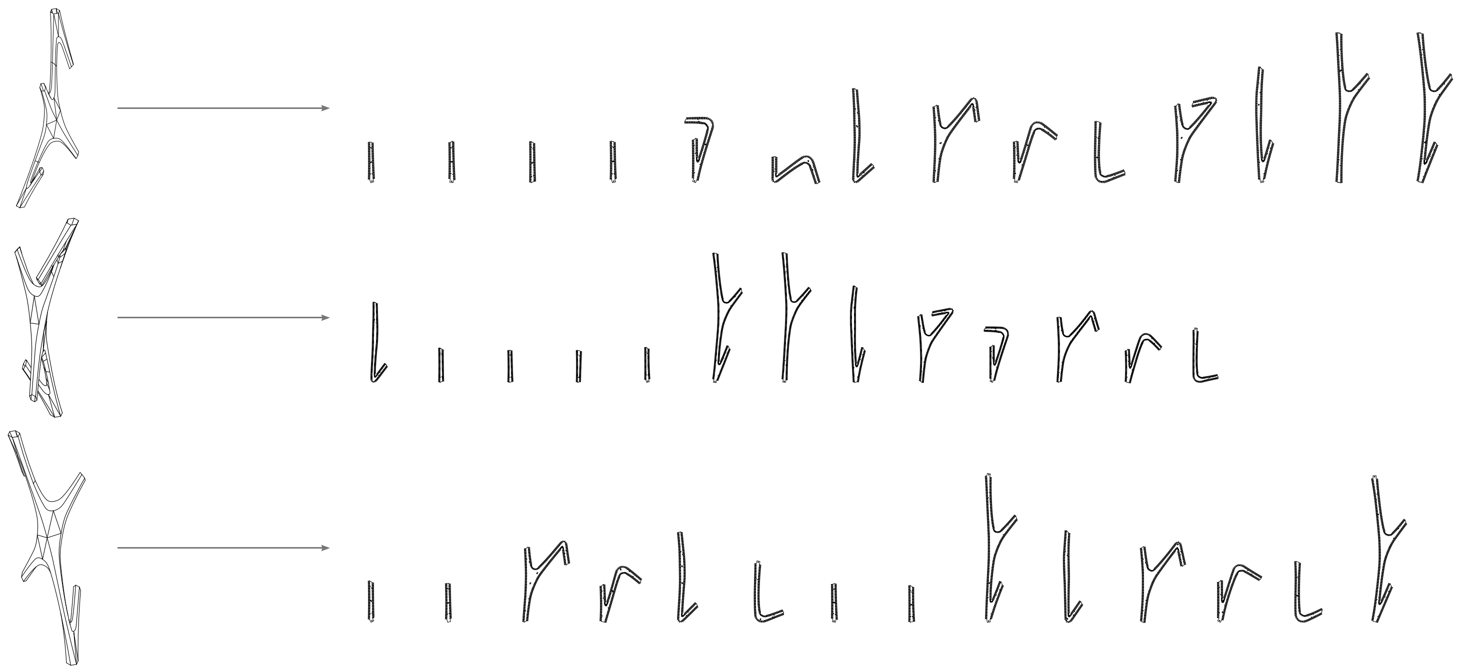
Exploded Isometric

MASSING 4 - 50 FRAGMENTS



GEOMETRY

MASSING 5 - 41 FRAGMENTS



Collaboration with Yo-Cy has been a huge impact with the continuation of this project. Upon creating the past non euclidean forms, they created five completley new forms for this project. Out of the five recieved, two were chosen that were beleived to be more successful in casting. Each form chosen was divieded into several parts to complete it as a whole. Each part to contribute to this whole was also divided into several pieces to be manufactured via precise laser cutting. Both specimens were aproximately five feet in height, with a foot print of two feet by two and half feet.

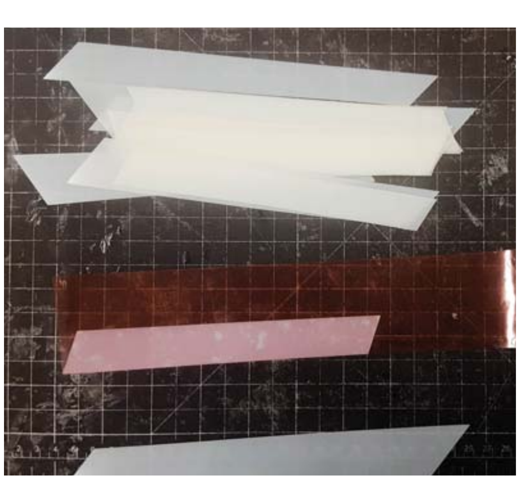
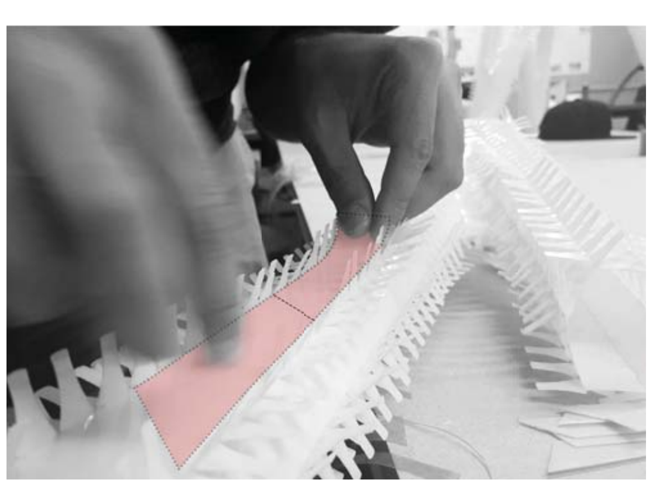
ASSEMBLY

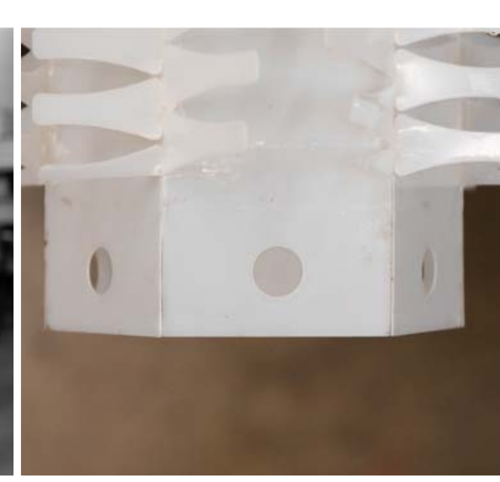




We were able to get in contact with Dragon Street Laser in Dallas, a local facility with a large size laser cutter, to help us in manufacturing the pieces provided by Yo-Cy. Once pieces were cut from Dragon Street Laser we began assembly of the formwork. The average cut time per geometry was roughly 8 to 12 hours. The average assembly time was of the formwork was 12 hours with two people.

MODIFICATIONS

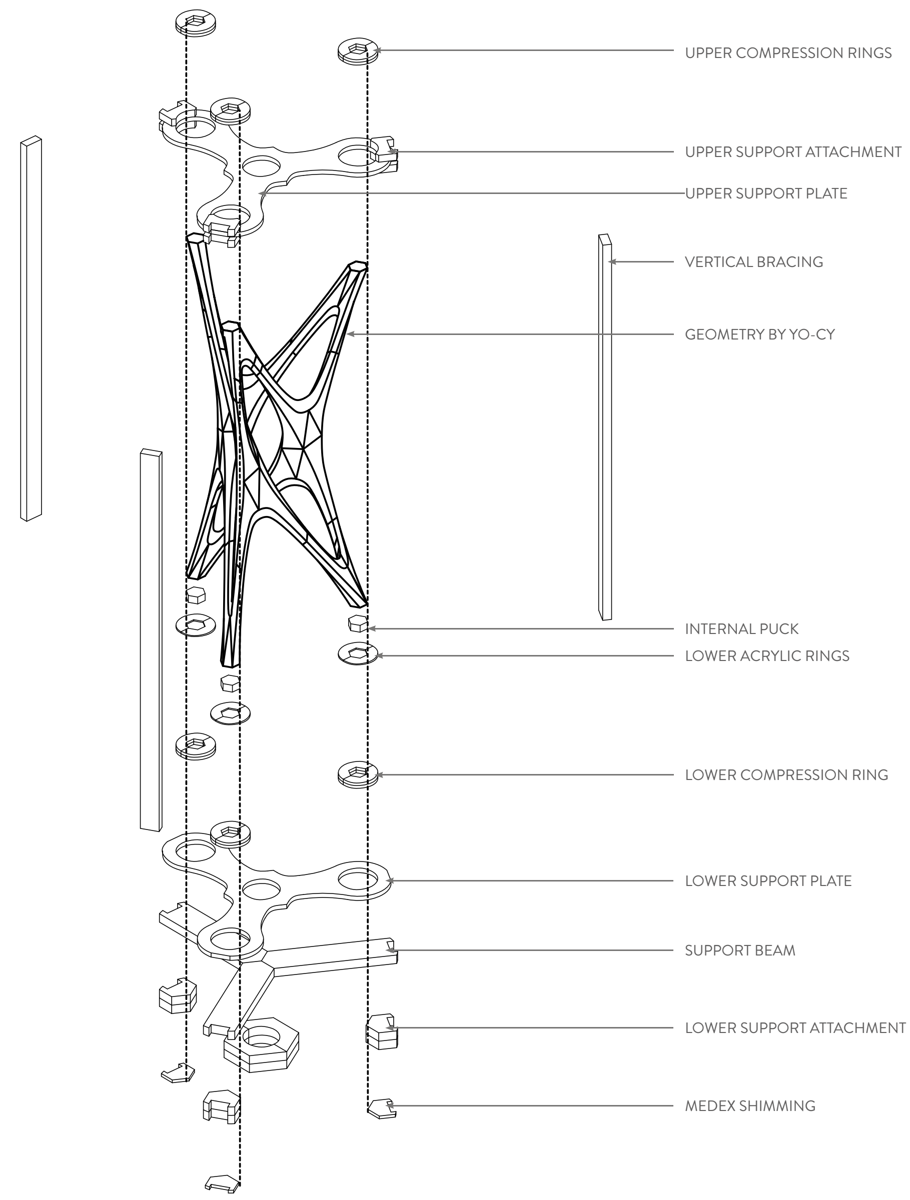


Once assembly of the scaffolding was complete there were a few modifications that needed to be addressed. One, being that the geometry was seperated into 4 sections. Attempting to resolve for this, it was decided to apply high-strength double-sided tape with a mylar bridge acting as a bandage. Two, the bandage would not be enough to hold the jointure from shear so once again high-strength double-sided tape was used with mylar attached to act as bracing on this jointure. The last modification that needed to take place was to create an extension on the laser cut pieces to attach to our base. This would in essense become a component in the function of the compression ring. The holes on the extension were originally to act as an area for a pin to enter to hold the formwork from moving off of the compression ring but concerns for puncturing the Mylar were high.

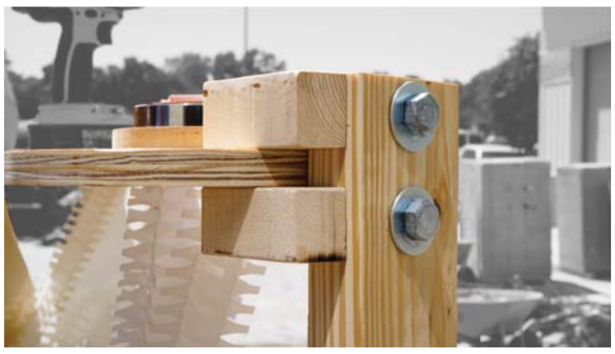
SCAFFOLDING

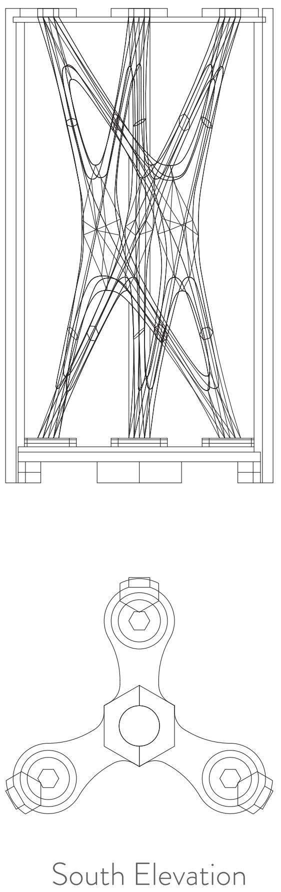
CONSTRUCTION

38" x 33" x 68" Scaffolding for Massing 4

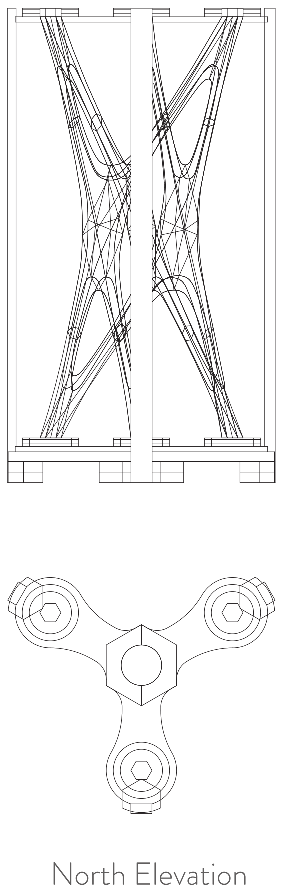


DETAILS

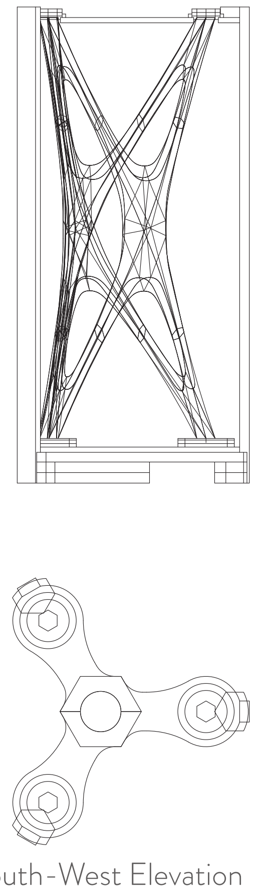




South Elevation



North Elevation



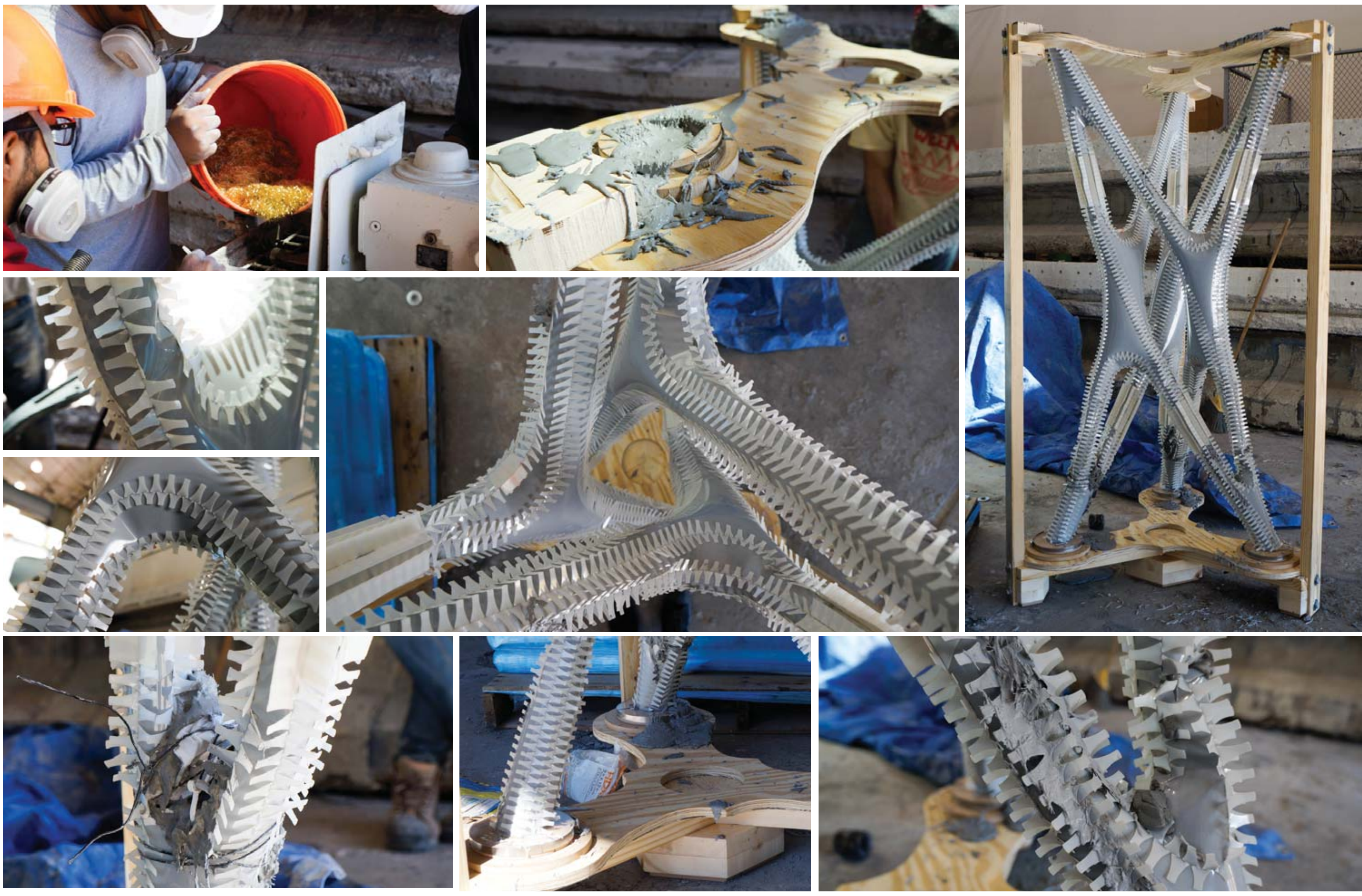
South-West Elevation

Scaffolding design for Massing 4 began early in the process on assembling the formwork for Massing 4. The understanding of the compression rings helped shape the design of the scaffolding. A few things were also taken into consideration such as, the mobility of transporting the structure to and from the Architecture building and Civil Engineering Building, the ability of the upper and lower formwork connection points to have the ability to adjust based on the pressures of the UHP-FRC within the formwork once cast without allowing for movement vertically, and to minimize the amount of scaffolding to allow for maximum vision on the formwork for casting and analysis.

The scaffolding arrived to the Civil Engineering building without that top plate to ensure stability throughout transportation. The Upper Plate was then assembled on site, followed by attachment of Upper Compression Rings. There was a miscalculation with the inner acrylic rings, therefore, the Upper Compression Rings were rendered inoperable. To resolve this issue, a single screw at each top node was placed to hold the formwork up.

CAST

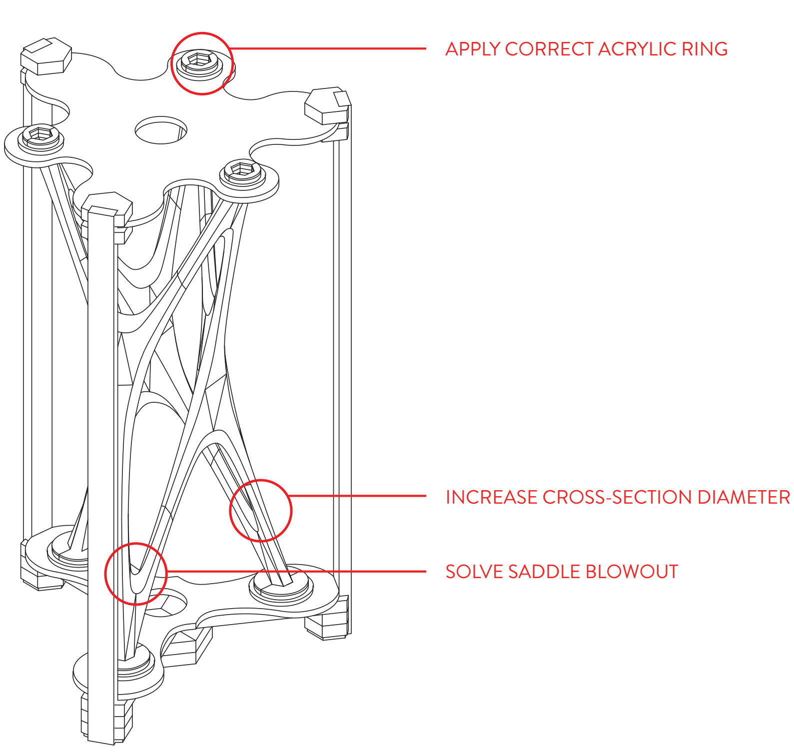
ULTRA HIGH PERFORMANCE - FIBER REINFORCED CONCRETE



RESULTS

Mixing of the UHP-FRC, developed by the UTA Civil Engineering department, took approximately 10 minutes. The knowledge and expertise that they bring to this project is crucial to understanding the results of the cast and the next steps we need to take in order to take this project to the next level. As we then began to pour the mixture into the formwork, careful documentation of the process was taken. There are three openings at the top of the scaffolding to allow the UHP-FRC to flow. The proccess of pouring would be that we rotate around the formwork and pour a little at a time, evenly distributing the concrete. The compression rings at the base were a success throughout the entire process. No leakage was visible at any of the three nodes. As the concrete was halfway poured a noticable bend in the formwork occured. This bend would appear at all three legs where the legs split into two. One reasoning behind this may be because of the weight of the concrete at the midway point too much for the small cross-sections at the lower half. The concrete was filled to the top and we checked for any drop in the formwork based on any movement occuring at the top of the scaffolding. All was well with the cast for about 10 minutes then a burst at one of the lower saddles occured. This was immediately patched with some fabric and wire. A couple minutes later a second burst occured.Two saddles were patched and no more blowouts occured and the cast was left to cure overnight. The next day it was discovered that two more bursts occured and the concrete had spilled out and onto the floor. This was very dissapointing to the team. However, if there was any positive points to be taken from this it was that we had solved what we were asked to solve in terms of creating a tighter seam by redifining the tabs of the formwork and also preventing any blowouts form occuring at the base of the formwork via compression rings.

NEXT STEPS



Scaffolding for Massing 5