Logic to Artefact

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Reciprocal Frame Structures

The objective of this study is to investigate Reciprocal Frame Structures (RFS), how a computational logic to model them can be understood and finally to apply that logic to construct a scale model, artefacting that logic.

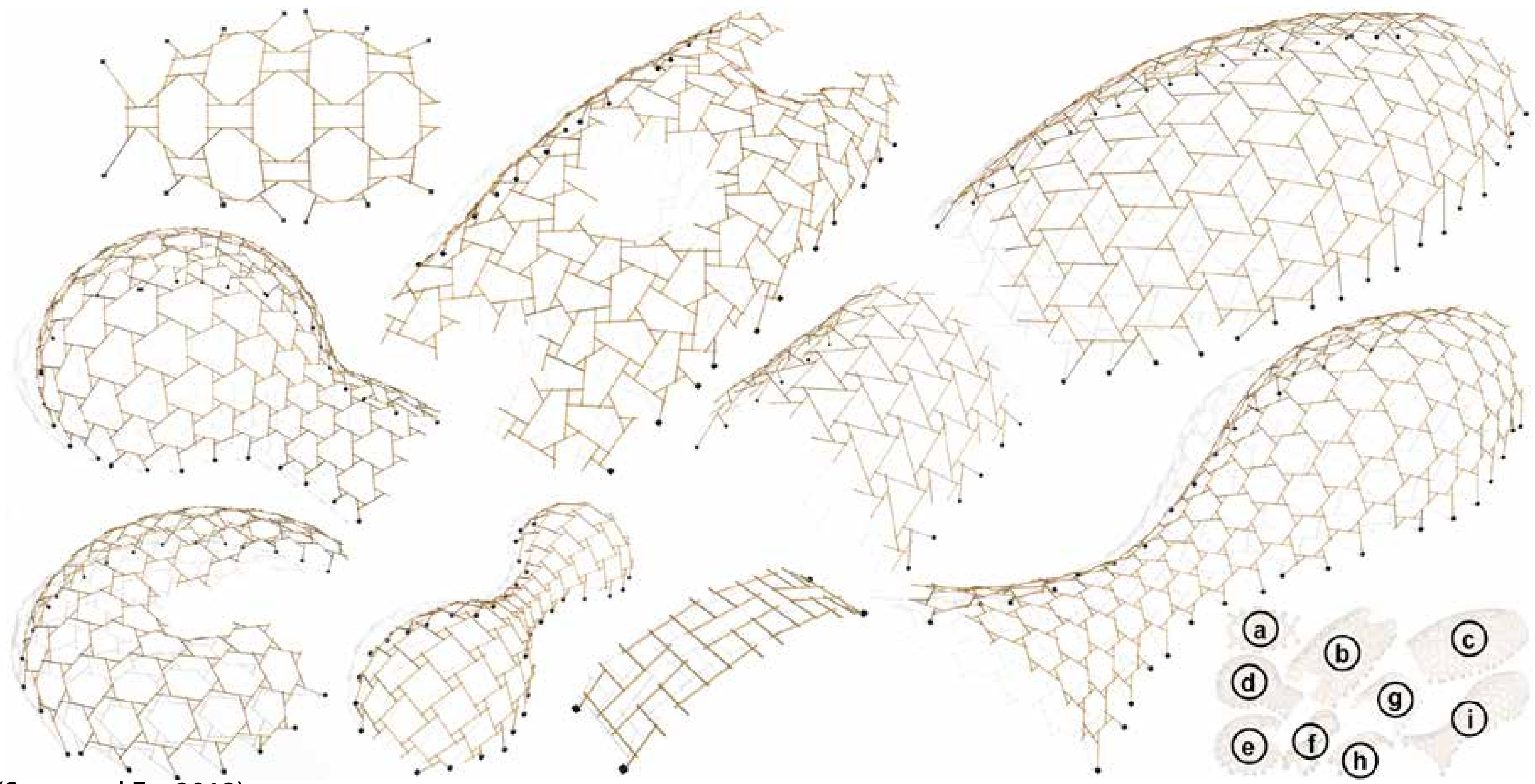
(ZanteChristo-Architects, 2013)

What are Reciprocal Frame Structures?

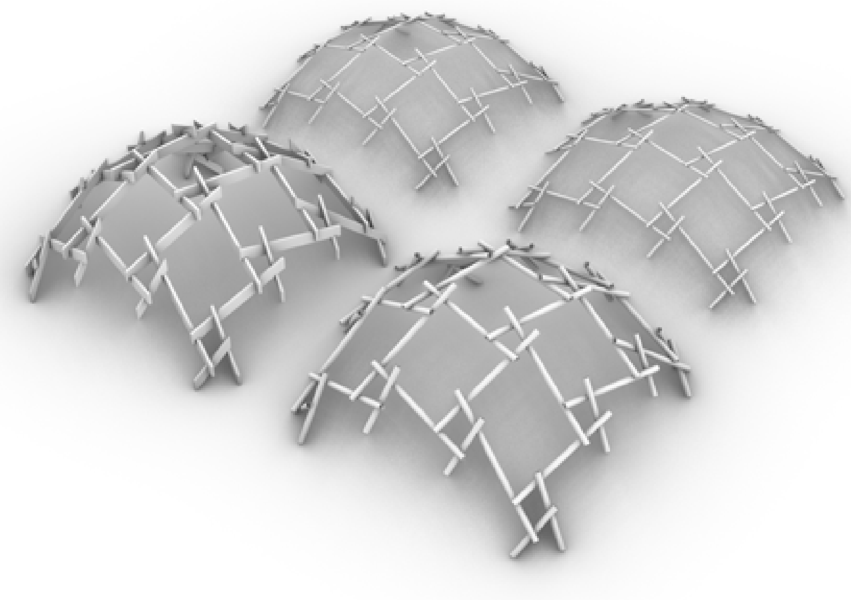
Reciprocal Frame Structures (RFS) are formed of an assembly of similar parts, typically beams or poles of equal cross section, which are patterned in a weaving manner creating a self supporting structure. They potentially allow large shell like structures to be realised with relatively small and simply produced parts which could make complex structures more economically and logistically feasible.

A note on the final design

The context which has led and informed the narrative of this design process has been to design a wildlife observation hide which focuses on the transition between entrance to view. This hide should emerge from an increasing density of parts from entrance to passage, before opening out onto view.



(Song and Fu, 2013)



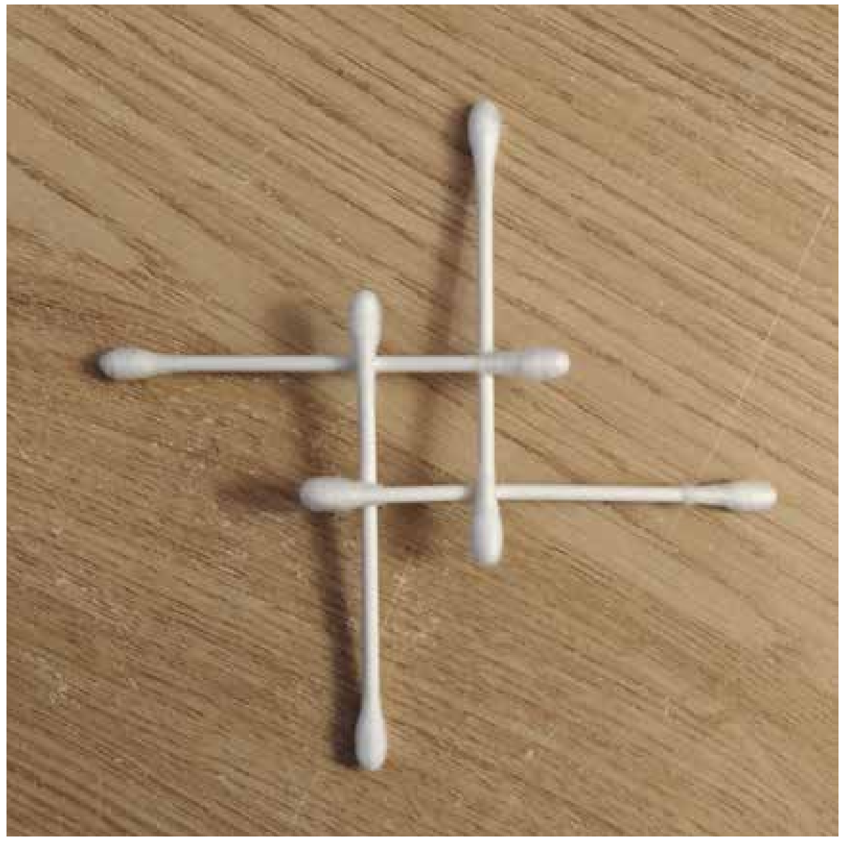
Base Logic

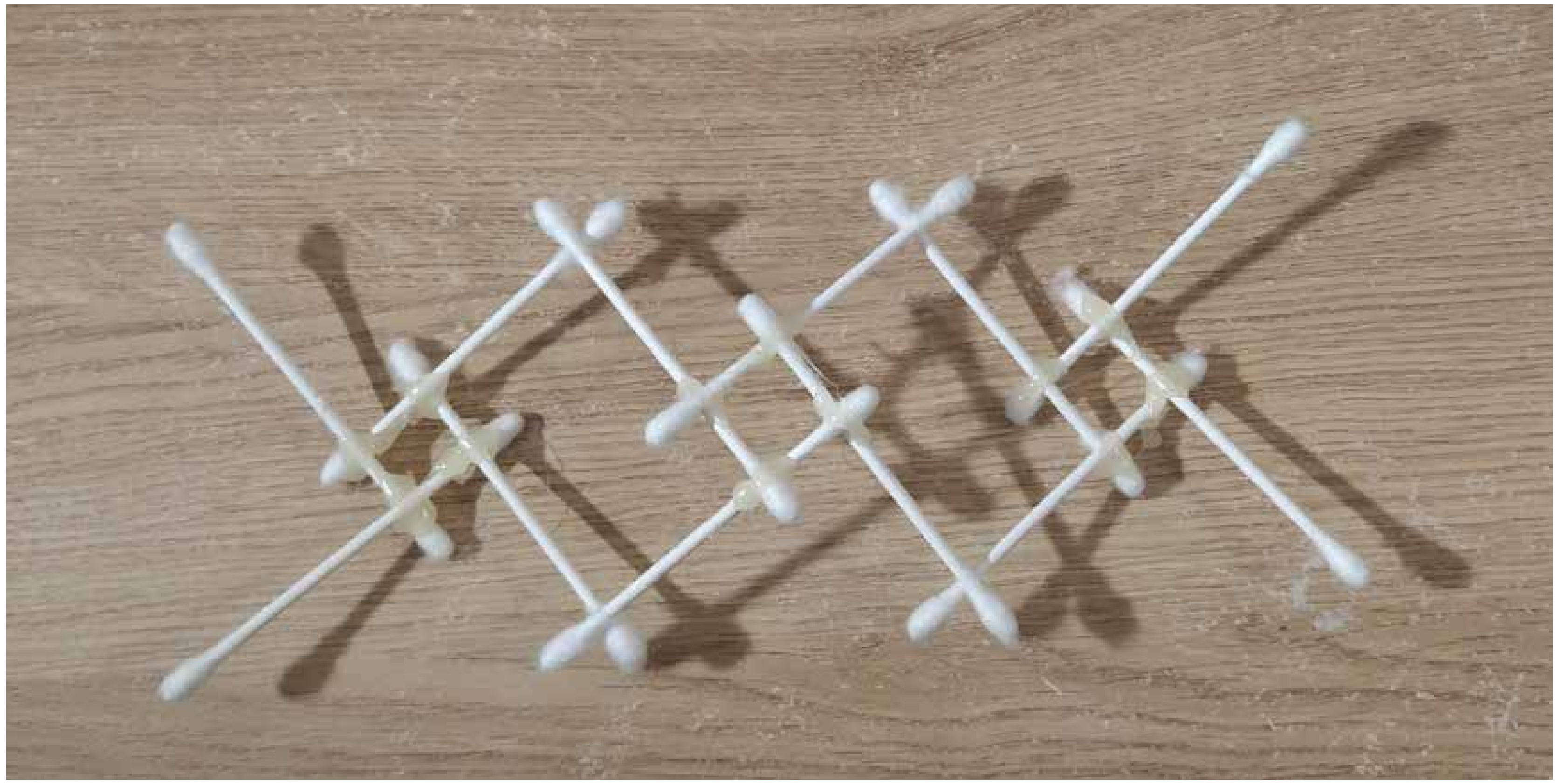
The basic logic of a RFS can be best understood through phyical modelling as seen here with the knifes resting on glasses. Where they cross over they support each other in space.

This logic when demonstrated below with earbuds shows that when these instances are replicated, the ends of the knifes or earbuds which were resiting on the glasses now become another center where these parts cross over.

By repeating this logic across a surface which has been split into faces such as a geodesic dome, a RFS can begin to emerge.

(Godthelp, 2019)





Initial Computational Logic

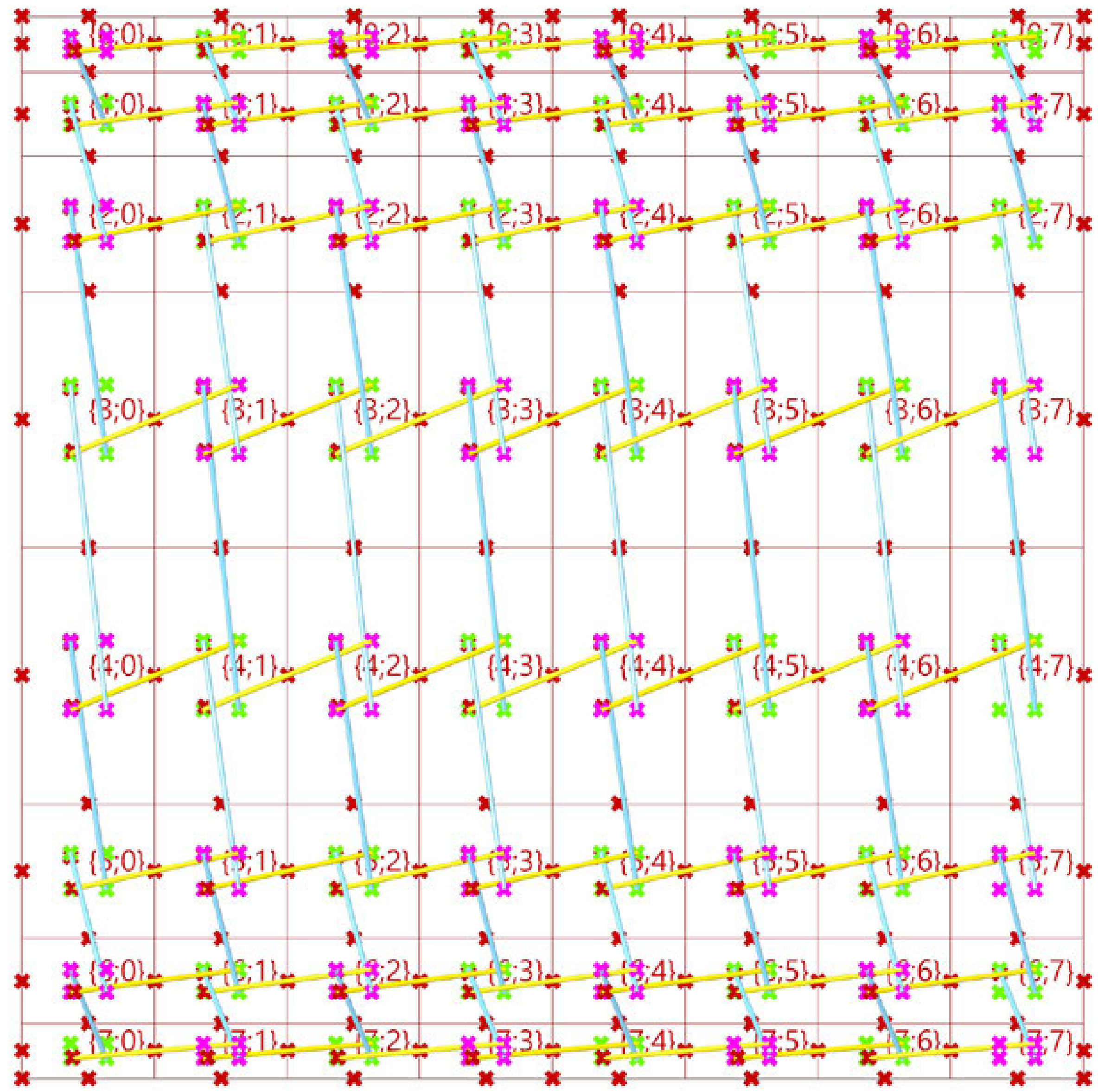
The initial computational logic uses a surface which is subdivided into multiple surfaces.

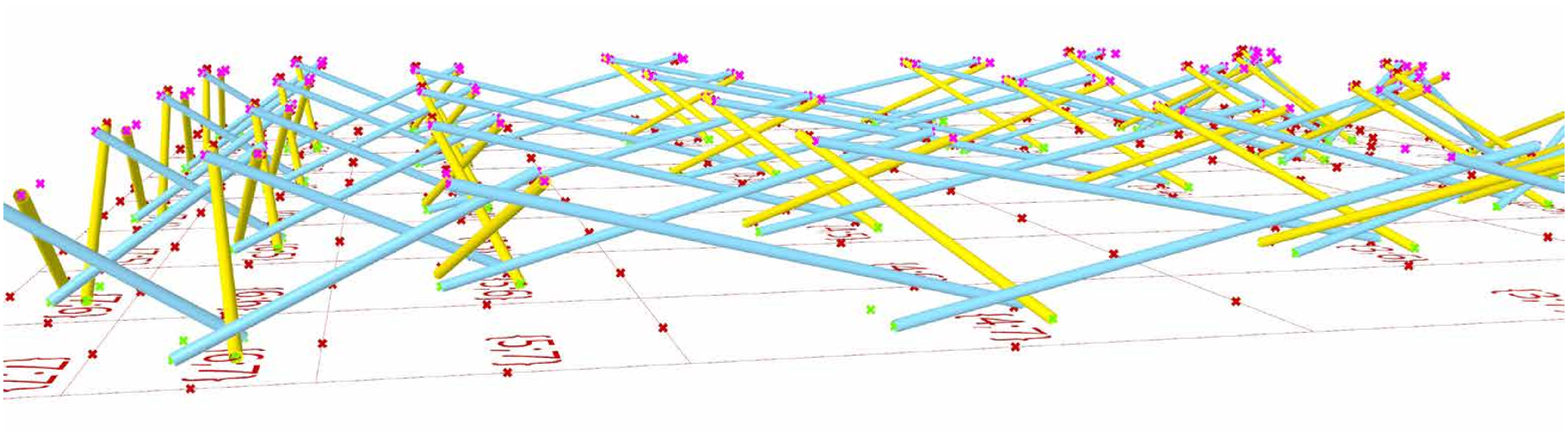
Lines are drawn from vertices of all the surfaces to adjoining surfaces using a pattern e.g. bottom left to top right vertex of surface to the right.

This creates a cross over pattern.

To turn this into a RFS, the vertices of every other surface in a chess board fashion, is moved away from the surface in it surface normal direction, as shown with the pink vertices.

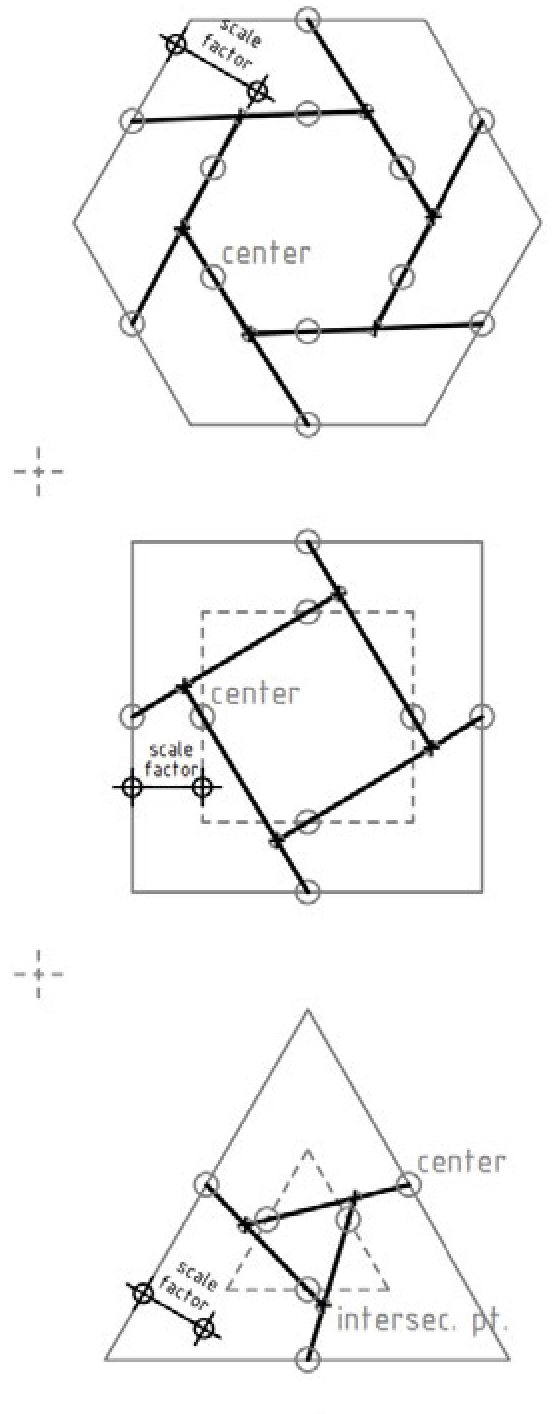
This allows the parts to overlap in a manner which allows them to be in clearance of each other and if allowed to rest on one another, should self-support each other.





Initial Computational Logic

When applying the logic to a basic curved surface, the elevation of the vertices did not need to be alternated. The offset from base surface of the vertices and the scale factor of the cross over points relative to their base changed how feasible and close to the base surface the structure was once the parts were allowed to collide with each other using the Kangaroo physics engine within grasshopper.



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center to center and offset

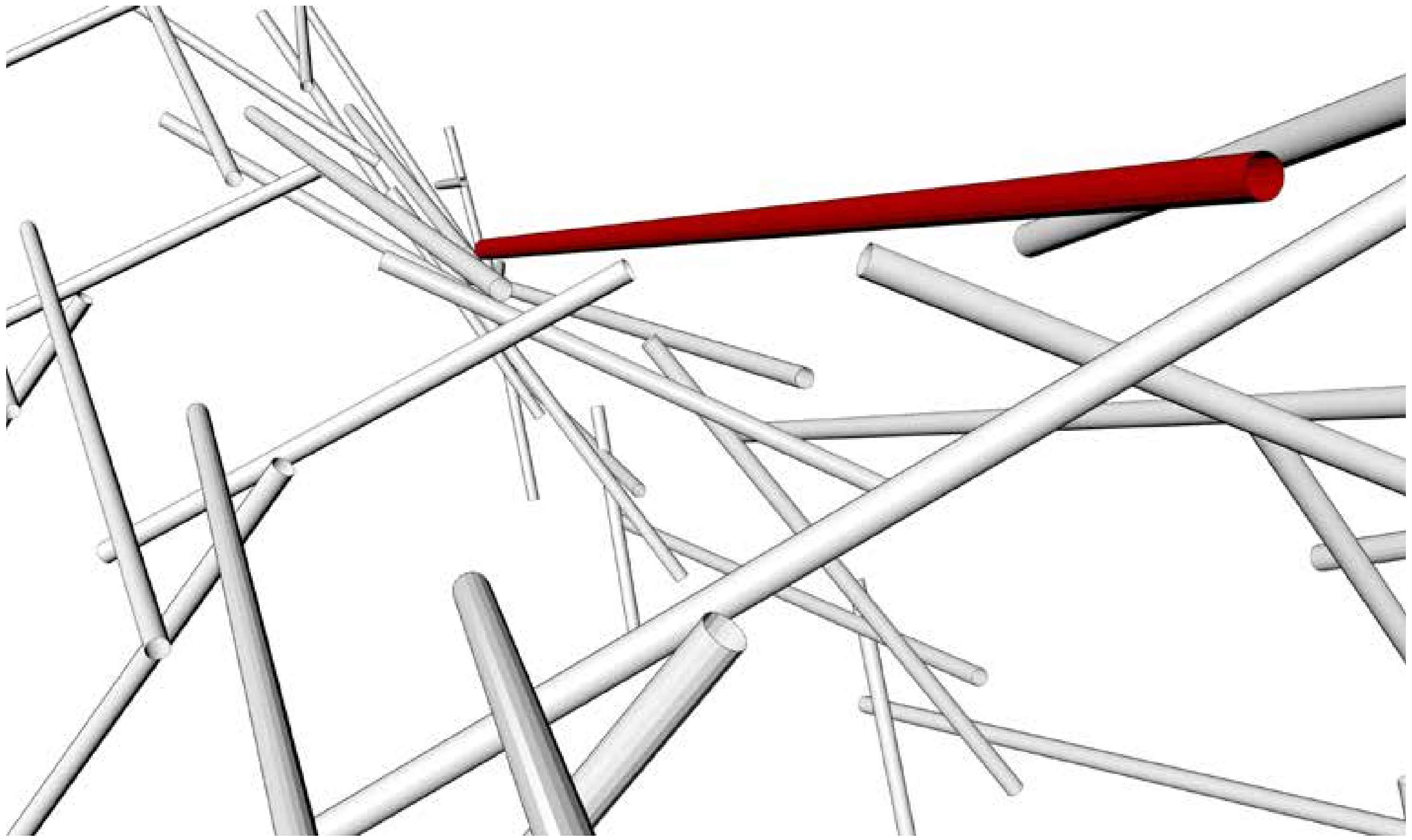
(Godthelp, 2019)

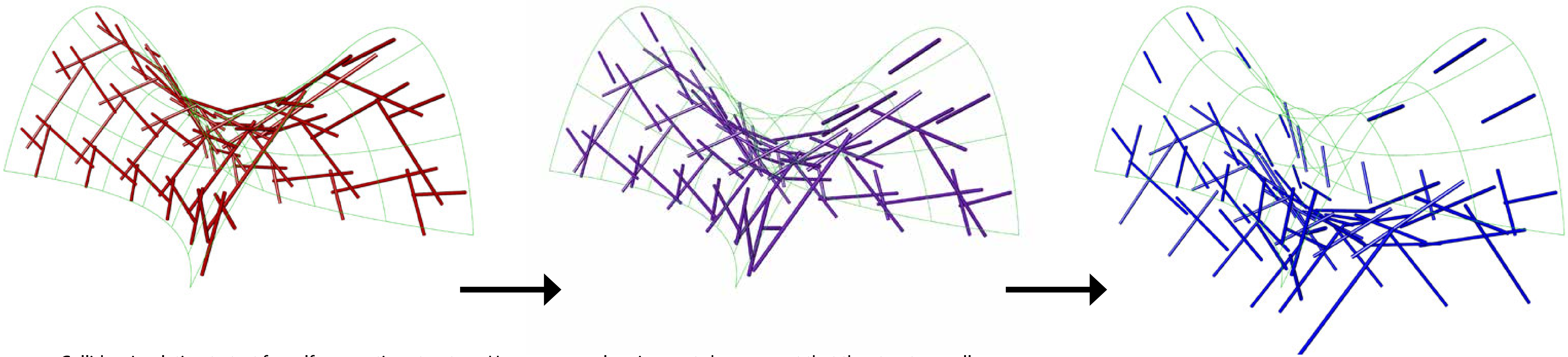
Application to complex geometry

When the logic developed is applied to more complex geometry such as this hyper parabolic surface problems arise.

Parts do not always overlap in a correct order or sometimes not at all as seen highlight in red on the right resulting in zero structural integrity.

To arrange straight parts in the correct order for more complex geometry raises many complications.





Kangaroo Collider simulation to test for self-supporting structure. Here, non-overlapping parts have meant that the structure collapses.

A kinky solution

With the problems of the initial computation logic a much simpler solution was found.

Treating all the divided surfaces as individual RFS, their outer points or knife handle ends all share their location with their neighbor, connecting lines which share a point creates a kinked polyline.

Rather than trying to decipher a best fit line or approximated geometry to fit a straight line part to this kinked line, why not embrace the kink?

There are many benefits to embracing the kink.

1. Allows for RCF patterns to be applied to more complex geometry.
2. Can be applied to conventional Digital Manufacturing (parts are still planar)
3. Kink/Bend point in element allows opportunity for stiffening at area of highest stress (near the midpoint of the part experiencing bending moments).

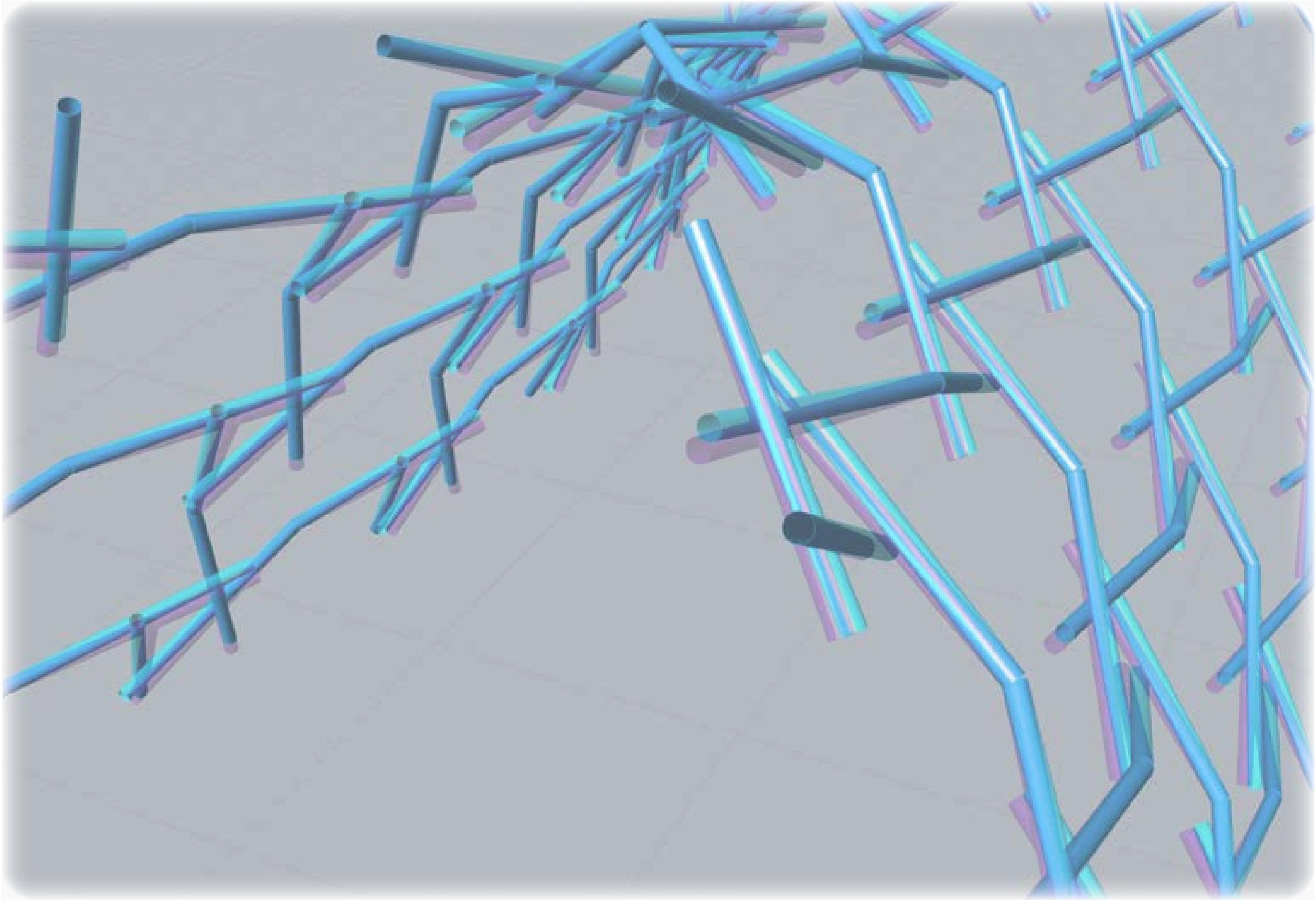
(Godthelp, 2019)

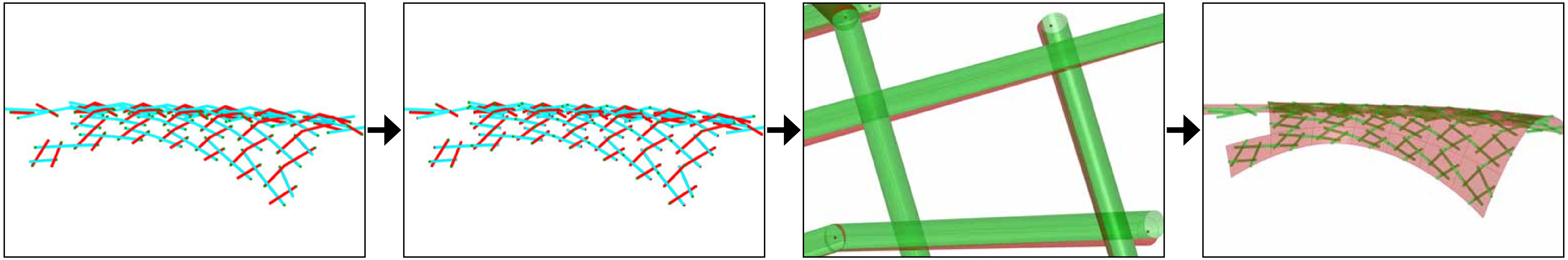
A kinky solution

The kinked points and points which sit on the perimeters of all the subdivided surfaces are fixed.

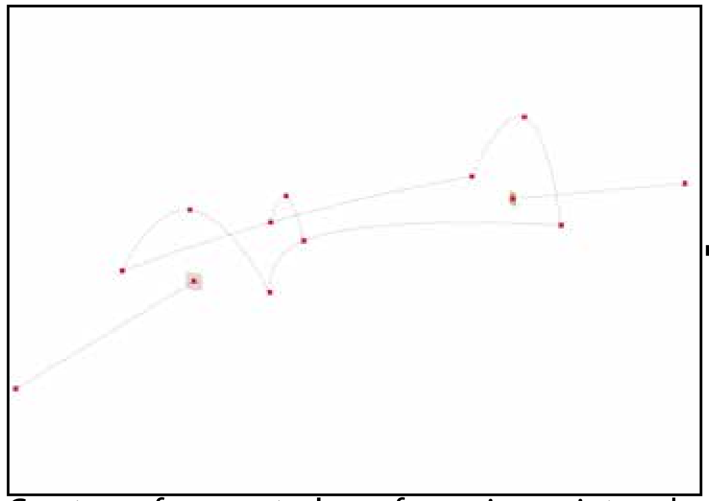
The points used for to structure the overlapping parts on each surface are initially projected away from the surface by the surface normal directions.

Using Kangaroo, these projected points are allowed to move along that normal vector until the parts collide, creating the base geometry to create the parts from.

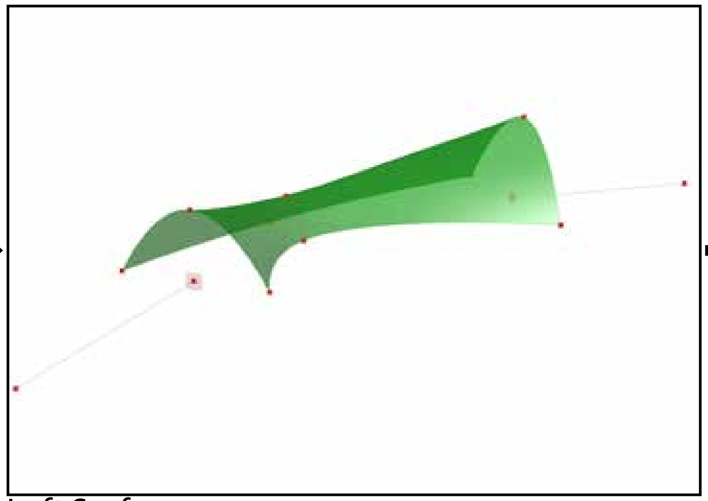




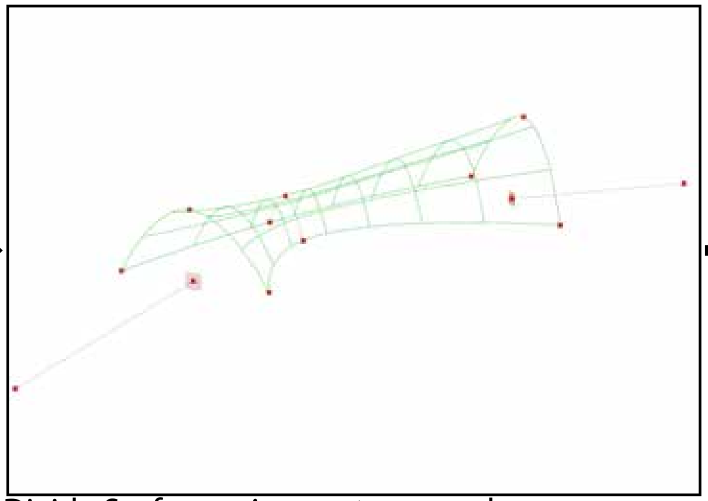
Data flow a



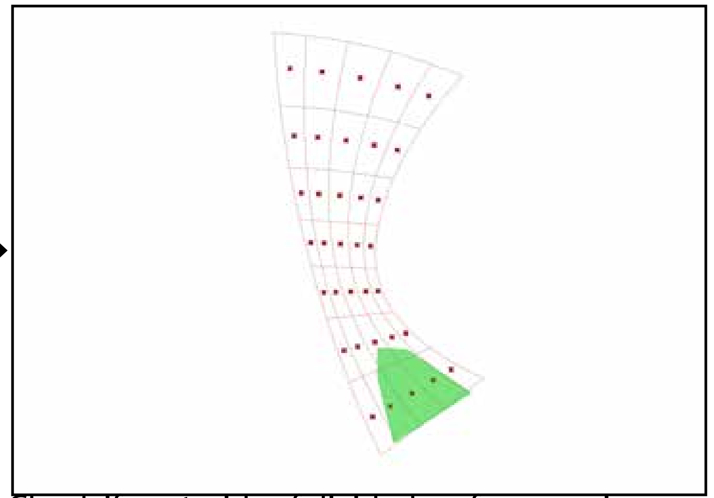
Create surface control geo from viewpoint and entrance planes



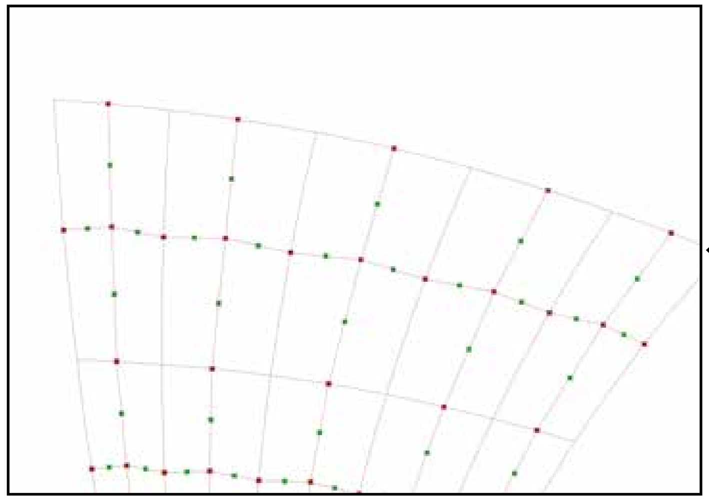
Loft Surface



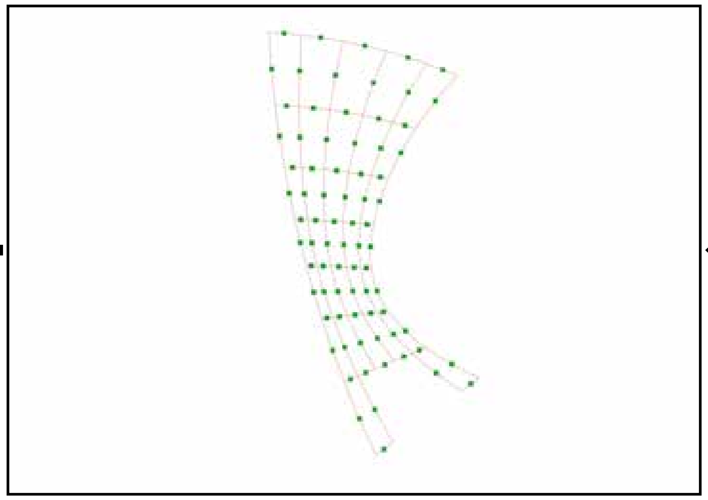
Divide Surface using custom graph mapper



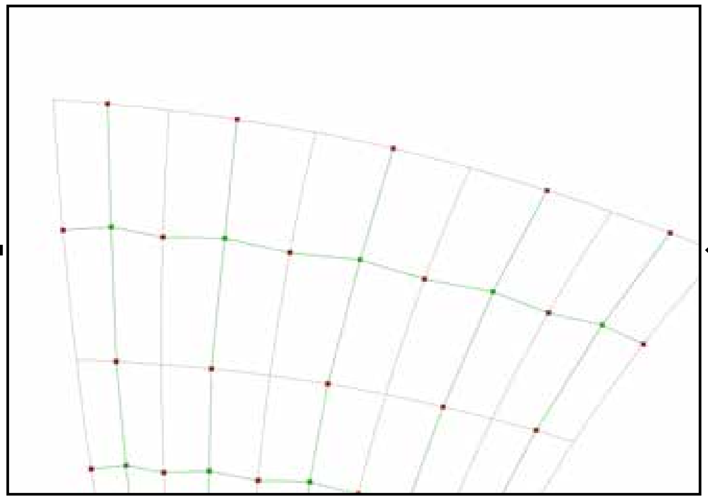
Check if centroids of divided surfaces are in brep



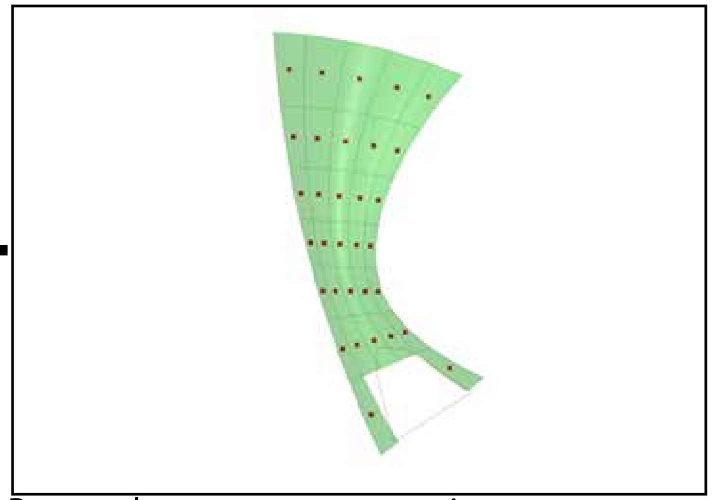
Create parametrized point on lines



Create lines from mid points of perimeter curves to centroid

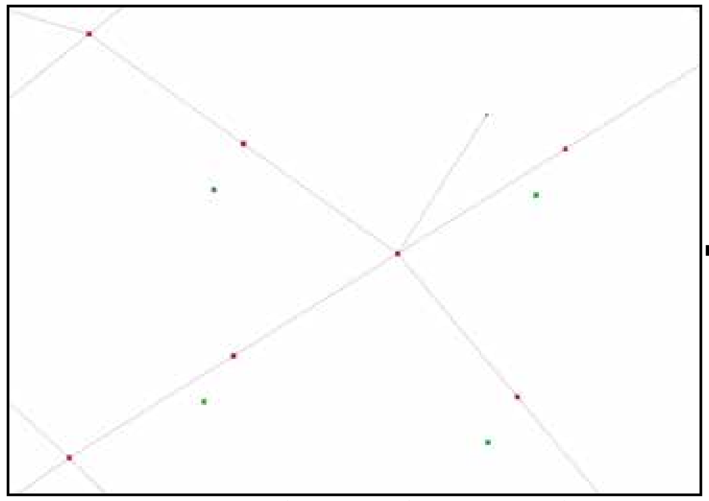


Get mid points of all divided surface perimeter curves

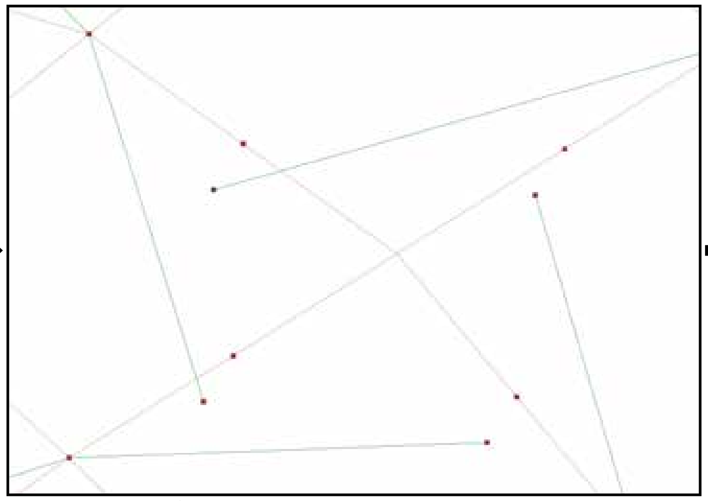


Remove breps to create emerging entrance

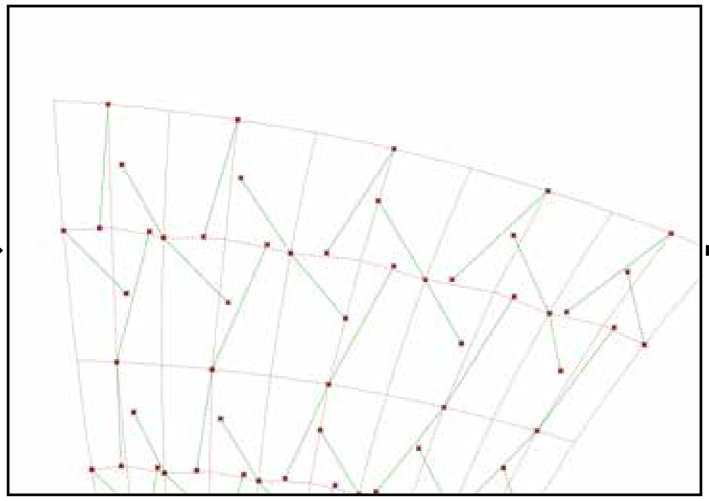
Data flow b



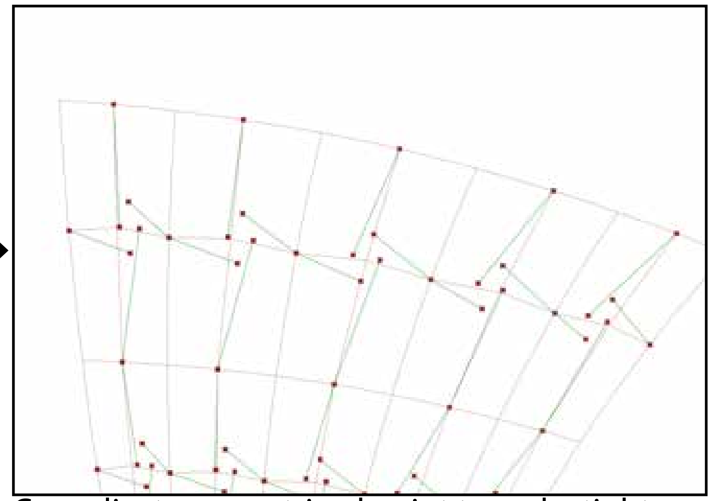
Move points away from surface by surface normal



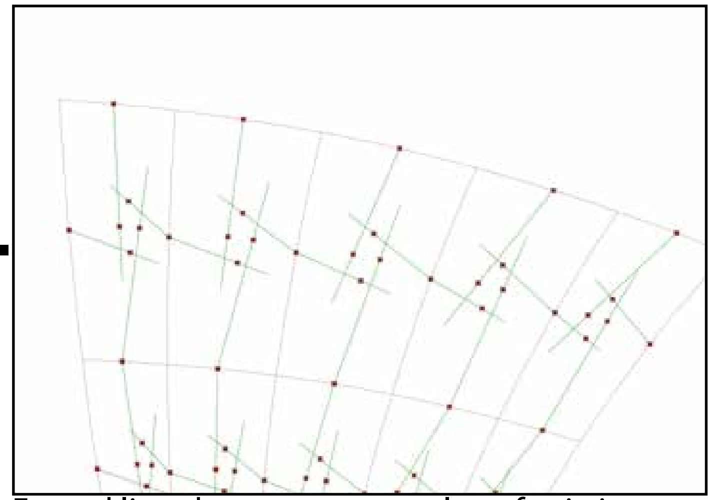
Create line from mid-point on perimeter curve to moved parametrized points



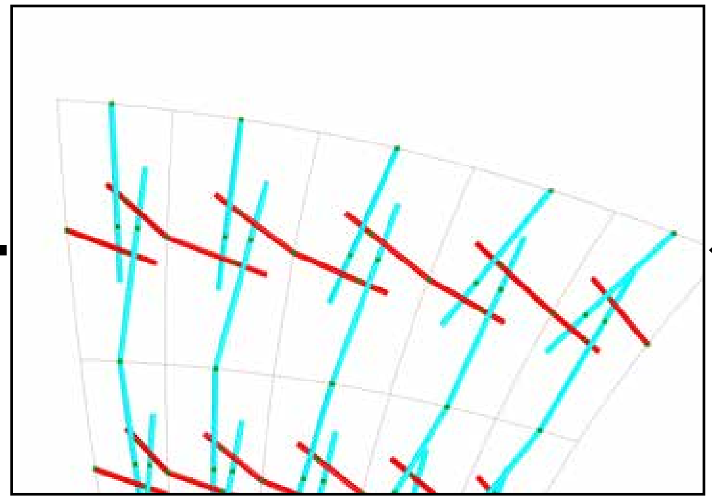
Can adjust parametrized point to make looser crossing over



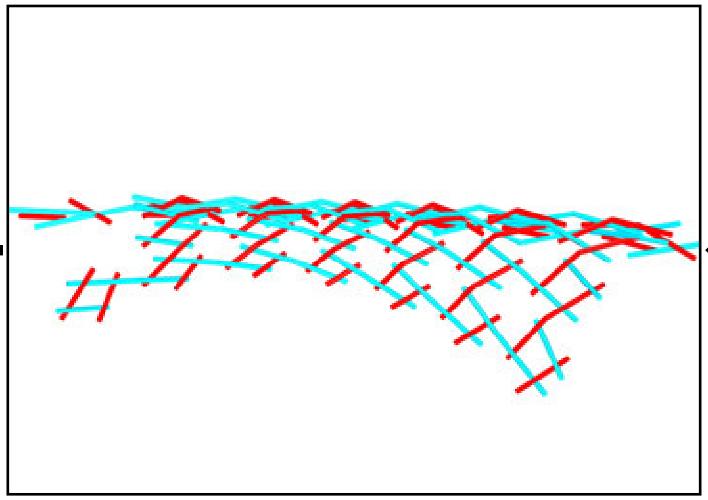
Can adjust parametrized point to make tighter crossing over



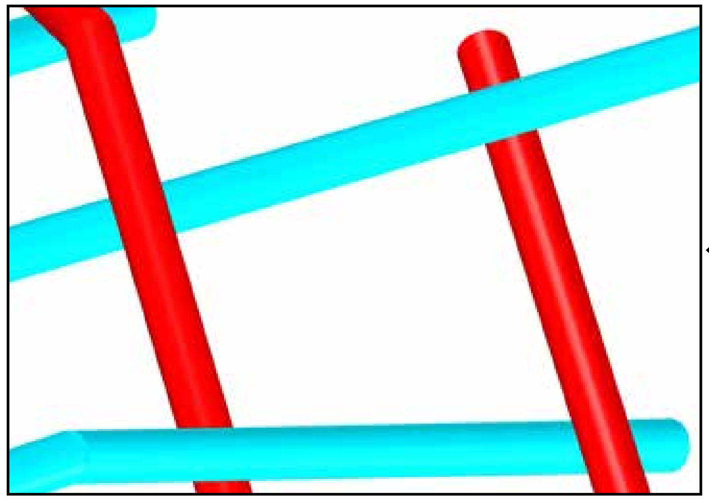
Extend lines by percentage value of existing length



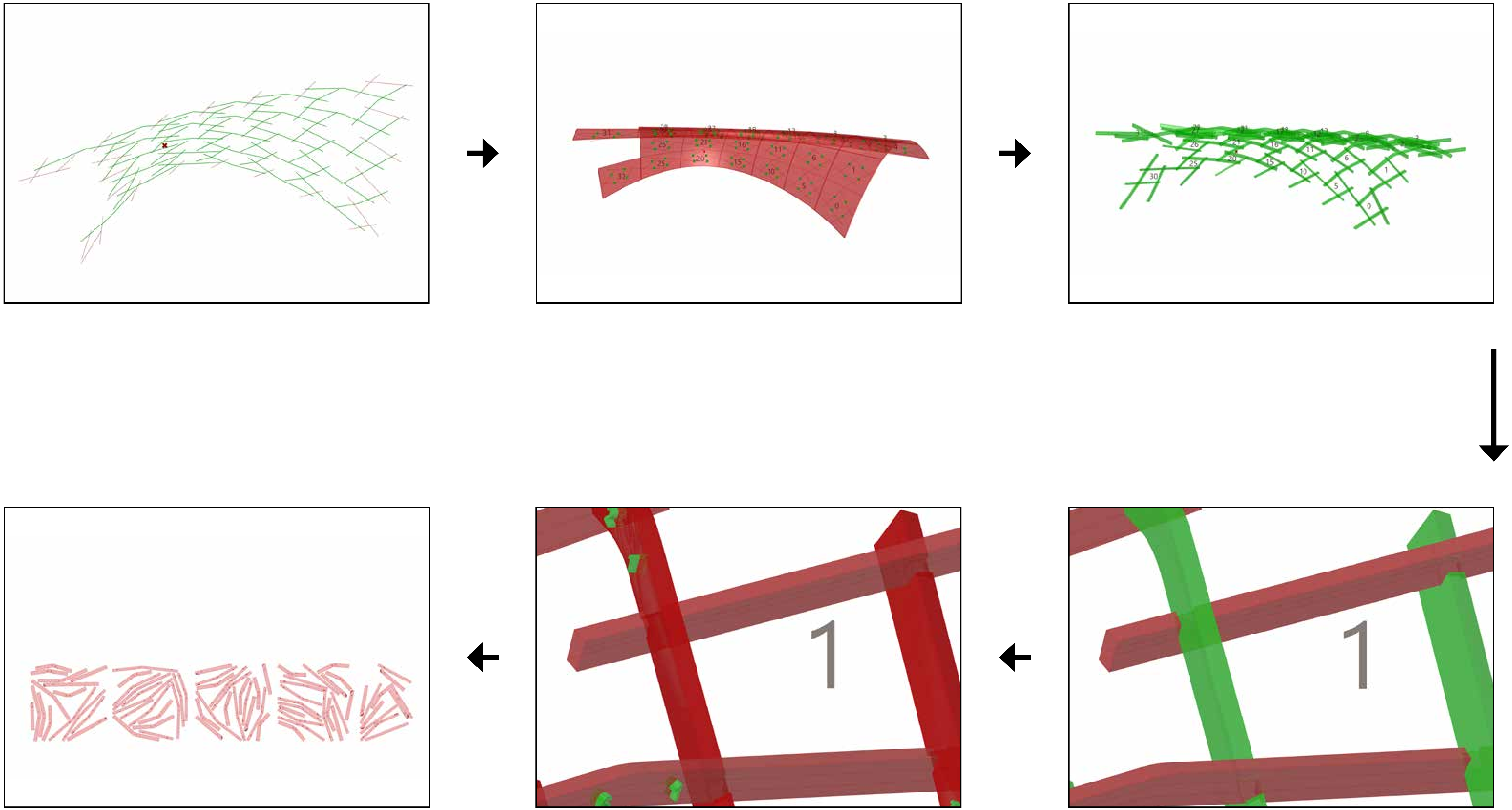
Add Piping to observe correct pattern cross over weave



Adjust in Kangaroo by moving weaved parametriced point up with collision



Design for Manufacture



Design for Manufacture

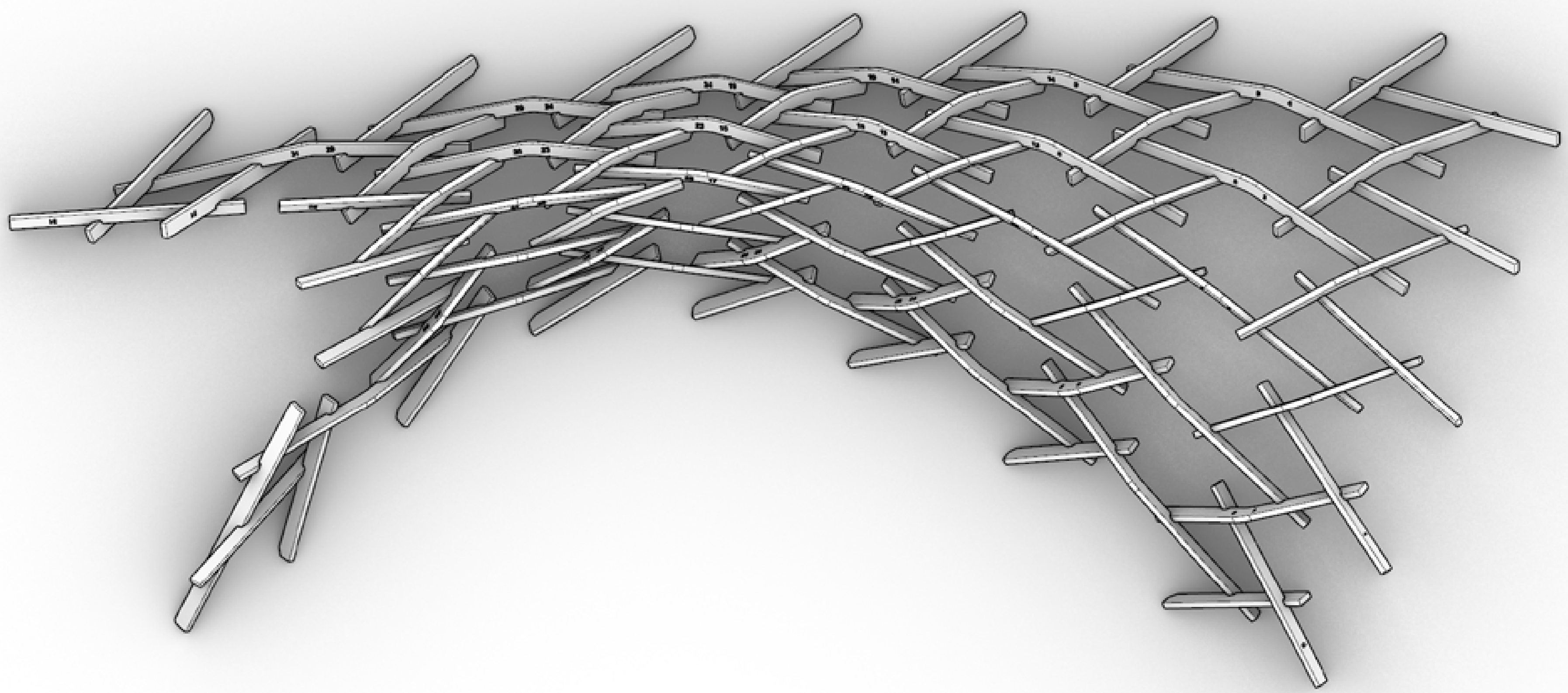
Design for fabrication using CNC machining/ FDM 3d printing.

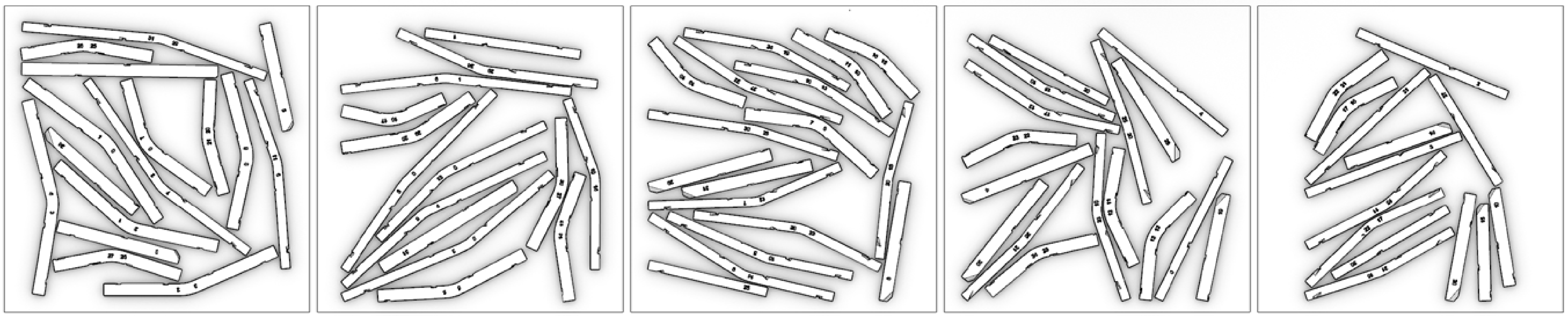
→ Could be fabricated using CNC Routing/ Lase cutting.

→ Development for FDM 3d printing due to accessibility (own one).

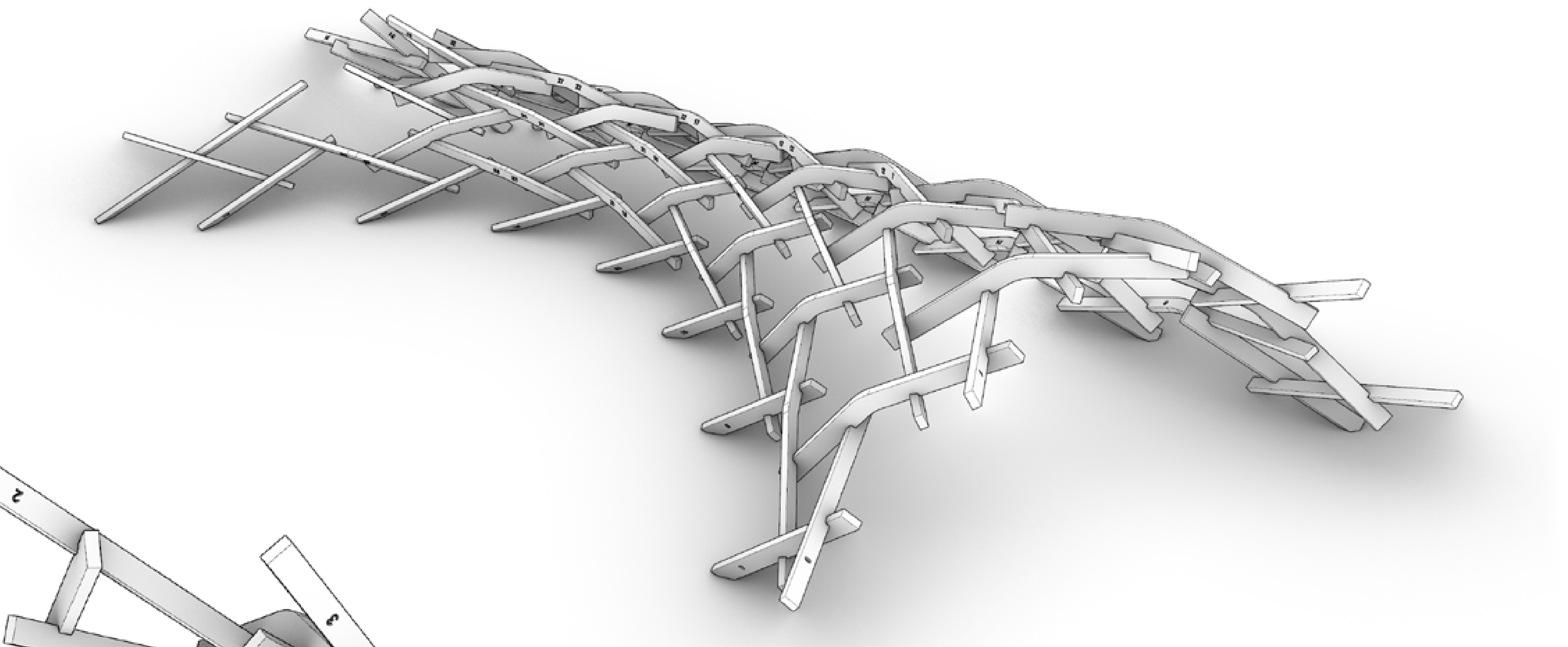
Logic

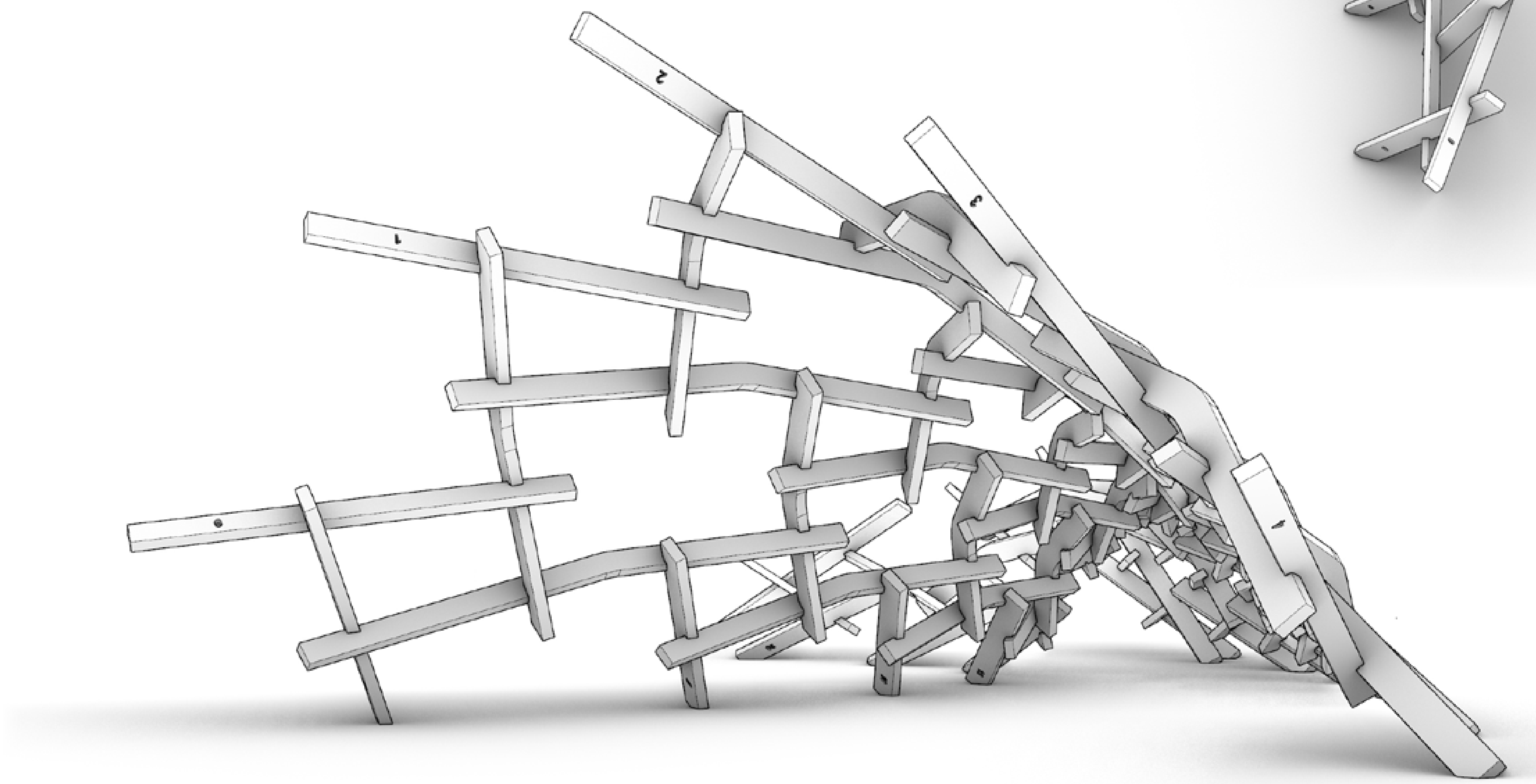
1. Create Planes and profile curves for elements from imported Kangaroo lines.
2. Extend supporting elements to ground and split with ground.
3. Assigning Locator numbers to ends of elements which share end points within indexed faces of divided initial target surface.
4. Create multiple thickness elements for Boolean differencing to allow for tolerancing (ease of fitment)
5. Sort Elements into patterns to allow for correct Boolean difference (correct notching of elements).
6. Engrave (Boolean difference) assigned locator indexes on elements.
7. Lay elements flat on build plate area using OpenNest





Final Design





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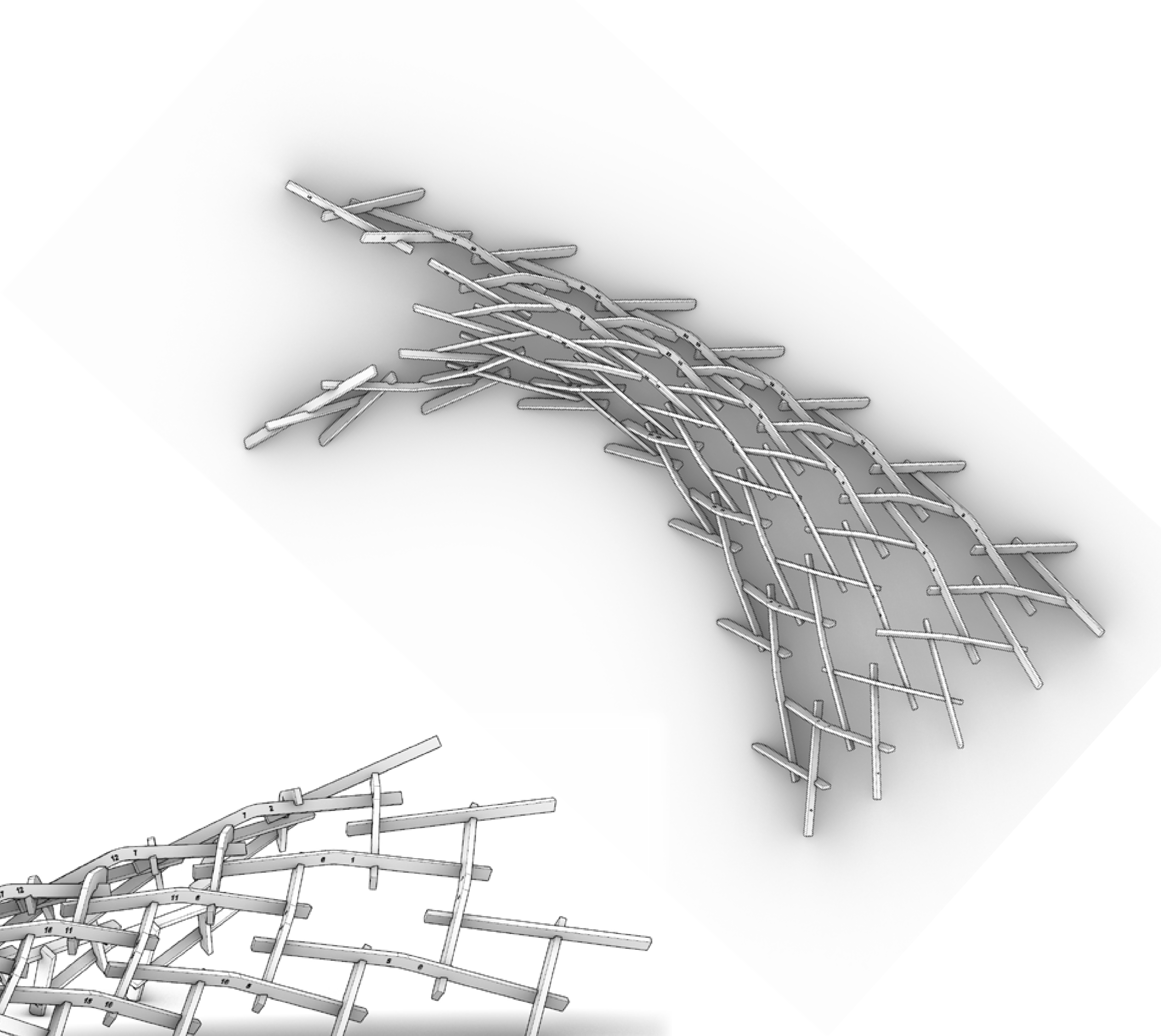
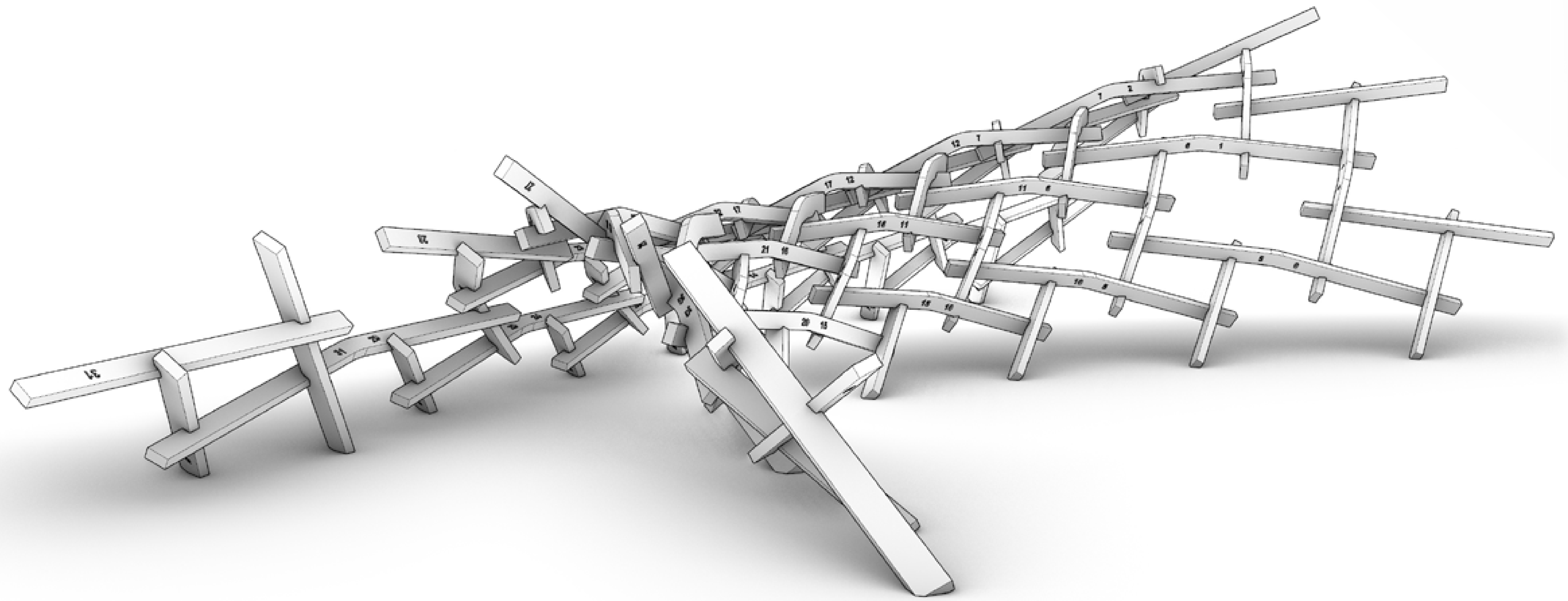




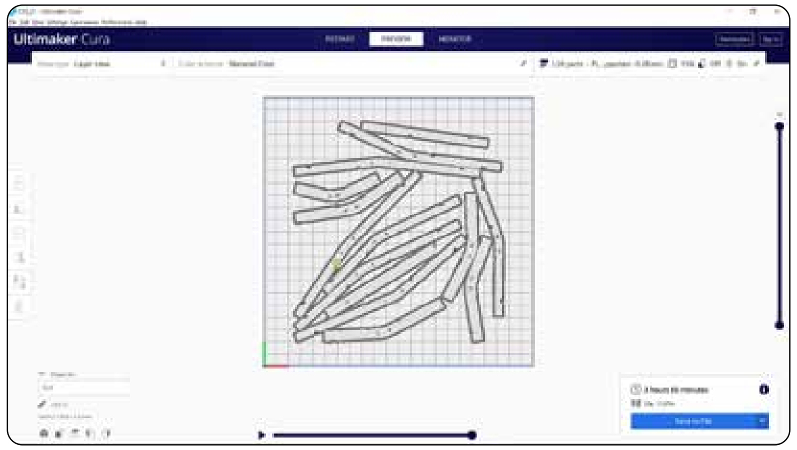
Fabrication

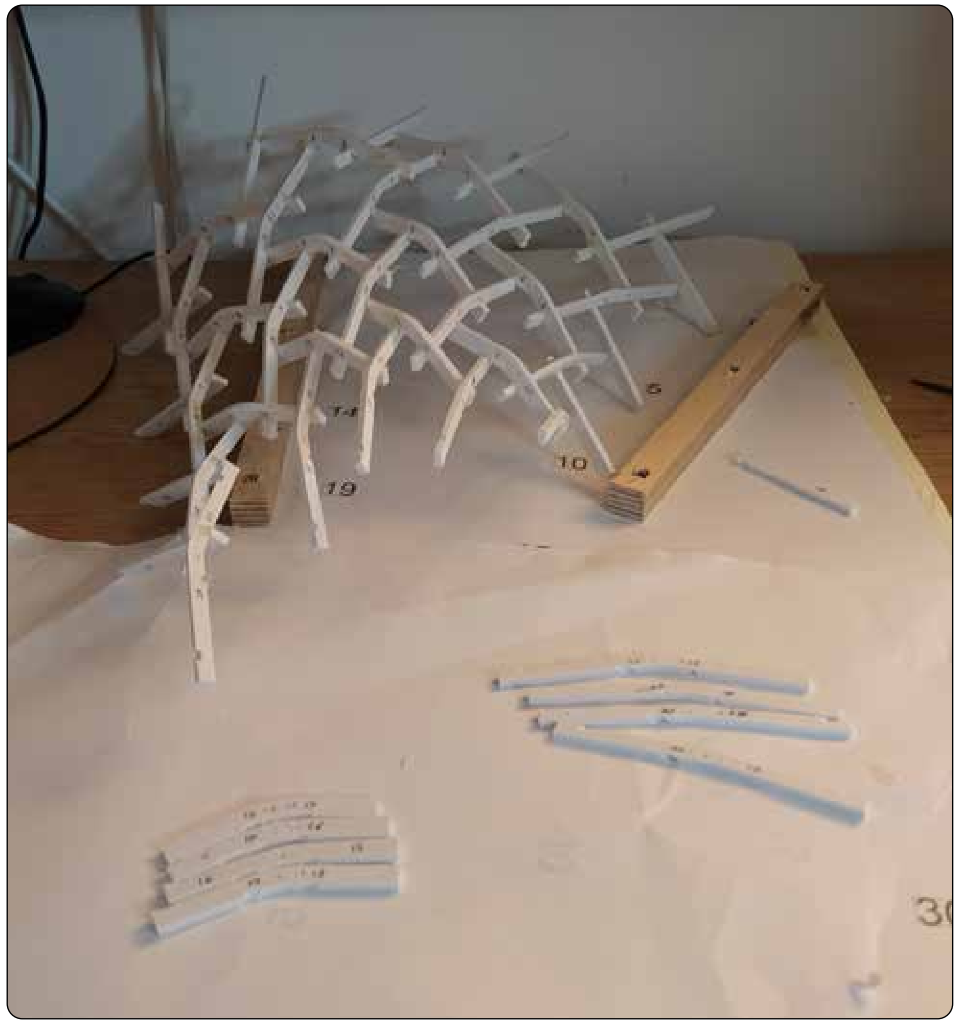
Digital Fabrication utilized a FDM 3D Printer printing 5 groups of parts totaling 77 parts over approximately 18 hours of printing.

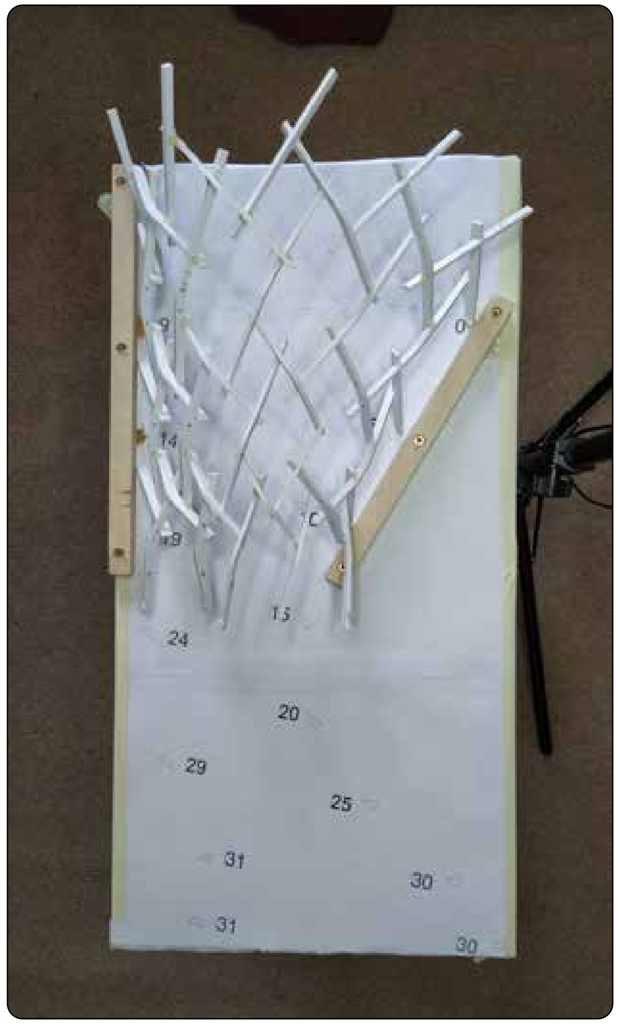
When printed locating identifier numbers were re-drawn on parts due to inconsistencies in print quality.

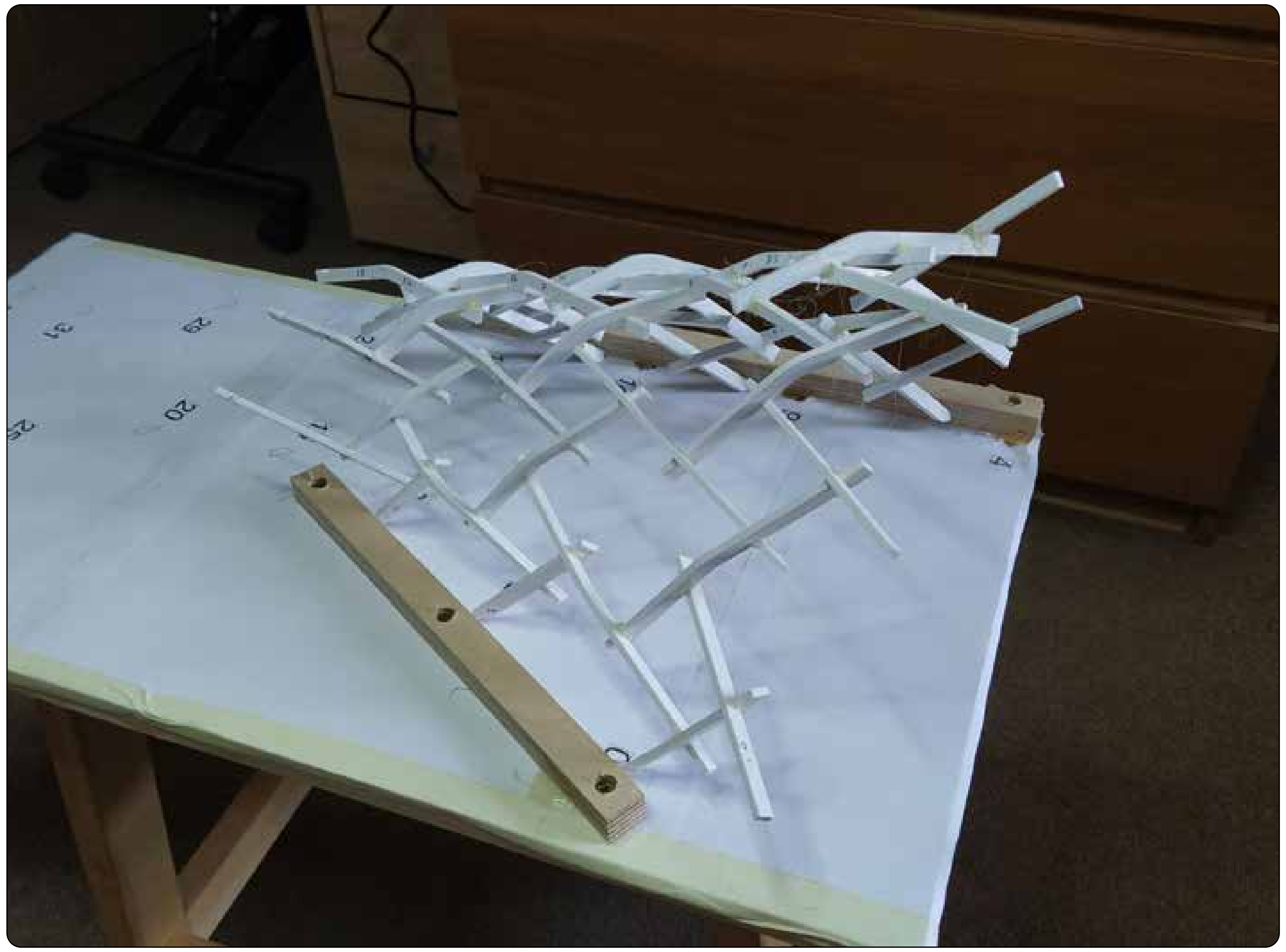
The model was then careful glued together using a hot glue gun for strength and flexibility of the joints over approximately 12 hours.

A reinforcing ring was required to help form the structure as it naturally wanted to splay apart with no fixed foundations.









Final Model

Final Model

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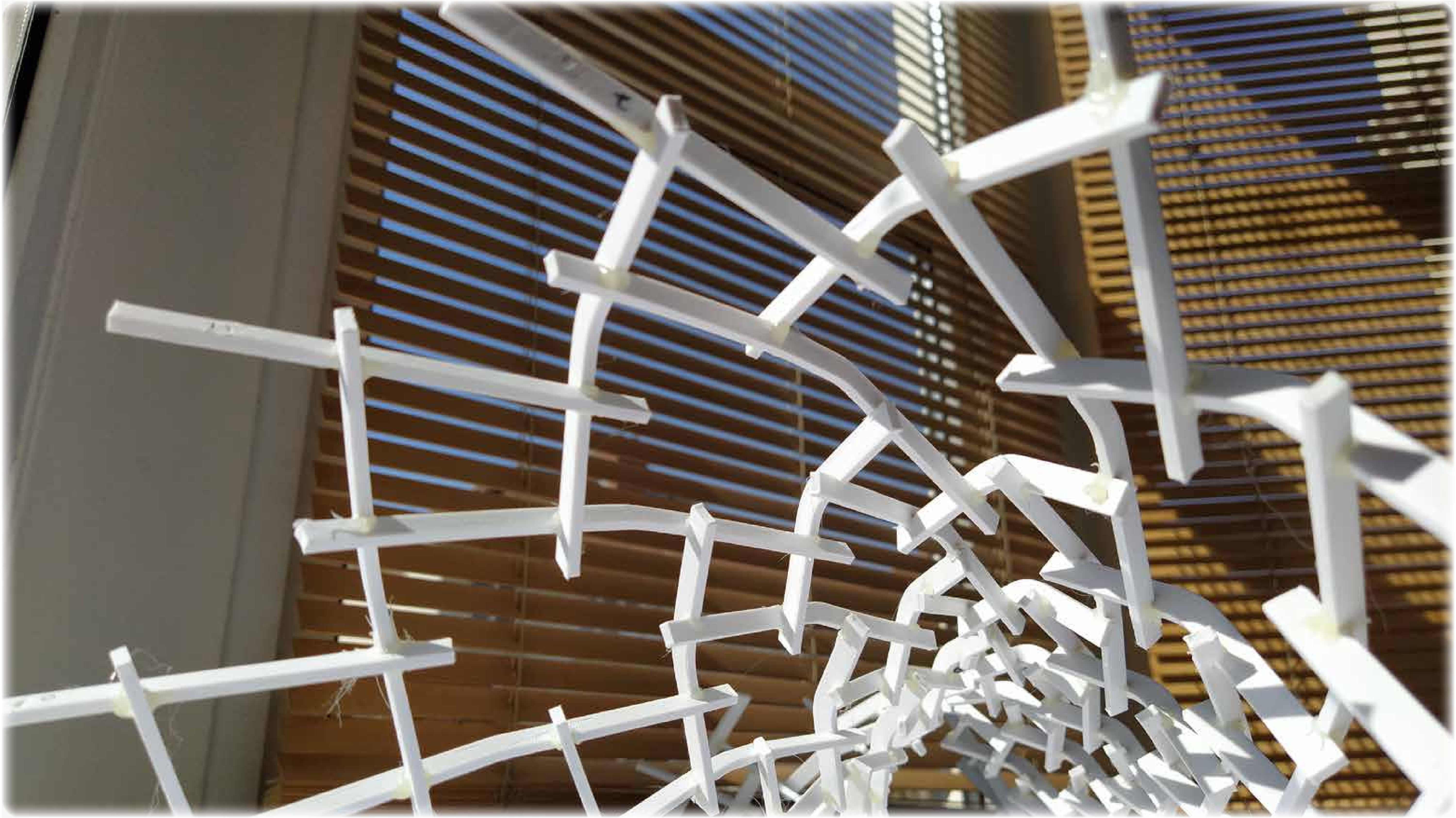

Further Development

Develop RFS (Reciprocal Frame Structure) Algorithm for triangular and quad mesh so that it can be applied to even more complex meshes and surfaces.

Develop an alternative fabrication algorithm for a more simplified joinery method so that assembly and fabrication processes are more efficient and viable.

Develop a fractal array of individual emerging beams which increase in density towards the entrance, finally becoming the structure.

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