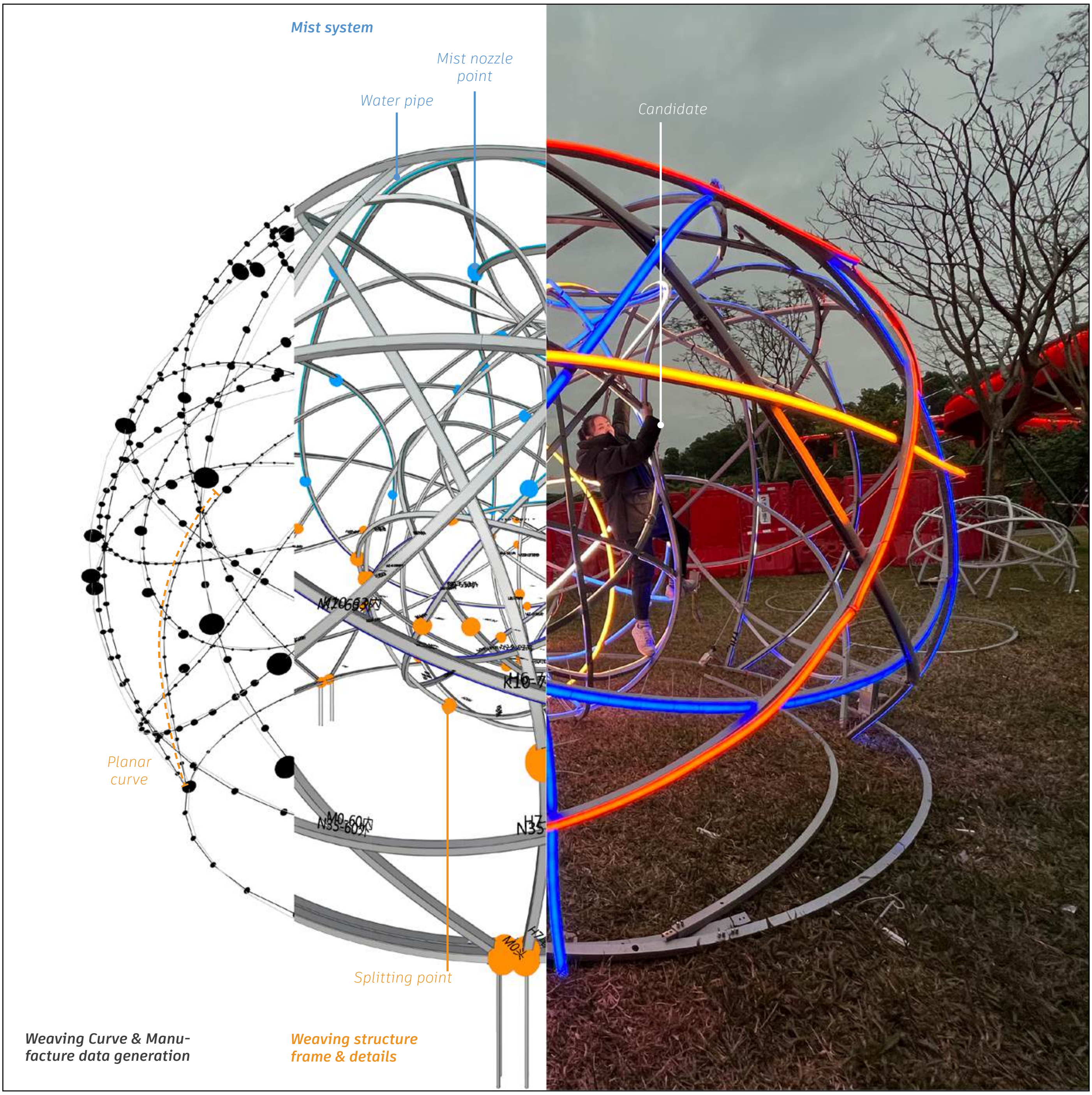
PORTFOLIO

2020-2023

CHIA HUI YEN,
M.S.Computational Design, Carnegie Mellon University, Class of 2026.



Project 4, Droplet, Shen Zhen, China

COVER LETTER

CHIA HUI YEN

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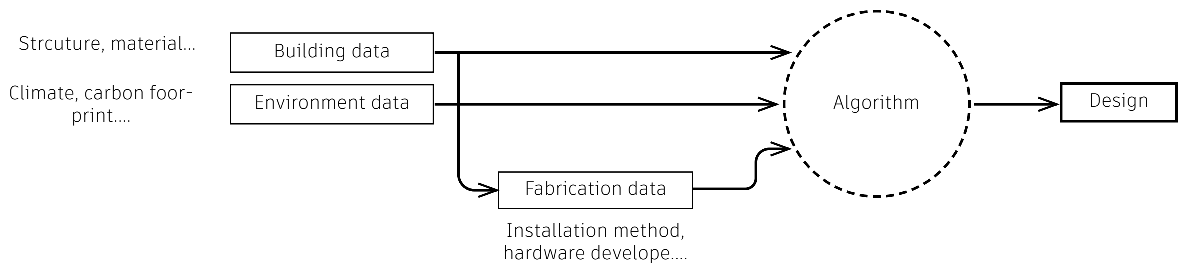
Bentong, Pahang, Malaysia/ Beijing, China

"To me, architecture design, is a rational response to current society and environment, and the form itself reflects the contemporary society in any shape or form. As an architect or designer, I firmly believe in an elegant, pragmatic, profoundly rational responds to human and societal needs. "



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Tutors: Prof. Huang Weixin, huangwx@tsinghua.edu.cn
Team: Chia Hui Yen, Ren Tian Ye, Hu Yao, Xia An Qi
Contributions: Concept 70%, Structure design and optimization 100%

Design optimization: Network

_Light-weight Interactive Light & Art Installation, group project

December 2022

Introduction

Located in Wangjing, Chaoyang District, Beijing, within the Vanke Times Center, the surrounding area boasts modern architecture and a bustling commercial district, including office spaces, shopping malls, and hotels. Moreover, Wangjing is also one of Beijing's cultural and creative hubs, attracting many young designers, artists, and entrepreneurs.

Our objective is to design a landscape installation for the central square of Vanke Times Center. The square is enclosed by five-story buildings, creating an enclosed courtyard-style central plaza.

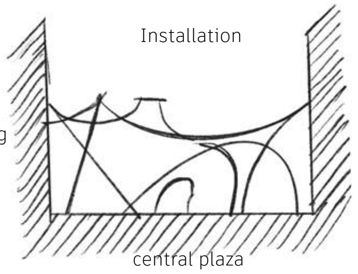
Abstract:

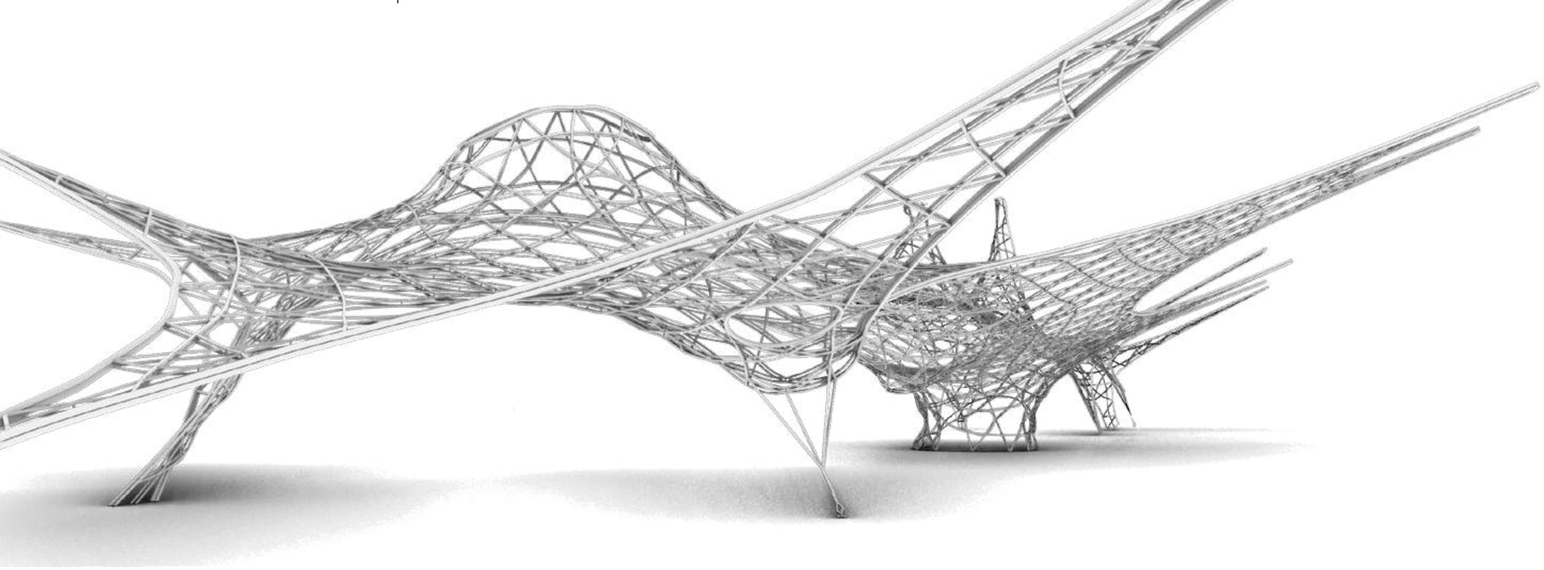
Design Concept — **Structure & Design Development**

Design Concept → Rationalization: Structure Analysis → Multi-objective optimization → Structure and Details Refinement

- Design Concept
  - Interactive design
  - Concept mesh
- Rationalization: Structure Analysis
  - Saddle surface as basic form
  - Factors affecting structure performace
- Multi-objective optimization
  - Form finding
  - Waeving grid finding
  - Materialization

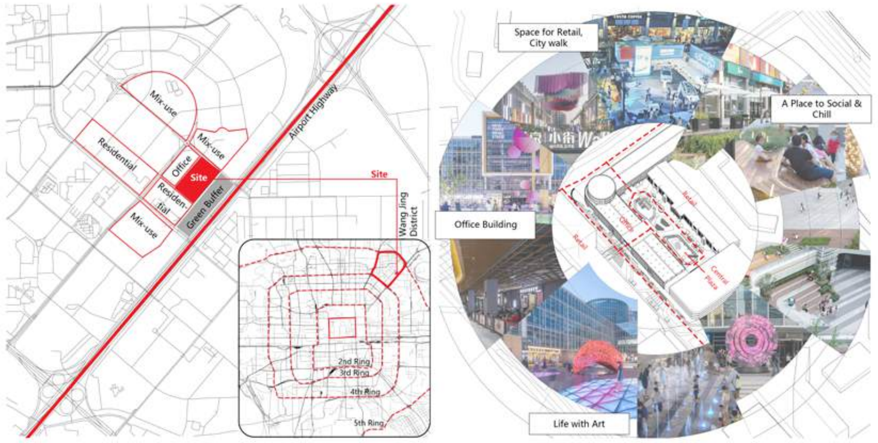
A net that intergrated into space and connect people together.



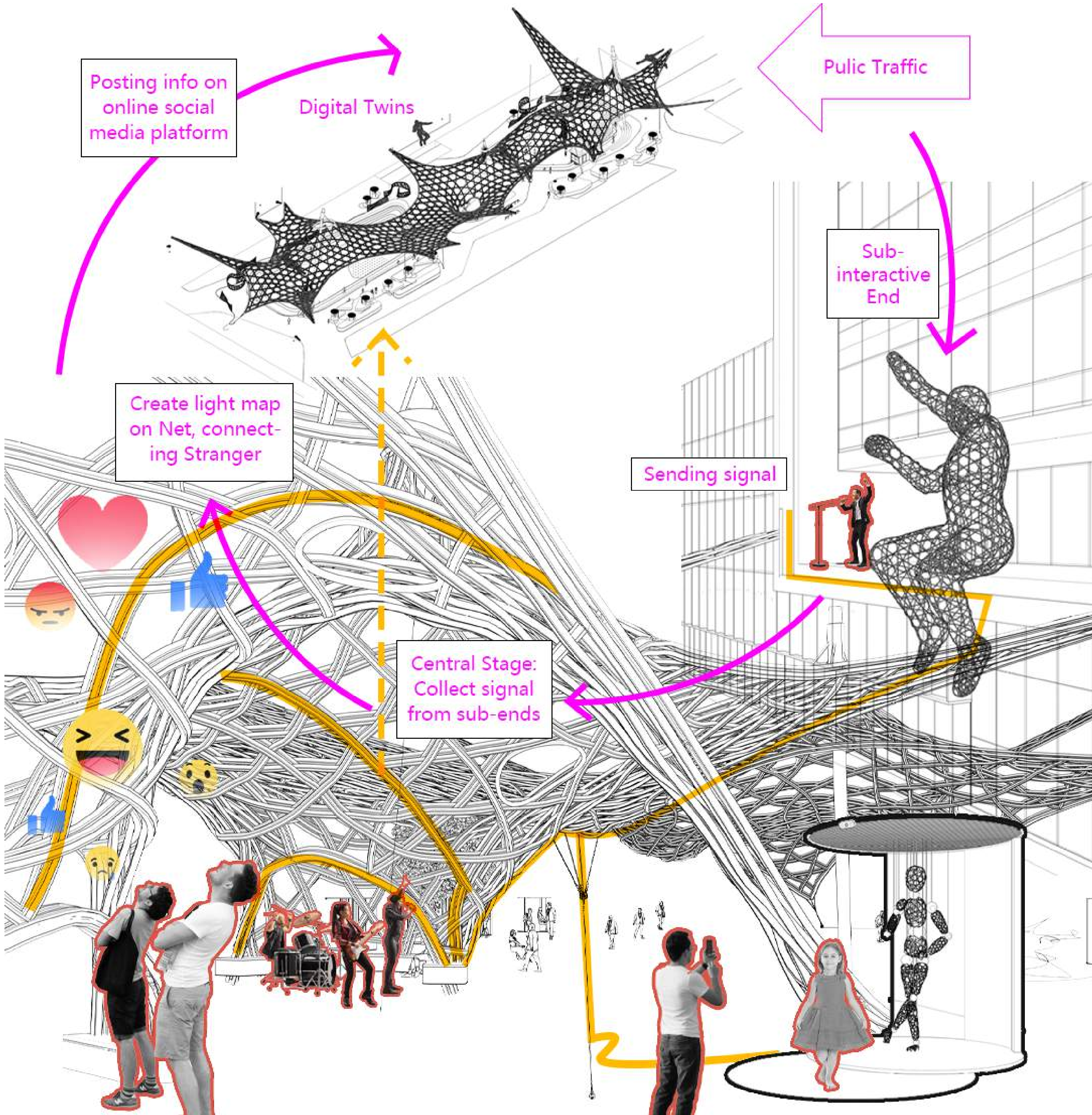


Site Study

The site map included the brief funtions of surrounding:

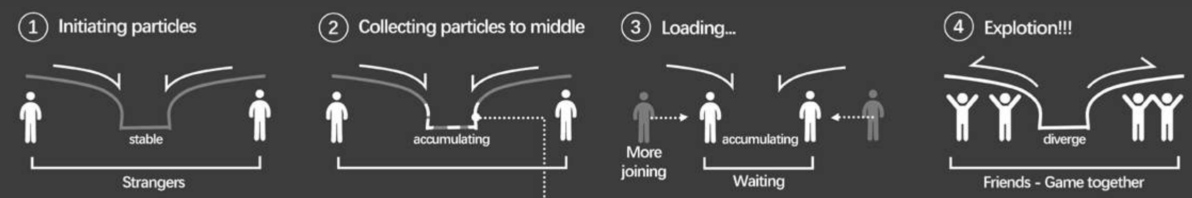


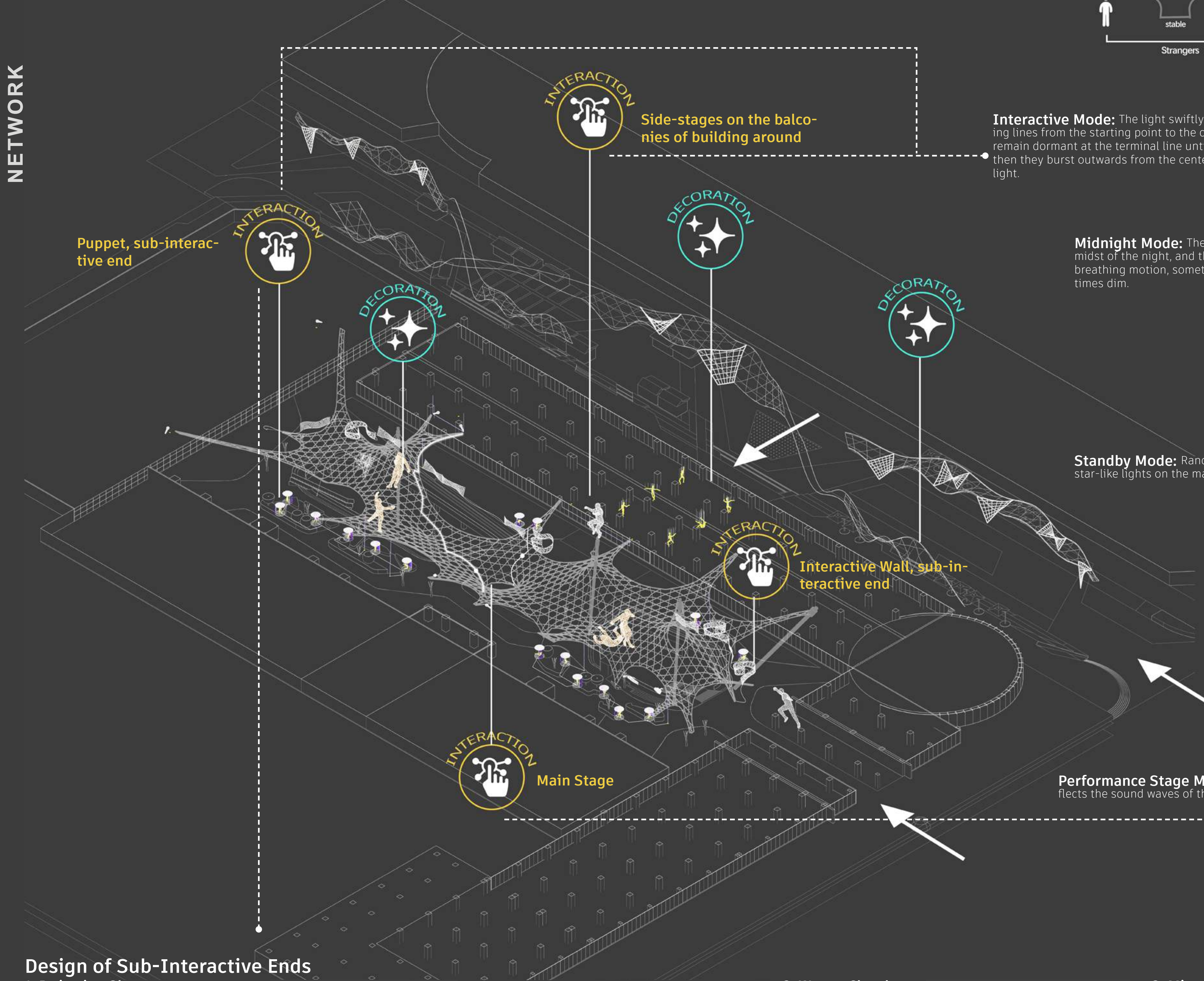
The square serves as a vital gathering, leisure, and activity space for the surrounding community. With the objective of landscape installation design, we can fully leverage the modern and cutting-edge atmosphere and vitality of this location. Our aim is to create a large-scale interactive game that engages people proactively, using uniquely designed spatial art installations. These installations will entice participants to interact with the game, receive feedback from the installations, and encourage them to capture and share their experiences on social media. This will attract more people to visit the square, as the installations are projected into the virtual world of the internet. Ultimately, this design will infuse the square with vibrancy and charm, stimulating commercial activity and enhancing the overall ambiance.



Design Concept: Interactive design of installation

The design of the installation is divided into decorative and interactive components. The interactive design features a main network structure constructed with weaving techniques, along with other woven accessories. Participants can interact with the accessories at the ends, and the light is then transmitted to the main network.



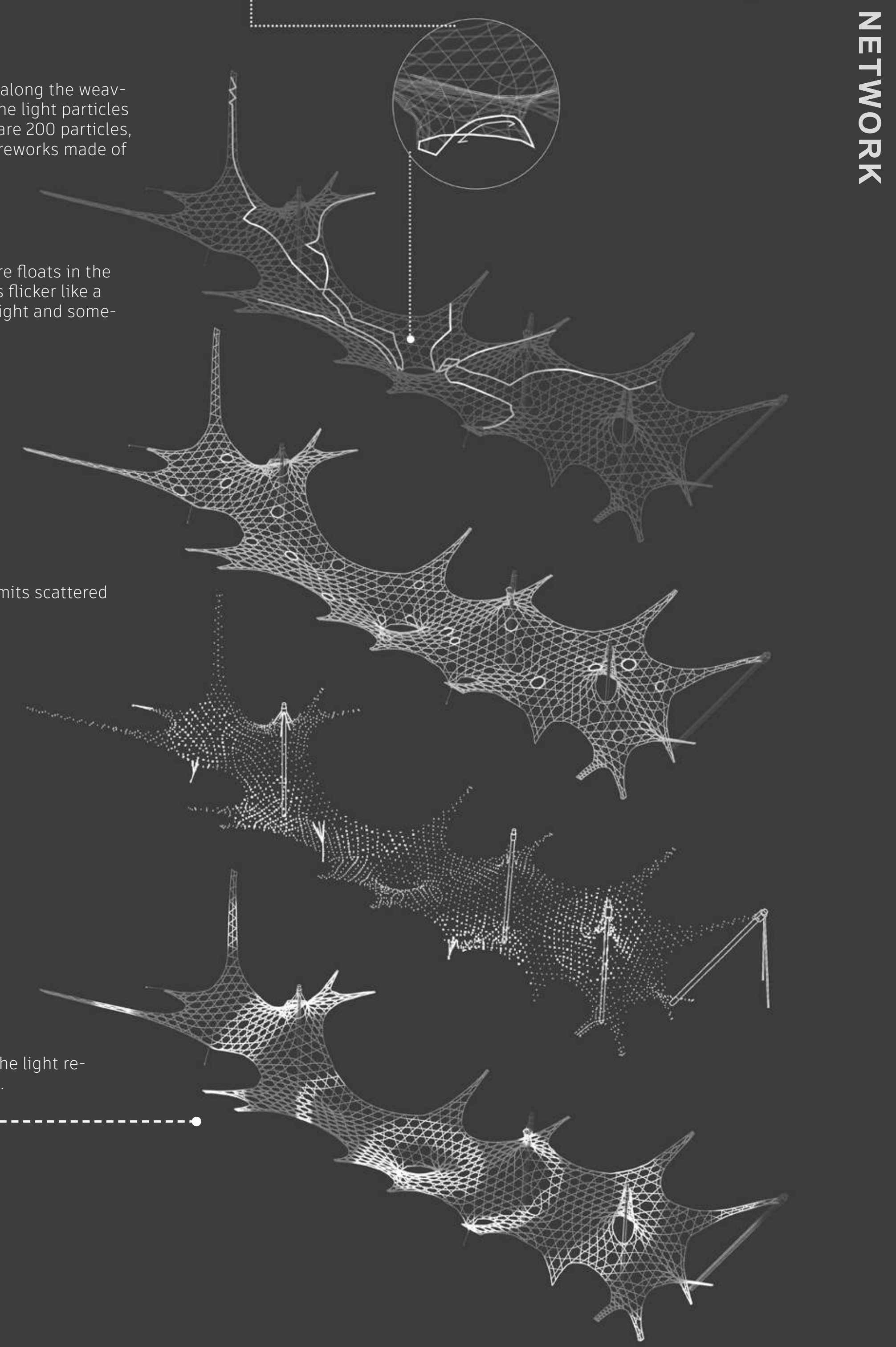


Interactive Mode: The light swiftly travels along the weaving lines from the starting point to the center. The light particles remain dormant at the terminal line until there are 200 particles, then they burst outwards from the center like fireworks made of light.

Midnight Mode: The aperture floats in the midst of the night, and the lights flicker like a breathing motion, sometimes bright and sometimes dim.

Standby Mode: Randomly emits scattered star-like lights on the main grid.

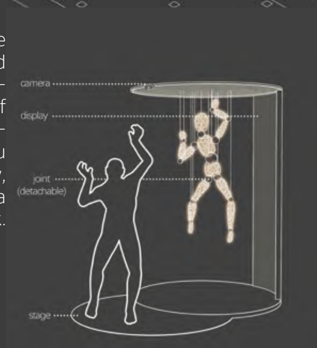
Performance Stage Mode: The light reflects the sound waves of the stage.



Design of Sub-Interactive Ends

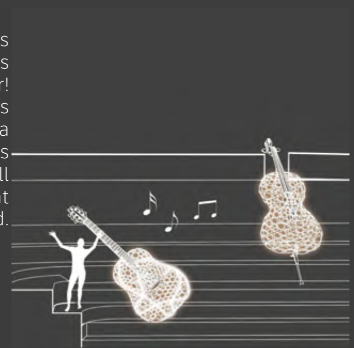
1. Imitation Show

Imitate dance movements and illuminate the little figure! The figure is suspended among the trees on either side of the courtyard. By controlling the hanging points of its joints, the limbs of the figure can be arranged into different dance poses. If you imitate the figure's movements correctly, you will receive a photo opportunity and a light dot will merge into the main network.



2. Woven Chords

How can woven chords produce sound? It turns out to be an electric guitar! Strum the strings of this giant guitar and create a folk melody unique to this evening. The guitar will generate light dots that change with the sound.

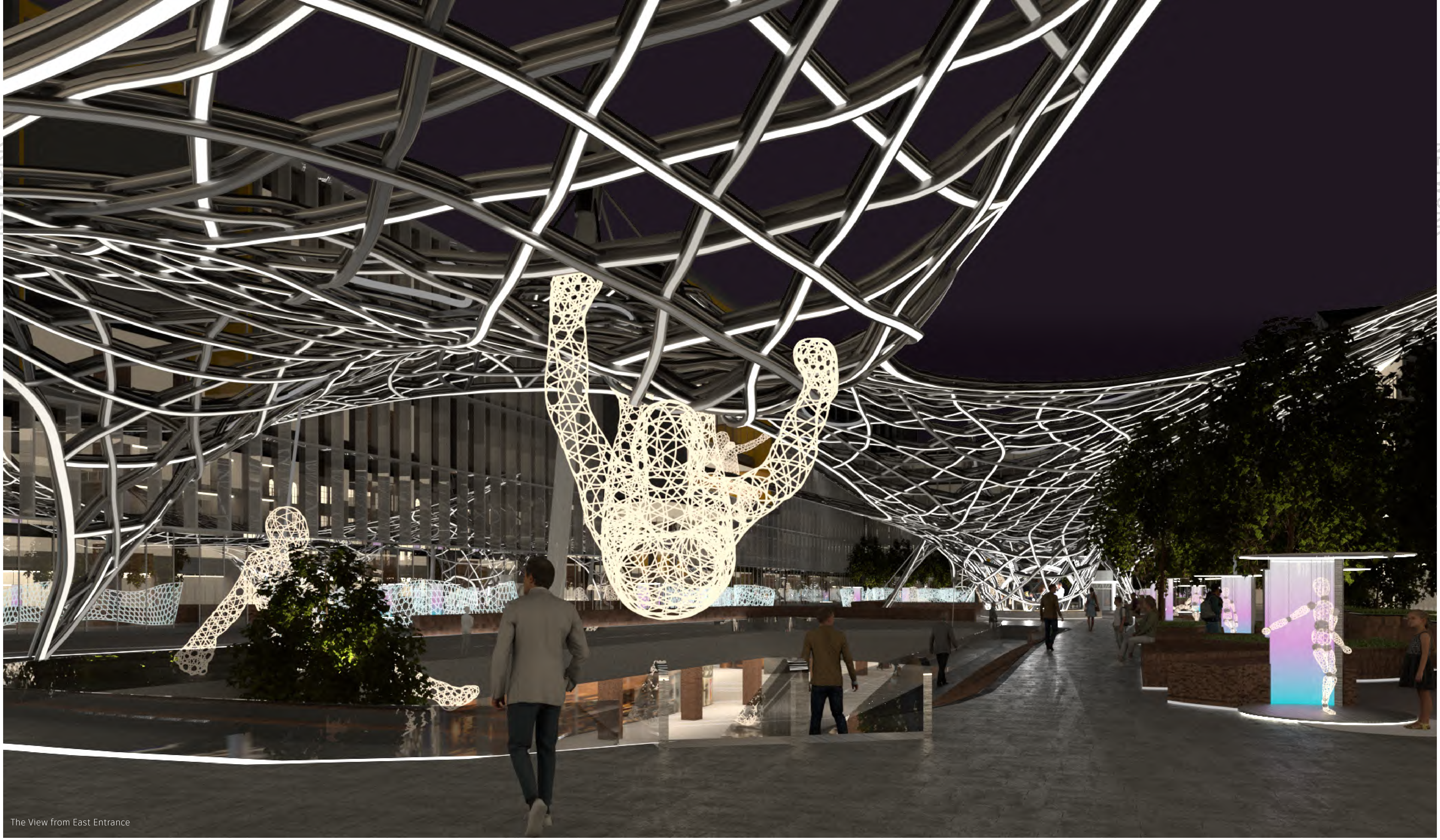


3. Microphone

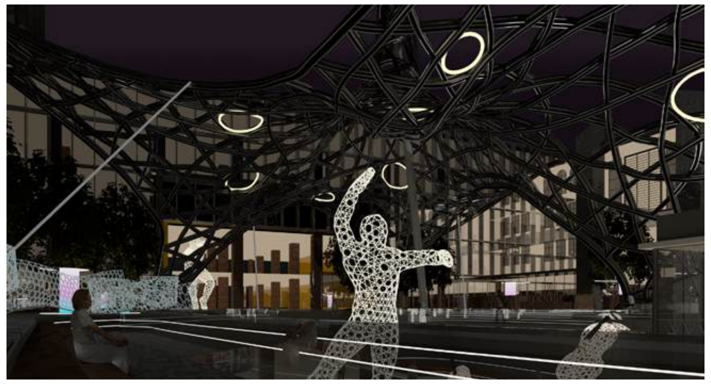
Want to sing a song together in the courtyard? Come to the balcony and find the microphone! Your voice will be transformed into light signals and transmitted to the main network through anchor points on the walls.

4. Graffiti Wall

By waving your hand in front of the graffiti wall, light dots on the wall will following the direction of your hand movements. Eventually, these light dots will converge along connecting lines and transfered to the main network.



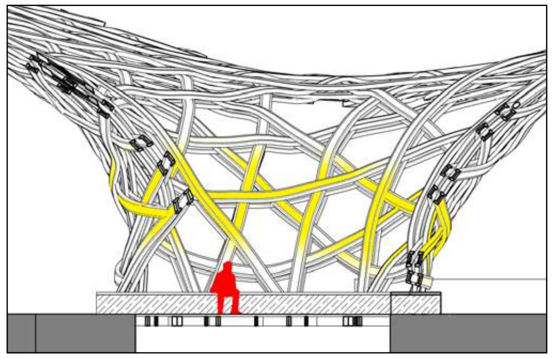
The View from East Entrance



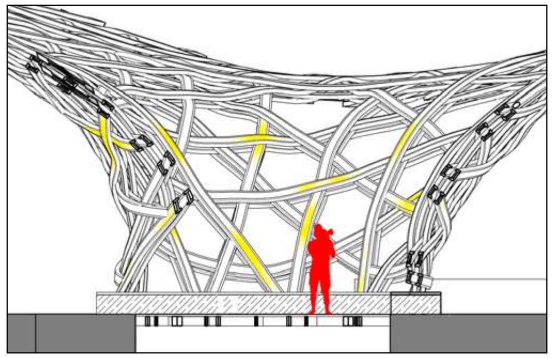
Midnight Mode: The aperture floats in the midst of the night, and the lights flicker like a breathing motion, sometimes bright and sometimes dim.

Operate from 12.00am to 7.00am

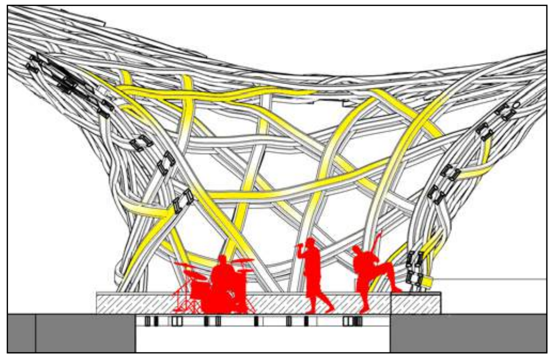
Midnight Mode: Performance mode



Midnight Mode: Performance mode

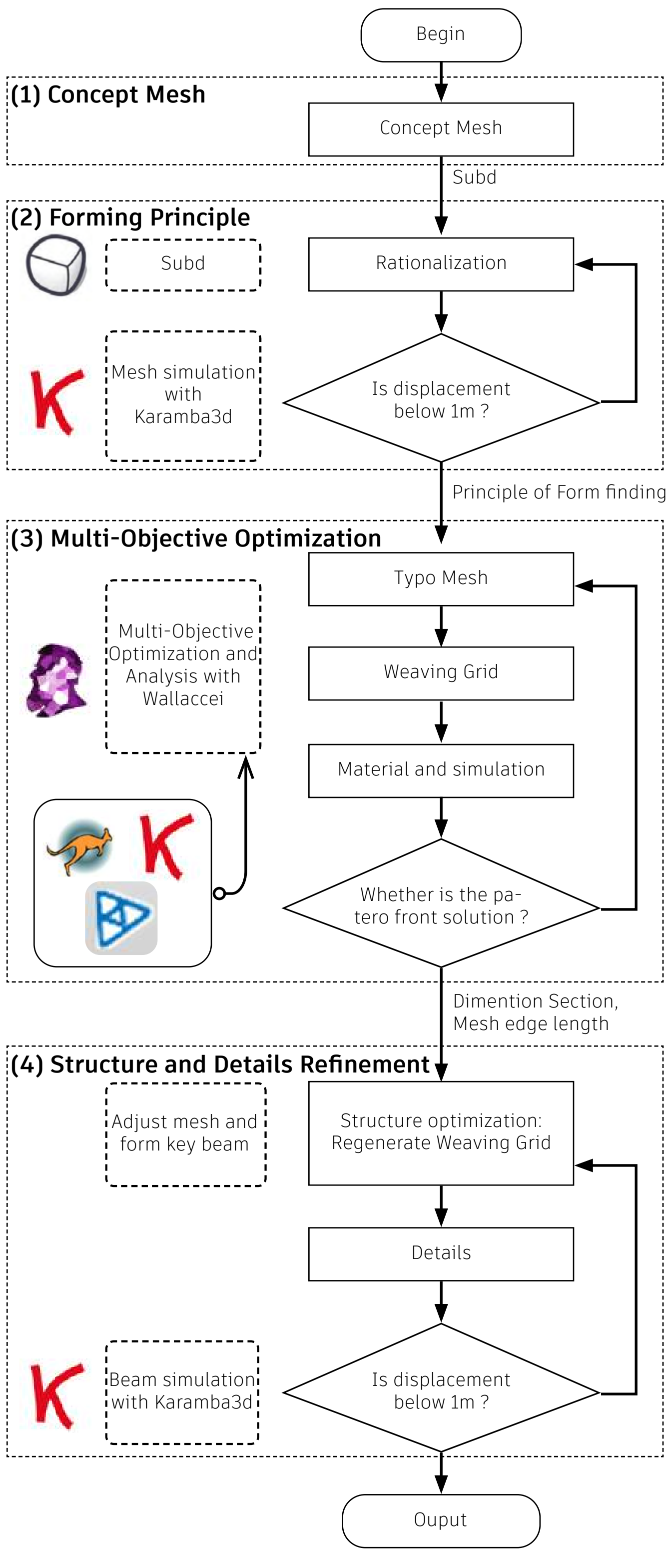


Midnight Mode: Performance mode

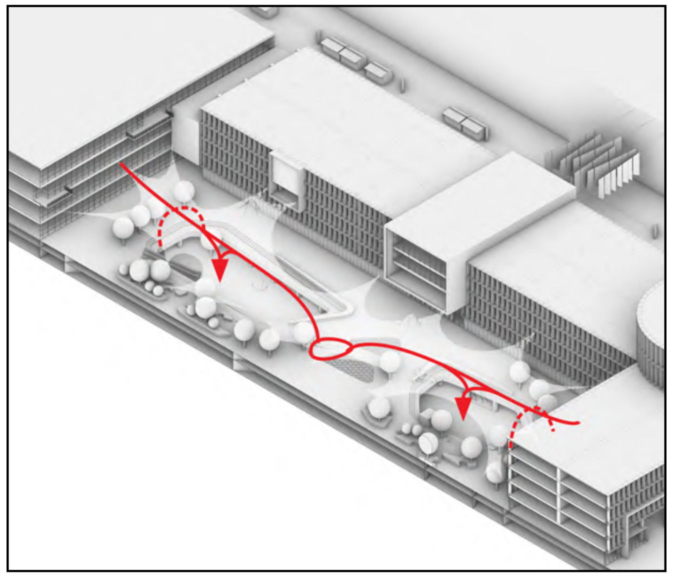


NETWORK

Structure Development:



(1) Concept Mesh

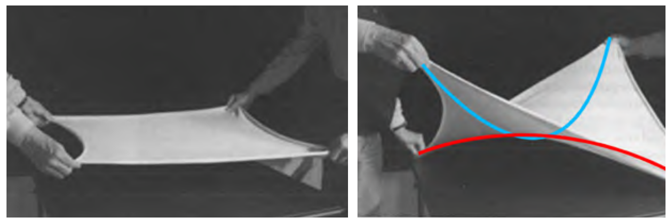


Saddle surfaces, characterized by negative Gaussian curvature, are advantageous in anticlastic forming due to their unique properties. These surfaces enhance structural integrity, distribute stress efficiently, and allow for material-efficient designs. The Gaussian curvature formula for a saddle surface (K) is given by:

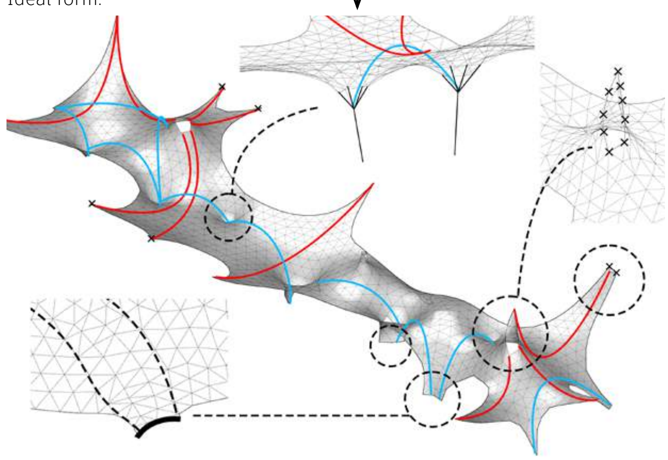
$$K = \frac{f_{xx} f_{yy} - f_{xy}^2}{(1 + f_x^2 + f_y^2)^2}$$

This formula helps analyze and utilize the negative curvature, contributing to the creation of visually appealing and structurally robust forms in various design and engineering applications.

Basic form idea:



Ideal form:

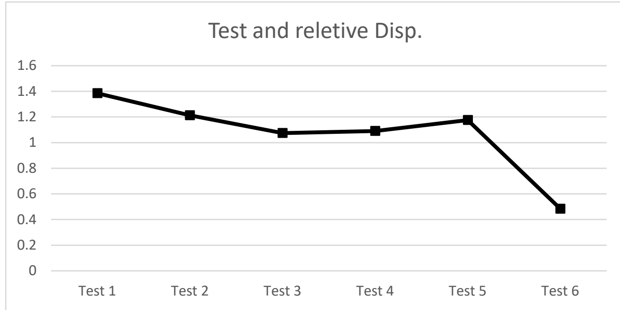


(2) Form Principle: Form finding & Structure Simulation

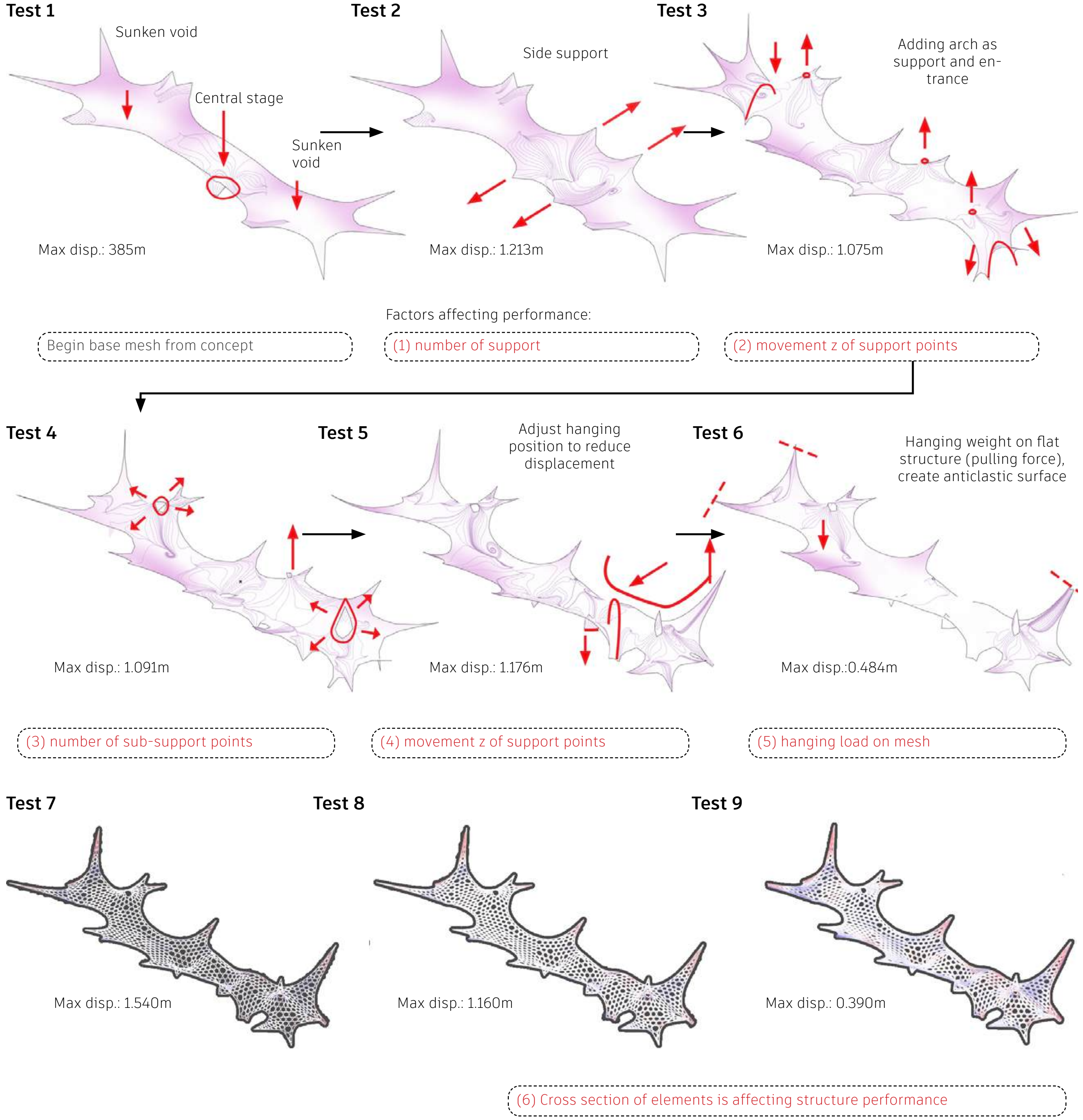
The main design of the structural design is based on the prototype of the woven structure generation technique using grid reconstruction algorithms, achieving large-scale freeform curved surfaces.
Try several type to test out the signifincant factor that affecting structure performance in order to apply it in the Multi-objective optimization later.

Factors affecting structure performance:
1) By utilizing the mechanical characteristics of saddle surfaces combined with tensioned membrane forms, the basic form is determined according to spatial functional requirements.
2) Adjustments are made to the positioning of anchor points and additional bracing elements to achieve a more evenly distributed stress distribution and strengthen the anchor points.
3) Material selection, grid pattern developement, and cross-sectional dimensions of the members are adjusted.

Different strategy and structure performance:



NETWORK



(3) Multi-Objective Optimization

Design Optimization by Multi-Objective Optimization. Split the process to three part, with different iteration times. Splitting parts to save iteration time spent, giving particular part more iteration round, more accurate result, and provide manual adjustment between process.
Process using Wallacei[1].

Part 1: Form finding
Geo: mesh
iteration: 300
total time: 20 min

→ Manual Adjust →

Part 2: Grid finding
Geo: curves
iteration: 100
total time: 20 min

→ Manual Adjust →

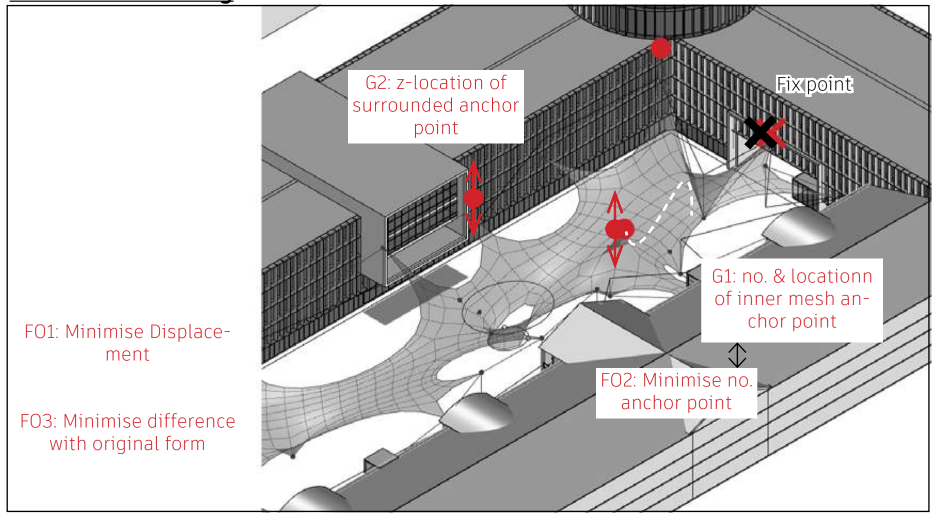
Part 3: Materialization
Geo: mesh
iteration: 50
total time: 20 min

less time spent, total iteration time: 01:17:54
higher flexibility, manually adjustment in the middle
higher accuracy, more iteration round at every part of optimization

NETWORK

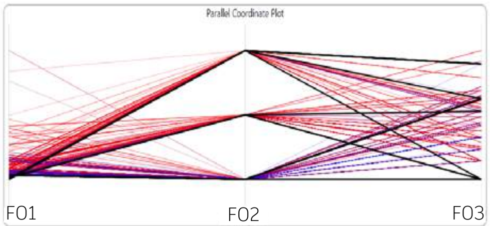
**FO: Fitness Objective, FV: Fitness Value, G: Gene

Part 1: Form finding

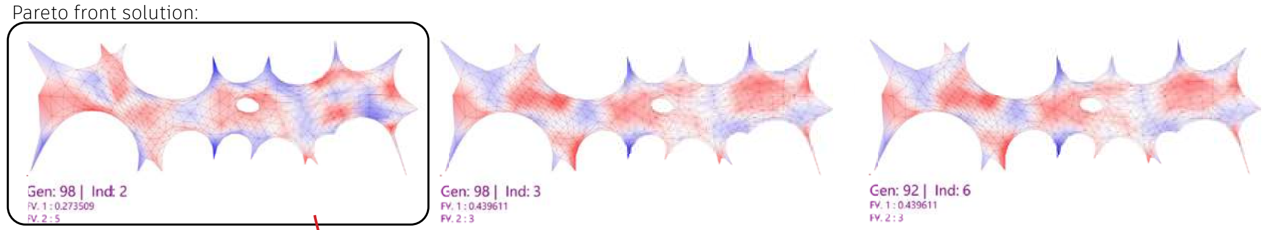


Go throught shell strength simulation by Karamba 3D plugin to find out the best structure performace mesh form.
Giving support point variable z-axis movement, to find the suitable height of support to form saddle surface.

Simulation result:
Simulation RunTime: 00:35:32
Size Generation: 10
Generation Count: 300

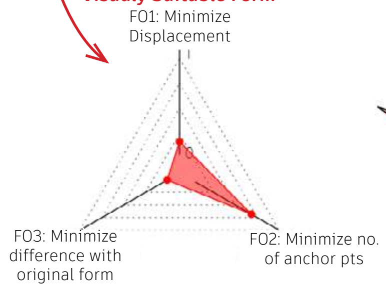


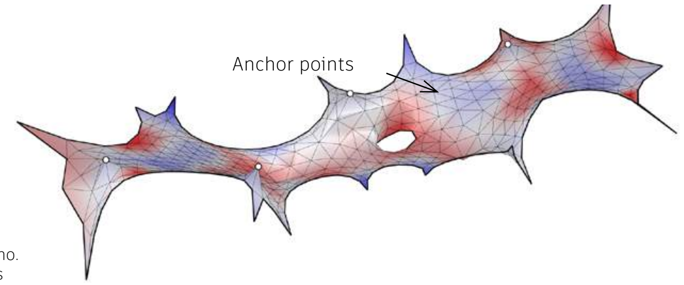
Pareto front solution:



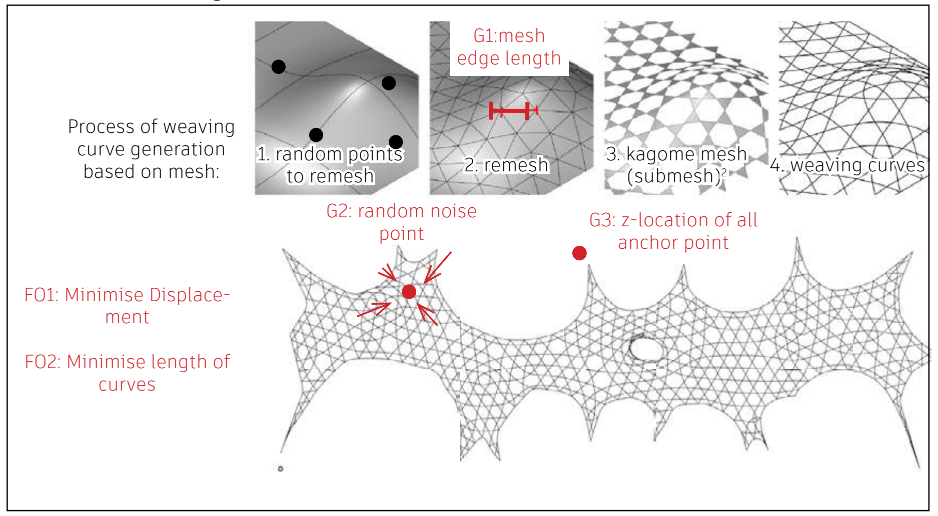
Final form result:
FO1: Minimize Displacement
Fitness Value: 0.240186 (m)
Fitness Rank: 504/2999
FO2: Minimise no. anchor point
Fitness Value: 5
Fitness Rank: 2047/2999
FO3: Minimise difference with origial form
Fitness Value: 72 690219
Fitness Rank: 0 / 2999

Visualy Suitable Form





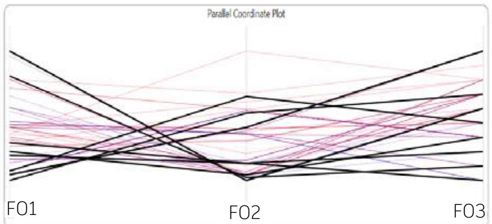
Part 2: Grid finding



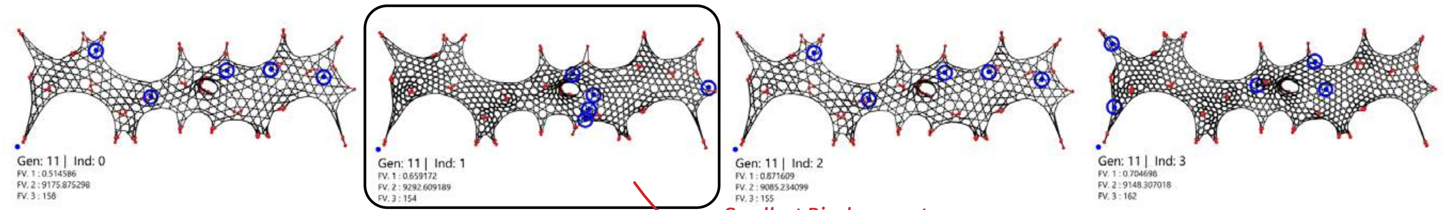
Weaving grid generate from the typology mesh from part 1 simulation. Go through grasshopper bending active simulation to find a suitable weaving grid size.
To set up kangaroo zombie solver, go through normal solver simulation, take a suitable threshold and tolerance for zombie solver in order to do repeatative simulation

Name	Threshold	Tolerance	Time	teratio	Disp
3	1.00E-15	0.0001	20.0s	6610	0.886242
normal solver	1.00E-15	0.0001	160.0s(?)	9120	0.886242

Simulation result:
Simulation RunTime: 00:22:55
Size Generation: 10
Generation Count: 20

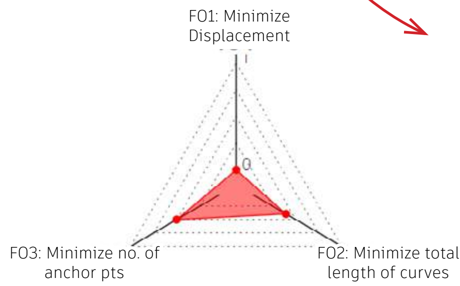


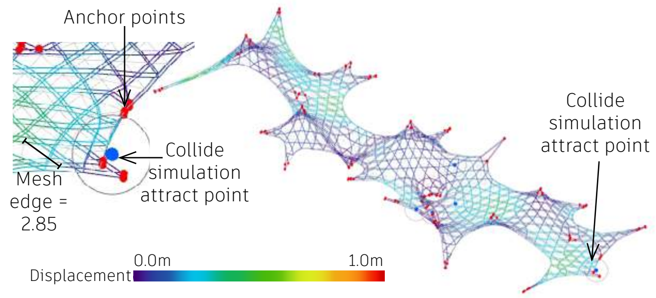
Pareto front solution:



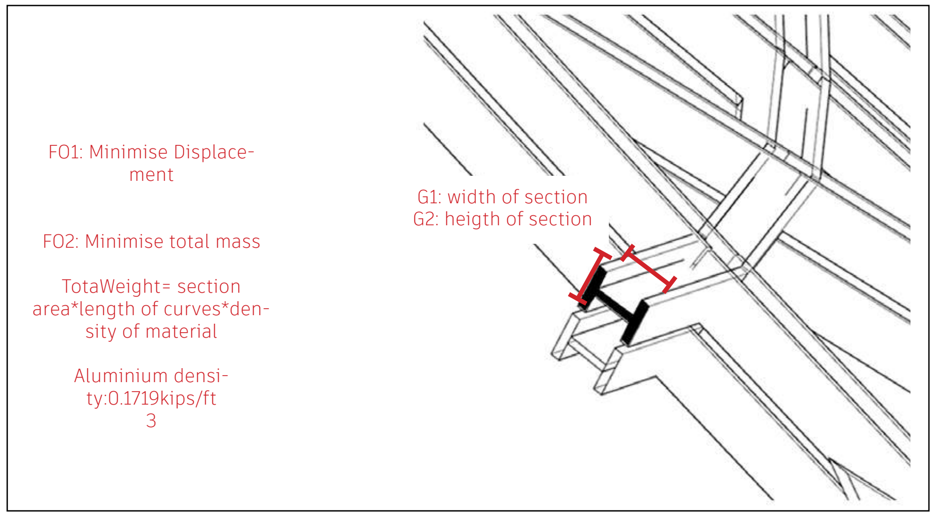
Smallest Displacement

Final form result:
FO1: Minimize Displacement
Fitness Value: 0.479445 (m)
Fitness Rank: 0 / 119
FO2: Minimize total length of curves
Fitness Value: 9565 854245
Fitness Rank: 92 / 119
FO3: Minimize no. of anchor pts
Fitness Value: 155
Fitness Rank: 80 119

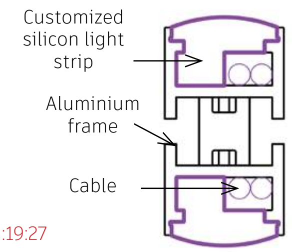




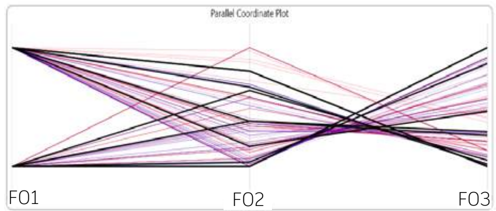
Part 3: Materialization



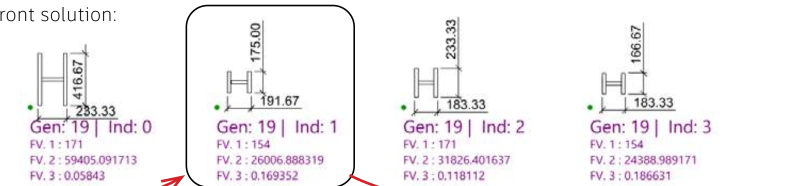
Propose a basic form for structure section that include light and electricity.
Go through Karamba 3d simulation to get a suitable section size

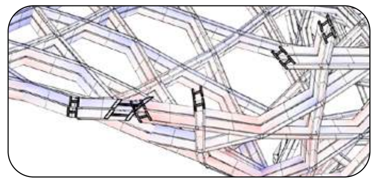


Simulation result:
Simulation RunTime: 00:19:27
Size Generation: 10
Generation Count: 20

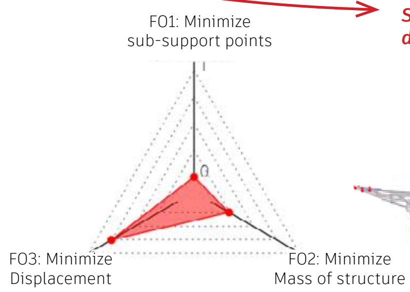


Pareto front solution:

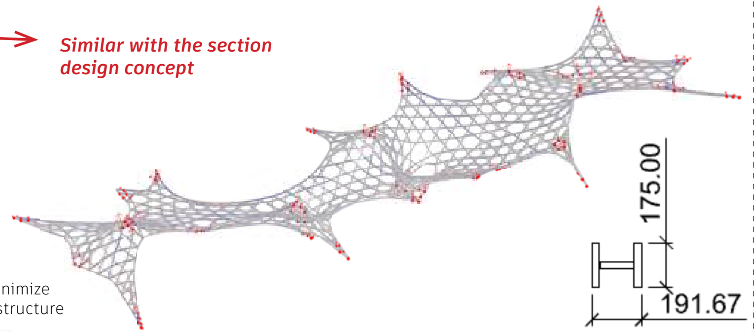




Final form result:
FO1: Minimise sub-support points
Fitness Value: 154
Fitness Rank: 0 / 199
FO2: Minimise mass of structure
Fitness Value: 26006.888319
Fitness Rank: 47 / 199
FO3: Minimise displacement
Fitness Value: 0.169352 (m)
Fitness Rank: 150/199



Similar with the section design concept



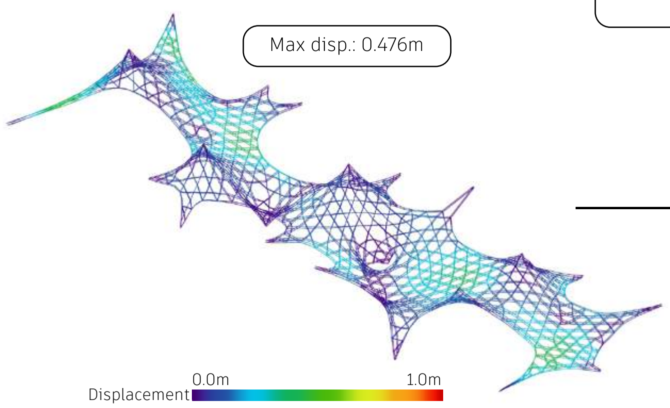
Reference:
1. Makki M, Showkatbakhsh M, Tabony A, Weinstock M. Evolutionary algorithms for generating urban morphology: Variations and multiple objectives. International Journal of Architectural Computing. 2019;17(1):5-35. doi:10.1177/1478077118777236
2. Huang, W., Wu, C., Hu, J., & Gao, W. (2022). Weaving structure: A bending-active gridshell for freeform fabrication. Automation in Construction, 136, 104184.

(4) Structure and Details Refinement

From optimizing the mesh pattern, make sure the main support is continuous

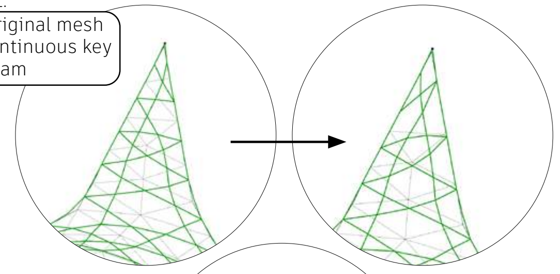
Mesh refinement:

Original:



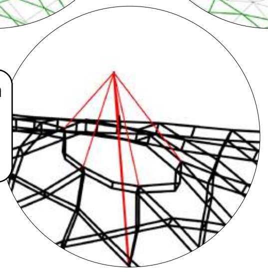
Refinement 1:

Modified original mesh to create continuous key beam

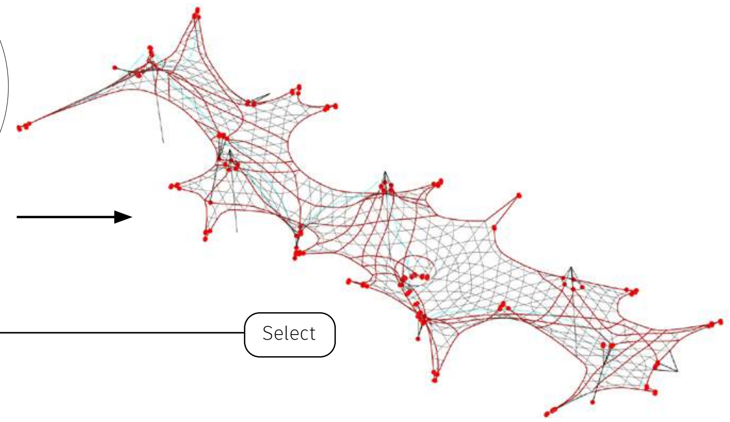


Refinement 2:

Modified mesh and generate rope to hang mesh



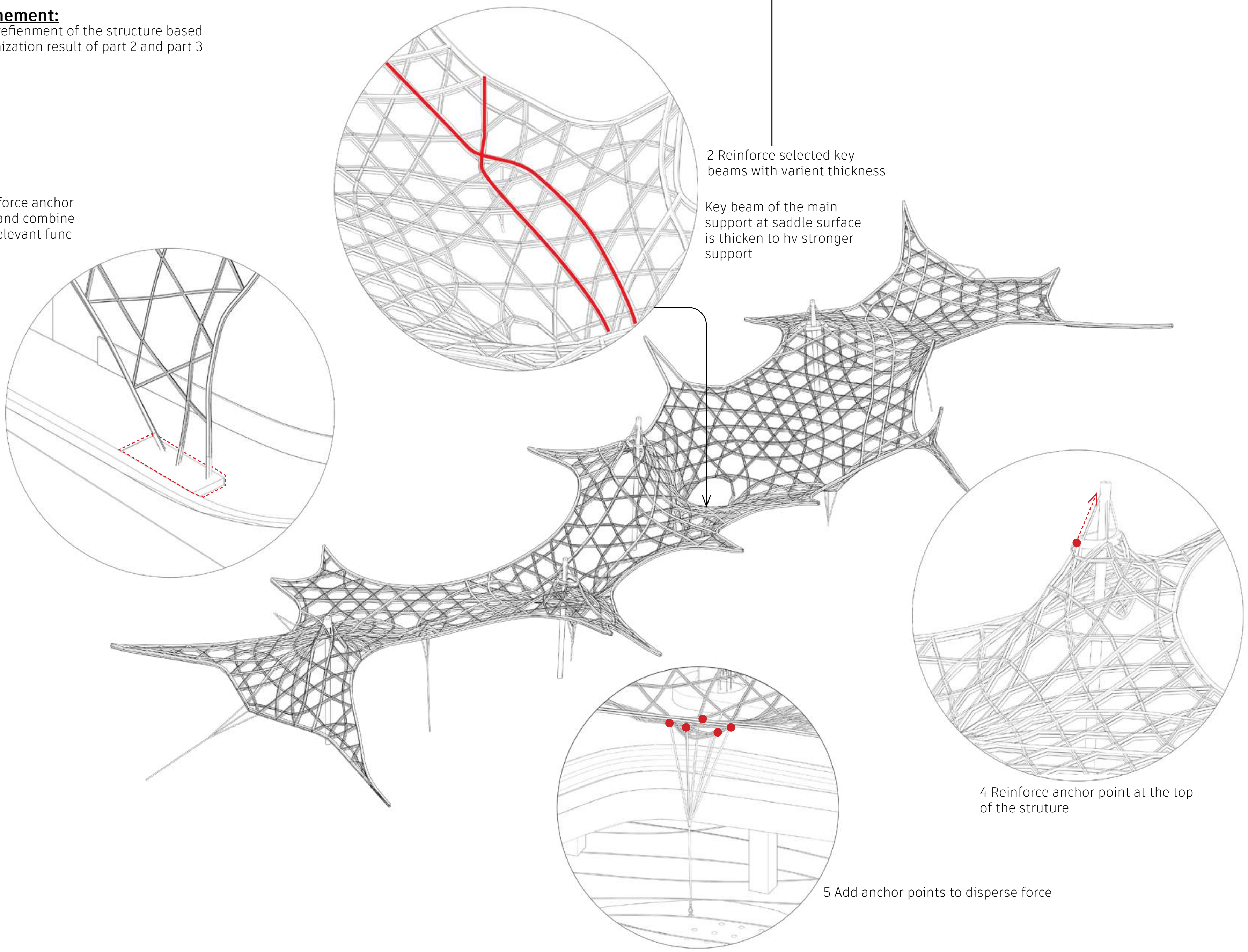
Refinement 2:



Select

Final refinement:

Go through refinement of the structure based on the optimization result of part 2 and part 3



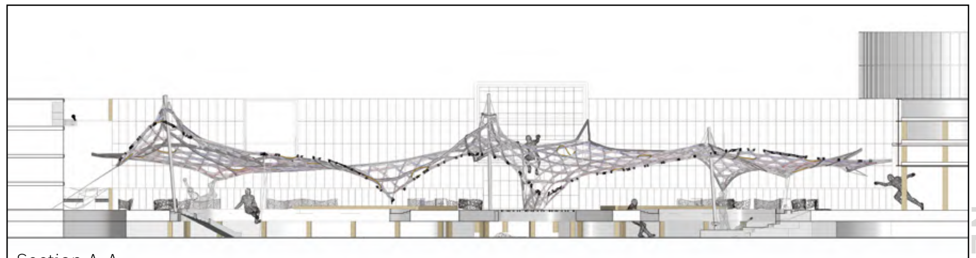
2 Reinforce selected key beams with varient thickness

Key beam of the main support at saddle surface is thicken to hv stronger support

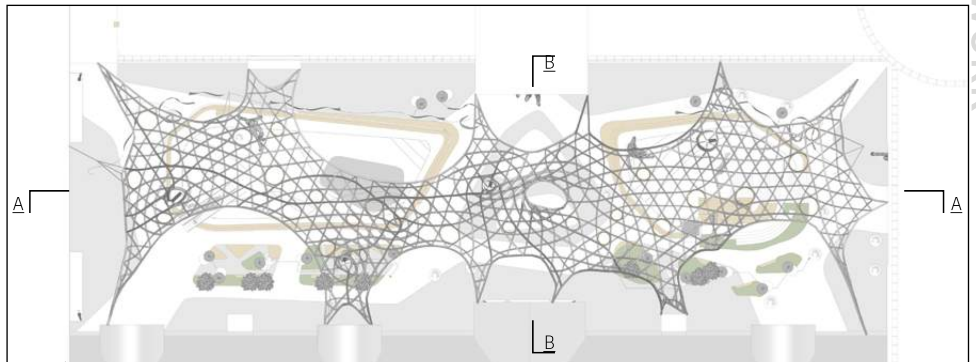
1 Reinforce anchor point and combine with relevant functions

4 Reinforce anchor point at the top of the struture

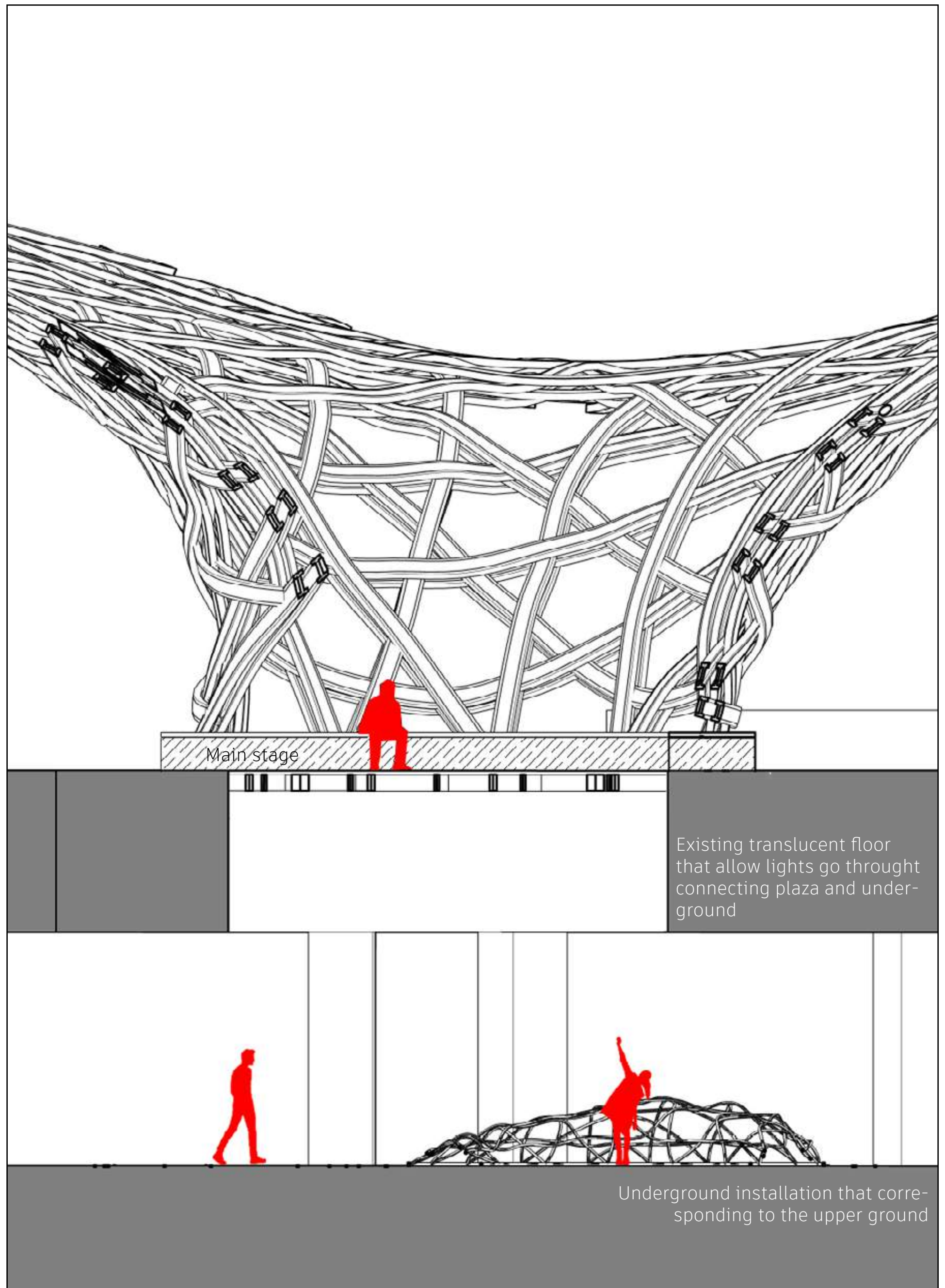
5 Add anchor points to disperse force



Section A-A



Top view



Section B-B

Tutors: Prof. Huang Wei Xin, huangwx@tsinghua.edu.cn
Team: Chia Hui Yen, Bai Jing, Hu Jing Yuan, Zheng Li Yu
Contributions: Artificial Fog System Design 100%, On-site Construction 20%

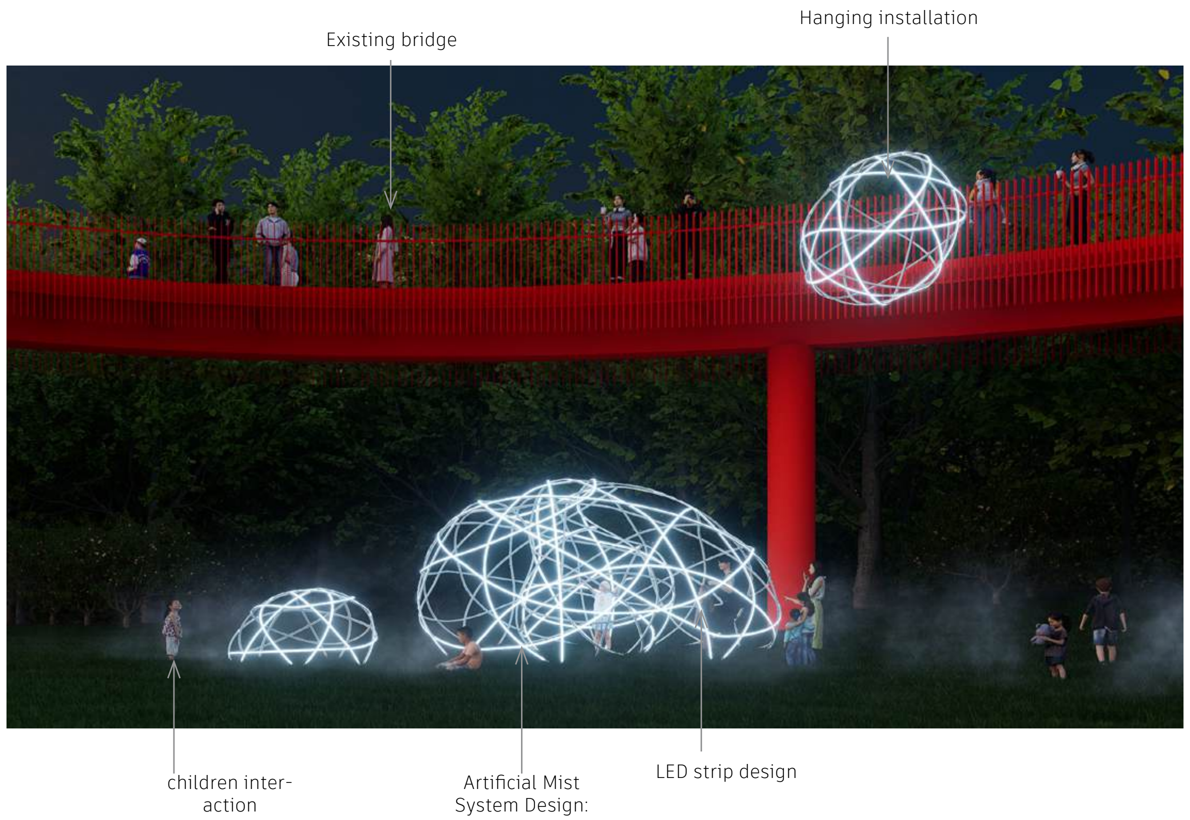
Digital Fabrication: Droplet

_Digital Fabrication, Structure design, Artificial fog system design

October 2023 - December 2023

Introduction

Inspired by water droplets, the concept features diverse droplet shapes distributed throughout the venue, forming illuminated woven curves for interactive engagement. Utilizing anodized aluminum profiles, LED strips, and misting devices create a dynamic interplay of shadows and offer a cool resting spot during the day,The intelligently generated structure mimics natural relationships, serving as both a stable form and an interactive installation for children, parents, and architecture enthusiasts. Technologies include generative and participatory structures, along with self-sustaining lighting.

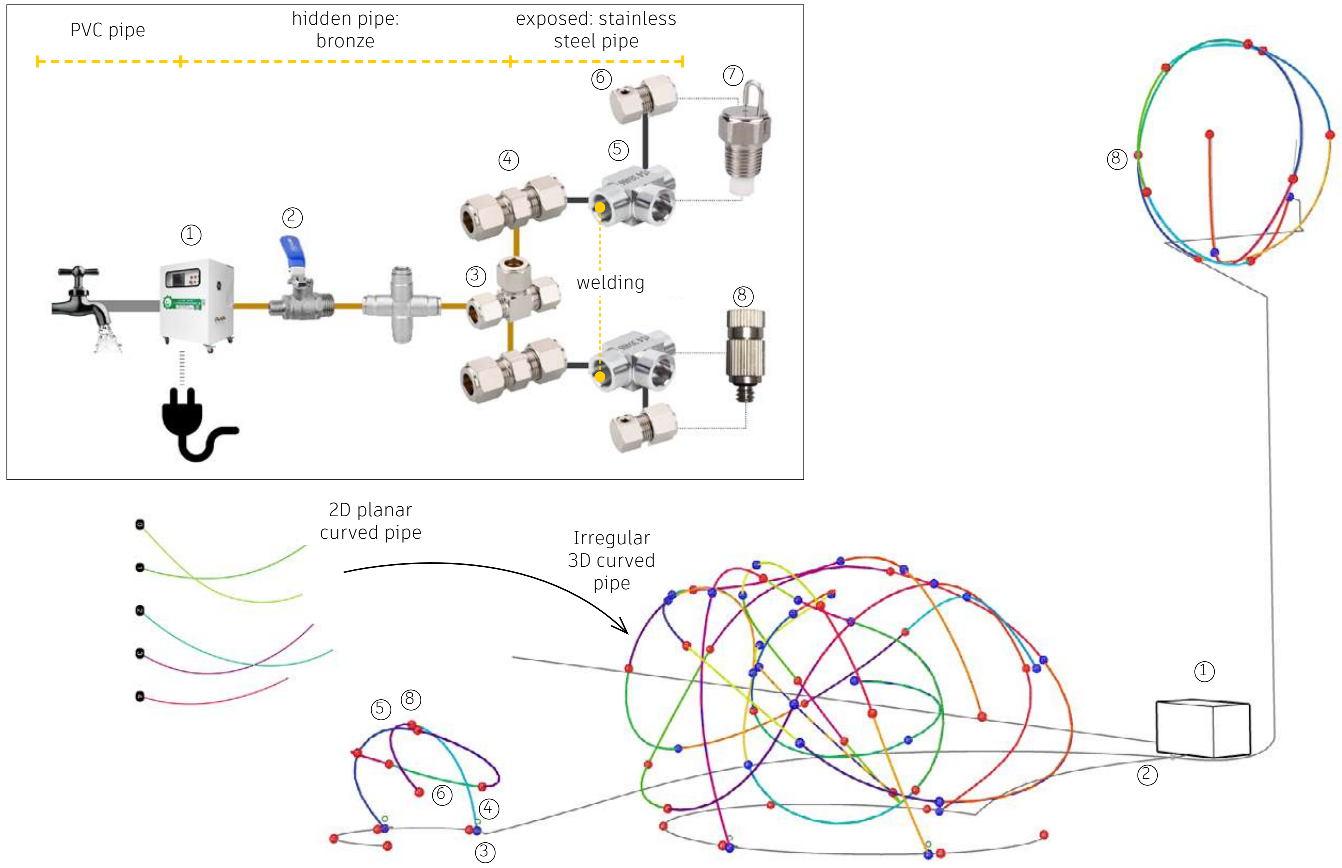


As a actual built project, the design module included LED strip system design. electricity system design, structure detail, structure fabrication and artificial fog system design. I participated in **structure manufacturing optimization design** and lead the **artificial fog system design individually**

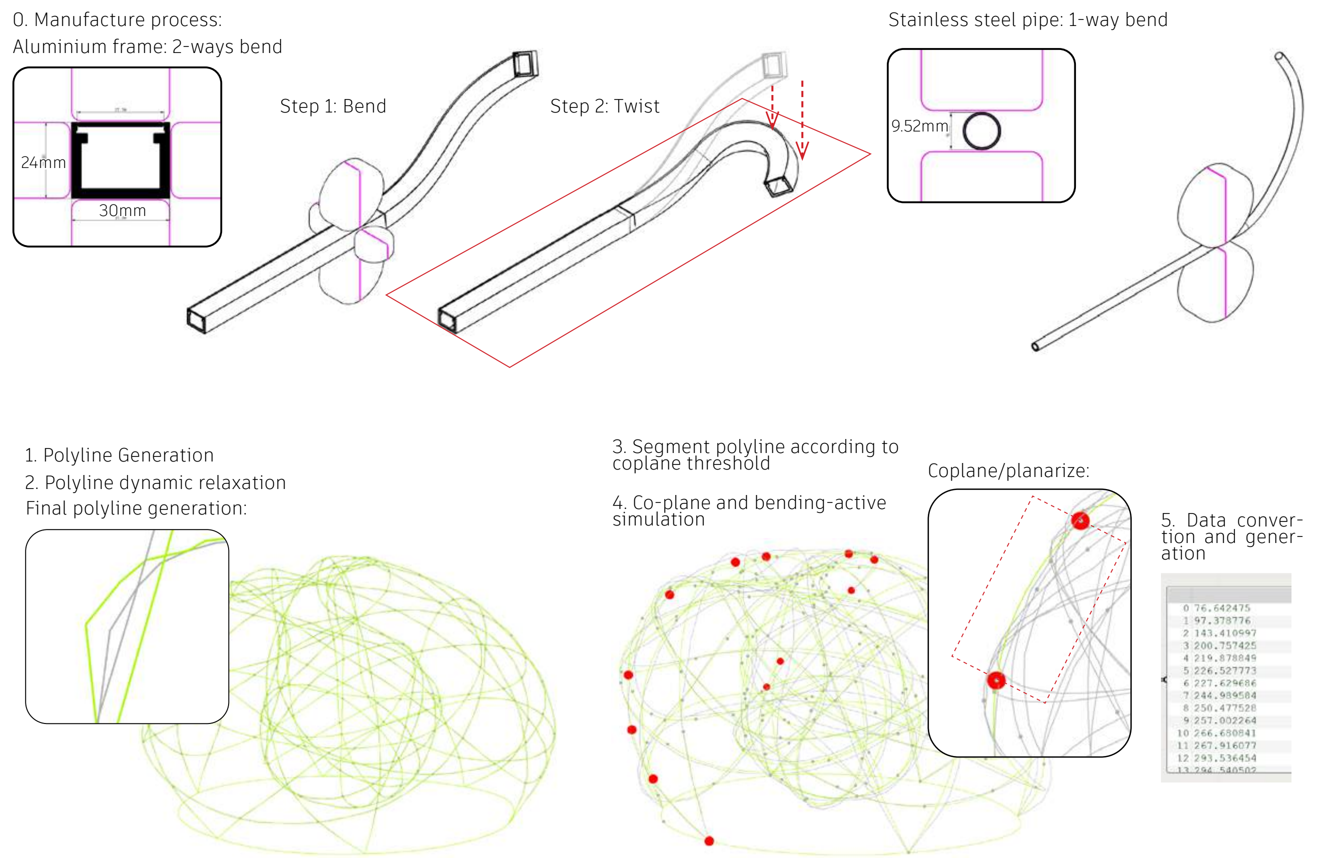
DROPLET

Artificial Mist System Design:

In line with the exhibition's nature focus, a landscape mist system is integrated, enhancing the woven structure with natural mist effects. A preliminary routing system design optimizes mist coil requirements, minimizing nodes and levels:



Structure Fabrication Optimization:



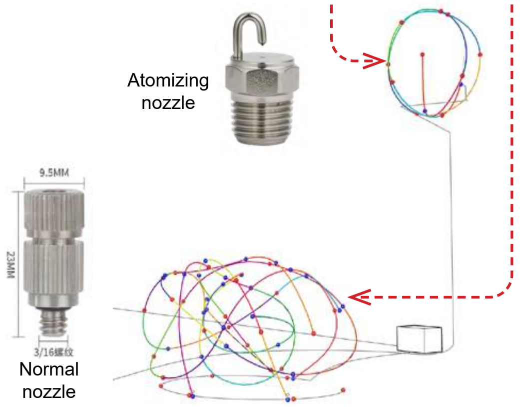
Structure fabrication optimization done by teammate, Hu Jingyuan

DROPLET

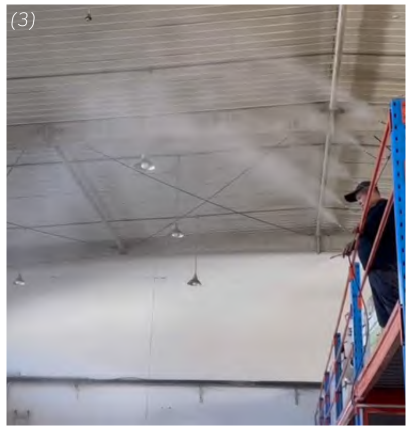
Artificial Fog System Design Process:

(1) Factory vist and experiment:

	Type	Pressure	Direction	Visually effect
(1)	Normal	4	Parallel	1
(2)	Normal	4	Verticle	1.5
(3)	Normal	6	Verticle	1.5
(4)	Atomizing	6	Parallel	2.5
(5)	Atomizing	6	Verticle	3



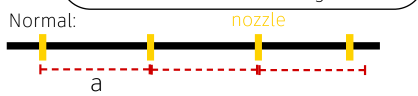
Testing out diffrent type of nozzle under different pressure, and differentiate types depends on visual needs



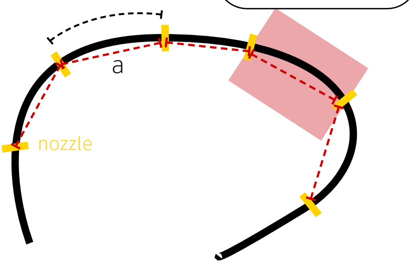
(2) Rod & nozzle design optimization

0 Needs:

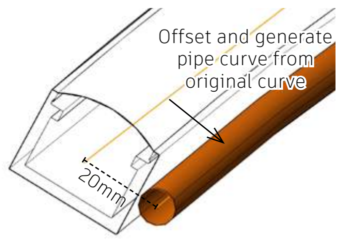
NEED 1:
Nozzle coverage length (a) based on nozzle type, calculation on irregular curve is different on straight-line.



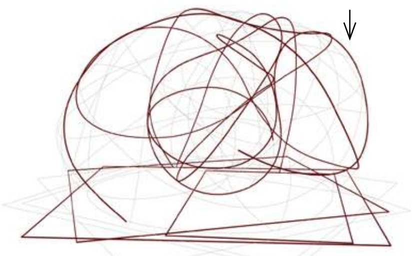
NEED 2: Segments should be a planar curve



1 Basic curve generation



Choose the curve that able to cover the largest area



2 Simulation Method:

0 Basic curve generation

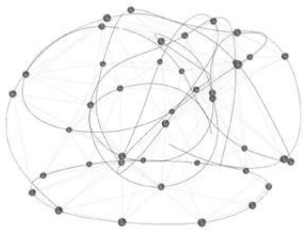
Generate offset curves from original curves

Iterate bounding rectangle, find out the biggest rectangle for each curves

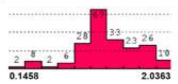
List the curve that has biggest cover area

Opt1. Kangaroo Simulation Method	Opt2. Simulated annealing Method
Equally generate point on curves	Project points from relative original curve to offset curve
Kangaroo collide to equally distibute points on curves	Using simulated annealing method to pick points

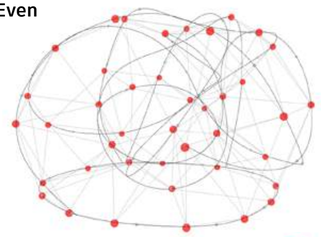
Opt1. Kangaroo Collide Simulation Method



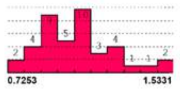
Distance between nozzles (m):
Uneven: 0.14m~2.03m



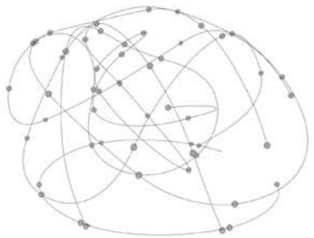
Even



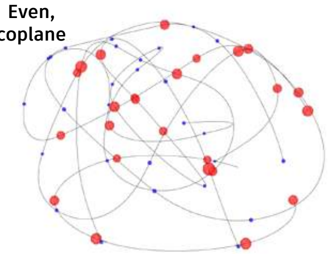
Distance between nozzles (m):
Uneven: 0.725m~1.53m



Opt2. Simulated annealing Pick & choose Method



Even, coplane

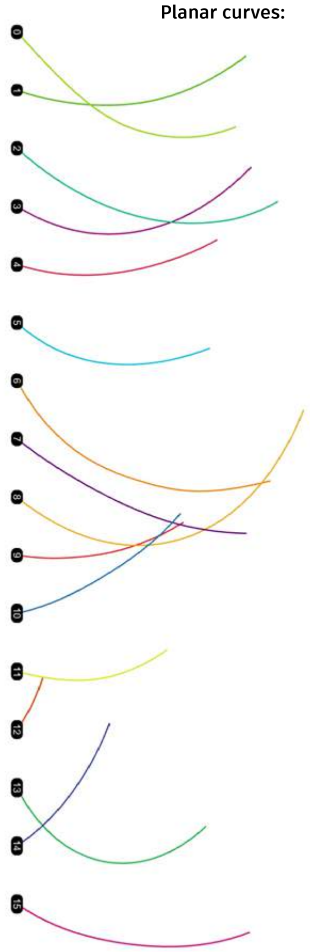


Distance between nozzles (m):
Uneven: 0.795m~2.325m

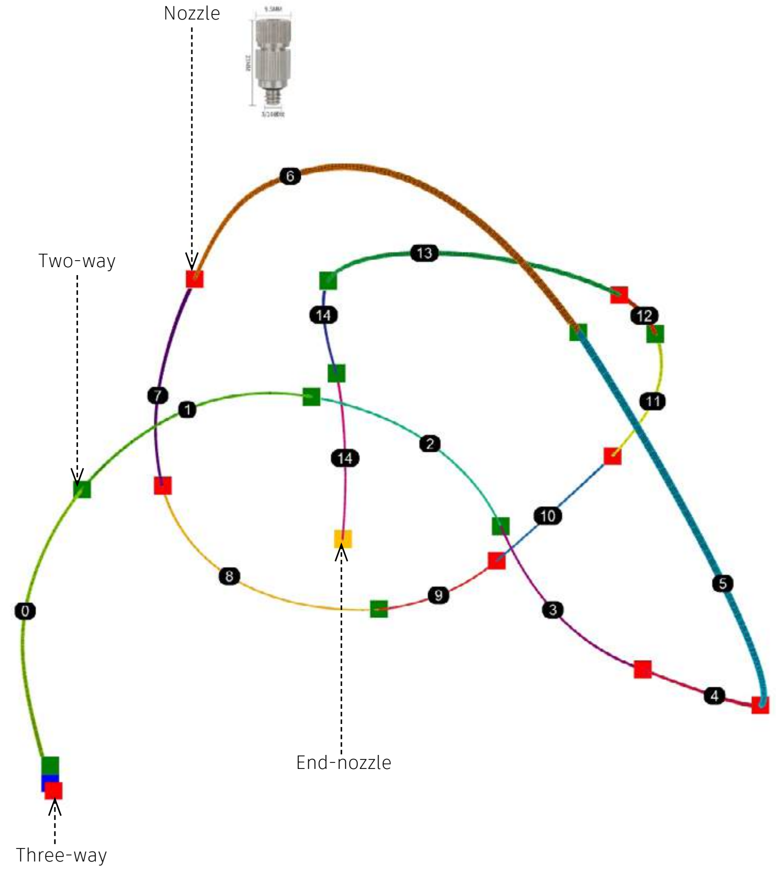
(3) Preparation, data management and fabrication process

1. Extract split curve segments, and unfolding rod, purchase raw material depends on needs

Planar curves: → **3D Irregular curves**

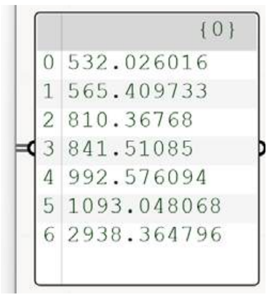


Avergge length=3.0m, purchase straight rod 4.0m



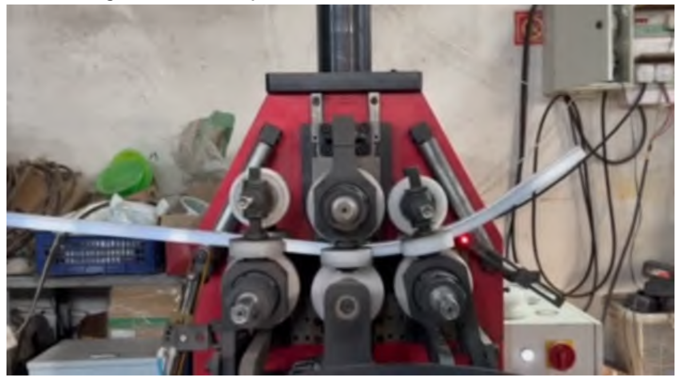
3. Generate roll bending data

By Ws Finder, a plugin for weaving curve genration, generate curvature of curves' segments as roll bending data, ready for manufacture process

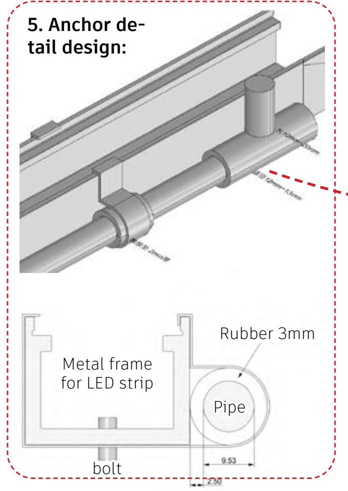


	{0}
0	532.026016
1	565.409733
2	810.36768
3	841.51085
4	992.576094
5	1093.048068
6	2938.364796

4. Go through Manufacture process



5. Anchor detail design:



6. On-site manufacture

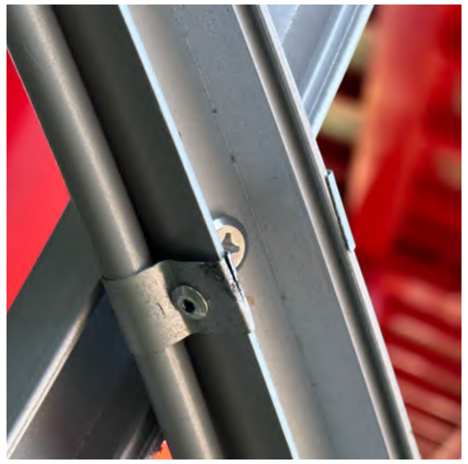
Joining detail

Process:

DROPLET

Site Photos:

Tailor the anchor holder design to specifically accommodate the metal frame, ensuring it effectively secures the water pipe in place.

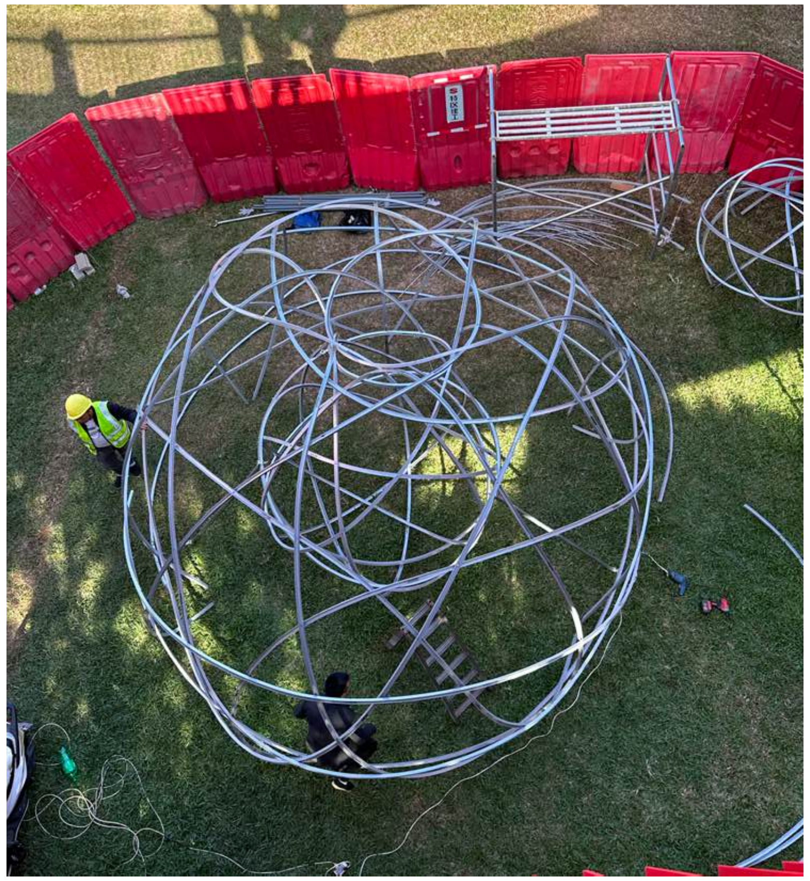


Positioning the nozzle parallel to the LED strip light enables the illumination of mist during the night, creating a captivating D'Arsonval effect.

The joint, designed collaboratively with teammate Baijin, incorporates a metal frame ending that interfaces seamlessly with the floor, ensuring a perfect alignment of the installation with the ground surface.

The appearance of the material for the planar curve before it is assembled into an irregular curve in 3D space.

The installation of the structure was primarily overseen by another teammate, Hu Jingyuan.



Site Photos:

Light strip testing, work done by collaborator team:

Mist tesing:

Can be lifted up easily

Installation process:

Contriburion:
I am primarily tasked with ensuring a unique combination of lightweight structure and a mist system in structure.

Testing process:
Verify the visual effect and adjust the pressure of the mist system, as well as test the timer control settings, such as a cycle of 1 minute on and 1 minute off.

Construction process:
Many elements need coordination during the component installation process, and I engage in communication with construction workers to ensure the seamless completion of the installation.

Candidate interacting with installation

Final photos by local media:

Tutors: Prof. Huang Weixin, huangwx@tsinghua.edu.cn
Team: Chia Hui Yen

STRUCTURE INSTALLATION OPTIMIZATION

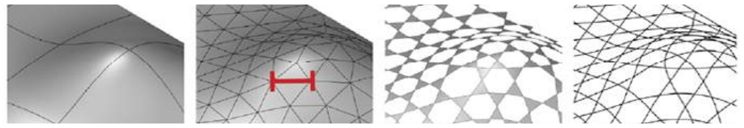
Installation automation:
Structure Installation Optimization

_Automated labeling systems, Weaving Structure Installation, Installation sequence optimization

June 2024

Basic Concepts of Weaving Structures:

A weaving structure is formed by connecting nodes fixed at different positions of the two mesh surfaces. The mesh structure is formed using different bending methods. The construction of the weaving structure able to adapt to the generation of a curved surface.



Abstract:

	Difficulties:	Current Solutions:	Optimization Directions:
Optimization (1)	Unstable Shape of Elastic Rods Difficulty in fixing the position of the rods, resulting in complex structures.	Regular Sequencing of Connections: From long edges to short edges. From the inside to the edge.	**Optimization of the installation sequences**
Optimization (2)	Irregular Positioning of Connecting Points Leading to difficulties in standardizing the structure.	Manual Marking: Time-consuming and costly.	**Development of an automatic rod marking system.**

Optimization (1): Optimization of the installation sequences

Research Methods:

(1) Simulate the Installation Process:
Run simulations to track how structures move and change during installation

↓

(2) Analysis of Sequence & Rod Performance
Compare changes in sequence and displacement to understand the basic rules of the process.

↓

(3) Generate Installation Guidelines:
Use these rules to create helpful installation sequences for workers.

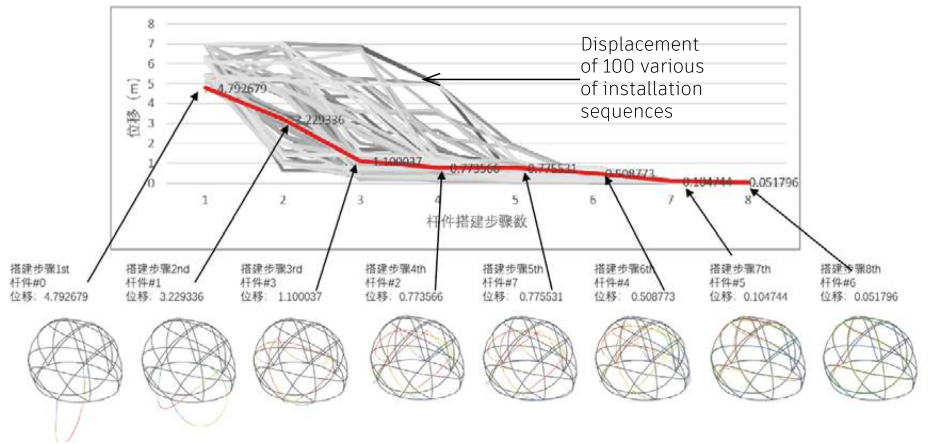


Figure: Simulation of the installation process for a specific braided structure according to certain sequencing steps.

Analysis Method for Installation Sequence & Rod Performance

1. Single Rod's Installation Convinience:

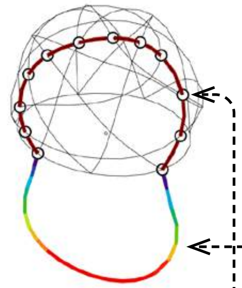
· Rod Positioning:
The complexity of balancing rods in space reflects the difficulty of forming shapes. A higher displacement value indicates more complexity and requires more manual labor for fixing.

· Rod Length:
Longer rods require more support, increasing construction difficulty.

· Rod Connection Points:
An increased number of nodes leads to more fixed workload and complex rod shapes, making the evaluation of construction stability a critical factor.

· Rod Types:
Divided into edge rods and internal rods; edge rods are prioritized in construction, but their differentiation is being standardized and optimized.

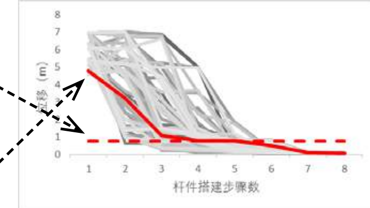
Rod #0 as example:



Rod Number: #0
Length: 6.845m
Number of Hinged Nodes: 12
Maximum Displacement: 5.153m

2. Installation Efficiency:
Evaluated through average displacement of structure, Δ_{avg}. Smaller displacement values indicate that rods are quickly approaching the intended shape.

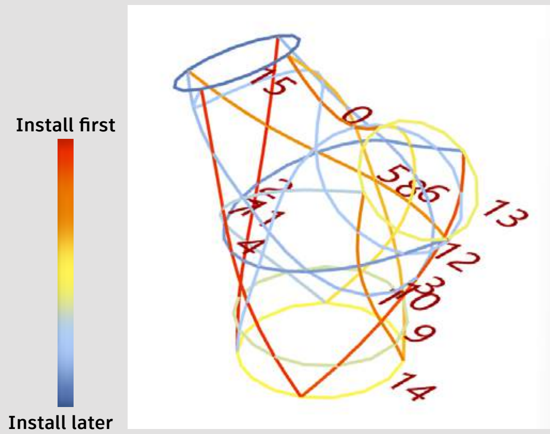
3. Installation Stability:
Evaluated through maximum displacement of structure, Δ_{max}. Displacement can indicate rod position stability, requiring support.



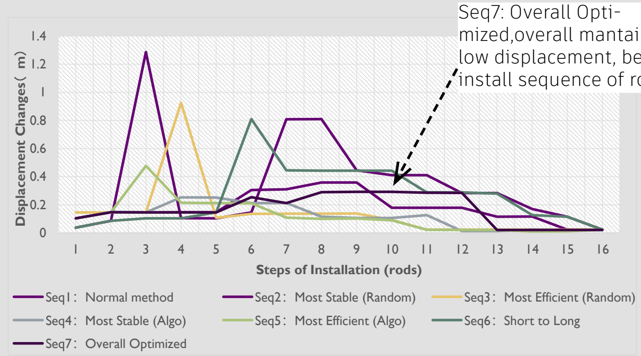
4. Starting Displacement
Structural displacement at first steps of rod installation.

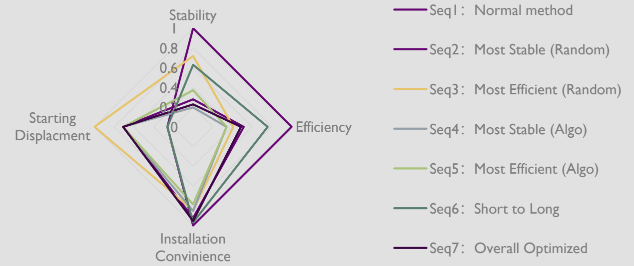
Results:

1. Result for Case 1, Triple-Connected Pipeline:

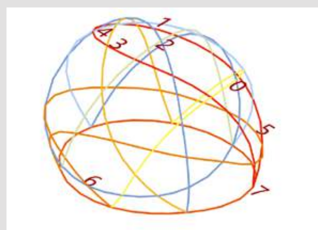


Overall Optimized Installation Sequence:
2, 4, 3, 0, 1, 8, 5, 6, 14, 13, 9, 7, 12, 10, 11, 15.

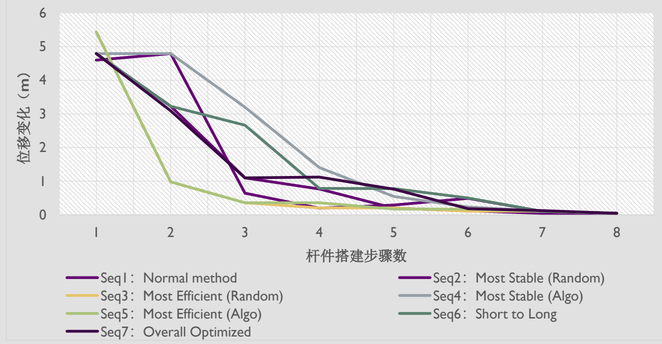


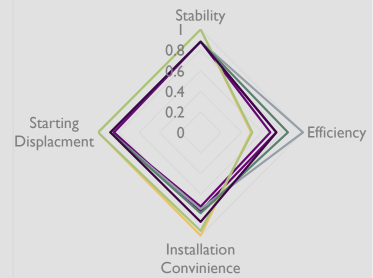


2. Result for Case 2, Half sphere:

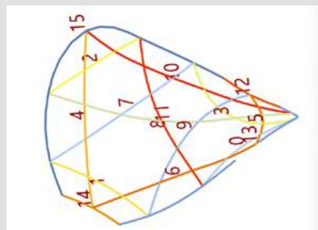


Overall Optimized Installation Sequence:
4, 7, 5, 3, 0, 2, 1, 6

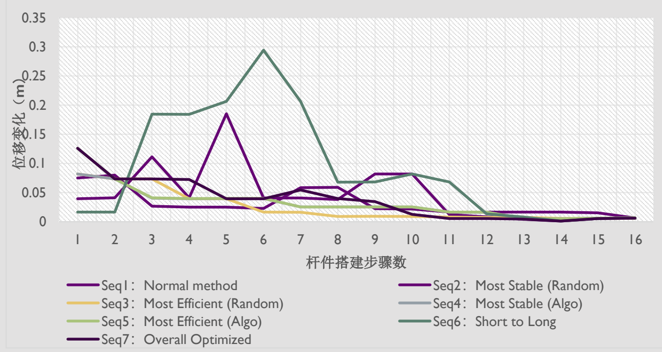


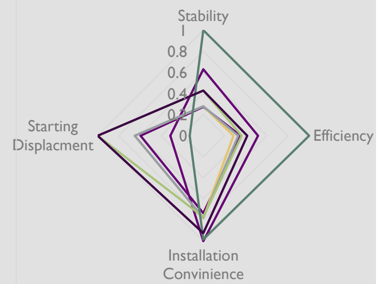


3. Result for Case 3,



Overall Optimized Installation Sequence:
10, 8, 12, 6, 5, 14, 4, 1, 2, 3, 11, 0, 7, 9, 13, 15,





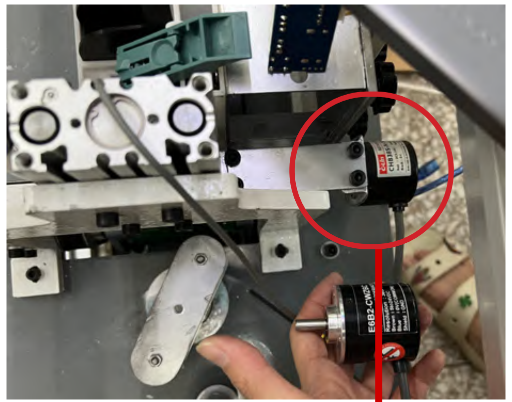
STRUCTURE INSTALLATION OPTIMIZATION

Optimization (2): Development of an automatic rod labelling system

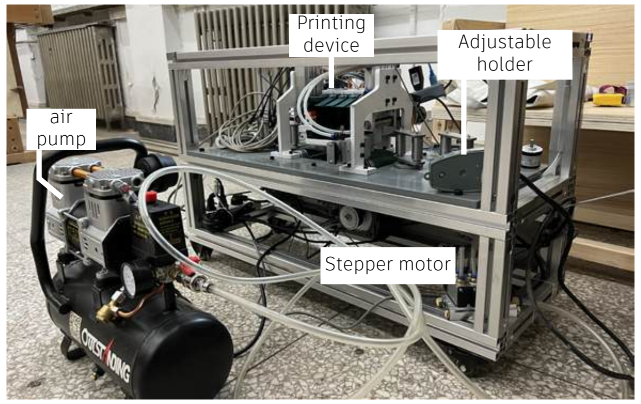
Below are the parts and details of automatic rod labelling machine, which is the essential part of the automatic rod labelling system, built by arduino, Delta dvpes2 series microcomputer, rotary encoder, stepper motor and Ink Cartridges.

Delta dvpse2 series. The WPLSoft software is used to compile the program, which is then input into the single-chip microcomputer.

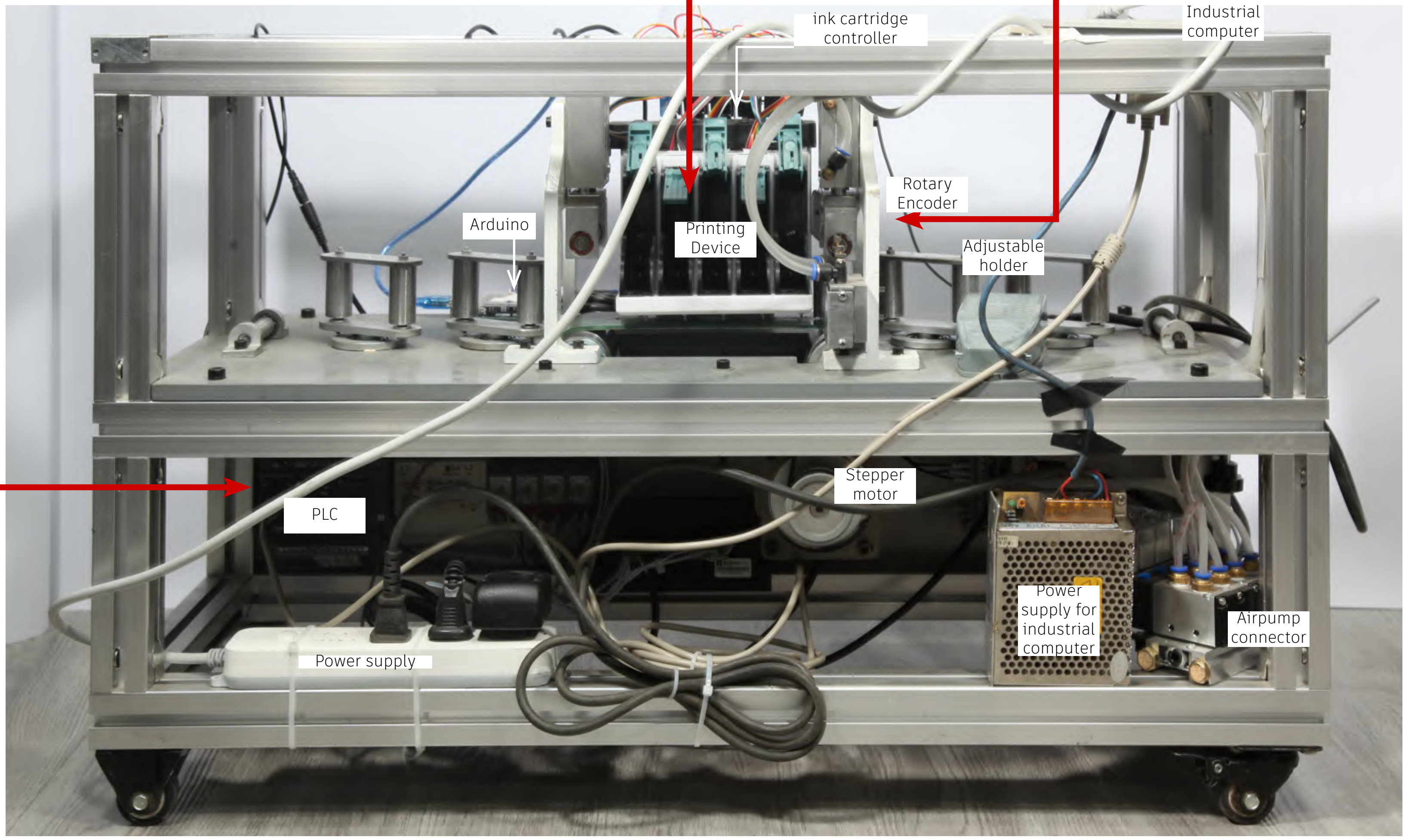
The printing device consists of 5 ink cartridges, 5 ink cartridge controller, and a protective case made by 3d printing.



The rotary encoder counts the number of rotations, with a rod radius of 8mm, control by an Arduino.

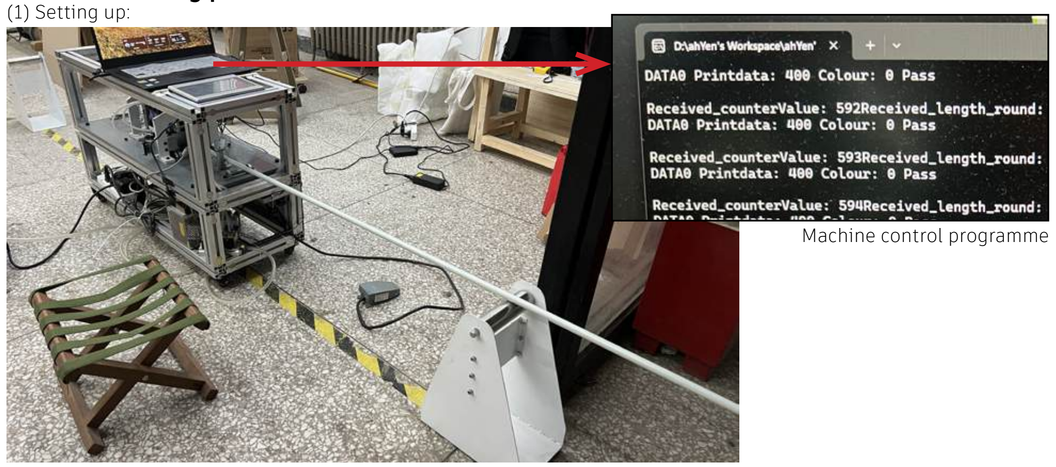


Overview of the whole machine, containing airpump, printing device, stepper motor and adjustable holder.



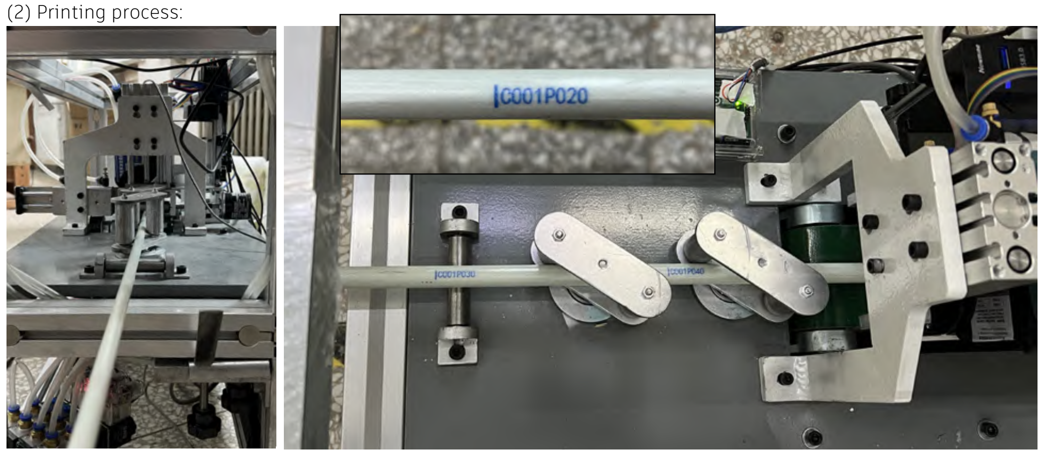
Machine working process:

(1) Setting up:



Machine control programme

(2) Printing process:



Overview of automatic rod marking system

The automatic rod marking system was developed to eliminate manual rod measuring and labeling. It prints specific content at designated positions on elongated rods. **Challenges included the need for multi-color printing, irregular spacing, and millimeter-level precision, with fixtures adapting to various rod cross-sections.**

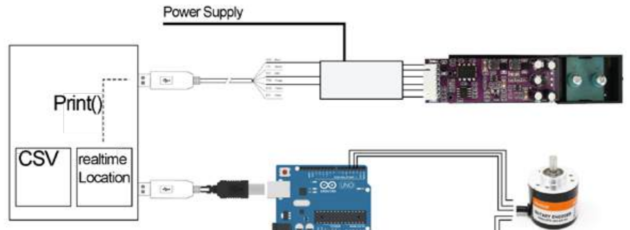
Development Process

The hardware design was split into two parts: the printing device and the rod transportation device. I prototyped the rod transportation device and had it produced by a manufacturer. The printing device was fully developed by me, modified from handheld inkjet printer components.

Technologies Involved

Key technologies used included mechanical design, serial communication, and electronic component assembly and control. This ensured accurate and efficient rod labeling.

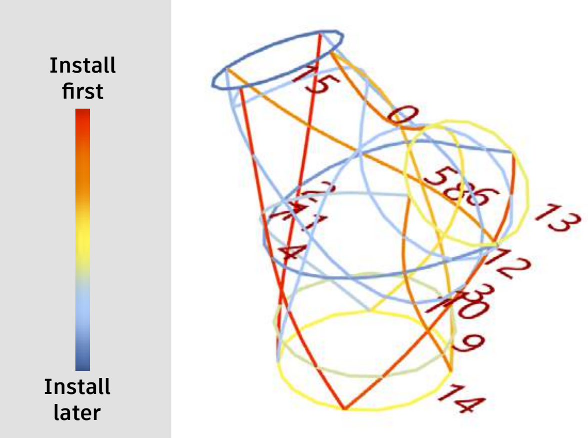
Machine control program structure:



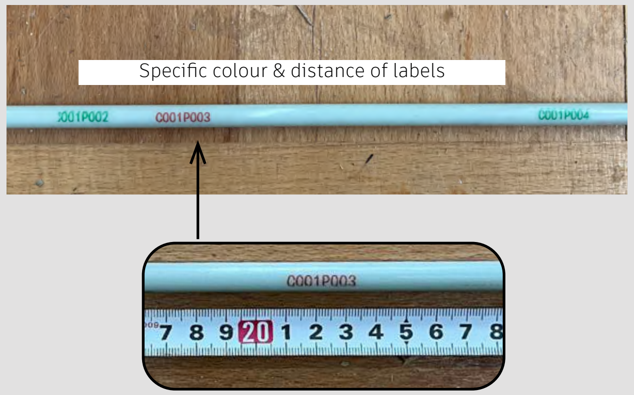
Conclusion

In summary, we propose digital methods to help and improve the construction of weaving structures. Our approach focuses on human-centered design and data analysis to establish construction principles. By optimizing the assembly sequence and using an automated rod marking system, we aim to solve construction challenges, improve efficiency and quality, and advance the technology of weaving structures.

· Accomplishment (1):
Clear and logical installation sequece



· Accomplishment (2):
Transition from manual rod marking to automated labeling machine



No longer mark the rod manually but with the machine developed

STRUCTURE INSTALLATION OPTIMIZATION

Tutors: Prof. Zhu Ning, zhuning@tsinghua.edu.cn
Team: Chia Hui Yen, Ren Tianye
Contributions: Designs & Scripting 80%, drawings 90%, modelling 95%
Notes: paper pending publication in Symbiotic Intelligence: Proceedings of the 6th International Conference on Computational Design and Robotic Fabrication (CDRF 2024)

Details & Joinery:
3D Printing Traditional Joints

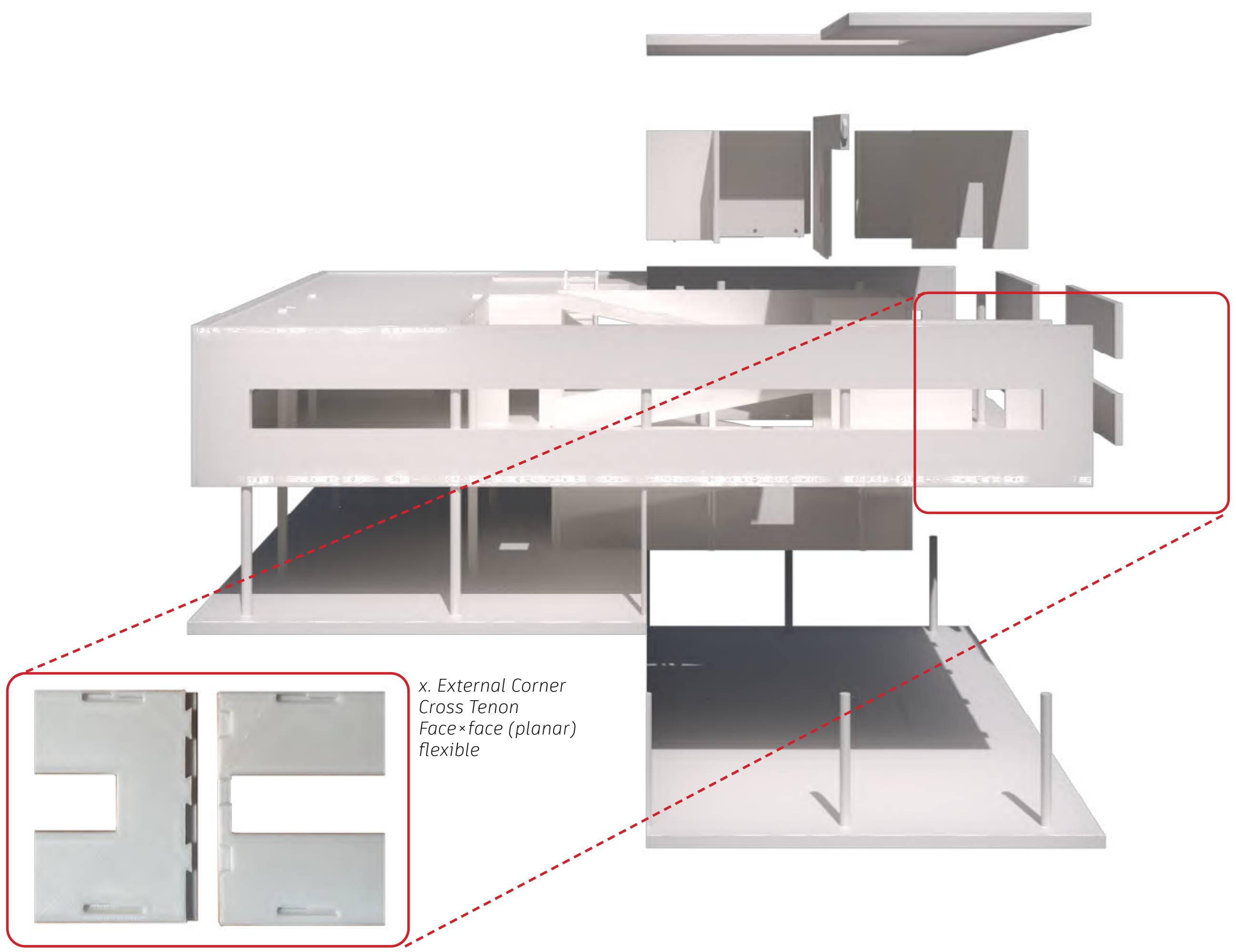
_3D printing, traditional joinery,digital fabrication

July 2023 - September 2023

Introduction

Large-format and relatively precise 3D printing equipment is often prohibitively expensive. In the production of large-scale architectural models, it is common practice to divide the model into smaller units, which are printed separately and then assembled into a complete model. Therefore, the search for suitable assembly methods is necessary. Currently, units of a 3D-printed model are usually joined with glue. However, the irreversibility of adhesive bonding, the toxicity of the glue, the limited weather resistance, and the indefinite structural strength pose challenges to the efficient use of 3D-printed models. Finer models often require special seam treatments at the joints, such as enlarging the bonding surface (Knoll et al. 2003: P37-38). Such methods do not address the drawbacks of irreversibility and glue toxicity. They do, however, inspire us to design assembly joints that do not require adhesive, thus offering a comprehensive solution to the aforementioned issues.

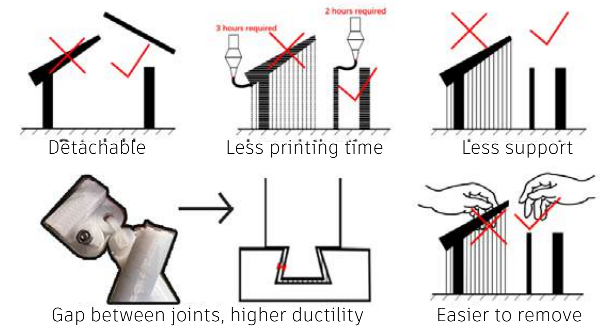
Graphical Abstact:



(1) Preface: Research Gap

3D printing joints for architectural models are in high demand in various contexts, including architectural design education, commercial applications, and exhibitions. However, current research on the parametric design of joints primarily focuses on large-scale models, such as furniture and replicas of historical buildings. There is a lack of investigation into models typically used in architectural design at the scale of 1:50 or even smaller. These models have plates of 2mm to 6mm thick, so the design of their joints cannot be directly adapted from the joints used in larger-scale models, taking into account the precision of 3D printers and material strength, among other factors.

This paper addresses the typification, standardization, and parameterization of connection joints for small architectural models at scales of 1:50 to 1:200. We conduct research into three different types of joint forms—surface joints, line joints, and point joints—along with their dimensional parameters and printing settings. The information above is compiled into a database. Additionally, we offer recommendations for joint combinations in various orientations to ensure secure assembly. Using a 1:50 scale model of a Savoy villa as an example, we validate and showcase our research findings. We also observe that printing detachable models, as opposed to printing integral models, offers advantages such as reducing printing time, minimizing the use of support materials, and avoiding the need for non-detachable supports.

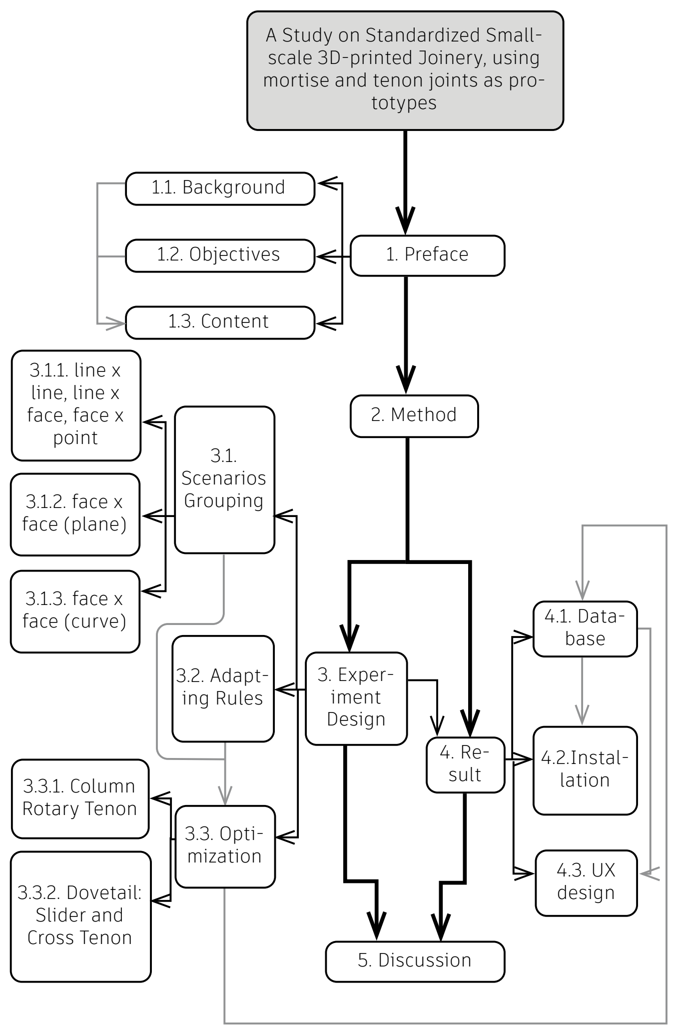


The advantages of assembly nodes

Cost and area limitation of 3D printer

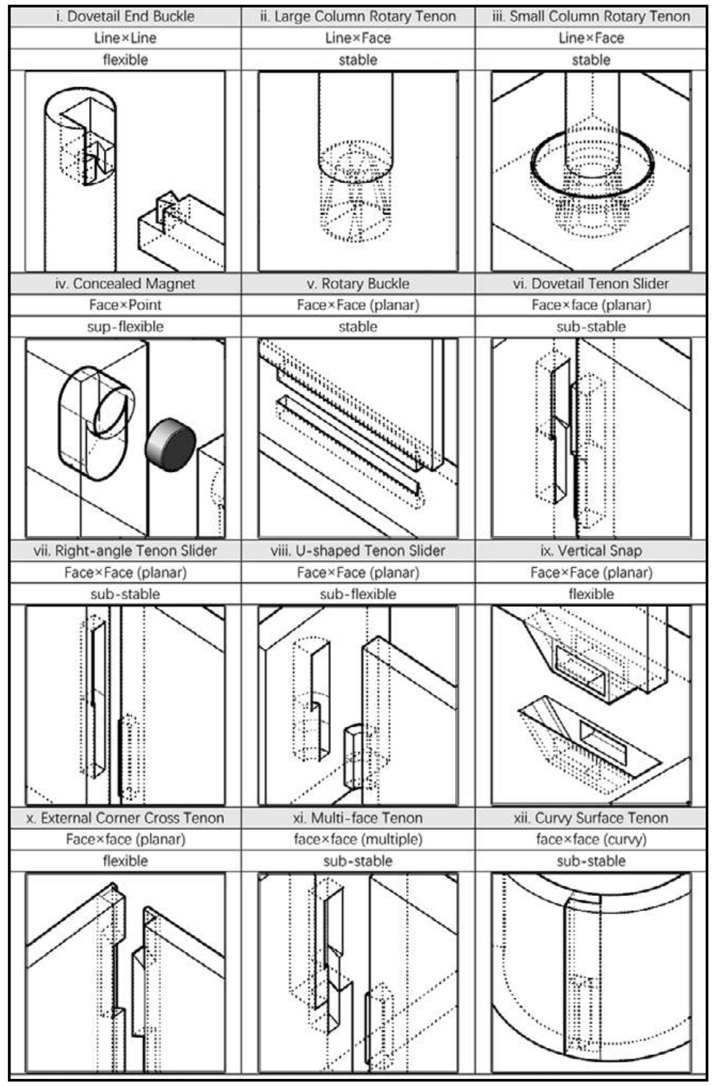
(2) Method

Computer modeling: Rhinoceros 7,
Model slicing: Creality Slicer, Ender-PLA filament was used as the printing material.
3D printers: Creality3D Sermoon V1, printing size of 15cm x 15cm, an accuracy of 0.2mm, priced at approximately 2000-3000 RMB. They are commonly used by students majoring in architecture.



Result

We have designed twelve joints suitable for various assembly scenarios with different levels of stability. A schematic representation of the joints is presented in below table.



**Stability levels: Stable> Sub-stable> Sub-flexible> Flexible> Sup-flexible

(3) Experiment Design

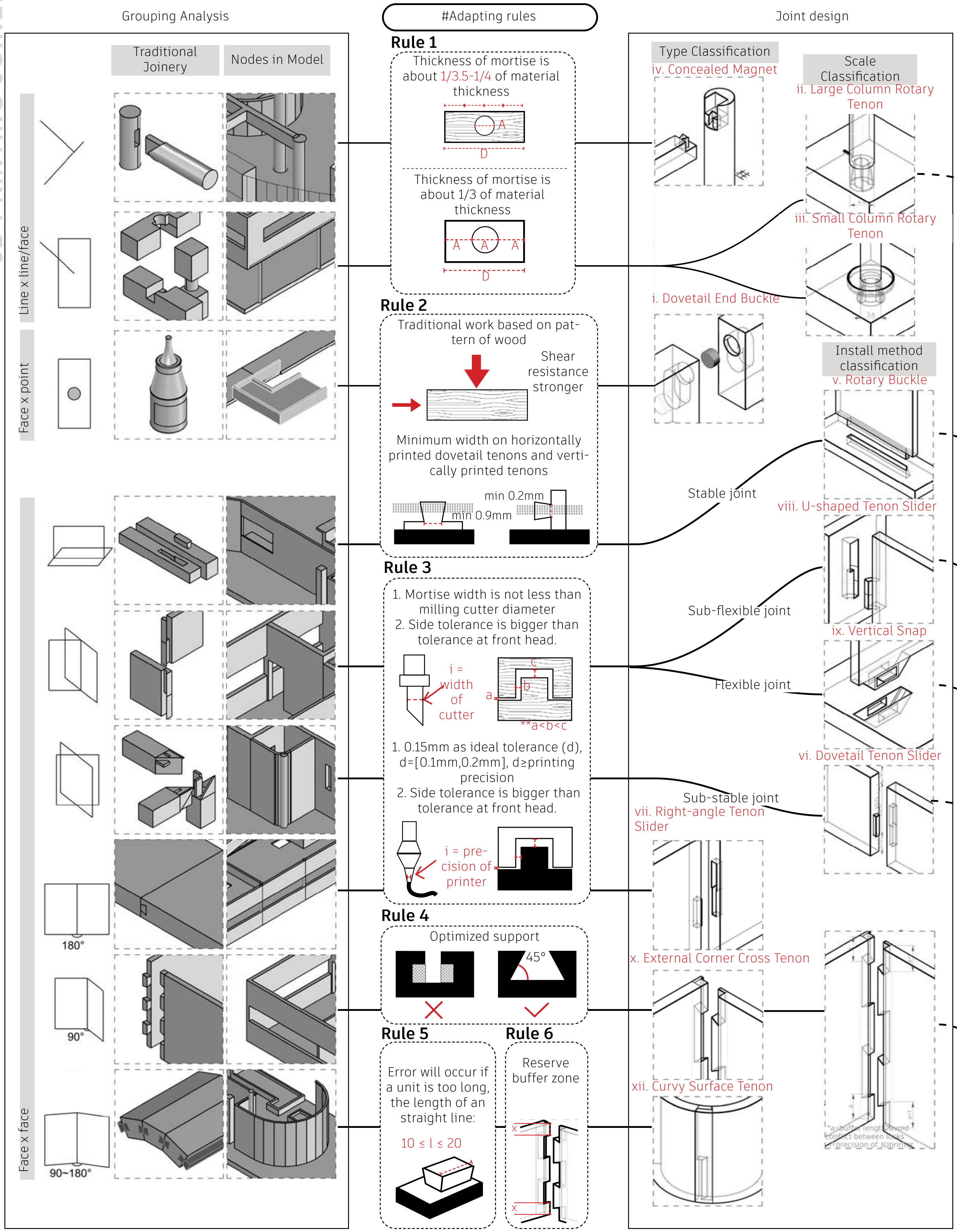
Our research process encompassed the following steps: 1. Joint prototype design, 2, Installation Method Research, 3. Printing Setup and 4.UX Design

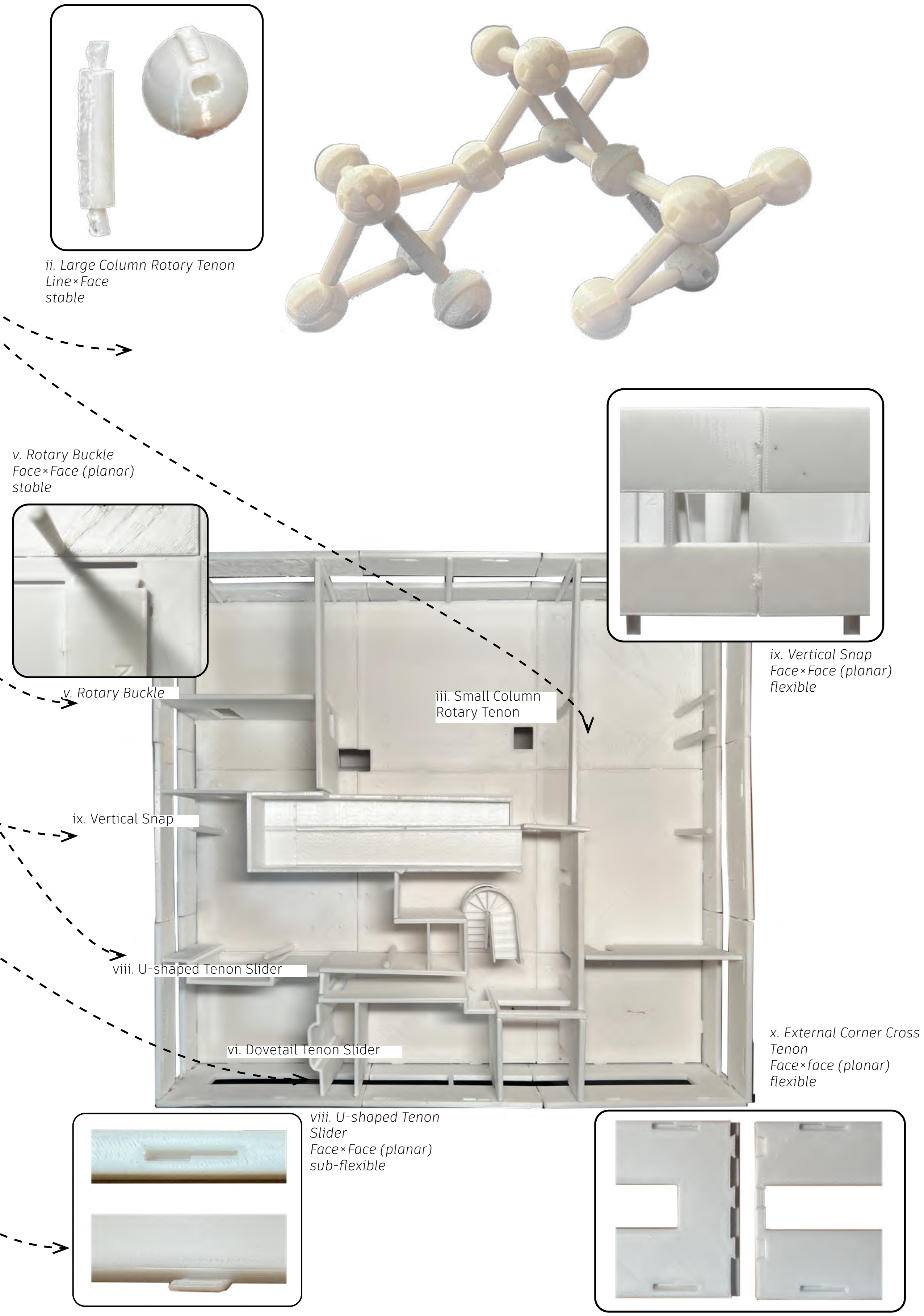
3.1. Scenarios Grouping

3.2. Adapting Rules

Application Example

Traditional mortise and tenon joints were categorized based on woodworking experience, including face-to-face (non-right angles), face-to-face (right angles), face-to-point, line-to-face, and line-to-line. We analyzed the applicable forms and size rules and adjusted them according to the characteristics of 3D printing.

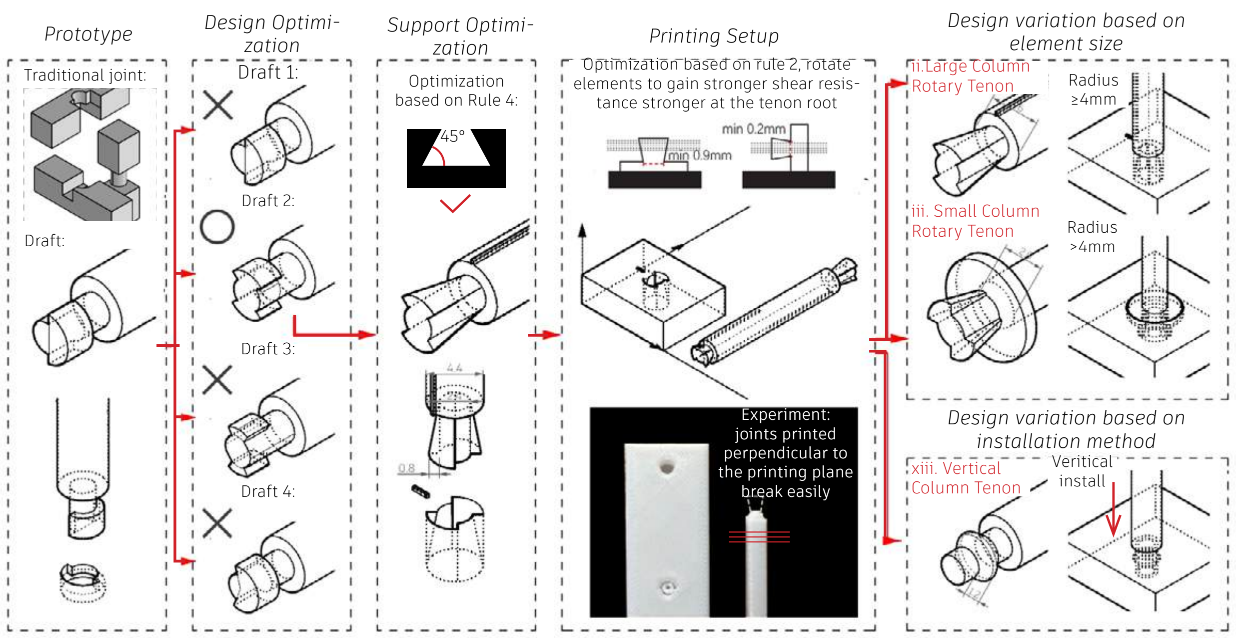




3.3. Optimization

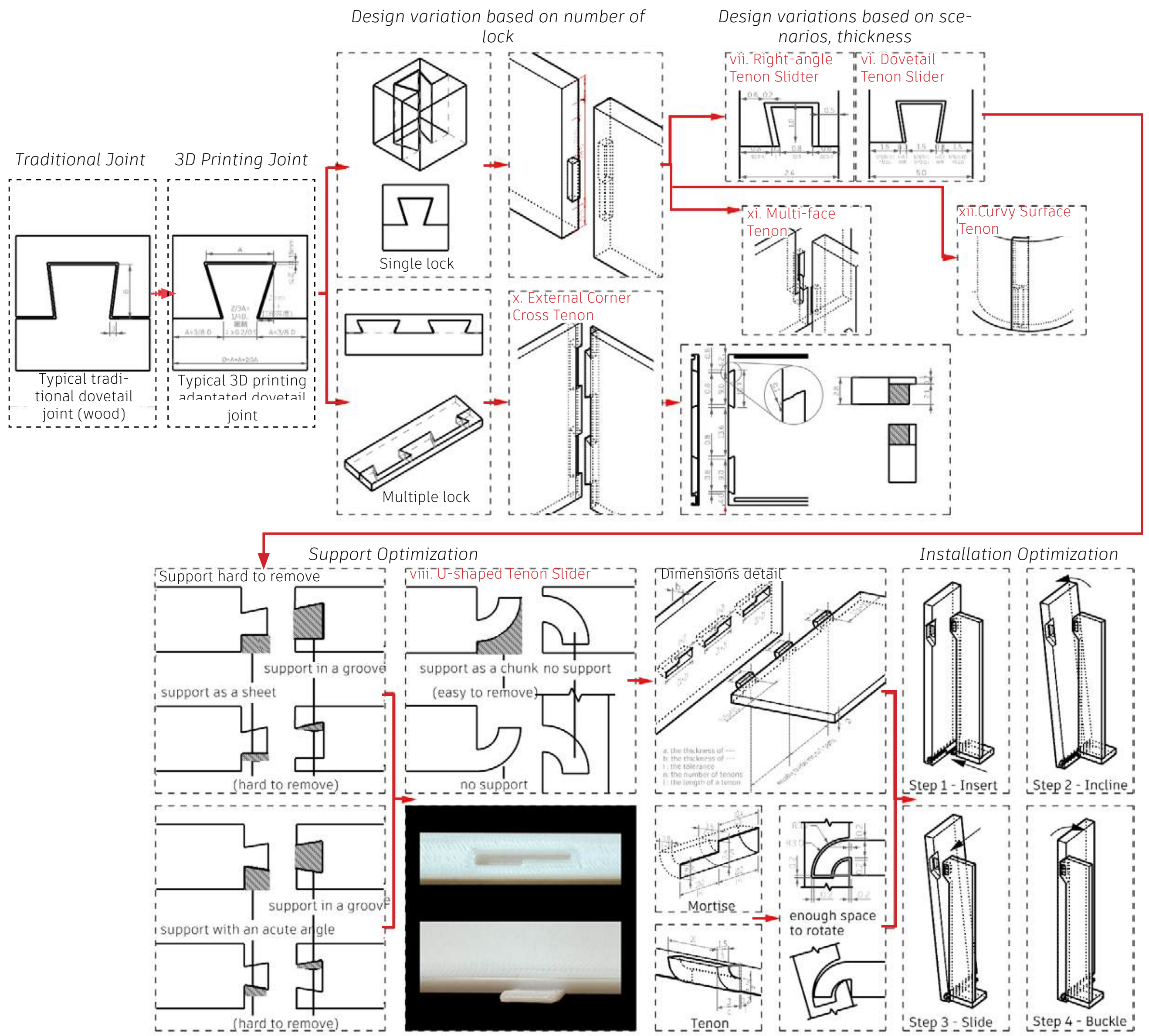
Iteration Example 1: Rotating Joint

Taking the variants of the traditional dovetail tenon (ii. iii. vi. vii. viii. x.) as examples, the design optimization process is illustrated in Figure 3.

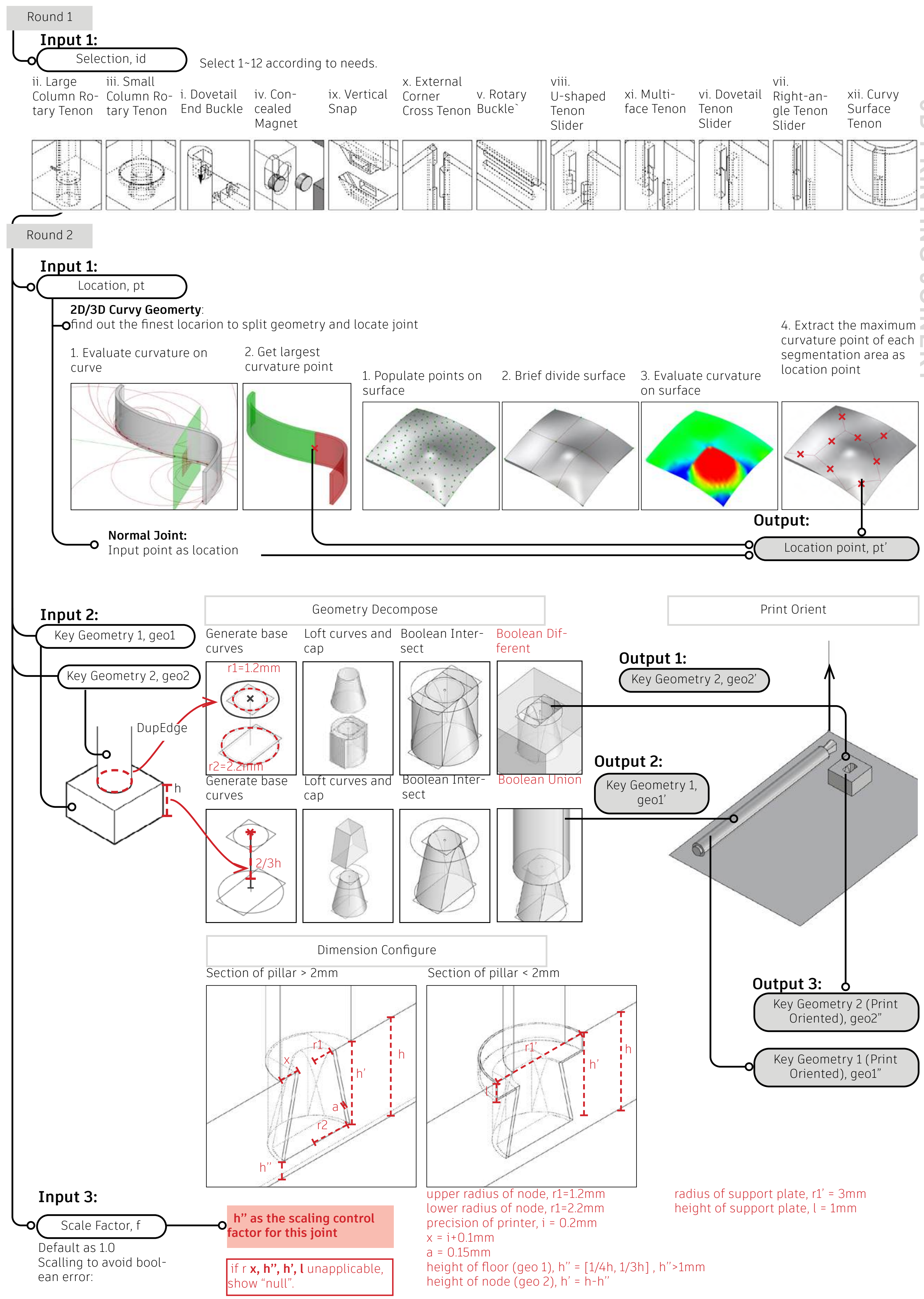


Iteration Example 2: Dovetail Joint

Dovetail as the most important prototype, it can be iterate to multiple varies type of join to apply on different scenerios.



4.1. Database: Geometry Generation Script Framework

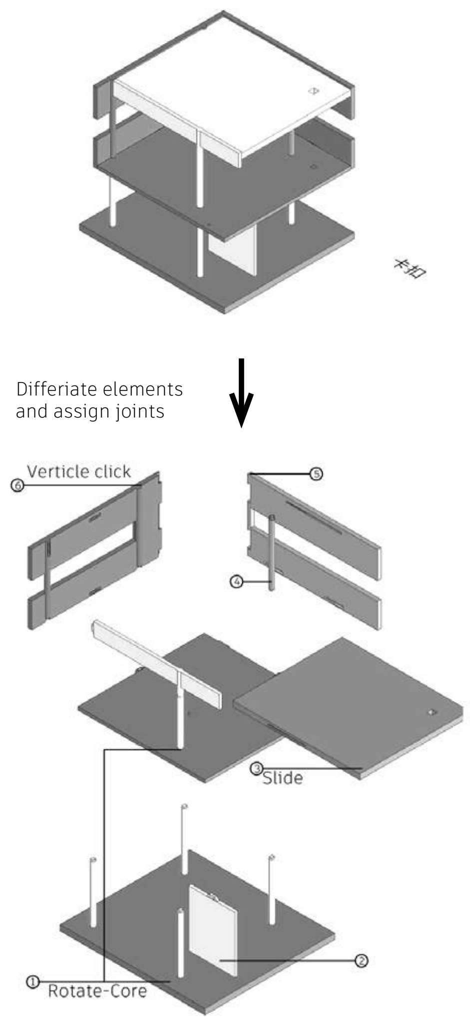


(4) Result

4.2.Installation

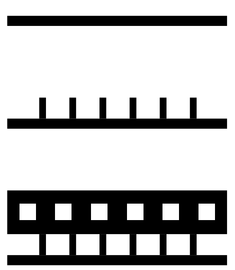
Assign Joint to Elements

0 Decompose Printing ELements

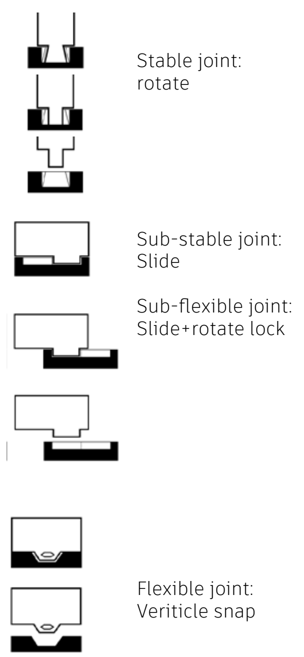


#Assemble rules

1 From lower to upper

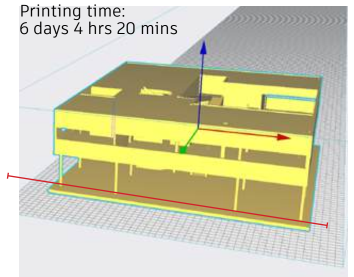


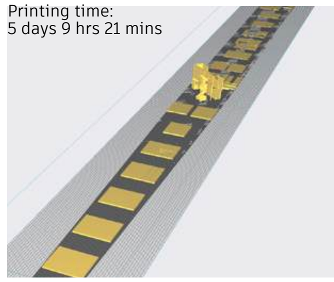
2 From stable joint to flexible joint



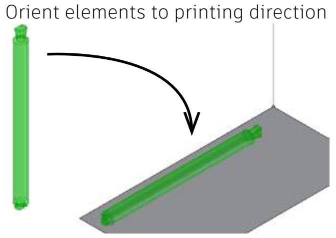
#Printing setting

Optimizing printing processsuch as way of printing toincrease strenght, reducesupport and shorter printing time

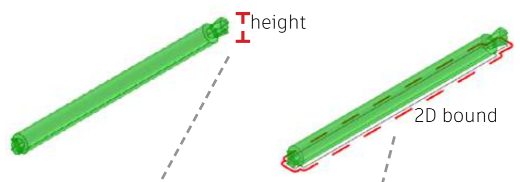




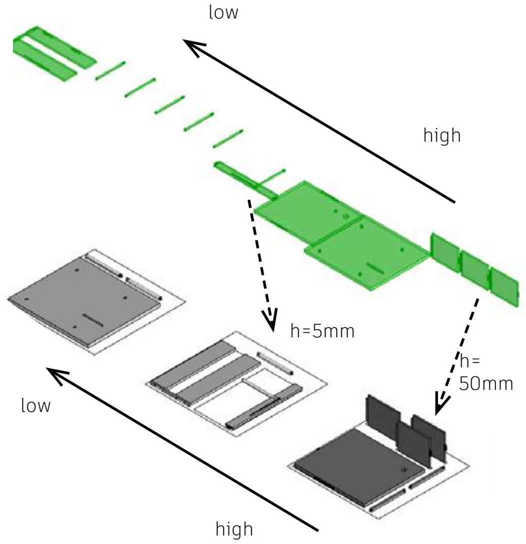
1. Orient elements to printing direction



2. Extract absolute height for each elements and shrink wrap outbound of elements and project 2D to XY plane



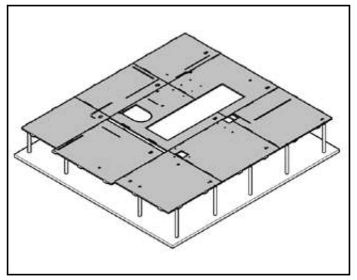
4. Sort by height and 2D packing bounderies of all elements by Open Nest/Circle packing/Galapagos



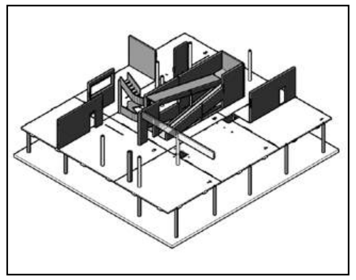
5. Convert file to STL file and Pirnt!

Installation Manual

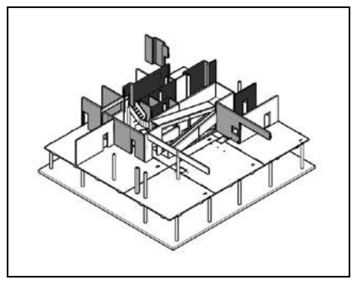
1. Framework zone: stable joint



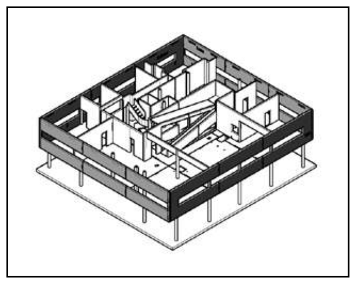
2 Core zone: sub-stable joint



3 Transition zone: sub-flexible joint



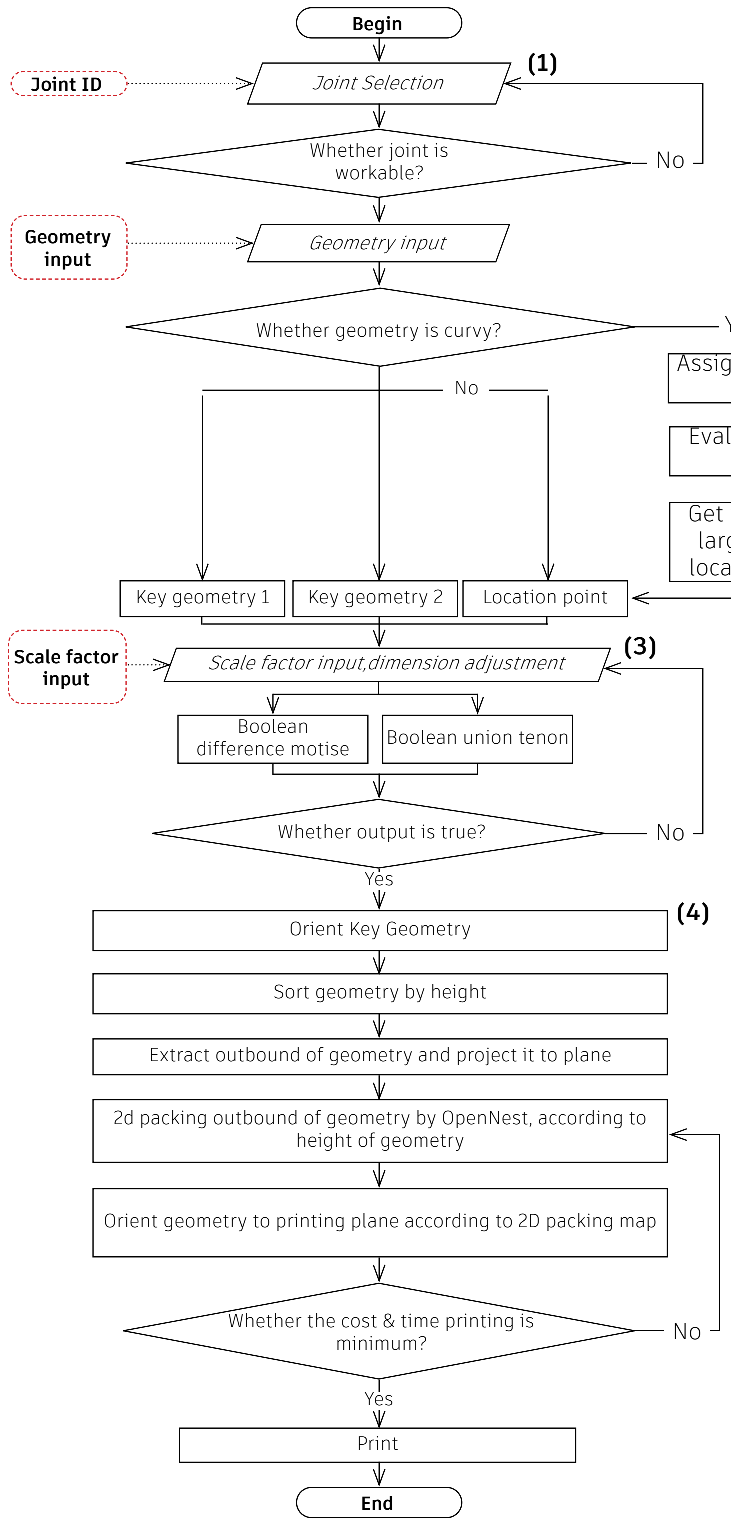
4 Periphery zone and trivial items: flexible joint



4.3. UX design

Algorithm flowchart and corresponding components:

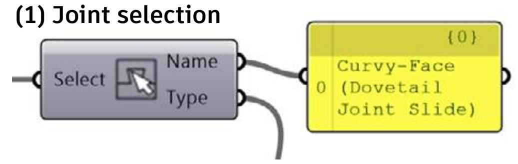
Optimizing printing processsuch as way of printing toincrease strenght, reducesupport and shorter printing time



Algorithm flowchart and corresponding components:

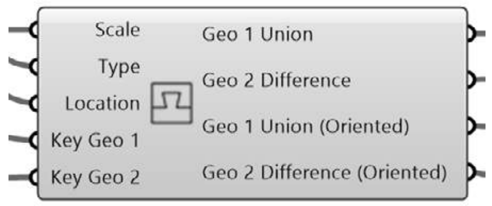
Optimizing printing processsuch as way of printing toincrease strength, reducesupport and shorter printing time

(1) Joint selection

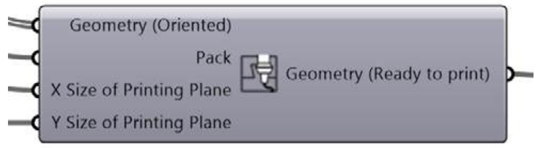


(2) Find Location on Curvy

(3) Joint Generator



(4) Orient to Print



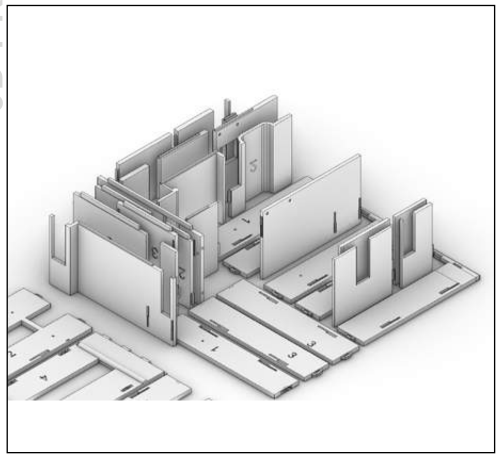
Physical Validation

The study of mortise and tenon joints was deeply explored in the past when material science was not as advanced as it is today. As material science progressed, rigid connectors and adhesives offered more convenient joinery support for constructions. However, as mentioned earlier, these connection methods present issues with weather resistance, structural strength, adhesive toxicity, and non-dismantlability. Hence, a prevailing approach is to combine both methods, incorporating simple mortise and tenon forms with adhesive materials like cement.

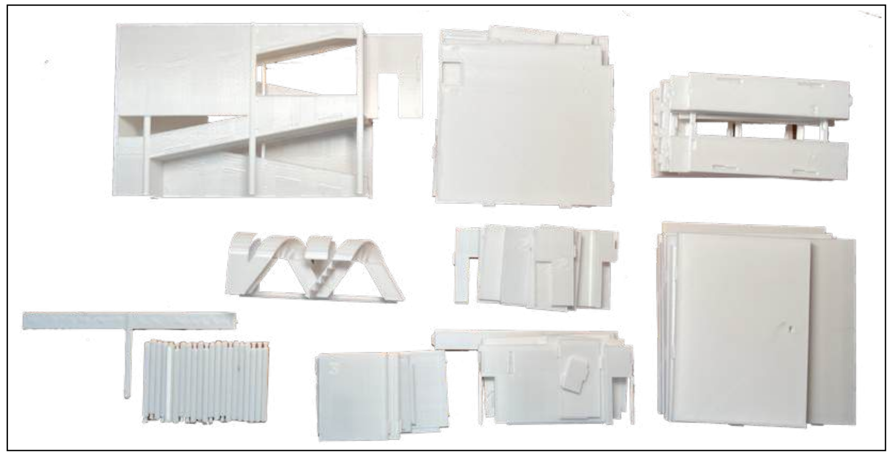
Similarly, for architectural model connections, we can adopt a similar approach. Due to the relationship between scale variations and material properties, directly shrinking the joints at a 1:100 scale and printing them is not feasible. Factors such as material properties, toughness, stiffness, adhesives, scale, printing precision, and manufacturing methods influence the process. Additionally, 3D printing, as an additive manufacturing process, possesses irreplaceable advantages, necessitating adaptations in joint design to leverage its strengths.

Therefore, our accomplishment includes using mortise and tenon joints as prototypes and, through experimentation and iterative design, obtaining nodes suitable for 3D printing with Photopolymerization Stereolithography (PLS) and meeting architectural model scale requirements. These joints enable connections for large-scale architectural models, surpassing 3D printing size restrictions and enhancing printing efficiency.

0 Printing

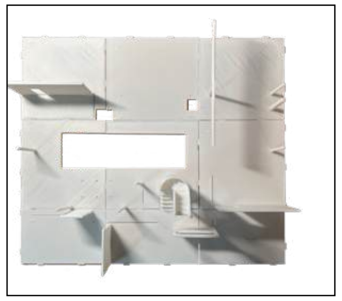


0 Preparation

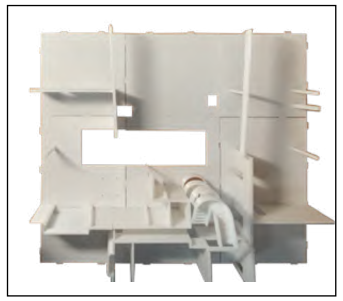


1 Core elements (1st floor)

2 Core elements (2nd floor)



3 Other elements (2nd floor)

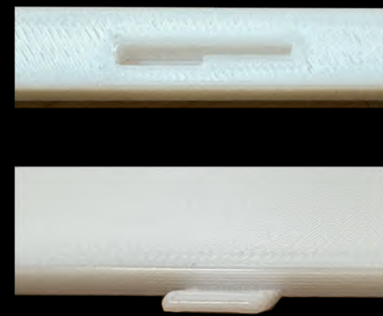


4 Outer walls (2nd floor)

3D PRINTING JOINERY

v. Rotary Buckle
Face×Face (planar)
stable

x. External Corner Cross Tenon
Face×face (planar)
flexible



viii. U-shaped Tenon Slider

Face×Face (planar)
sub-flexible

vi. Dovetail Tenon Slider
Face×face (planar)
sub-stable

ix. Vertical Snap
Face×Face (planar)
flexible

x. External Corner Cross Tenon
Face×face (planar)
flexible

ii. Large Column Rotary Tenon
Line×Face
stable

Other Interior Photos:

Tutors: Prof. Zhou Huan, zouhuan@tsinghua.edu.cn
Team: Chia Hui Yen
Solo work

THE FOREST

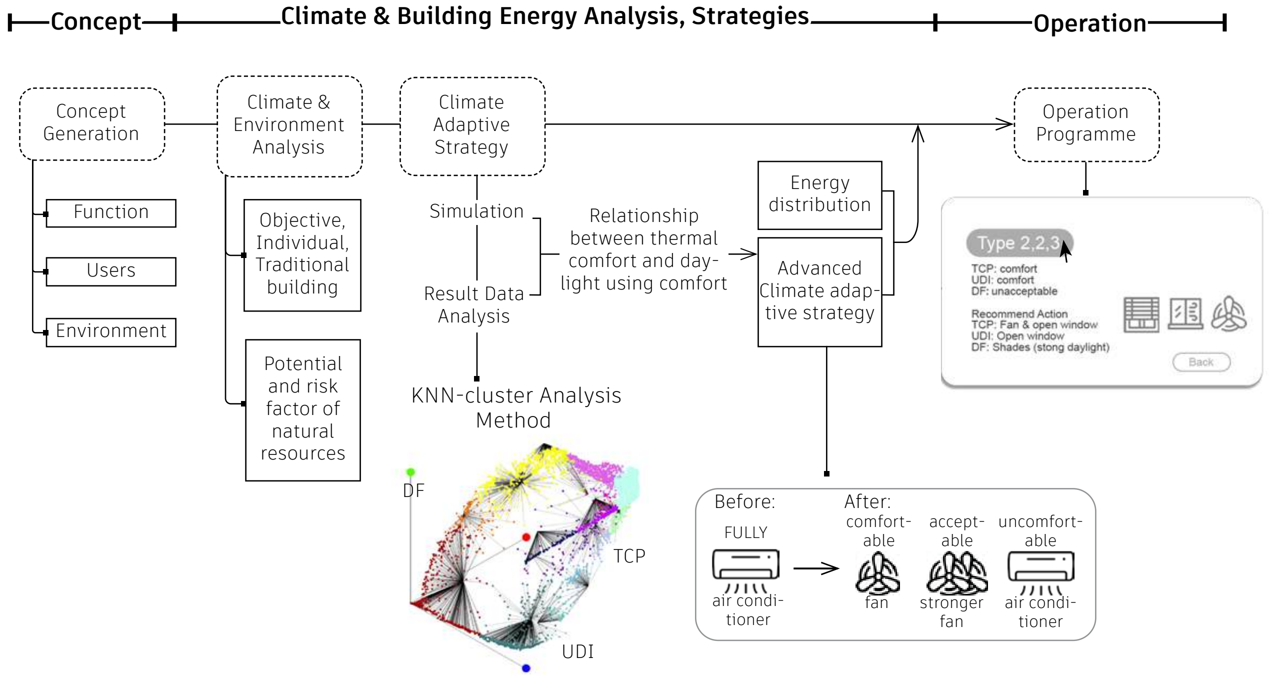
Building Performance:
The Forest Community Center Environment Optimization

_Climate adpative design, Programme design

July 2023 - September 2023

Introduction

This project is located in Kuala Lumpur, Malaysia, within a tropical climate zone. Through a comprehensive analysis of the local climate, we have simulated responses tailored to the intense sunlight and abundant daylight conditions. The objective is to explore a balance between thermal comfort and effective utilization of natural light in the tropical climate. The project employs different climate-responsive strategies for various sections of the building to minimize the overall energy consumption.



Concept Generation

1 Devide portion of spaces for tourist to discover local arts and crafts and a chilling place for the local passby by their dynamic flows.

2 Based on the consideration of climate adaptation, extract the form of Malay House and create an open space for market at ground floor and enclosed space for museum at upper floor.

3 Create gap between the module of exibition to improve the natural ventilation. Also, open up at as main passway.

4 For the ground floor, input a certain number of flexible module and create an free, public atmosphere of local market.

5 Lastly, lay a specific designed-roof on top, shaded the whole museum from sun-rays.

Climate & Building Energy Analysis, Strategies

1. Site Characteristic Analysis and Climate Adaptive Analysis

Analysis site characteristic from Objective factor (weather) and Individual factor (clothes, activities, and local standards), take traditional building adaptive s strategies as references.

Objective factor: Weather

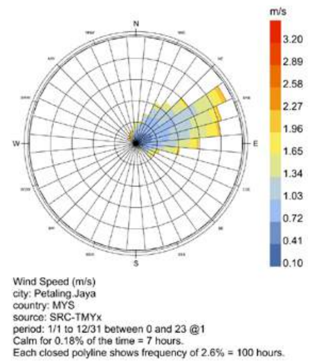
Factors of wind & sun towards thermal comfort

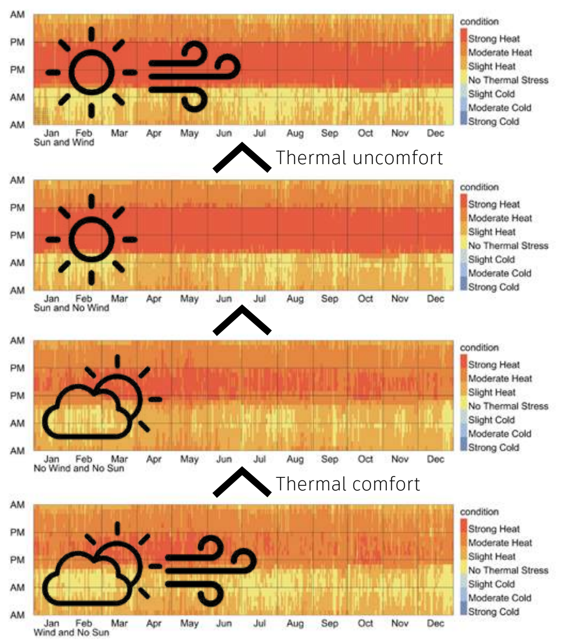
Limted wind energy and strong solar energy.

PMV factors are humid

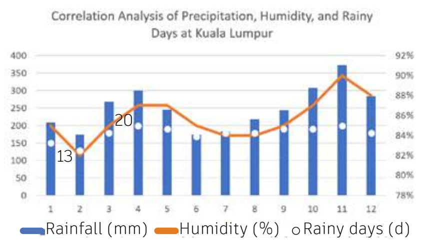
Therefore, strategy should focus on shading and maximise use of solar power, by installing BIPV system.

Wind Rose:





Rain & Humidity



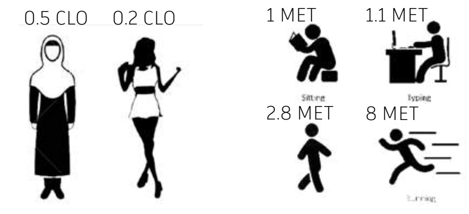
According to research, the predominant influence of outdoor climate on the thermal comfort of occupants in naturally ventilated buildings, with optimal comfort temperatures determined by average outdoor temperatures.
Besides, the significant impact of relative humidity on indoor thermal comfort, necessitating strategies to maintain optimal humidity levels through effective air circulation and heat dissipation.

Result:
Wind & no sun> No wind & No Sun>
Sun &Wind >Sun & no wind

Individual factor

1. Clo rate
Clo rate are wide range: 0.2 to 0.5

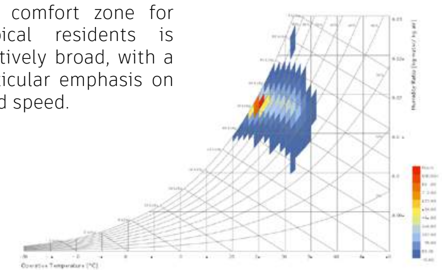
2. Metabolism Rate
Activies in community center are wide range:



NORMAL STANDARD

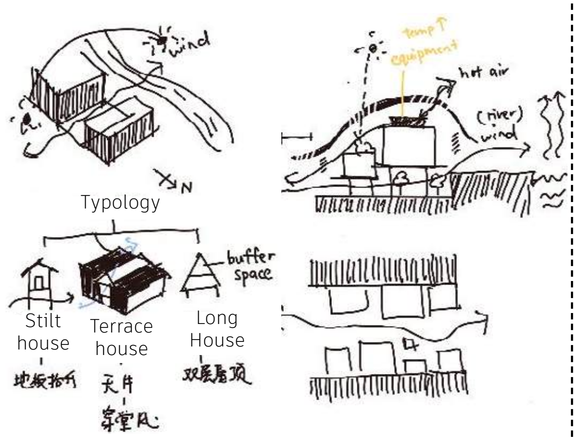
3. Malaysia standards

The comfort zone for tropical residents is relatively broad, with a particular emphasis on wind speed.



Traditional Buildings Typology for reference

Based on typology of traditional architecture, developed a series of climate adaptive method to apply on "the Forest building", method covered air flow (natural ventilation), daylight usage, water reuse, electricity from solar panel and material selection.



Conclusion:

Environmental Factors:

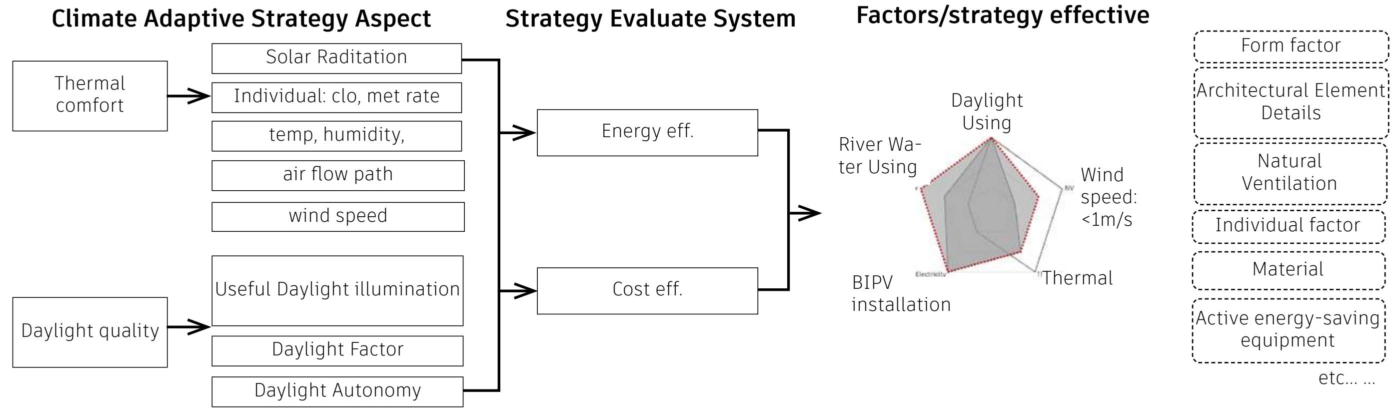
Wind: *Low potential for use.*
Sun: *High impact on thermal comfort, High potential for use*
Rainwater: *High potential for use.*
Humidity: *Negative influence on thermal comfort.*
River: *Risk of flooding, but potential for use.*

Individual Factors:

Metabolism Rate: *Wide and diverse range.*
Clothing Rate (Clo): *Restricted.*

These factors collectively contribute to the overall evaluation of thermal comfort and environmental suitability.

Balancing daylight levels with solar heat gain is essential in tropical climates. Daylight may lead to increased heat gain, impacting thermal comfort.

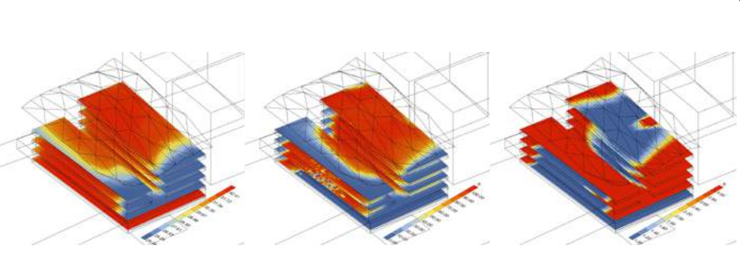


Reference:
1. International Organization for Standardization. (2005). ISO 7730: Moderate Thermal Environments - Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort.
2. Jones, P. (2009). Thermal comfort factors in hot and humid regions: Malaysia.

2. Relationship between Daylight and Thermal Comfort

(1) Problem: Thermal and Daylight Simulation

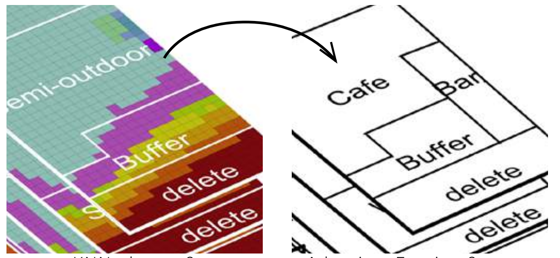
Go throught daylight and thermal simulation with the basic elements like floor area, roof top and surrounding buildings, in order to develop further startegy. From the simulation result, we can seethe trend of daylight useful i (UDI) and thermal comfort is different sometimes even invert, UDI and DA is positively related. DF is irregular.



Themal comfort percentage (TCP) | Useful daylight illuminance (UDI) | Daylight Factor (DF)

(2) Optimization Process:

Classify thermal and lighting considerations by KNN-cluster Analysis Method to 3*3*3=27 Types, to derive suitable activities and design strategies tailored to climate conditions.



KNN-cluster & Visualization | Adaption: Funtion & strategies

(3) Result:

Strategies for thermal comfort:

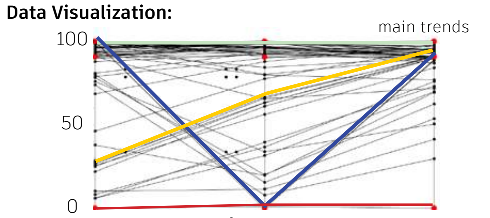
Before: FULLY air conditioner → After: comfortable — fan; acceptable — stronger fan; uncomfortable — air conditioner

RANDOM ALLOCATE ACTIVITIES → Less dense & Chill; Dense & Active

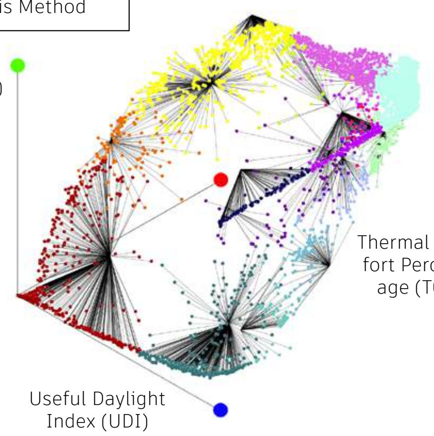
Strategies for Daylight usage:

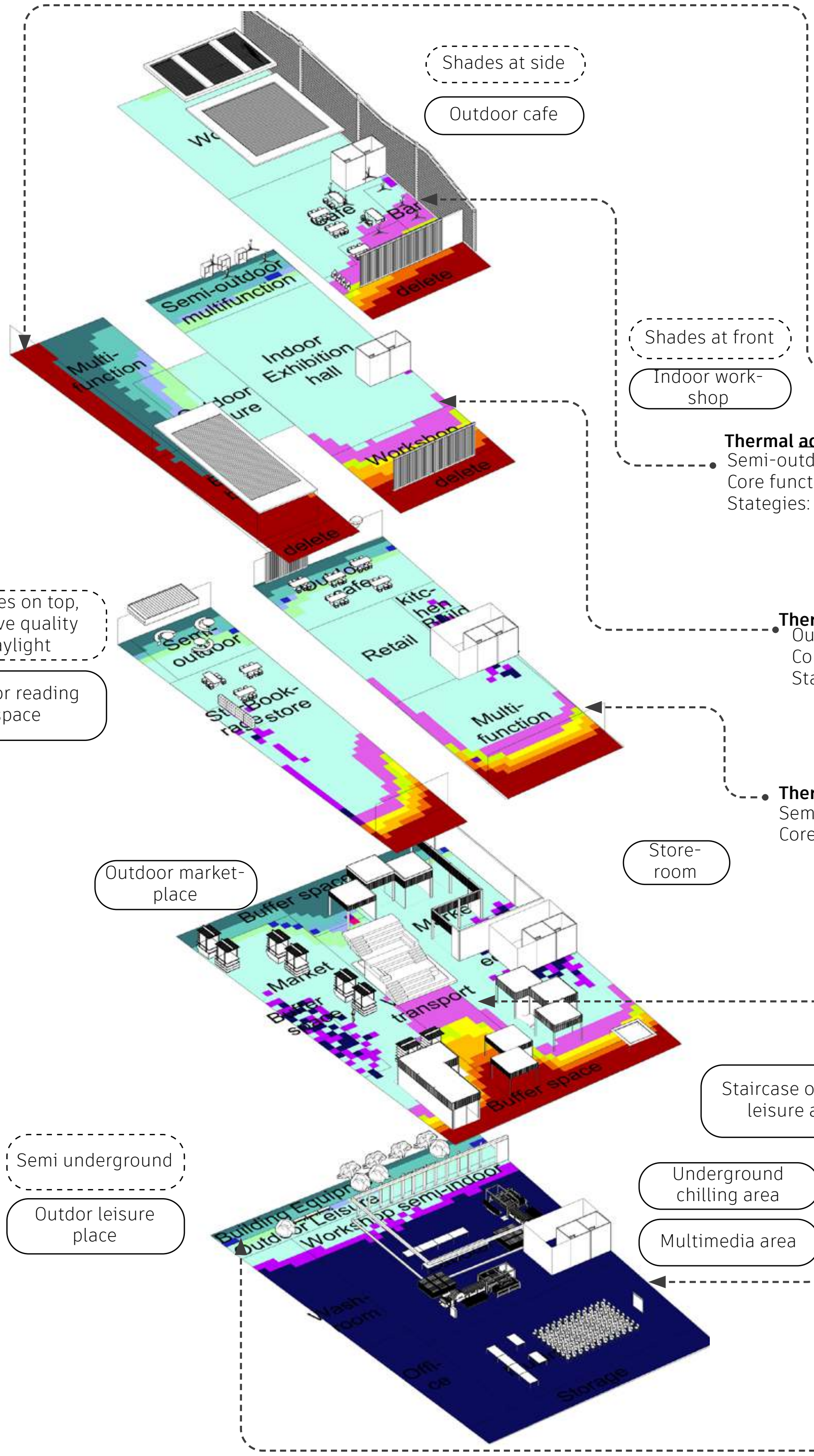
Before: FULLY electric lighting → After: comfortable/ acceptable — daylight, shades; unacceptable — electric lighting

Data Visualization:



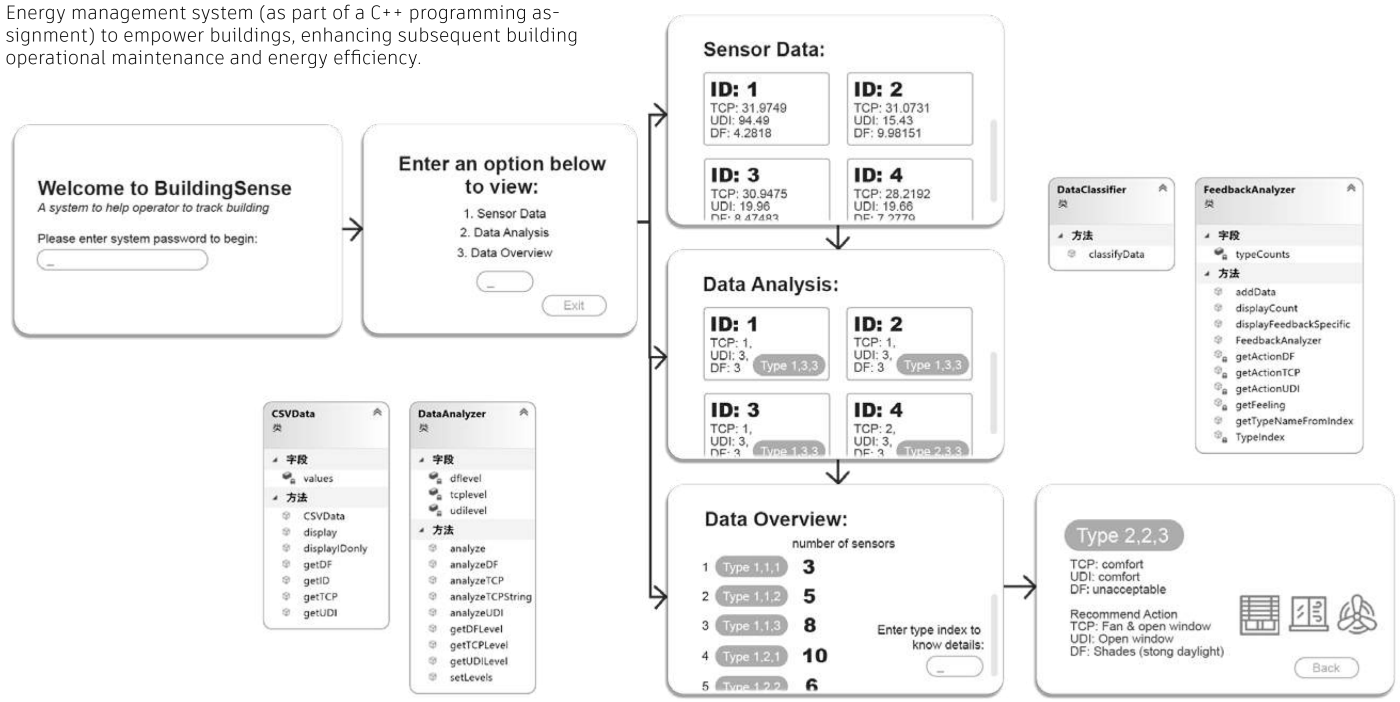
KNN-cluster Analysis Method





(4) Operation

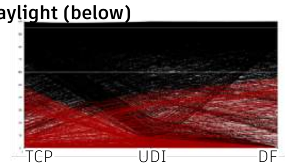
Energy management system (as part of a C++ programming assignment) to empower buildings, enhancing subsequent building operational maintenance and energy efficiency.



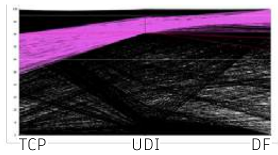
Opaque wall at side

Indoor workshop

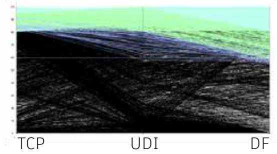
Thermal uncomfortable and unacceptable daylight (below)
Semi-indoor, Indoor, fully air conditioner and artificial light support



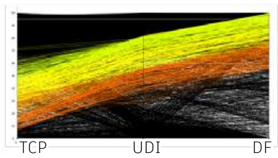
Thermal acceptable and comfortable daylight
Semi-outdoor area, Core function Stategies:



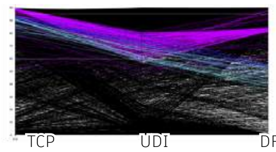
Thermal comfortable and comfortable daylight
Outdoor, semi-outdoor area, Core function Stategies:



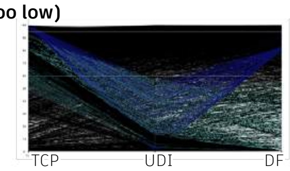
Thermal uncomfortable and acceptable/comfortable daylight
Semi-indoor, Core-function



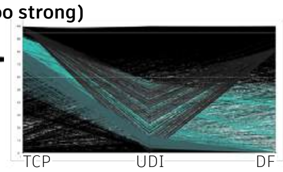
Thermal comfortable and acceptable daylight
Semit-outdoor, outdoor: Outdoor leisure



Thermal comfortable and unacceptable daylight (too low)
Semi-indoor, indoor
Fully artificial light support



Thermal comfortable and unacceptable daylight (too strong)
Outdoor, semi-outdoor, outdoor leisure



THE FOREST

THE FOREST

The view of main hall of museum

Main Hall

Art Market Entrance

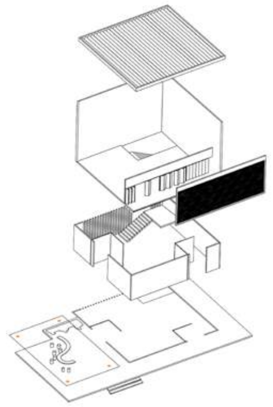
Main Entrance

To amphasize the local environment, the space of museum is opened up and to lead in nature and tropical environment. Also applied climate adaptive design by implated natural ventilation system in the building.

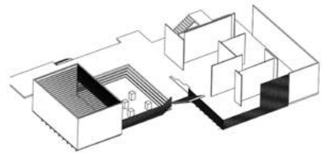
A specific-designed roof with islamic pattern is to cover up the open space.

Enclosed exibition/studios modules are implanted under the roof. Ground floor are the flexible, small unit modules, the upper floors are the larger exibition halls and studios.

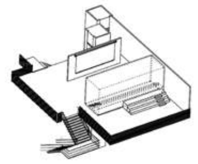
THE FOREST



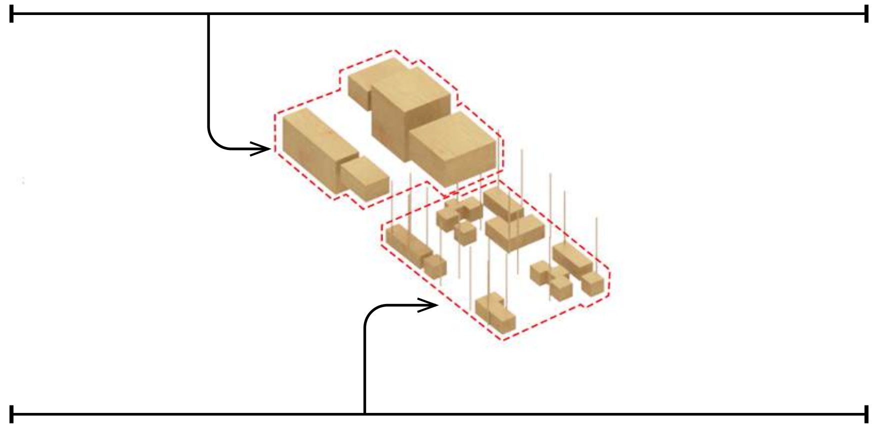
Enclosed Duplex Gallery



Semi-open Gallery

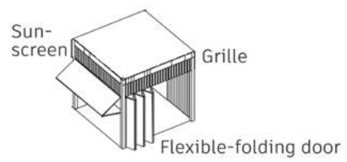


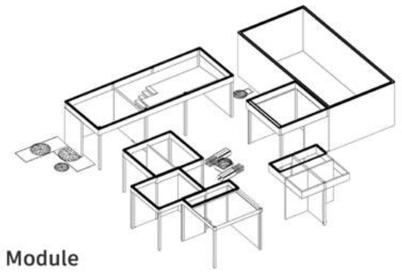
Multimedia Space



Atmosphere of Arts & Crafts Market

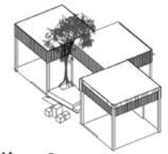
Prototype





Exibitions Module

Combination - Market



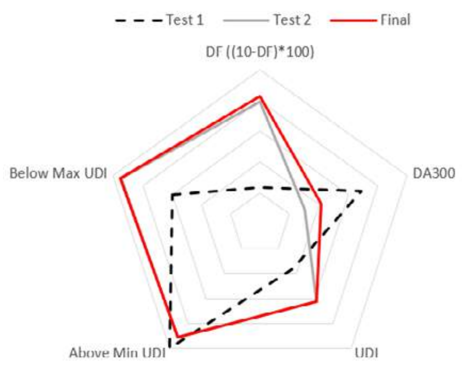
Chilling Area

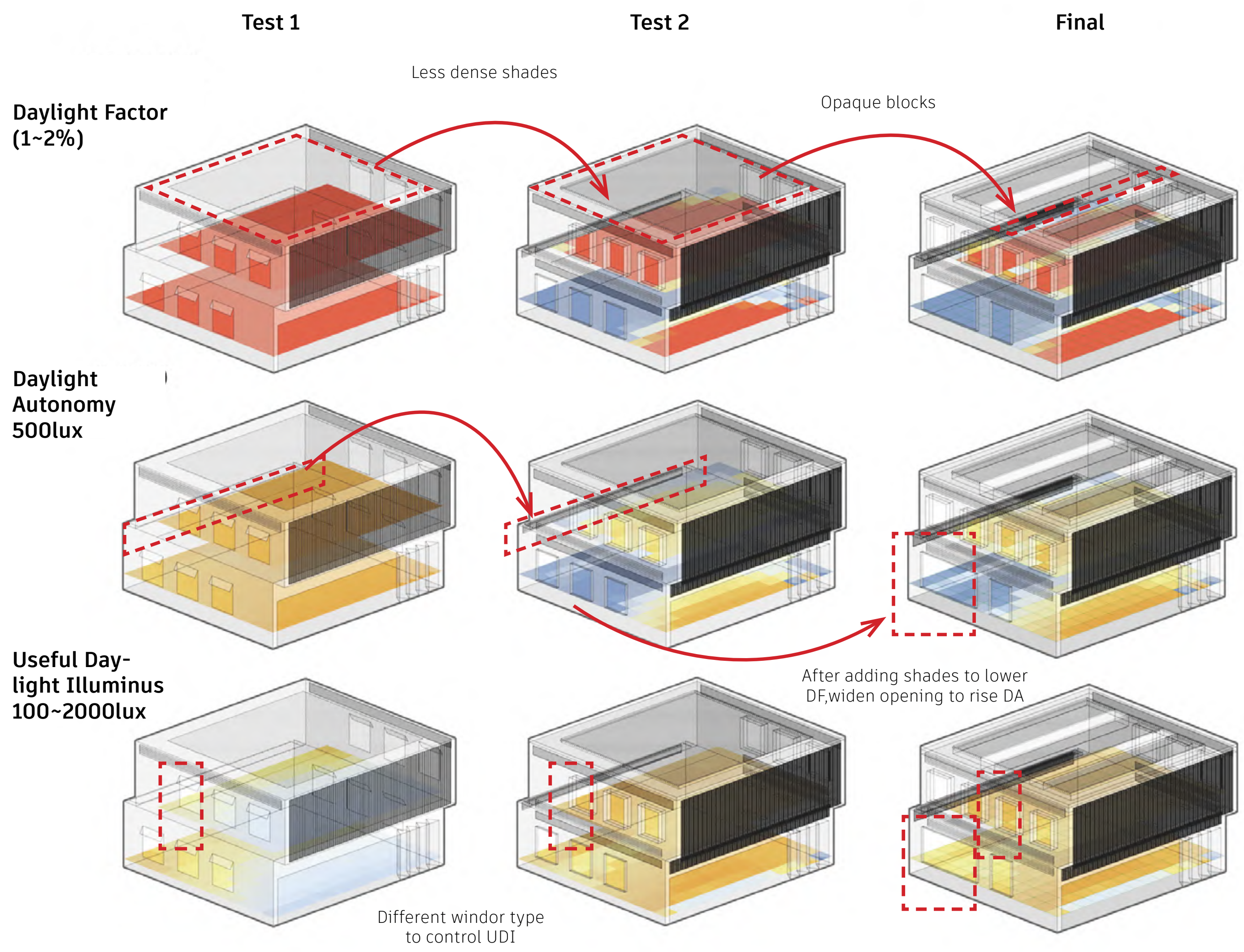
3. Indoor Daylight Simulation and Optimization

Examining daylight quality in one of the semi-indoor areas (core-function box) serves as an illustrative example. This box operates with natural air and occasional air conditioning based on the time of day.

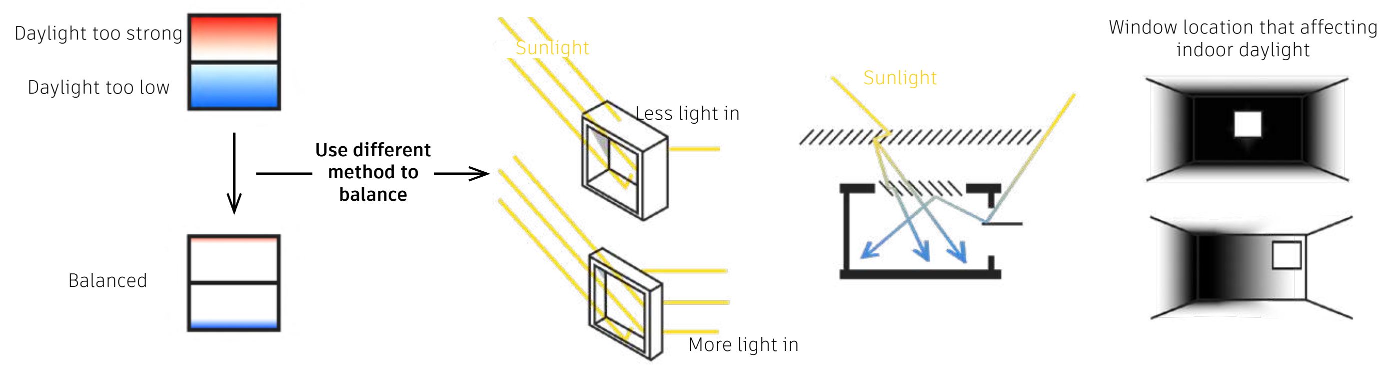
In our simulation, we used Daylight Factor (DF), Daylight Autonomy (DA), and Useful Daylight Illuminance (UDI) as indicators to enhance the lighting design. Given Malaysia's abundant sunlight, we set a 500 lux threshold (DA500). Effective Natural Illuminance Levels (UDI in lux), representing comfortable indoor lighting, fell within 100-2000 lux per the Malaysian standard MS2680. MS2680-2017 mandates a daylight factor for living spaces not below 2%.

Ultimately, adjusting roof shades, window types, depth, window-to-floor ratio, and placement increased effective DF from 23.4 to 82.5, reduced DA from 68.76 to 41.8, and improved UDI from 36.27 to 62.2. In inadequately lit areas, electrical lighting supplemented the design.

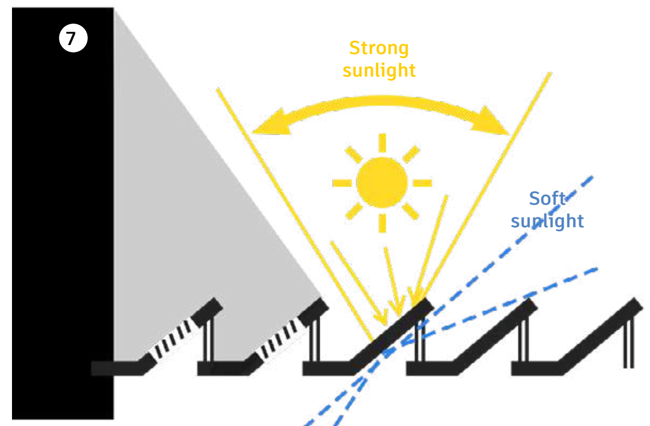




Strategies:



1. Implementing a well-ventilated atrium with full height.
2. Creating gaps between indoor spaces for efficient air circulation, leveraging the chimney effect.
3. Using operable grilles at the top of indoor spaces for natural ventilation.
4. Employing both fans and air conditioning as needed.
5. Installing multi-angle grilles to filter intense sunlight while maximizing daylight usage.
6. Utilizing various window types for light control.
7. Maximizing shading from surrounding buildings, incorporating roof openings for ventilation and lighting.
8. Installing BIPV panels in sun-exposed areas.
9. Incorporating tropical plants and concrete slabs.
10. Utilizing river water and geothermal energy for cooling.
11. Using concrete baffles at windows for shading and harnessing concrete's high thermal mass to stabilize ambient temperature by absorbing heat during the day.



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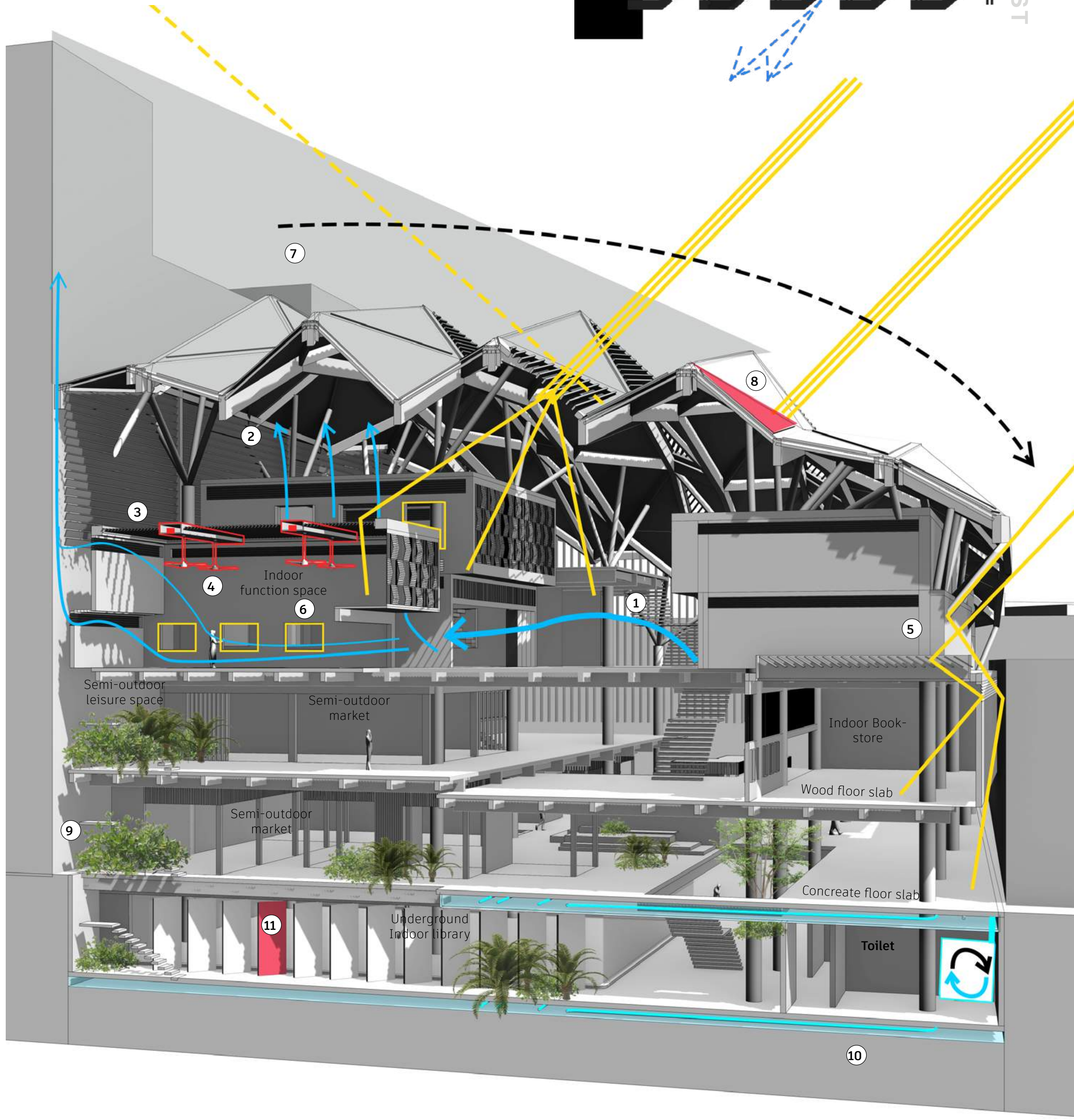
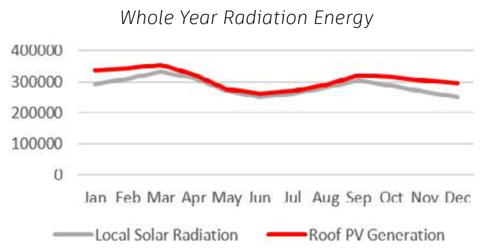


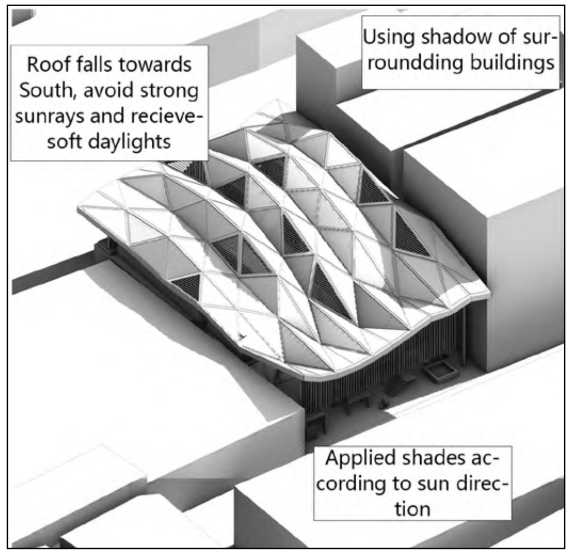
4. Strategy and Evaluate System

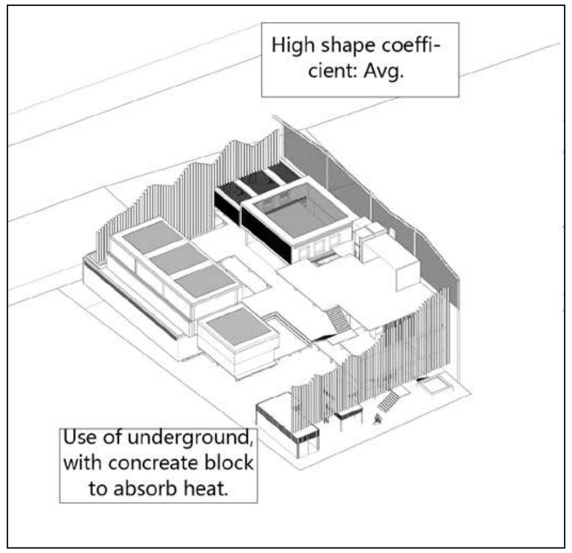
Based on typology of traditional architecture, developed a series of climate adaptive method to apply on "the Forest building", method covered air flow (natural ventilation), daylight usage, water reuse, electricity from solar panel and material selection.

(1) Thermal and Daylight adaptive strategy

Daylight Comfort Strategy: Employing the shadows cast by surrounding buildings, the roof slopes towards the south, mitigating exposure to intense sunlight while welcoming ample daylight. Shades have been strategically applied based on the direction of the sun.
Thermal Comfort Strategy: Embracing a high form factor, we leverage the use of underground spaces with concrete blocks to absorb and manage heat effectively.

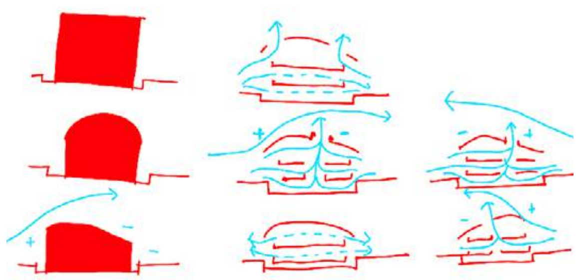


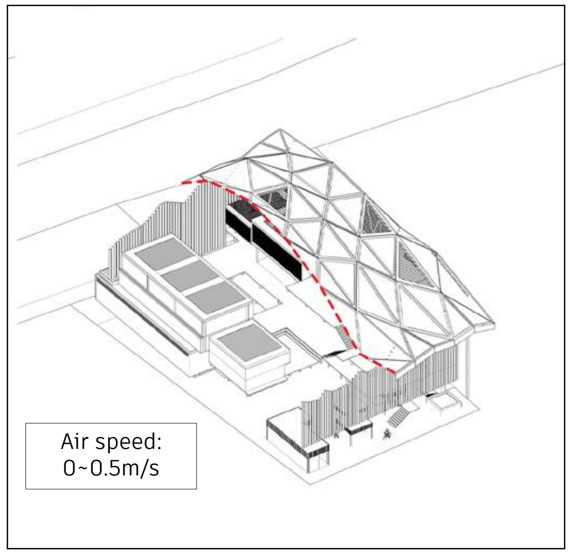




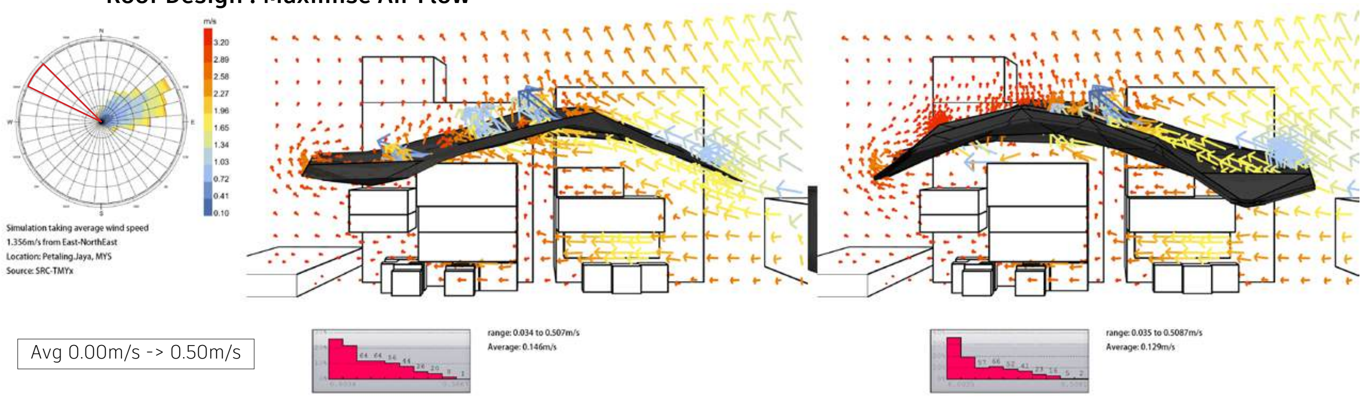
(2) Natural Ventilation

Enhanced form factor coincides with the creation of a central avenue, allowing for cross-ventilation. Gaps are intentionally left between function boxes, with openings at the top facilitating the release of rising hot air, thus generating a chimney effect.





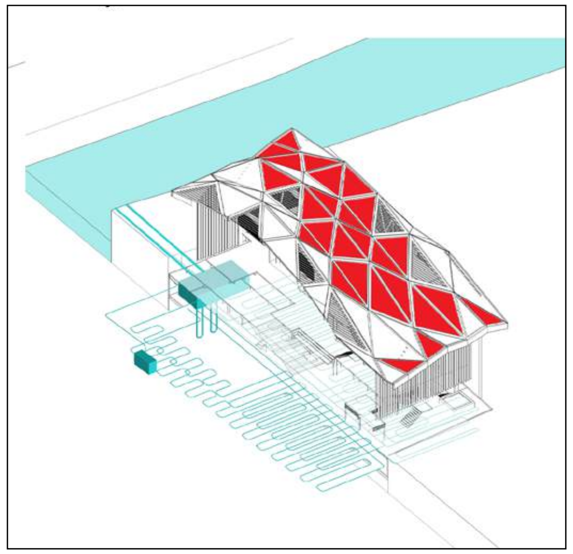
Roof Design : Maximise Air Flow



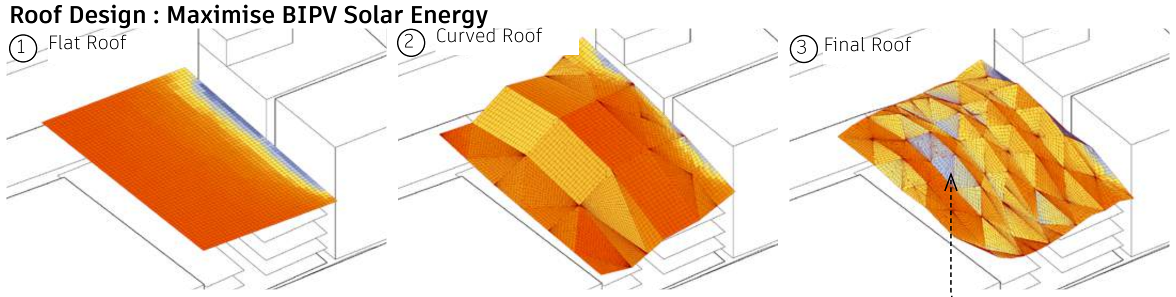
(3) Active strategy of climate adaptive design: BIPV Solar Energy & River water reuse

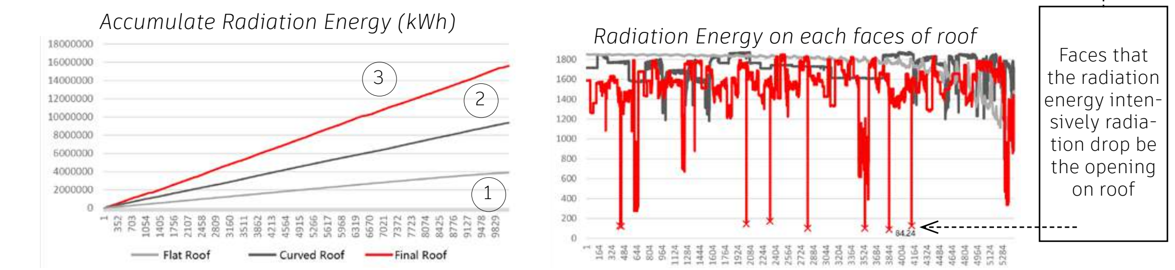
The building making efficient use of natural resources for cooling, shading, and energy generation.
The roof, equipped with BIPV panels, is meticulously designed to maximize radiation absorption while strategically creating openings to allow for ventilation. Through the introduction of river water underground, a cooling system is established, serving as an air conditioning heat sink between the floors.

	Area (m2)	Solar irradiance (kWh/sqm/year)	Total radiaton received per year	Annual electricity production (kWh)	Total Price Saved per year
Roof	1699	122705	2804000	420600	RM299,013.05



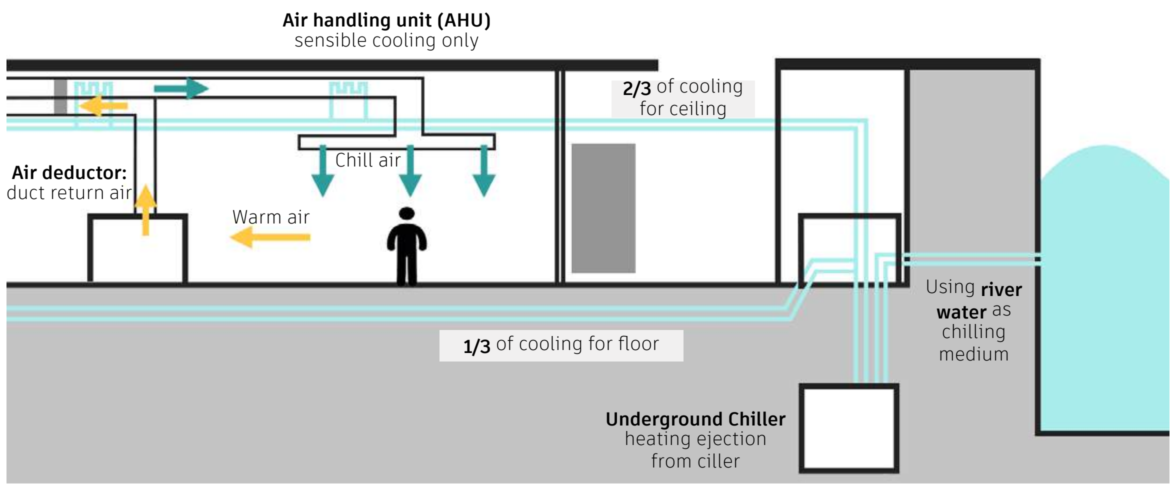
Roof Design : Maximise BIPV Solar Energy





Cooling system:

Using river water as cooling medium, transfer water to underground to undergo cooling, and transfer it to builing as cooling medium, cooling the air in building.



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