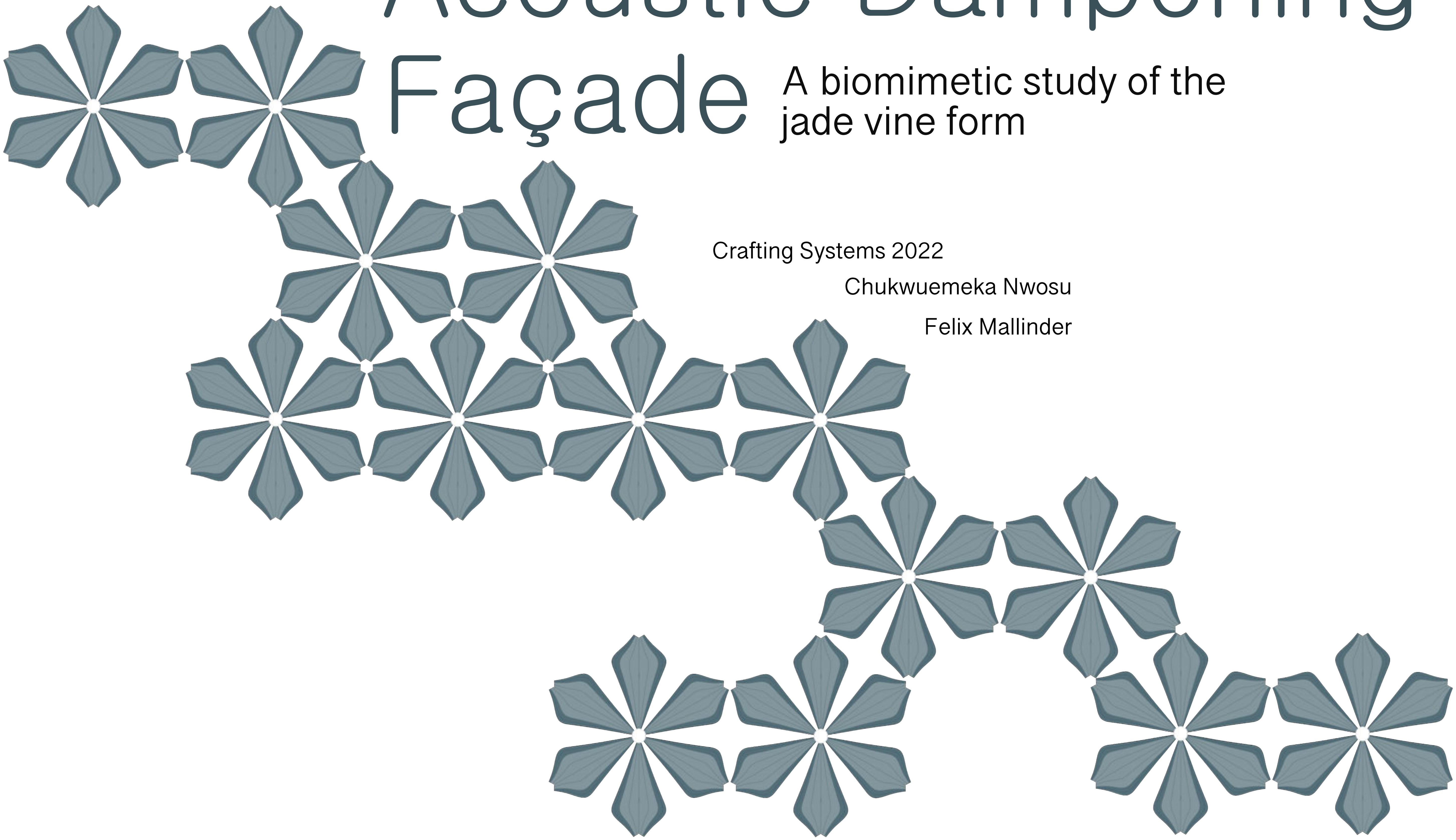
Acoustic Dampening Façade

A biomimetic study of the jade vine form



Crafting Systems 2022

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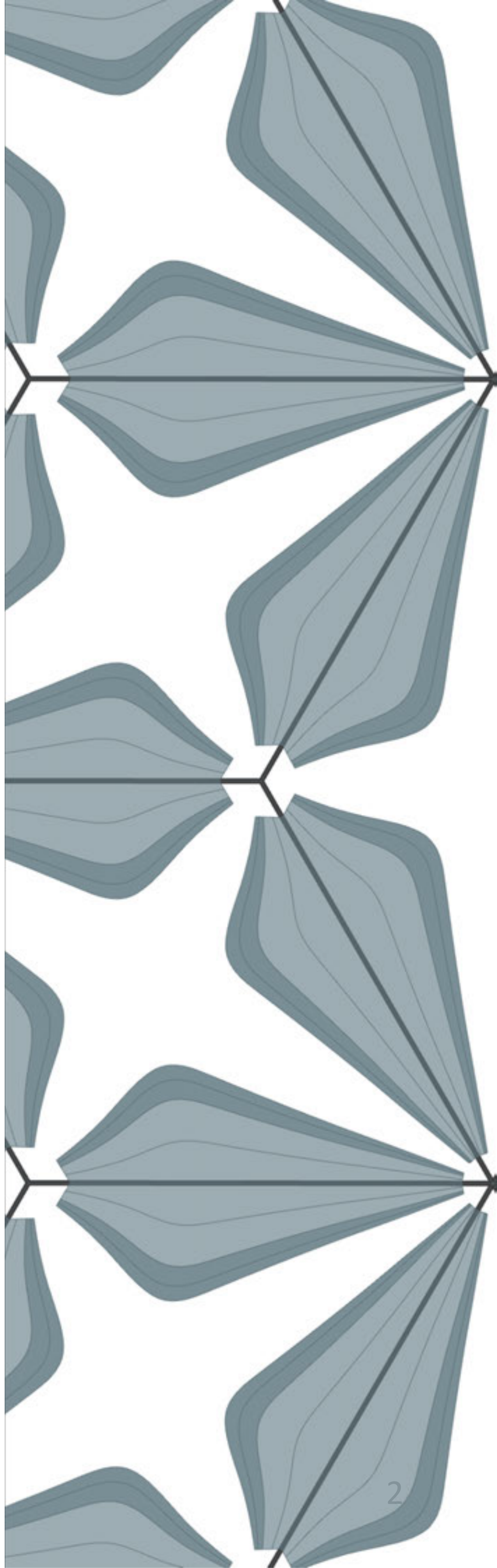

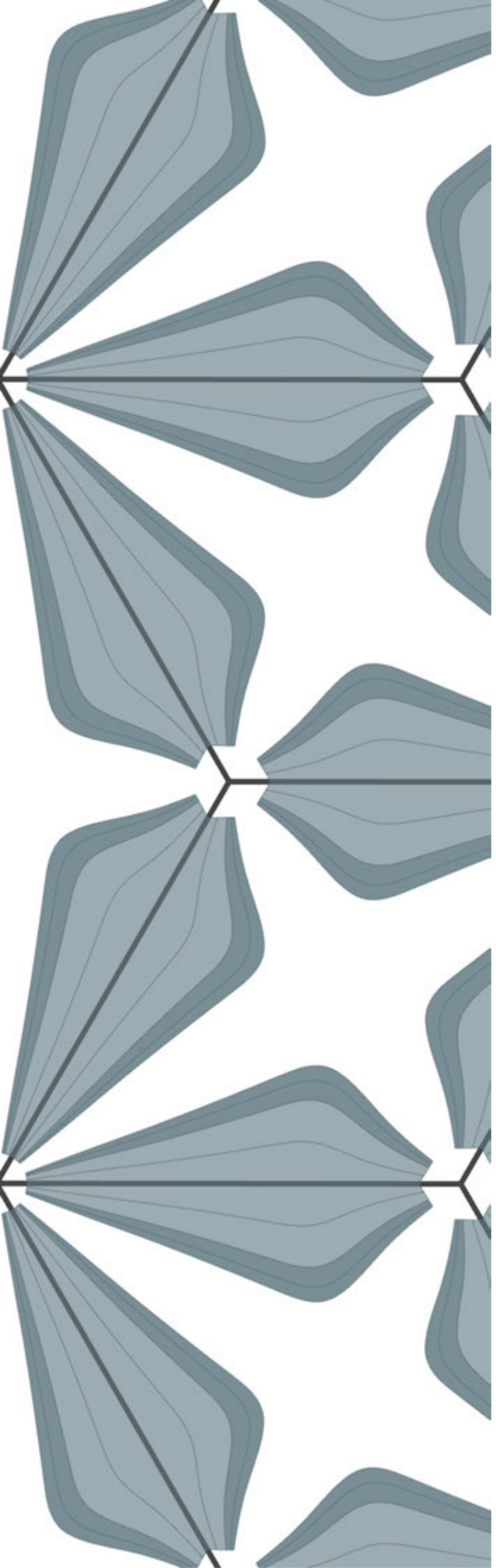

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Problem Definition

We aim to create an adaptable morphology which will assist users to minimise the felt effect of office noises.

Challenge

Acoustic levels and quality of sound are both massive factors in the productivity and ability to focus, in any work environment. Although reducing these sounds can be complex as the purpose of these spaces can be ever-changing and so two, the types of sounds produced, from group work to meetings, to private-work, different situations carry different acoustical needs and open plan spaces fail to meet the requirements of these all, simultaneously.

Context

It is important in office spaces to allow area of collaboration and connectivity but in a world of hybrid meetings and continual online presences there is inevitably times where, reduced sound levels and improved acoustic qualities are needed to allow users to share these spaces. We identify our context within office locations where quiet areas are hard to come by or generate from lack of space and aim to build a deployable mechanism that will allow users to adapt this existing space for the same purpose without need to relocate.

Functions

For a successful solution to our problem our design functions must be able to reduce and soften the perceived volume of office space acoustics to the user. We look to adapt a morphology which will be able to achieve these goals whilst also being deployable, meaning the user can set the system for different situations. This is an important function as our context looks to multi use scenarios with various noise levels and requirements.

[1] Office space context, image by Alex Kotliarskyi

Design Inspiration

Jade Vine

Botanic gardens

On our visit to the Bristol university botanic garden, Nick Wray identified the jade vine plant, (Strongylodon macrobotrys). He told us how this plant's method of pollination is unique, as its one of the only plants to be pollinated by bats, as a result, the form is optimal for attracting bats through echolocation. From this logic, we identified that the form of this leaf must carry an acoustical manipulation property that could enable us to manipulate, distort and redirect acoustical interference by abstracting the morphology of this plant.

[2] Jade vine leaf, Bristol Botanic Gardens Photo by Lidia Badarnah, 2023

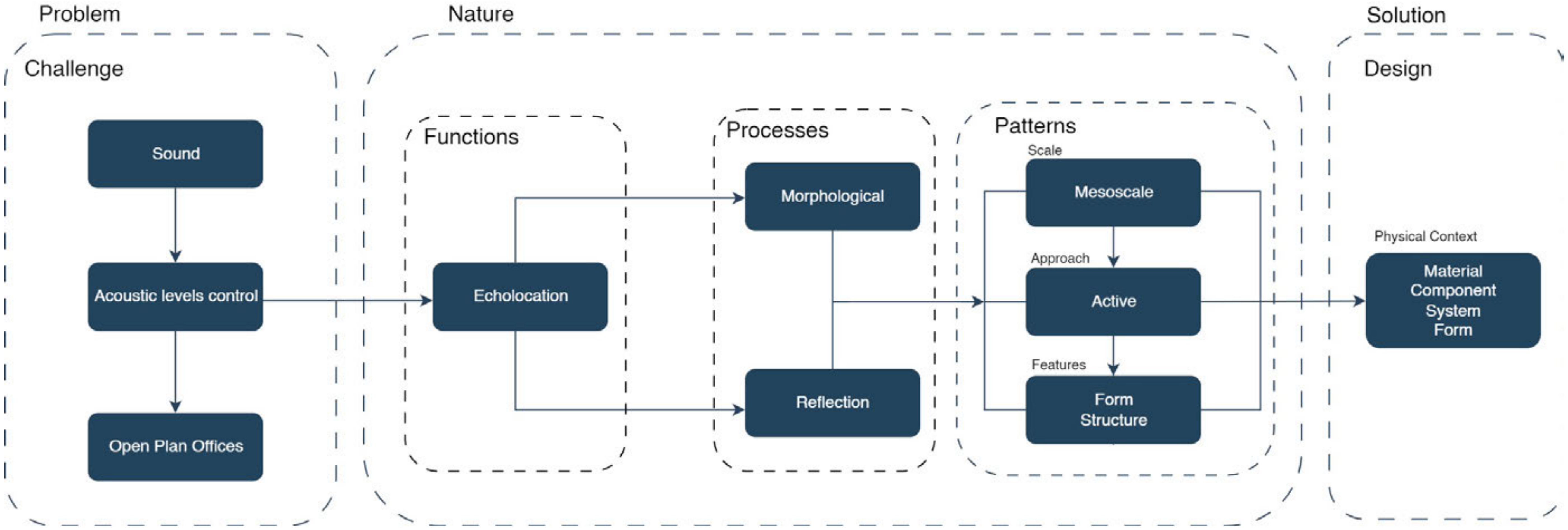
[3] Jade vine sketch, by Alina Lupu, 2020

Potential for a solution

The jade vine plants morphology, particularly its concave shape, enables it to use echolocation for bats to identify it for pollination, this process has been adapted in the design of the form of the panels. The concave shape of the jade vine plant allows it to focus sound to its pollinators, similarly, the acoustic panel has been designed with a concave shape to mimic this process to focus sound to a listener and reduce unwanted reflections and echoes in the surrounding environment.

[4] Jade vine plant, photo by David Clode 2017

Environmentally Driven Development



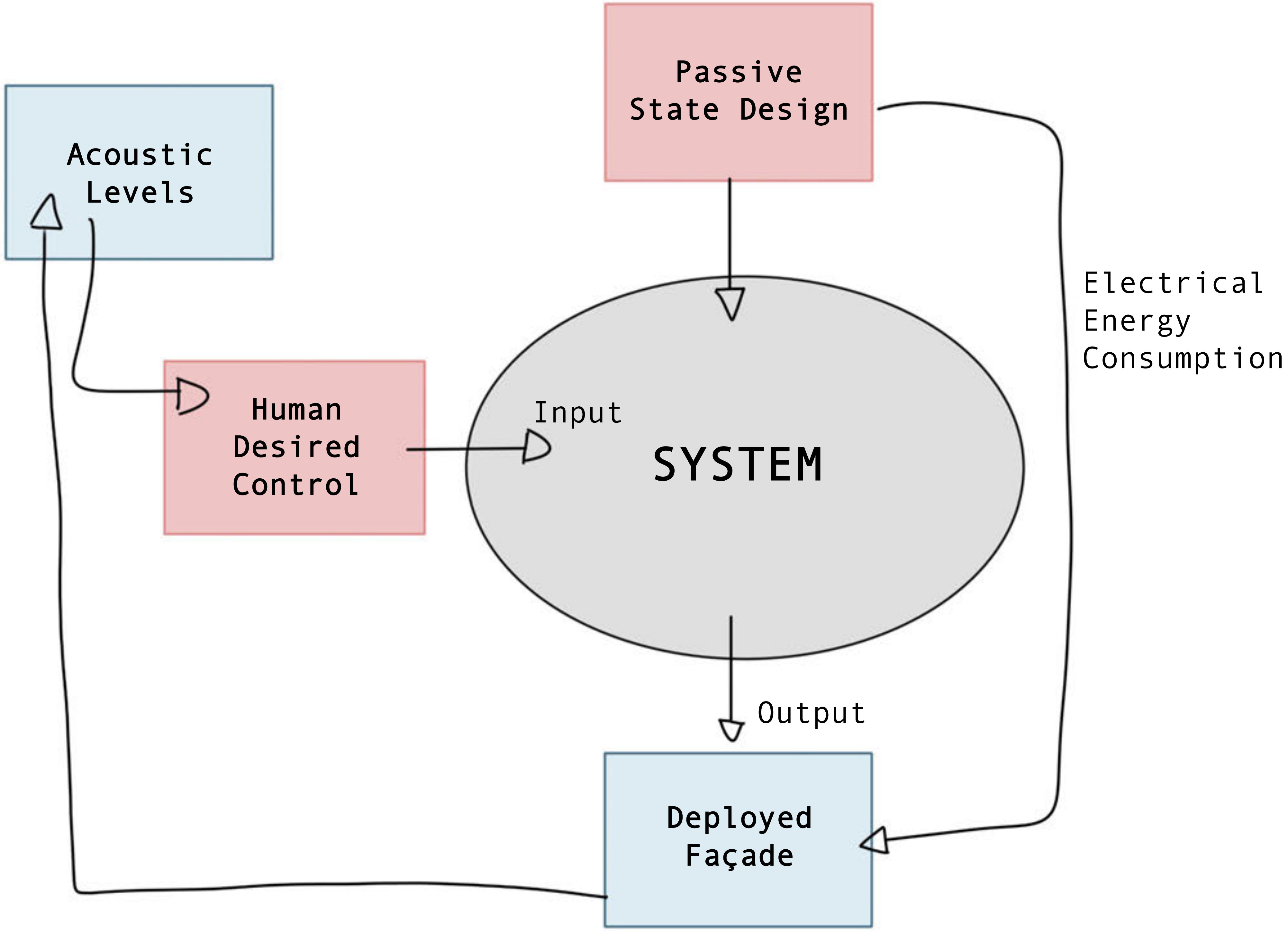
System

Design statement

The focus of our system design is user-driven input. This is important to our design as we identify the requirements of acoustical levels to be ever-changing a preferential in the given context, hence the 'sensor' in this system is the human. When identifying a situation in which the form would be needed, they would trigger the system to begin a process of form changing.

The geometry in the system relies on two design states, passive and deployed. We can consider the passive design as a 0 state, where no, extra acoustical manipulation is occurring due to form. The deployed state can be considered ad the output of this system, it is the product of morphological change. This change is driven by a mechanical system which is powered by electrical energy consumption. The system can be controlled in reverse transition from deployed to passive, again consuming energy for controlled movement.

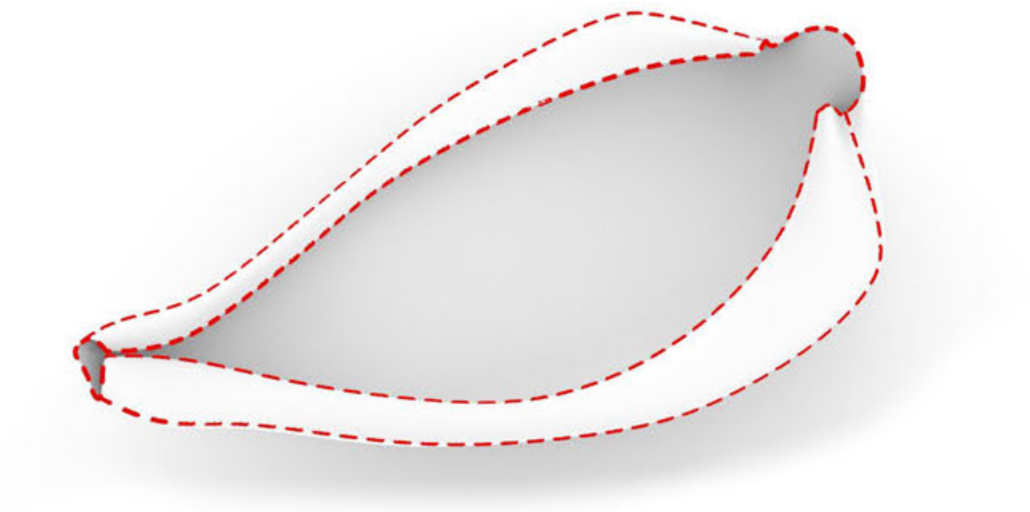
Overall the system relies on simplicity, a user-controlled two-state system.

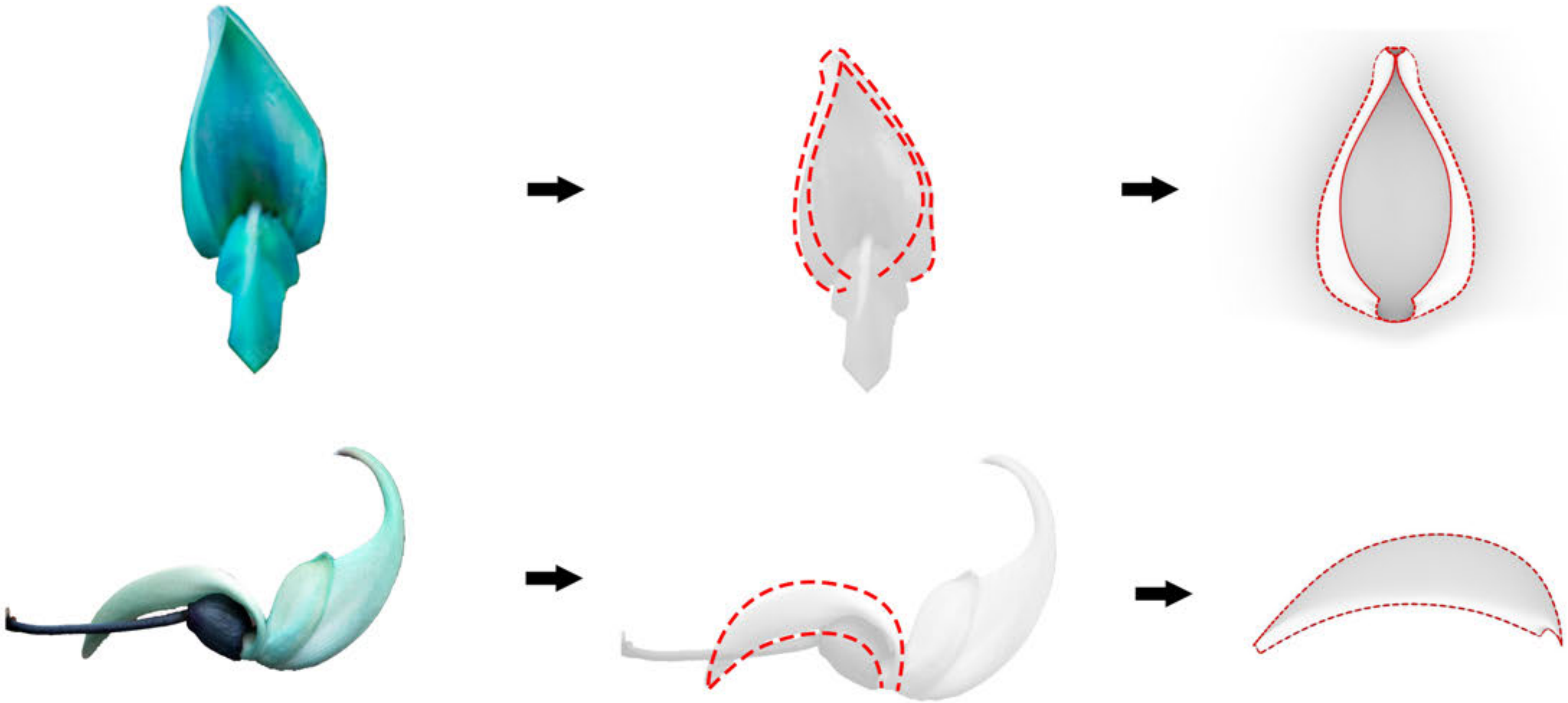


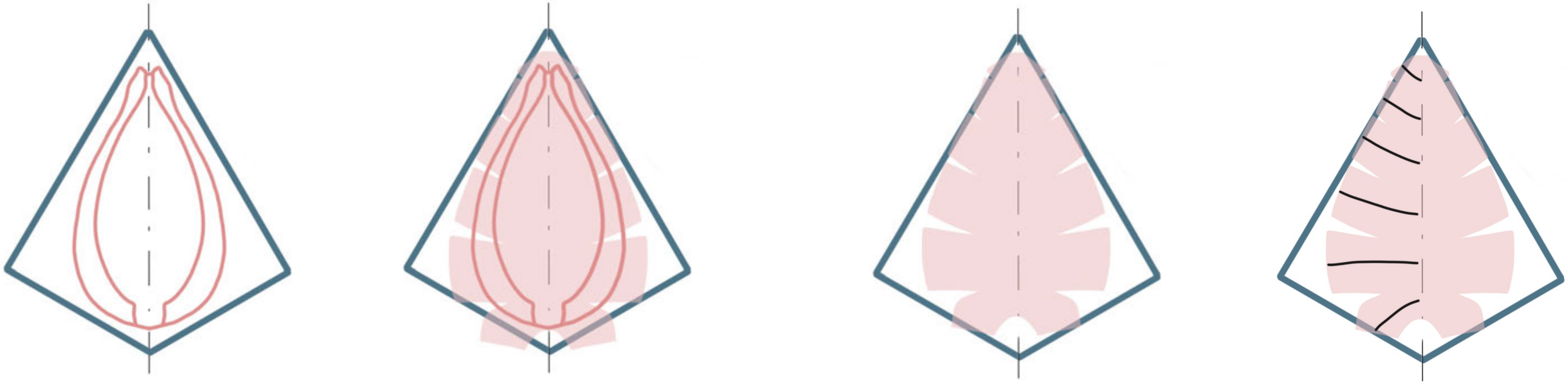
Form Abstraction

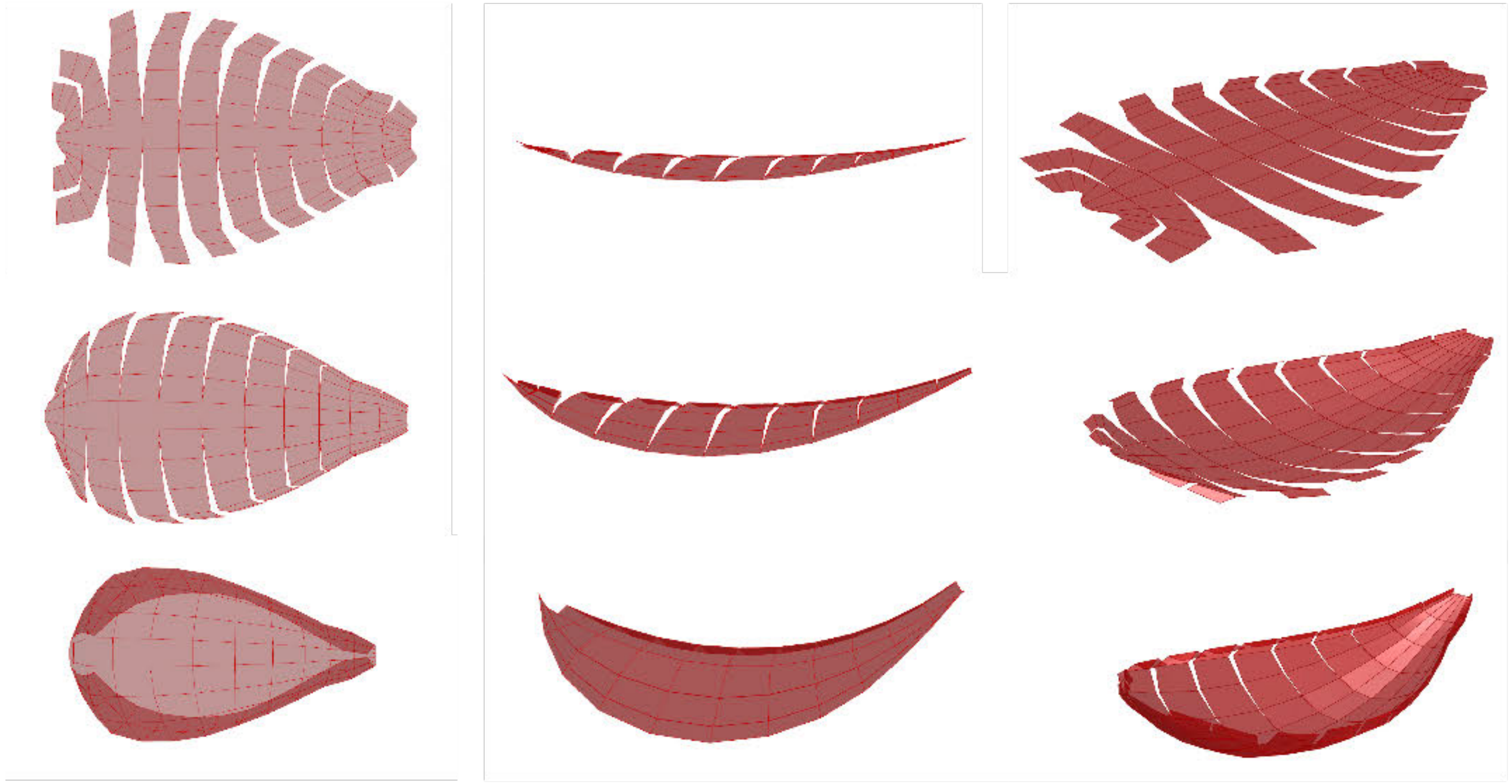
Shape logic & Abstraction

The aim of this project is to abstract the identified acoustic qualities of the Jade Vine leaf through the curvature of the form. To do this we have generated a rhino model which mimics the form from a series of images of the plant structure. From modelling the form use computational techniques to reduce the curve complexity to a series of planar quads. In doing so we can produce the form in a two-state system, unrolling the quads in strips, generating a net of the form.









Mechanisms

To drive the transition between states the design will operate a mechanical control over each of the quad strips. As shown, we can identify linear spines through these strips.

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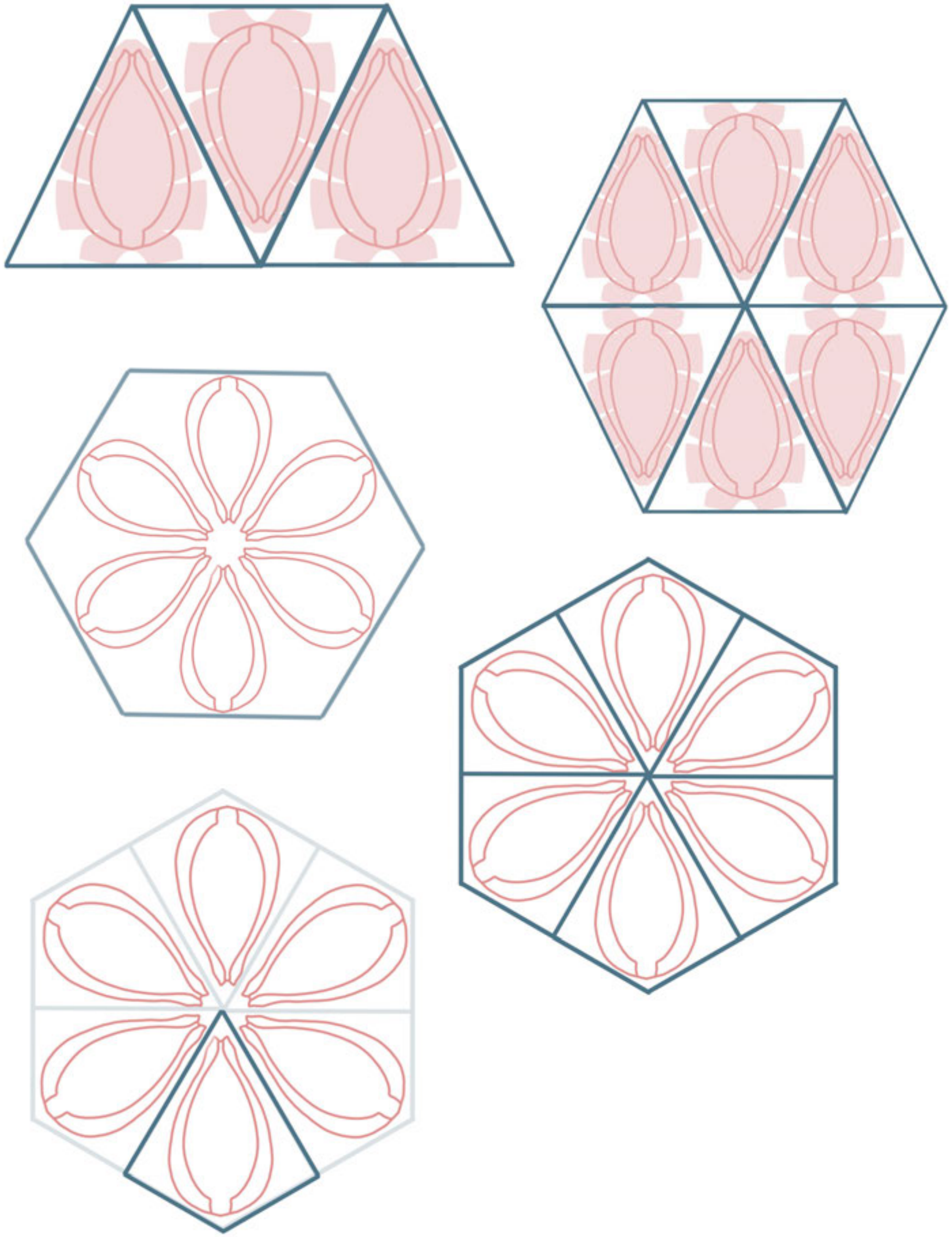
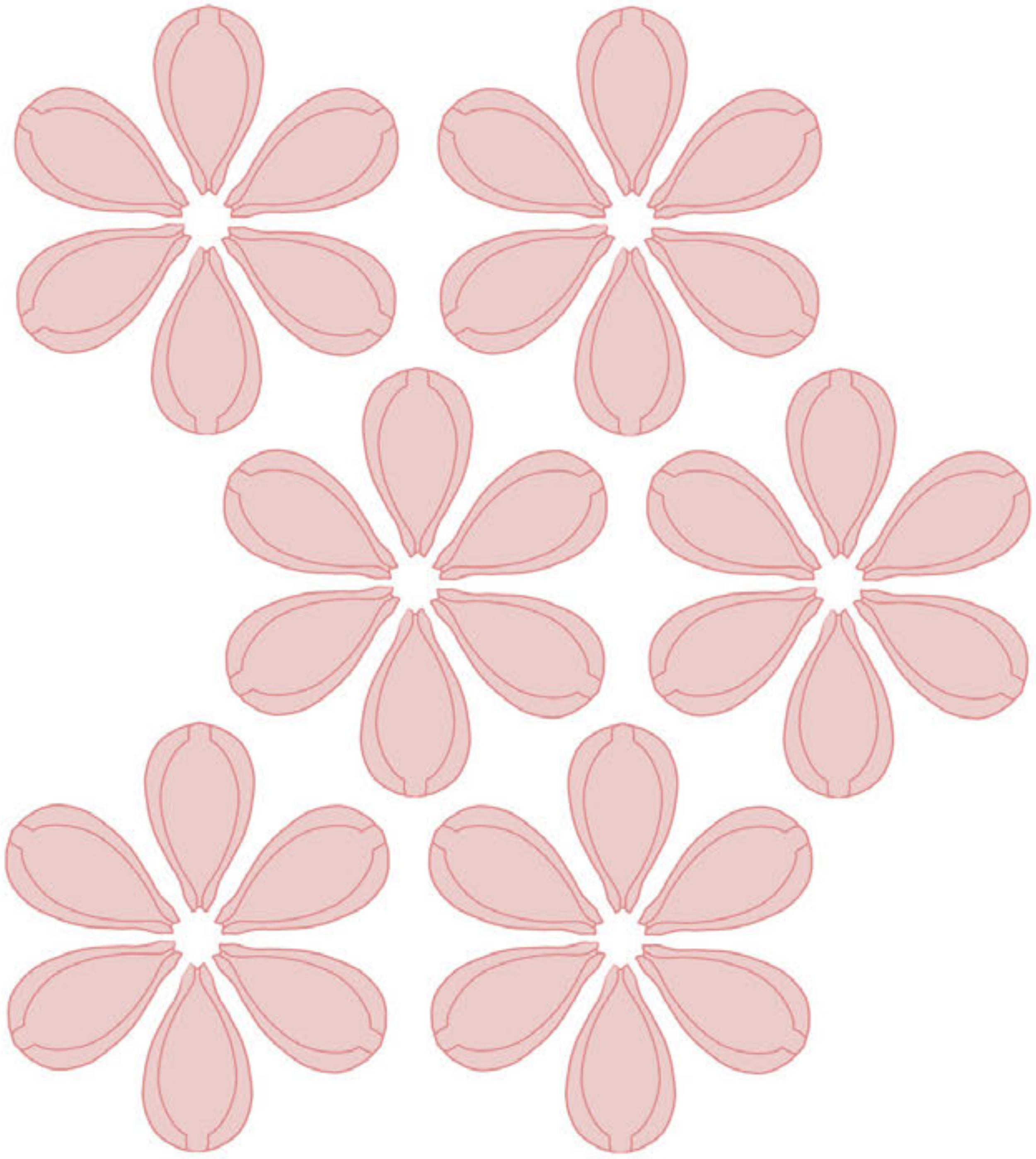


Global geometrical configurations

Taking inspiration from the configuration of flower structure we looked to configure the leaf in a repeated pattern, on the façade. The chosen hexagonal configuration was found to maximize the coverage in in the undeployed state.

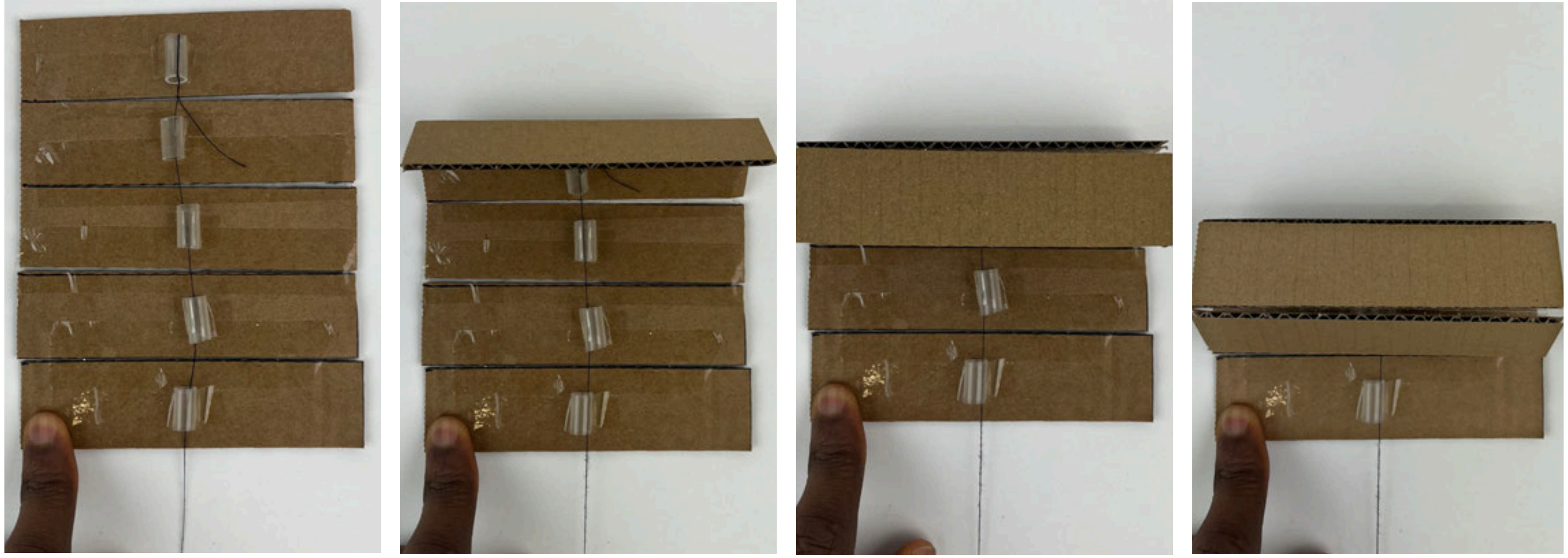


Early-Stage Prototyping

Sketch Modelling

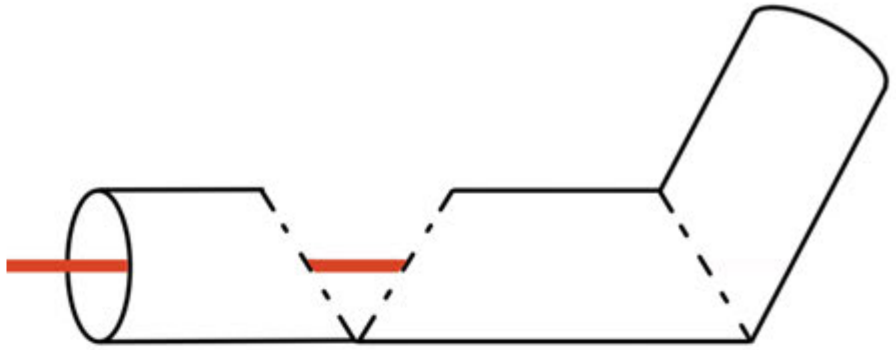
Prototype 1

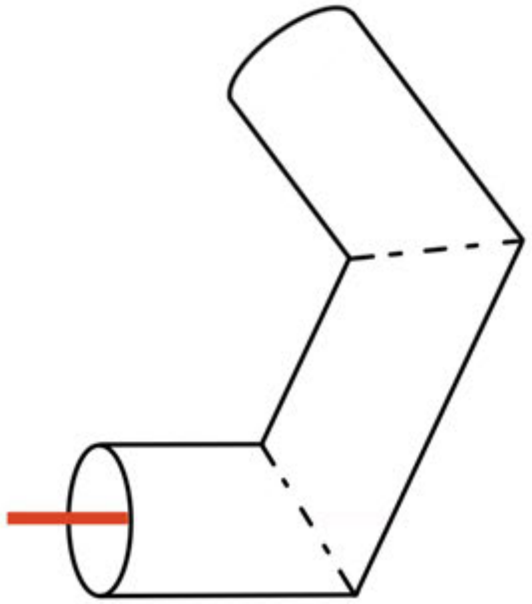
In this first experiment, we looked at how a string pull system can be used to manipulate a surface. The line of tension in this scenario runs central to cardboard panels with tape hinges, this is comparable to the expected movements of ‘veins’ along the ‘leaf’ surface. In this test we found the flexibility of the tape allowed a smooth movement and minimal force needed on the string, this is something we will consider when expanding the model scale and needing to minimize the applied force.



Pipe Mechanism

The next step of experimentation is a consideration of how we can manipulate the movement of this surface further. In th
experiment, each panel bent toward the string as far as the hinge would allow, the only thing stopping the full fold was the small p
expand this logic we look to develop an extended piping system that could control the angles of each panel, in turn allowi
manipulate a planar form into a more complex curved surface. The below diagrams detail how we intend to implement this mech
cutting each pipe with angular incisions will allow us to replicate the curves of the jade vine form by identifying and replicating th
here.





Unrolled Net Deployment

Paneling

A further step of complexity to the rolling panel logic is to add multiple 'veins' across the surface in several directions. As seen in model 1, this stage continues the logic of the first experiment but allows a greater manipulation of the planar surface. The expectation of this test is it will allow us to better mimic the jade vine form with multiple curves, to do this we generated a mock example of an unrolled net of a curved surface similar to that of the jade vine (as seen on the right).

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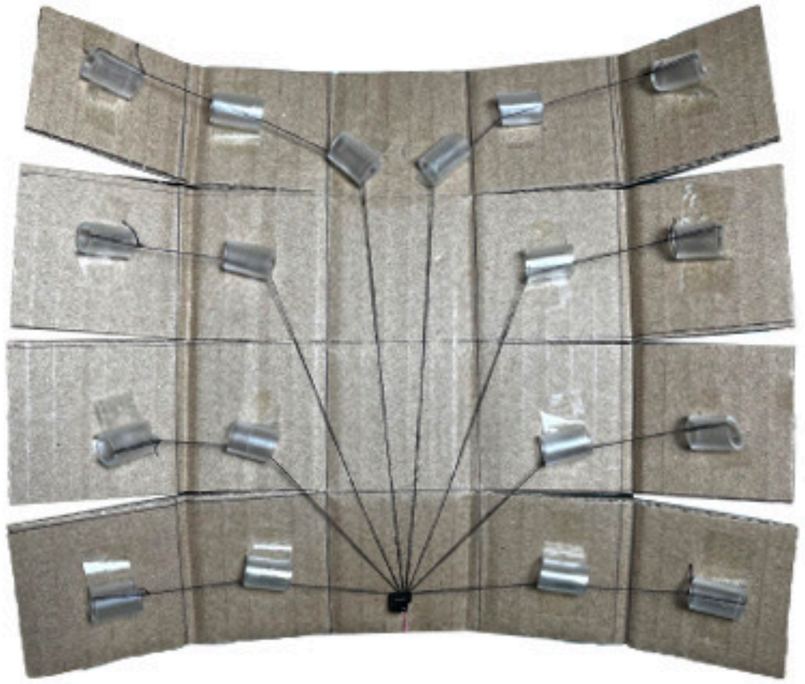
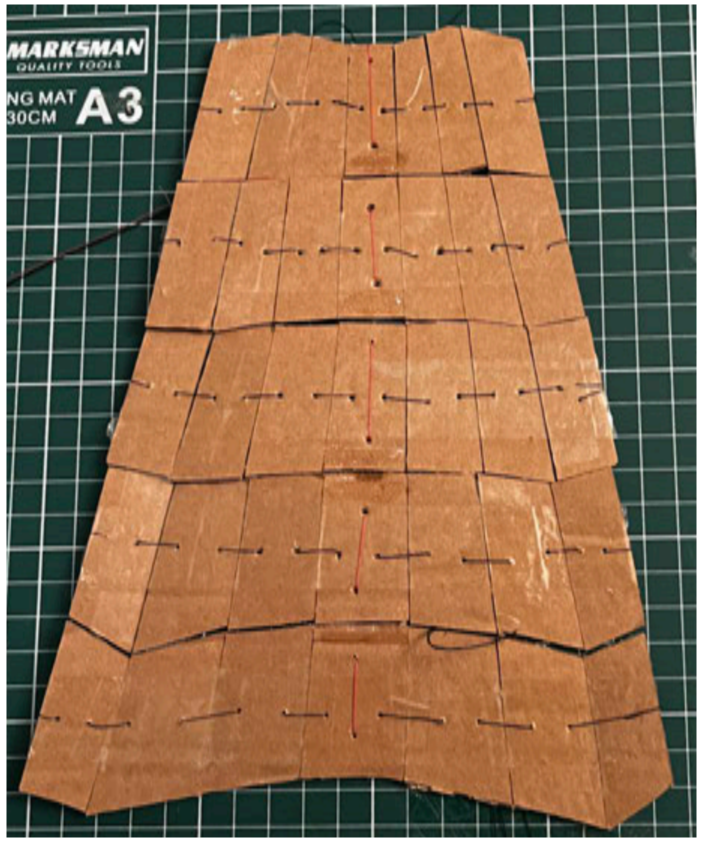
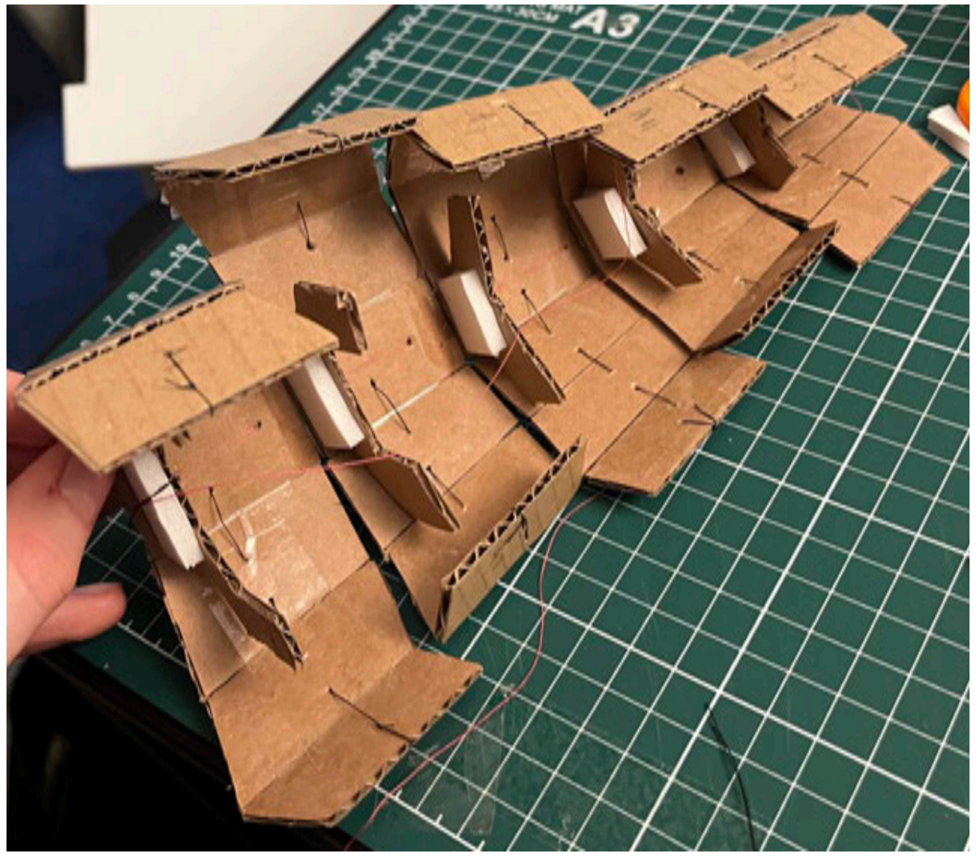






What we learnt?

As expected, it was evident with the additional spines there was a large increase in the tension forces carried through the veins, hence the flexibility of the hinges had to be ensured to be as flexible as possible. In this sketch model (model 2) that method carried a few issues, at this scale the combination of many hinges and moving strings meant the model surface was unstable and difficult to operate. Although unsuccessful we put this down to scale and material quality and aimed to continue our experiments at a greater scale.

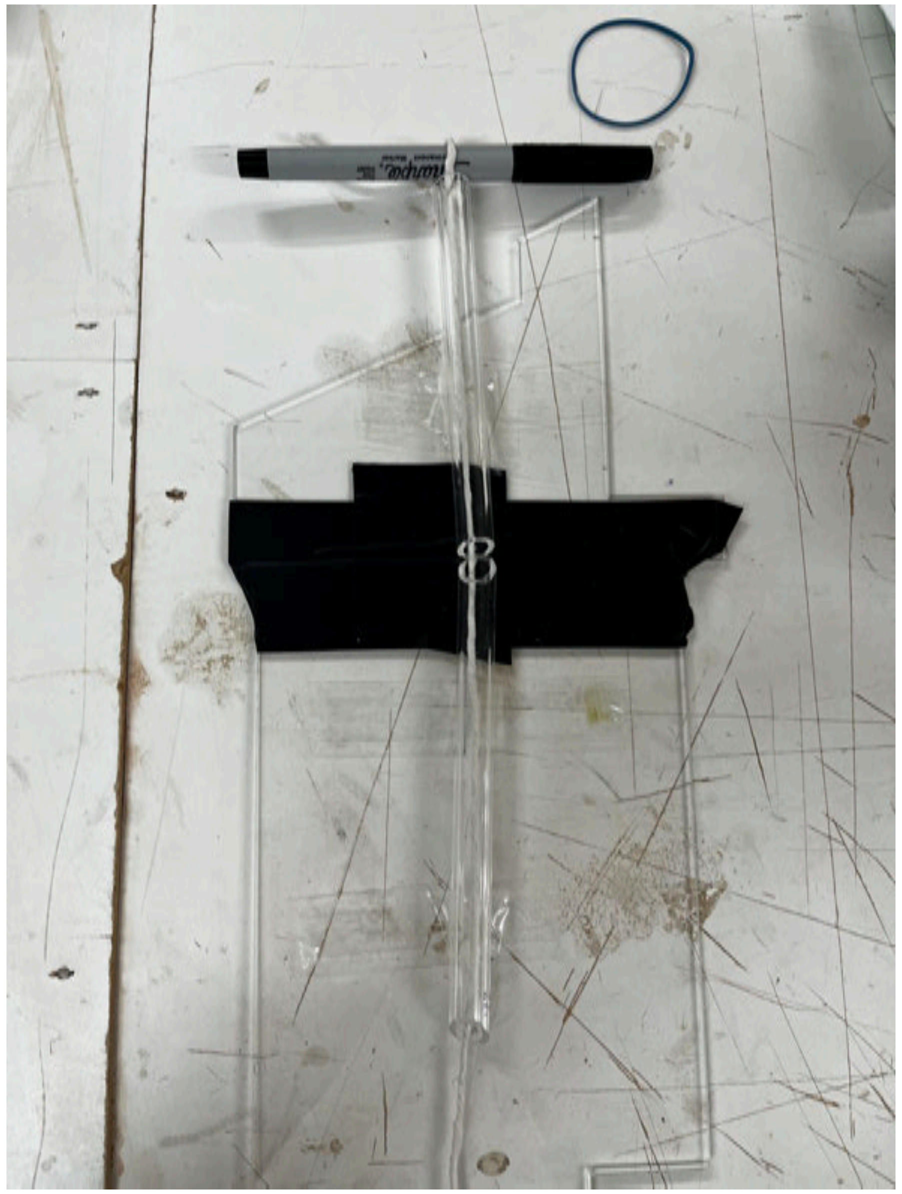
Large Scale Sketch Model

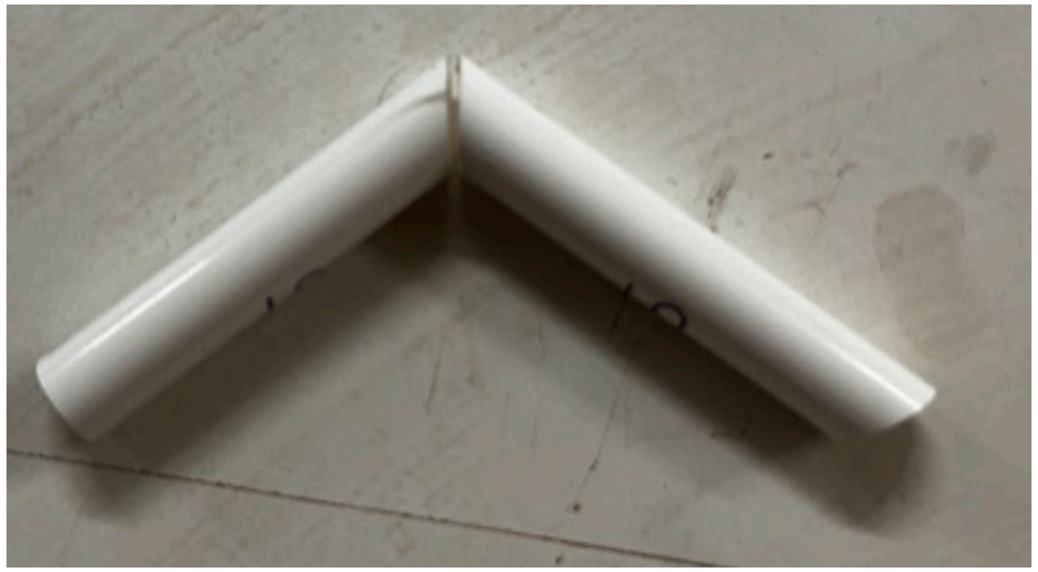
Paneling

Following on from the results of the unrolled net experiments we attempted fabrication on a much larger scale. To do this we took an exact extraction of the jade vine form, as shown previously, and divided it into 49 quads - we then laser cut each quad from sheets of acrylic. Learning from the more successful trials we continued with a tape hinge system, in this case, we used polythene tape to allow a greater adhesion and strength to bare the much greater weight on the material.

Piping

In this stage of testing, we introduced the piping logic, which intended to constrain the movement and bends of the quad surfaces. Each pipe was modelled computationally to sit along the surface of the panels, as they were joined to each other within the model we could identify the angles of joins between each section of the pipe. Then replicating these angles in the physical pipes by cutting half of the joining angle from both pipes at the adjoining surface.





Issues

Unfortunately, when attempting to combine the piping and the surface panels an issue had been identified with the lengths of pipes and panels not matching up. Upon further inspection of the the computational model we realised that there was an impossibility with planarity of the surface through our method of division from the original jade vine surface, this meant that when trying to produce the panels through laser cutting the shape received wasn’t the bounds of the quad expected but instead a projection of the quad onto a planar cutting surface.

Design Solution

New design

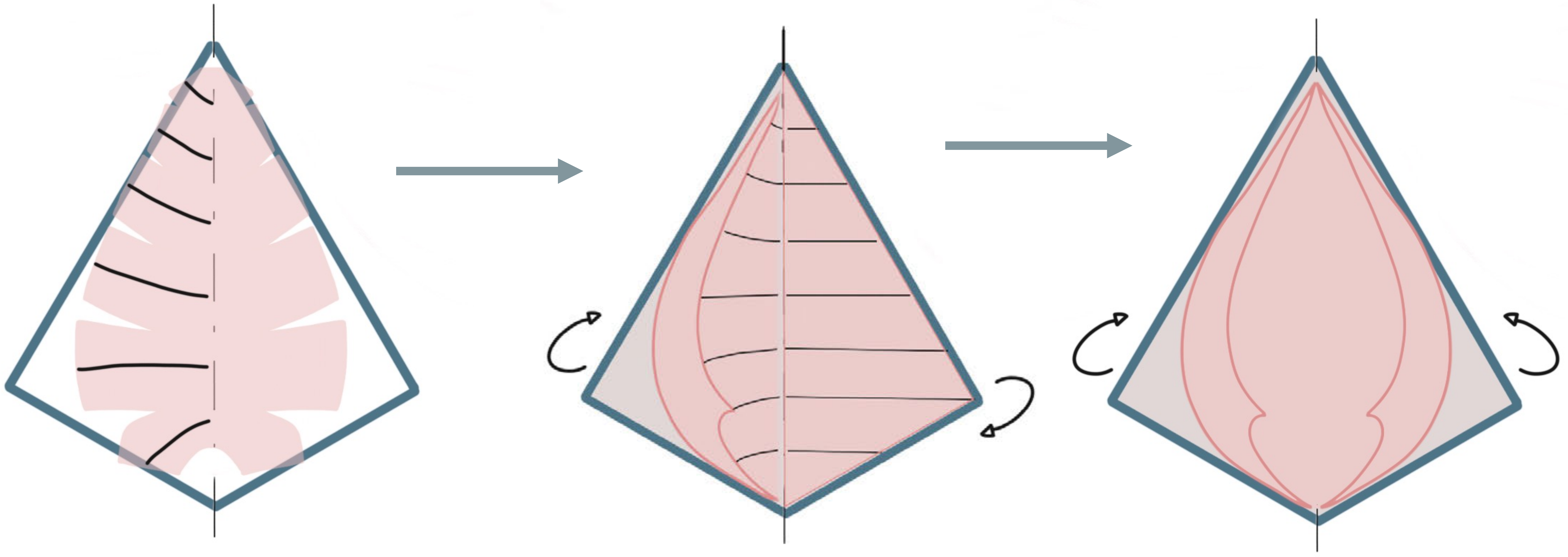
Simplification

Reflecting on the failed fabrication we looked to take a step back to rethink the fundamental of our design methodology, knowing now that replicating the jade vine form like for like in a paneled surface would be impossible with our chosen fabrication methods. We made the choice to instead of mimic exactly, identify the curves of the form, which give it its acoustic properties and replicate them in a new form more manageable for fabrication. Given this opportunity to adjust the form we looked to take on the triangular shape shown below, such that we could maximise the coverage in our chosen configuration.

Spines and fabric

To avoid any repeated issues with trying to planarize complex curved surfaces, we decided to use a tensile fabric for the surface instead. In this case, it allows us to focus on the spine movement for unrolling and the use of fabric would allow a loft between these curves with a factor of flexibility and adaptability when moving between deployment states.

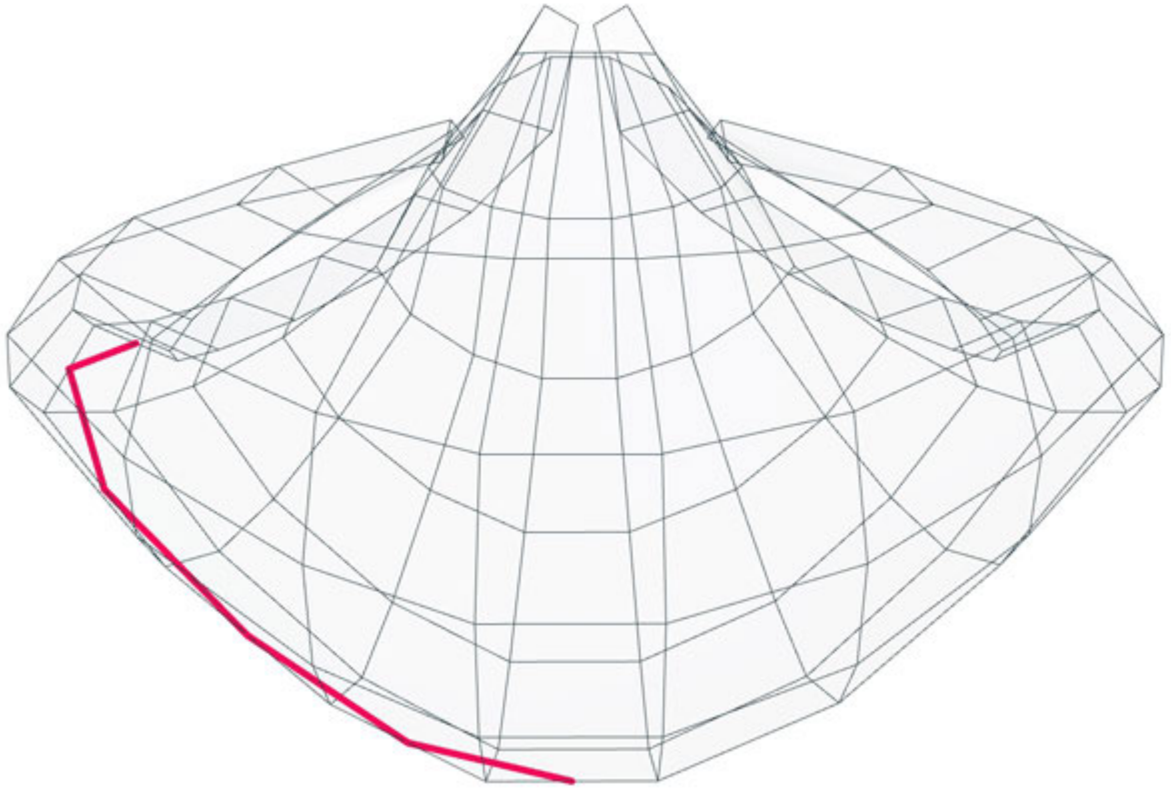
The following solution will show how we plan to transition the movement of the jade vine into the triangular form.

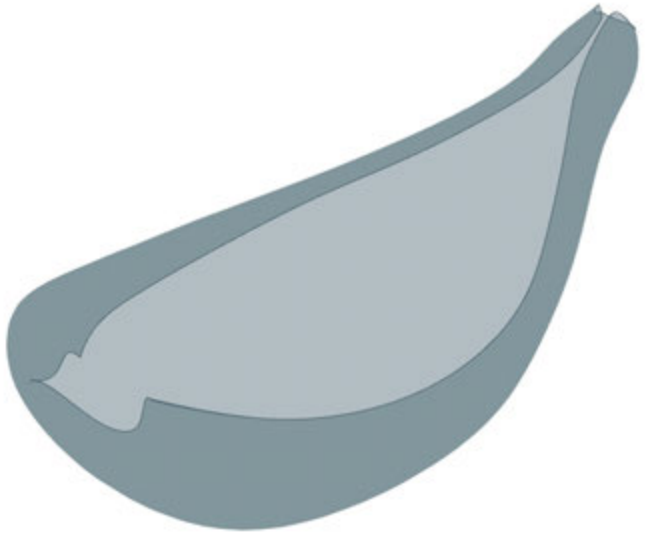


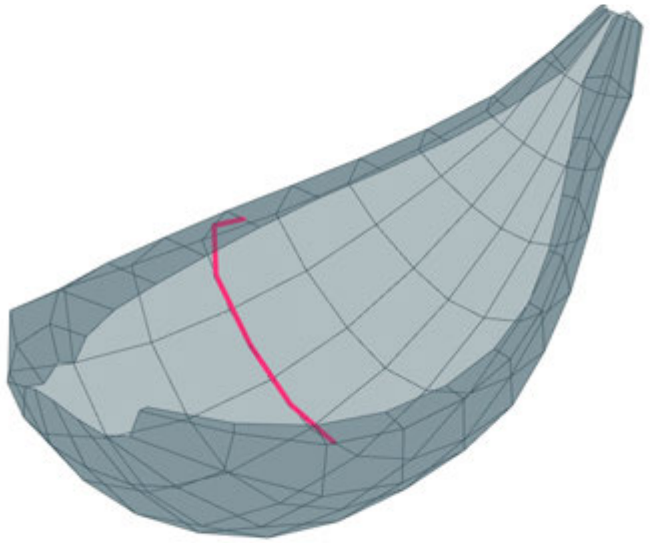
Extracting the Spines

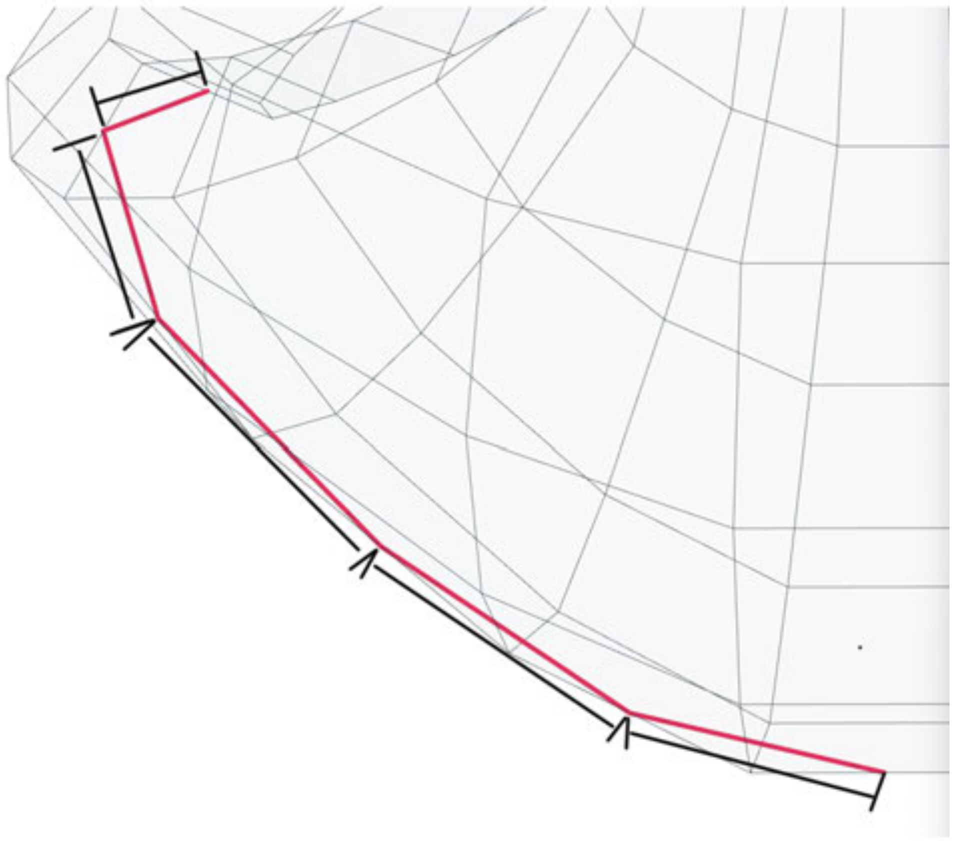
Triangular fittings

To extract the curves from the jade vine form we used the original panelled model and identified the spine of maximum curvature, as shown on the right. From this curve, we looked to extract the angles between the line sections as well the lengths of each section. The idea being if we identify these lengths relative to the total line length, we can rebuild the curve form as new parameterised lengths. The following page shows our process of abstracting this curve and rebuilding it in a new form with the same properties.



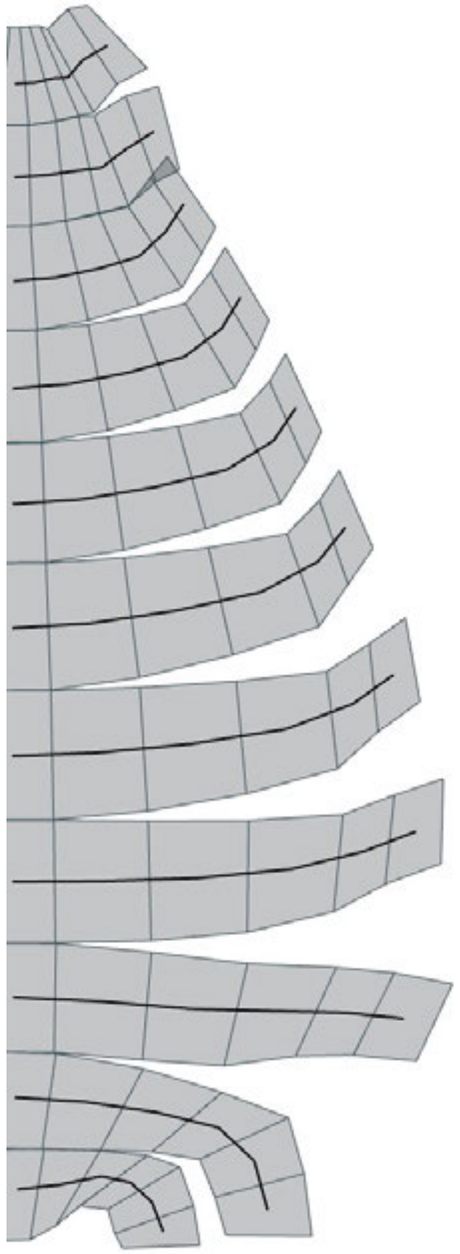






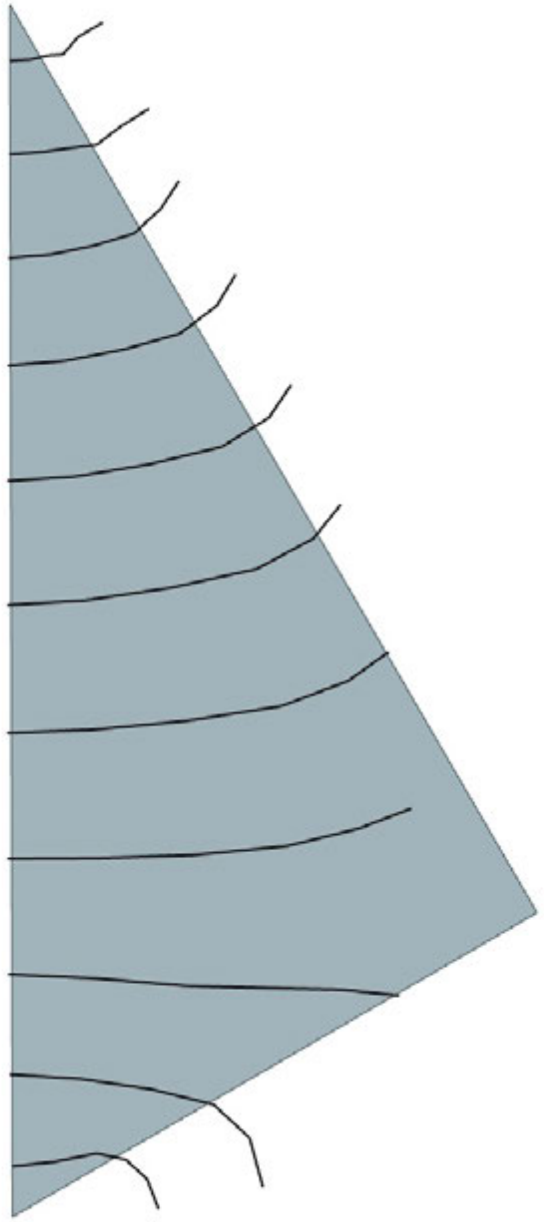
Extract

The first step was to extract the 2D direction of the spines in an undeployed state.



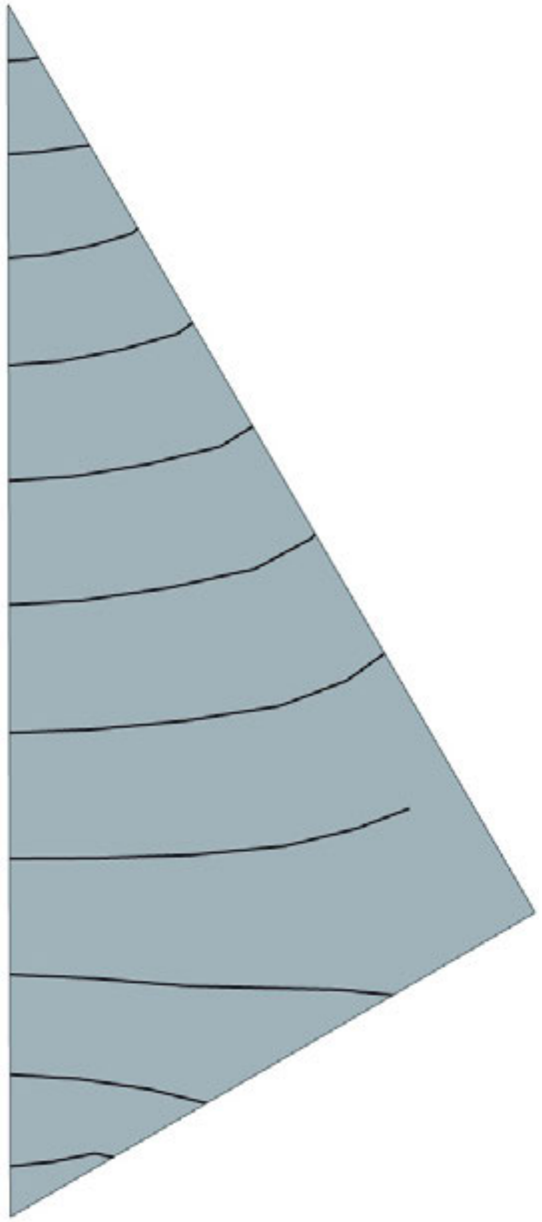
Compare

Taking the triangle from the global configuration and projecting the actual leaf spines over this we can identify how they will be built on this new surface.



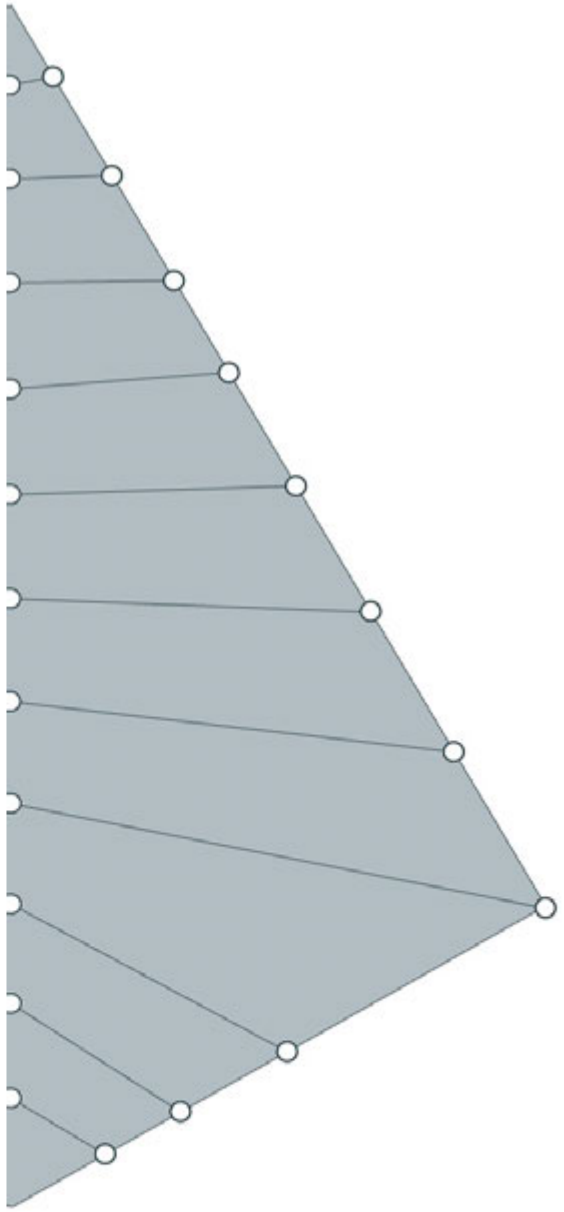
Trim

With the new surface we fit the curves, reducing the lengths of any that extend its bounds.



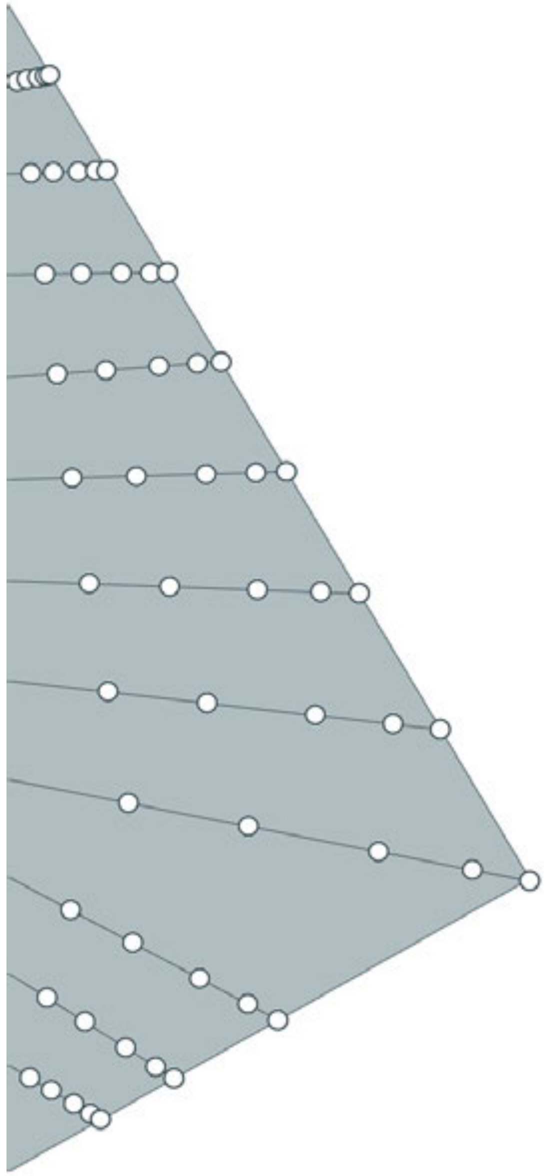
Reform

To reduce the complexity of the lines we fit these to straight and controlled spaced lines. We do this by taking the original start points and extending in its own direction.



Divide

Dividing the curve into 5 segments, using the extracted parameter lengths from the original curves, this is the first step to replicating the jade vine spine logic.



Replicating Form

From the new spine lengths and sections, we can apply the same angles as identified in the model curve. This allows us to generate a coherent and uniform surface, lofted between each spine. It is evident in the central image that the spines are now uniform in their design and only vary in length. From this stage, we were able to test visually the movement of deployment and also begin to model new components for fabrication.

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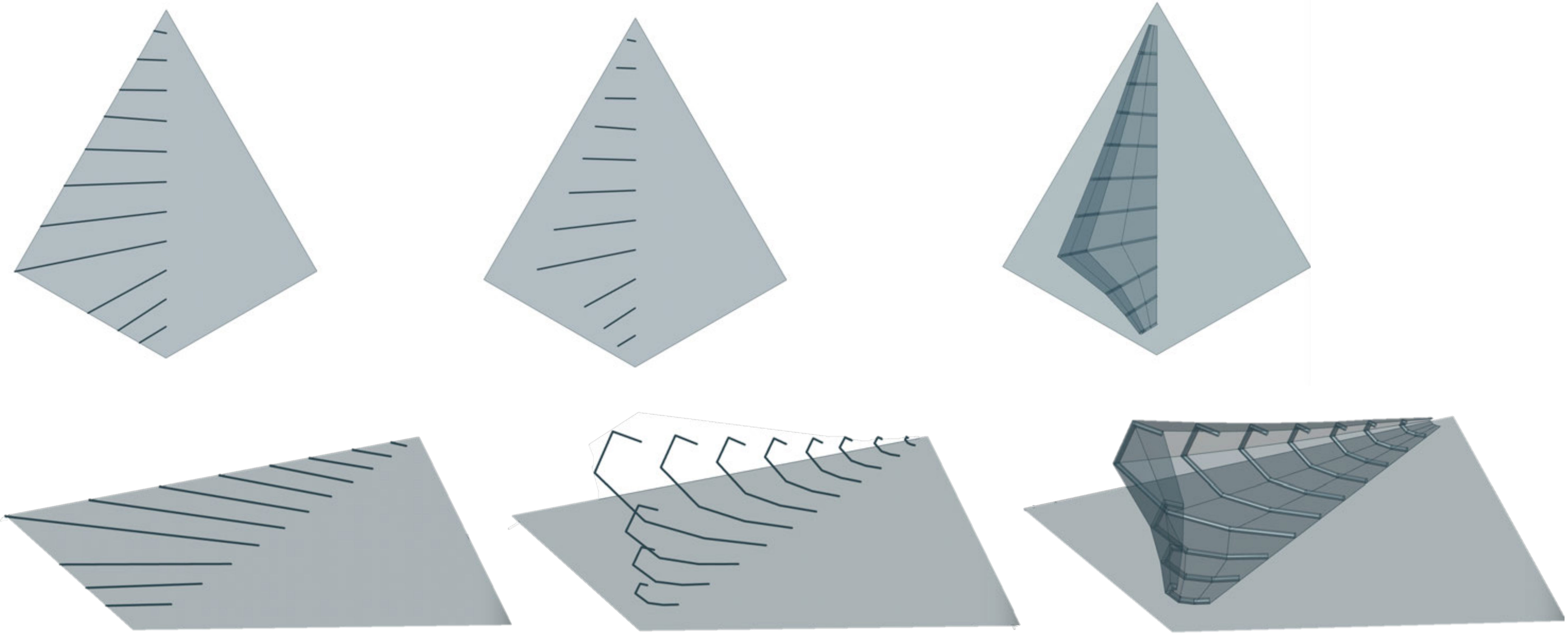
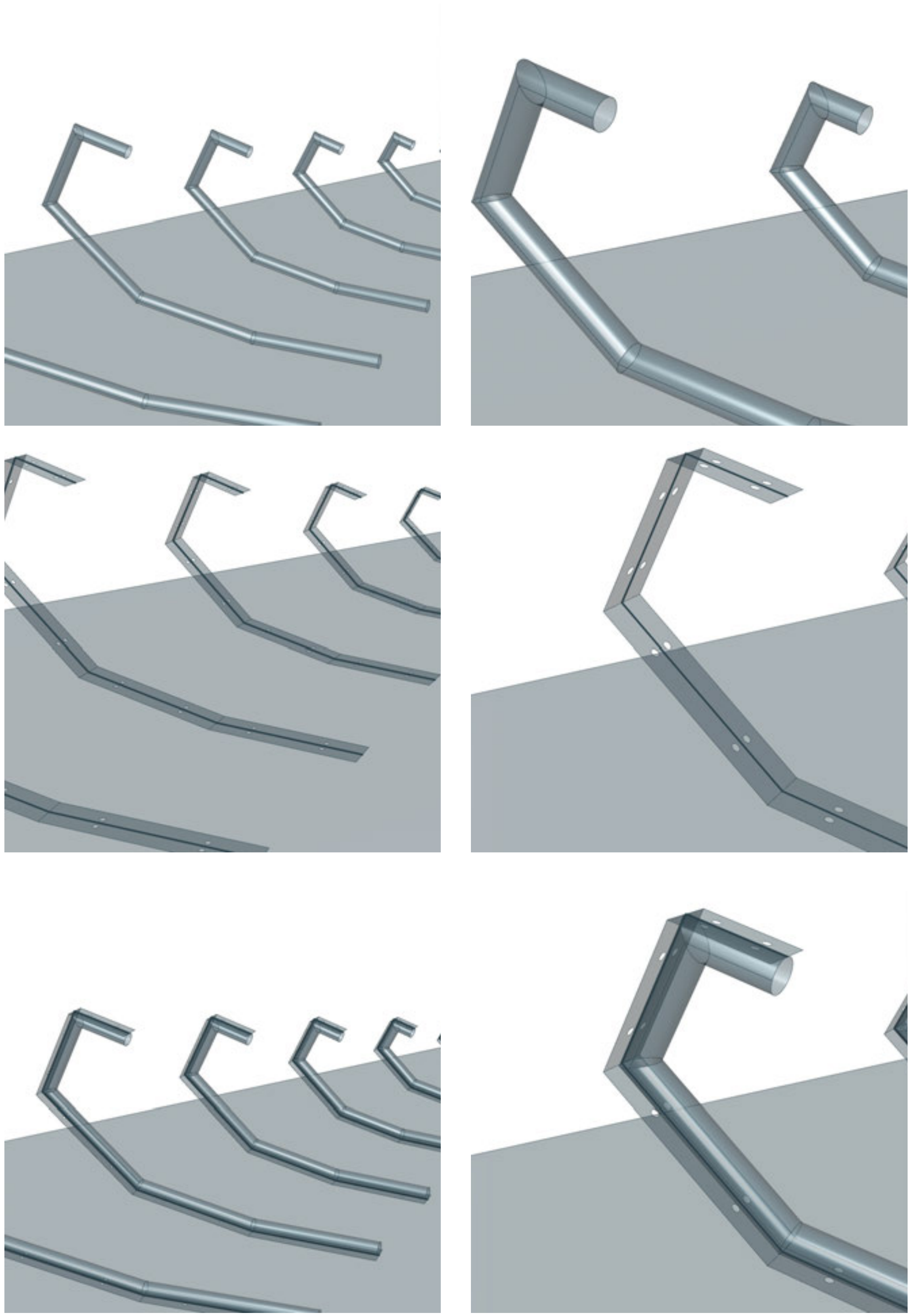




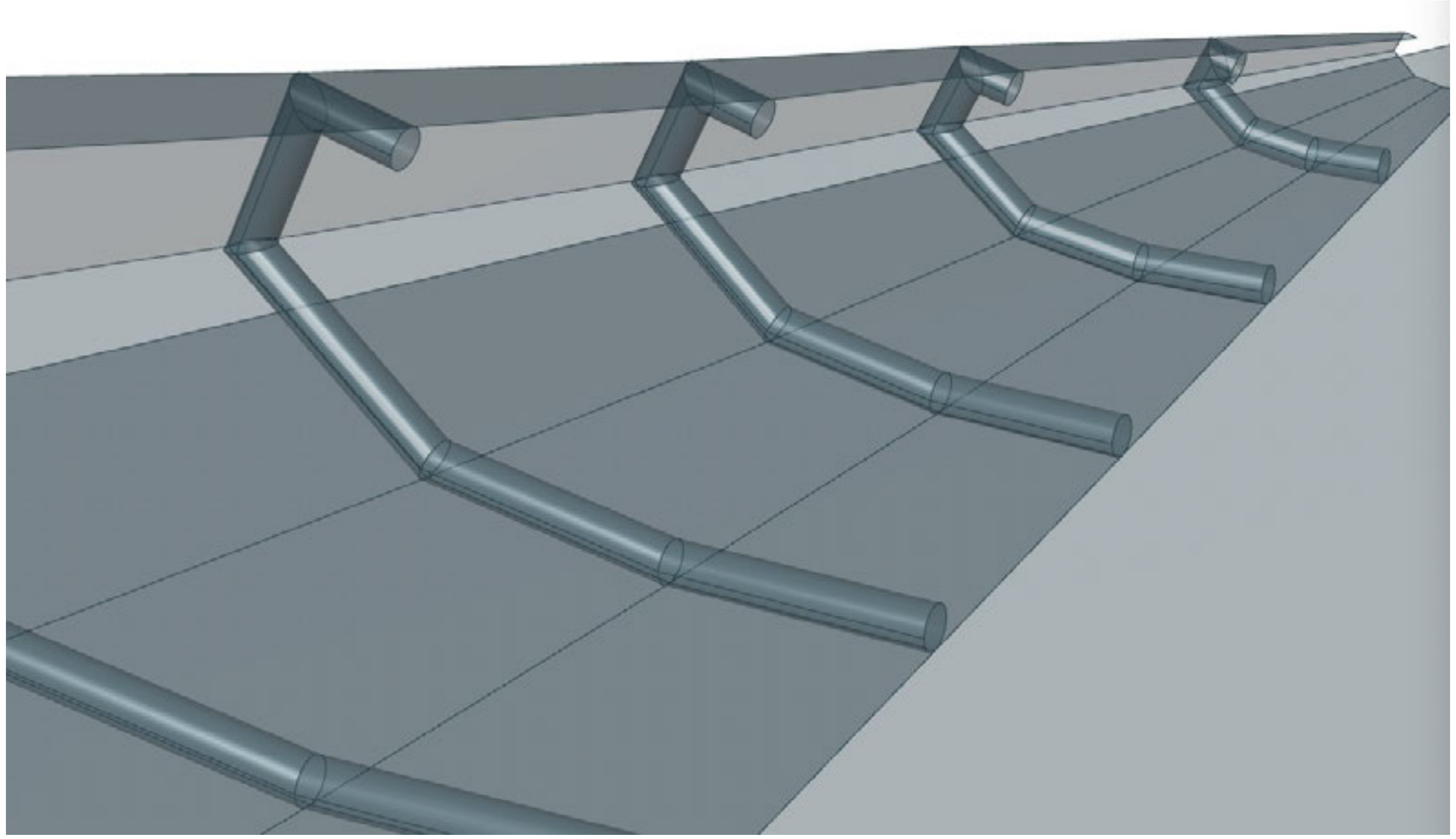
Piping

Mechanical system

Continuing the pipe logic from the previous design we again implement the same process but this time we a level of simplicity to improve fabrication and robustness as each section is connected linearly.

Panel attachments

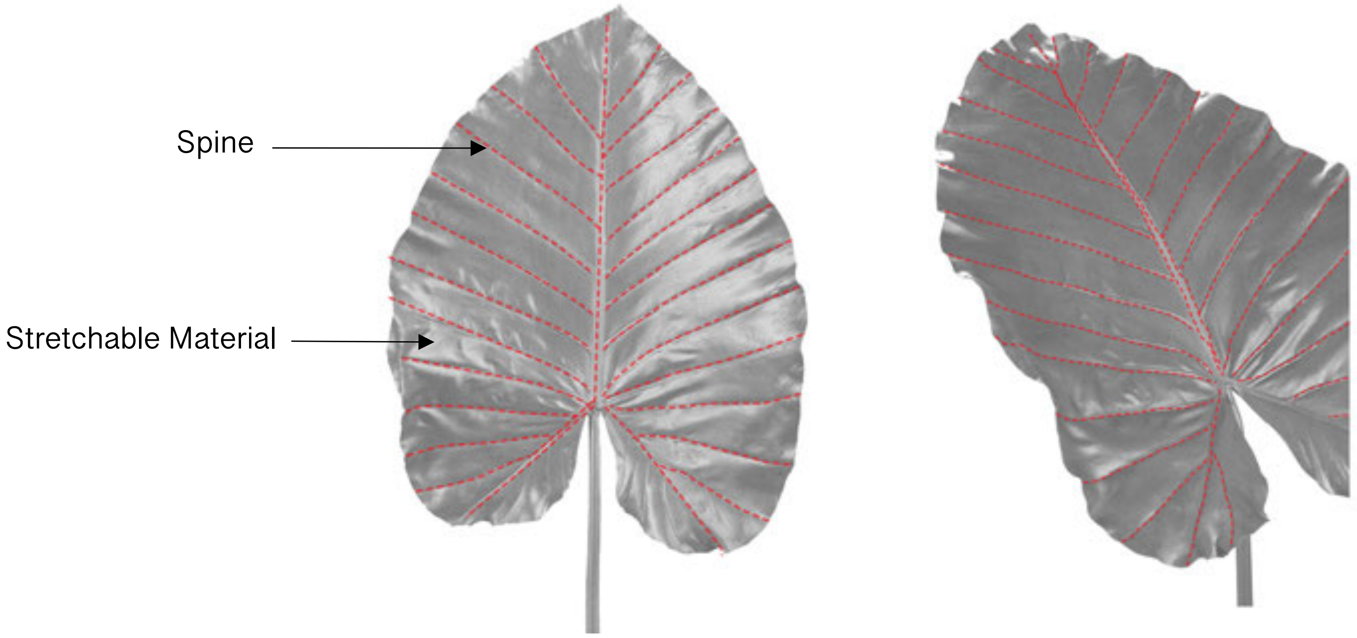
To allow the use of the hinging mechanism used before we again implement a panel system, although this time we ensure planar by attaching them only to the pipes and not each other, again the linear formation of the spines help with issues of with strength as ensuring planarity.



Material not panels

Panels pose a major limitation because of their rigidity and stiffness, The need for a material that could stretch arose while testing. Tensile fabrics were determined to be the adequate material for deploying the structure due to their inherent structural properties and flexibility. we looked at the spine of a leaf and the leaf skin as an analogy for the design of the deployable petal of the acoustic façade. The structural elements of the leaf act as a spine and provides strength to the leaf, while the leaf skin stretches and conforms to the shape of the spine, creating a flexible and adaptable covering, Leaves that move in response to stimuli utilize this process in their movement.

We abstracted this morphology of the leaf petal in our design, in the acoustic petals, the structural elements will be the plastic panels and pipes which will provide a sturdy framework for the fabric covering. The fabric itself is then stretched and tensioned over this framework.




[5] ETFE (Ethylene tetrafluoroethylene), Photo by Neil Young/Foster + Partners 2022

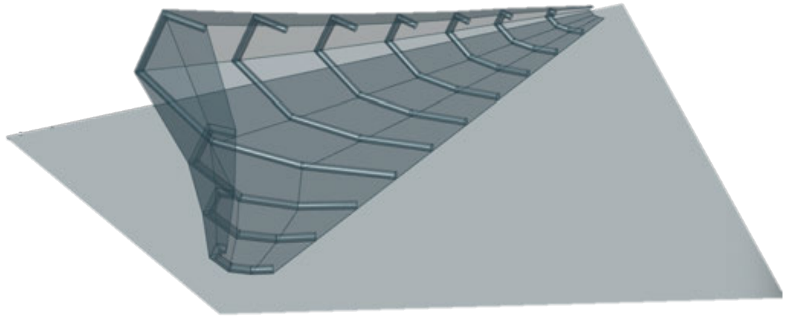

[6] PVC (polyvinyl chloride), Photo by P. Mills-Senn, 2019

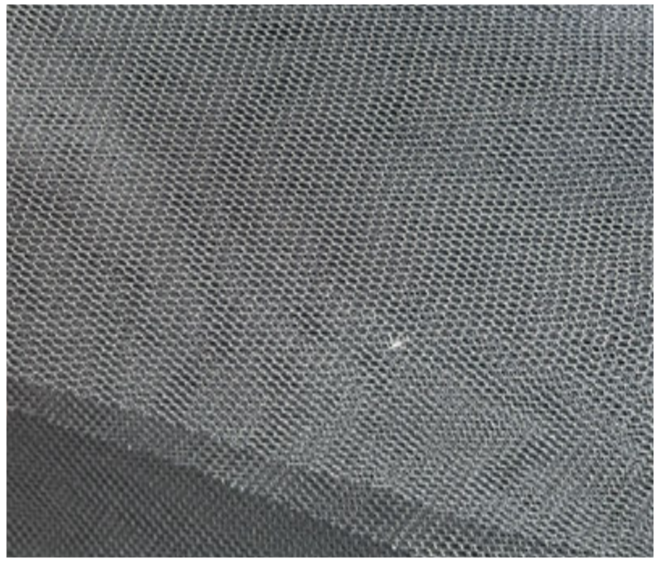

[7] HDPE (high-density polyethylene), Photo by Tension Structures, 2020


[8] PTFE (polytetrafluoroethylene), Photo by akaatent, 2019

Tensile fabrics

Tensile fabric can provide a number of benefits. The material's versatility and elasticity make it perfect for building intricate structures and shapes that effectively reflect sound. It can also be used in a deployable system due to its flexible design and low weight. It also posseses a smooth surface that can reflects sound. A tensile fabric like ETFE or other related tensile fabric material would be required to conduct a feasibility study, however wire mesh was finally selected because it is flexible, easy to work with and has properties that are similar to those of tensile fabric.

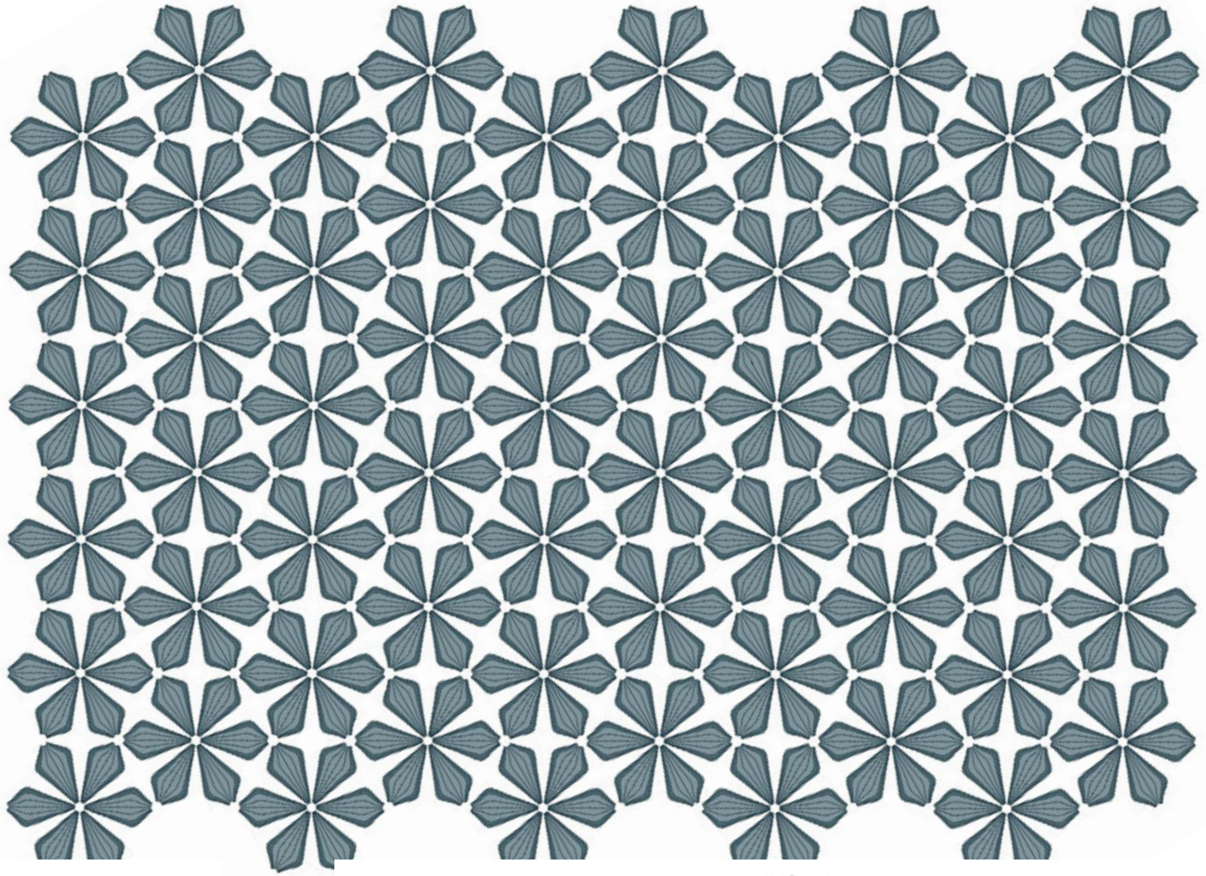


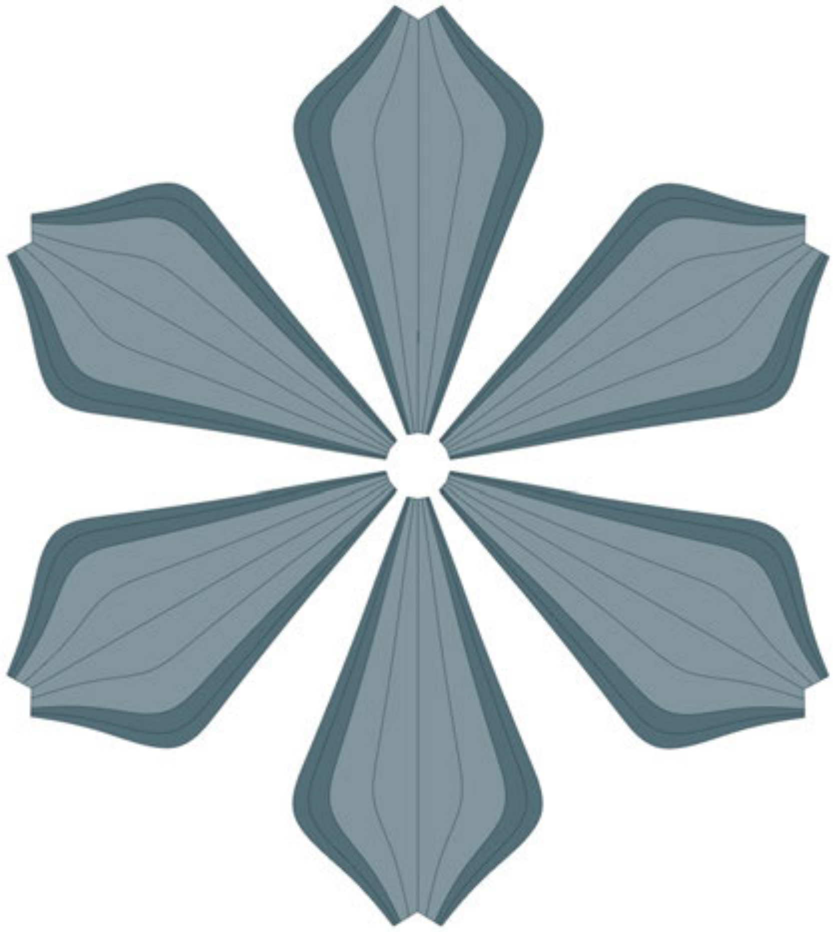


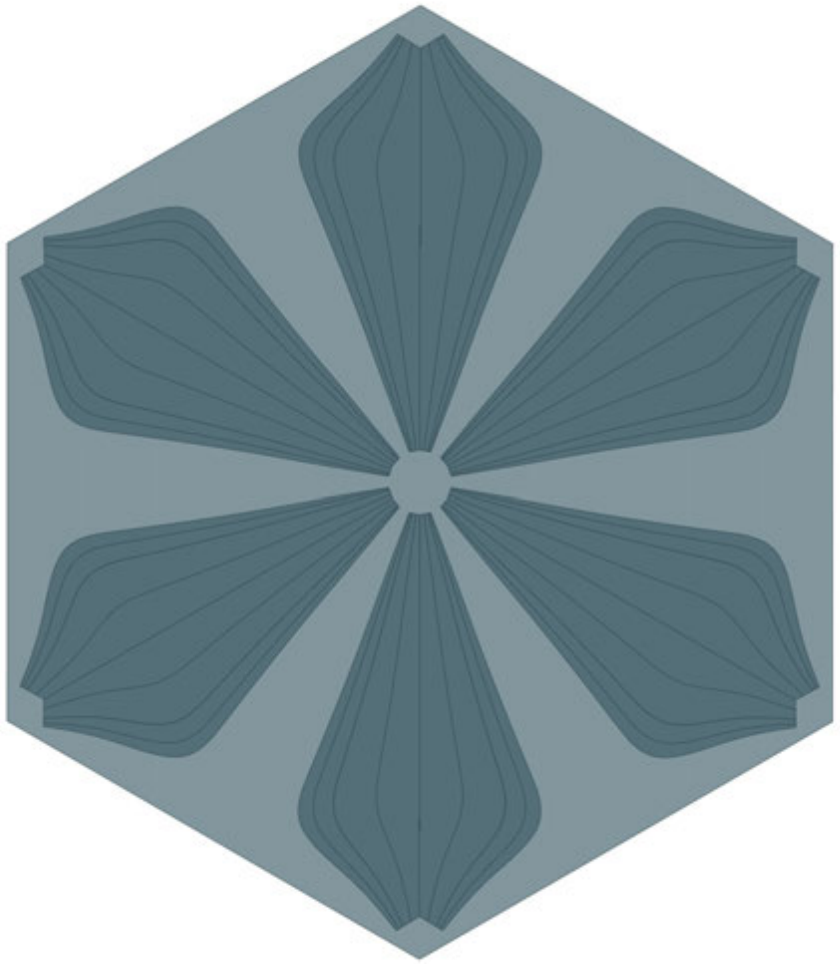
Facade Geometry

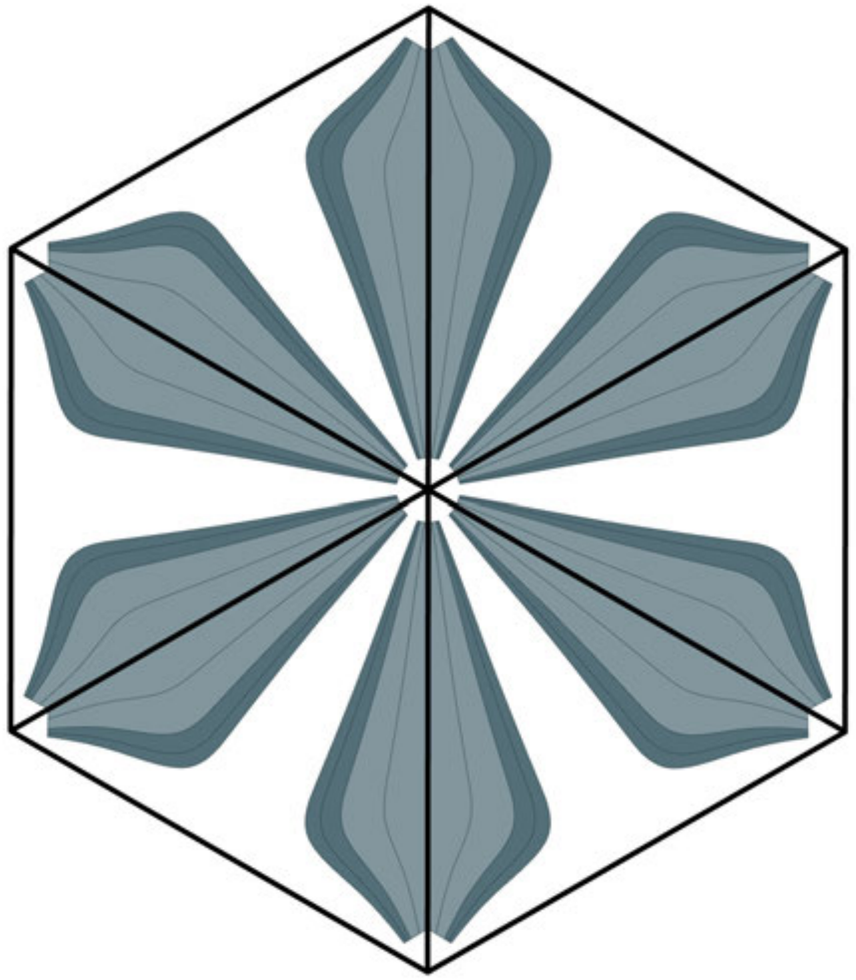
Now that the design of each half petal is ensured, it can be mirrored and rotated around the central point to satisfy the design configuration. The hexagonal shape or 'flower' allows for a repetition of this geometry in various formations to form a complete façade or façade panel. For manufacturing and implementation in the office context, the design has continued development as a primarily rectangular pattern as shown on the next page, although scale and resolution are to be dictated through testing.

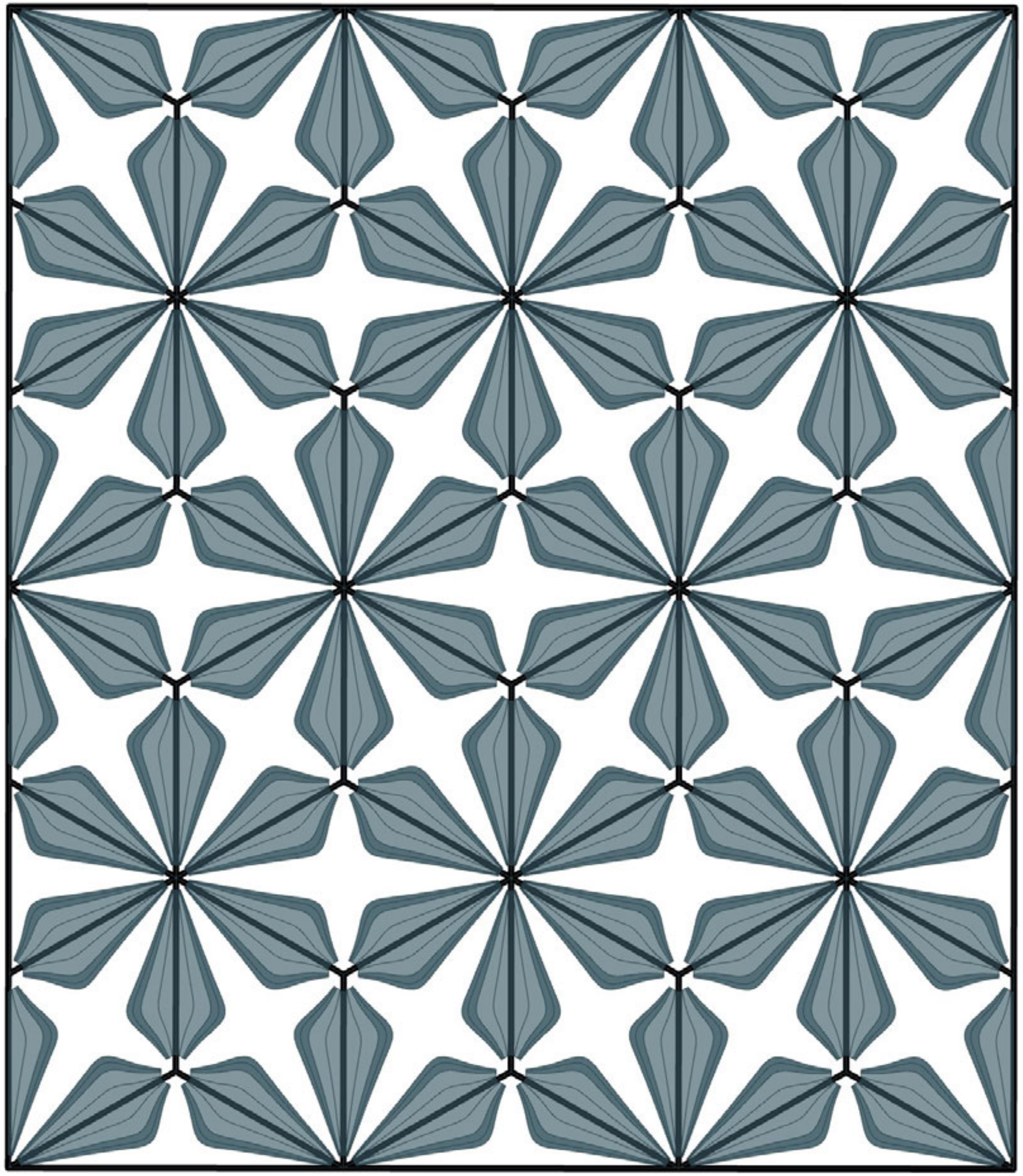
The system is held together by a series of pipes as shown in the last images, these run along the central spine of each petal as well as in between each flower for structural support. The secondary purpose of these pipes is to contain the wires and cables for deployment and operation as a whole system.

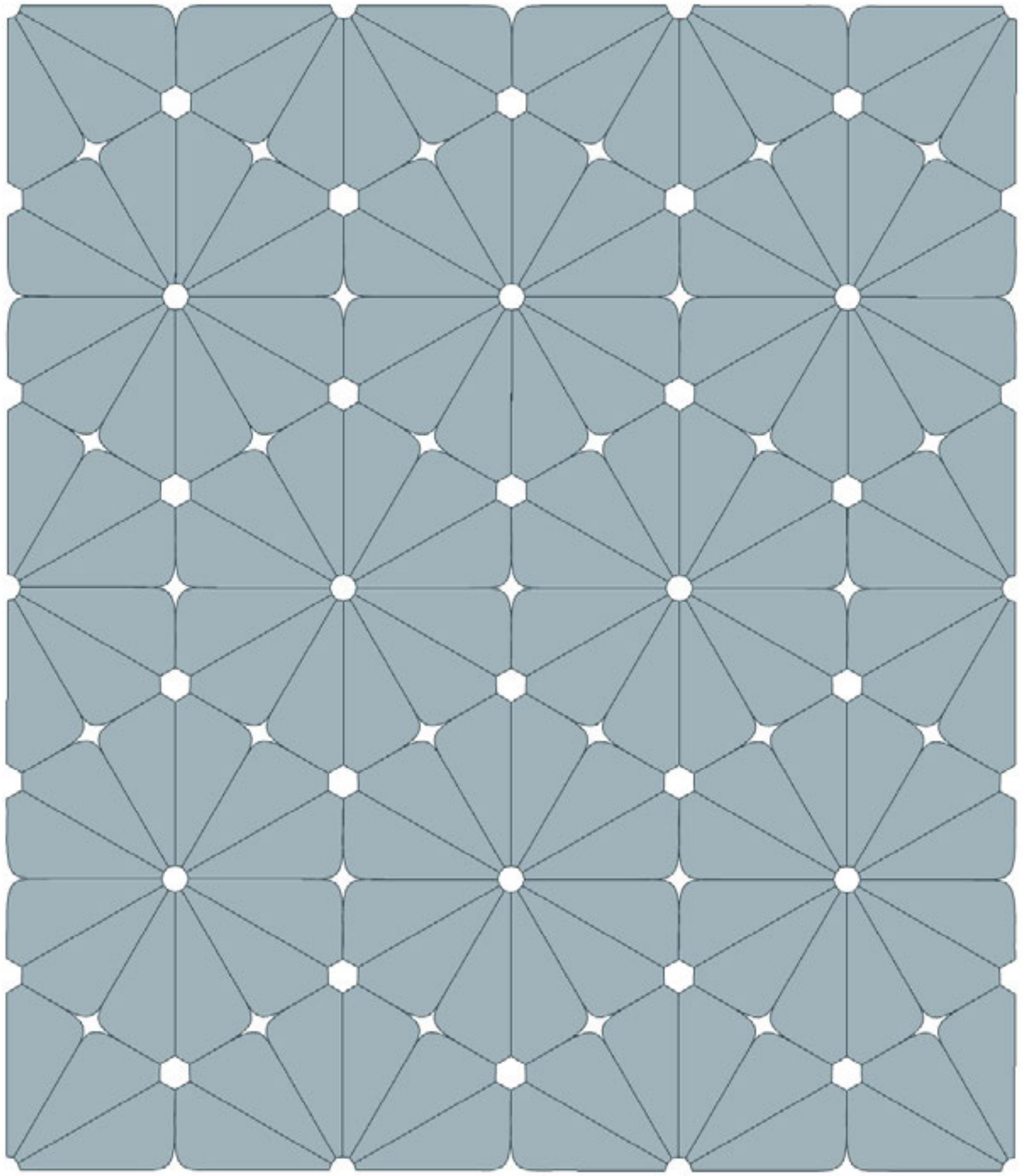












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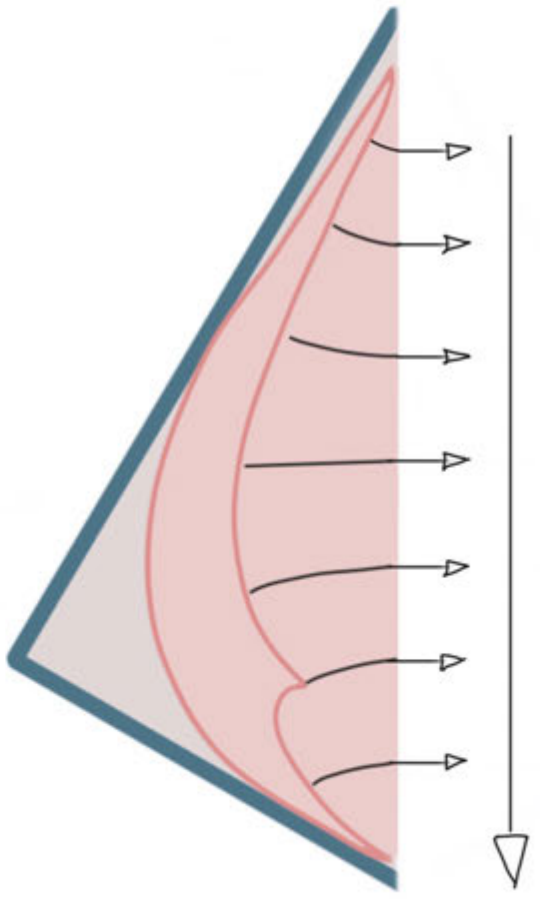
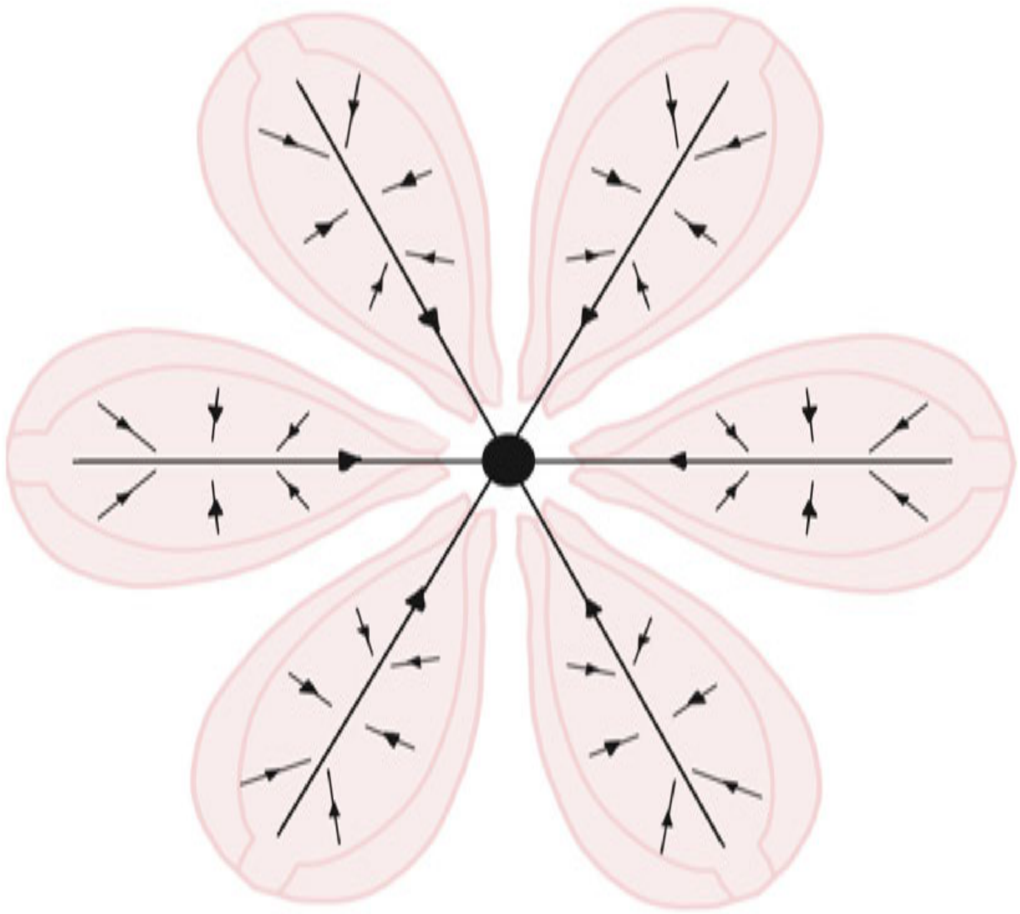
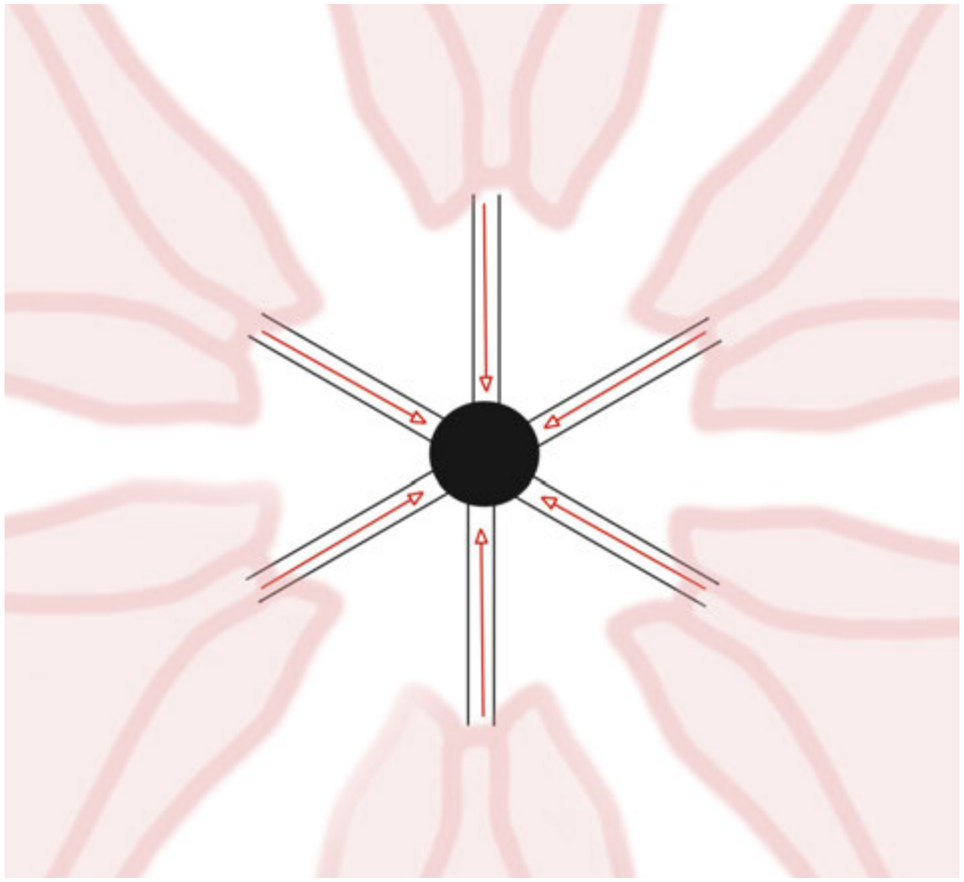


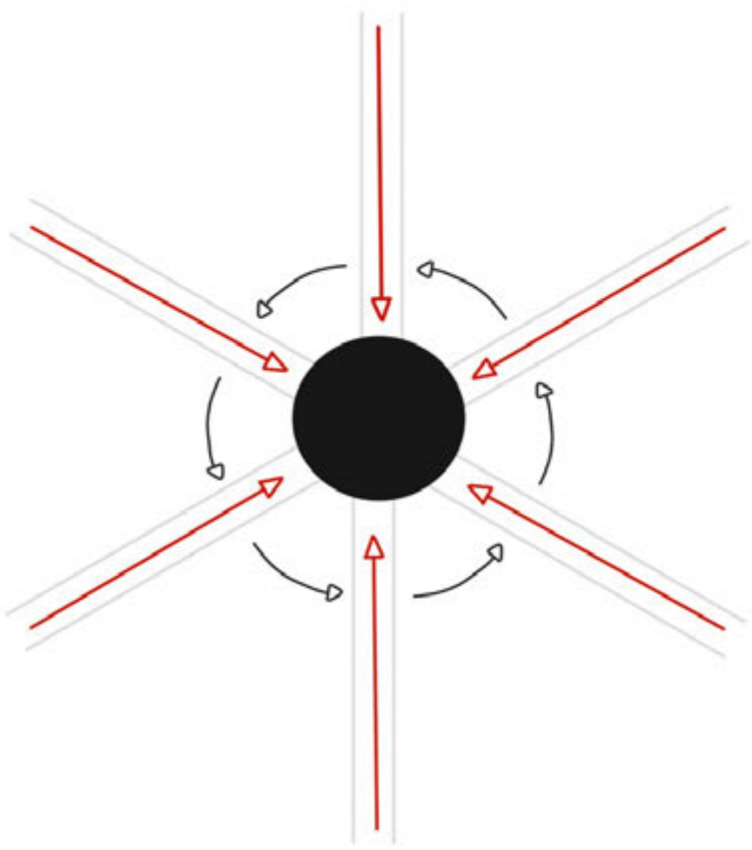


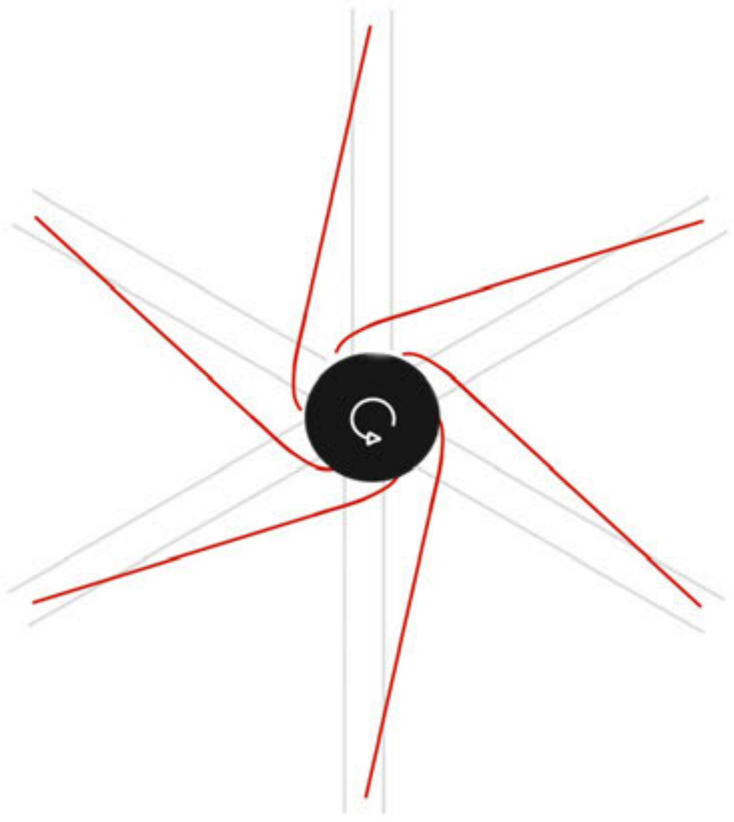
Movement in façade

Tension cable attachments

The global control for the façade will continue as an extension of the tension cables of each 'petal', as the force is extended through each central spine of the leaf it will be joined at a central point, found in each hexagonal collection of petals. Applying a rotational force to the central point will act as a winch to the cables along each leaf-spine applying equal a consistent force to each as it transitions to a deployed state. Due to the small resolution chosen for the configuration, this deployment method would need to be controlled electronically with a motor or servo to apply the rotational force.







Testing

Testing Logic

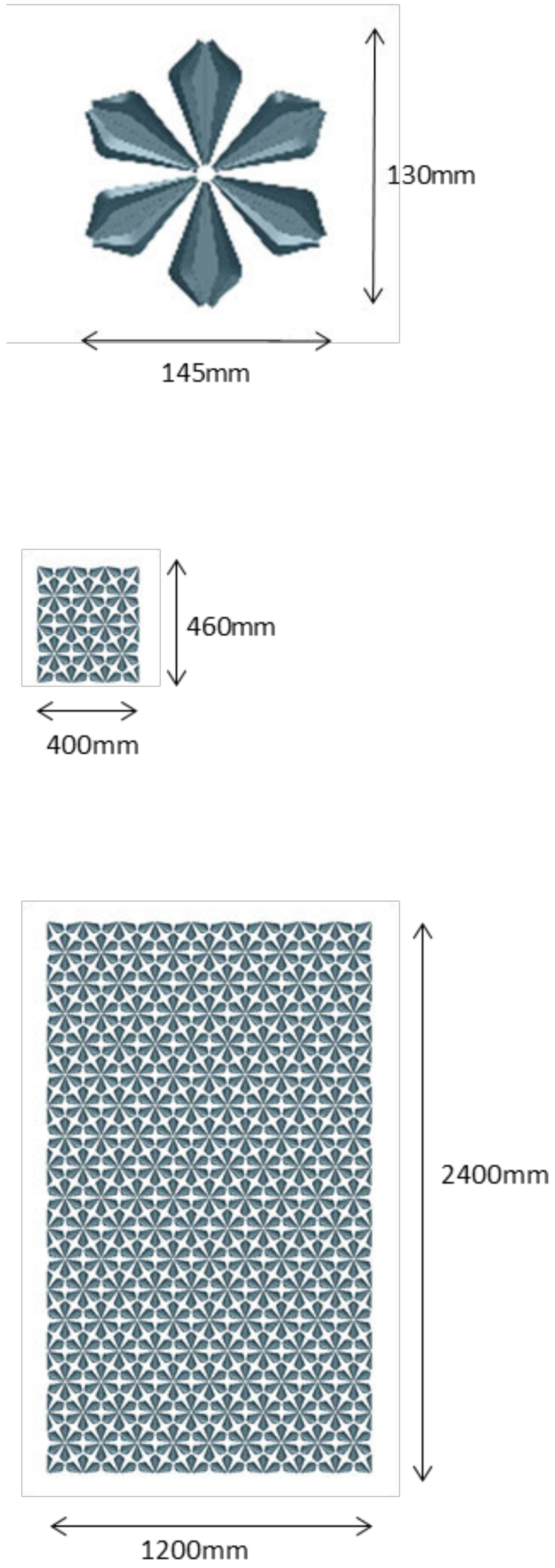
The testing logic involved measuring the reverberation time in space using computational simulation tools. The tools have been used to test how the sound waves bounce off the sound-dampening facade and return to the listener.

The Pachyderm plugin for Grasshopper has been used to simulate the sound transmittance in the space based on a real-world office size scale. By placing a sound source at the centre point of the room and a listening point at the rear of the sound-dampening façade, the sound level was recorded at the point of the listener.

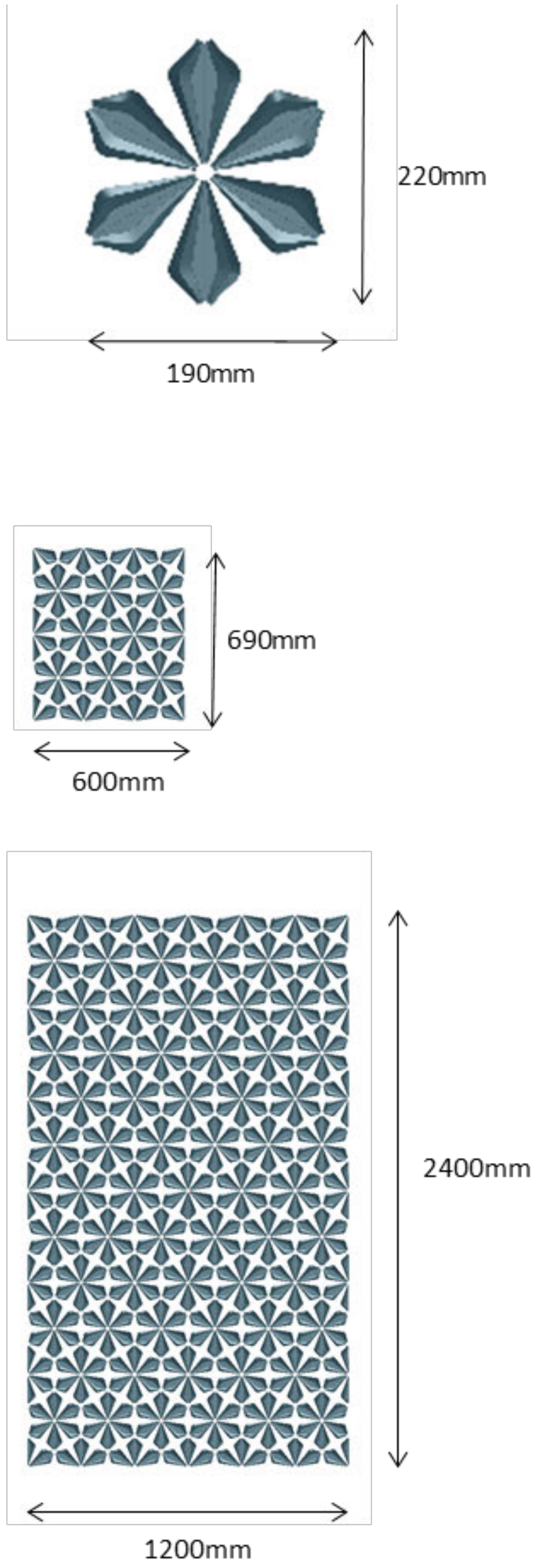
The testing of the reverberation time has also been done at 7 octaves and the decay time has been measured in the space from the listening point. This process is repeated with a ray count of 1000 and 2000 rays.

The average decay times measured at each octave have been used to determine the average reverberation time for the room. This was tested for the 3 scales and configuration of the façade dampening panels to determine the adequate scale in which the façade dampening panels perform optimally.

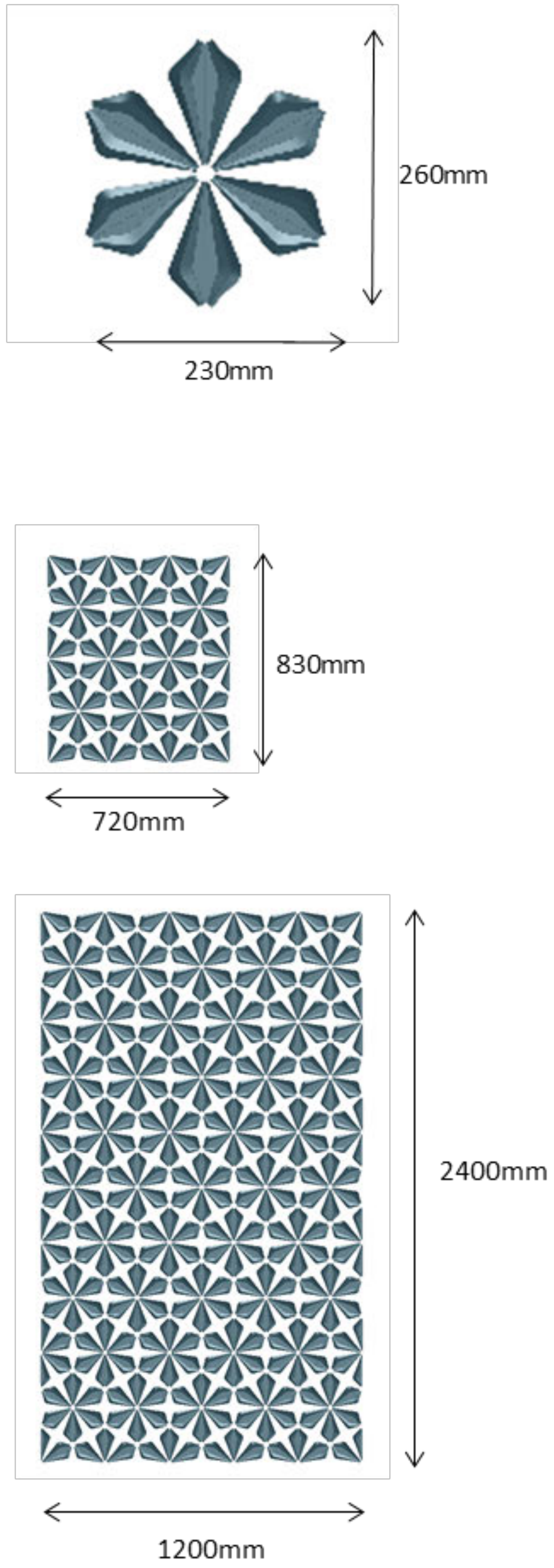
Panel A



Panel B



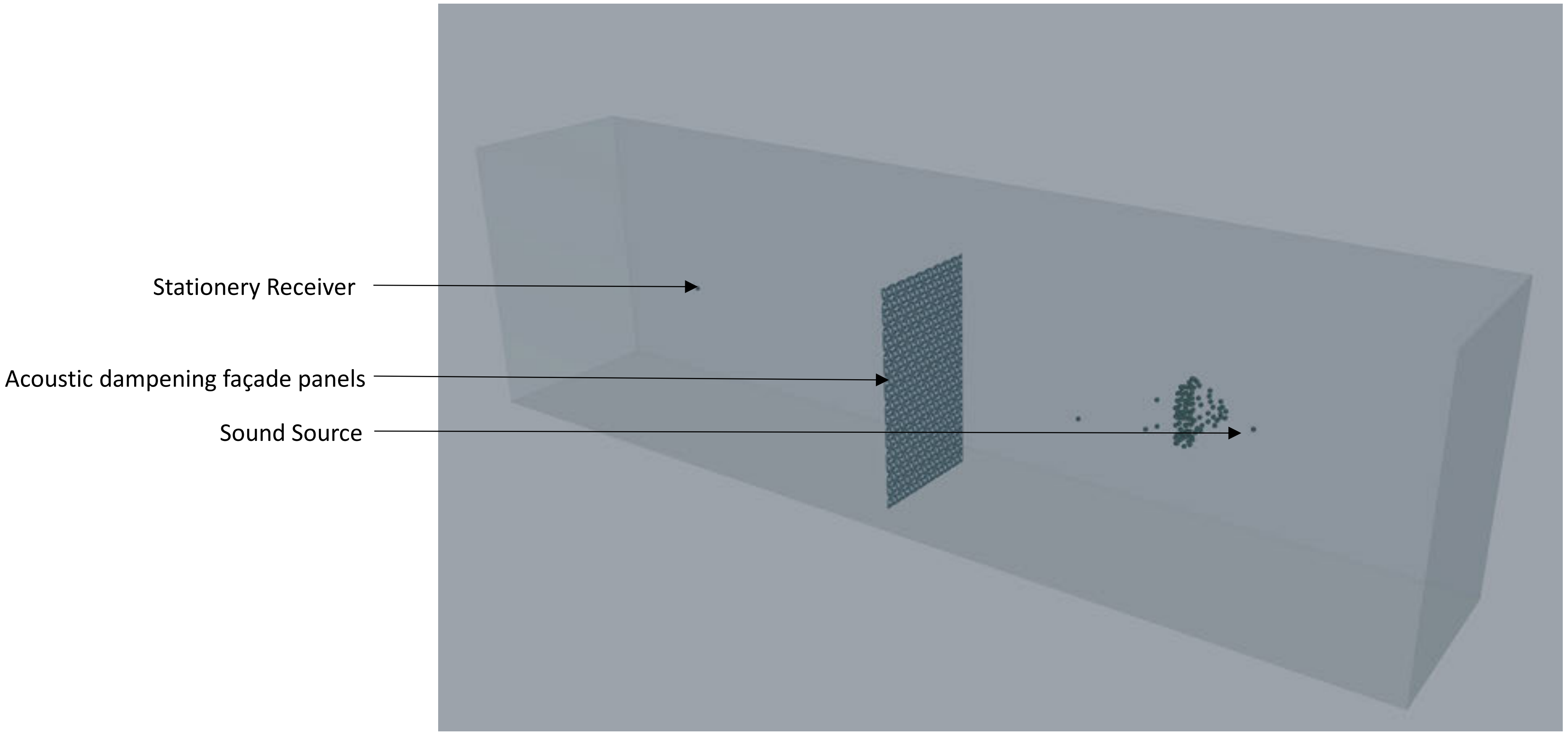
Panel C

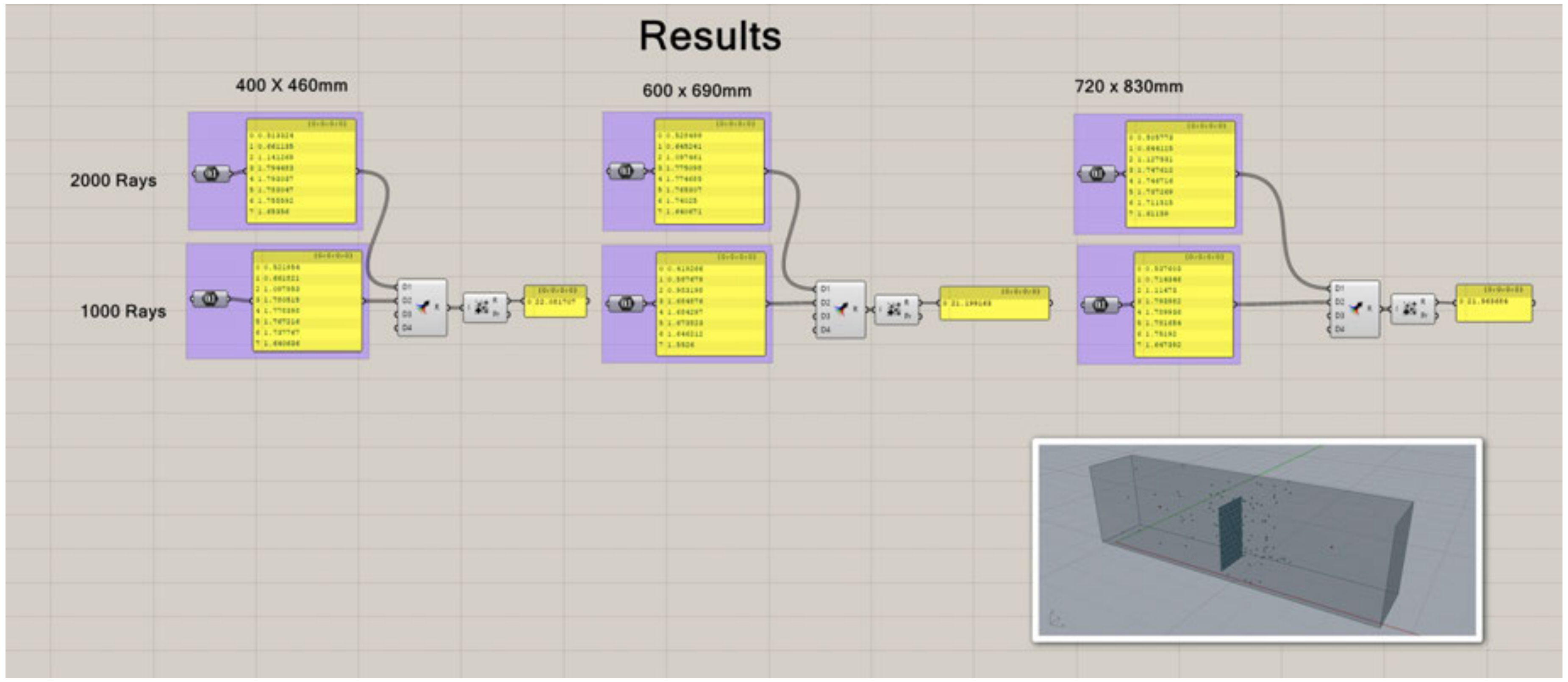


Testing Results

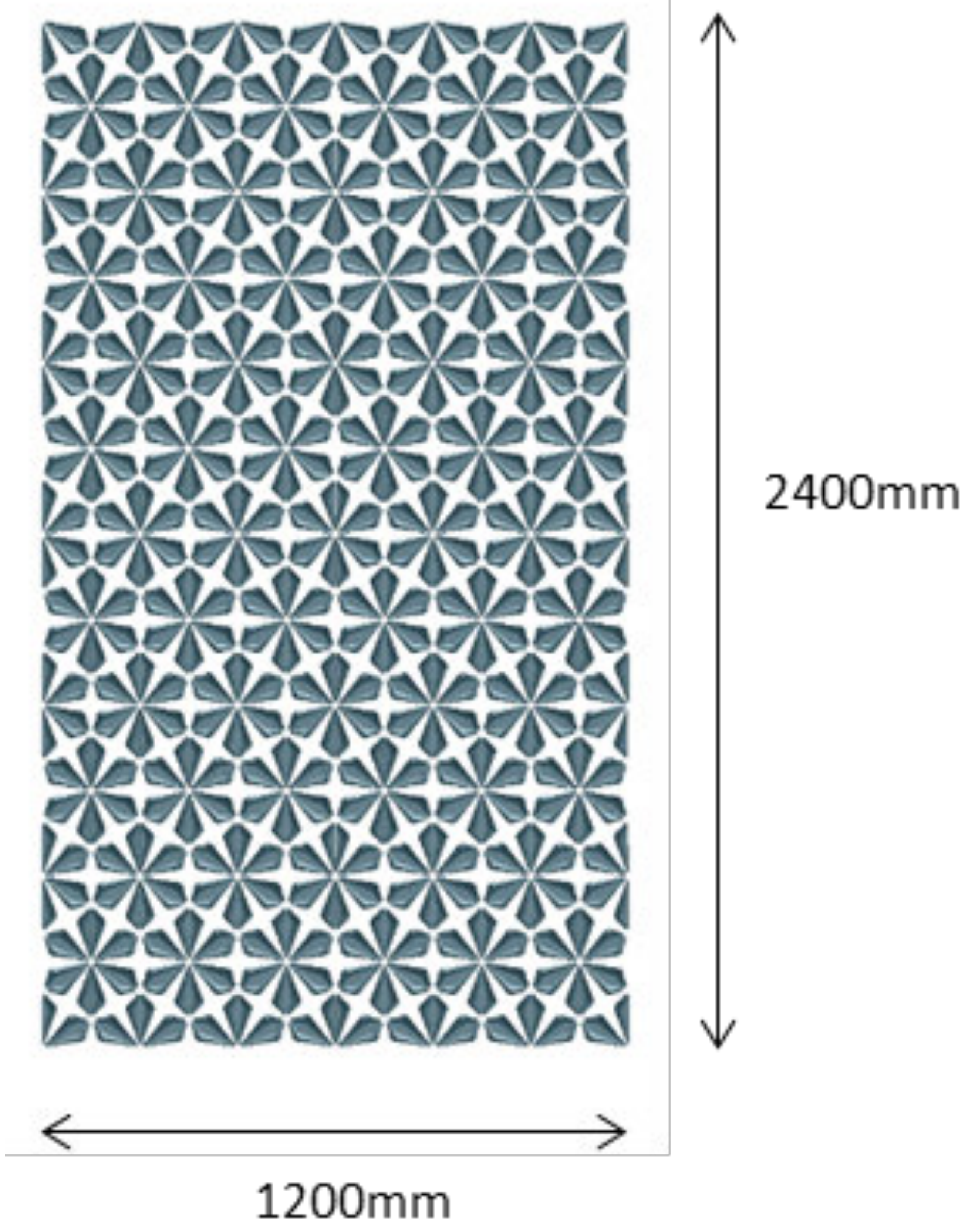
Result Analysis

The results of the simulation revealed reverberation times ranging from 0.5 to 1.8 seconds for the acoustic dampening panels at the proposed scales. The desired reverberation time for speech in an open plan office is a maximum of 1 second, The average of the results for each panel has been calculated to determine the superior-performing panel with results close to the desired reverberation time. This will be the factor to decide upon the settled scale for the final design. The details of this acoustic analysis will not be explained in further detail and lie beyond the scope of what is addressed in this project, however, for further testing, the expertise of an acoustics engineer can be employed to carry out more accurate testing and analysis of different configuration to get more detailed and accurate results.



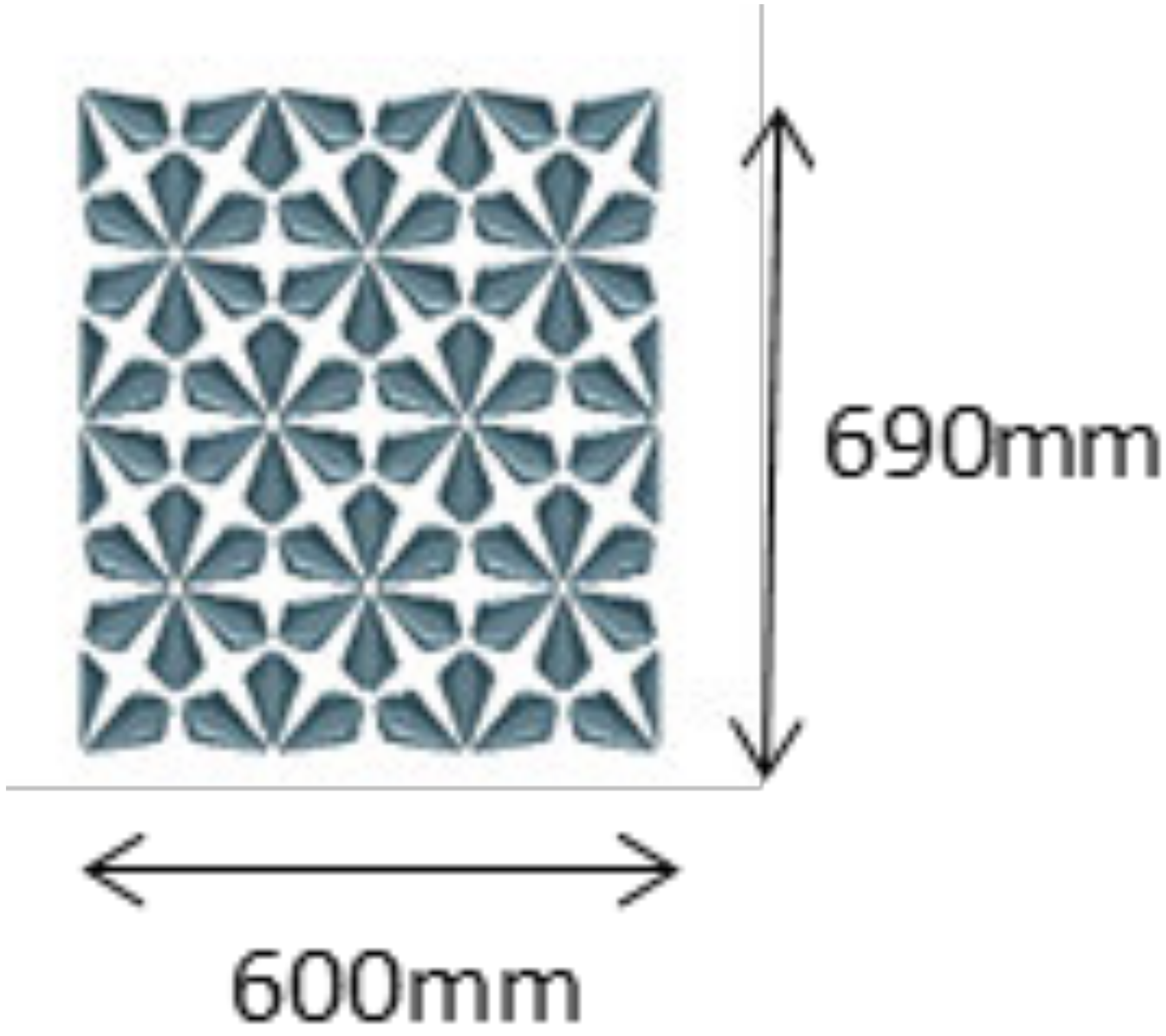


Panel B



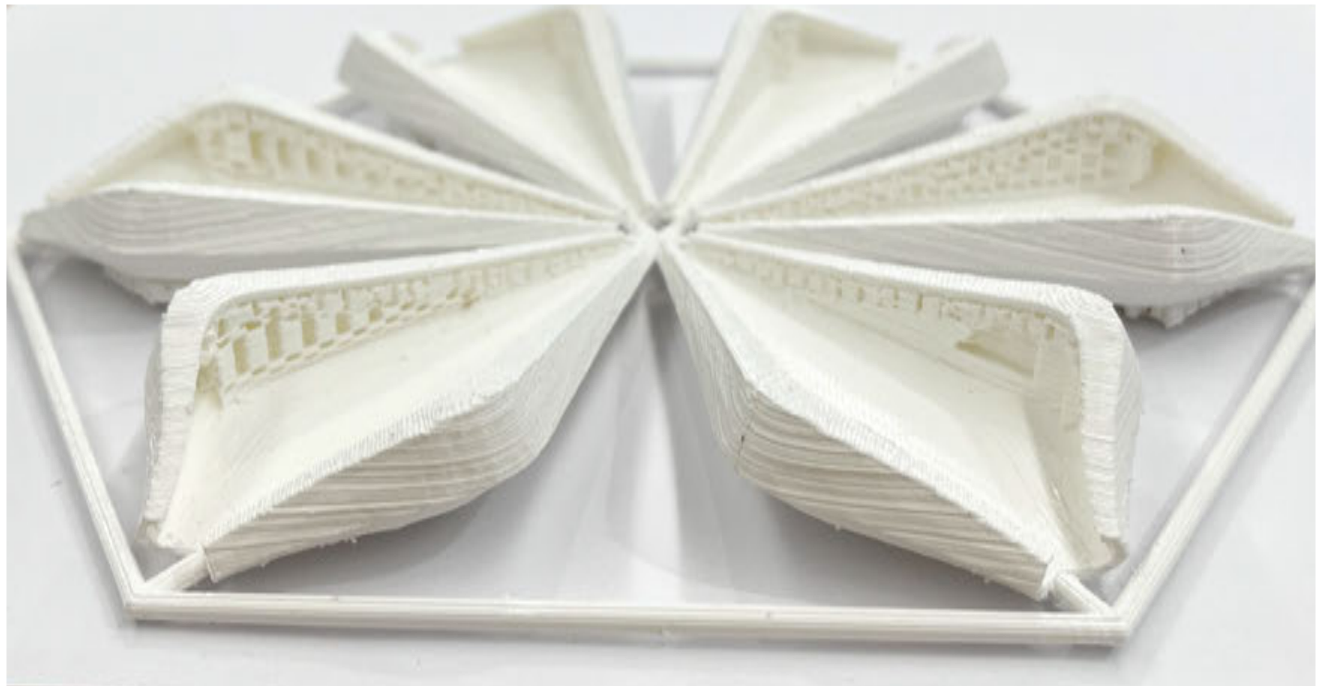
Settled upon design & scale

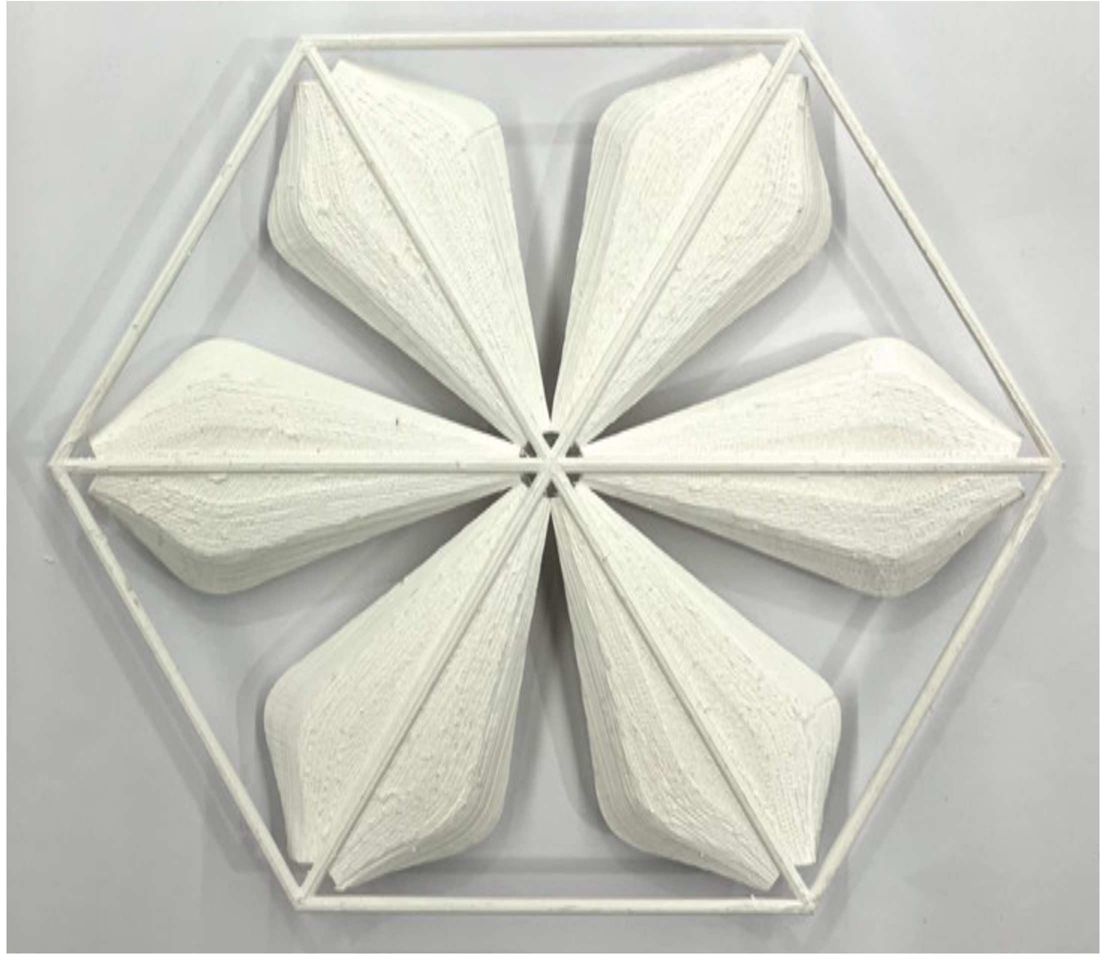
The acoustic dampening façade which resulted in the least reverberation time was Panel B and this has been used as the proposed scale for the final design configuration.



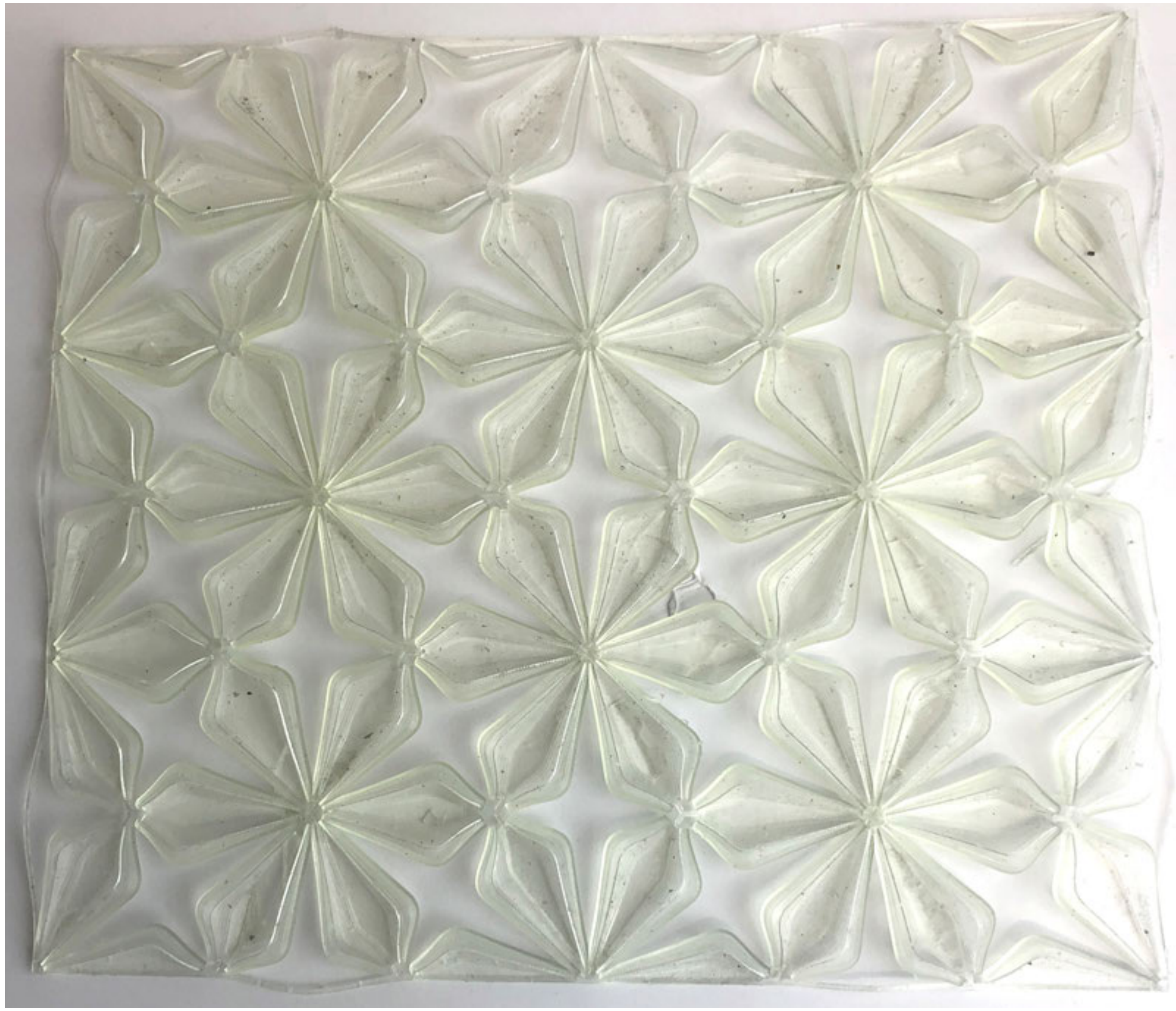
3D printed solution

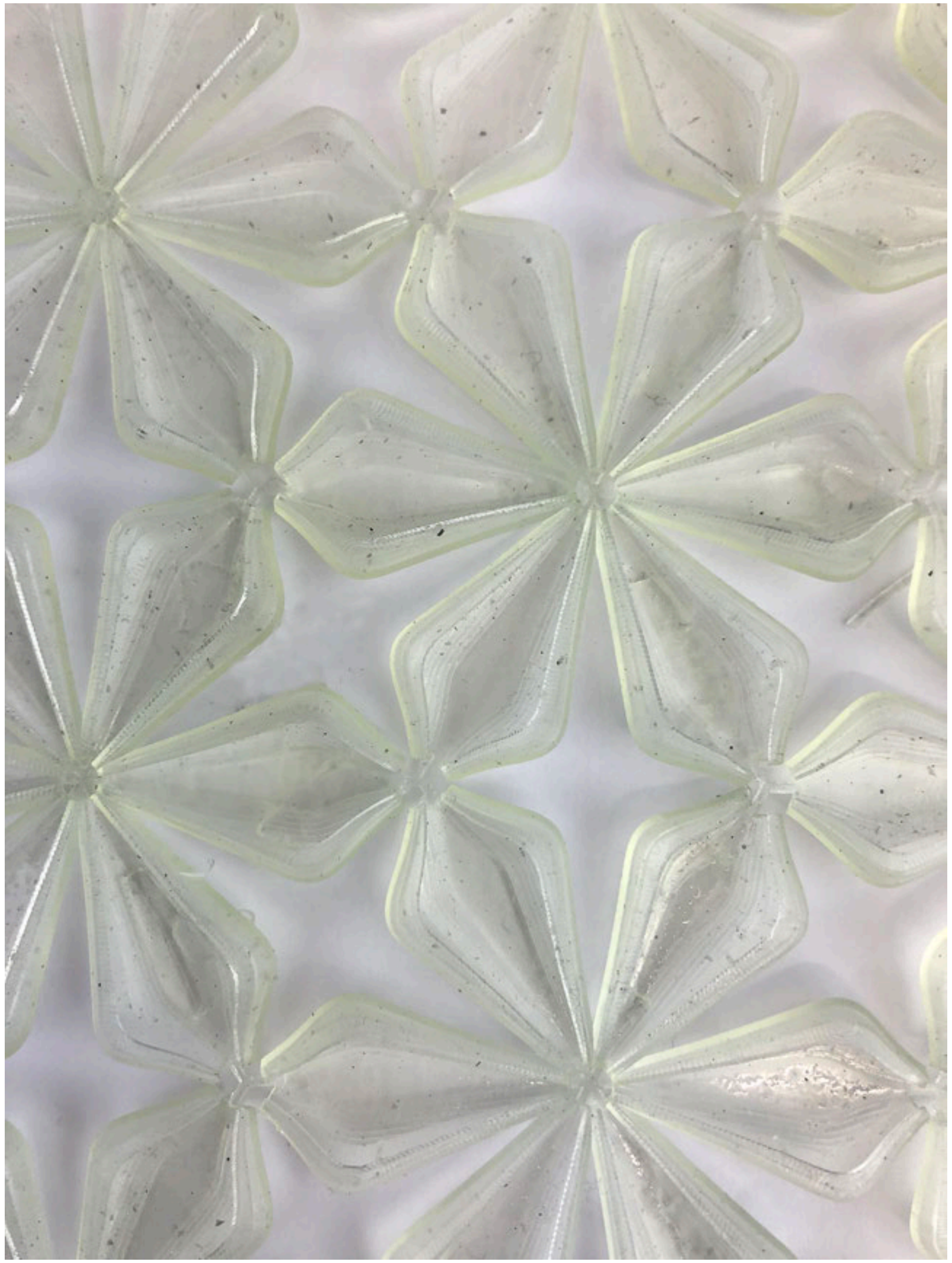
1:1 scale





1:2.5 scale





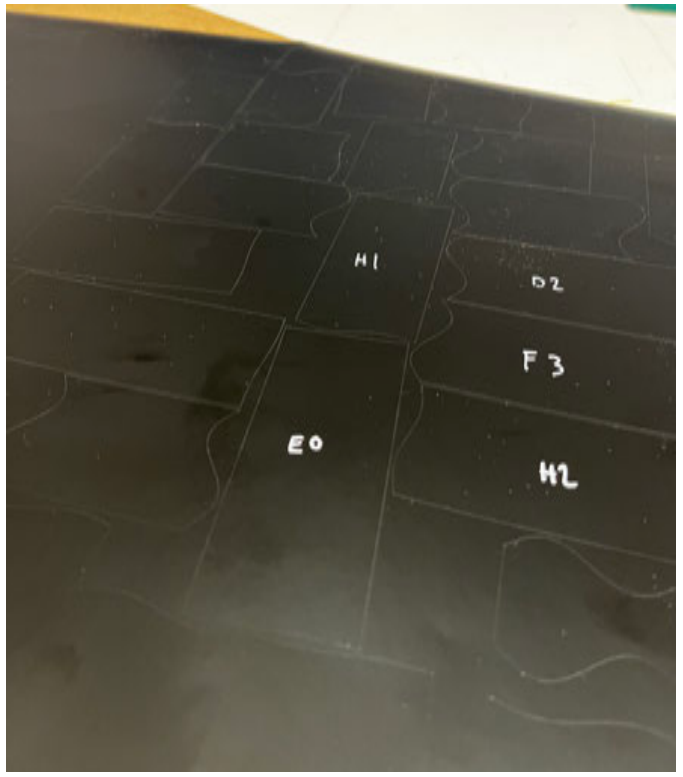
Results in Context

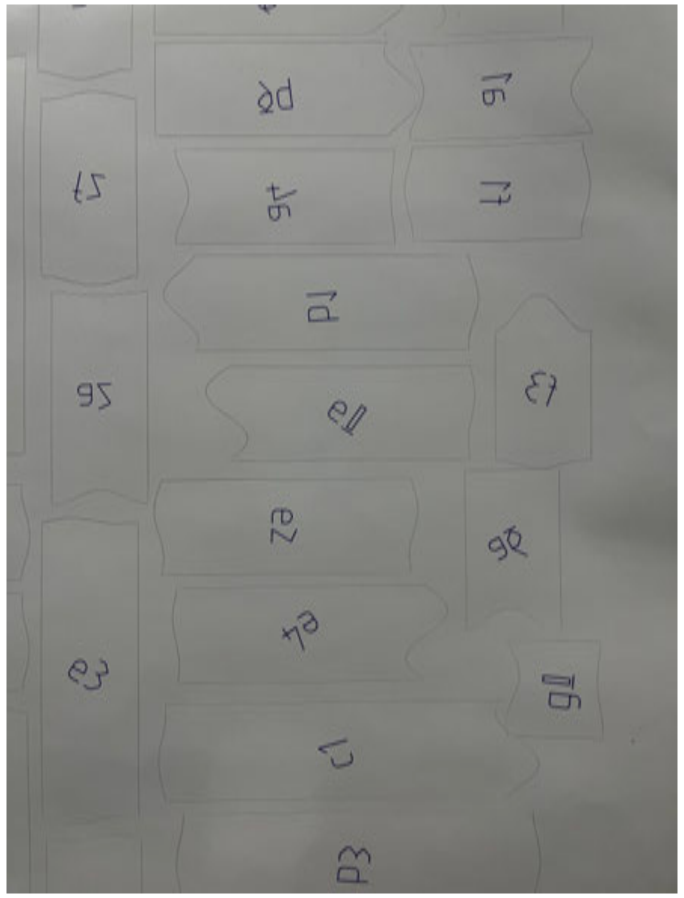
Fabrication

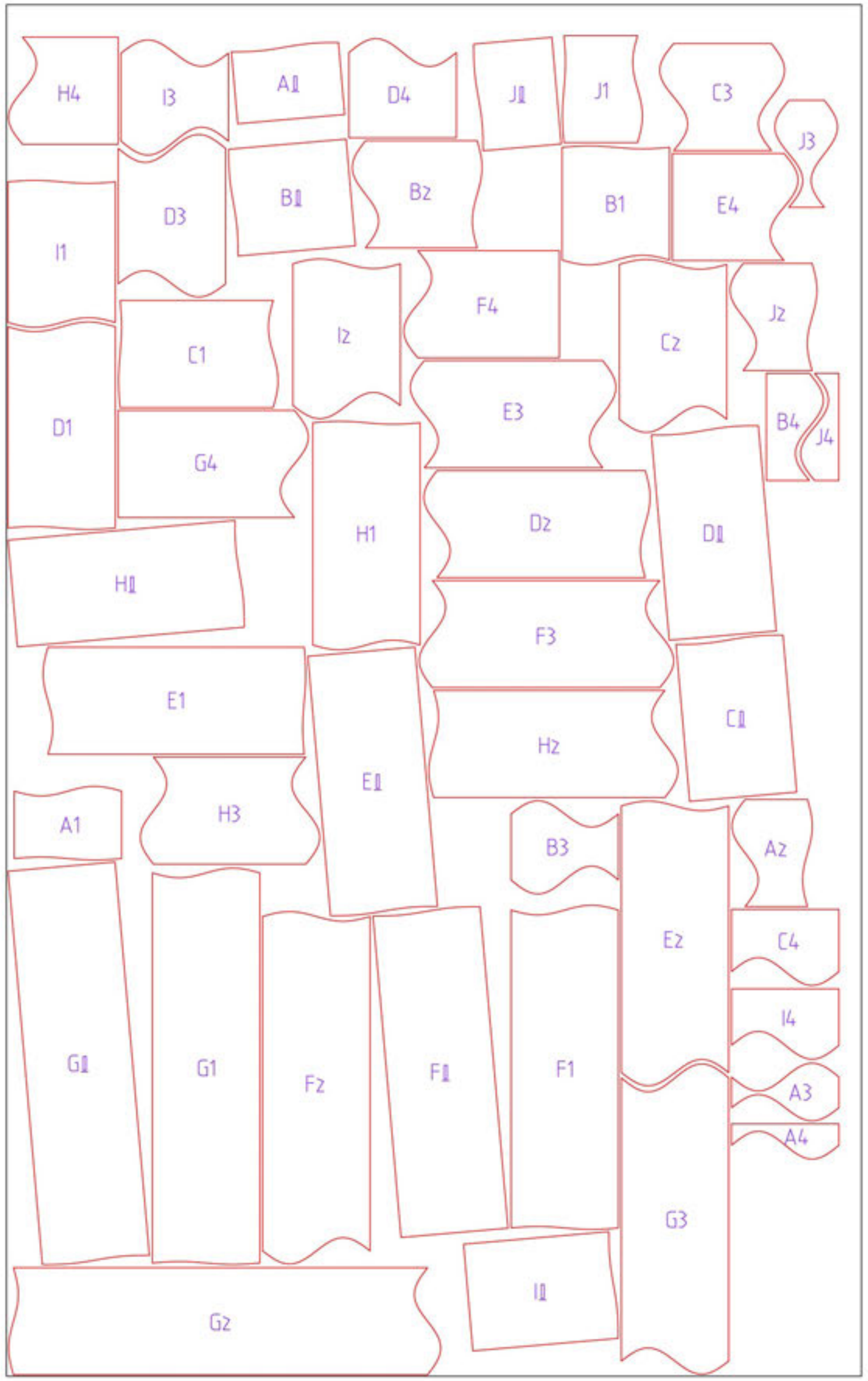
Pipes

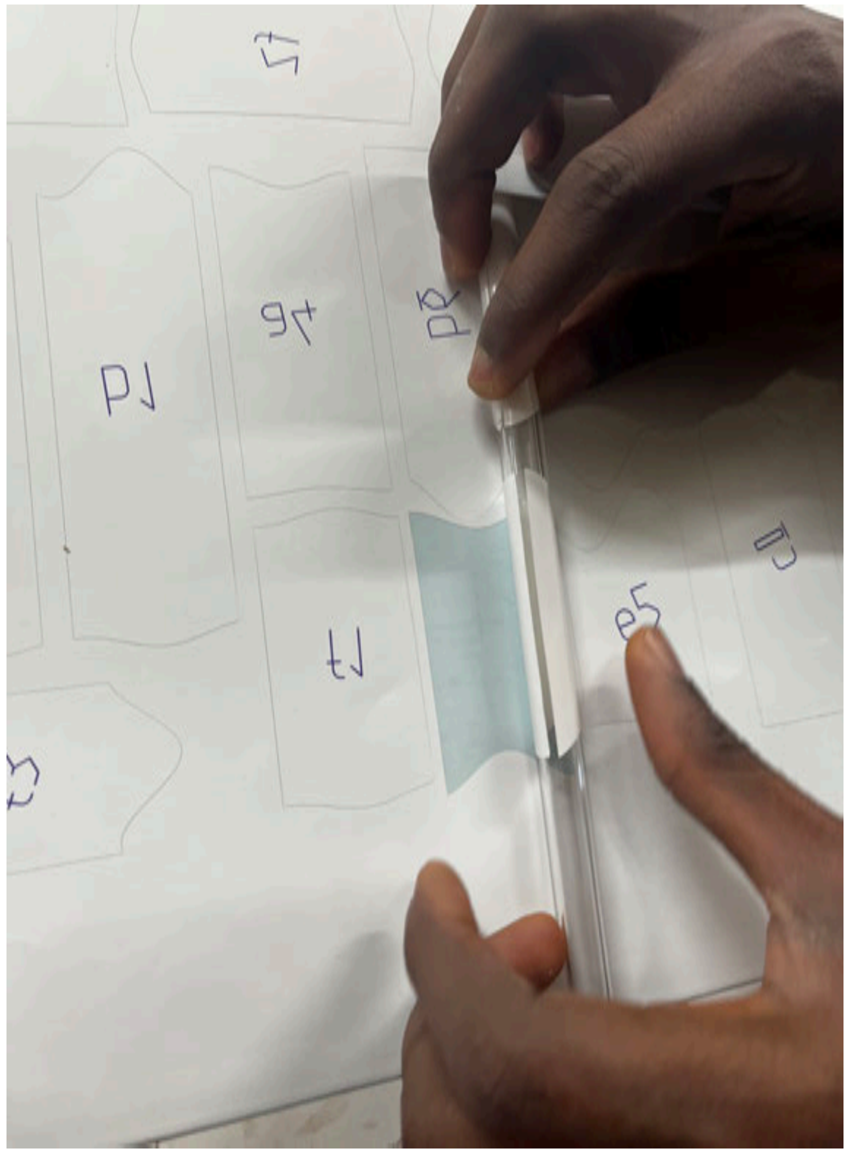
Layouts, Vinyl Stickers

In the fabrication process of the pipes, It was essential to find the angles at which the pipes joined each other in the model and use these angles in the fabrication model. A process was developed which involved using the diameter of the pipe procured for fabrication and measuring it using a micrometre screw gauge. The diameter of the procured pipes was used to inform the diameter in the parametric model. The next step involved unrolling the pipe geometry as a cylindrical surface and projecting the resulting surface onto a plane. The unrolled surfaces were then labelled with text to identify each surface, enabling ease of identification during the fabrication process. To determine the outline for cutting, boundary curves were generated from the unrolled surfaces. The resulting boundary curves were laid out optimally, using the Open Nest plugin to minimize wastage in the vinyl material. The final step involved sending the output curves to the vinyl plotter for cutting.





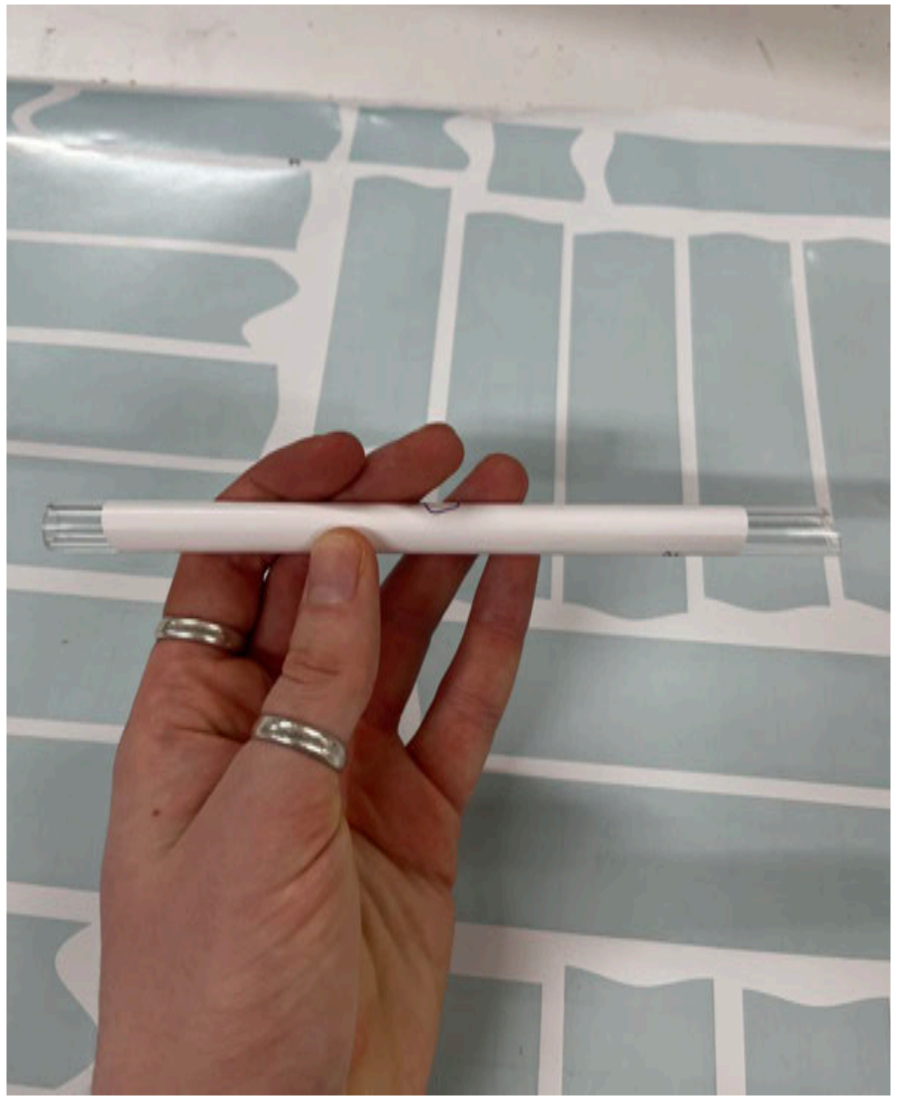


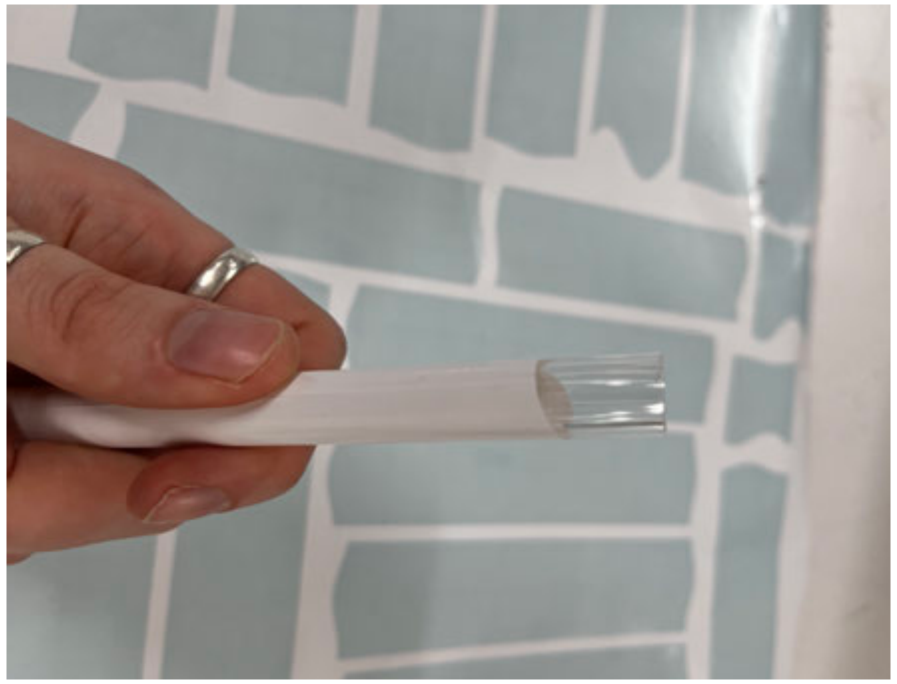


The next step in the procedure required determining the vinyl sticker that went with each pipe section using the tags for those segments. The vinyl cut-outs were then carefully removed from the vinyl sheet.

The vinyl stickers were neatly and precisely rolled back onto the pipes to allow for the cutting of the pipes. As the angles of the pipe were visible through the vinyl, this served as a kind of "template" for each segment of the pipe.

Thereafter, the band saw machine was used to make precise cuts in the pipes that had been rolled in vinyl. The band saw machine was used to cut as close to the angle as possible using the vinyl template as a guide.



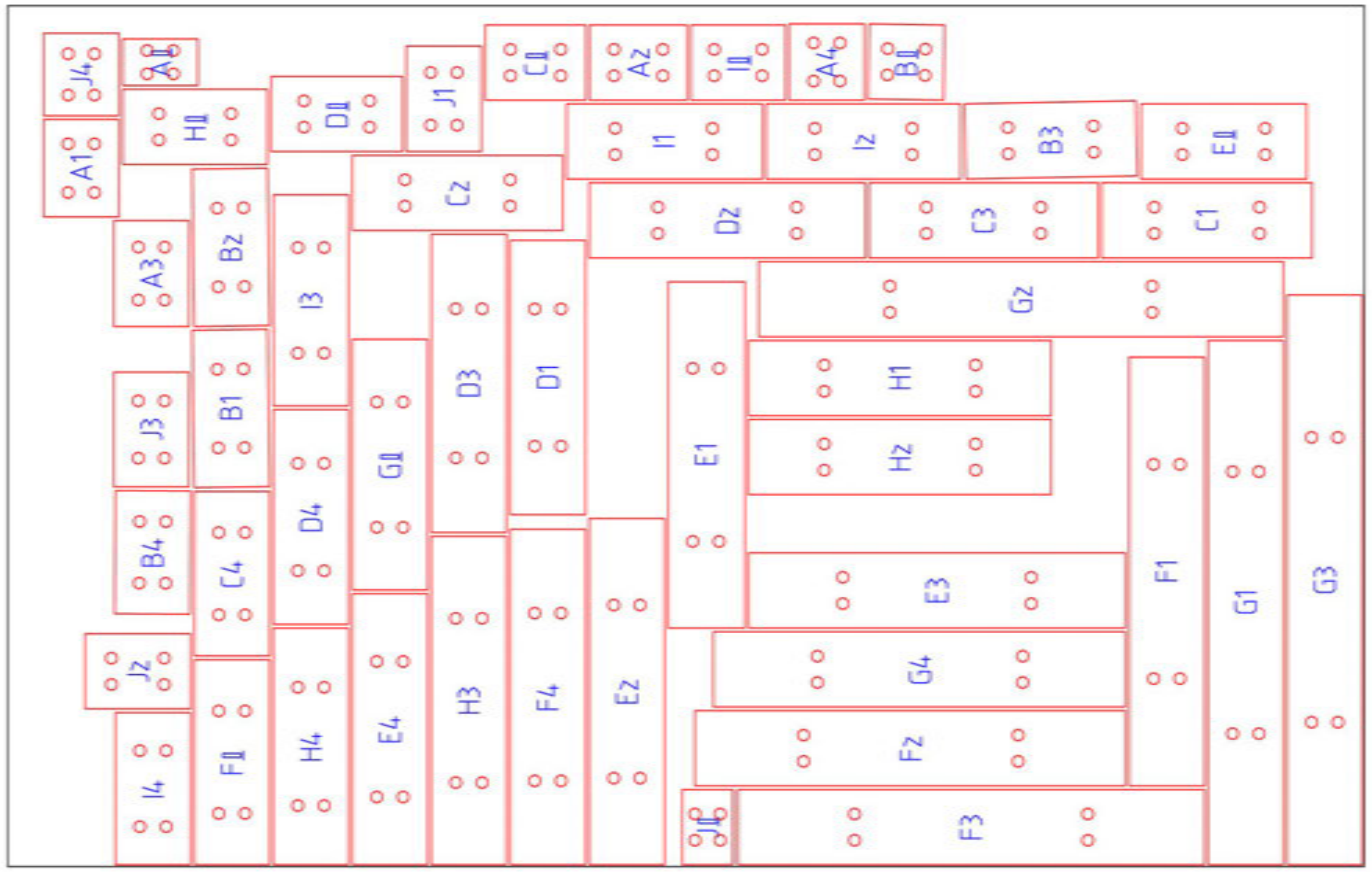


To determine the exact angles for each pipe segment, a disc sanding machine was used as an alternative method when the band saw was unable to achieve the desired angle required.

The machine's rotating disc with sandpaper was used to sand the pipes down to the required angles. This method was particularly effective for pipes with very minimal lengths, where cutting with a saw could be dangerous.

The disc sanding machine allowed for greater precision in achieving the desired angle than the band saw alone could achieve and was more effective in ensuring the end-to-end segments matched and aligned with each other.

A string was passed through the pipes to connect all the segments of the pipes and to facilitate the pipe angles which would determine how the system reaches its deployed or undeployed state as the string is tensioned or relaxed.



Panels

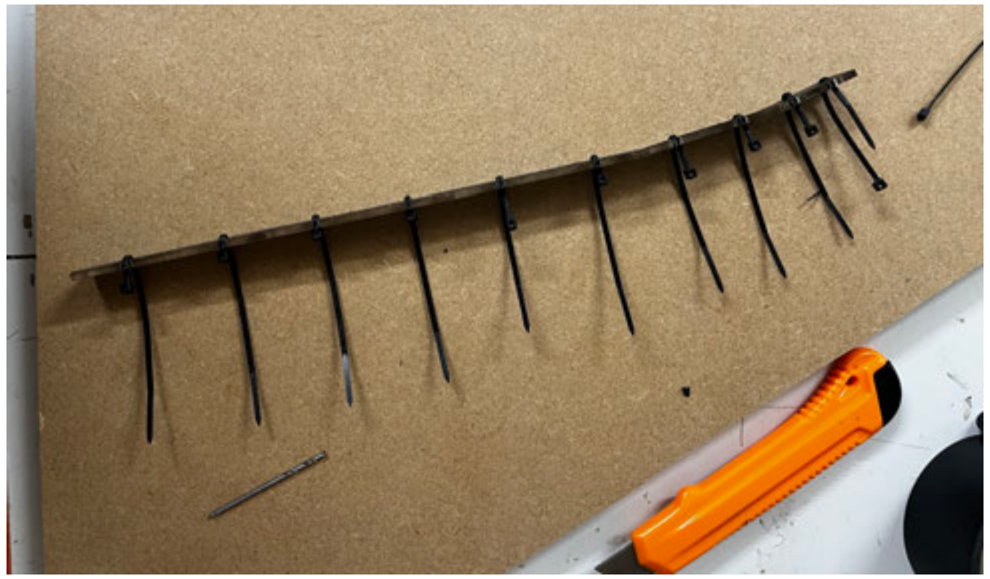
The panels were created to act as a host for support hinges for the pipes, and it was also necessary for the panels to fasten the pipes to themselves in a way to resist the movement of the position of the pipes in the panel. To achieve this, holes were created in the panels to allow for the fastening of the panels to the pipes using zip ties. For the fabrication process of the panels, the panel surface in the un-deployed state was projected to a plane with text tag identifiers for each segment. The boundary curves of the surfaces were exported to the laser cutting machine for cutting. The cut-outs were arranged based on their linear position in groups within the global system.

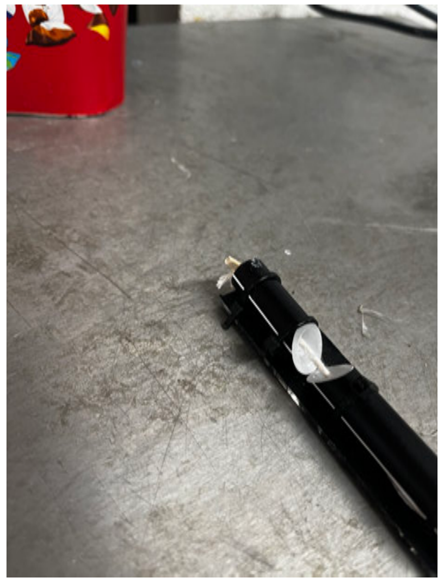
To allow for easy movement of the panels to reach their deployed and undeployed state respectively, the hinges needed to be flexible as well as light in weight to have the least resistance to the tensioned force from the strings. Rubber tape was determined to be a suitable material to meet the requirements. Each panel was laid out flat and arranged in its local groups and then pasted along the length of the tape. The tape was then cut out to fit the panel boundary. The resulting component allowed for the rotation of the panels freely across the hinge axis.

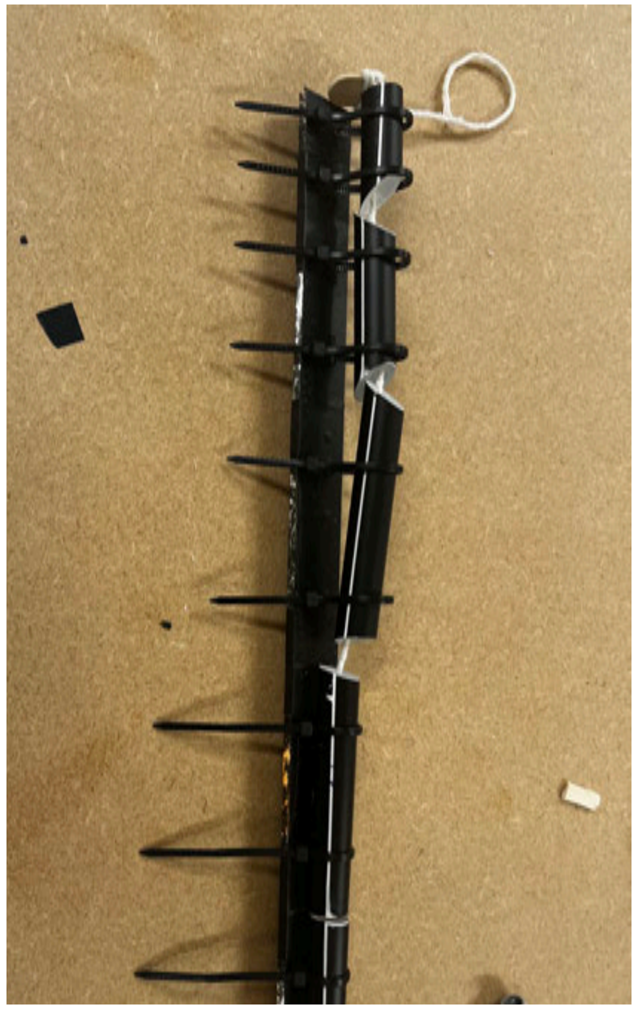
Panels

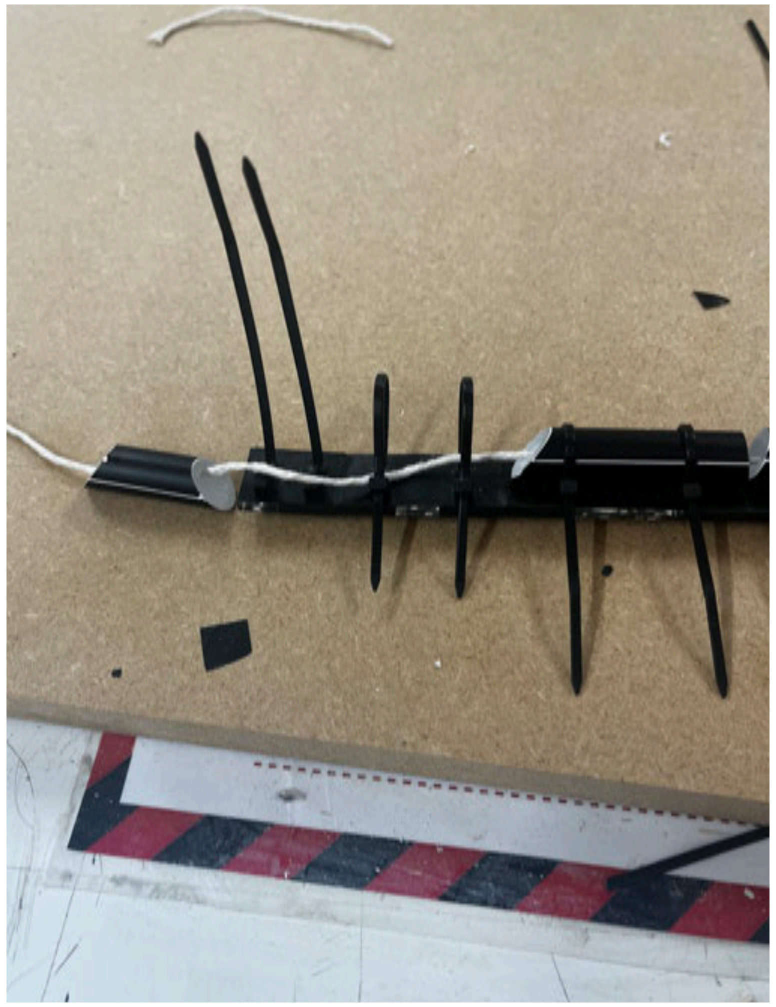
Assembling

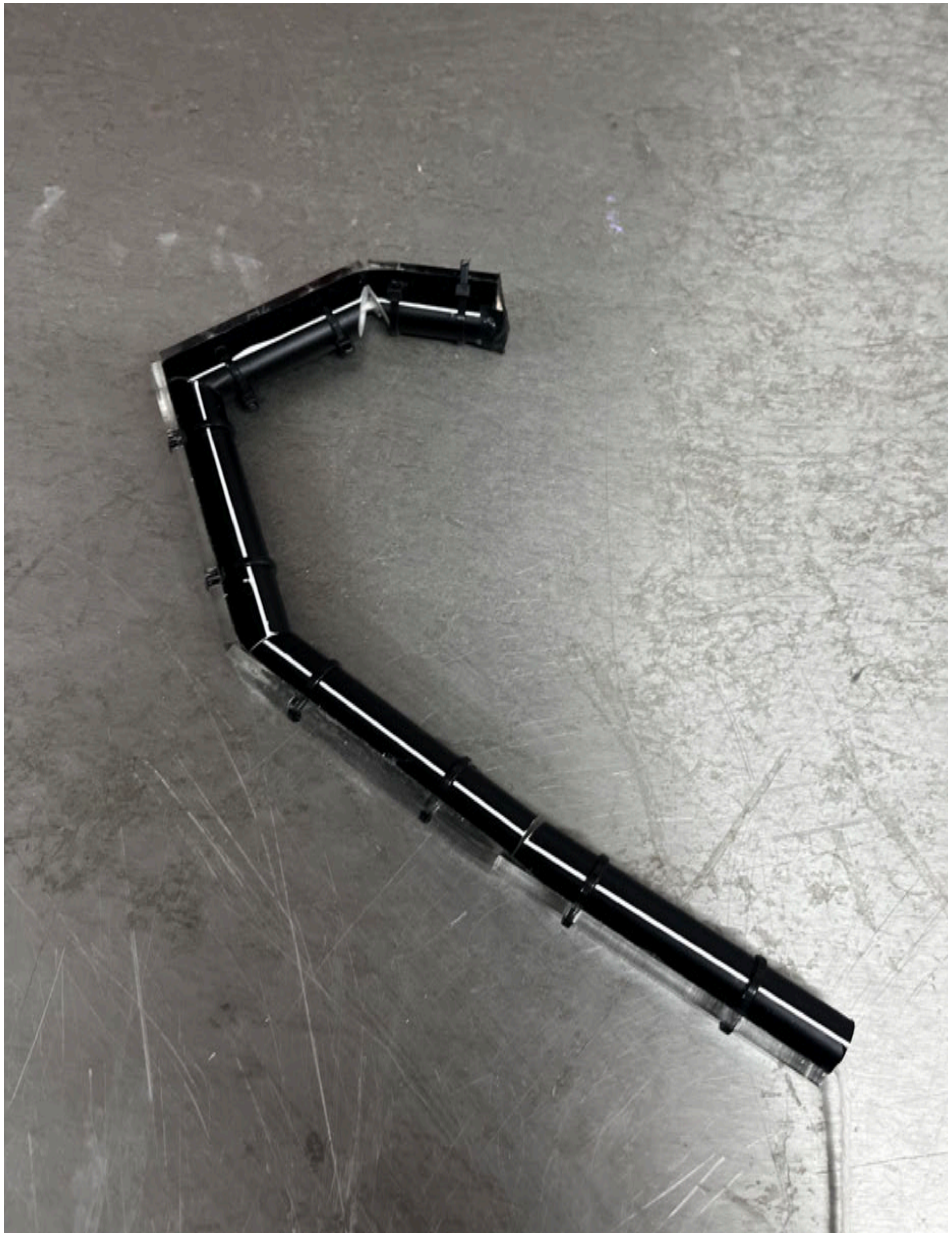
The pipes were grouped with their strings attached during the panel building process, and zip ties were used to fasten them to the hinged panels. The zip ties were first threaded through the holes that run across the hinged panels. The pipes were then put on the hinged panels and tightened to the necessary stiffness after the zip ties were in place, guaranteeing they would stay in their designated positions without shifting or moving during deployment.

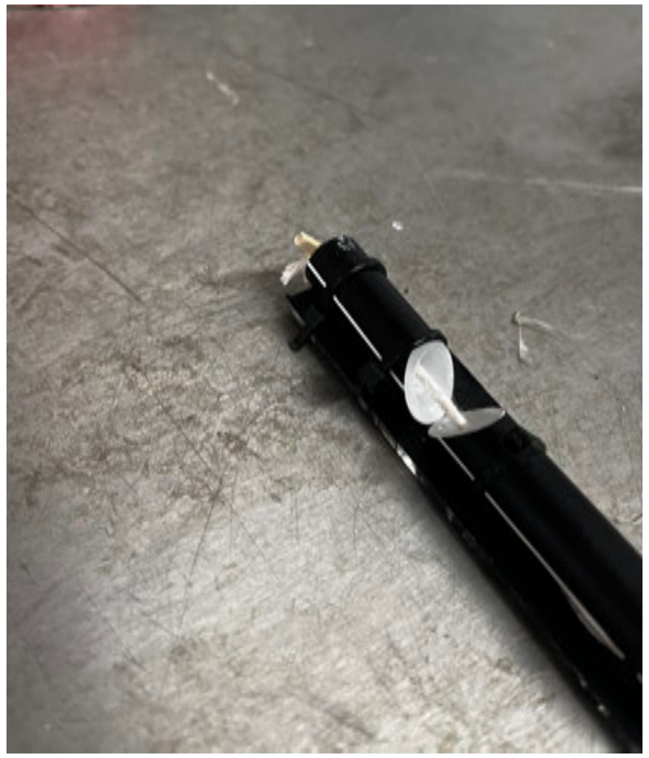


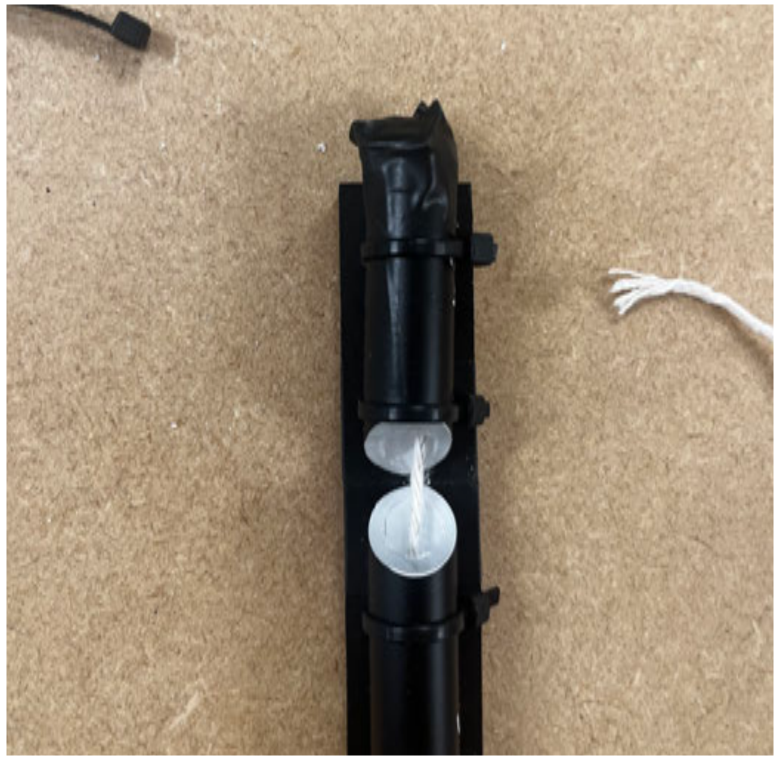








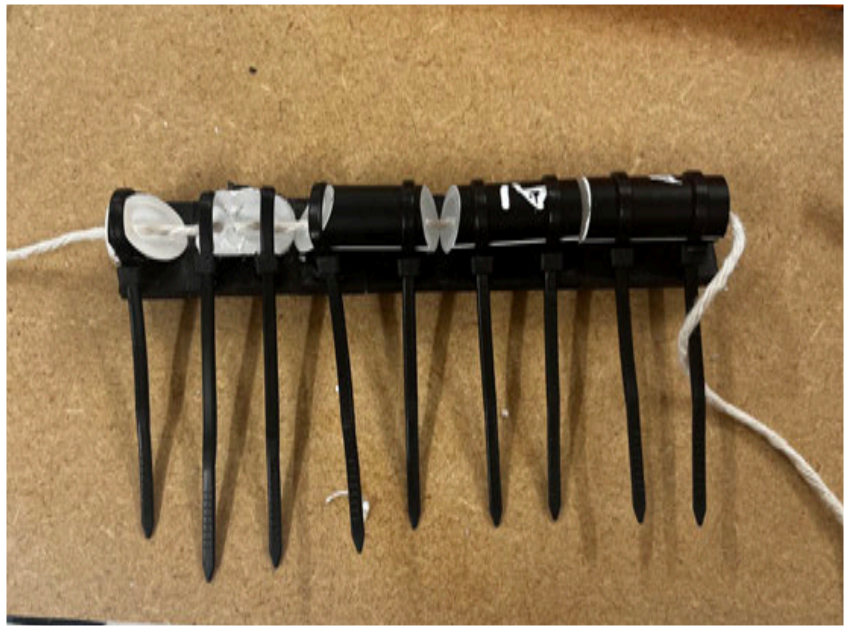


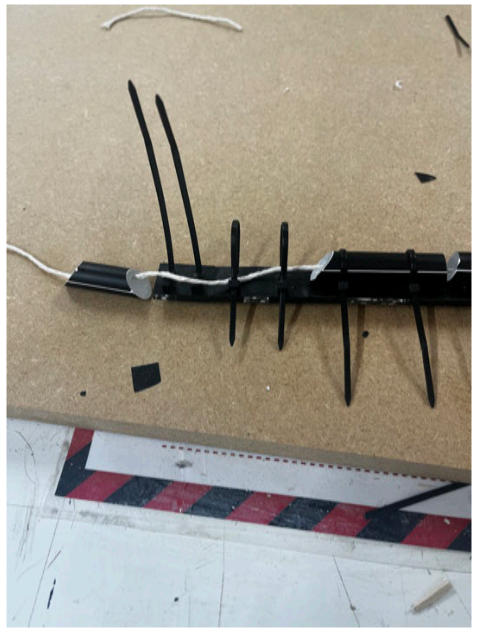


Tension Mechanism

Assembling

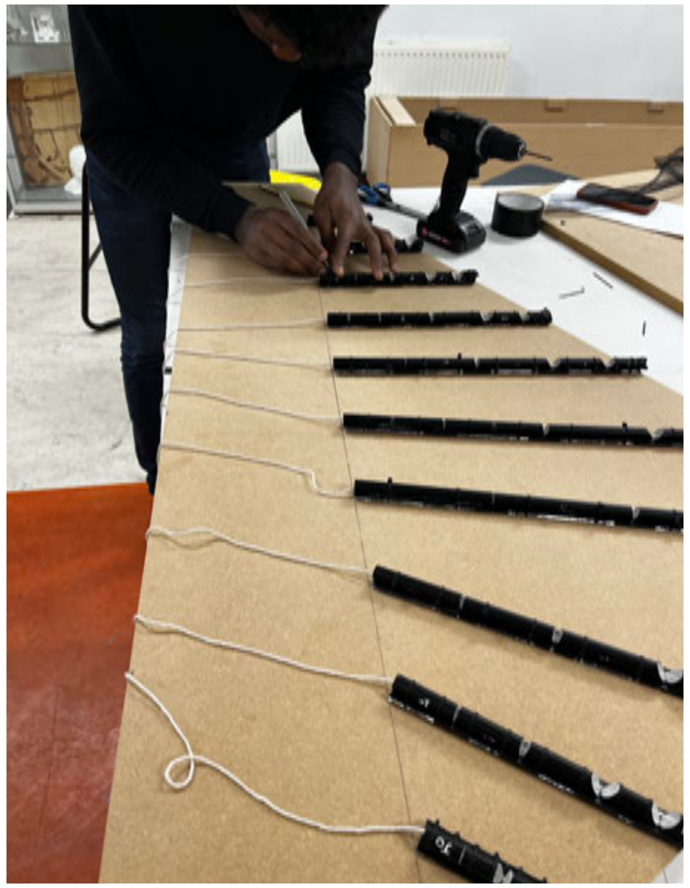
To ensure the correct deployment of each pipe segment, it was crucial to creating a tensioning mechanism that produced a linear force aligned with the axis of the pipes, To avoid any twisting of the hinges. Strings were attached to the end of the pipe groups and fastened with a stopper to prevent the pipes from slipping out, thereby generating resistance and transferring stiffness as the tension increased and as each pipe segment reached its deployment angle.

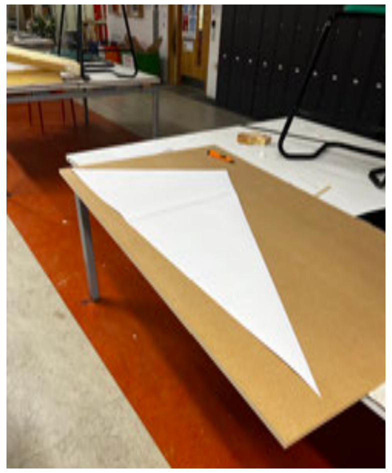


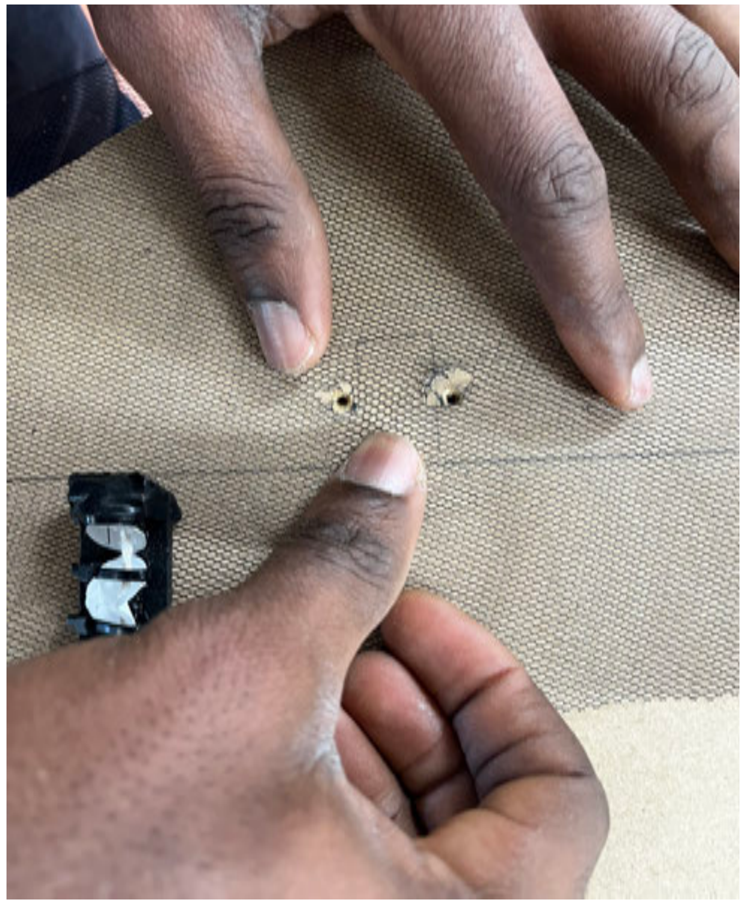


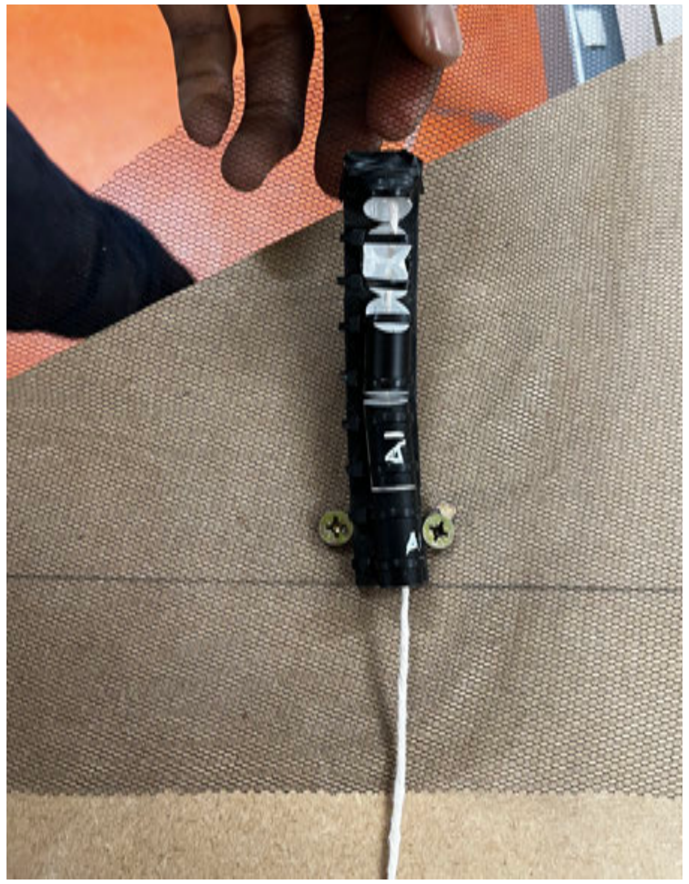
Material attachment

It was important that the material that covered the system be flexible and capable of stretching with minimal resistance during deployment while also reverting to its original shape when not deployed. Following thorough analysis, it was concluded that a tensile fabric material would be most suited for this application. However, a wire mesh was eventually used as it mirrored the qualities of tensile fabric. The triangle's base was also printed to provide a template for cutting the wire mesh material. This allowed for the precise placement of each panel group on the base triangle. These locations were identified. Following that, for each set of panels, the wire mesh material was carefully positioned beneath the panel pieces and fastened with zip ties.



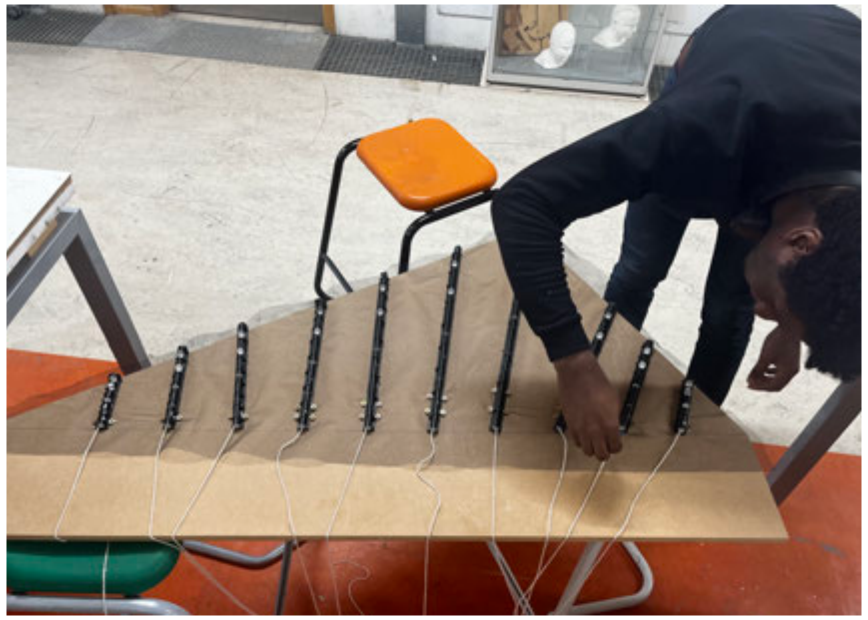


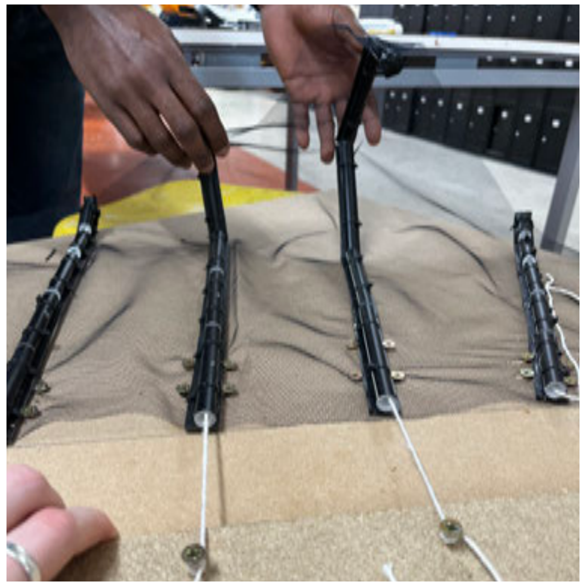




Assembling

To make the pull mechanism work, it was essential to guarantee that equal tension was spread throughout all panel groups. To do this, all of the strings were attached to screws. Each string's tension was established by rotating each panel group to its deployed position. The screw-holding base wood was likewise relocated to the deployed position. The panel groups are then set up in their deployed condition, and the strings are tensioned. Once the tension is established, the base wood may be slid forward to relieve the tension, allowing the panel to return to its undeployed position.





Testing and documenting movement

Assembling

The testing of the system was carried out after assembly, the base wood was moved backwards to increase the tension, and the panels transformed to their deployed state, and upon release, the panels returned to their undeployed state. The outcome was as expected.

Scan To Watch

Testing and documenting movement

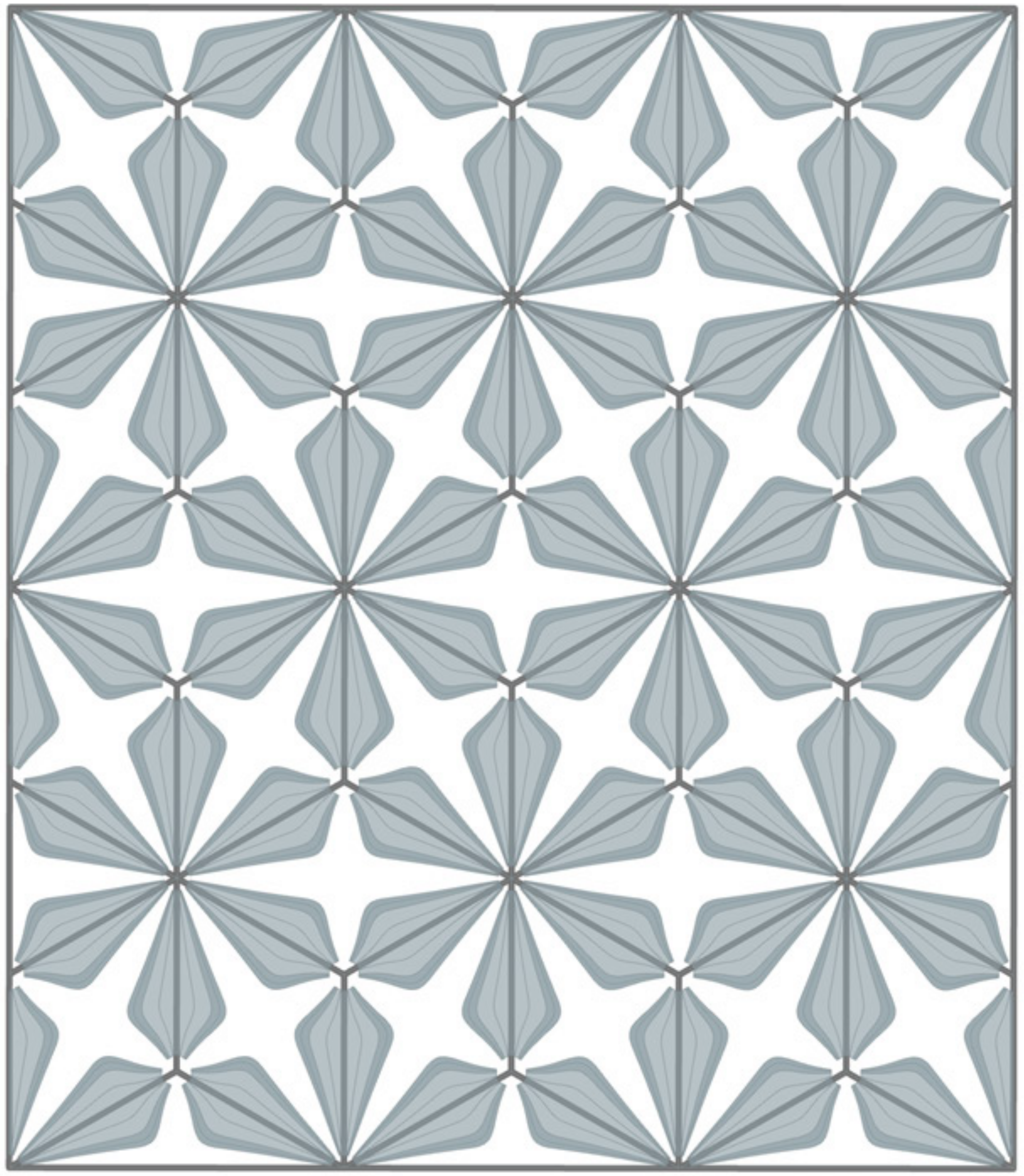
Improvements and Further Development.

The prototype has to be improved in a number of areas in order to increase its functionality. The shutdown of the fabrication facility compelled us to use hand cutting and sanding, which affected the accuracy of the panels and pipe angles. This was a major challenge and led to the misalignment of several of the panels during deployment. Therefore, a better fabrication technique that makes use of CNC cutting or robotic cutting can be taken into consideration to create correct pipe angles, improving accuracy and alignment.

The system's hinges were also discovered to be weak, and the tape applied to stiffen them was insufficient to stop movement of the panels in their lateral position. To increase the efficacy of hinges, it will be necessary to investigate different materials that are both flexible and strong.

The system's scale was a constraint as some of the panels were too small to deploy properly. However, managing the prototype's weight must be balanced with expanding the system's scale. To ensure that the prototype can be deployed effectively.

Lastly, the fabric used in making the pipe can be improved by using materials that are effective in absorbing sound.



Appendix

References

[1] A. Kotliarskyi (2017), people doing office work, available at: https://unsplash.com/photos/QBpZGqEMsKg

[2] L. Badarnah (2023), available at: https://www.linkedin.com/posts/lidia-badarnah-912a0330_universityofbristol-responsive-buildings-activity-7044714133702725633-VL3F?utm_source=share&utm_medium=member_desktop

[3] A. Lupa (2021), Jade Vine Sketch, available at: https://alinalupu.art/2021/06/30/daily-sketches-20-strongylodon-macrobotrys-jade-vine/

[4] D. Clode (2017), Jade Vine Flower, available at: https://unsplash.com/photos/2kPfHxwb6XY

[5] Nigel Young/Foster + Partners, Canary Wharf Crossrail Station, London, UK, available at: https://seele.com/facades/membrane-tensile-structures

[6] P. Mills-Senn(2019), Fabric's role in revitalizing neglected urban areas, available at : https://fabricarchitecturemag.com/2019/02/01/2810/

[7] Tension Structures(2020) Westfield Galleria in Roseville, available at: https://www.tensionstructures.com/portfolio/roseville/

[8] akaatent(2019), The Importance of PTFE/TEFLON In Modern Shade Tensile Structures, available at: https://akaatent.com/ptfe-teflon tensile-shade-structures/