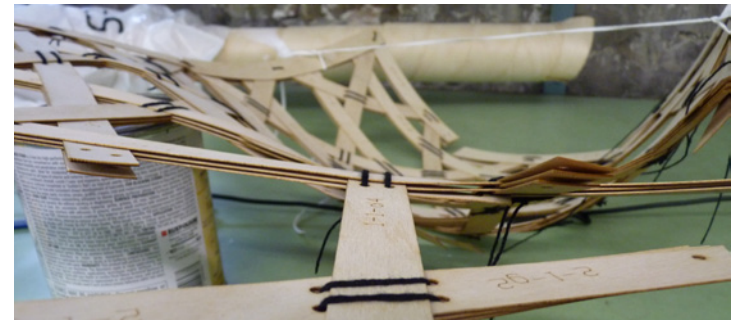
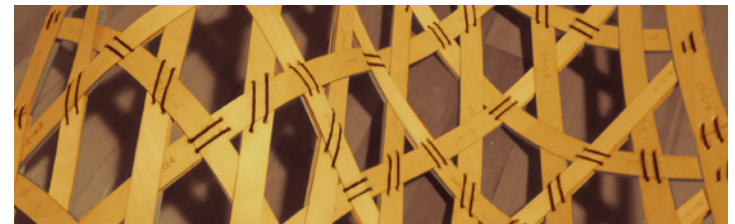


# ARCH 678 FINAL REPORT 12.21.2010

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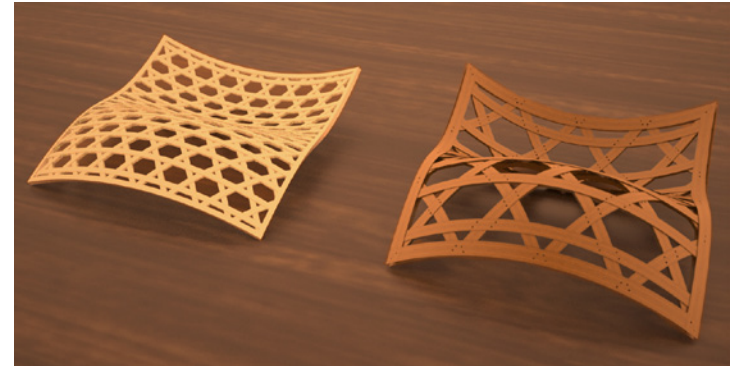
## INTRODUCTION

A clear understanding of objectives met and content learned is illustrated throughout our design process from early iterations to final model. This report will give a concise overview of our initial objectives and approach as well as our improved understanding of concepts and methods relating to the grid shell.

We began with an experimental approach: our scripting was an iterative process beginning with the stock script provided in class and ending with a completely re-engineered product. Our attitudes toward fabrication adapted as our focus in the second project became less real-world oriented and more effective in its own right. The first model was extremely successful in respecting hypothetical site constraints involving delivery, material and joinery. However, this initial approach resulted in a delicate scale that was far too ambitious to physically complete. Learning from this approach, we adapted our second project to suit more immediate, realistic limitations (leaving the importance of mimicking a real world construction scenario aside) and shifted development attention to perfecting the appropriate application of joint and material members.

## GEOMETRY AND FORM

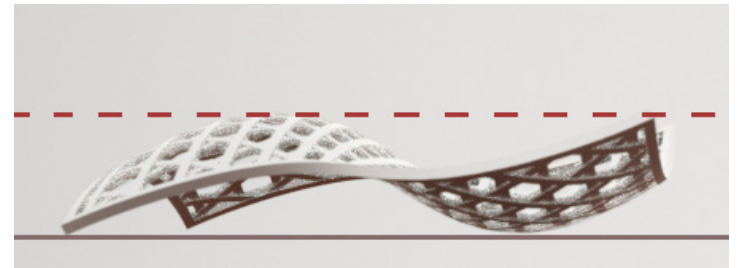
The form of our initial design was based heavily on the built geometry of the Metz Pompidou. Our doubly curved surface related back to the waves of the project, while remaining buildable in model form. It was important in our approach to maintain a realistic amplification as we based our design off of real-world construction limitations. As our second approach related less to a realistic fabrication and assembly, it gained a more extreme curvature. It was important however, to maintain the same limitations of the double curve: thus we avoided building to suit a spherical form, but rather a domed surface. The final element affecting our form was the material limitation of the wood. We will discuss this further in our design process and fabrication explanations.



COMPARISON OF FORM:

LEFT, FIRST PROJECT  
RIGHT, FINAL DESIGN

INCREASE IN AMPLIFICATION FROM FIRST PROJECT TO FINAL

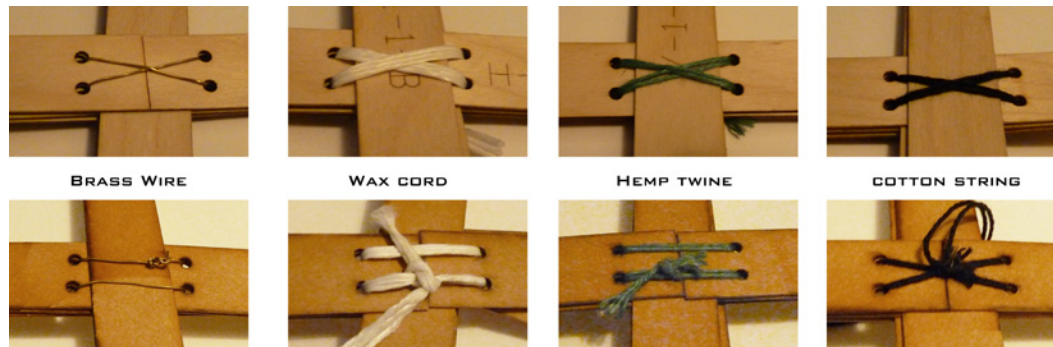


## DESIGN

While defining the limits of our form, the veneer material also presented important design considerations relating to the rigidity and density of our bands. To save time and material costs, we made the decision to halve the number of bands from our first model and scale their dimensions to suit the material stiffness. This decision resulted in fewer joints and therefore, a reduction in weakened connection points and significantly less construction time.

### Weave

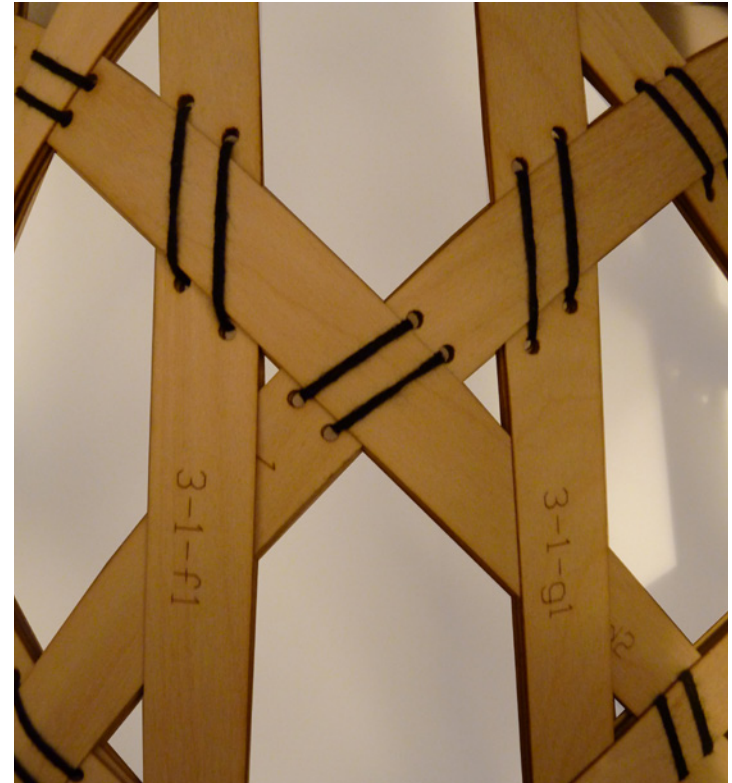
In addition to material stiffness we also incorporated a weave into the original grid design. This weave not only reduced upward deflection inherent in the joint design at the end of each member, but also ensured forces were transferred within the structure as a whole rather than carried through each member individually.



### Joints

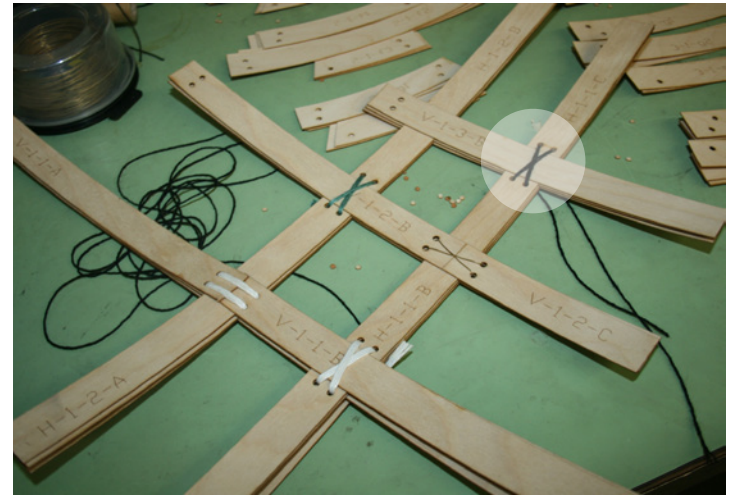
Before the weave was introduced during the design of our final model, we relied on effective connection joints to maintain a smooth transfer of forces. Despite the obvious advantage of assembly time with regard to rivet connections, we originally opted for a lashed joint. This decision afforded us more secure and controllable connections in addition to minimized material weight and cost. The lash joint was also attractive for reasons relating to our 4-hole scripted method of connection (description included in the holes explanation). We consciously decided to lash our material continuously through each of the four holes, implying a cross stitch rather than two parallel loops through opposite holes. The obvious benefits of this allowed us to keep the tension consistent throughout the entire joint and similar to the weave, minimize deflection at the ends of each connected member. With the cross stitch, there were not only two parallel ties clamping the edges down, but also a third, center point on the opposite face, providing extra rigidity while maintaining compressive strength.

WEAVE DETAIL





The change in joint material was a key distinction between our first attempt and the final model. The original model incorporated a brass wire joint, which was extremely well suited for the model's cardstock material. Its rigidity was an added benefit when sewing the wire, meanwhile it provided some problems when making last minute shifts in the model during assembly. The wire had excellent tensile control where it allowed us to finish the stitch by twisting (hence tightening) rather than knotting. As well as it worked initially; the wire was not an appropriate material to introduce to the veneer structure of the final project. Its strength would no doubt have sheared through the grain of the wood, while its slippery nature would fail in providing essential friction for the joints. For the final project, a series of joint tests were conducted. Our initial hypothesis involved large holes and a wide string to introduce a distribution of shearing force on the veneer. We found, however, that the wide string did not give us the amount of tensile strength required in the connection. As a result, we developed a cross stitch that involved sewing a thinner thread material twice through the joint. During our mockup we also noted the importance of the knot in ensuring a tight tie. Beginning with a simple granny knot, we then experimented with more complex knots, settling on a reef knot for its simplicity and added strength.



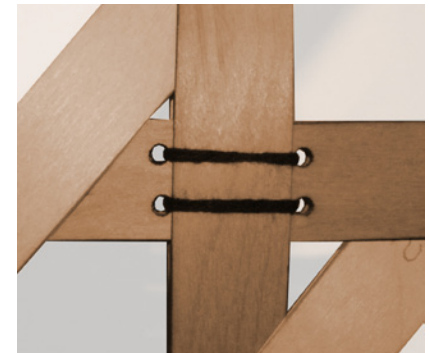
## Holes

Our initial approach to holes involved a design that not only lashed continuing bands together, but also strengthened each joint. Rather than keeping with the trend of a single rivet connection on each slice location, our decision to tie members together implied multiple holes offset from each slice by the exact width of the intersecting/ overlapping member. In the end, we considered a number of options, but a simple cross-stitch implied by two sets of straddling holes provided each connection with optimized strength and rigidity. Rather than singularly relying on the compression of a rivet and having to introduce a secondary strategy for adhering the ends of each connecting band, our multiple holes ensured that the friction of the joint as well as tension within the stitch would provide a secure combination without jeopardizing the integrity of the member material.

While our overarching connection strategy remained the same throughout both designs, there were some noteworthy improvements made during the development of our final model. The most obvious improvement made was an enlargement to the diameter of each hole. This quickened the pace of sewing each joint (keeping in mind we needed to thread each stitch through twice for the final model) while better suiting both the band and joint material. A second and essential change made between each model was the hole orientation. Initially, our script had not accommodated the direction of the lateral bands within the grid shell; thus the holes were not entirely parallel to the band which they were designed to keep in place. In our final model, the script was developed to solve this problem, ensuring each connection joint, whether perpendicular or oblique, was equally as strong.

ORIENTATION OF HOLES:

PERPENDICULAR MEMBERS



OBLIQUE MEMBERS



# Edge Bands

Our approach to edge bands changed dramatically from first design to final model. Initially, we had assumed the edges were acting similar to a tension ring, keeping the curved form in place. In response to this assumption, we designed our first model with vertical edges connecting the top and bottom bands together to literally “box” the ends of the structure in. It was intended that this approach would be more effective while keeping with a similar style of stitched joinery. Once 50 percent of the model was built and an edge band placed in its intended location, we realized that the curved surface was relatively self-supporting and the boxed edges were only loosely clamping down on each member. A re-evaluation of this approach suggested that we could rely solely on a successful clamping of the edge bands to provide what little framing the grid shell surface needed. This revised strategy resulted in a re-design of the holes as well as an eventual widening of the edge bands. Each of these changes can be observed in the most recent grasshopper script developed as well as in our final model.

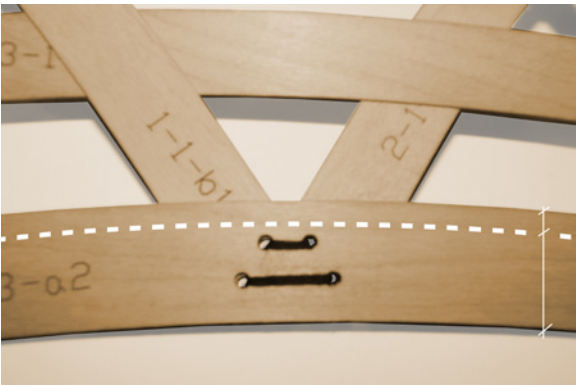
# BUDGET

In order to fit within the prescribed budget, we made the following decisions: we replaced expensive brass wire with more effective and donated black threading, engineered efficient member dimensions (cut intervals and overall length) and strategically arranged our laser cut sheets to minimize waste. Please see our budget breakdown for further details regarding the costs involved.

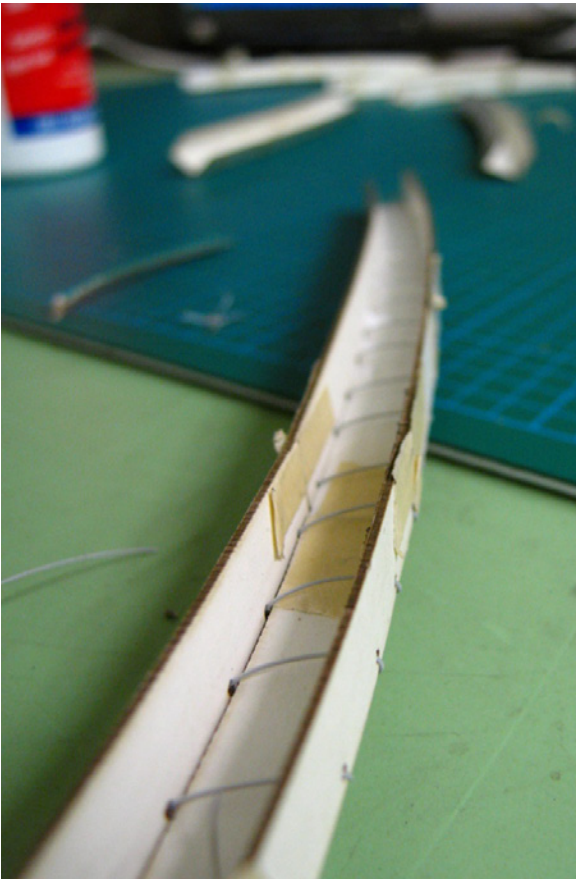
Budget breakdown:

Joint material (black thread)	Donated	\$0.00
Lasercut time	Paid for by ARCH 678	\$0.00
Needle for threading	Recycled brass wire from first project	\$0.00
4 sheets of veneer	4x \$12.00/sheet	\$48.00
		<hr/>
Allowable budget:		\$70.00
Total Expenses:		\$48.00
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Percent of budget used:		68%

FINAL EDGE BAND



ORIGINAL EDGE BAND DESIGN



# SCRIPTING

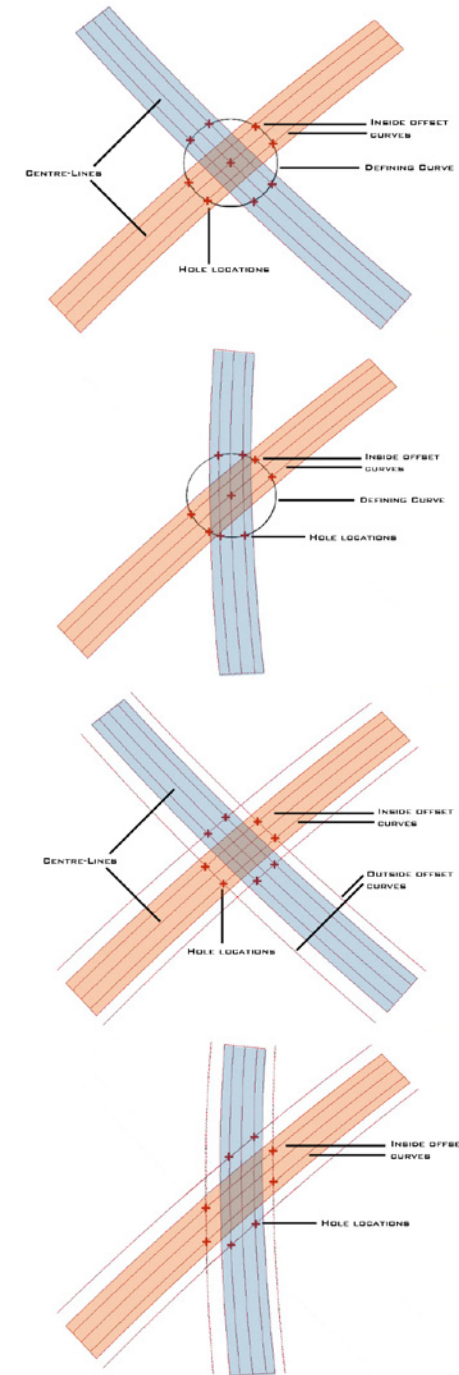
Though our design maintained its general form from the first model to the second, we made sure to rigorously review the Grasshopper script and evaluate whether each step was working as efficiently as possible. Scripting with more confidence and familiarity with the procedure, we were able to conceive a simpler sequence in order to achieve the same ends. Certain issues were reworked - pertaining particularly to the hole locations. These improvements will now be discussed.

Our second script produced a model with fewer, but wider bands. This allowed holes to be larger, and intersections cleaner. It was decided that our division and placement of holes along the bands should be reconsidered - both in terms of their arrangement, as well as the method used to producing them.

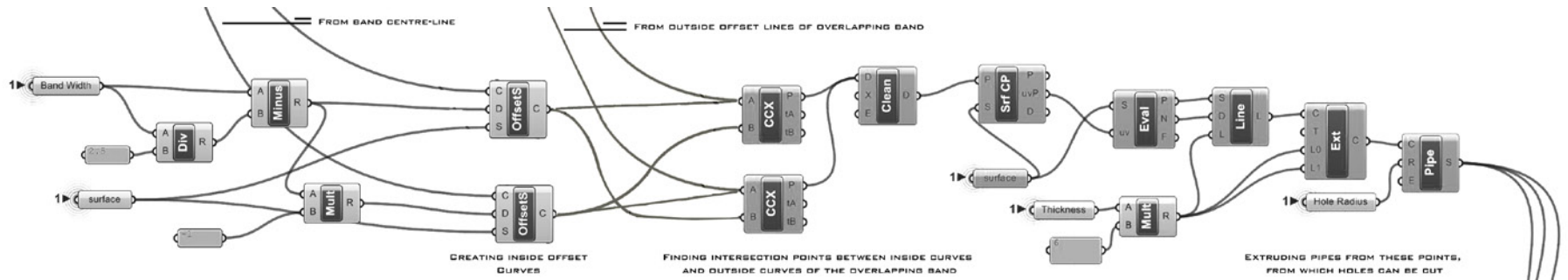
The location of the holes in our initial design were informed by finding the intersection points between the centre-lines of two overlapping bands. These spots provided the midpoint for a circle to be drawn on the surface. Two lines were also offset from both these centerlines to a specified distance. The junctions where this circle perimeter encountered an offset line became a location for a hole. From here, a line normal to the original surface was extended; around which a caped pipe was created (refer to image on next page). This solid shape cut the original band - making the holes.

Our main concern with this method was that it was hard to correlate the hole diameter with the distance of its center-point to the overlapping band. In other words, the proportion of hole width was not tied to anything relative. Additionally, the system worked well in terms of the bands intersecting perpendicular to each other, but not the ones that were overlapping at oblique angles. In these cases, holes did not line up with the sides of the band they straddled - so that when cable was thread through them, the tension acted on the side of the cavity, rather than the edges of the inside band - making the design significantly less coherent.

Our second attempt solved these problems using a much more efficient technique. As before, each band would have two curves offset from their centerline, that remained within the width of the band. Then two additional lines were offset outside the width of the band - to a distance that was equal to the determined radius of a hole. Once every band had these series of described lines, the intersection points were found, from which extruded pipes were created, as explained above. This system meant that whatever the angle bands overlapped, the points where the holes would be drawn would remain relative to both.







We encountered an issue when holes were drawn on the ends of bands that fit into an edge strip. It was realized that the holes would often be too close to the edge band's sides - compromising structural integrity. Our solution was simply to widen these edge pieces so that every hole was a specified distance from any side.

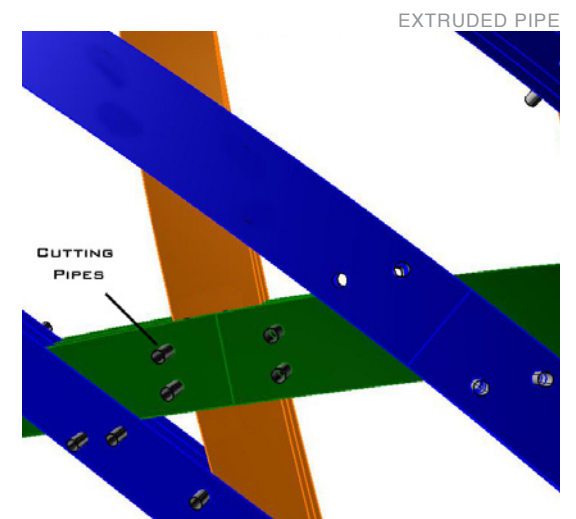
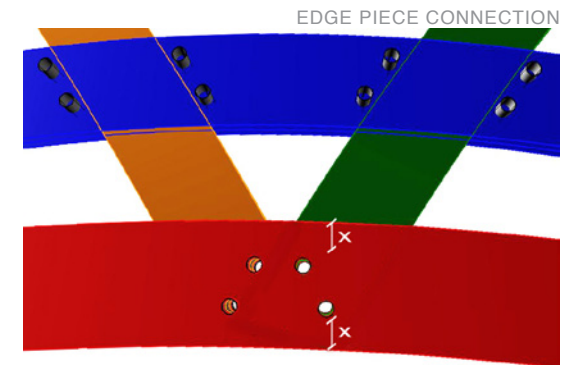
Corners were dealt with uniquely, where two holes were drawn in locations that allowed both edge pieces and the lateral band to be lashed together.

## FABRICATION AND ASSEMBLY

### Squish | Unfold

The process of bringing the model from digital space into a physical form changed dramatically between our first and final iterations. In our first attempt, we laboured over the squish script, attempting to debug the indexing of pieces. This was done with relative success. Unfortunately, the inconsistency of the few remaining indexing failures forced us to re-squish from Rhino with a revised approach. We divided each band into separate layers and as a group, took shifts squishing each individual member. From that point, we manually labeled and arranged each member in AutoCAD. Because we lacked confidence in the accuracy of this multi-step process, before assembling the model, we would lay out each member to ensure the labeling and orientation was correct. This was a successful yet extremely time consuming approach.

In our final model, we opted to use the unfold tool rather than squish. While it required the same level of preparation and manual organization, it took far less computing time to flatten each piece. Again, we exported our pieces to AutoCAD where we labeled and arranged them for lasercutting.



## Lasercutter

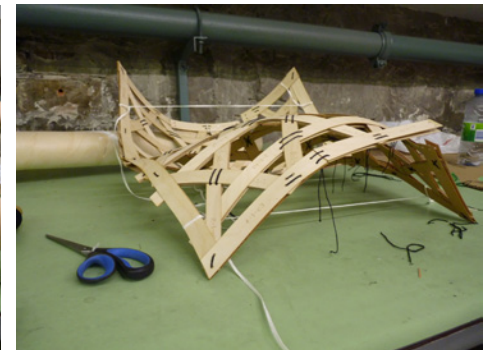
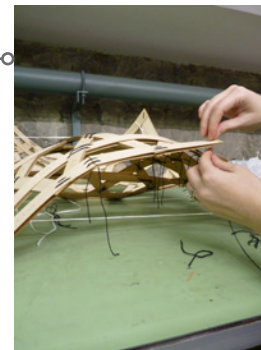
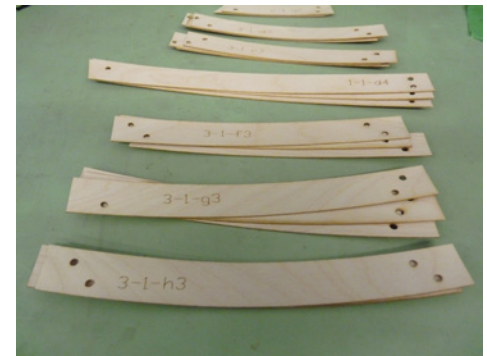
Our first project presented few problems when lasercutting. The material was heavy enough to support itself and in the end, the only delay we encountered had to do with the holes. Our hole sizes were designed rather small and as a result, when they were not completely cut through by the laser, we were forced to spend a great deal of time manually punching them out with thumb tacks.

In our final model, the veneer presented some problems in the lasercutter bed. Due to its light weight, when cut, the pieces would often blow around within the cutter. A quick solution of taping the veneer to a plywood base solved the bulk of this problem.

## Assembly

Much like a typical construction scenario, we delegated assembly tasks under headings of “skilled trades” and “site manager.” Two of our three team members were responsible for assembling: one held the form of the model, while the other stitched the joints. The third member of the team called out, arranged and oversaw the assembly of pieces. For this task, our 3d model was relied on heavily to navigate the placement of each member.

The order of assembly involved us starting at a corner and working out from one edge piece along the axis of a single diagonal member. We fastened joints and braced the model as we assembled. This ensured the model held its own shape throughout assembly rather than having to be shimmied into place after the fact. When it came to the final half of the model, we found that it was necessary to have a third set of hands as well as some tension ties to hold the dynamic surface in place.





## OBSERVATIONS

While we focused our efforts from design to script to fabrication, on improving the shortfalls of our initial project, there remain a few issues that could stand further development. The first exists in our edge pieces. During assembly, we observed that where an inflection point meets a slice (happens only at the mid span of our double curved edge pieces), a twisting occurs and thus causes extra strain and eventual deformation on the joint. To prevent this problem, we would have located the slices of these bands at 1/3 intervals rather than the midpoint. Another area of improvement remains in our joint threading. Although our joints were quite successful, on occasion, a lack of friction within the thread itself provided an added challenge when attempting to tie the appropriate tension. Although it would have added to our budget (which was a serious concern), it may have been worthwhile to invest in joint tests with cat gut or even waxed thread in addition to the donated material we received.

## CONCLUSION

Recycling the successes of our first scheme not only allowed us to jump start a second iteration, but also to develop new areas of interest while designing our final model. Slight differences in approach kept the final iteration more purpose built while our first attempt remained respectful of real-world construction processes. The evolution of our joints benefitted from the success of our first project, while adapted to effectively suit the material requirements of our final model. Design changes in scale, material and amplification were developed while changes made to our script, rhino export process and fabrication all contributed to a smoother, more efficient assembly. In the end, the success of our final model hinged greatly on lessons learned from past attempts.

