3D NATURAL PRINT II: PROTOTYPING AND DETAILING OF 3D PRINTED STRUCTURAL SYSTEMS

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Material and Structure/Material Matter Lab VI
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FIGURE 01: 3D print of Global Geometry 1:20

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PART 0

INTRODUCTION

Natural fibers in recent years have been of interests, due to them being lightweight, sustainable and some of them have tensile strength similar, if not more, than steel. In this project, we aim to create new typology for outdoor bandshells, which are composed of a 3D printing natural short and long fibers. The short fibers are used to carry the compression forces of the bandshell, whilst the long fiber help with the distribution of tension forces at specific places that need them. The global geometry undergoes FEM analysis, thickness optimization before it is discretized according to the force flow, followed by the thickness optimization of the short fiber lattice and long fiber.

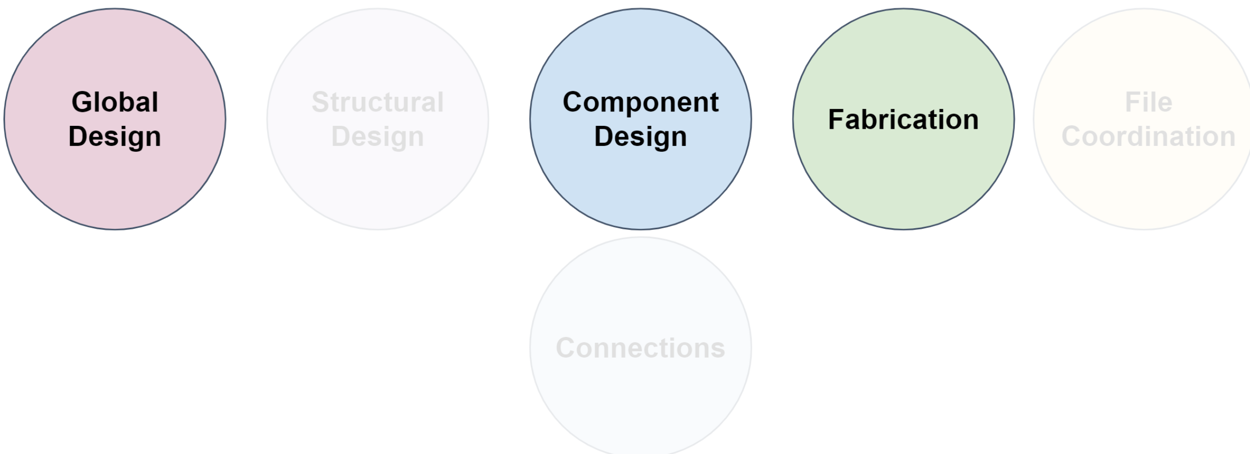


FIGURE 0.1: Role in Cooperatiion Model

0.1 PAVILION DEVELOPE STATEGY

Key roles in the project were development of formfinding workflow and defining overall geometry, discrtization and planarization, resolution of geometric problems, component design explorations and assembly strategy.

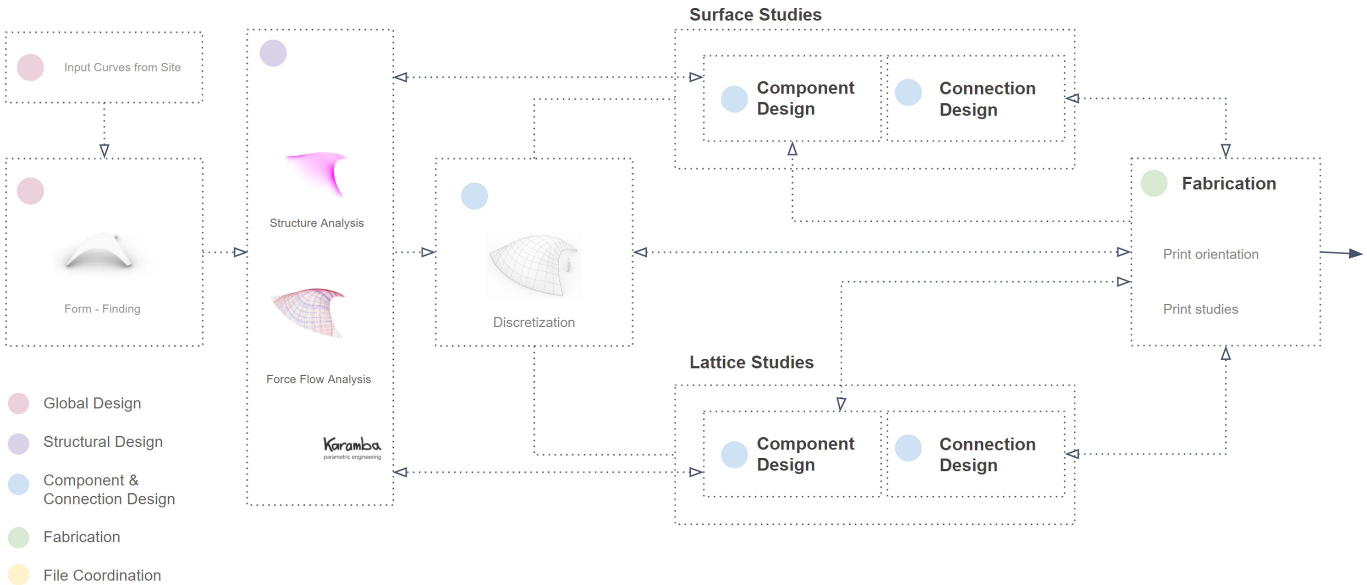
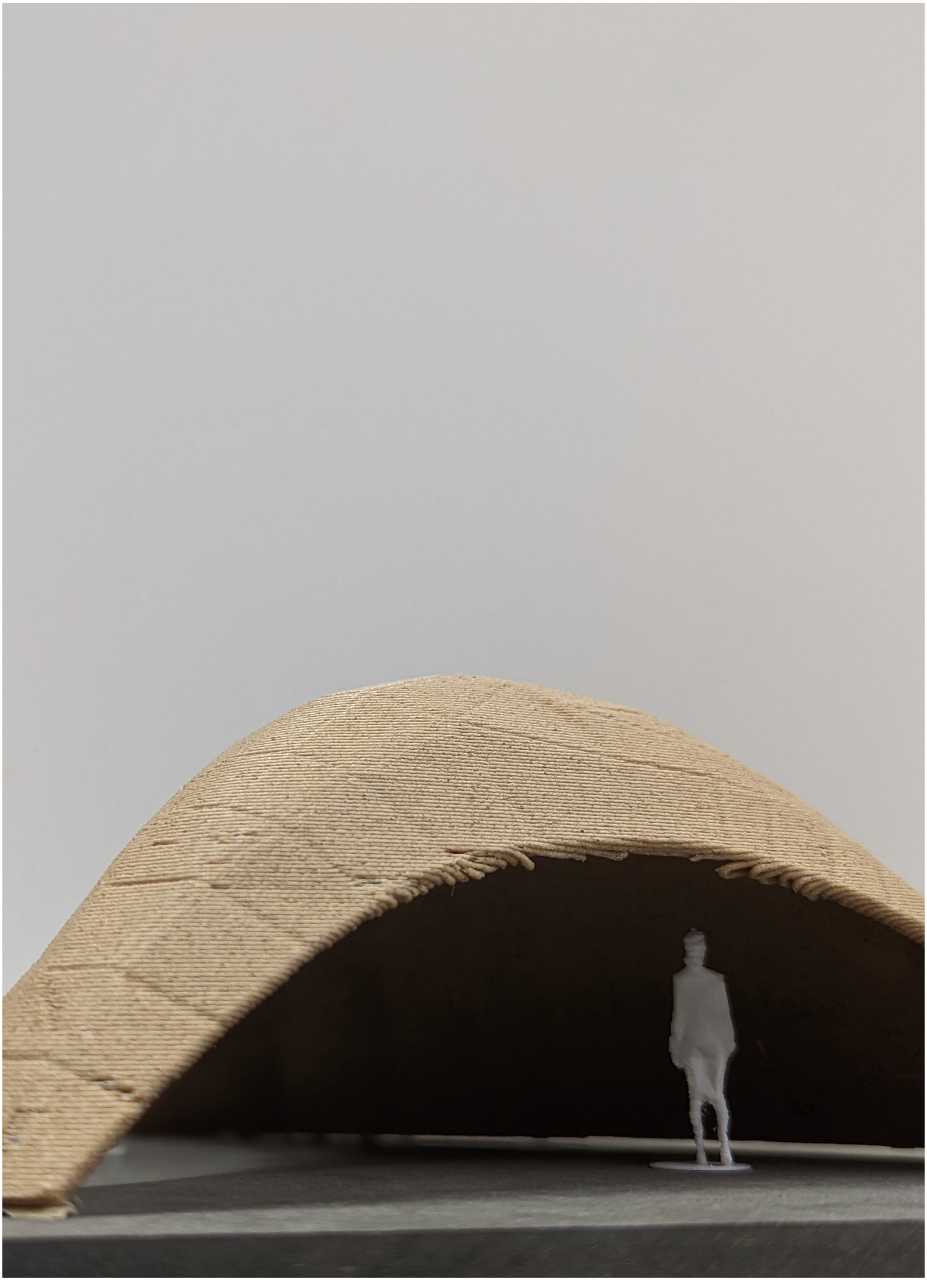


FIGURE 0.2: Diagram of Design Workflow



PART 1
GLOBAL GEOMETRY DEVELOPMENT

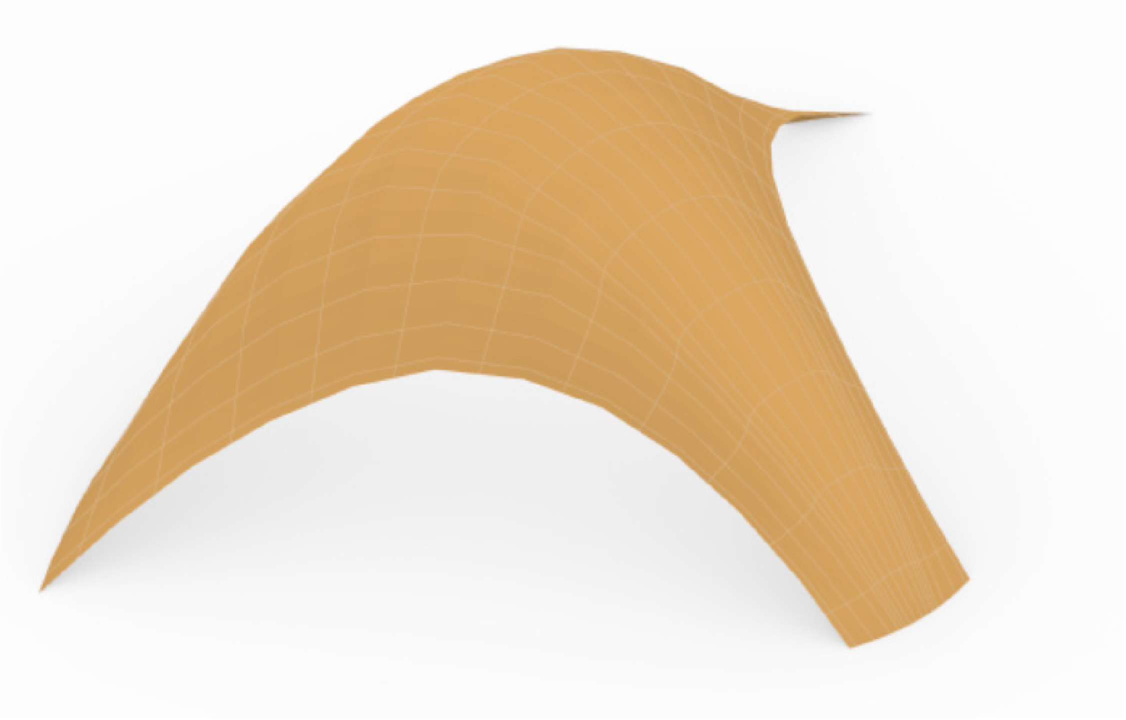


FIGURE 1.1: Global Geometry determined by last semester

1.1 GLOBAL GEOMETRY

Acoustic shells are inspired by the design of the human ear, they sound waves are enhanced and directed towards the audience. The sound waves propagate by the reverberation created inside the shell, where its concave shape direct the sound to the audience. The project geometry was created using Rhino VAULT V2, and later optimized for thickness

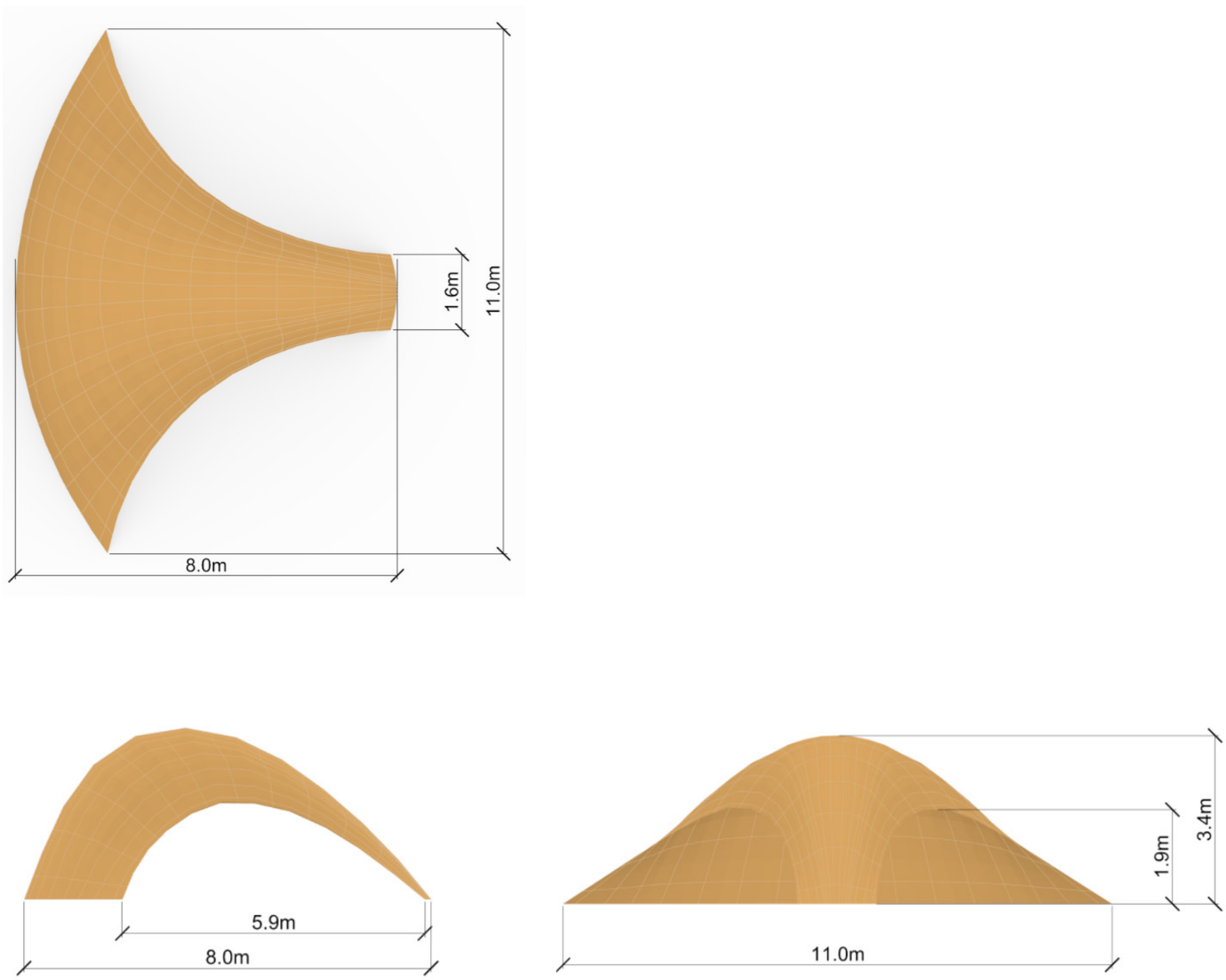


FIGURE1.2: Global Geometry dimension

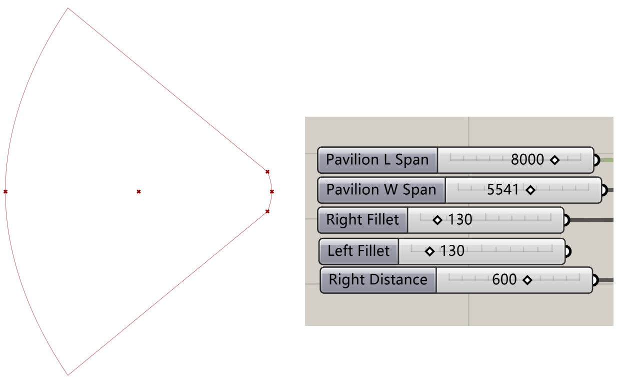


FIGURE 1.3 Outline Generator for both methods

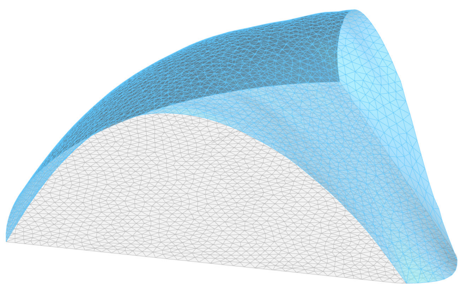


FIGURE 1.4 Kangaroo method based on outline

1.2 FORM FINDING

Computational workflow is introduced for both Rhino Vault 2 and kangaroo methods in order to facilitate change in dimension and shape of the global geometry.

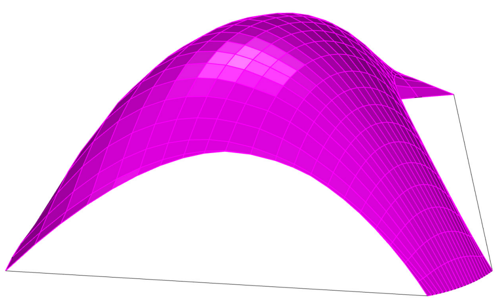


FIGURE 1.4 RhinoVault method based on outline

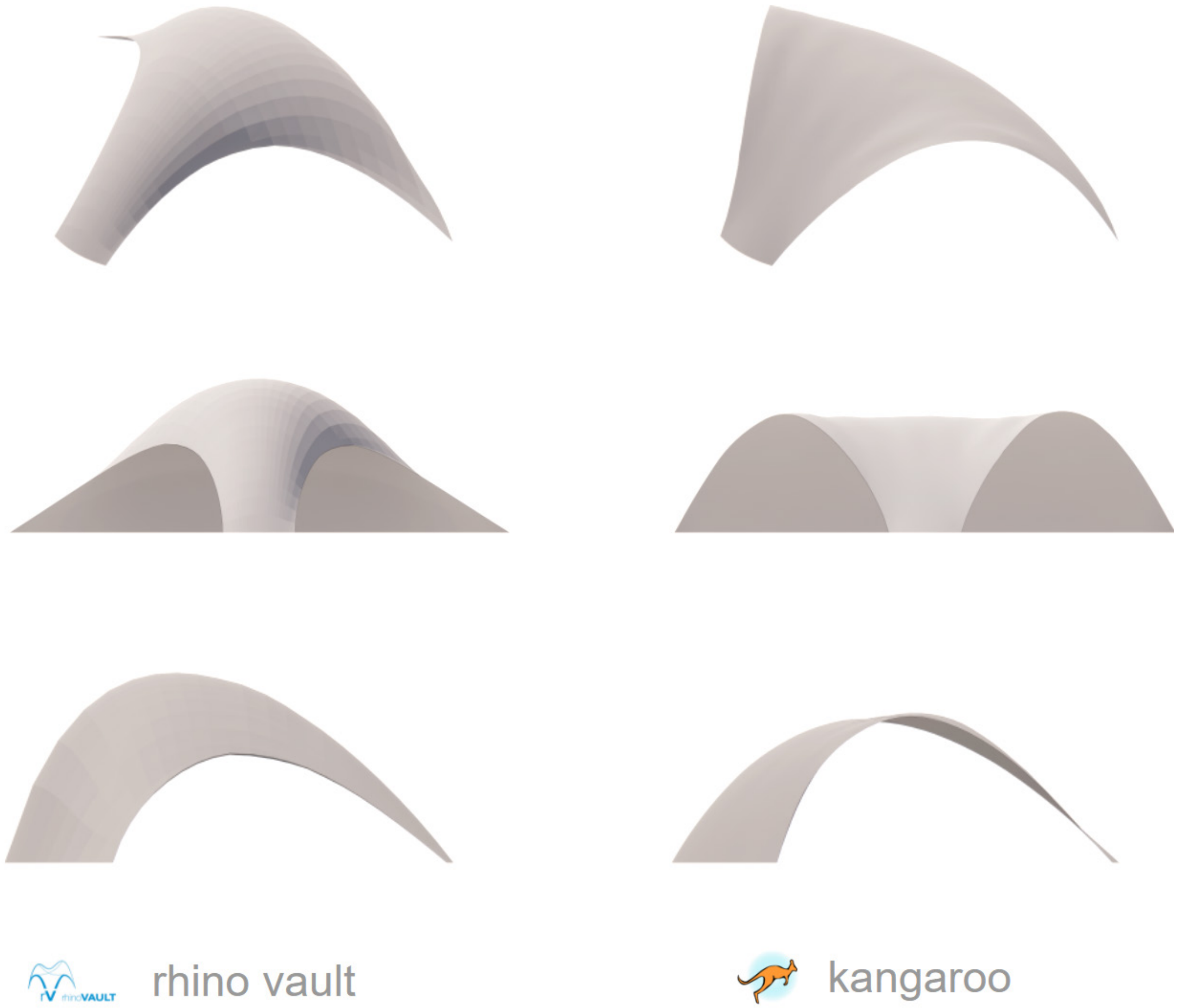


FIGURE 1.4: Difference between rhino vault and kangaroo

Form forming was tested in 2 different engines, using Rhino vault 2 and kangaroo. the same starting mesh and boundary conditions (predefined by site conditions) were used. Using these boundary conditions, multiple optimums were possible. Both engines calculated the loads at each node differently, giving different results. the kangaroo verion reaulted in a cross vault- like form with its apex in the middle of the open edges. The RV2 version had a dome like result with its apex in the center of the geometry.

The dome like form from rV2 was more visually interesting and was selected as the global design.

PART 2

DESIGN DEVELOPMENT

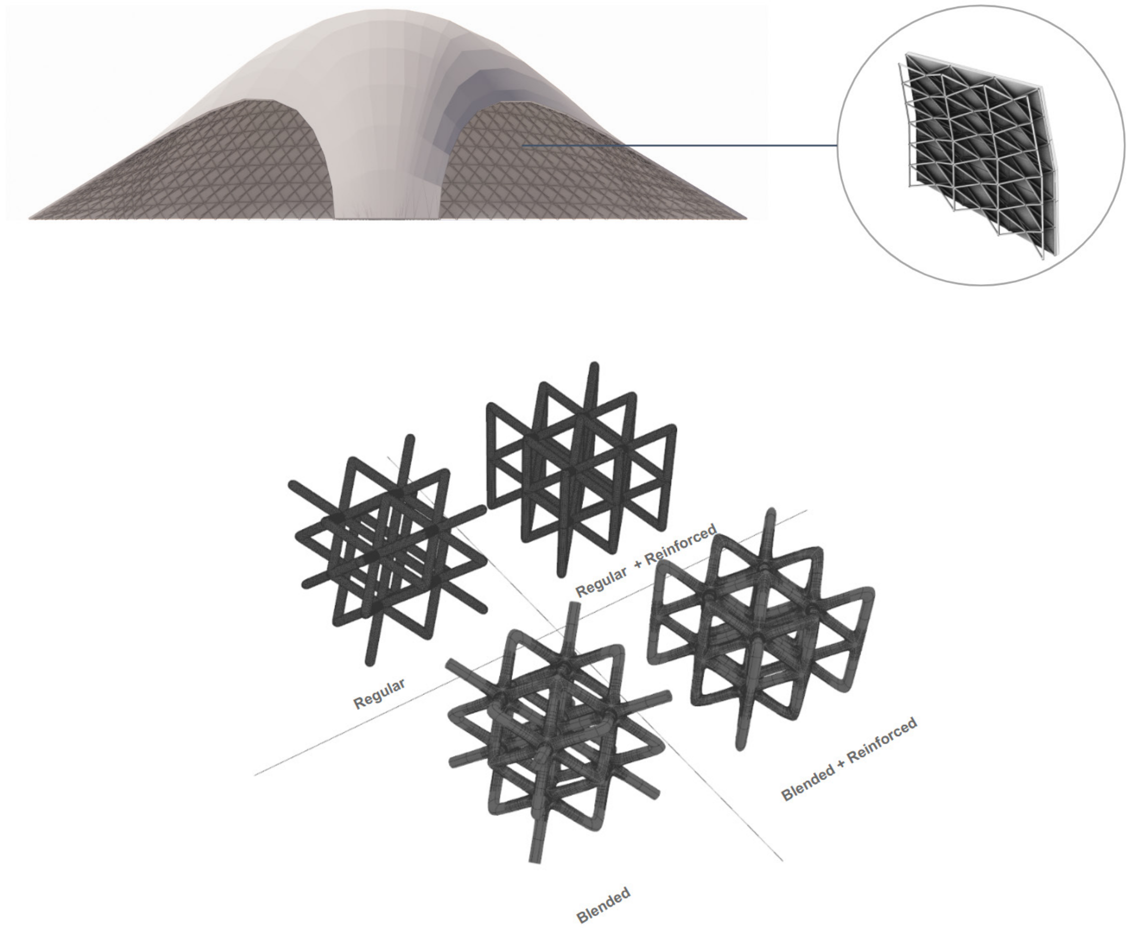


FIGURE 2.1.0: Typology of lattice structure

2.1 SURFACE VS LATTICE STUDIES

Based on previous design developments, surface based and lattice based component designs were explored.

The lattice based component consisted of a thin planar surface with a lattice underside. The goal of this component design was to reduce the overall material use to achieve

However, some simple structural studies were conducted to compare the amount of material required for an optimized surface component versus the lattice component to reach similar structural goals. It was concluded that this difference was not large.

Since the complexity of fabrication for the lattice component is significantly more than the surface component (more connection complexity), it was not a feasible option.

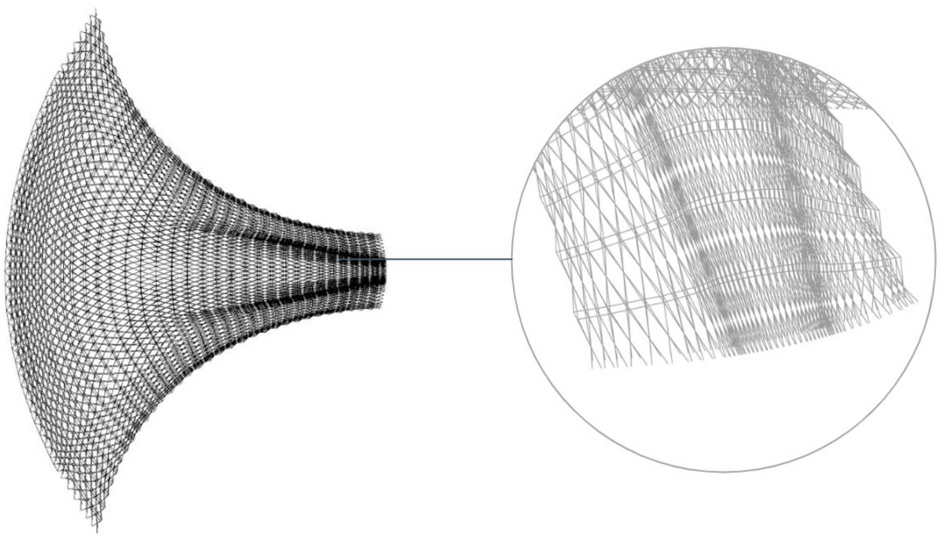


FIGURE 2.1.1: Lattice distribution issue due to discritization

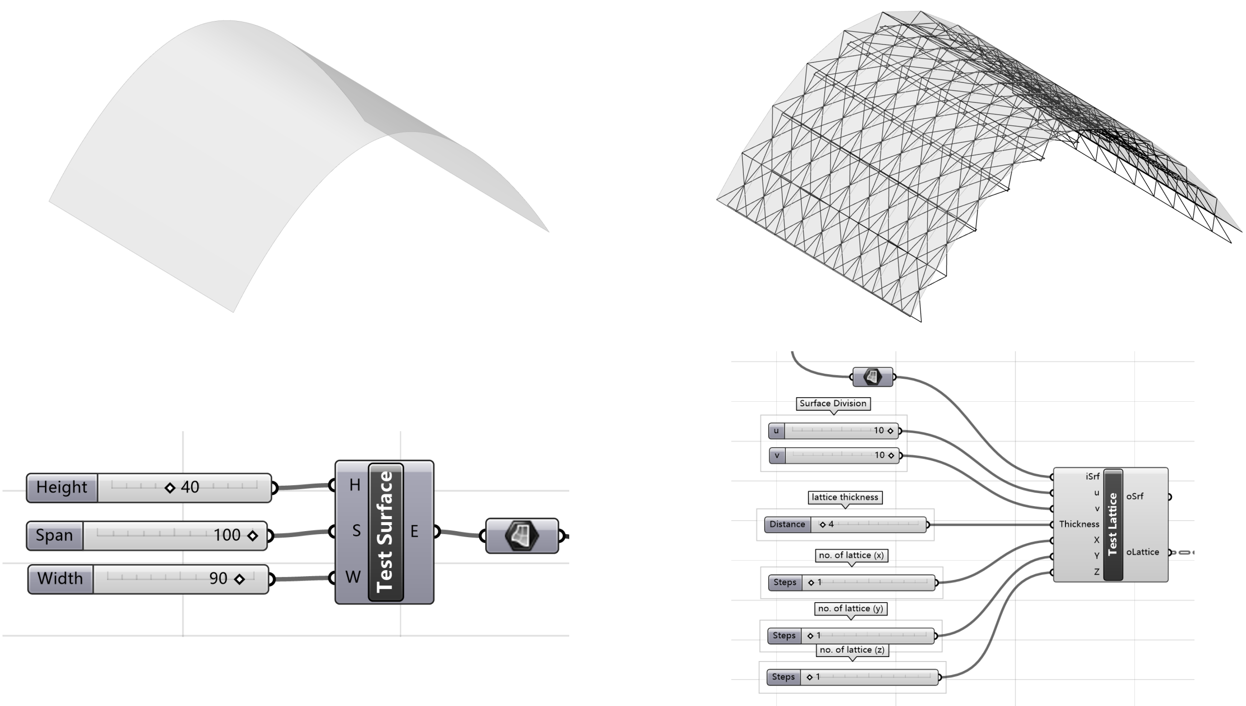


FIGURE 2.1.2: Lattice vs Surface test setup

2.2 DISCRETIZATION

The main goals for the discretization patterns are:

1. To fit into 1m x 1m x 1.2m 3D printer dimensions
2.Minimal effect on structural performance
3.Seams between pieces can be hidden by the fiber orientation

The first iteration (original study)

1.Discretization based on stress lines
2.Extracted the compression stress lines and simplified them
3.Discretized pieces using the long fiber placement as an offset, such that the long fibers are not on the component edges.
*4.Components were split according to fabrication constrain (1m * 1m * 1m). components that were significantly smaller (e.g. at the tip) were merged to form larger components. this process was optimised to create 72 components in total.*

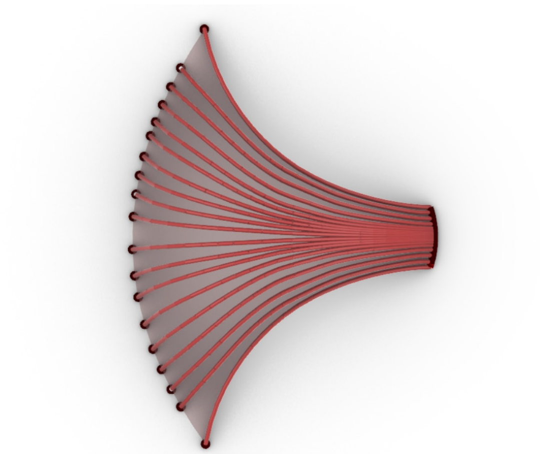


FIGURE 2.2.1: Lattice distribution issue due to discritization

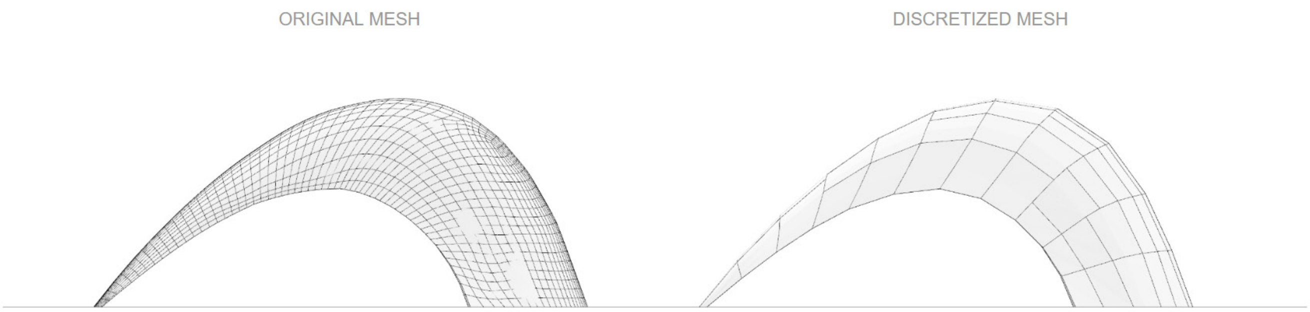


FIGURE 2.2.2: Comparsion between original meshh & discretized mesh

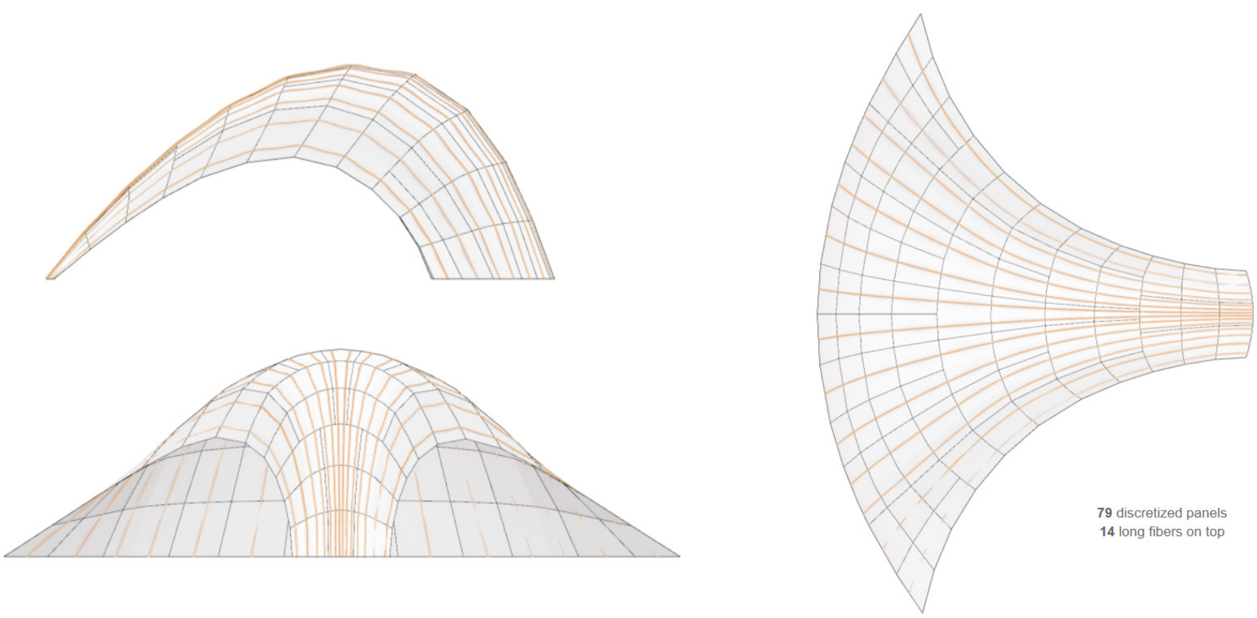


FIGURE 2.2.3: Long fiber Placement

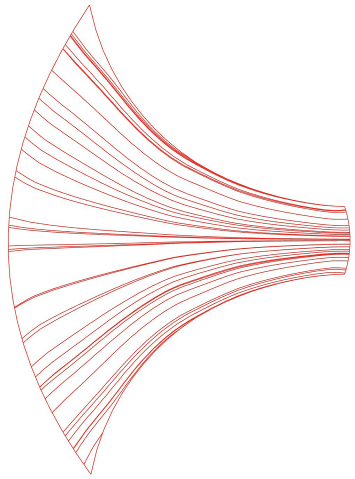
2.2 DISCRETIZATION

Detailed Process:

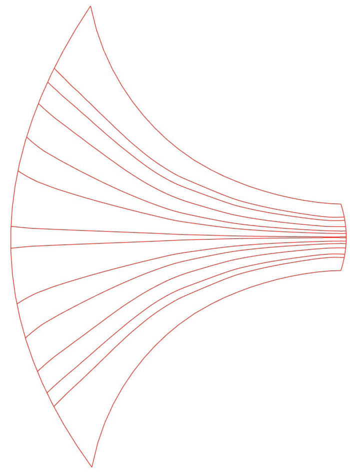
The first discretization approach follows the stress lines. It started with filering out the stress lines that are evenly distributed on the global geometry surface to get 12 clean stress lines, which is intended to be printed with long fibers on each discretised pieces. (Figure 2.2.4 a-b)

Given the connector between the discretised pieces, we need to offset the filtered stress linest to avoid the long-fibers to be printed along or near the edge of the connectors. To do so, we first divided the selected stress lines and offset the dividing points in both x and y dimensions, so as to get the first iteration of the discretised surfaces. (Figure 2.2.4 c-f)

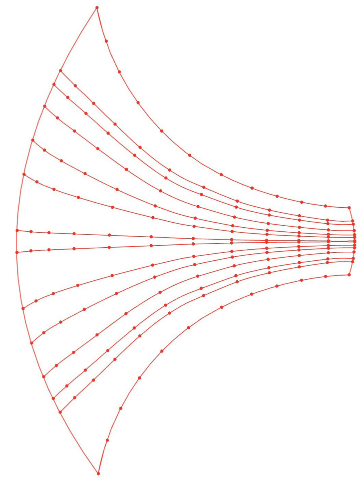
We then check each divided surfaces to see if the sum of any two adjacent surface area is less than 1 square meters, and the edge length after merging is less than 1.2 meters. If any adjacent surface pairs meet such criteria, we then merge them together. This process could be iterated multiple times until all the discretised surface can not be merged further. (Figure 2.2.4 g-i)



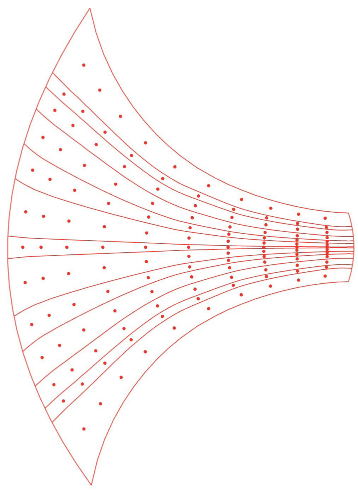
(a) intial stress lines



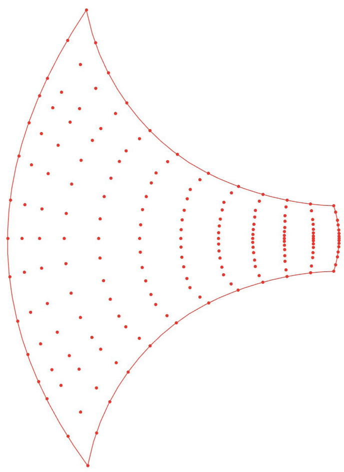
(b) filtered stress lines



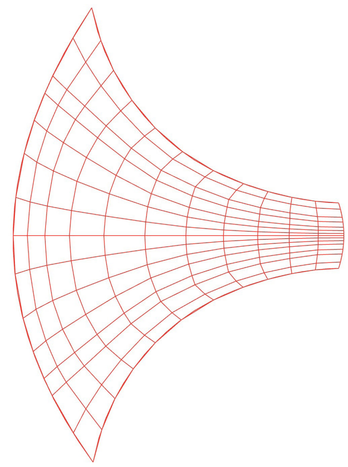
(c) dividing points along the stress lines



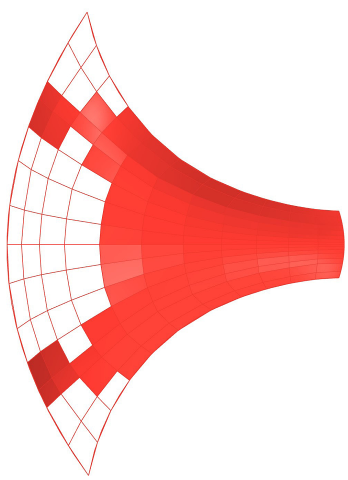
(d) offset the points



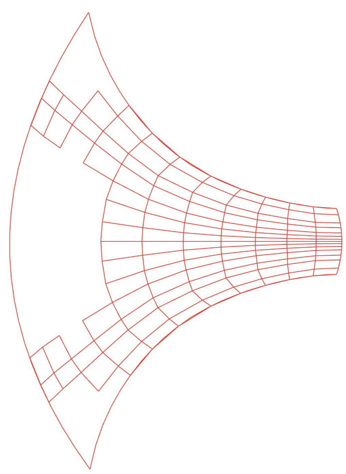
(e) intersecting points



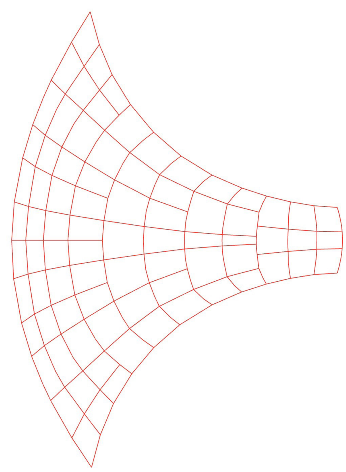
(f) intersecting curves to form the first discretised surfaces



(g) check which surfaces need to be merged and which don't



(h) to be merged surfaces



(i) merge the surfaces for multiple iterations

FIGURE 2.2.4: discretisation process

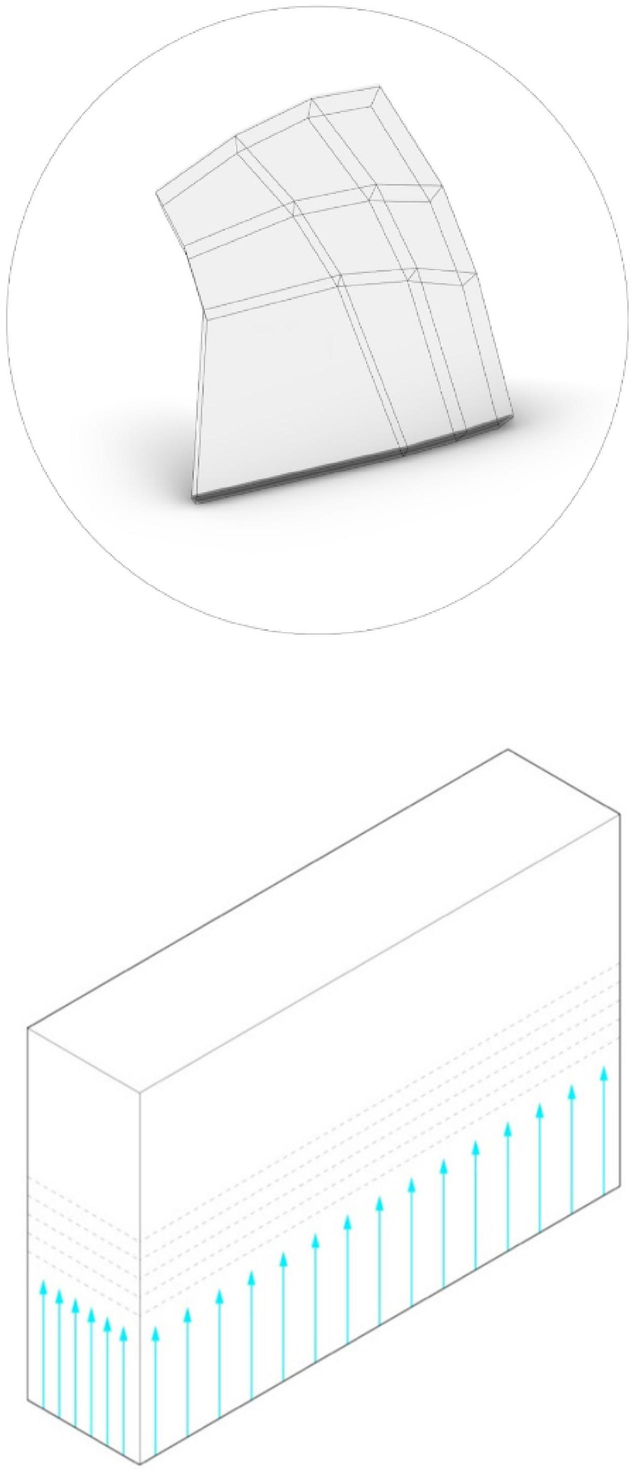


FIGURE 2.3.1: Component printing orientation

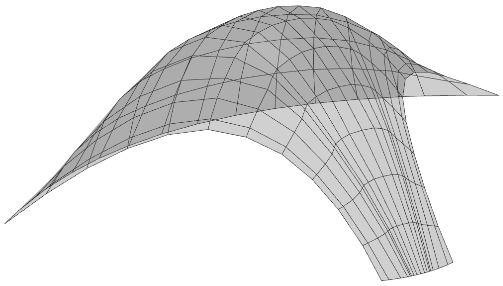


FIGURE 2.3.2: Discretized Output Mesh

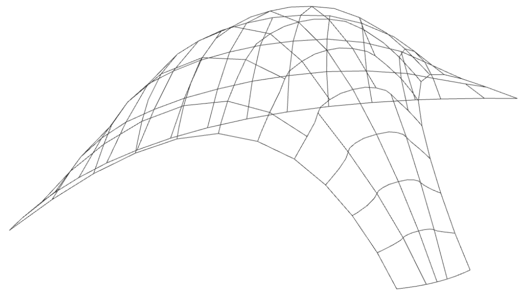


FIGURE 2.3.3: Discretized Output Boundary

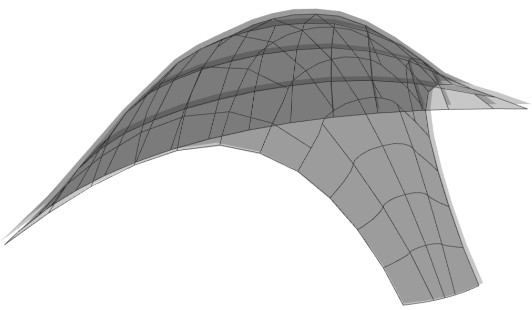


FIGURE 2.3.4: Paired Discretized Mesh

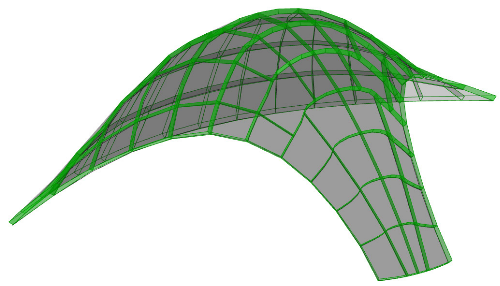


FIGURE 2.3.5: Edge Planarize for joint and print

2.3 EDGE PLANARIZATION

The first iteration of component design had planar edges with double curved surfaces on both sides. compared to a overall geometry with planar pieces, this approach had a smoother shape.

The discretized panels were offset to account for panel thickness. These panel edges were initially non-planar and did not aligned with the mesh boundary, and could not be used to model the connections and did not have the true panel thickness. A computational workflow was design to ensure that all the edges we planar and printable.

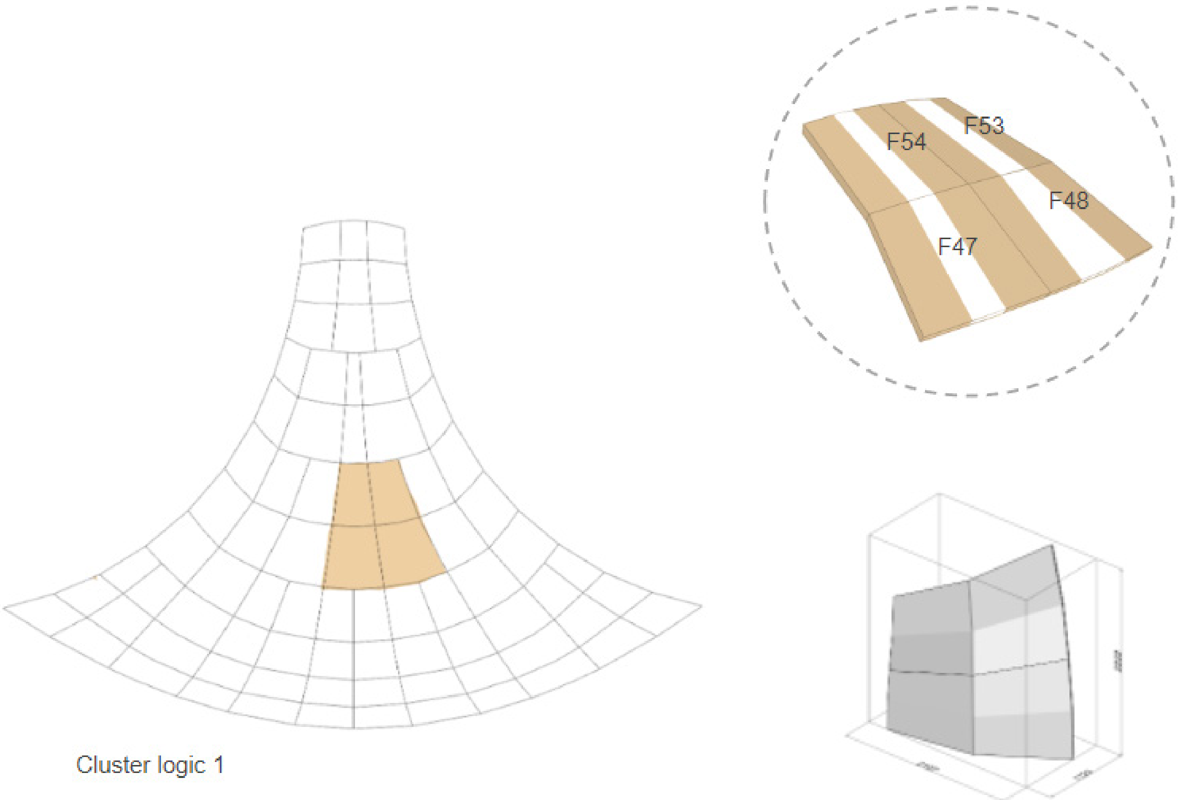
The component with planar edges would be printed vertically, with the long fiber print running in 1 direction.

However, this discretization and component design approach assumed continuity of the long fibers at the joints between pieces. The inherent nature of long fiber 3D printing did not allow for such long fiber continuity.

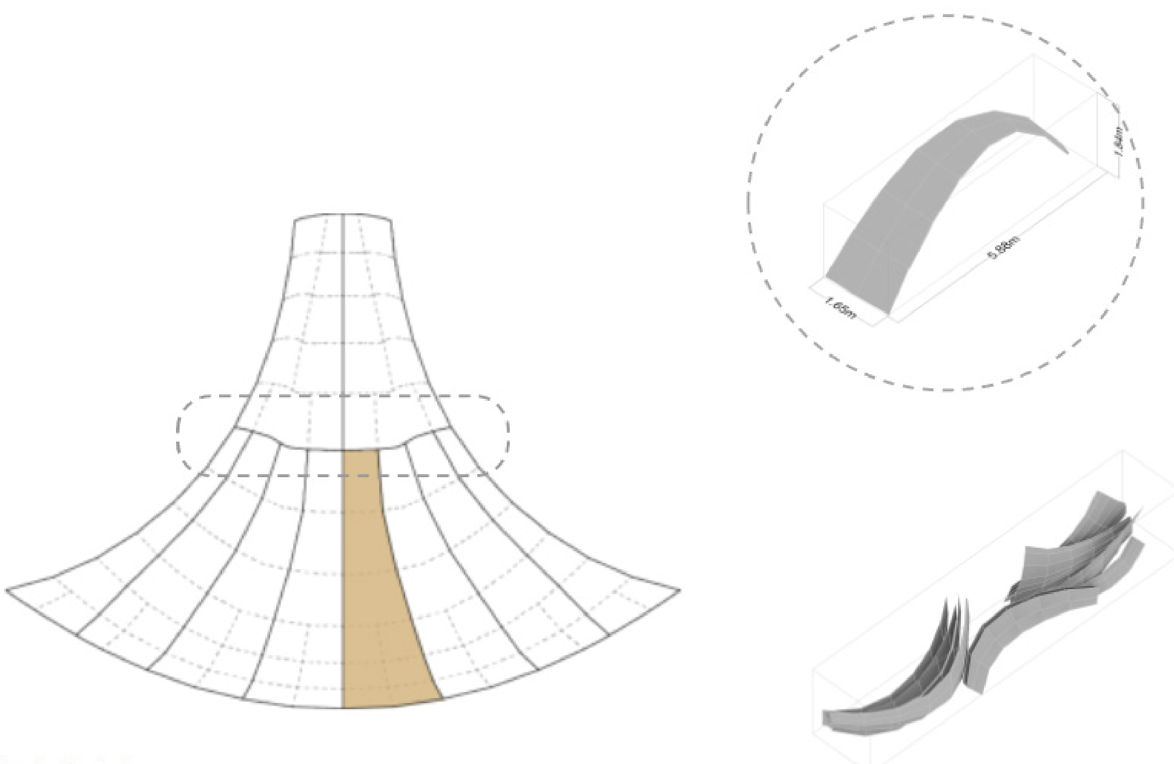
2.4 FABRICATION LOGISTICS

On the fabrication end, a method for clustering and preassembling the 3d printed components would ease on site fabrication and the disassembly and reassembly process.

The components would be clustered into larger pieces which still fit in the transportation constraints, and pre assembled using more permanent joints. This method would require less on site assembly.



Cluster logic 1



Cluster logic 2

FIGURE 2.4: Cluster Logic

PART 3

COMPONENT LEVEL REINFORCEMENT
LONG FIBER PRINTING

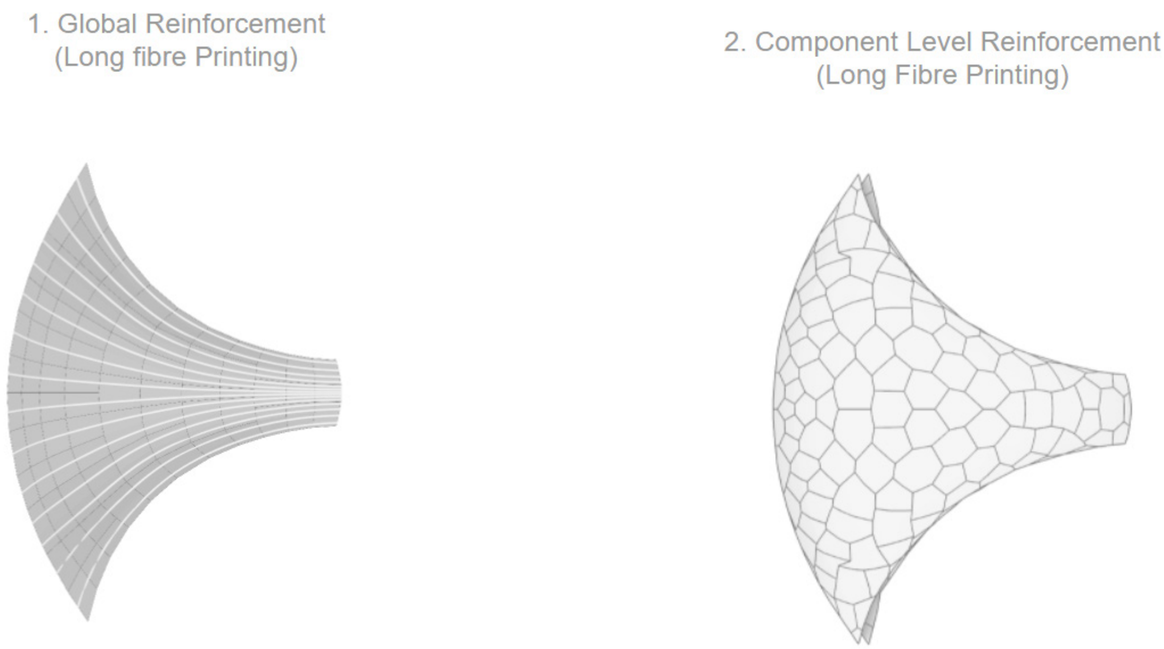


FIGURE 3.1: Long Fiber Printing design options

3.1 LOCAL REINFORCEMENT APPROACH

The next approach for discretization and component design was based on using long fiber 3d printing to reinforce each component locally to optimize material use.

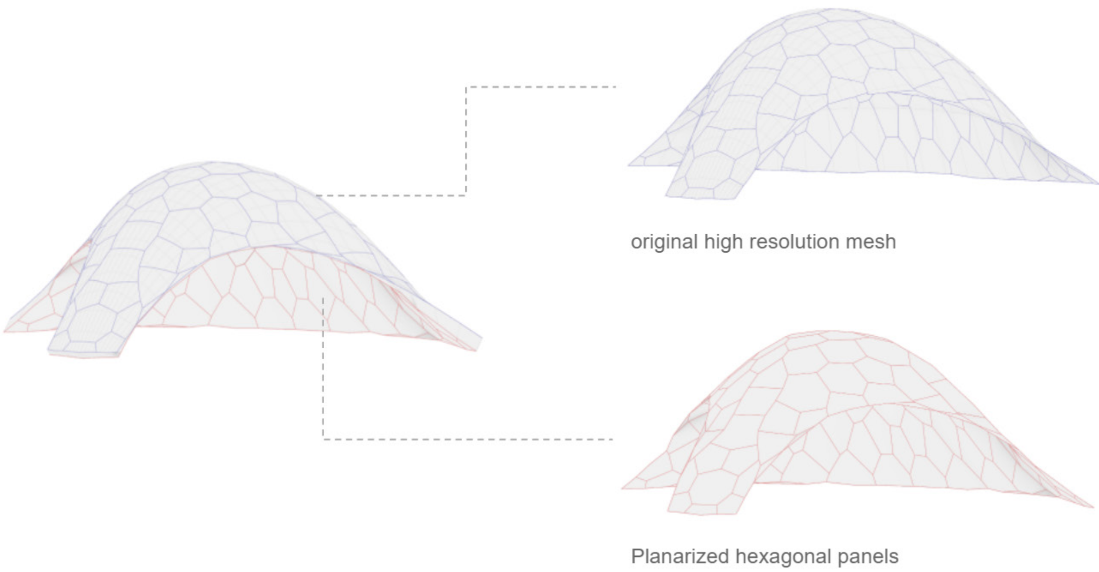


FIGURE 3.2: Component Build Up

3.2 COMPONENT BUILD-UP

The reinforced long fiber pattern would be extracted from the structural analysis of the overall geometry. As the long fiber pattern is multi directional, the base of the component is to be printed flat. To retain the smoothness of the overall pavillion shape, the interior surface of the geometry would be planarized for fabrication, while the exterior retains the smooth original mesh, resulting in the following build- up

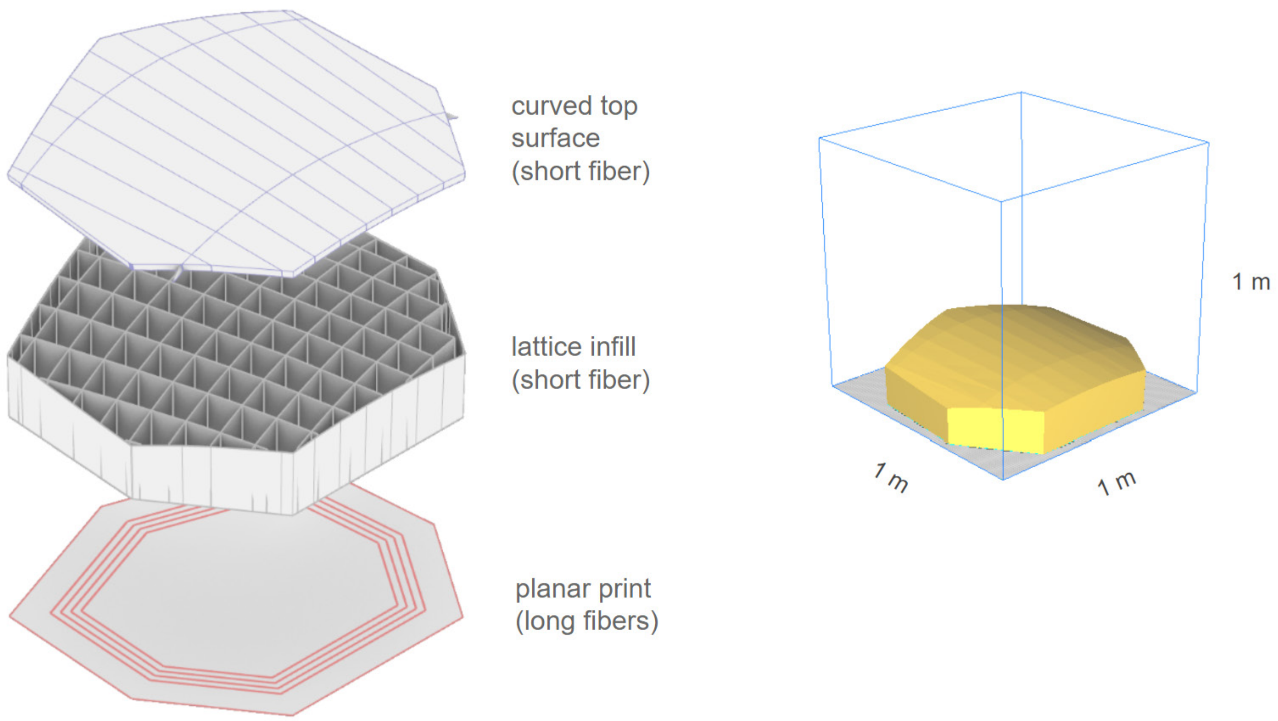


FIGURE 3.3: Component Build Up

3.3 DISCRETIZATION & PLANARIZATION

Two iterations of planarization were investigated:

Quad discretization
Using the current quad discretization, the quads were planarized.

Result: large deviations of up to 30 cm from original mesh, resulting in thick components (number o fpieces)

Joining strategy: bolts with lap joints

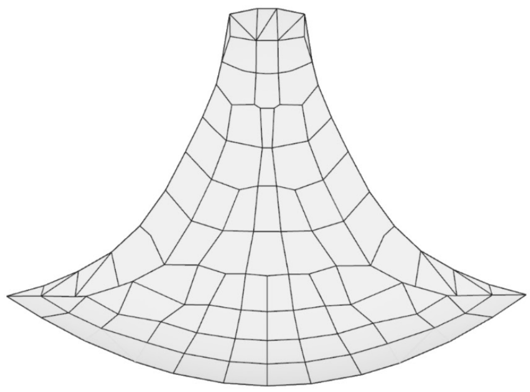
Agent based hexagonal discretization

*This approach took the Buga pavilion methodology as a precedent. using an agent based **circle packing** algorithm with the ABxM framework.*

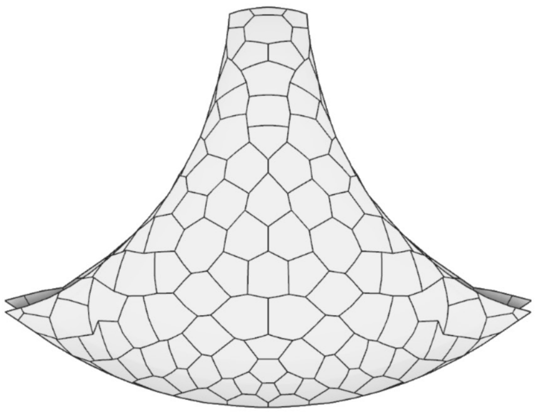
*Agent rules: - within fabrication limit of 1m*1m*1m, maintaining geometry boundaries and to keep as close to the original geometry as possible*

Results: deviation of up to 15cm from original mesh. (number of pieces)

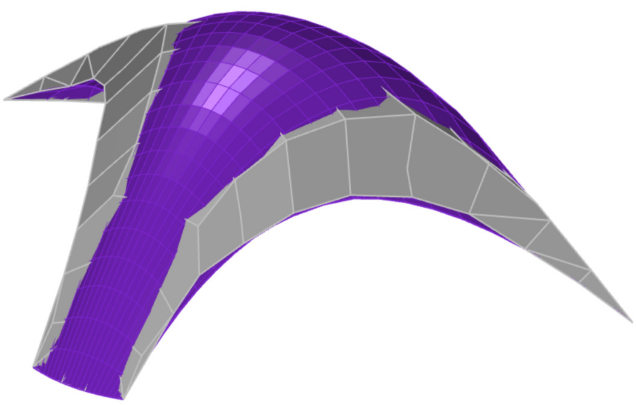
Joining options: butterfly joints



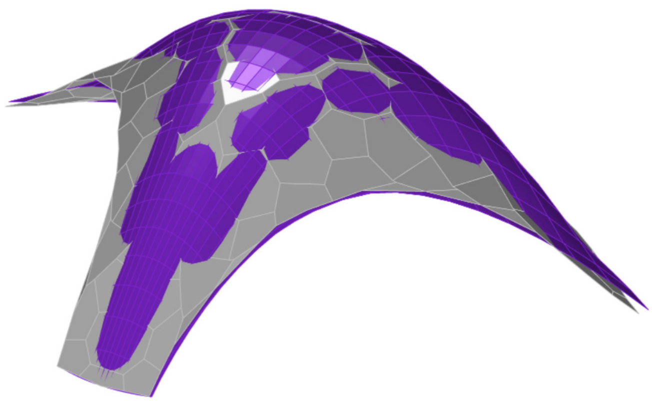
Discretized model-
Quad and rectangular
86 discretized panels



Discretized model-
pentagon and hexagon
104 discretized panels

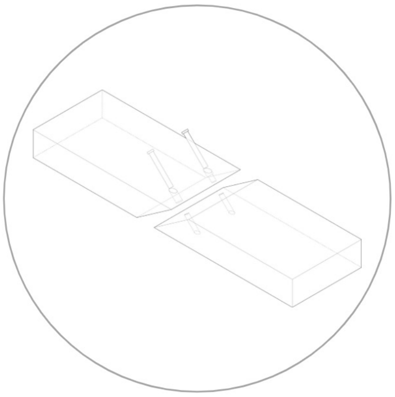


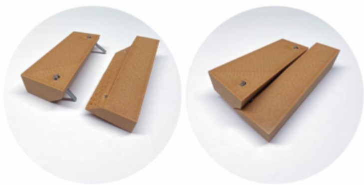
Discretized model-
Quad and rectangular



Discretized model- pentagon
and hexagon

SCREW CONNECTION





STICK CONNECTION