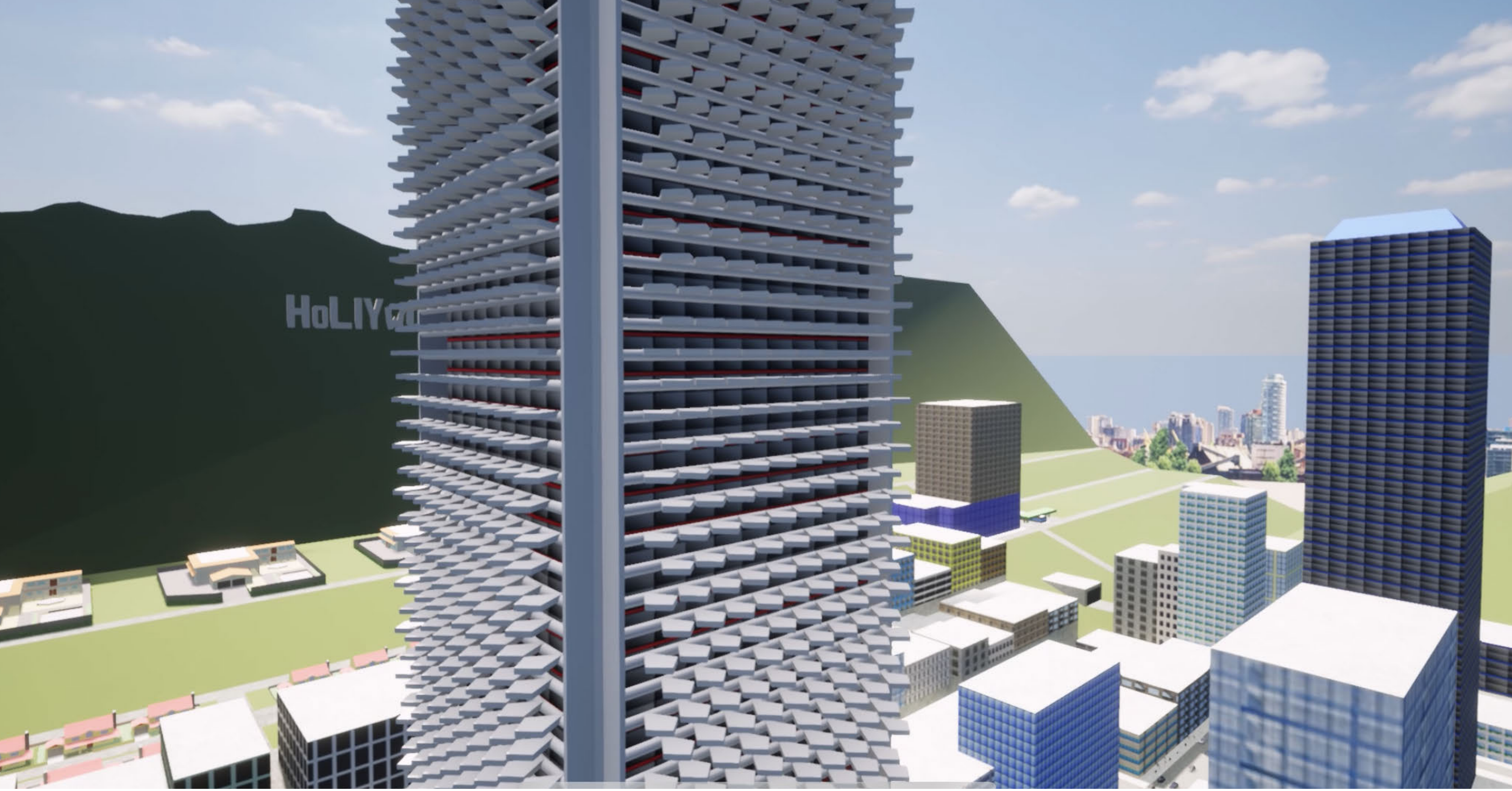

THE PINE RESPONSIVE FACDE SYSTEM

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ADEYINKA ADEWOYIN 22043639

CRAFTING SYSTEMS

To regulate internal temperatures with sensors inside the building to help achieve desired thermal comfort. Each area of the building will have its own internal sensors which link with the external facade, once the sensor has surpassed the limit of the desired internal temperature the facade system will be deployed until it has reached a desired temperature or humidity levels.

PROBLEM

Overheating in internal building causes discomfort to residents and occupants in high rise buildings in urban areas which can lead to serious heath issues over time as well as having a negative impact on the environment using high energy solutions to cool buildings and contributing to urban heat island.

Urban heat island, causes and effects.

Urban heat island is an area within a large metropolitan city which is warmer than its rural surrounding area. Heat energy is generated from people and public transport, and in densely constructed urban areas of high rise buildings along with high activity can concentrate these energy and have a larger impact on the surrounding temperatures.

With the rise in global average temperature increasing every year, the issue of urban heat island is rapidly rising effecting more and more areas, The increase in Solar radiation which passes through the glass in high rise buildings in commercial, residential, hospitality, and other sectors can heat the internal surface temperatures. Heat retained in these surfaces can take a long period of time to release the heat energy stored inside the surfaces, if the surfaces never fully release all the energy stored, the next time they absorb solar energy the temperatures can increase much quicker as the internal temperature of the surface is not as cool as it was before.

The increase in solar radiation has lead to the increase of in temperature leads to overheating in internal high rise buildings causing discomfort to the occupants and residents which over a long period of time can have serious health issues as well as effecting productivity, health, safety and general well-being of a person.

According to the Environmental Protection Agency, the annual air temperature of a city with 1 million people can be 1.8–5.4 degrees Fahrenheit (1–3 degrees Celsius) warmer than its surroundings.]

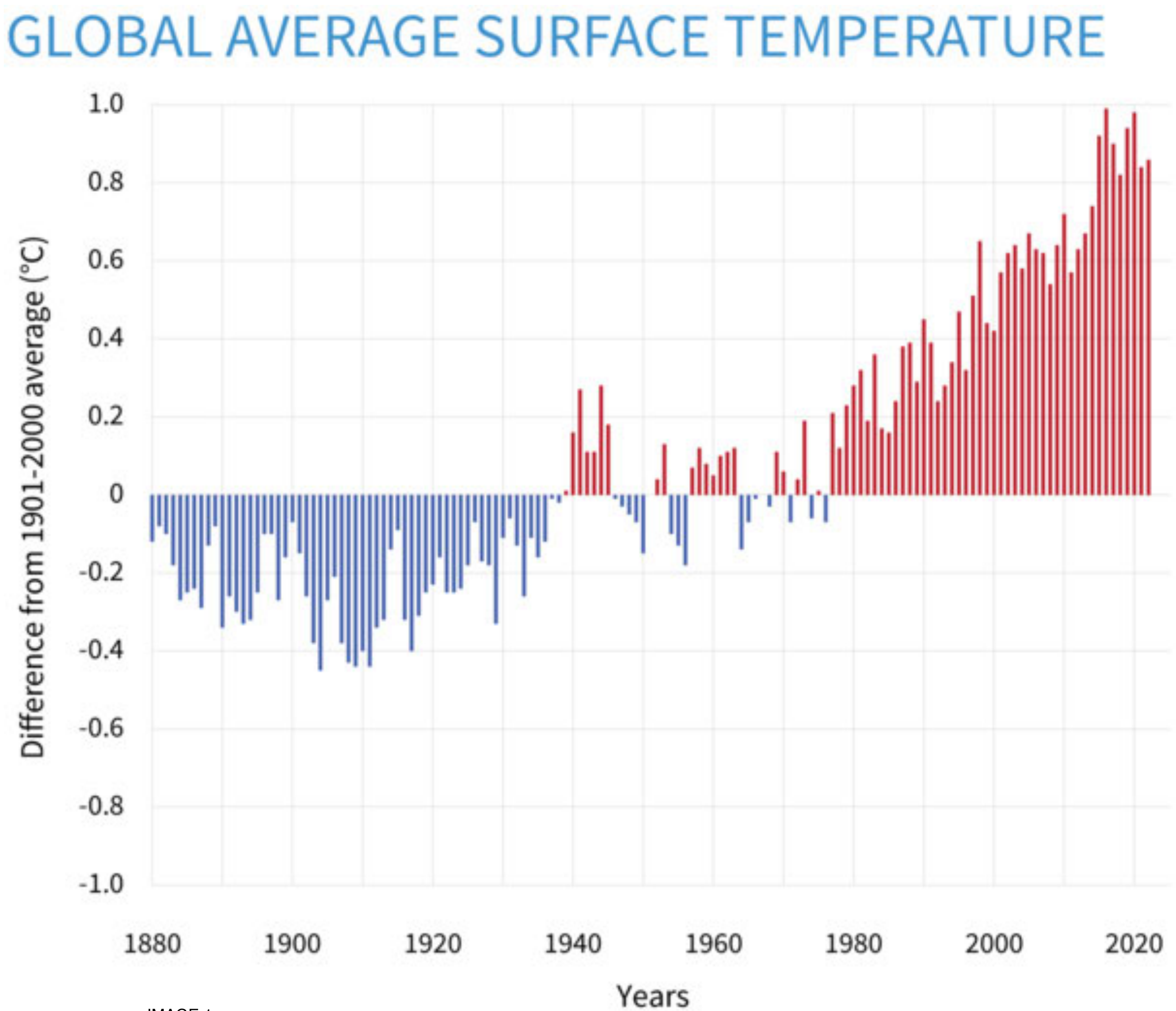


IMAGE 1

Yearly surface temperature compared to the 20th-century average from 1880–2022. Blue bars indicate cooler-than-average years; red bars show warmer-than-average years. NOAA Climate.gov graph, based on data from the National Centers for Environmental Information.

The 2022 surface temperature was 1.55 °F (0.86 °Celsius) warmer than the 20th-century average of 57.0 °F (13.9 °C) and 1.90 ˚F (1.06 ˚C) warmer than the pre-industrial period (1880-1900). (Lindsey and Dahlman, 2023)

Aims and Function

To develop a system in response to the global energy challenge, by regulating internal building temperature with a dynamic responsive building facade system, inspired by nature.

Current solutions to reduce internal temperature are high in running costs, with the current high costs living crisis which is effecting all sectors, companies aim to reduce costs in multiple ways. The most common practice in industry to cool internal spaces is air conditioning units. Air conditioning units are not environmentally friendly as they contain refrigerant which contribute to greenhouse effect.

A research conducted by the Arizona State University has found that releasing excess heat from air conditioners running during the night resulted in higher outside temperatures, worsening the urban heat island effect and increasing cooling demands. (Arizona State University, 2014)

To regulate internal temperature, sensors inside the building with set temperature will help achieve thermal comfort, increase in solar levels will lead to an increase of internal temperature within areas of the building. Each area of the building will have its own internal sensors which link with the external facade, once the sensor has surpassed the limit of the desired internal temperature the facade system will be deployed until it has reached a desired temperature or humidity levels.

Sensors in each section of the building will trigger the facade system in relation to the internal temperature of the buildings, to regulate thermal comfort there will be set levels of responsiveness of the facade system.

To Minimise there amount of solar radiation into the building

To regulate temperature within the building

To reduce heat loss in low levels of internal thermal comfort, and increase heat loss in high levels of internal thermal discomfort.

To reduce energy costs within the building

To reduce the effects of Urban Heat Island.

- Interpret form-finding and pattern language into the conception, design development, validation, and communication of an innovative design.

- Design an algorithm that demonstrates a critical understanding of the theoretical knowledge required to integrate into computational and fabrication methods systematically.

- Identify a research question relevant to a critical computational urban design theory and carry out a small-scale enquiry-based project in response to a given brief.

- Reflect critically upon ethical issues and identify an enquiry-based exploration for relevant computational and fabrication methods into architectural system design research and practice.

- Explore and communicate key theoretical concepts, computational processes, simulation, and rapid prototyping methods to generate and validate an architectural system proposal.

Los Angeles

Los Angeles was selected for this project due to the location having one of the worst urban heat island in California.

A UCLA study predicts that by 2050 the number of days with temperatures of 95F (35C) or hotter will reach 22 a year – more than double the number that the Los Angeles region sees now. (Center for Climate Science, 2016)

LA has a multitude of existing projects which all battles the effects of rising temperatures, from cooling down roofs and cooling down pavements.

A study from the LA County found that 67% of the population are vulnerable to extreme heat. (LA County Climate, 2021)

Exposure to extended periods of high temperature can cause a range of direct and indirect health impacts in addition to discomfort. In turn, these can have knock-on consequences on wellbeing and workplace productivity.Some factors heat can have an effect is Heat Stress, Maternal Stress, Mental Stress, and injury & accidents. For the most vulnerable people, high temperatures can lead to death. (Climate Change Committee, 2022)

A study focused on the US found that average productivity in the US on individual days declines roughly 1.7% for each 1°C (1.8°F) increase in daily average temperature above 15°C. Another study has found that in a typical year, annual heat-related losses amount to more than 0.5% of economic activity in more than half of US counties. (Climate Change Committee, 2022)

Site Location:
Financial District LA, CALIFORNIA

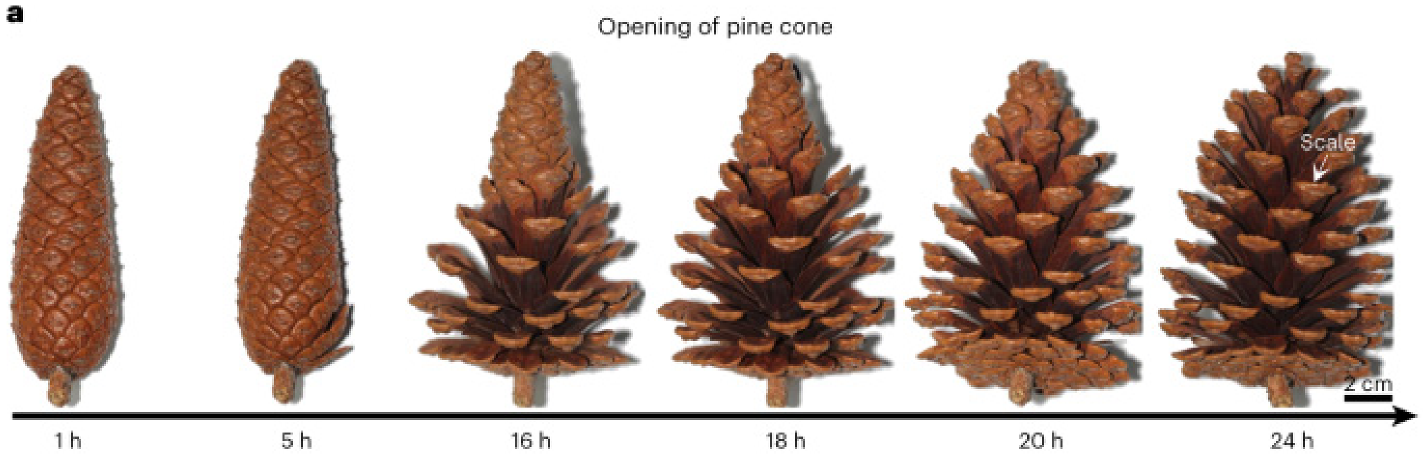
PINECONE

The ability to react to external environmental factors to protect the seeds inside.

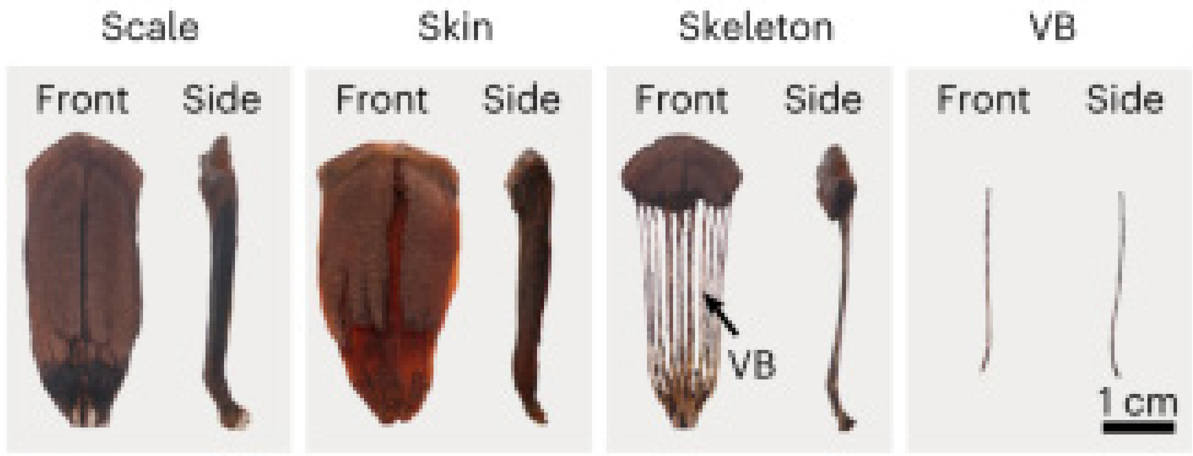
Pinecones have been commonly used to predict the weather; if rain and humidity are in the air, the scales will clamp up overlapping one another and sealing the cone into a tight ball. Opening up when the conditions are dry and windy allowing the seeds to be carried a greater distance.

Pine cone scales have multiple layers with different qualities. The outermost side of the scale (which faces downward when the scales are open) is made of a layer of loosely packed, stretchable cells. The inner layer (facing upward when the scales are open) is made of stiff fibres tightly packed like cables.

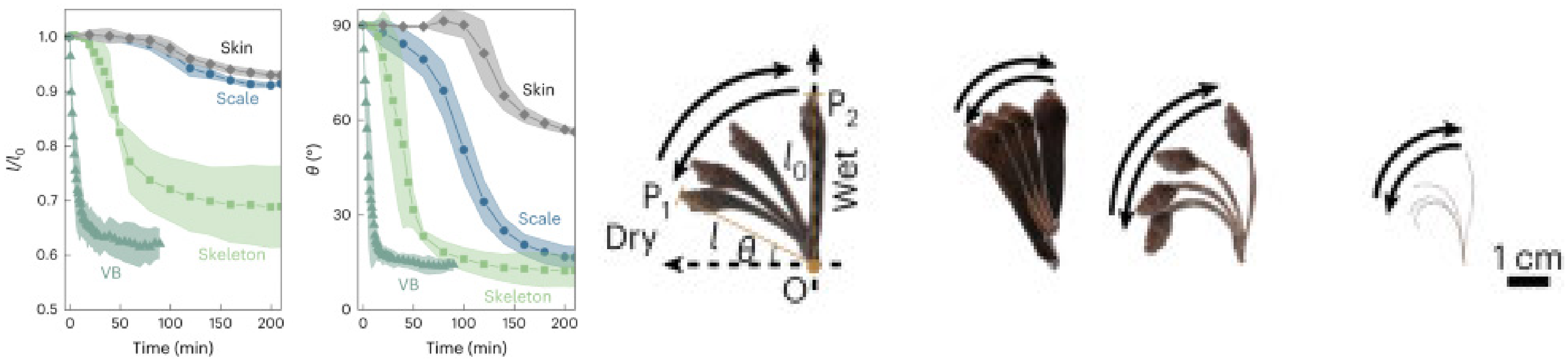
IMAGE 2. Photo by Josh Sorenson: https://www.pexels.com/photo/shallow-focus-photography-of-brown-pinecones-976842/



This shows the overall movement of each of the segments within the pinecone over time.



Front and side views of an individual segment of a pinecone.



This show the movement of an individual segment in relation to time and the levels of humidity inside the cell structure of the individual segment. As there is an increase in humidity/ water levels inside the structure the gaps in between each cell structure fills up it moves in the direction to close the pine cone. When it reaches 20% humidity it can take just 1 % change to trigger the system to close.

High Temp. Outside → High Humidity Inside → Open System Deployed

High Temp. Outside → Low Humidity Inside → Open System Deployed

Low Temp. Outside → High Humidity Inside → Closed System deployed

Low Temp. Outside → Low Humidity Inside → Closed System deployed

https://materialscommunity.springernature.com/posts/unperceivable-motion-mimicking-hygroscopic-geometric-reshaping-of-pine-cones

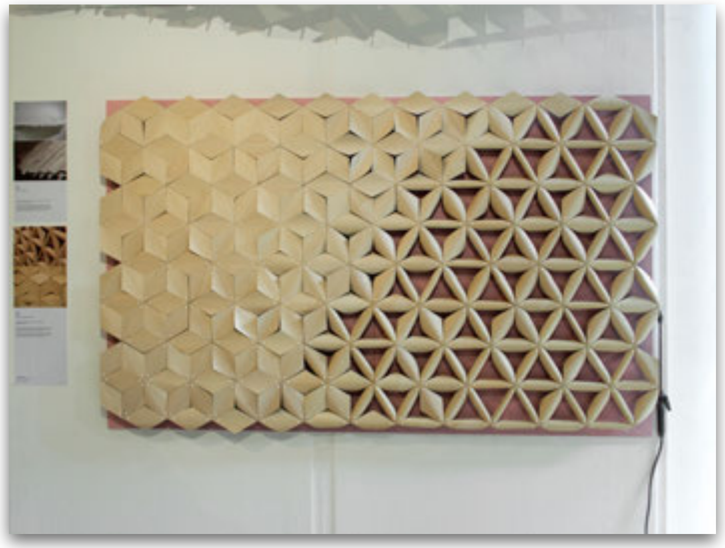
Examples of Similar facade system

Water Reaction, Pinecone-Inspired Material that Reacts to Moisture. (CONCEPT)

A project by Royal College of Art student Chao Chen

Chao Chen studied pinecones and found they were made up of two layers, one which absorbs more water than the other layer. When wet the outer layer expands more than the other layer causing the scale to bend and close.

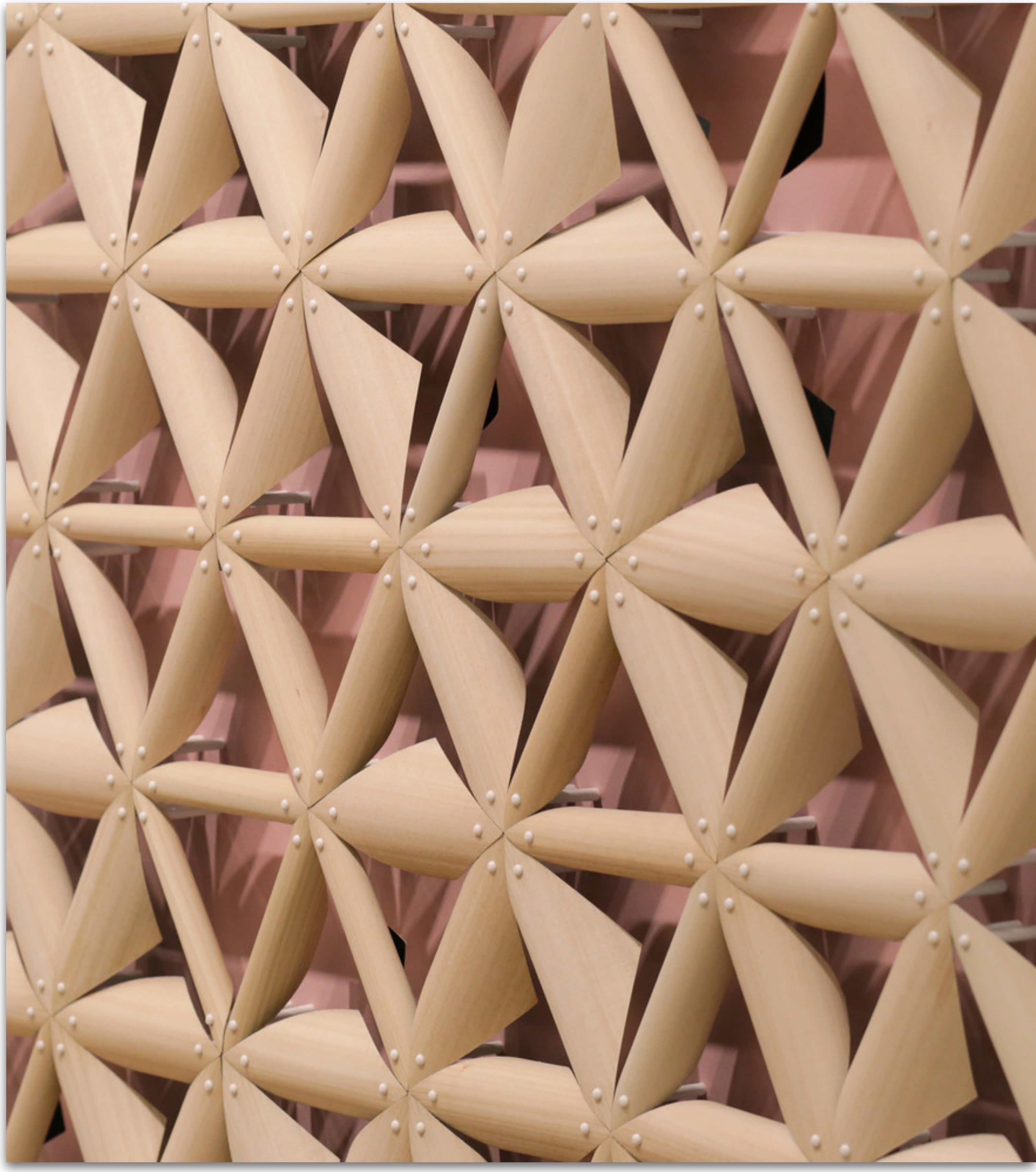
He set to replicate the response to moisture using fabric, thin film and a layer of veneer. By using a porous veneer where the fibres expand across the grain, he created a tile where the outer layer elongates and curves the material away when wet.



He proposes to use this structure for shelters which protects the user from the rain, but when the sun is out the segments curl up creating an opening to allow light inside.

This can be replicated in small structures as well as larger buildings.

The spaces which require more light throughout day, like residential buildings, hospitals can benefit.



https://www.archdaily.com/769820/chao-chens-pinecone-inspired-material-reacts-to-water

Examples of Similar facade system

HYPER MEMBRANE
Cordt Zollfrank, a chemist, forest scientist and materials researcher at the Technical University of Munich (TUM) who came up with the idea of using a vegetal structure that moves without the need of any energy input. Currently, Hypermembrane's structures are just static, but the long-term goal is to develop mobile structures that can adapt to weather conditions just like pinecones.

(Keller, 2018)

ETH ZURICH, Institute for Building Materials has developed an alternative to motor- driven sunshades.

The BiLayered wood, uses 2 layers of wood, just like the 2 layers found inside pinecones, the double layers of wood makes use of changes in humidity throughout the day," explains Vailati. In the humid morning air and at night, the planks are flat and vertical, while at midday, when the sun is high and the air is dryer, they bend noticeably and thus provide shade. *(Keller, 2018)*

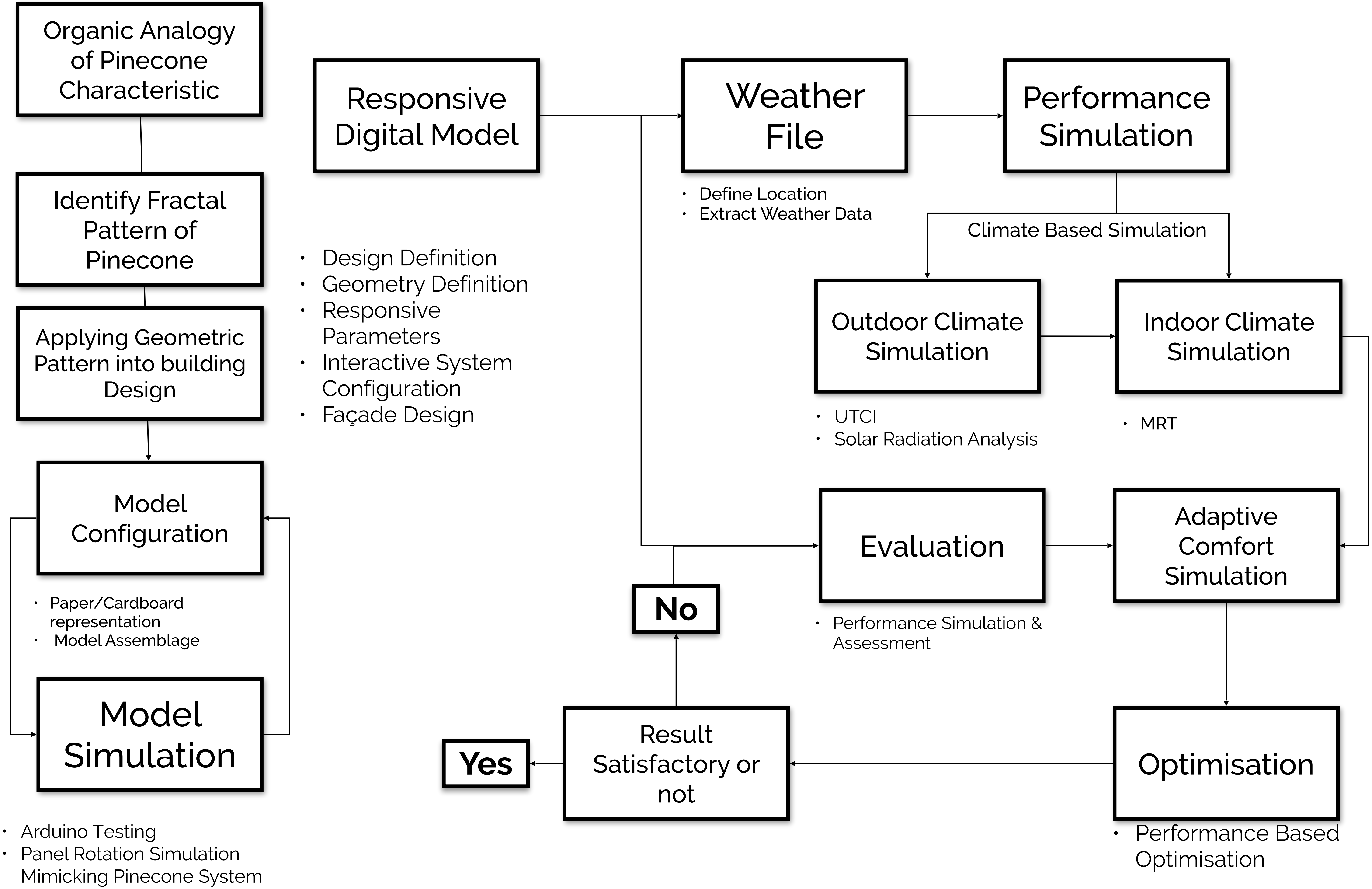
Denmark University Kolding Campus

The campus is fitted with dynamic solar shading, which adjusts to the specific climate conditions and user patterns and provides optimal daylight and a comfortable indoor climate spaces along the façade.

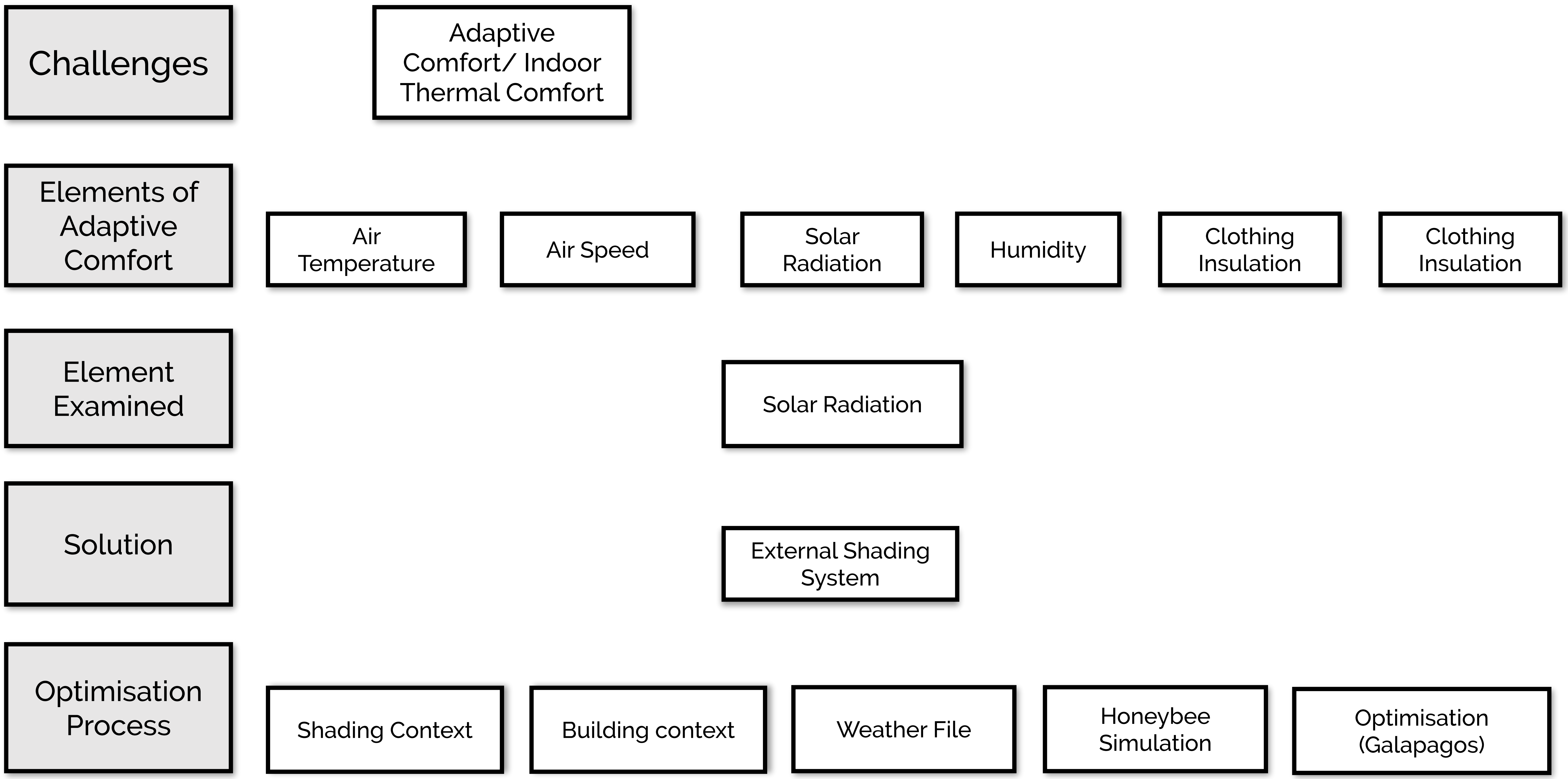
The solar shading system is fitted with sensors which continuously measure light and heat levels and regulate the shutters mechanically by means of a small motor.

(SDU Campus Kolding, 2015)

Workflow Diagram of the Pine Responsive Façade System



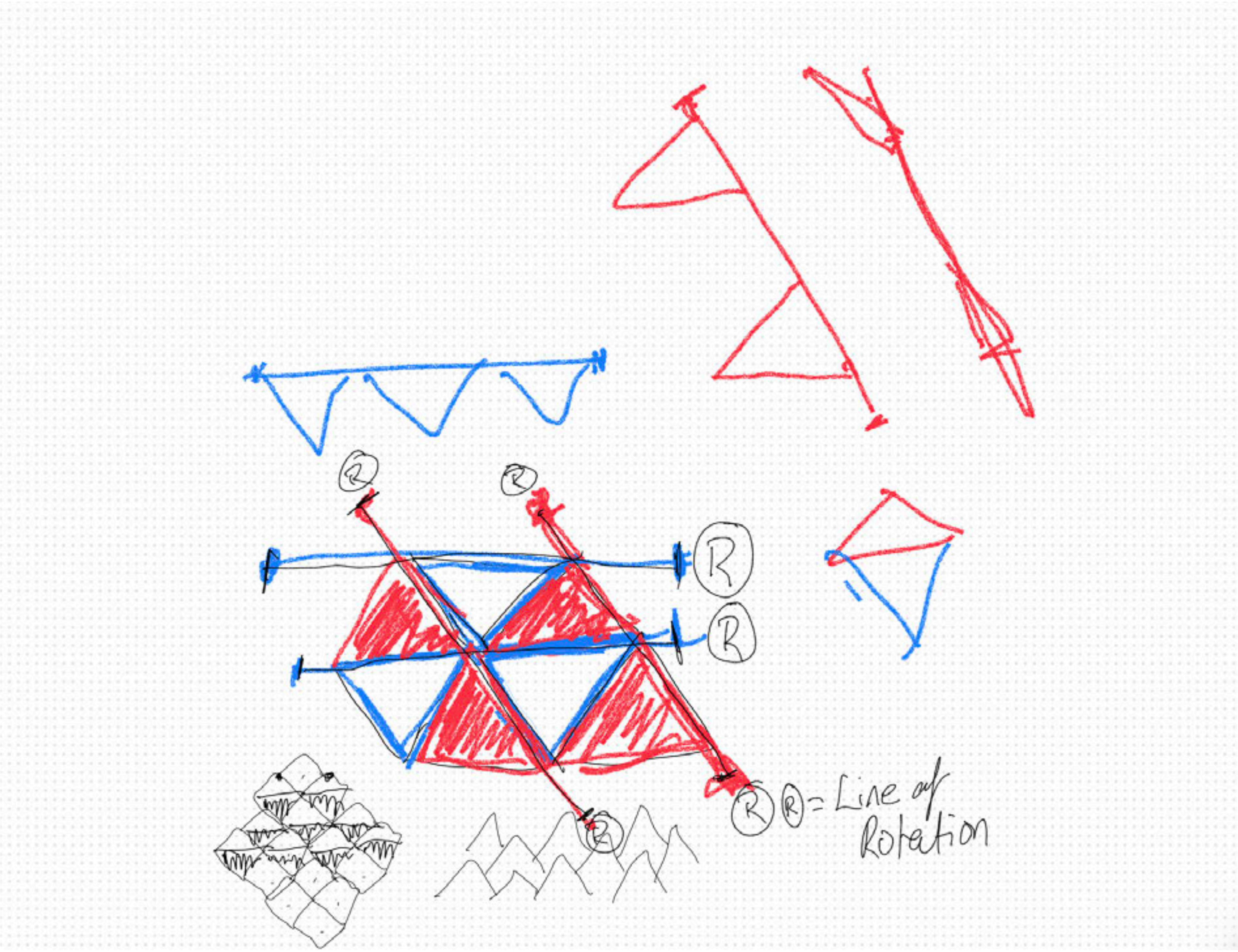
Adaptive Comfort Schedule

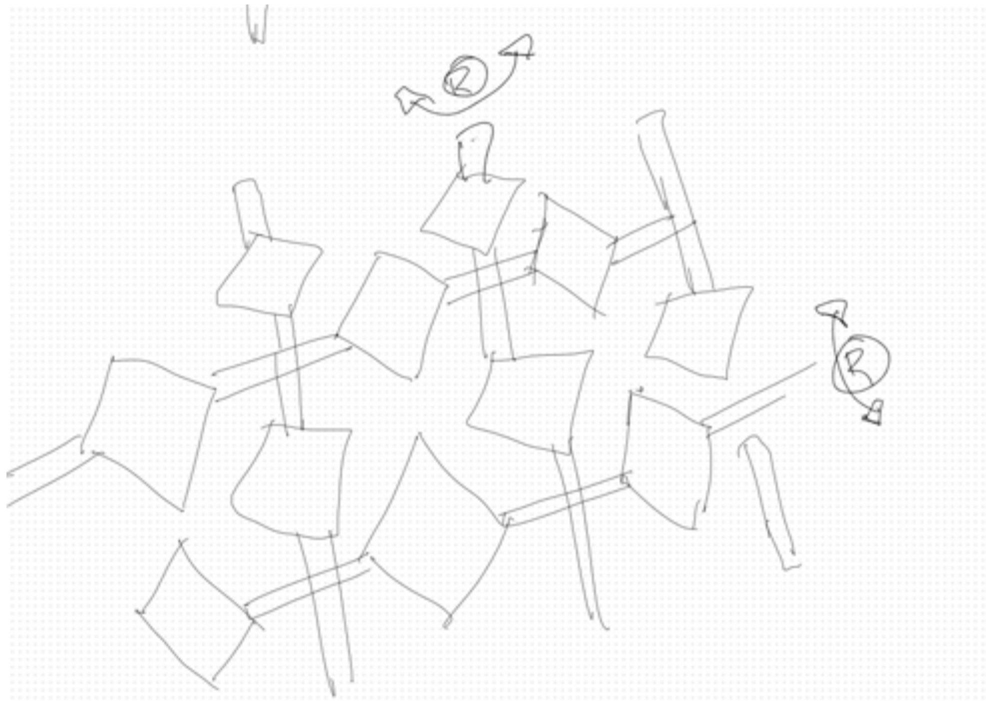


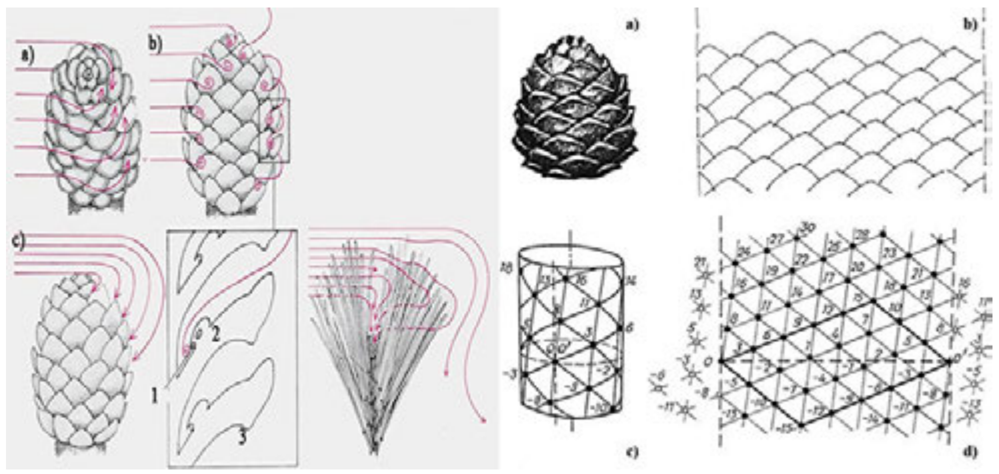
Honeybee/Ladybug Adaptive Comfort Simulation

Defining Geometry for Simulation	Create Building Geometry	Define Geometry by Zone	Assign Zone Geometry in Honeybee	Add Context Surface (Shade)
Honeybee Energy Simulation	Add Weather File	Run Energy Simulation	Read Zone Comfort Metrics	Visualise Result
Ladybug Adaptive Comfort Calculation	Honeybee Mean Radiant Temperature	Outdoor Temperature (Drybulb)	Visualise Result	Percentage of Time Comfortable

Organic Analogy of Pinecone Characteristic





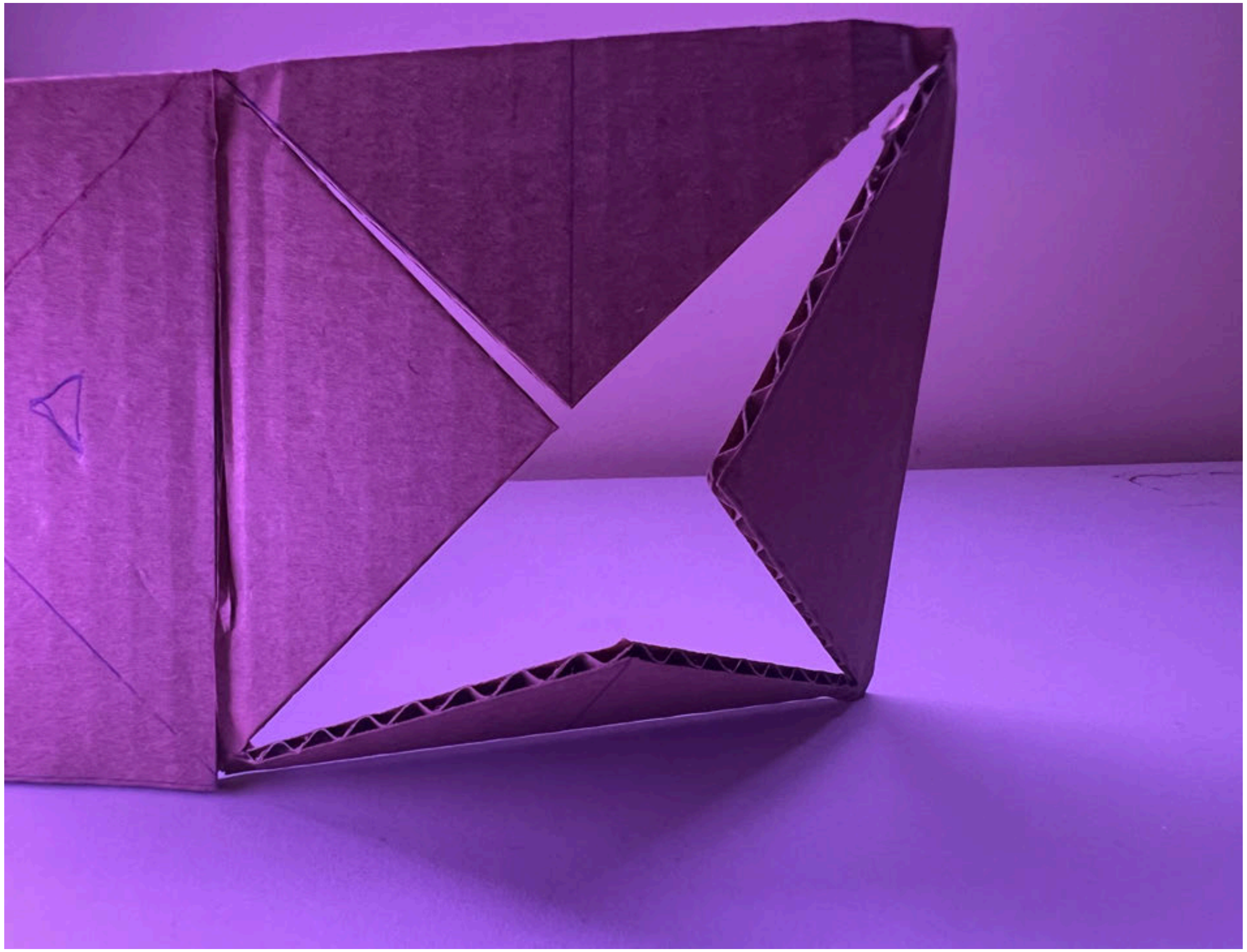


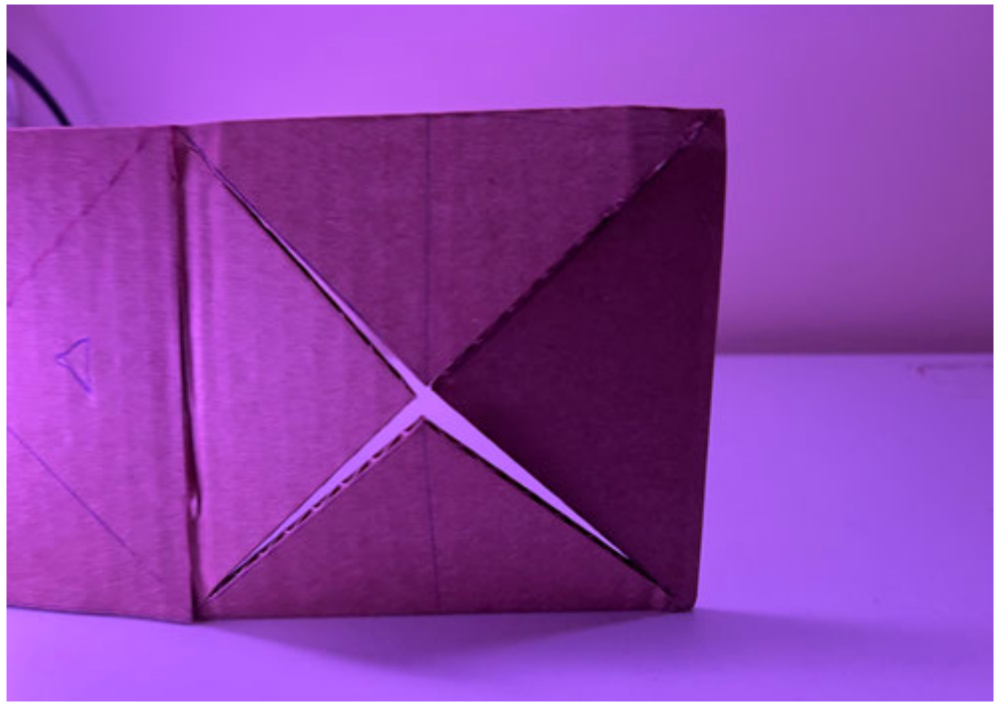
https://wfmmedia.com/biomimicry-inspired-facades-computational-design/

First Steps we did was analysis the shape of the pinecone and break down the shape and decide the geometry of the opening and which parts of the pine cone we would use for the facade, We decided that we didn't want to replicate how the pinecone would open, instead use the response function of the pinecone in relation to its surrounding and use the shape and layering system of the pinecone where it would require the bottom to open first before the top.

DESIGN DEVELOPMENT

Identify Fractal Pattern of Pinecone

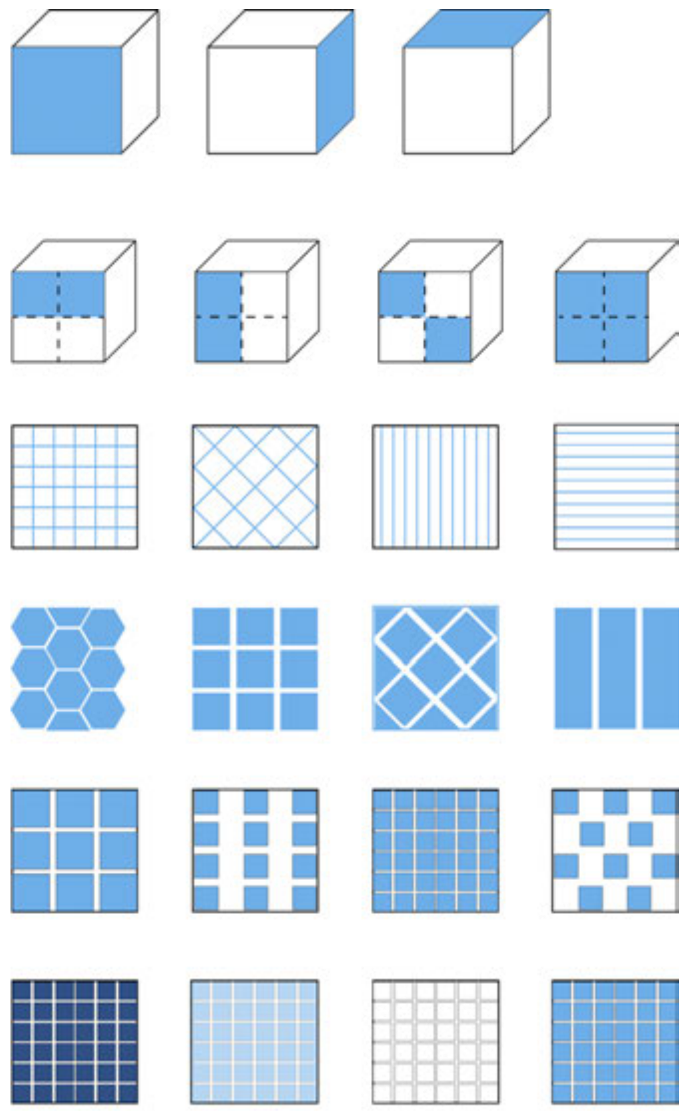




We created a grid structure on cardboard, started creating different openings, and see how the opening of each panel would effect the surrounding panels.
With this design with the 4 segments opening out in all angels in each panel we found that there was gaps on certain angels of opening which would would not be able to create any shade if it was required. This design also did not resemble the pinecone to the specifications which we had set.

DESIGN DEVELOPMENT

Identify Fractal Pattern of Pinecone



Selection of position on the envelope

Selection of position on the selected façade

Selection of support structure (frame, cable, etc.)

Selection of grid size and spacing according to shading / self-shading

Selection of panel size, pattern and shape

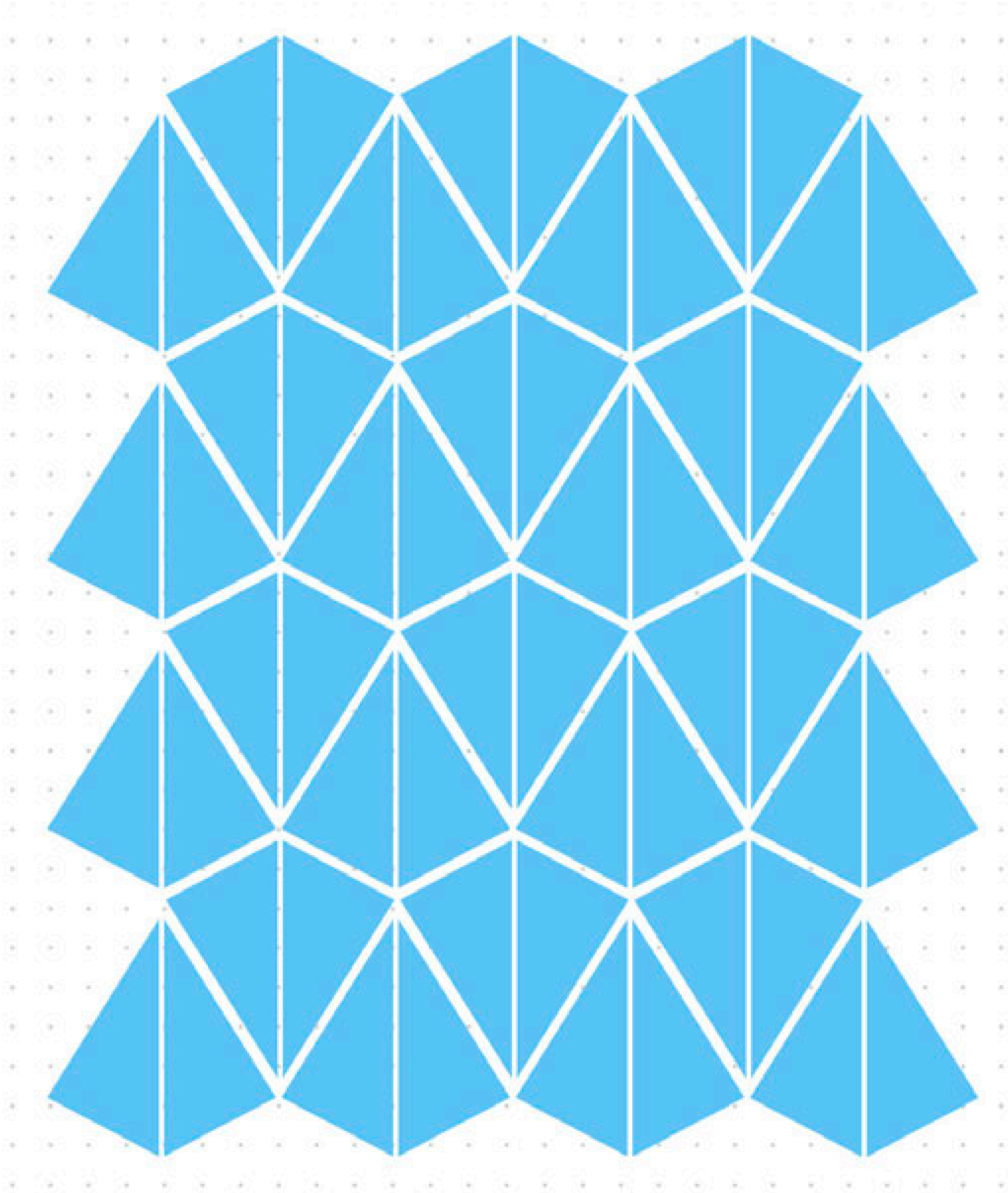
Selection of panel color and transparency

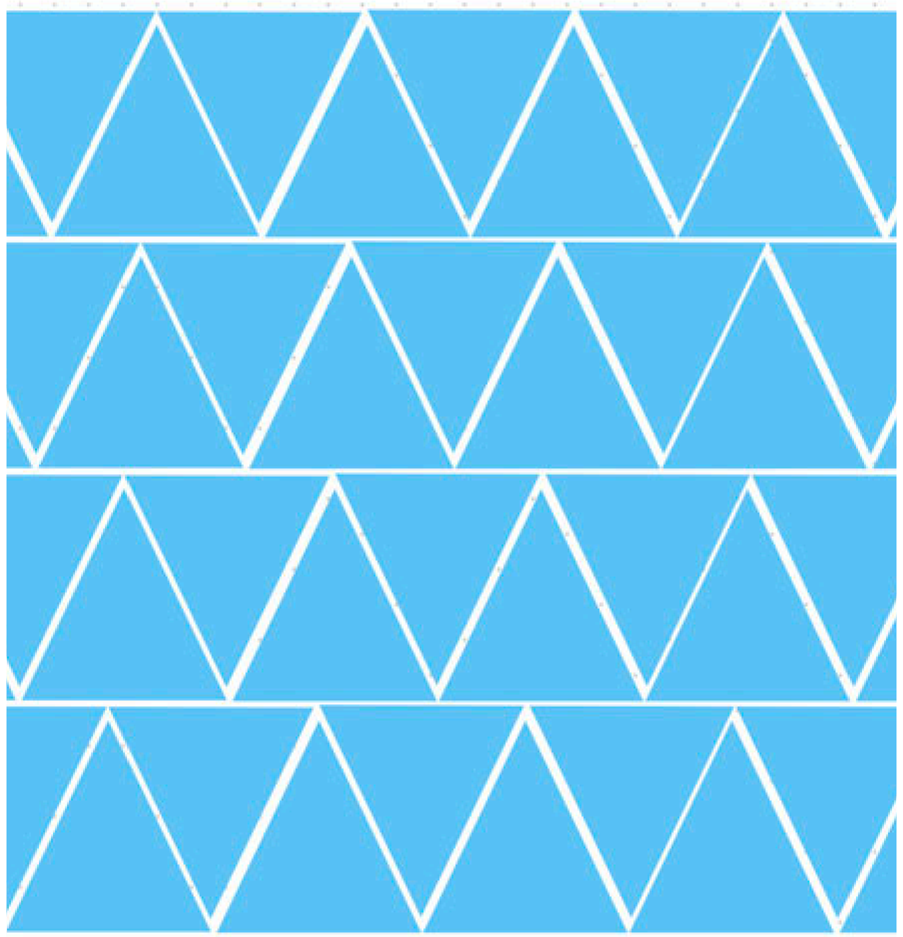
Design process of Adaptive Solar Facade. *(Nagy et al., 2016)*

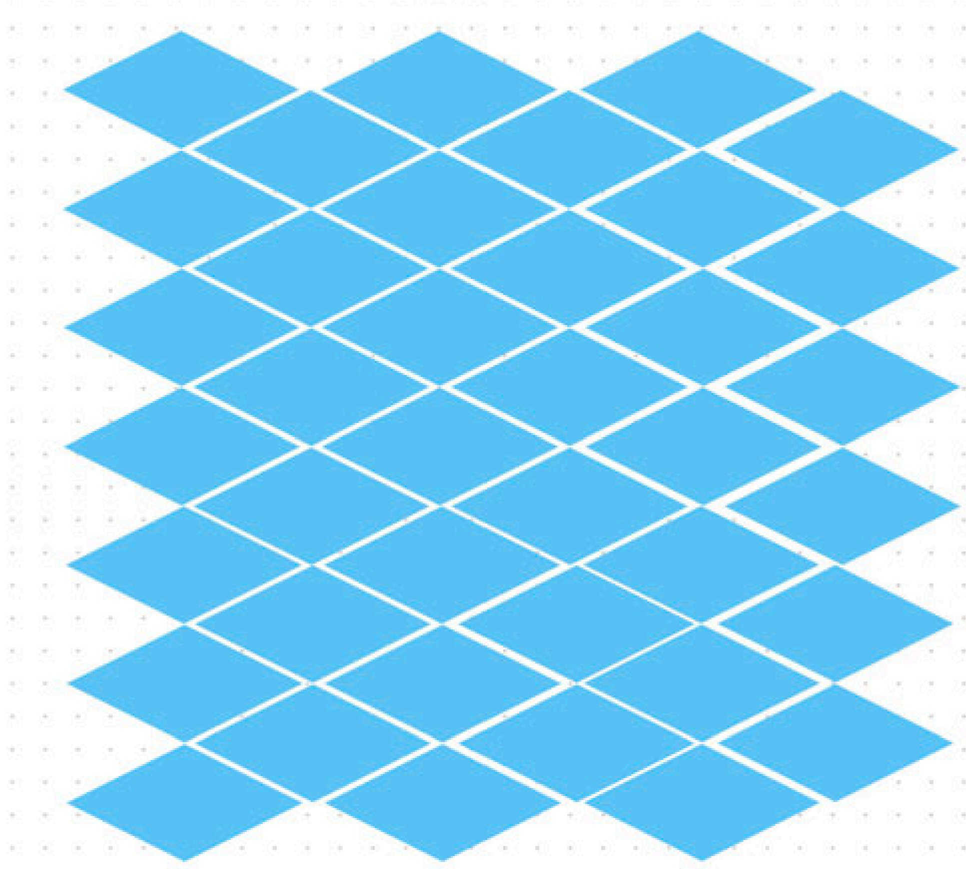
Modules on a building facade, mounted in frames on a cable net structure within the shading layer of the facade. *(Nagy et al., 2016)*

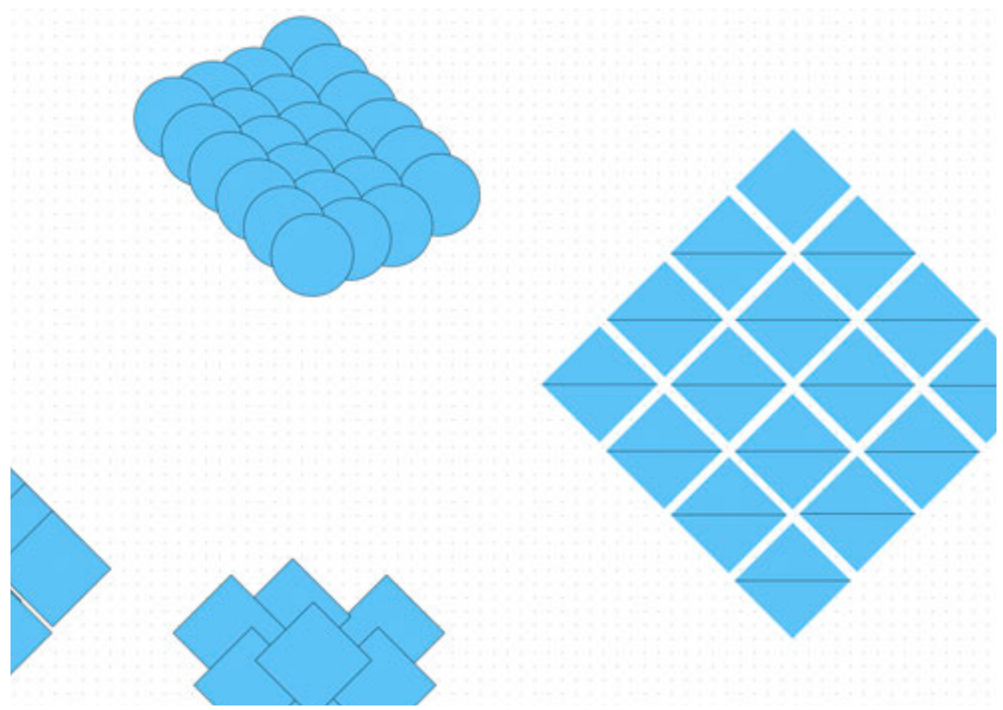
DESIGN DEVELOPMENT

Identify Fractal Pattern of Pinecone



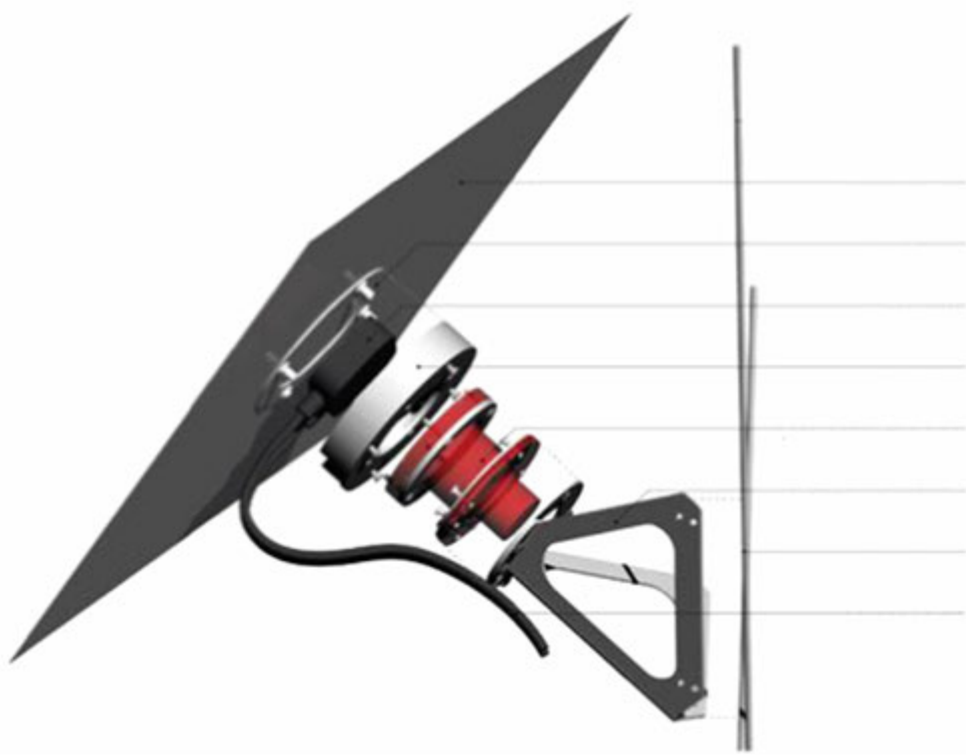






For the design development we carried out a form finding method by creating a digital grid which allowed us to create the shapes a lot quicker, move them around and quickly evaluate each design changes, from shapes, forms and layouts.

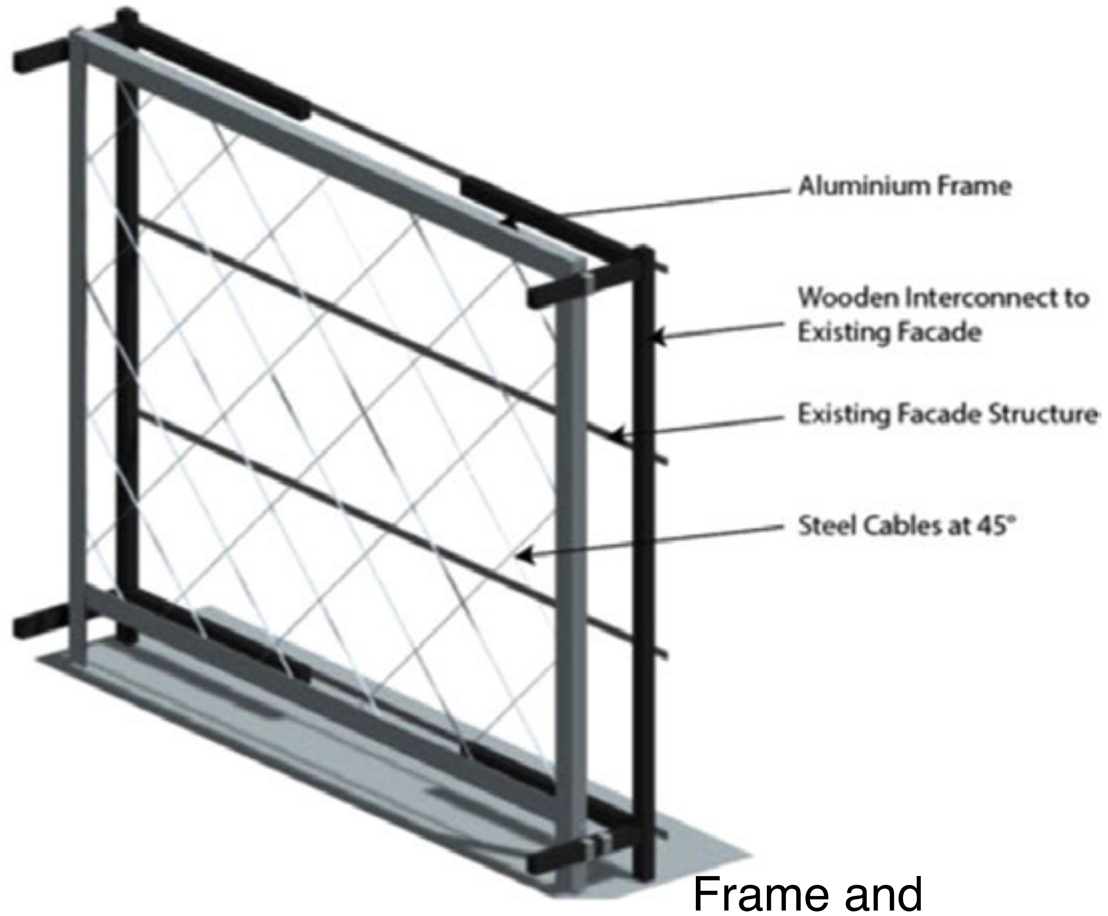
Design Configuration of a Responsive Solar Facade



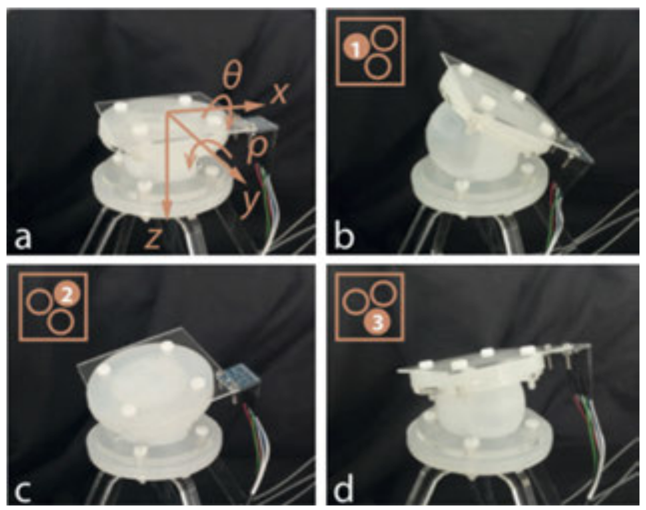
Materials and Assemblage

PHOTOVOLTAIC PANEL
PANEL ADAPTER
JUNCTION BOX
ELECTRONIC SHIELD
SOFT PNEUMATIC ACTUATOR
CANTILEVER
CABLE NET STRUCTURE
PV POWER CABLES

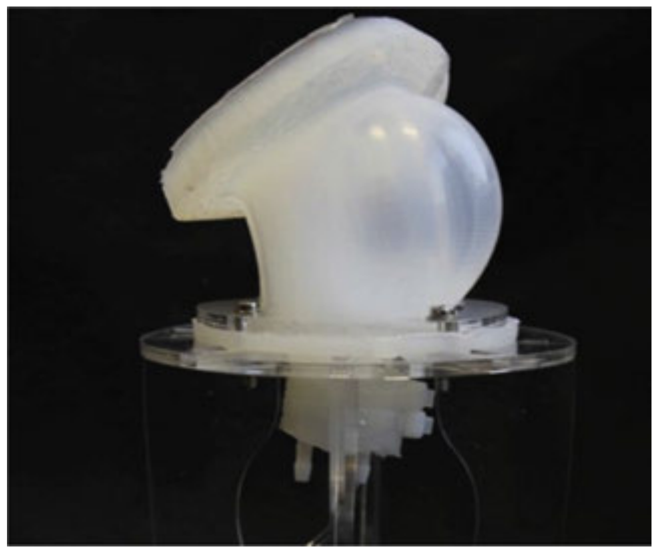
A typical Adaptive Solar Facade module *(Nagy et al., 2016)*



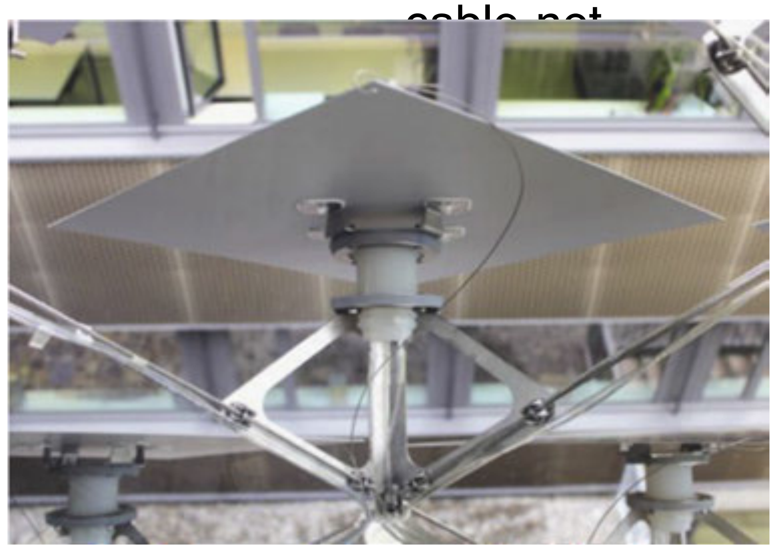
Frame and



Kinematics of an actuator.

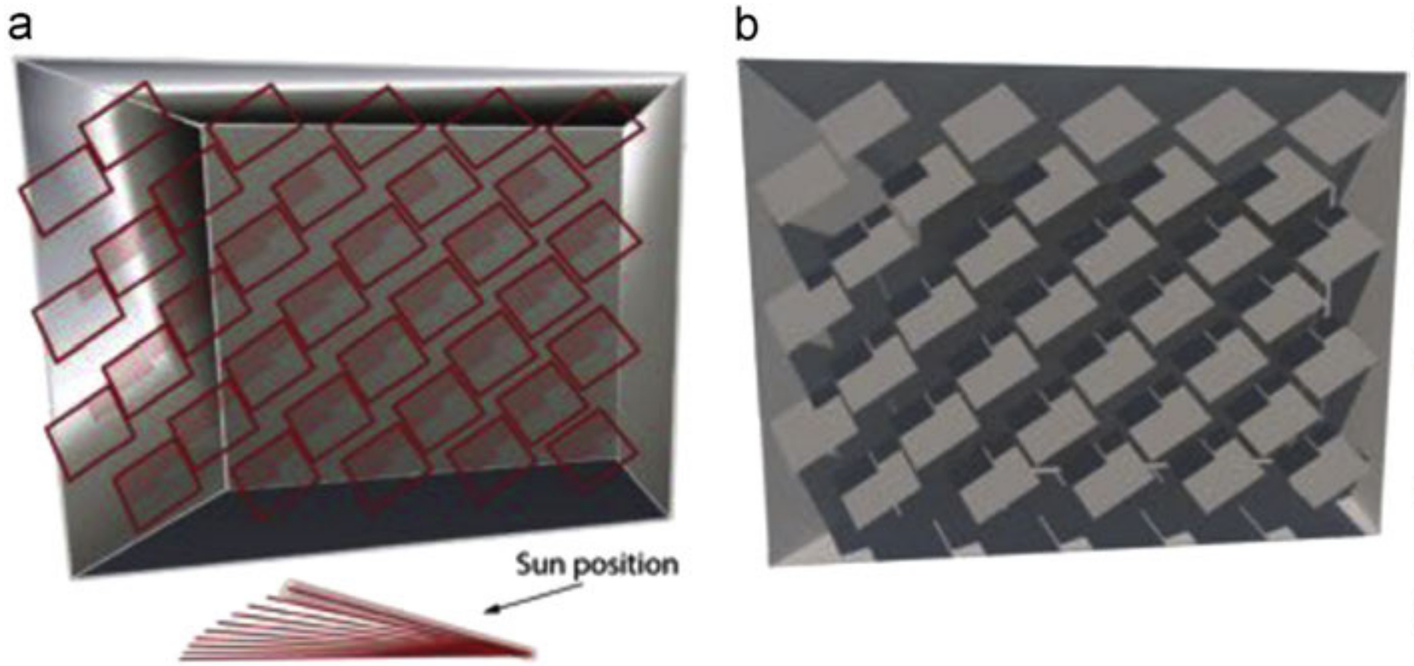


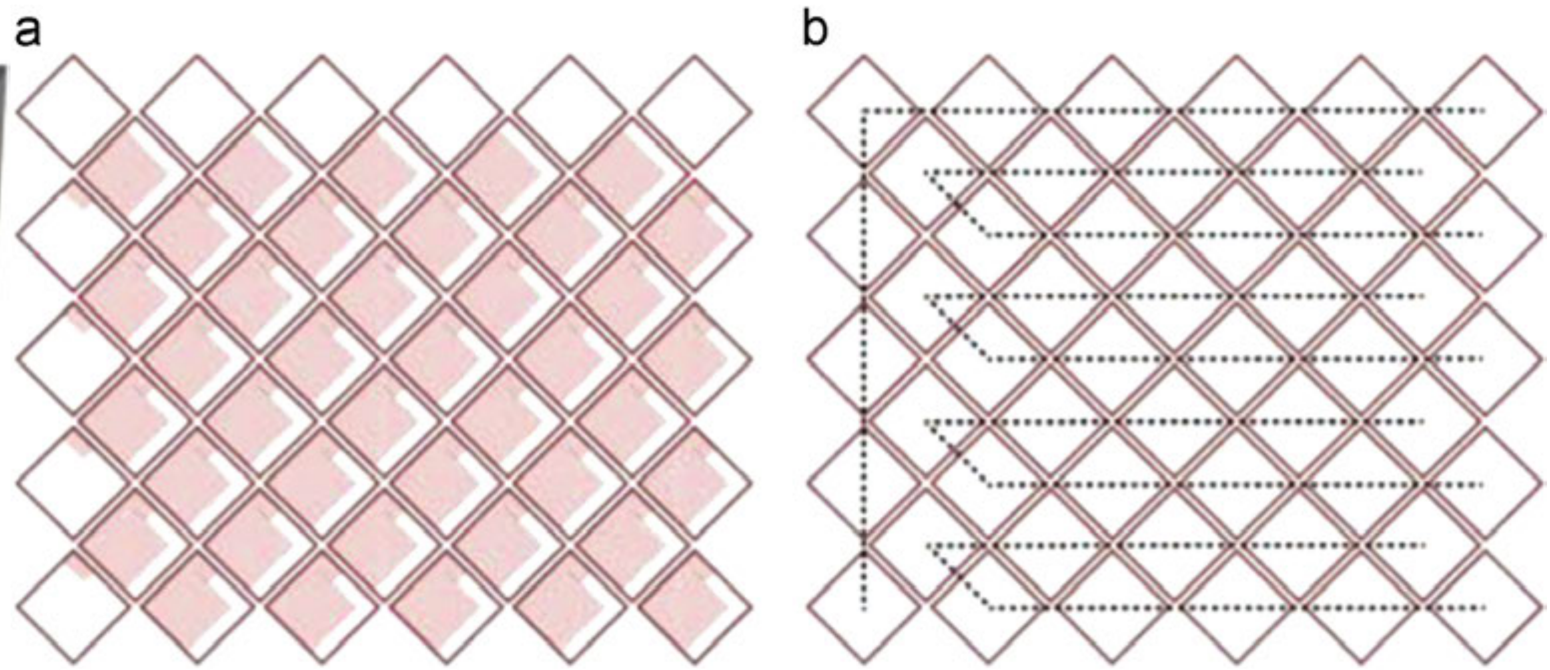
Soft pneumatic actuator bending to different angles under applied pressure Nagy et al., 2016)



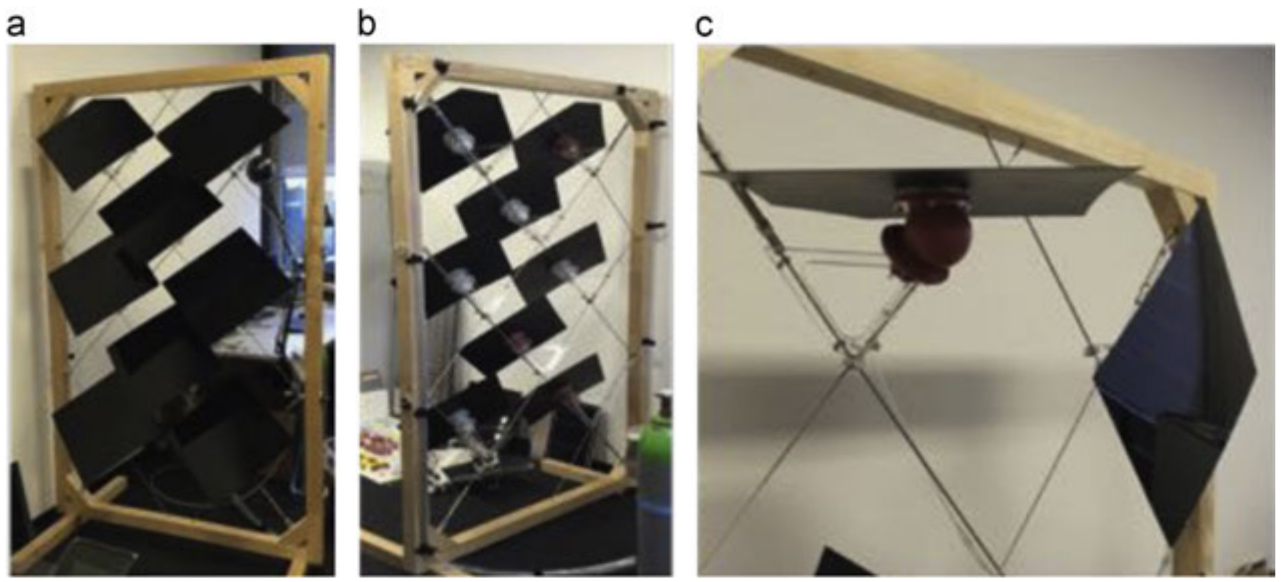
Cantilever design with double bent and laser-cut stainless steel *Nagy et al., 2016)*

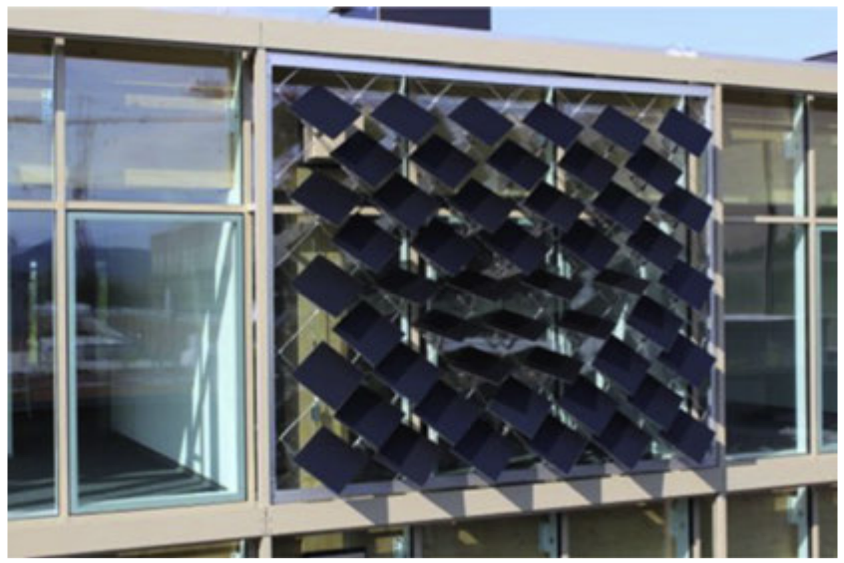
Design Configuration of a Responsive Solar Facade





Module Shading pattern within Rhino/Grasshopper for a specific sun position *(Nagy et al., 2016)*

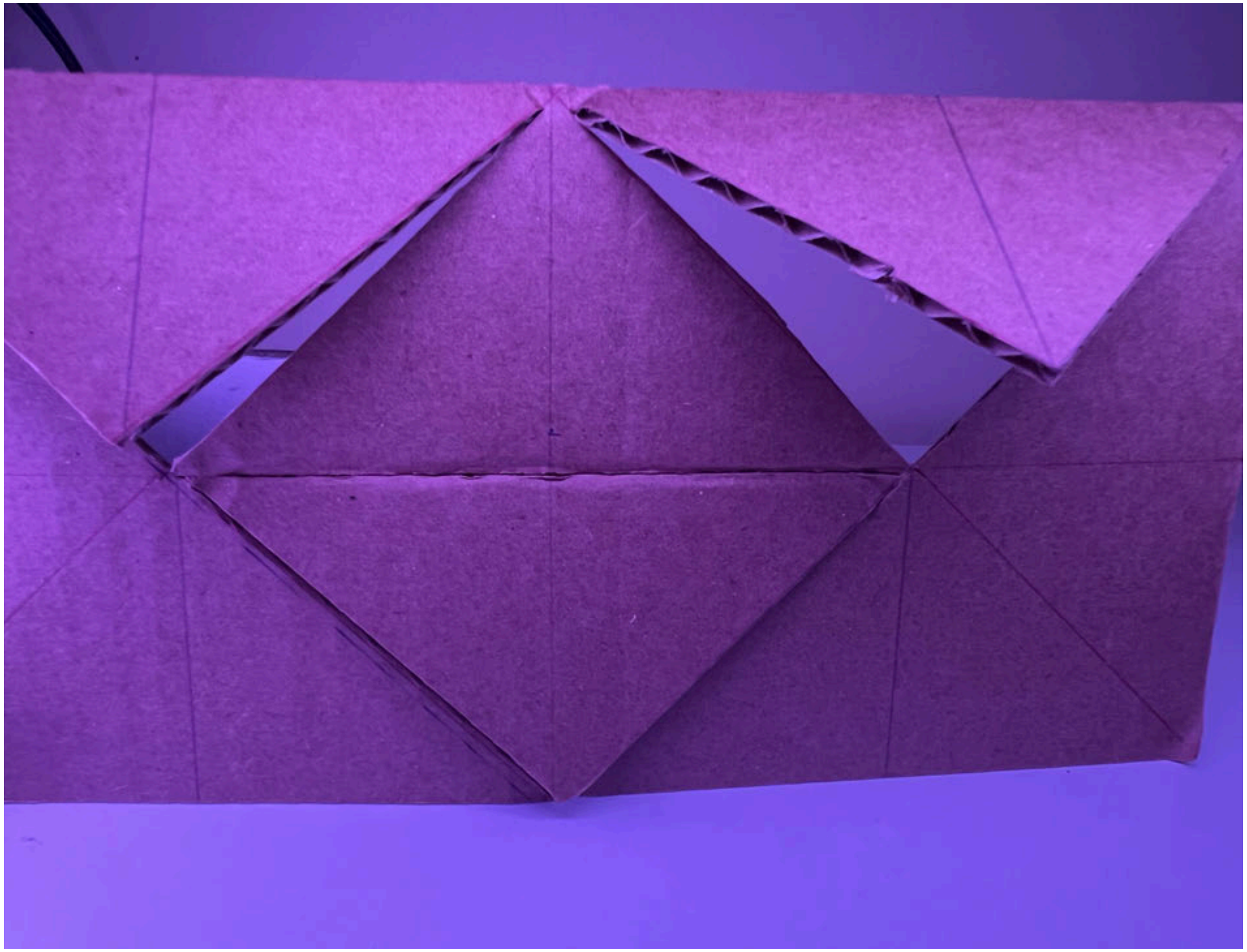


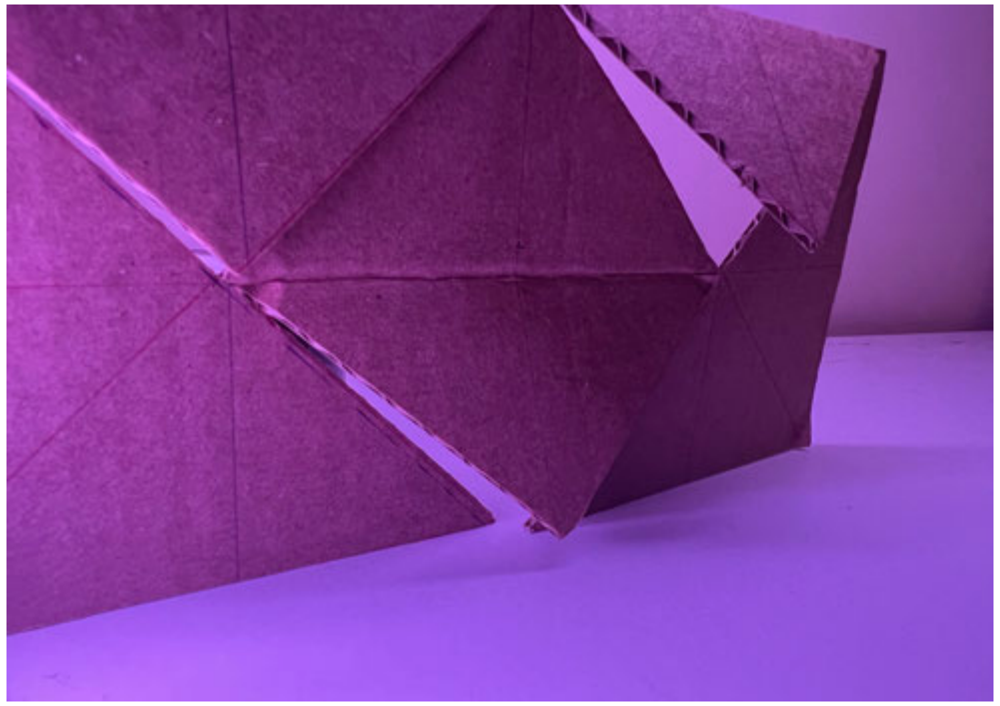


Open and close configurations of panels on a wooden frame with the actuators and cable net. *(Nagy et al., 2016)*

DESIGN DEVELOPMENT

Identify Fractal Pattern of Pinecone

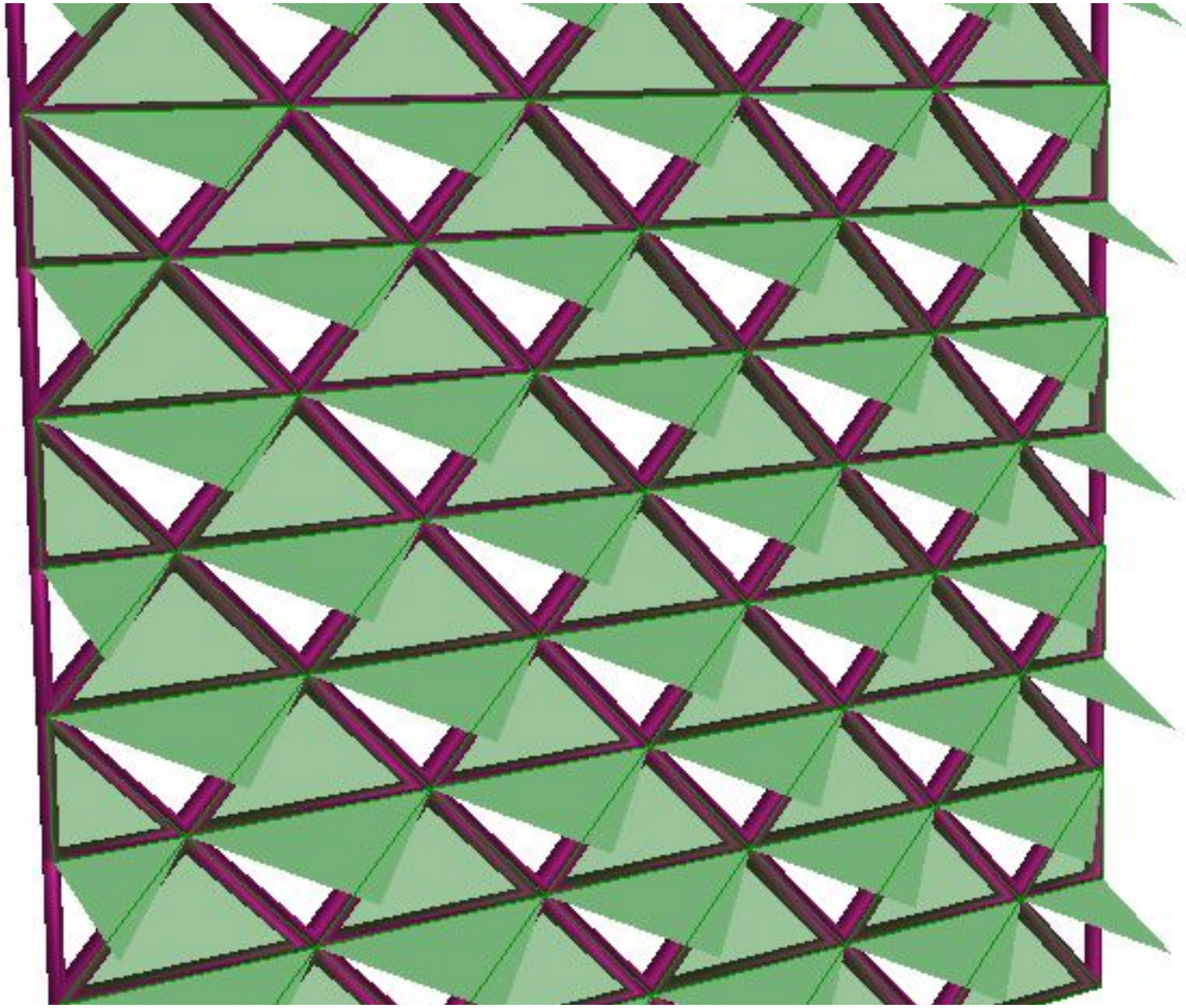


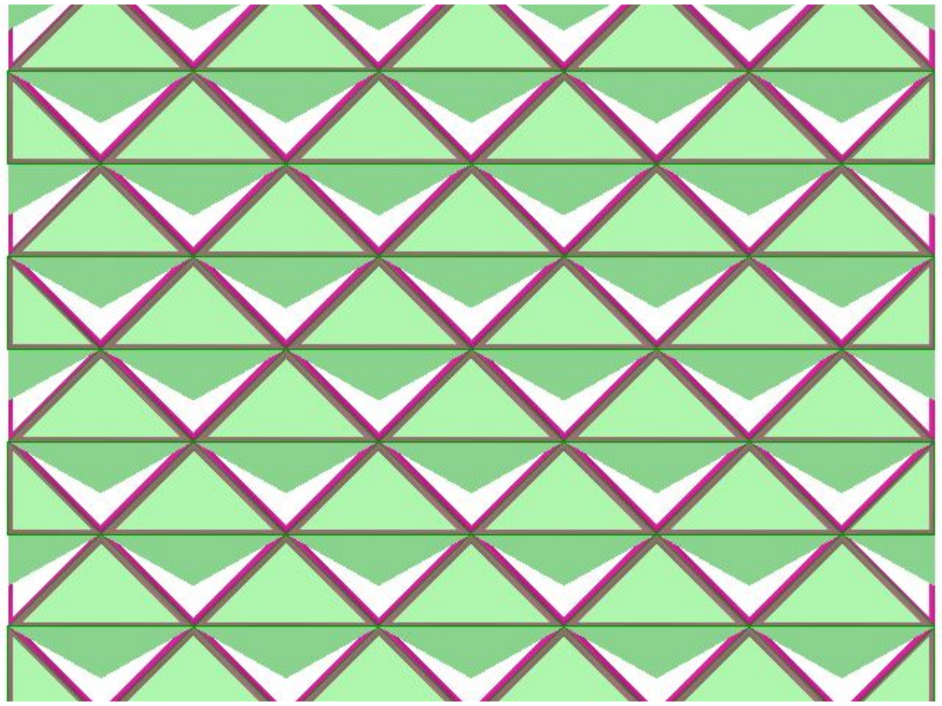


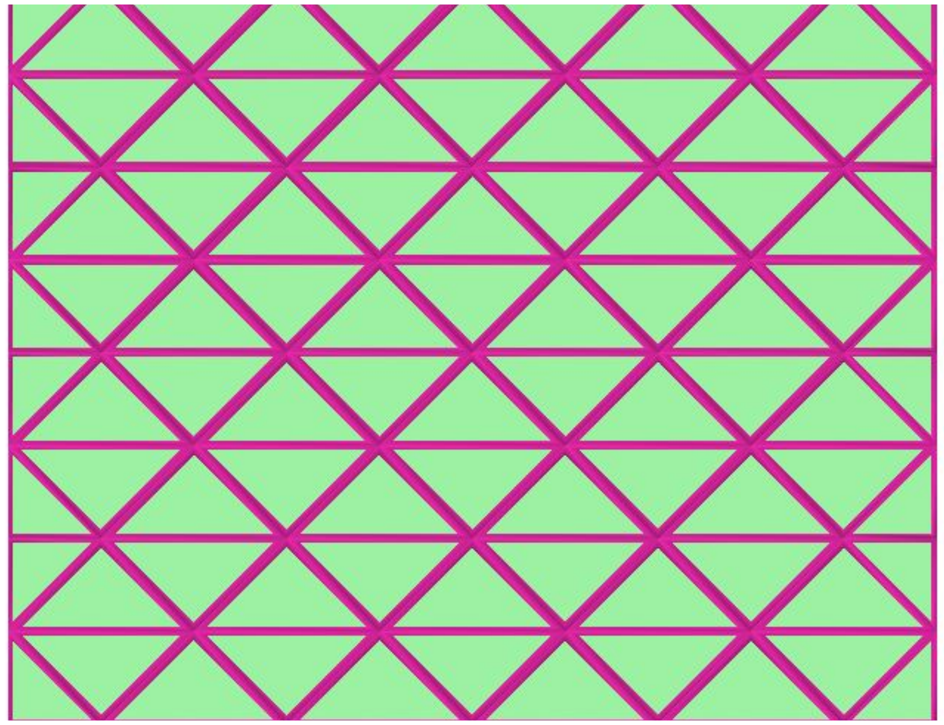
For the next structure we used a Diagrid structure, for the iteration of which segments will open and close. We played around with a few variation of openings before deciding on a finalised structure we were happy with which also fit the specifications of our design brief.

DESIGN DEVELOPMENT

Applying Geometric Pattern into building Design





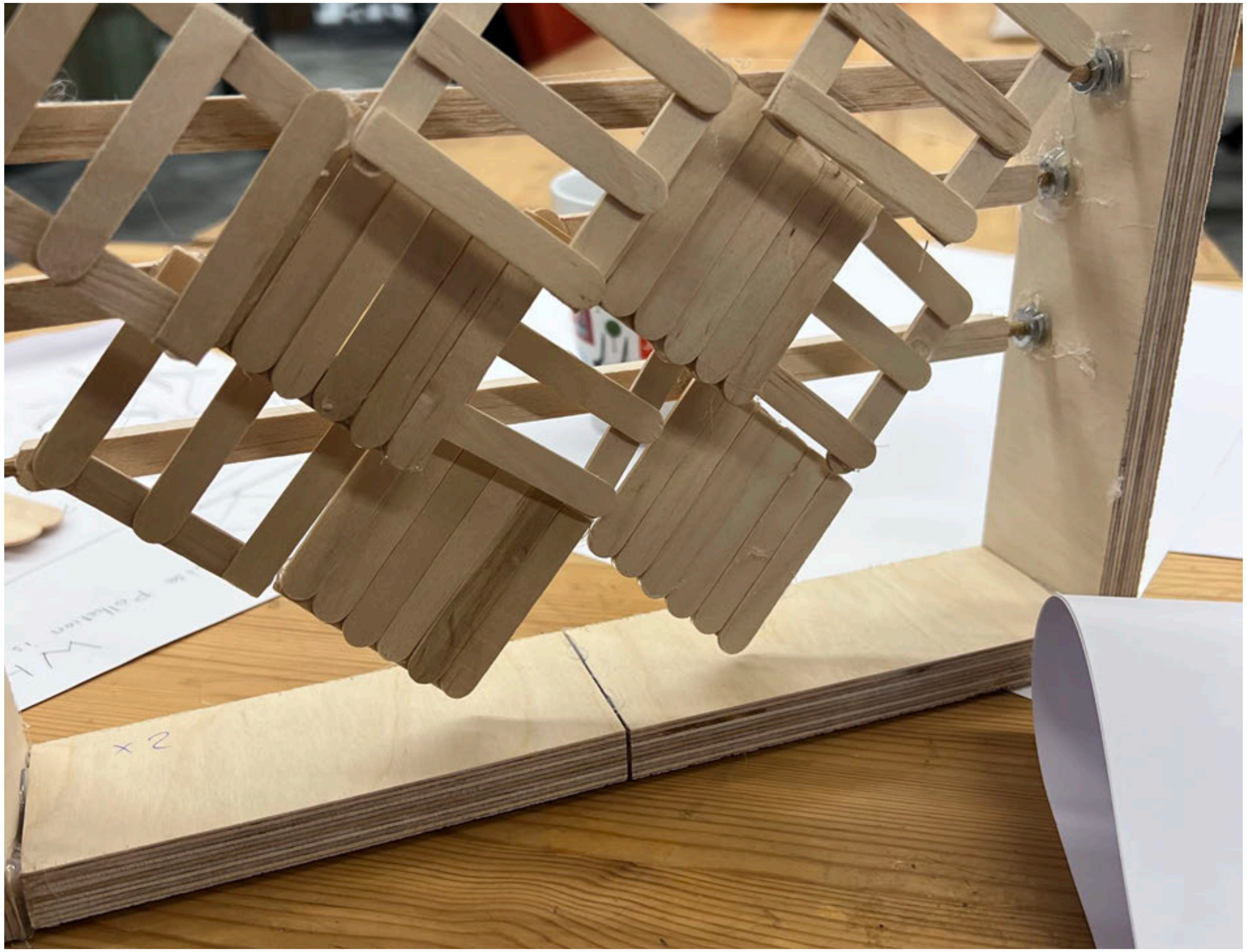


We simulated the structure of our chosen design on grasshopper and Rhino, creating the Diagrid structure, and the openings of each segments in each panel. We identified the rows in which each of the panel would open, and we decided that each individual row in each segment would act independently, depending on users needs.

Things to determine moving forwards:
- Size of the panel
- How the panels would open.
- Purpose of the panels which do not open.

Prototype

Model Configuration



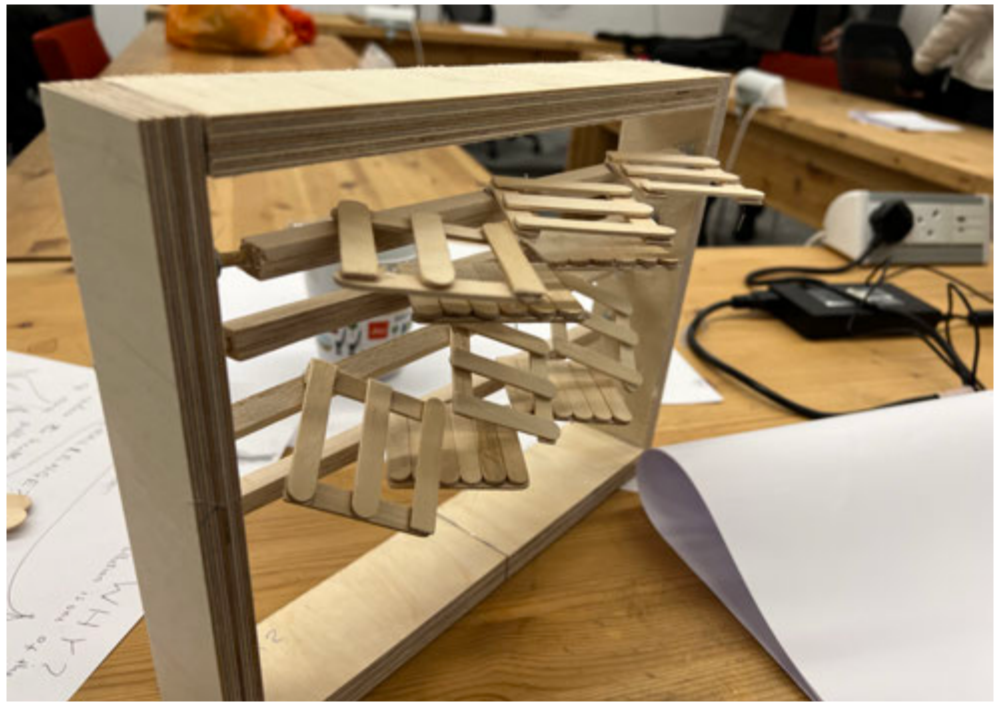
Our first sketch model took on the geometry of the Diagrid and set to recreate it with the motion of each individual row.

As we started creating the grid with each segments we quickly realised that we could overlap the rows, and offset the segments in each row which allowed us to have the same grid structure we developed but without the individual sections of the panels which in our original model were all static.
This design allows us to create a greater level of control inside each panel, which would allow the user more control of the desired temperature inside the building.

First levels of movement was devised on the rotation, and the degree of rotation.
The movement would happen from the rotation of the rod, in which each segments are fixed, the level of rotation is between 0-90˚degrees.

Prototype

Model Configuration

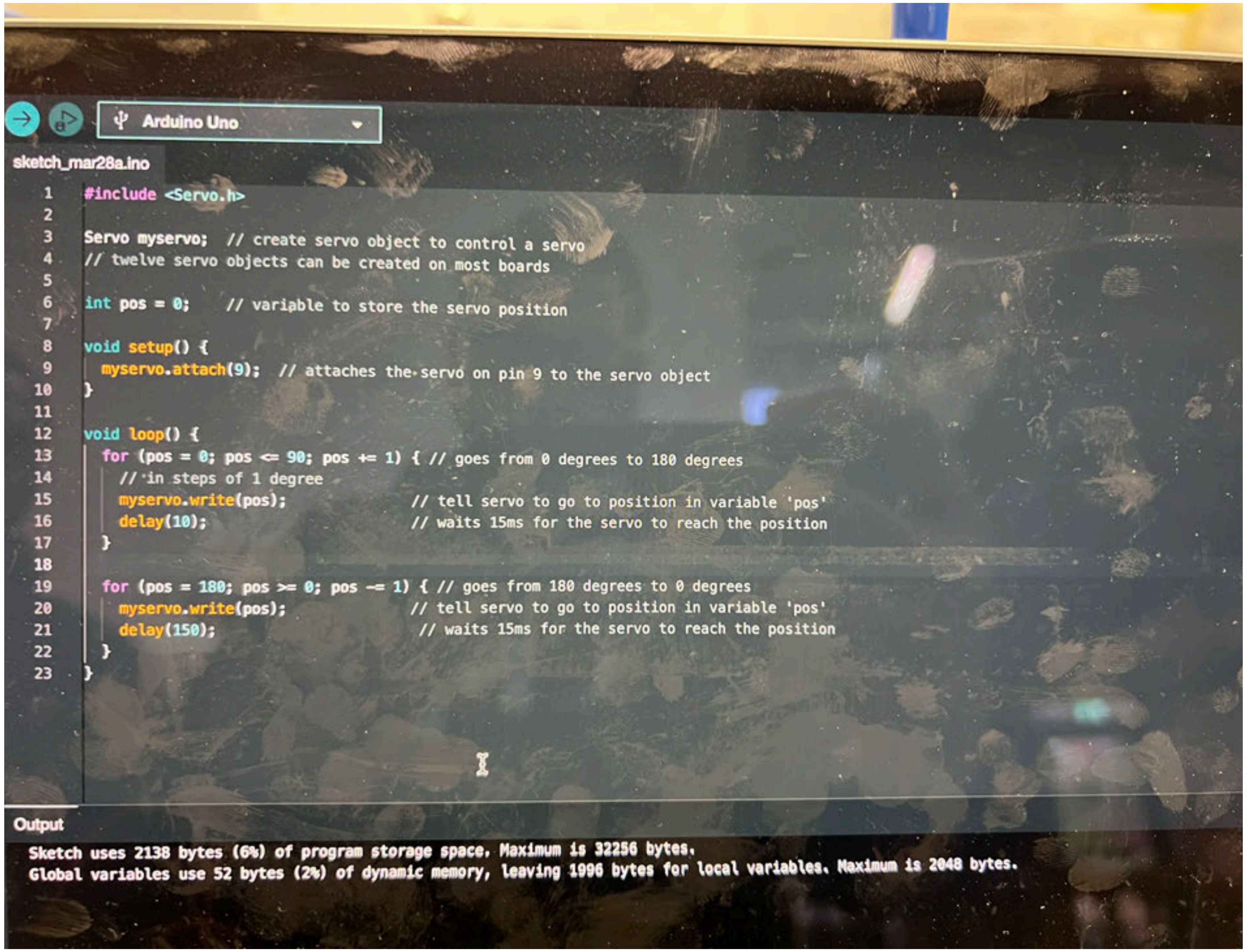


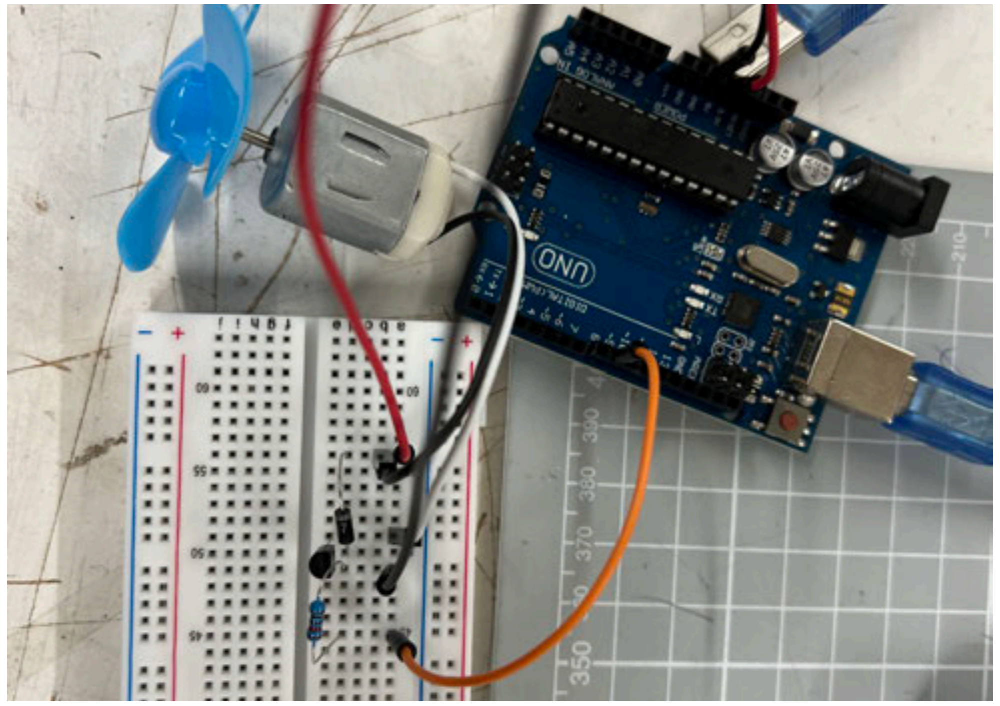
Continuation of development and analysis of the prototype:
We looked and analysed the movement of each row and evaluated how each row would move and how the movement would affect the temperature inside the building, by looking at how the movement would create shade.
The scale was changed from each row representing a floor level to the 4 rows in the panel as shown in the pictures representing the size of each floor, as this would allow more degree of control between each floor.

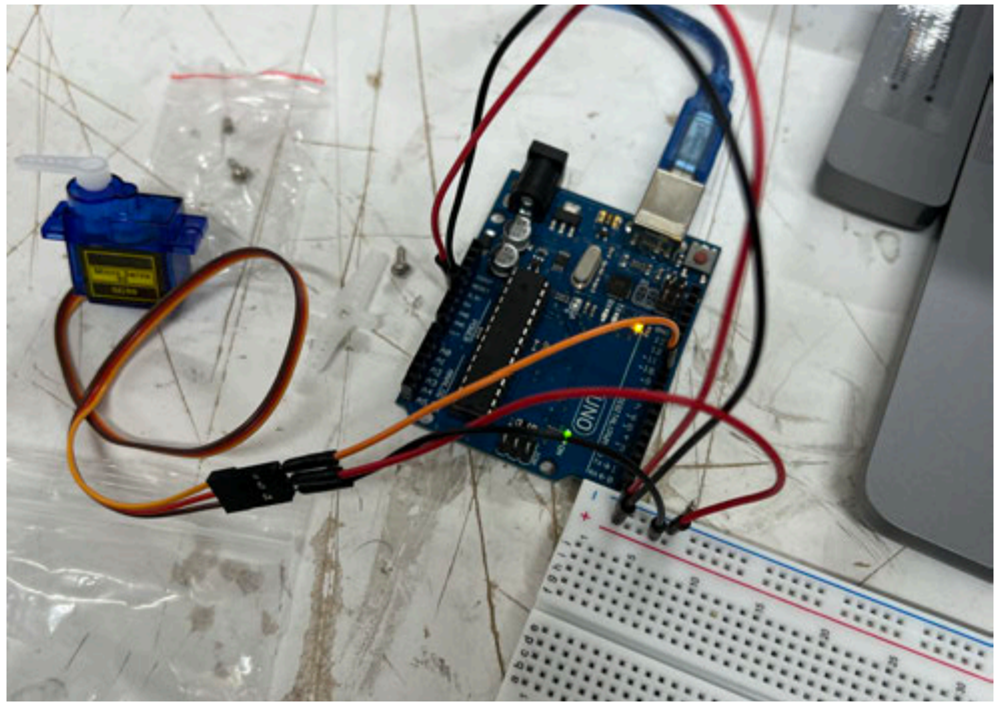
With the level of rotation between 0˚-90˚degrees.
We looked at how each row would move independently, we reapplied that each row in each panel would need its own actuator in order to move. We found that, as you move the bottom row of the panel it would move the segments above, mimicking the movement of a pinecone, as the movement is determined for the bottom to open in order for the ones on top to open.
We decided to only have one point of rotation, on the bottom row, which now would only need 1 actuator per panel.

Arduino

Model Simulation



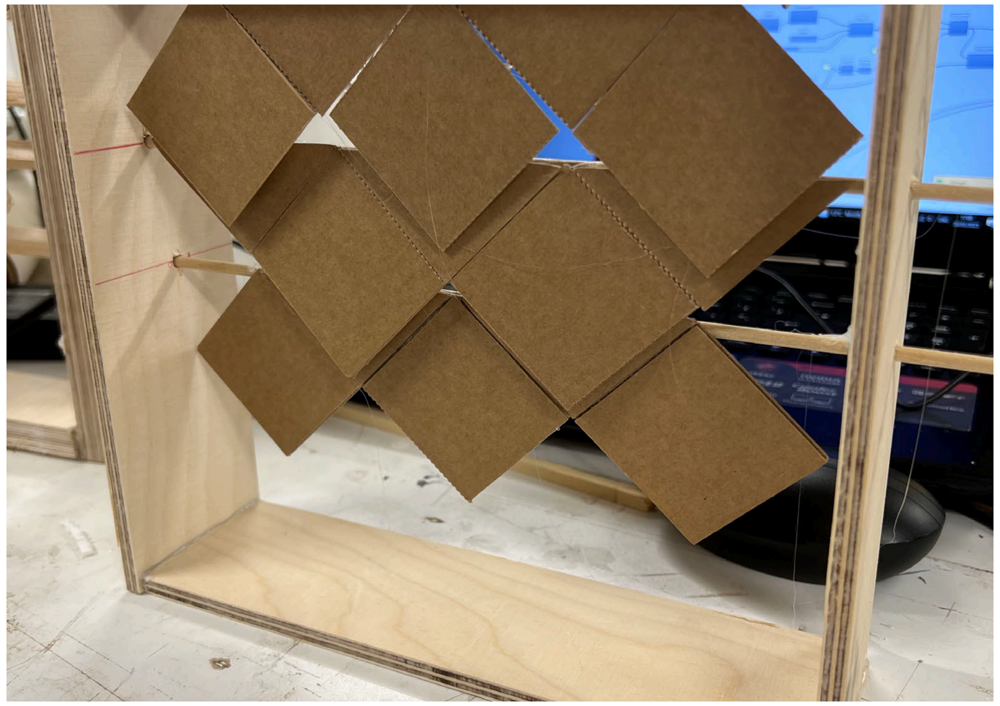




Simulation
In order to test out the model simulation of the rotation of the row, and how the rotation would effect the surrounding rows in the panel, we used an Arduino Kit, attached with a servo motor and a DC motor to creating the rotation.
The DC motor proved unsuccessful as the motor was powerful to spin, the control in the script was to change the speed of rotation, rather than the degree of rotation.
With the Servo Motor the code input allowed us to choose the degree of rotation, defining the movement from 0˚-90˚, and to repeat from point 90˚ back to 0, as well as defying the starting position after the movement and the speed of movement both from 0˚-90˚ and 90˚ -0˚

The successful test of the Arduino kit with the servo motor allowed us to move onto the next step of testing it out onto the prototype model,
We had to Rethink of the model as the size of the servo motor would not have the strength to move a row of segments.
The decision was taken to create a more lightweight model which would react in the same way, as well as the ability to connect it up to the motor.

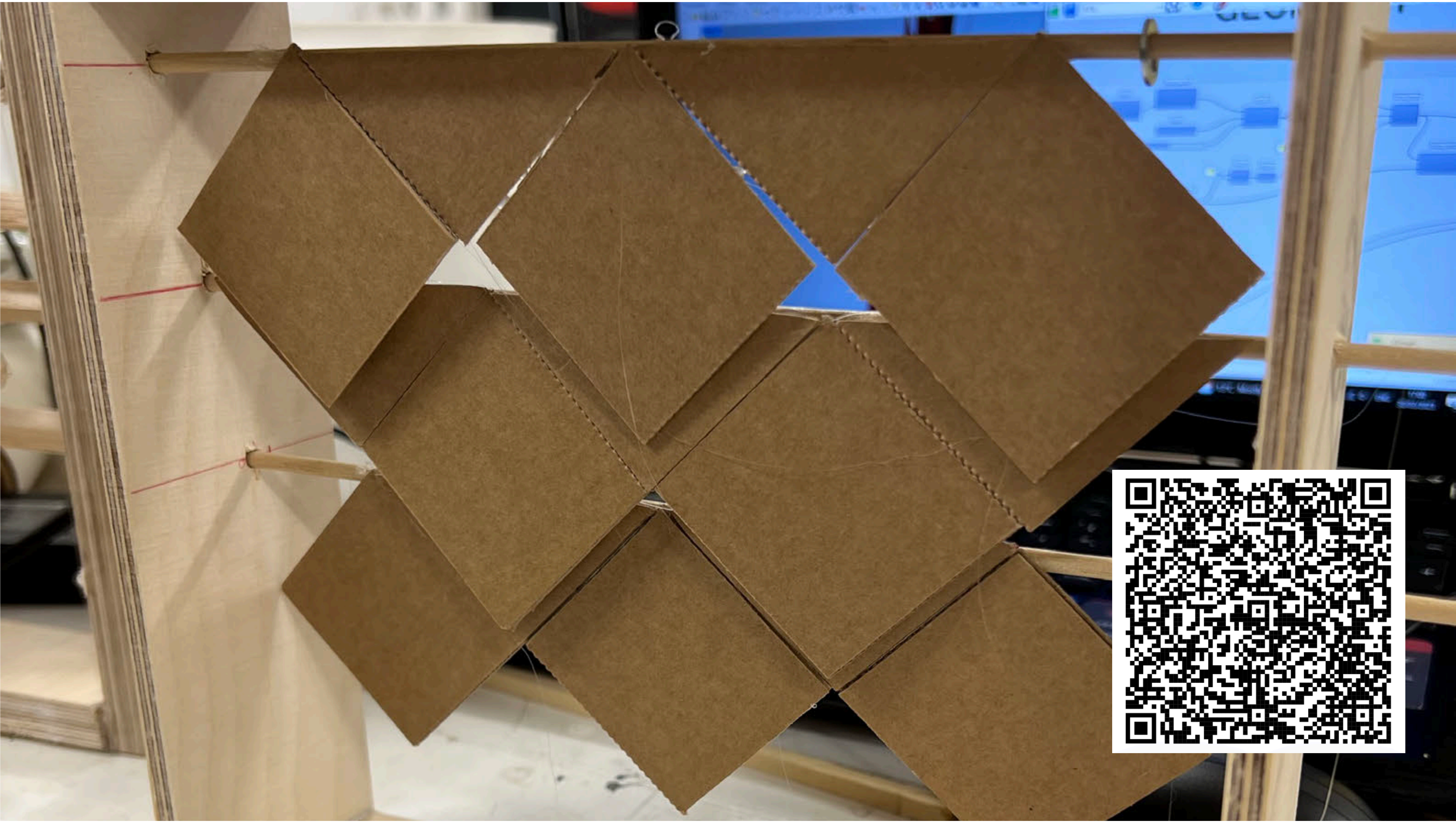
Prototype 2



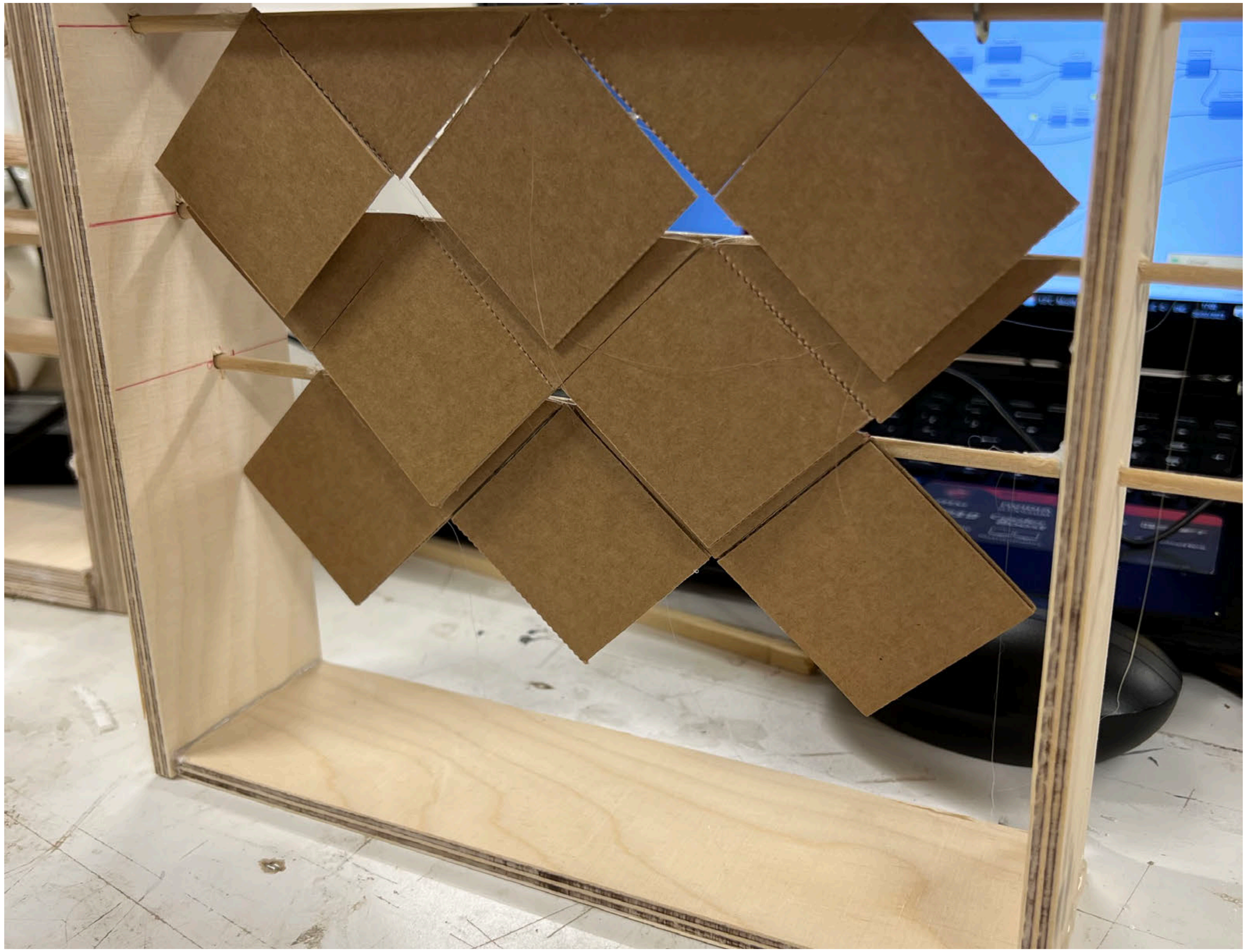
The new lightweight model. This was created from cardboard, and smaller dowels attached to the frame, compared to lollypop sticks in the first model, which also used a larger wooden dowel attached to a circular dowel, attached to a washer to allow movement.
In this model the cardboard segments were attached straight to the smaller wooden dowel, without the need for a square dowel, although this was now lighter the surface area has decreased from the original model, meaning that more was needed to create a structure that wouldn't break, the half segments added in between in whole segments were added for 2 purposes; to give the strength to each row; to create more surface area in between the gaps where the segments from the other rows could come into contact and create a higher degree of movement.

In the first prototype we found the movement wasn't as fluid, and rotation would stop after there was no more contact with the panel, there was also risks of each section getting stuck due to the gaps. This problem was removed once the additional segments were added.

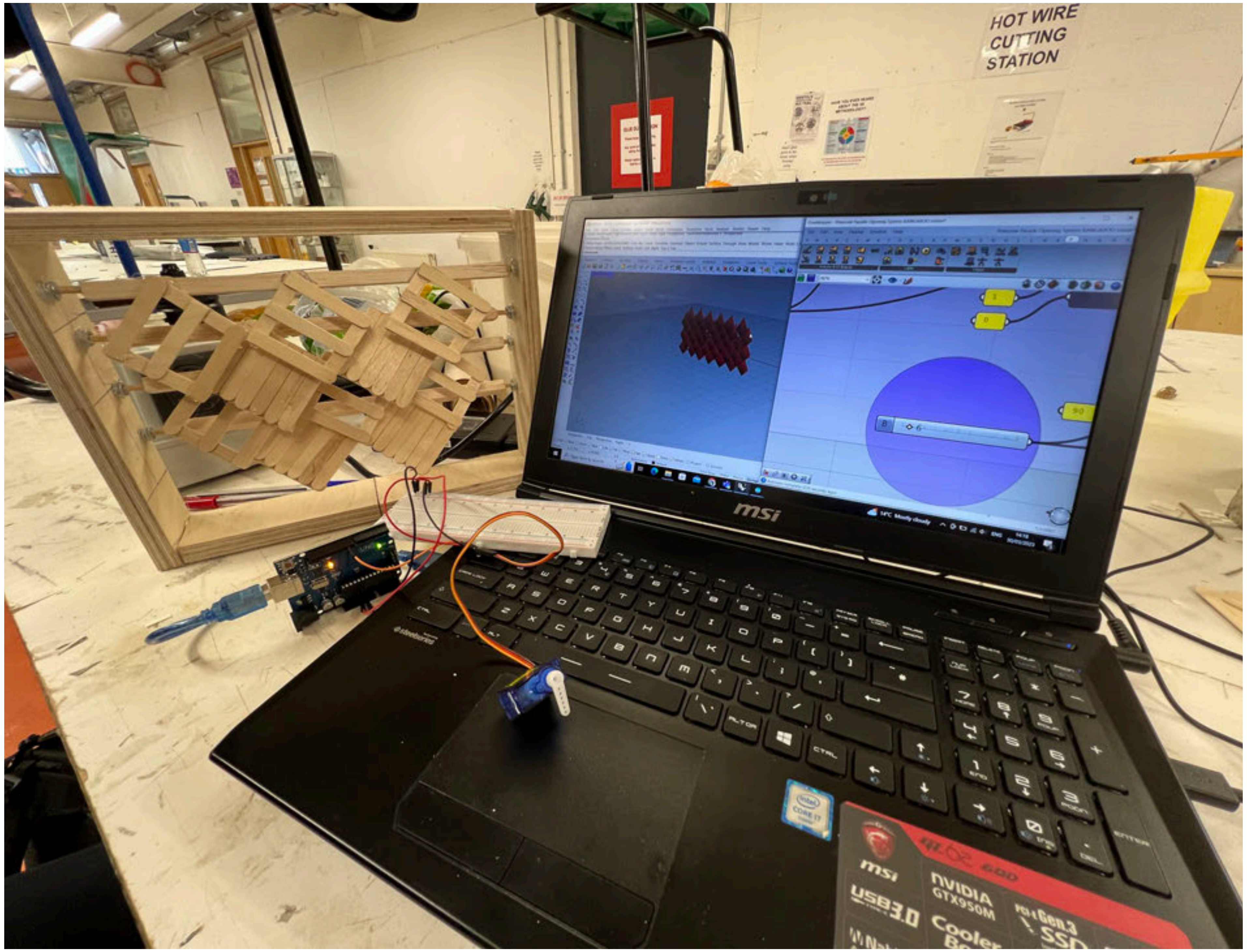
VIDEO

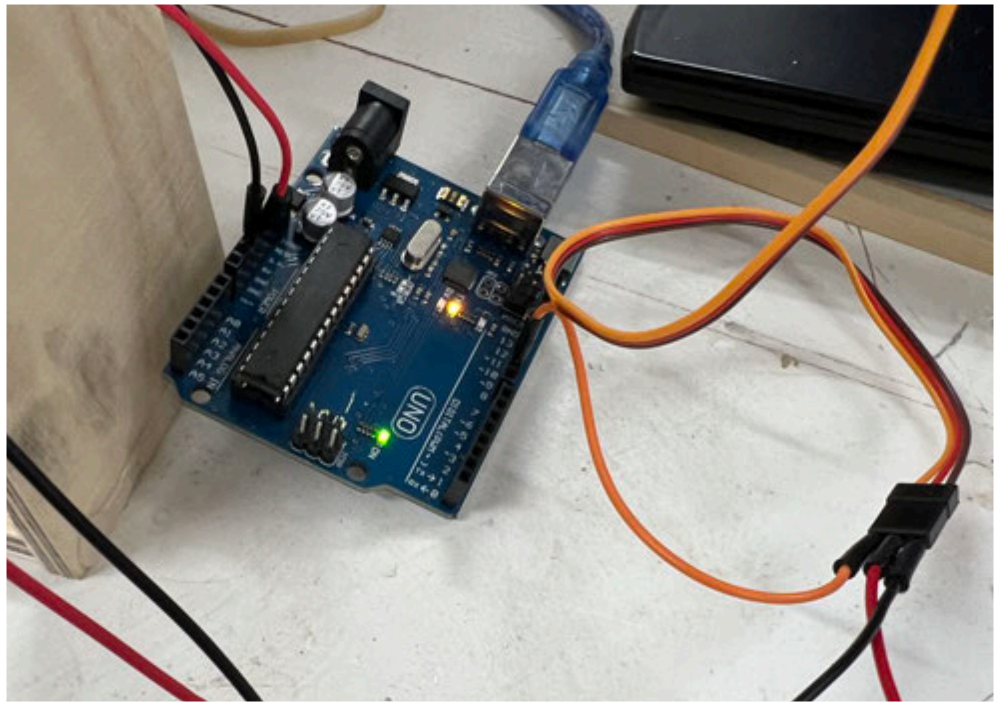


Response of each row in relation to movement of an alternative row.
https://uweacuk-my.sharepoint.com/:v:/g/personal/aashish2_sapkota_live_uwe_ac_uk/EbsEmF4uAwRDl0hijtUp1qsBrXLGke_Te6WKgvH6FwkFzg?e=Tqq5eZ



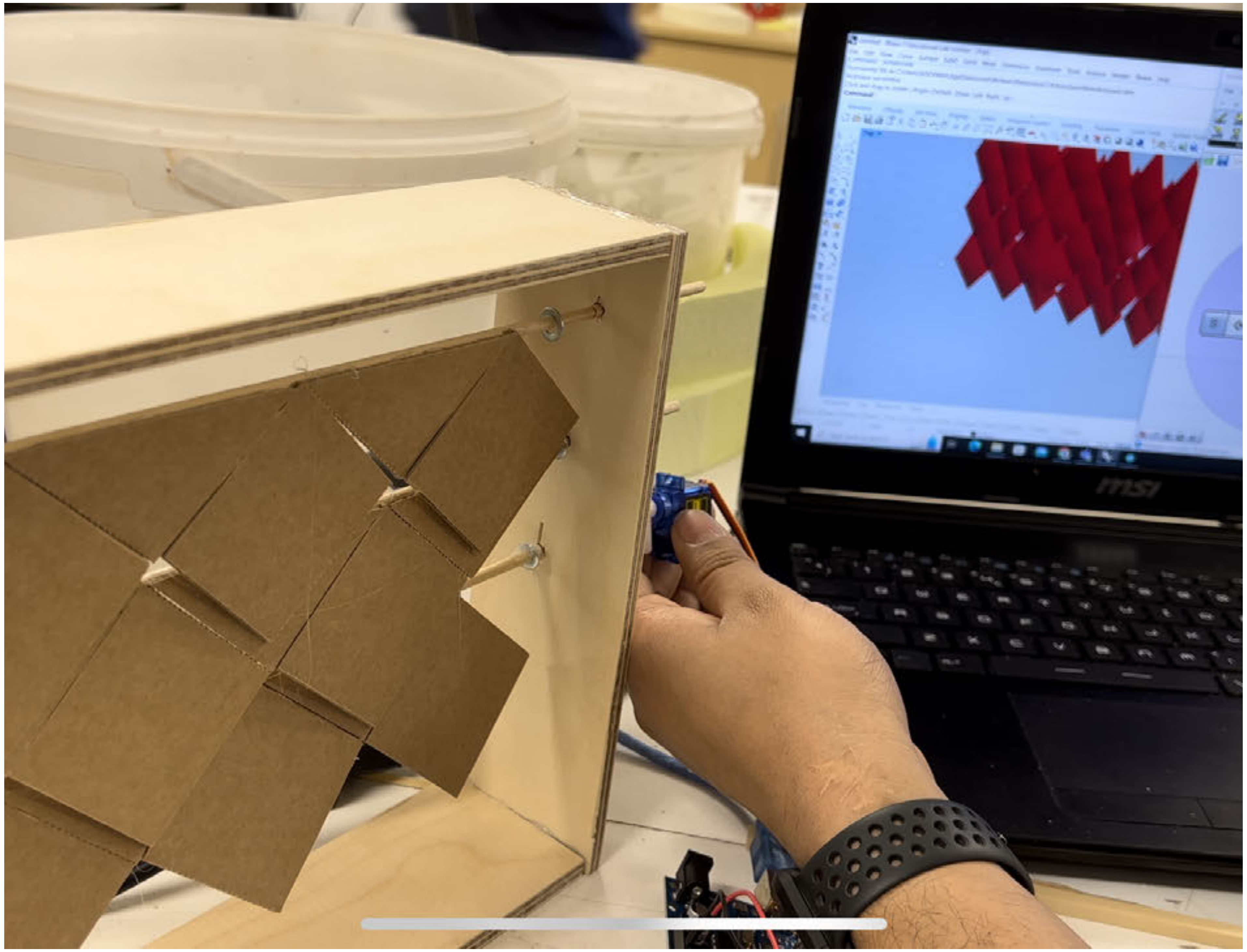
Testing the Arduino kit onto the model,
This test just linked the Arduino servo motor to the rod of the bottom row, the Arduino script ran a loop so we could see the movement and how it effected the other rows of segments within the panel. We found the strength of the servo motor was powerful enough to demonstrate the movement, however it needed to be held, as some angels caused the servo motor to move rather than the row. This wasn't a big issue as a real motor would be fixed into place.





The Arduino Kit was then linked to a grasshopper script to test out if the movements could be controlled from the script,
The video shows the Servo motor arm moving in the degrees given in the grasshopper file.

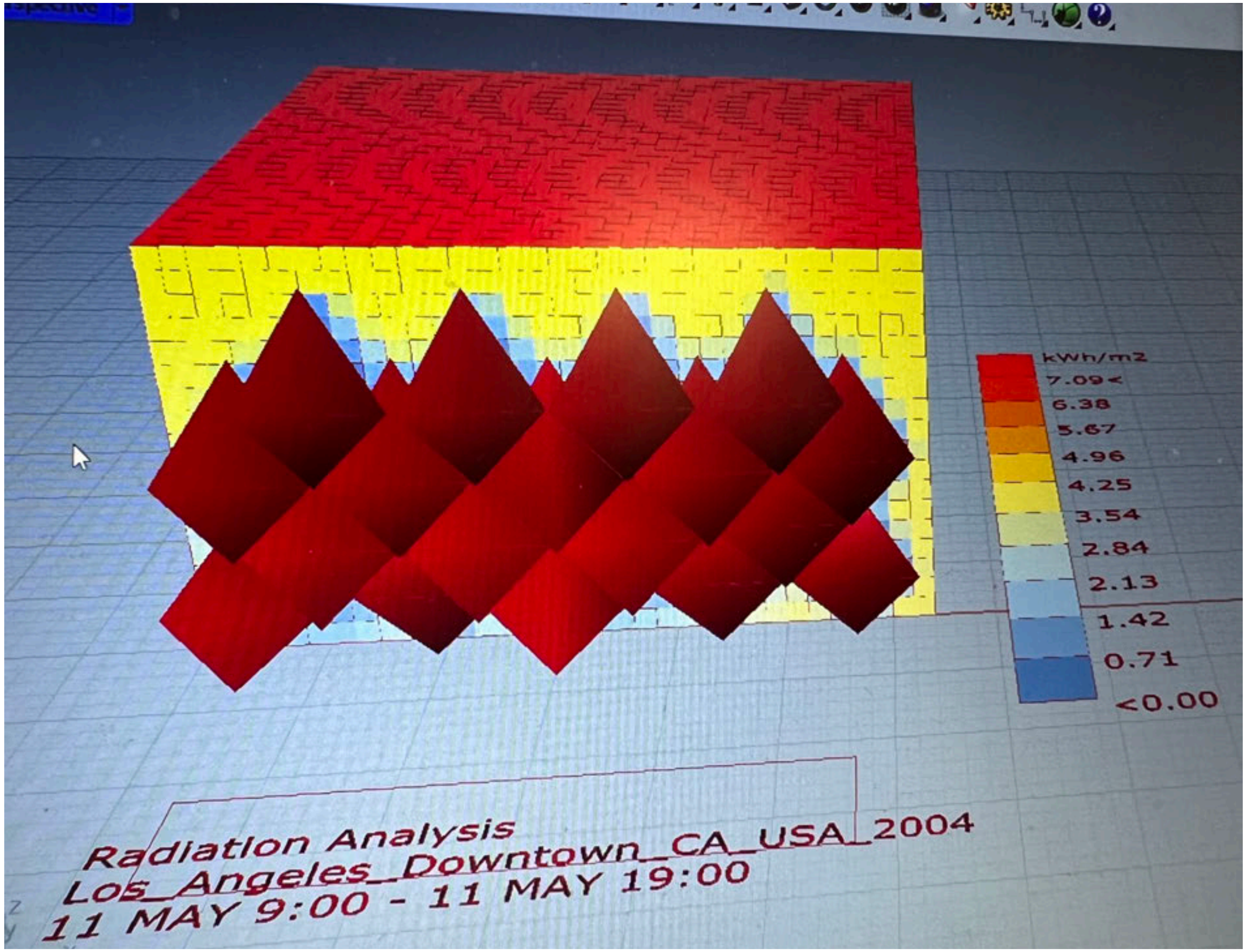
https://uweacuk-my.sharepoint.com/:v:/g/personal/aashish2_sapkota_live_uwe_ac_uk/ESG65c_3p3dBkOxXc-nXLyIBSQlmQZLzUF1FlF_hym6oSg?e=PaqeY9

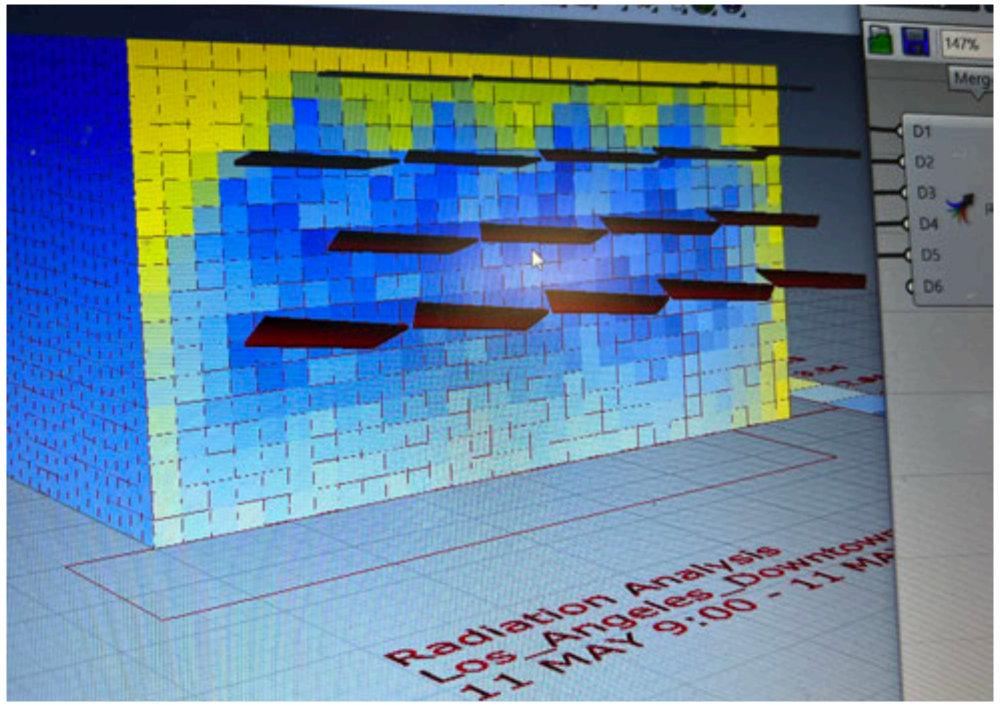


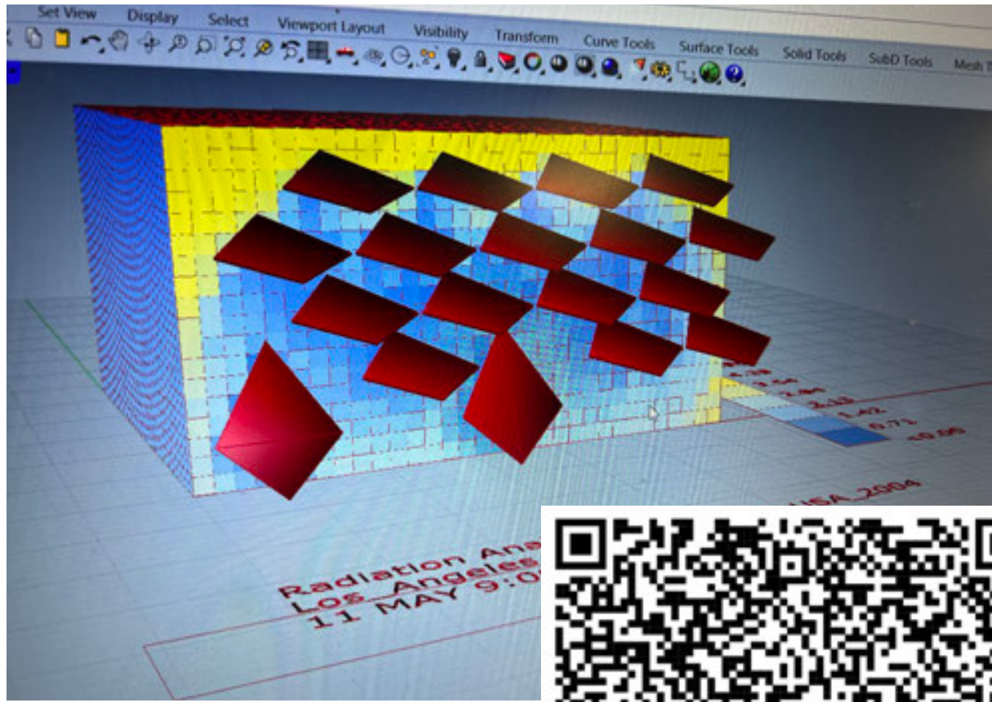
Testing the Arduino kit onto the model,
Once the grasshopper file with the model was created and was linked to the Arduino model we could simulate the movement on the physical and digital model with a single mode of control.

The video demonstrates the movement of rotation in both physical and digital model.
In order for this facade to be responsive, and react the same ways as a pinecone, the next step would be to test it against outdoor and indoor climate simulation.

Outdoor Climate Simulation

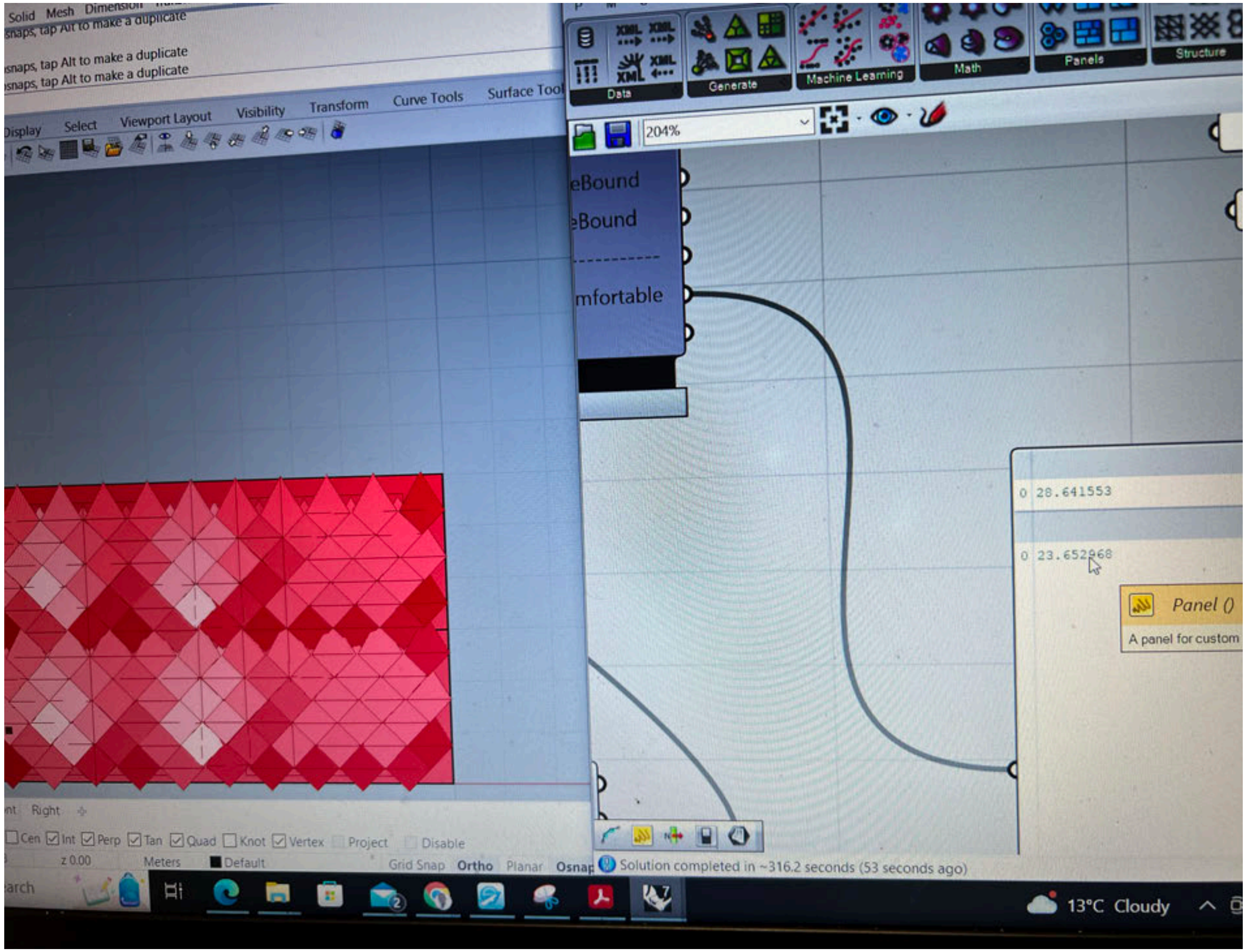


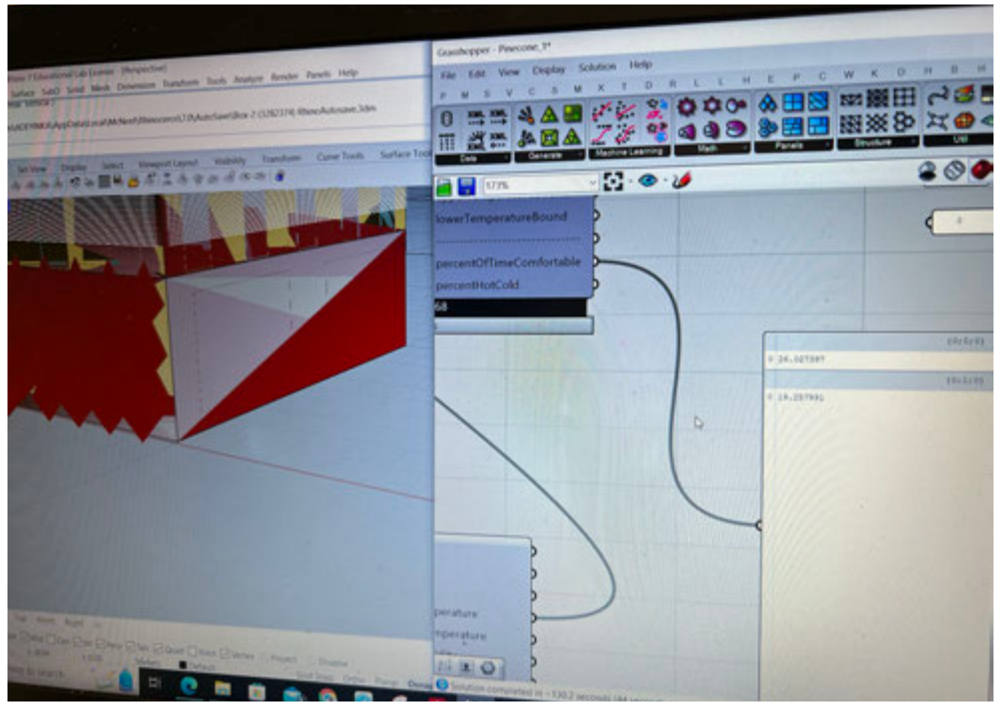


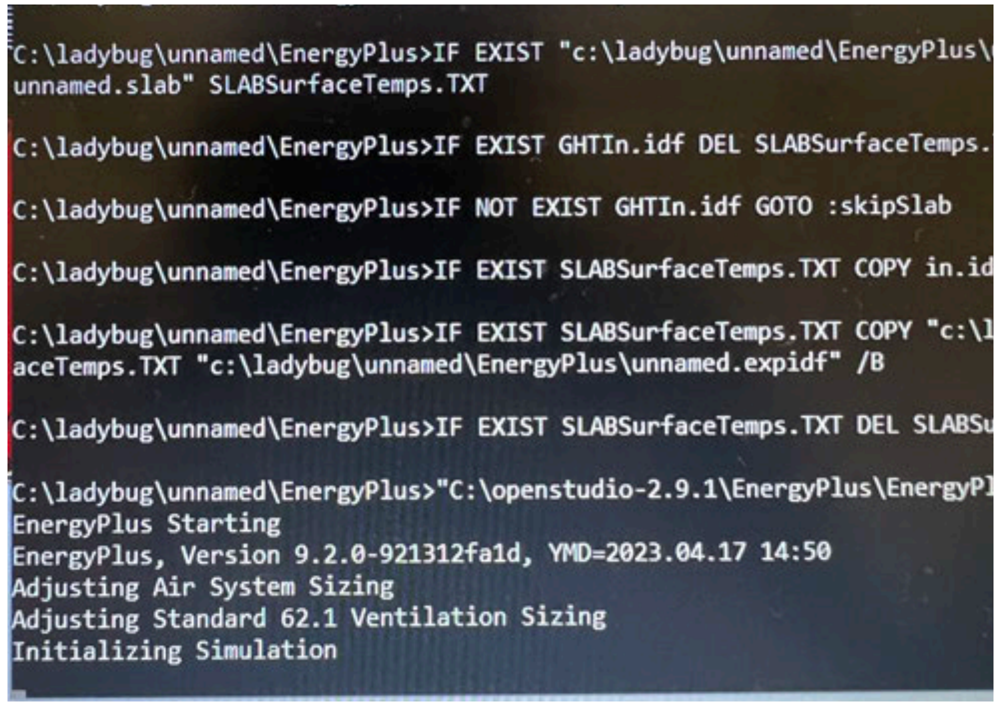


Solar Radiation Analysis of the exterior of the buildings from 9am-7pm and the percentage of solar energy onto the building.
The coloured grids shows the cooler spots on the buildings where the segments have been deployed compared to the area which are not covered and they have more surface area which the solar radiation is at the highest.

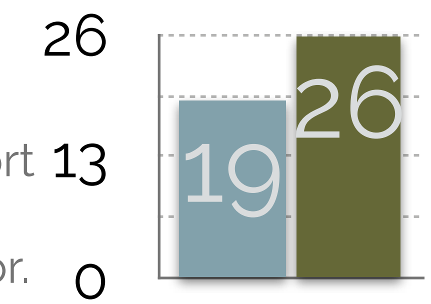
Indoor Climate Simulation



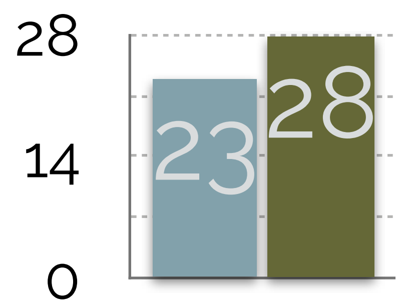




Indoor simulation, The panels extend over the 2 bottom floors of the building, the energy simulation looked at the % time of comfort within the spaces in each floor in relation to the opening of the panels. The graph on the right shows the % time of comfort for them the system is open vs when its closed. When its closed the % of comfort rate rises on both floors from 19% to 23% on the ground floor and 26% to 28% on the first floor.



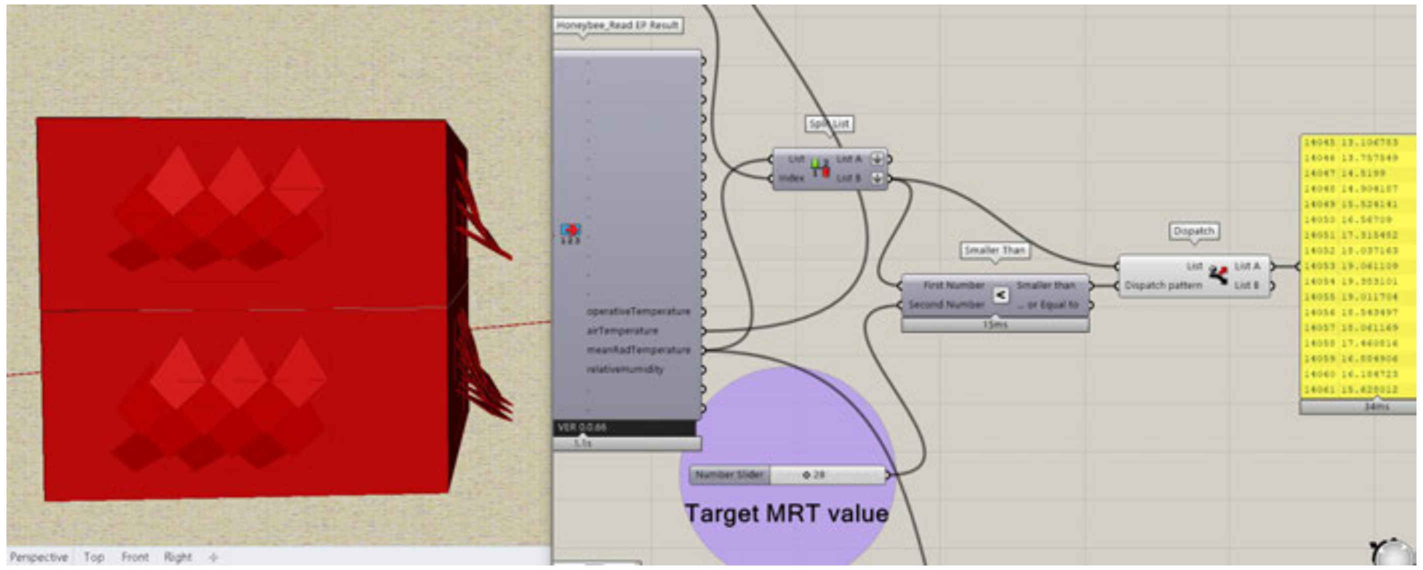
% TIME OF COMFORT

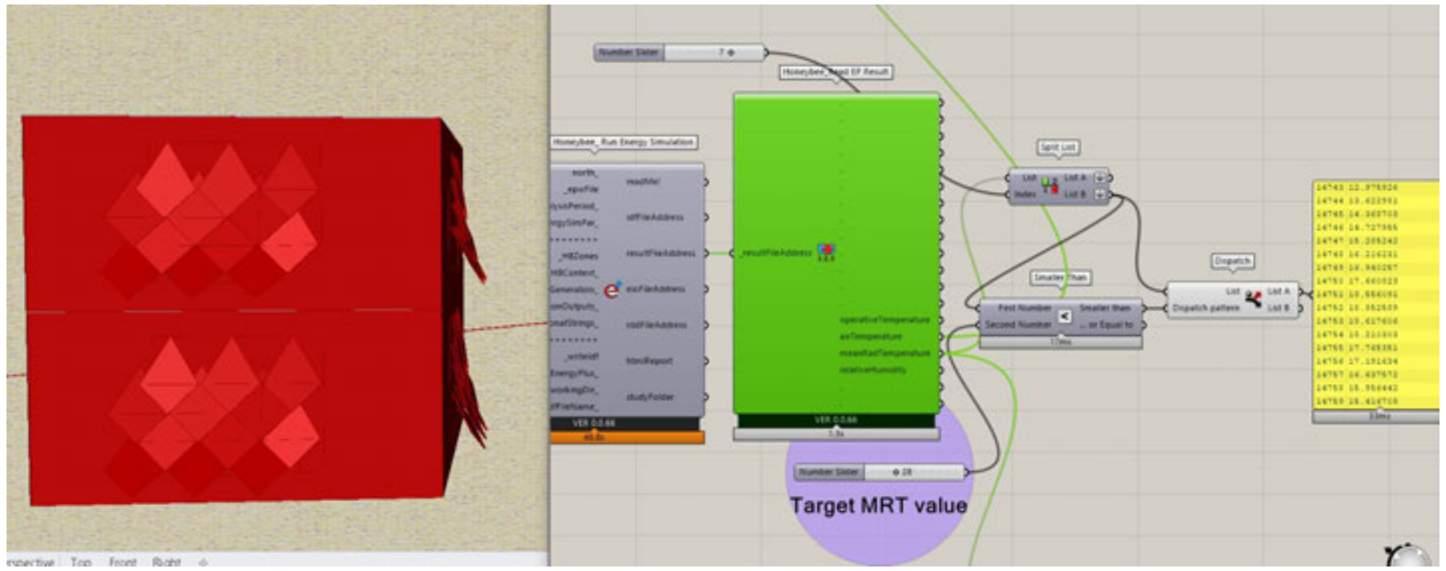


% TIME OF COMFORT

Mean Radiant Temperature calculation at Different Angle of Panel Openings for Shade

Mean radiant temperature (MRT) refers to the average temperature of all the surfaces surrounding a particular point or area, as experienced by an individual standing in that area.

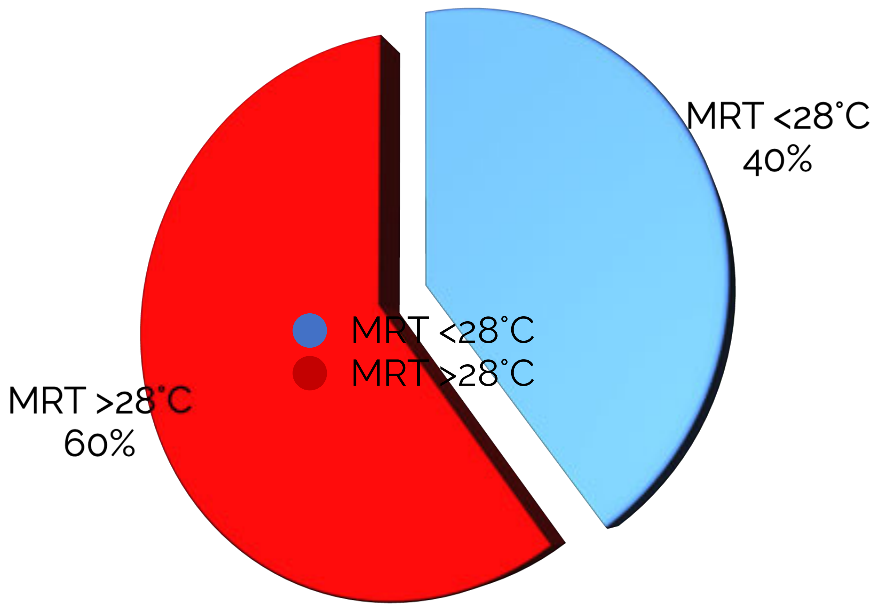


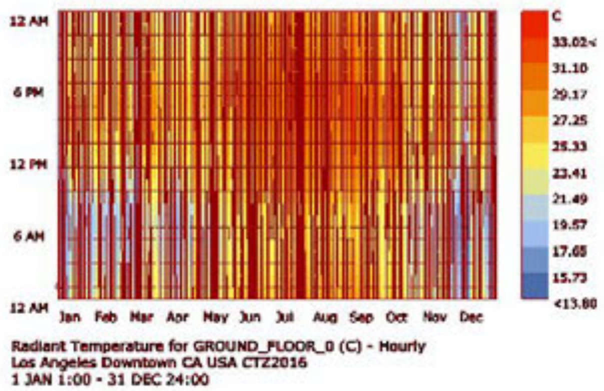


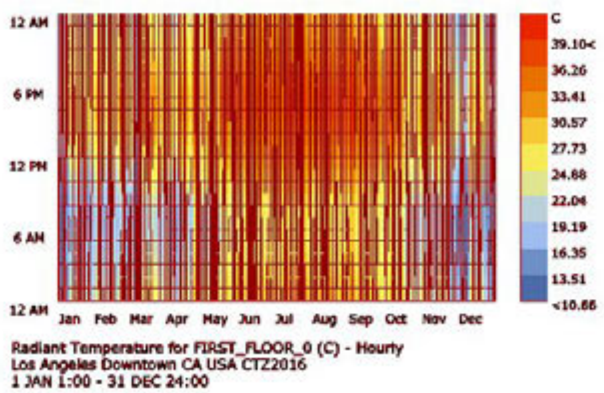
In the absence of shading panels, the MRT calculation provides insight into the percentage of hours throughout the year in which temperatures exceed 28˚C and fall below 28˚C.

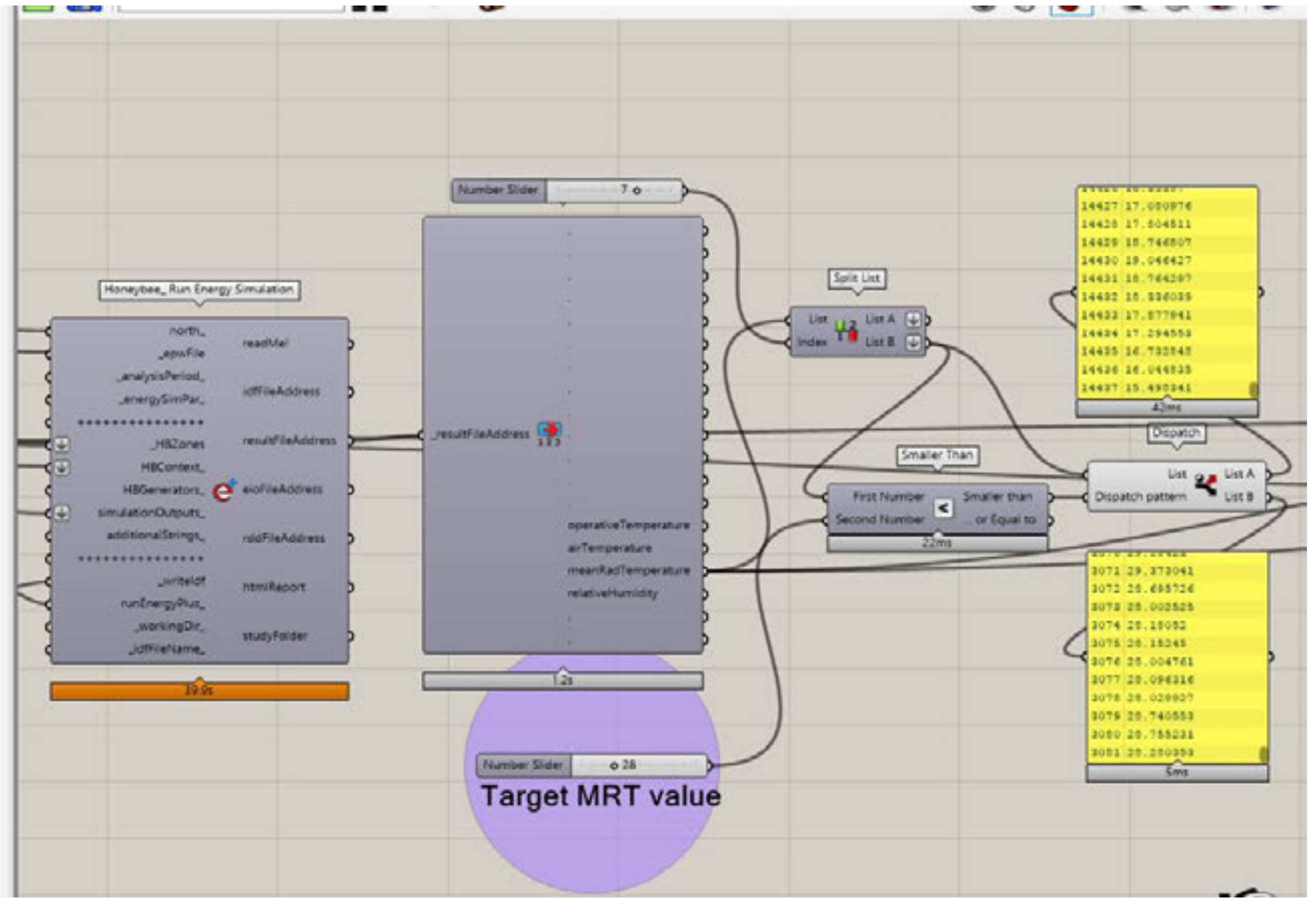
MRT calculation without the shade panels

Mean Radiant Temperature @ 28˚C without shade panels





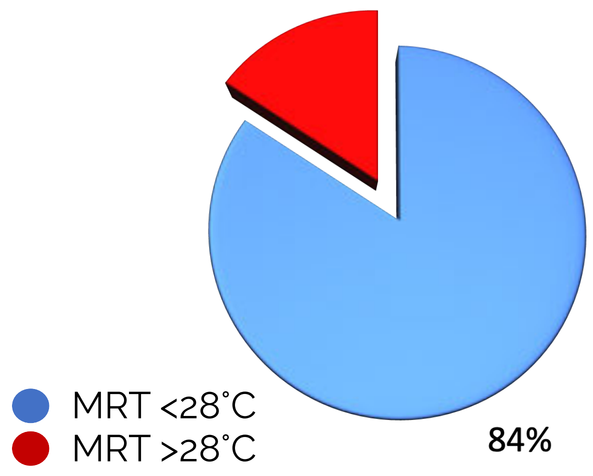




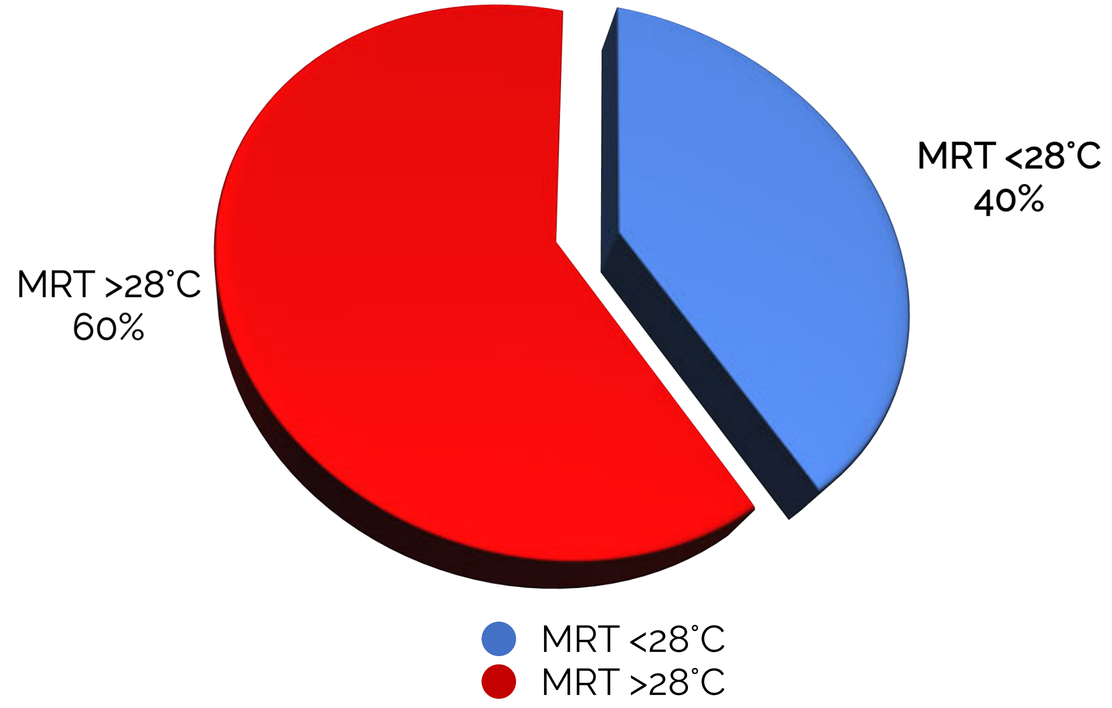
Mean Radiant Temperature Calculation With the Shade Panels Opening at 30˚

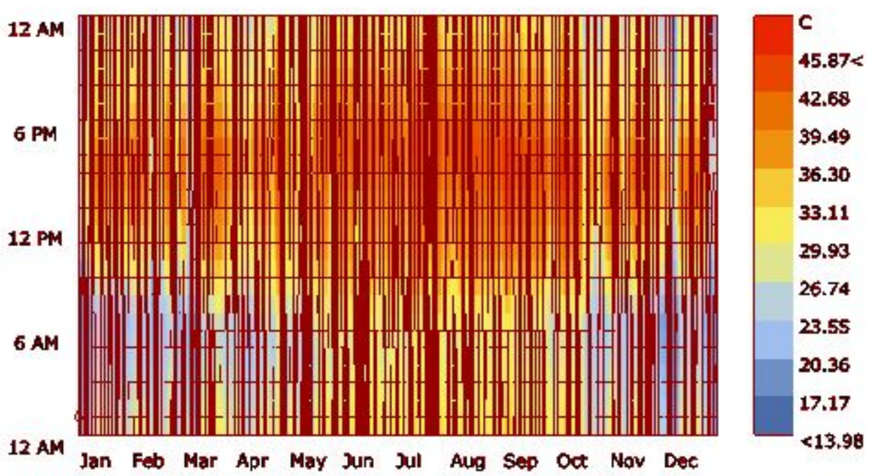
The deployment of the shade panels at a 30˚ angle in the Honeybee energy simulation results in a significant reduction of the number of hours in which the temperature of each zone (floor) exceeds 28˚C. Specifically, this reduction amounts to 44%.

Mean Radiant Temperature at 28˚C with shade panels

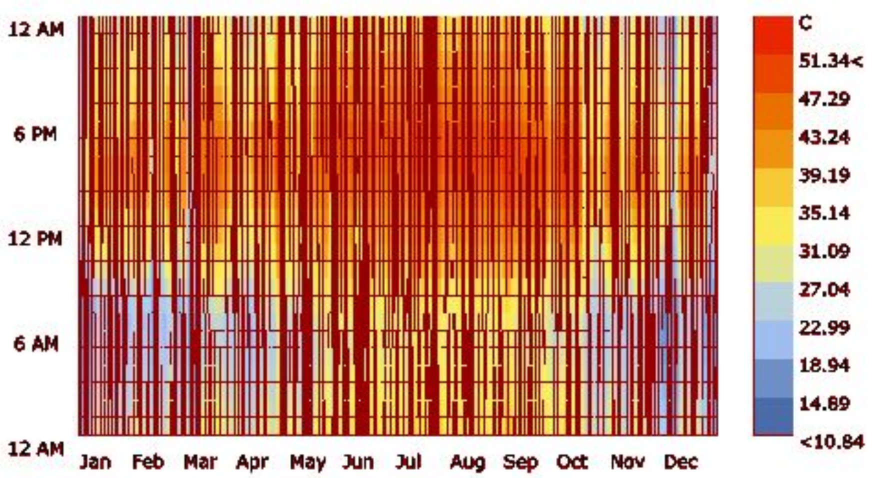


Mean Radiant Temperature @ 28˚C without shade panels

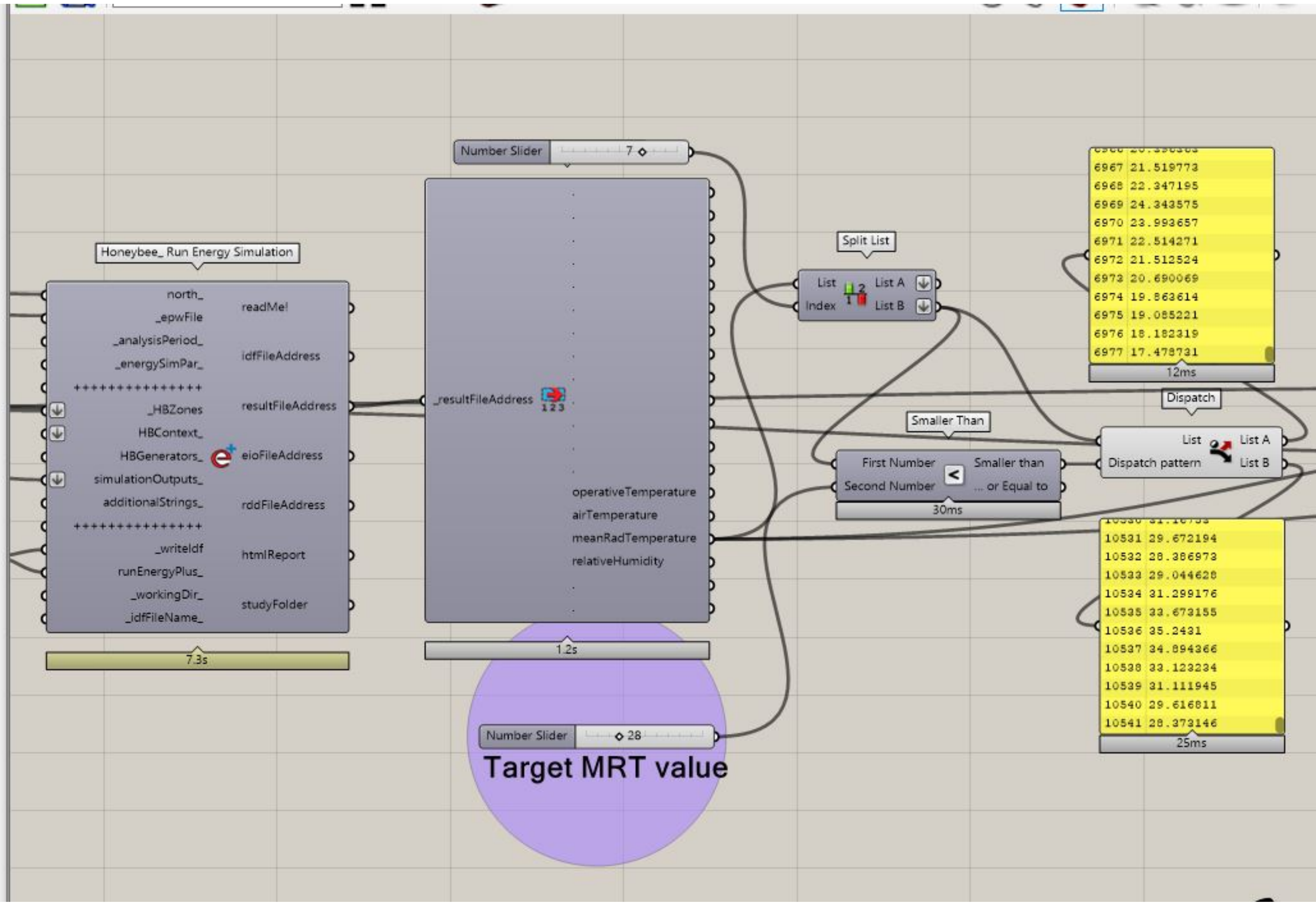




Radiant Temperature for GROUND_FLOOR_0 (C) - Hourly
Los Angeles Downtown CA USA CTZ2016
1 JAN 1:00 - 31 DEC 24:00

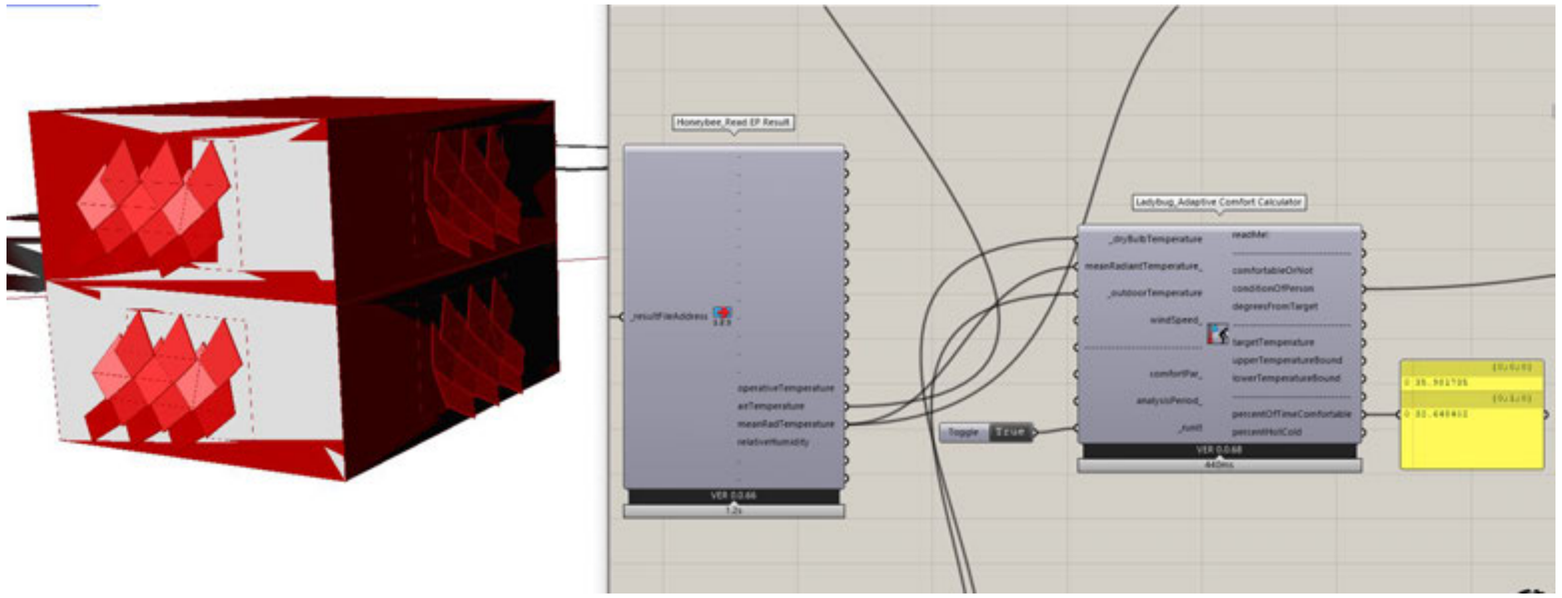


Radiant Temperature for FIRST_FLOOR_0 (C) - Hourly
Los Angeles Downtown CA USA CTZ2016
1 JAN 1:00 - 31 DEC 24:00

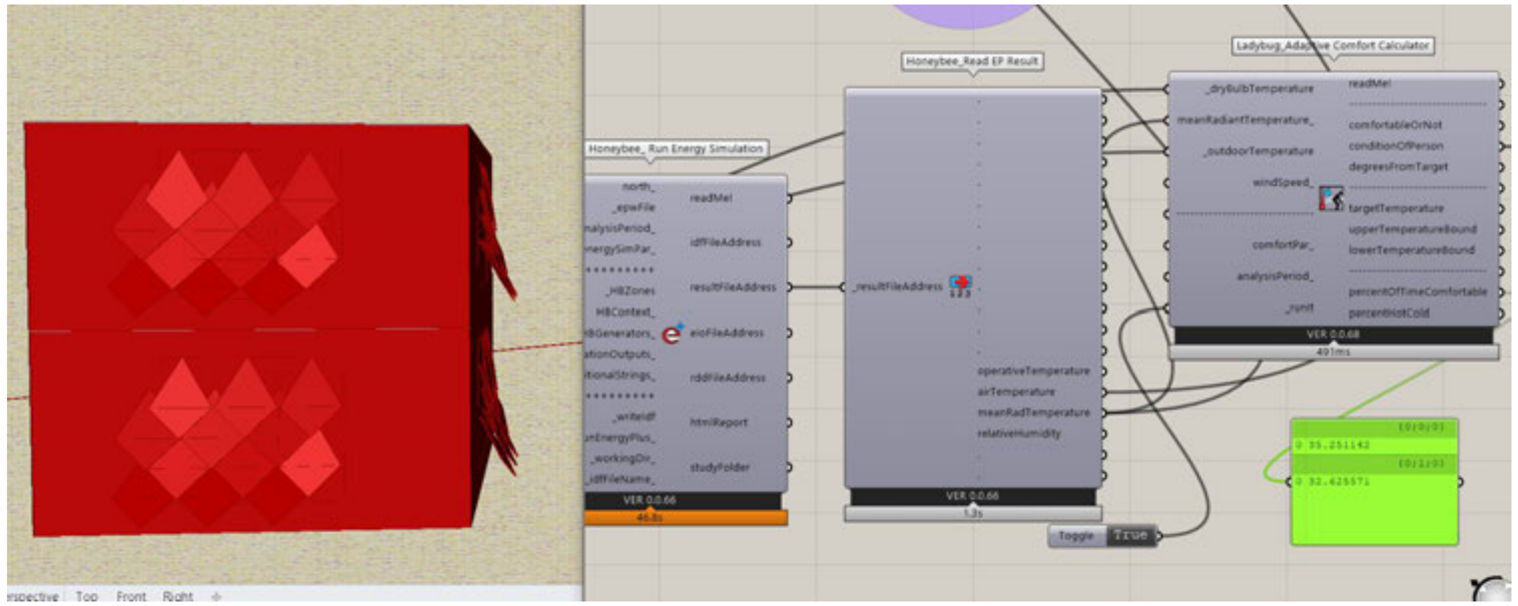


Adaptive Comfort Simulation at Different Angle of Panel Openings

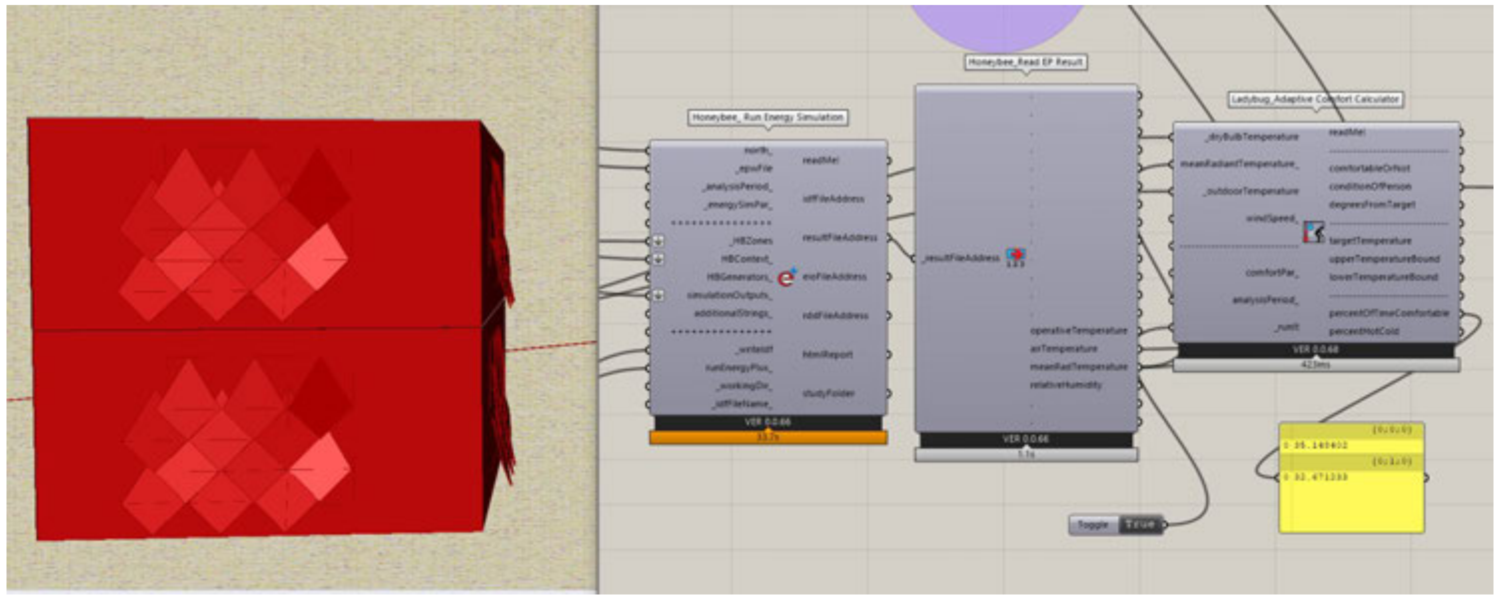
The Adaptive comfort simulation is a technique that employs temperature thresholds of excessive warmth and chilliness to evaluate the degree of comfort perceived by occupants in an enclosed area. The default value for this simulation is established at 23.5˚C, which is used as a reference for assessing the thermal comfort of a given space.



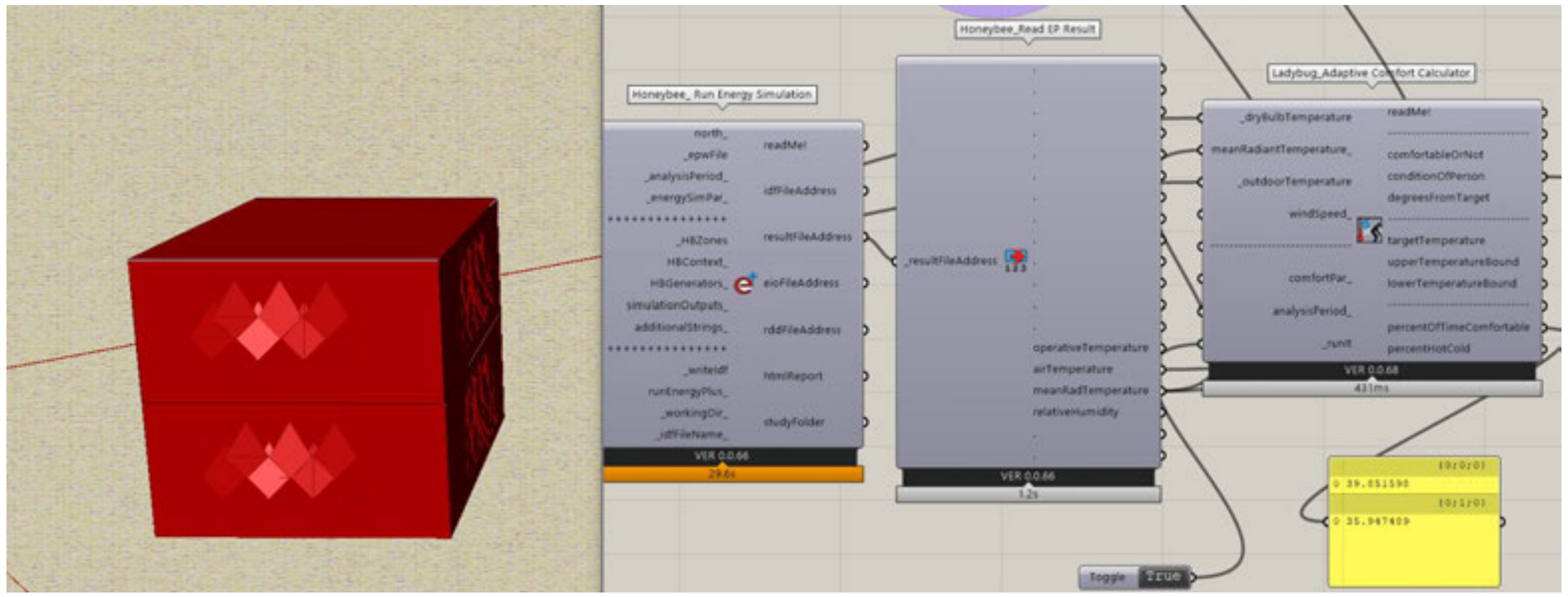
Shade context @ 45˚ panel opening



Shade context @ 30˚ panel opening

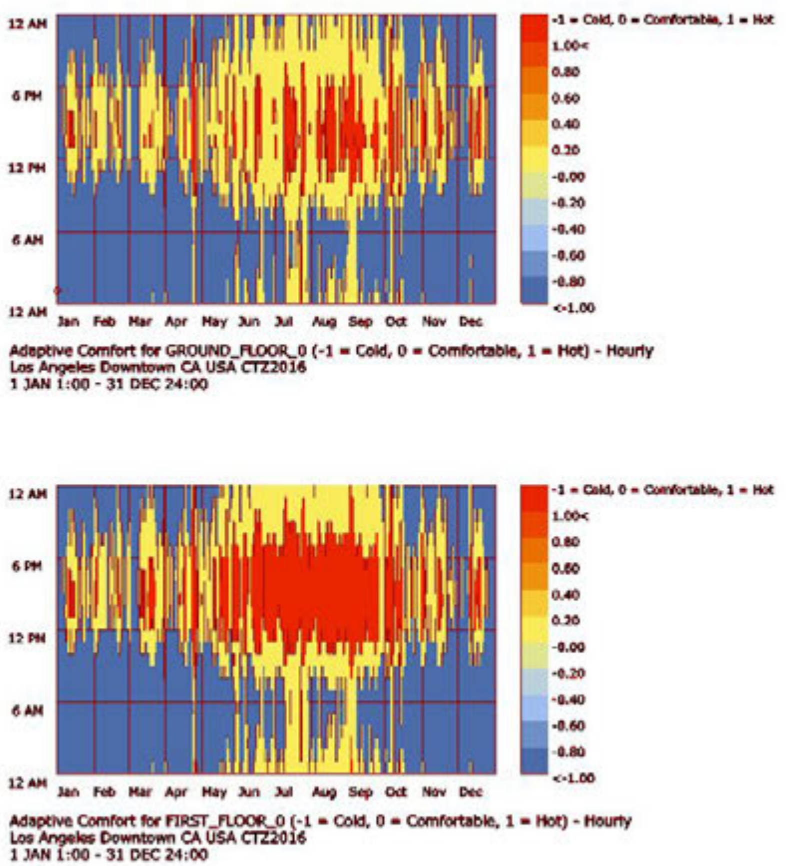


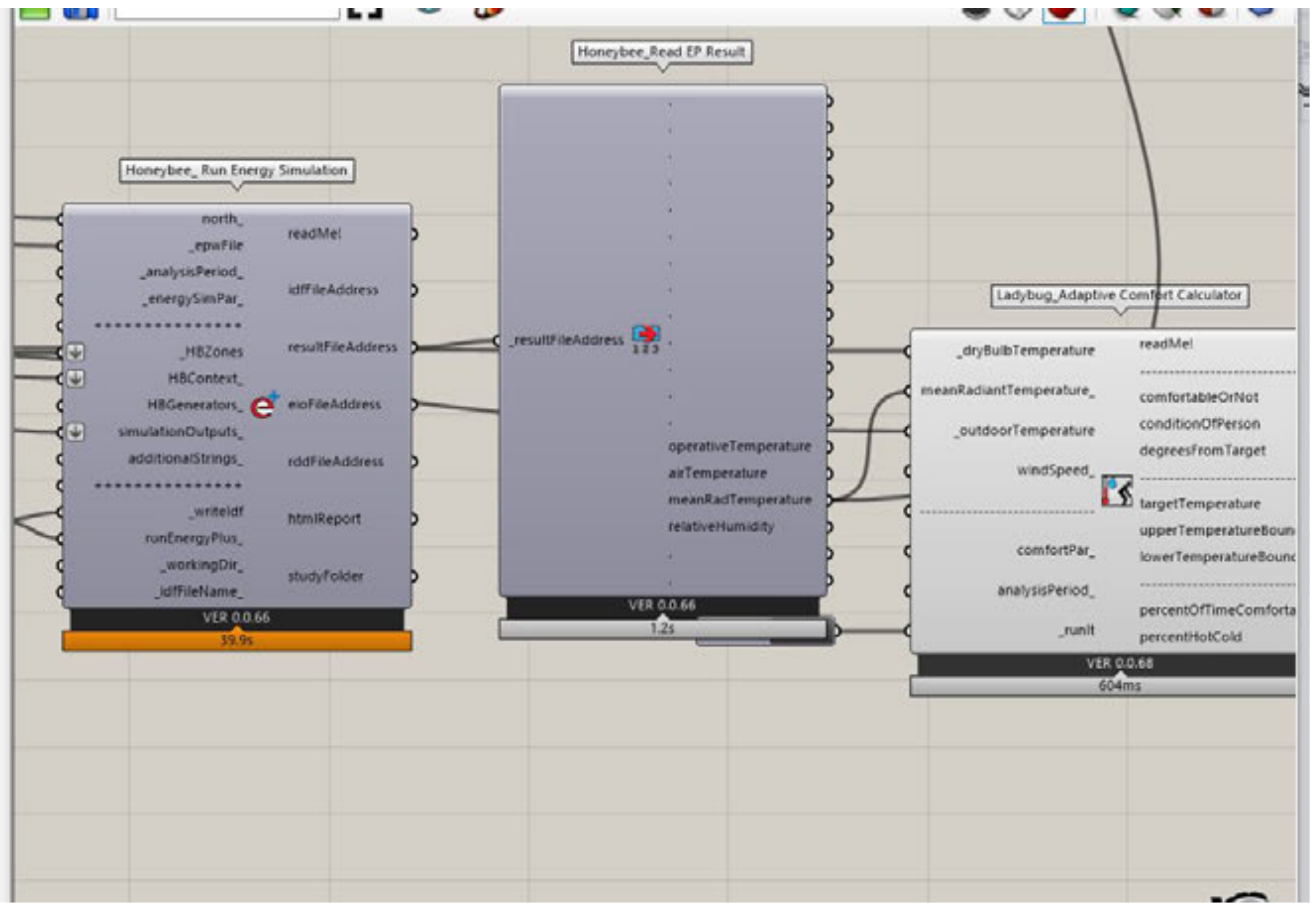
Shade context @ 15˚ panel opening



Shade context @ 0˚ (closed)

Adaptive Comfort Chart

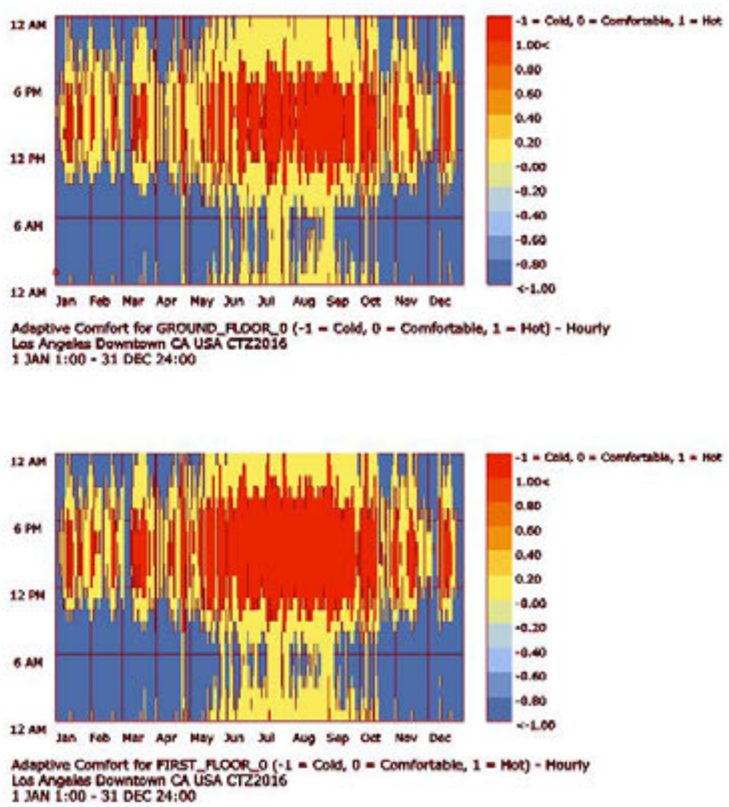


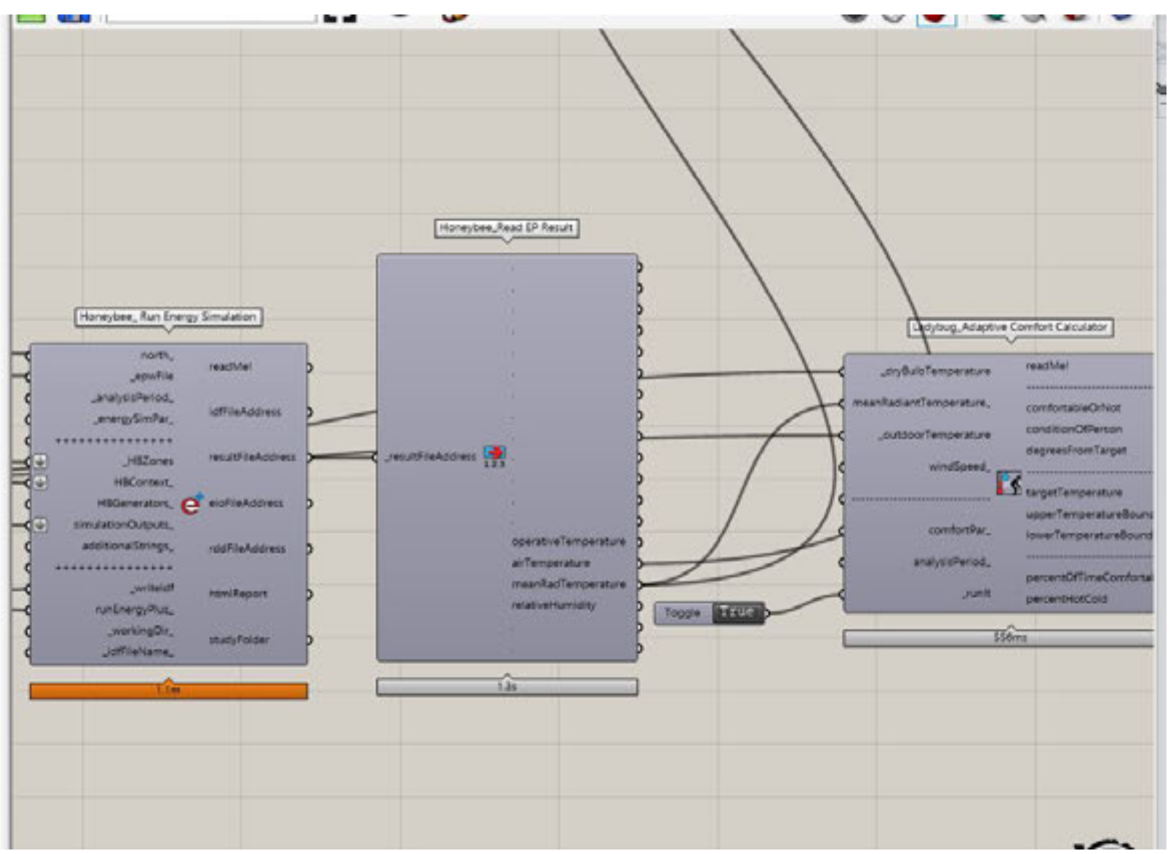


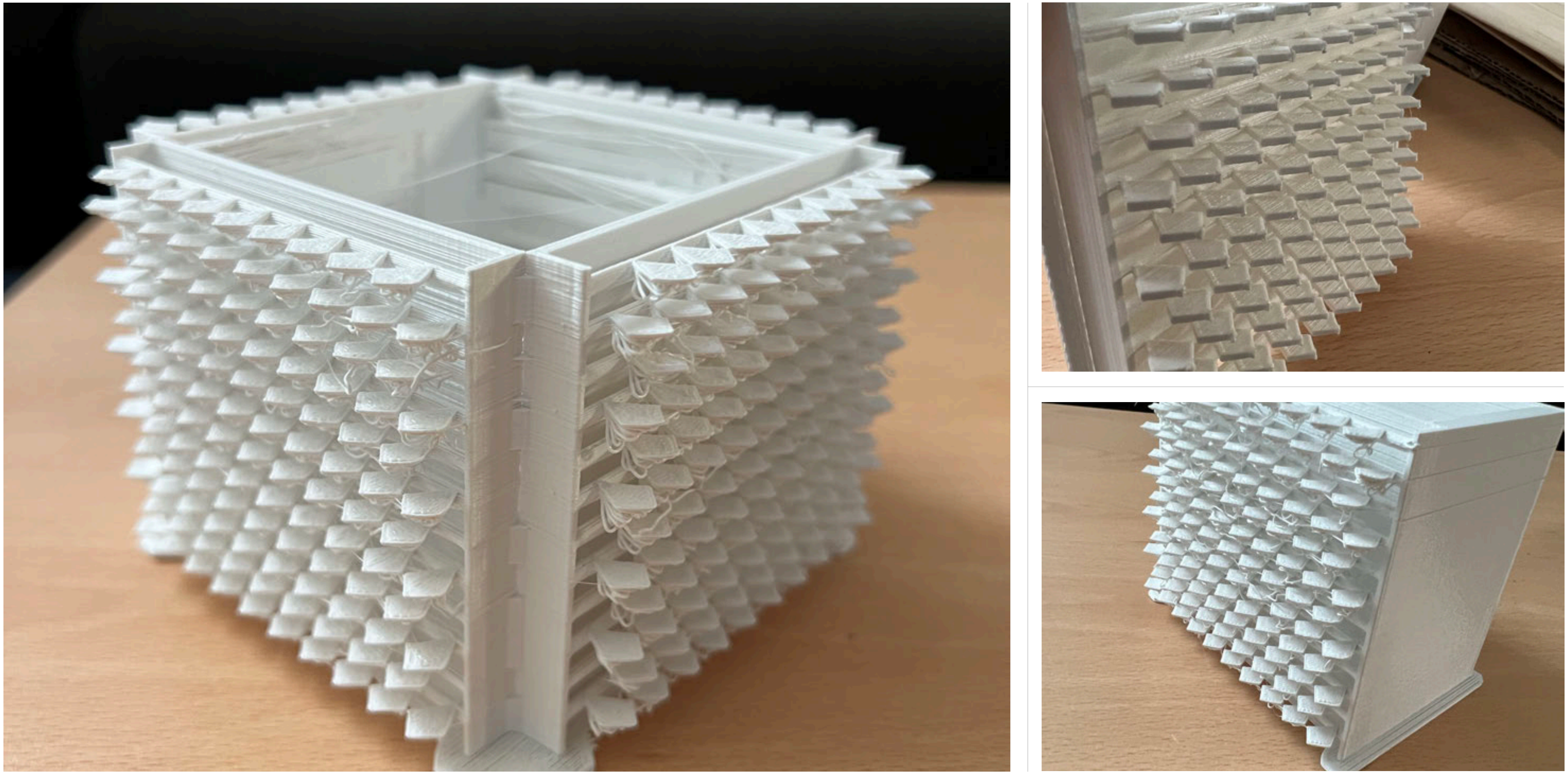
With shade panels

Without shade panels

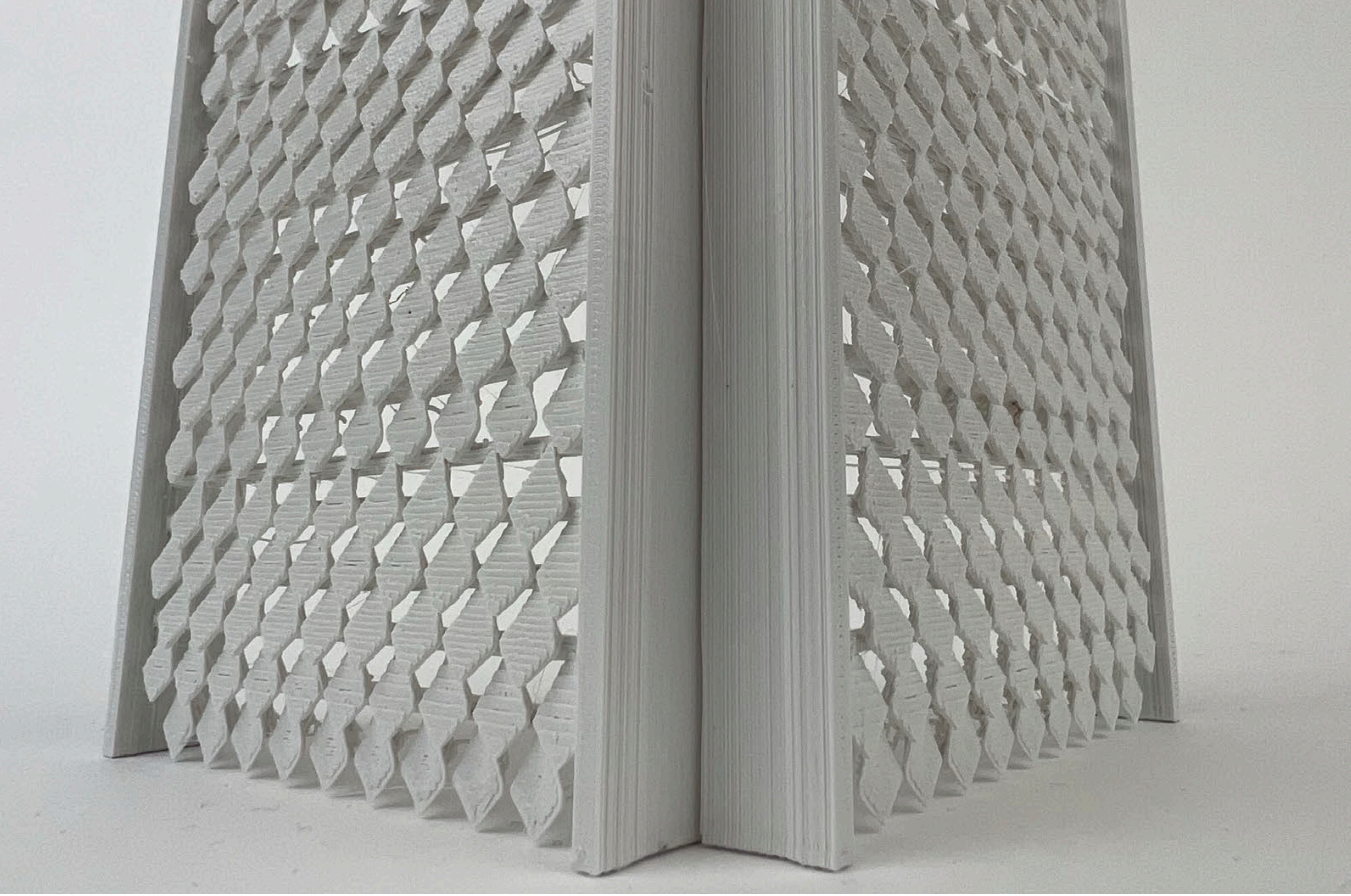
Based on multiple iterations incorporating varying angles of panel openings and without any panels installed, it has been observed that the upper zone or floor consistently registers a higher level of thermal comfort as compared to the lower zone or floor.



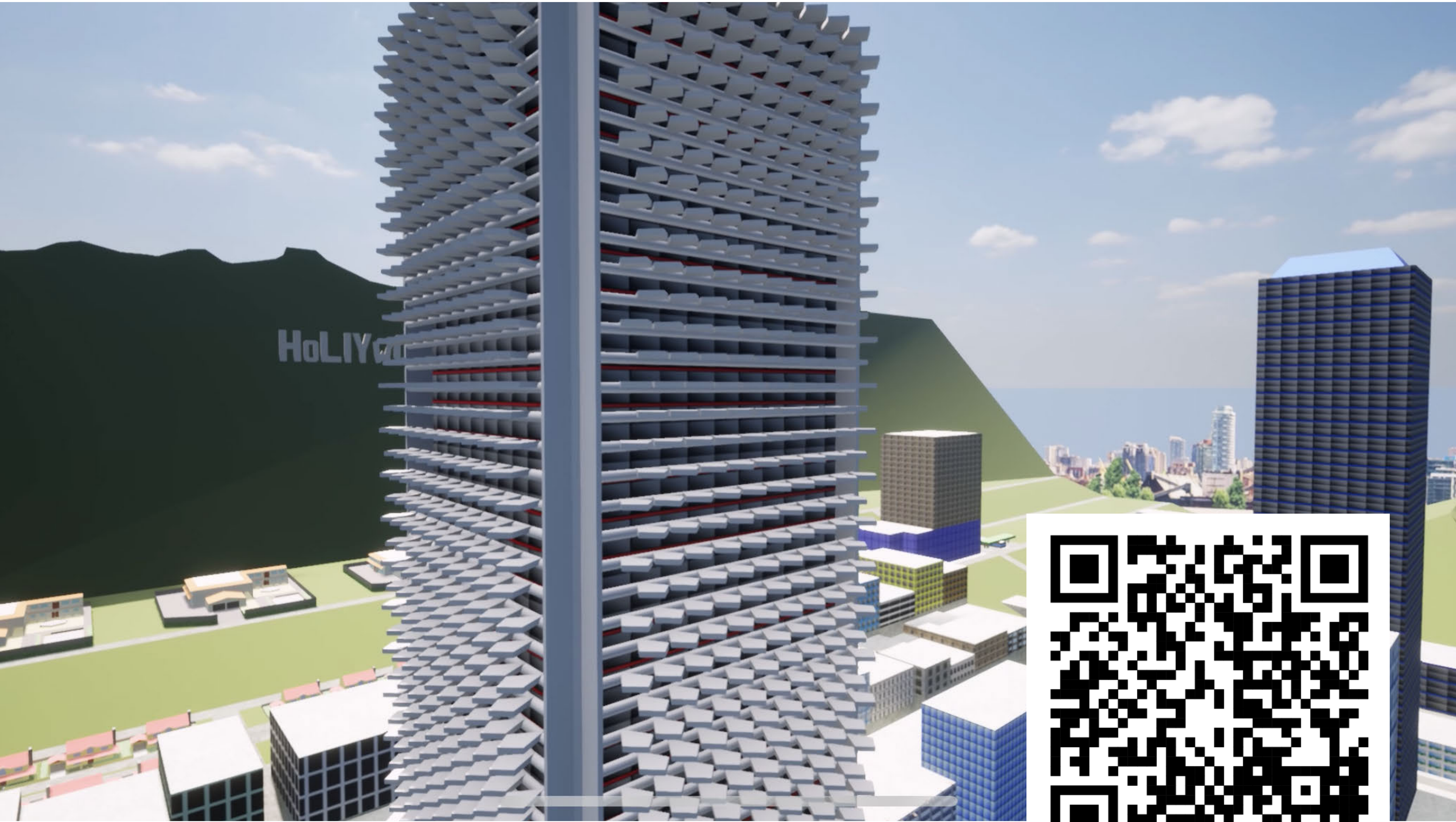




3D printed models of the building facade, open system

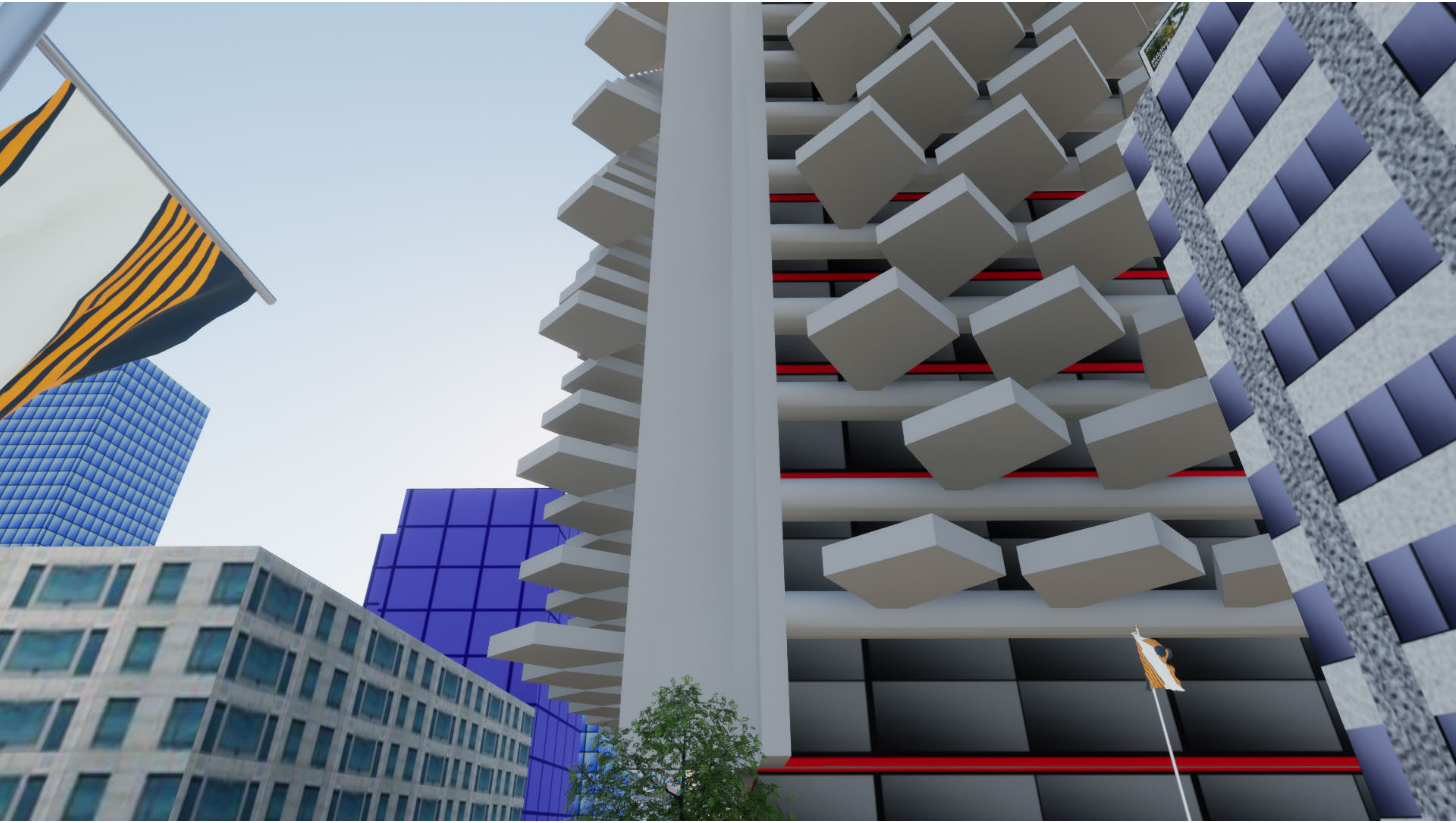


3D printed models of the building facade, closed system

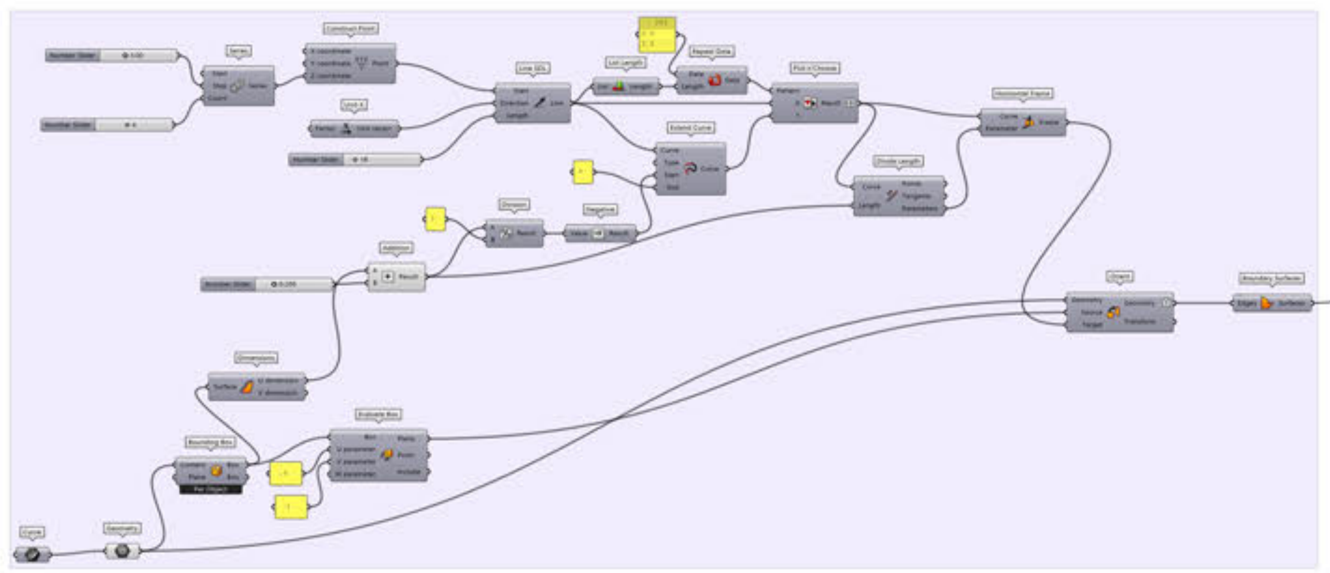


Pine Facade Full Render Animation

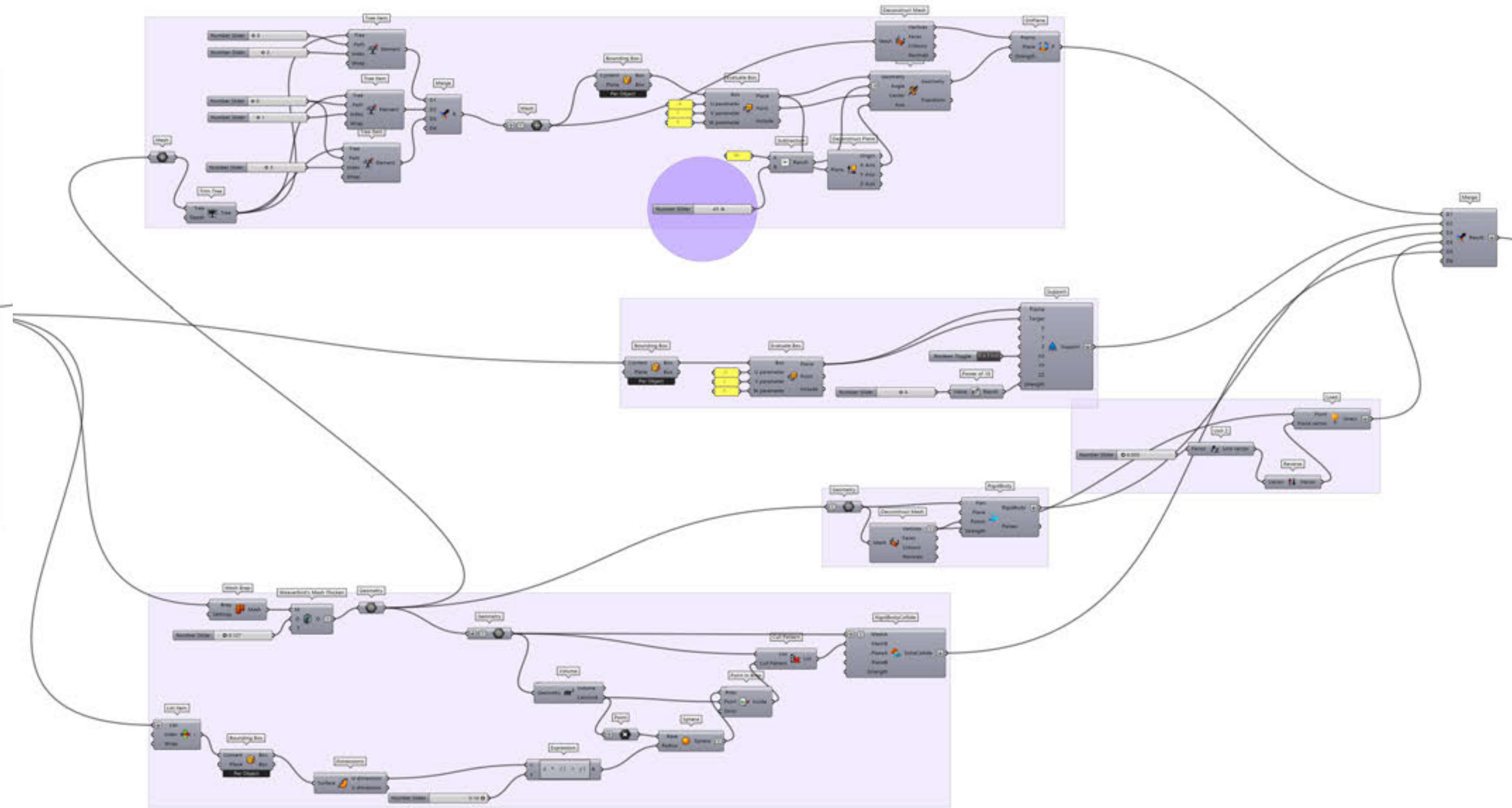
https://youtu.be/gDZek8-5pCA

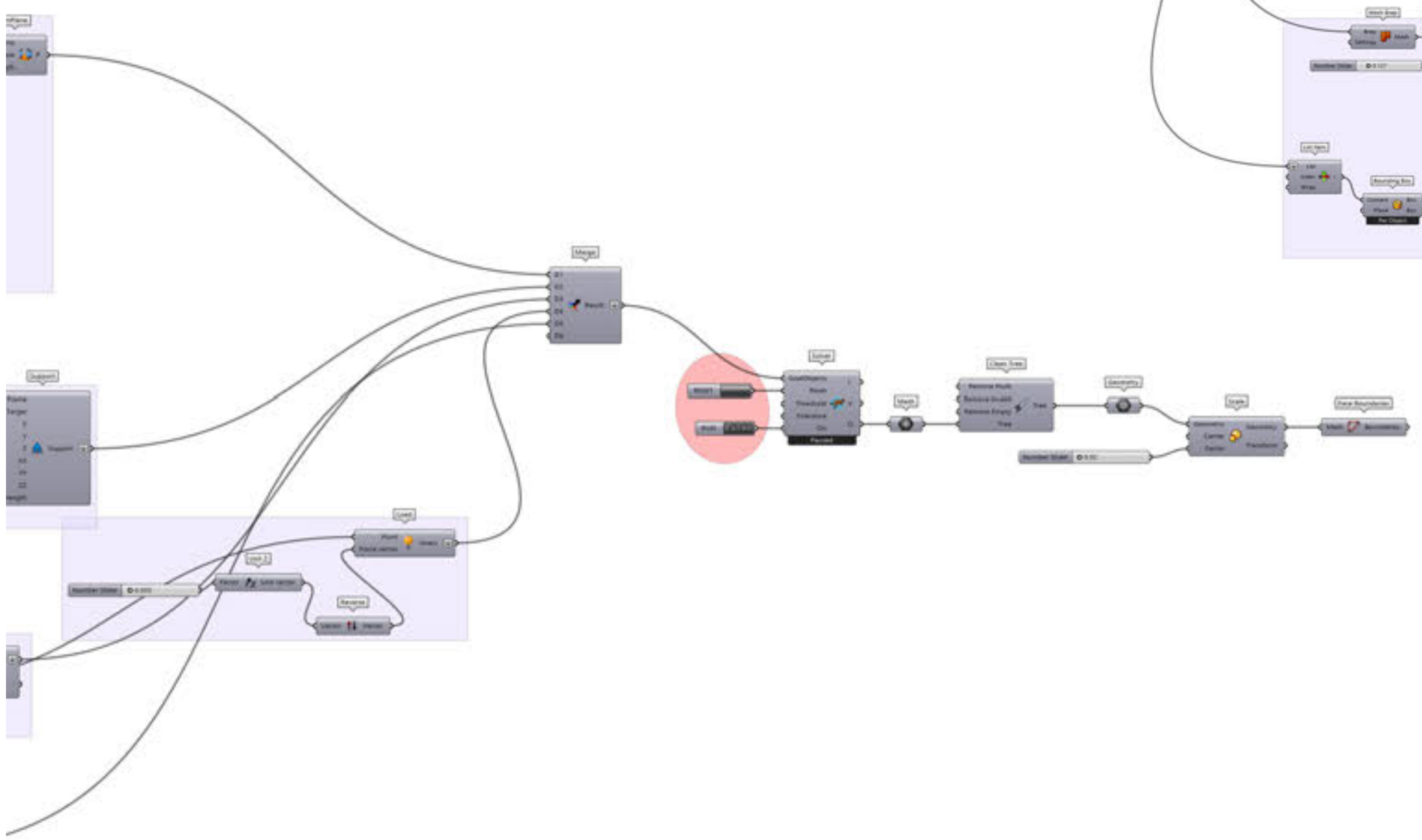


GEOMETRY



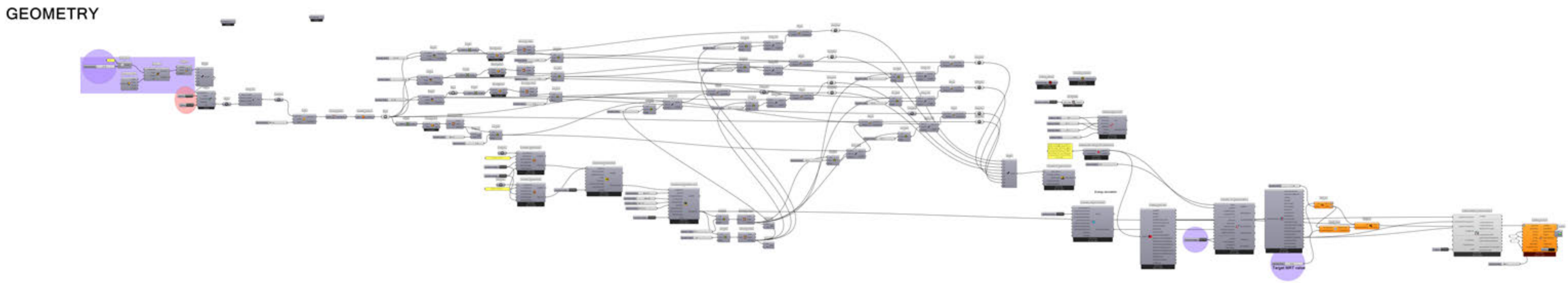
SIMULATION





The final geometry created in grasshopper linked with weaverbird and kangaroo simulation to create the rotation. In this simulation we started off with only 2 segments on the panel which rotated, before selecting the entire row.

Energy Simulation



Summary/Conclusion

The proposal seeks to attain a comfortable thermal ambiance by employing shading strategy that align with the temperature requirements of the intended occupants.

The indoor simulation which shows the % of comfort rate rises on both floors from 19% to 23% on the ground floor and 26% to 28% on the first floor, there is room for further analysis from this simulation which can be carried out to multiple floors, and evaluate the results from the top floor compared to the lower floor and how the comfort % changes.

The deployment of the shade context in the Honeybee energy simulation results in a significant reduction of the number of hours in which the temperature of each zone (floor) exceeds 28°C. Specifically, this reduction amounts to a maximum of 46%. This finding may have important implications for the design and optimisation of buildings, particularly in hot climates, where mitigating heat gain is a crucial consideration. Therefore, this result is noteworthy and warrants further investigation in the field of energy-efficient building design.

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