Timber Tectonics in the Digital Age

RYAN MARUYAMA'S PORTFOLIO

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Date: 5.20.18

Topic: Week 7

Beams + Columns

Loads on columns are primarily axial. Noticing the change in the column's dimensions, it is observed that when the dimensions are increase the overall bending is reduced. This relates back to the equations of the cross sections.

From the beam and column handout it mentions the modulus of elasticity as well as moment of inertia. E and I. Both equations are imperative to the deign of the column or beam as it combines the notion of material and geometry.

Various shapes of the columns were observed, they consisted of the box, circular, and I shape. The overall dimension of 9x9 was remained, but the effects varied.

We find that the circular column has significant bending compared to the I shape and box. When we think about load path and resistance of loadings in the primary bending direction, we find that the circular shape is the weakest. The box compared to the I shape makes sense that it is able to resist more loads purely based on the amount of resisting geometry.

Generally a beam performs in the same manner as the column except the load is applied on is longitudinal section versus its ends.

The one element worth noting that could potentially be different in a beam than a column is its end restraints. I have found in my past experience that most having a fundamental command of the end releases is imperative to the performance of the beam. Case 1 is a pin support where both Rx and Ry are free to rotate. In case 2 we find that when the ends become fixed, that the beam performs quite differently. Less deflection, but more attention to the connection detail at the supports. This could be a positive and negative for detailing. The overall section can be smaller but that means that more bolts, dowels, etc. are to be applied at the supports.

The picture on the right citation: Trada John Hope Gateway Biodiversity Centre Page 5. This precedent was important for me in my design thinking is how the engineering and architect decided to represent the moment and pin connections in such a beautiful way.

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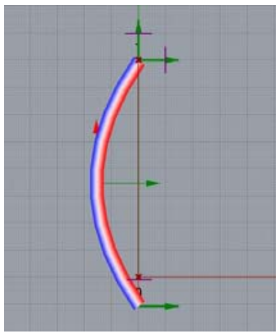
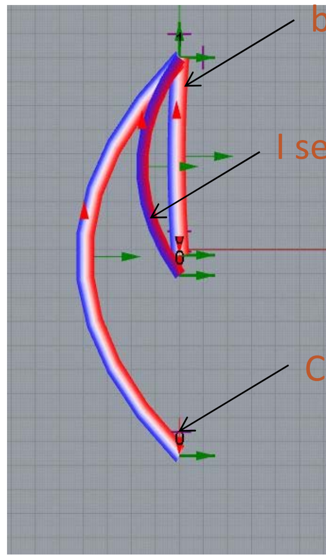
Beams + Columns

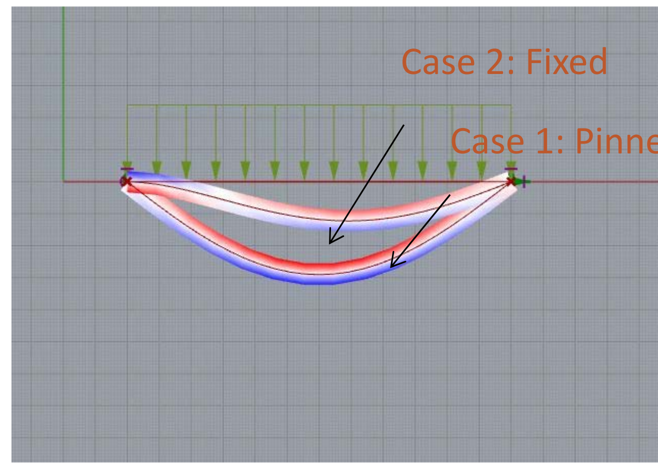


Column: 6x6
load – 150lbs

Column: 9x9
load – 150lbs



Overall dimesnsion remained within 9x9. load – 150lbs



Overall dimesnsion remained within 9x9. load – 0.25lbs/ft

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Frames + Trusses

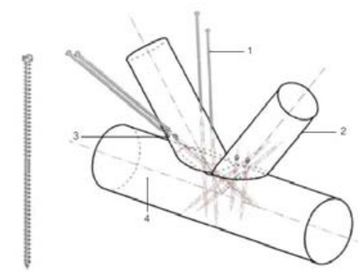
Shape of the truss determines a significant amount of the effects of stress distribution within the overall system itself. Truss depth is integral to the overall performance of the truss itself. With more depth, the smaller the members can be. With less depth, the members need to take on larger stresses, therefore having larger members.

Exploration for this part will go through relaxing the default rigid joints, and support conditions and how it changes the results. The top image shows no nodal restraints, where the bottom shows a rotation in the y direction (into the page). We find that without restraint the nodes are free to rotate (giving a potentially higher deflection amount). With restraint on rotation, we find that the members start to have s shape bending. Meaning both ends are fixed. This could be a problem, as in trusses tension and compression bending is typically undesired.

Translation restraints for x,y, and z were not utilized because such restraints defeat the purpose of the long span truss type.

The default support system is a pin and roller. Both these elements are the typical set up for a determinate system of analysis. We find when adding an additional restraint to the overall system the deflection decreases. By intuition, when the deflection is less than the original, with loads unchanged, members in the system experience higher load concentrations.

Most bridges are set up with roller joints in the direction of traffic. This is to alleviate any unwanted stresses at the support joints. It is important to note the type of truss and its supports. For example, if this is a pedestrian truss, we don't want a roller on one end because motion of the planes could potentially cause nausea or sickness. By analyzing the support systems, its important to know the function of the structure itself and its application while design the overall system.



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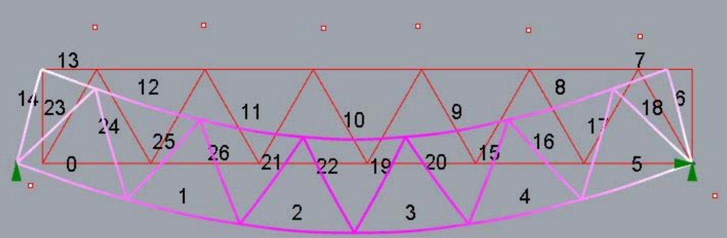
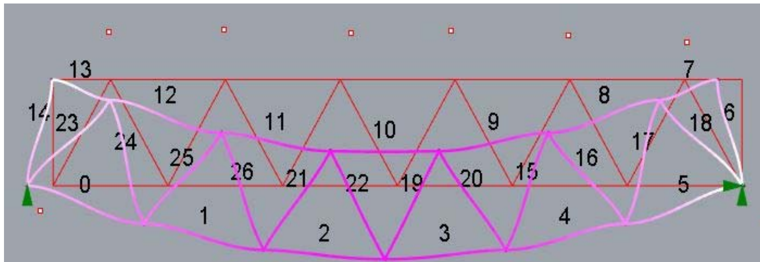
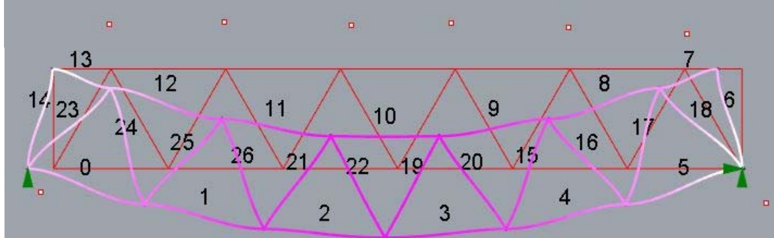
Frames + Trusses



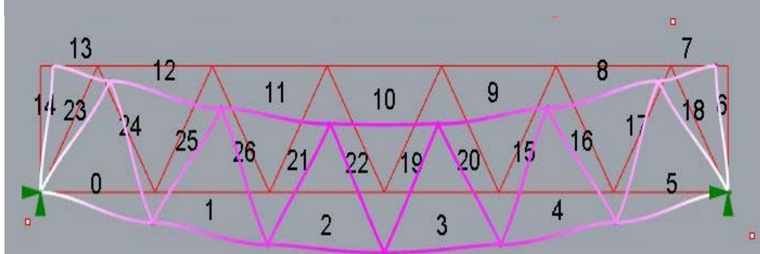
Joints Released



Roller - pin



Rigid Joints



Pin - pin

Date: 5.20.18 Topic: Week 7

Shells + Gridshells

Grid 1 Deflection: 0.025608 (2x4 members)

Grid 2 Deflection: 0.004198 (2x4 members)

Grid 3 Deflection: 1.1843s (2x4 members)

Cycling through the various types of grids, I was interested to find what grid would be appropriate for the 20x20 grid shape (in accordance to the final project). We find by looking into the deflection results that the best performing grid is the G2 triangular grid. But this is a lot more material than G1. Where G1 is performing fine it is less material and better for construction. We also look into the hex grid. With a lot less material used, the deflection due to the same grid break down gives quite high deflection values. Not the best choice for this grid type.

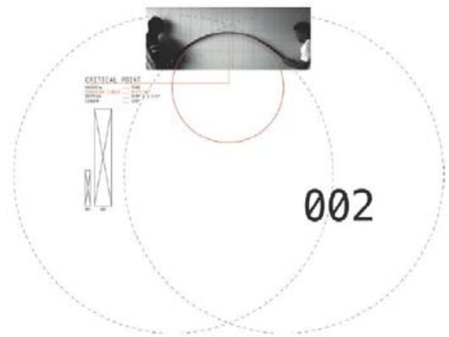
A strained gridshell is when the grid mate is transformed into a gridshell using cranes, manpower, etc. During this process the gridshell forms bending stresses. Its important to have movement at nodes.

Unrestrained gridshells refer to shells prefabricated and fixed into final form. In turn its internal bending stresses come from asymmetric loading and self-weight.

Using the kangaroo relax function I was able to output a geometry and put it back into karamba. Looking at the height of the arch as well as the dimension of 20' wide, I was very impressed to see that such an arch had an overall deflection of 0.001!

Next plan of action is to put this geometry somehow, into a lathe work where such arches can be intertwined so that the strength of the members come from the unrestrained type of system, where their own bending can be apart of the overall system.

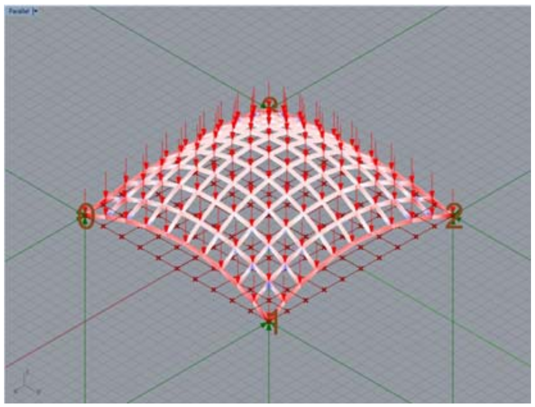
Theres an inherent geometry system in place with the gridshell as seen in the pictures on the right. This bend, that will be mentioned further in the arch analysis goes in depth on how this geometry works best with the material properties (how far can the material bend) and the action / reaction on how the material receives load.



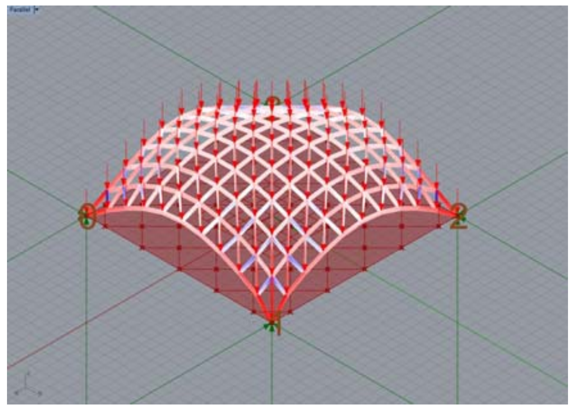
Date: 5.6.18

Shells + Gridshells

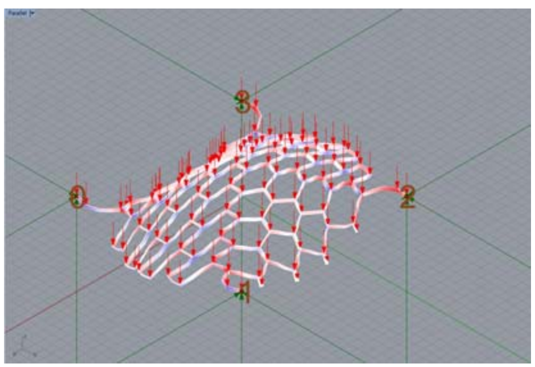
G1



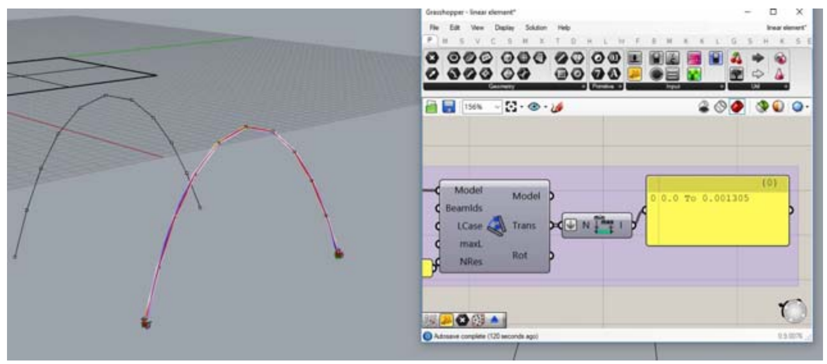
G2



G3



Catenary Arch



Date: 5.20.18

Topic: Week 7

Domes + Arches

Studying the form of the dome and the arch, I find the natural curves following the hyperbolic function, or something similar to that geometry provides very interesting results. The strength of the overall system is quite stiff compared to the rectilinear models as seen in previous examples. When I perform analysis, I pay very close attention to deflection accounts. Typically the system is failed at 1-2" depending on code requirements and overall fracture and fatigue accounts.

Performing analysis, typically I start off with elements that fail, or I would knowingly provide member sizes and arrangements that I know are too thin or too large is spacing just to see if there are any surprises. The action of the dome caught me off guard, as the point loads I kept having to increase until the results came out to be nearly 10kips per loading sequence. This is an incredibly large loading for member sizes of only 1.5' x 1.5'

Using the kangaroo relax function I was able to output a geometry and put it back into karamba. Looking at the height of the arch as well as the dimension of 20' wide, I was very impressed to see that such an arch had an overall deflection of 0.001!

The arch itself has this inherent property to allow the force to flow seamlessly through the material. The one epiphany I had during this exercise was the fact that the form follows force and force follows form. The integration of the material and the forces is imperative for this form finding to work. I shocked that not many builders, engineers, architects use this form more often. I would assume that with such a small amount of material supporting such a great amount of force is one of the most efficient bodies of material out there. This begs the question of should be design rectilinearly?

The one part of the overall dome, arch, gridshell reading that I really appreciated was the workflow between traits of the engineer and architect. Since the dome and gridshell concept involved vast knowledge of compression and tension, its important the geometry and forces are paid attention to right from beginning of the project.

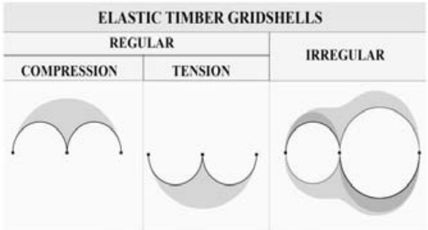


Figure 1-*Clusters Concept*

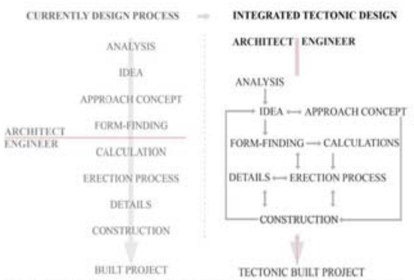


Figure 19- *Design Process for elastic timber gridshells*

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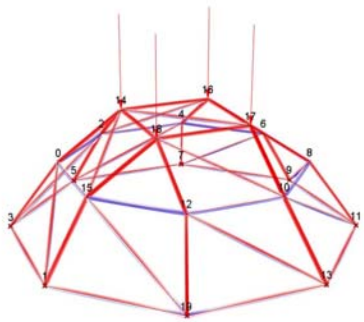
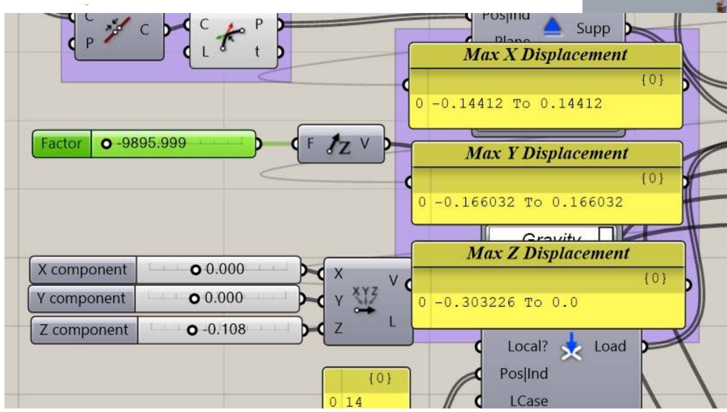
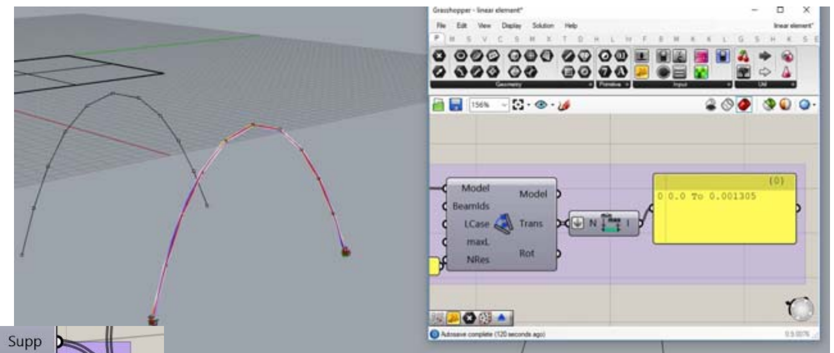
Domes + Arches



Dome





Catenary Arch

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Topic: Week 7

Folded Plates

The formal design solution for the pavilion stems from the primitive catenary curved surface. Anchor points for the surface are located as shown, and serve as the form's overall support system once processed into grasshopper + karamba.

From the surface itself, the folded plate algorithm is produced as seen in the valley and mountain folds. Once the surface is produced, the overall shell is unrolled so flattened pieces may be connected together to create the form.

Structural analysis was performed by two methods. Ridges of valleys and mountains were traced to create a ridged beam system (synonymous to a gridshell). However, we found that utilizing the beam system we were not tapping into the potential of the geometrical system in its entirety. Therefore we performed a second check based on the shell overall. Looking forward we will combine both systems to utilizing main beams to support the shell in high stress areas.

After midterm, it was imperative for us to look into the rigid connections of the folded plate. We found that using carpentry joints would be the best option to provide lateral support for the overall structure. We also found that by modularizing the units, it would help with transportation.

Showcasing the wonders of engineered wood products. Currently we had a homogenous system. At the time we were thinking LVL and or plywood for the system. After the review we are more geared towards utilizing CLT and glulam. We believe that by hybridizing the two materials in one integrated design, that we will be able to showcase the abilities of both materials. A goal of ours is to not only display these engineered wood products, but also utilize the inherent abilities of each material in our design.

The folded plate is not a good idea and it wont work. Yes, we understand that there are materials with certain capabilities and performance limits, however our team's vision goes beyond what is possible. Our team discussed the possibilities between the waffle shell (product 1) and the folded plate shell (product 2) and agreed to continue with the folded plate. We believe between now and the next review that the new hybrid shell of glulam and CLT will contribute towards the overall success of the pavilion.

Hinges as connections are not stable. This comment is completely valid. In the analysis itself, the shell requires rigid joints at the valley and mountain folds. Introducing hinges for "ease of construction" is something that our team should shy away from. This comment for the connections stems directly towards construction. We have been discussing the possibilities between mechanical joints and or carpentry joints. Some factors that affect joint possibilities include wear and tear on joints as they are constructed and dismantled. Joint strength and restrictions on a certain axis will also have an impact on our decision, although we have yet to hash out the potentials of both connections in relation to construction.

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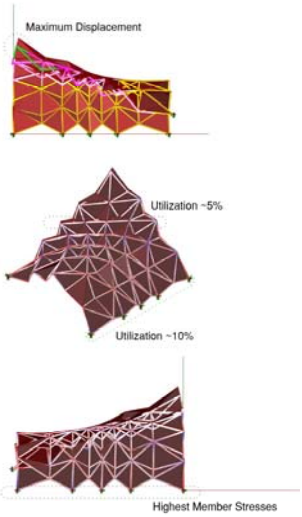
Folded Plates

STRUCTURAL ANALYSIS

SUPPORTS	Disaplcement x.xxx feet | Stress [y.yy ksi]
Fully Fixed	0.086' [-6.02ksi]
Rx Release	0.091' [-5.89ksi]
Ry Release	0.082' [-5.60ksi]
Rz Release	0.086' [-5.99ksi]

MAXIMUM LOADING	-1.921 kips / ft. with a displacement of 2 inches

JOINT DISPLACEMENT	Disaplcement x.xxx feet | Stress [y.yy ksi]
Rx Release	0.095' [-6.99ksi]
Ry Release	0.759' [-12.6ksi]
Rz Release	0.108' [-6.96ksi]
Rx + Ry Release	0.119' [-7.81ksi]
Rx + Rz Release	4.344' [-39.7ksi]

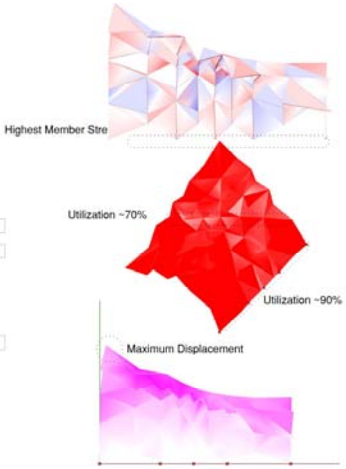


STRUCTURAL ANALYSIS

Thickness	Disaplcement x.xxx feet
1/8"	6388'
1/4"	1599'
1/2"	402'
1"	105'
2"	13'
4"	0.189'

MAXIMUM LOADING	-1.180 kips / ft. with a displacement of 2 inches

JOINT DISPLACEMENT	Disaplcement x.xxx feet
Rx Release	0.085'
Ry Release	0.643'
Rz Release	0.108'
Rx + Ry Release	0.127'
Rx + Rz Release	2.256'



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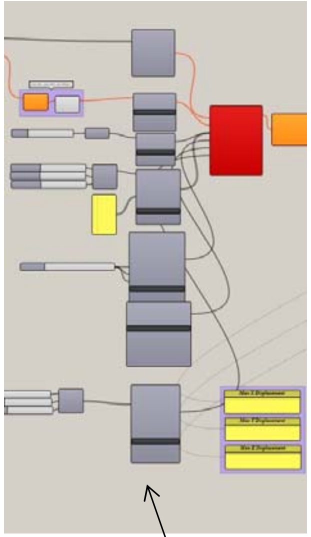
Synthesis

Throughout this term, the levels knowledge learned has been quite the journey from single member analysis to complex systems integration of vertical and horizontal members. Its always great learning a new computer program, especially if it involves real construction capabilities. The step wise function of how the course is set up could not be better, personally I would have it no other way.

Our final presentation of the folded plate is an integration of all parts learned from the start of the quarter until now. Each module has helped inform our design in a unique way, and has been integral to the final output we will be presenting during the final presentation.

The first module was the beams and columns. Starting with this analysis makes the most sense. How are loads transferred from one member to the next, as well as how support conditions are dealt with in karamba. We find that when we change, member sizes, material type, as well as support release conditions, (simply supported, fixed support, rotational and translational releases, all have a final effect on how the body reacts to loading). My past senior at the consulting firm always told me, "garbage in garbage out" which is meant to show if the inputs are not correct the results will also not be correct. Knowing the support conditions, joint conditions, how the members are attached, what the members are, etc. all inform the design. Its best in the beginning to play with these input conditions to find what is the best fit, what works and does not work prior to deciding on the final design.

The frames and truss module were more important to investigate the joint conditions, loading patterns at nodes as well as geometrical patterns of the intermediate chords. Deflections were observed to be greater when joints were fully relaxed. The issue with this type of system is it creates bending moments within the members which by right should only experience axial compression and tension loads. When setting up the system, its important for it to be as efficient as possible. If the system calls for axial loads, joint connections should be released, if the deflection is too high, it's important to analyze the body as a rigid system. Being conscious on the rigid system is important the construction is more complicated!



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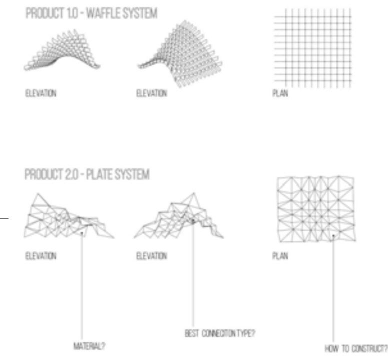
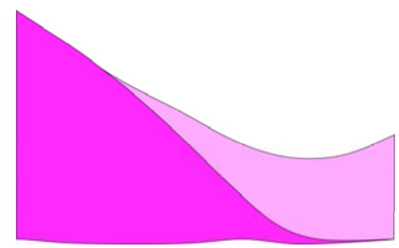
Synthesis





Shells, gridshell, diagrids, domes and arches, was a giant leap from more rectilinear systems to a more curvilinear system of analysis. The complication of such analysis was fun to investigate, but at times difficult to control. It was found during the reading and research for these more circular shaped dome types the catenary arch was the most successful system to take load with the least amount of material. Find this shape was not difficult. By applying the relevant elastic modulus to the shell and applying a single upwards point load (against gravity) gave a geometry that helped us form find.
This helped me see that following the hyperbolic function to find an efficient form would be the best start to the form finding for the pavilion. Studying the function of E, and geometry shapes (hyperbolic function) I found that it could be said that force follows form and form follows force. When these two elements of action and reaction of the material are optimized we can observe that the overall system had very limited deflection amounts.

Finding the overall form from the catenary arch and applying that to the system, we then looked at various systems of the waffle, beam system and finally the shell. We decided to settle with the shell due to its challenges and aesthetic properties. Integrating all the systems together, we decided to make the final model out of plywood, offsetting the surface to create a shell type truss system. Since the pavilion is outside the realm of actual outside loading (wind, snow, public loading), the only thing we wanted to focus on was the dead loads. In a sense switching from engineered ply to a more common material meant that we would reduce the dead load and in the then having a more expressive form.

Looking forward from midterm, we believe that our final form wont change too drastically. From a analysis standpoint, we have decided to stick with folded plate. However, from what we have learned from a material, construction, and engineering material standpoint, we will go in a direction of more of a double skin. Utilizing the top and bottom shell as a truss, and connecting shell plates as intermediate members will help us achieve the form with minimized deflections.