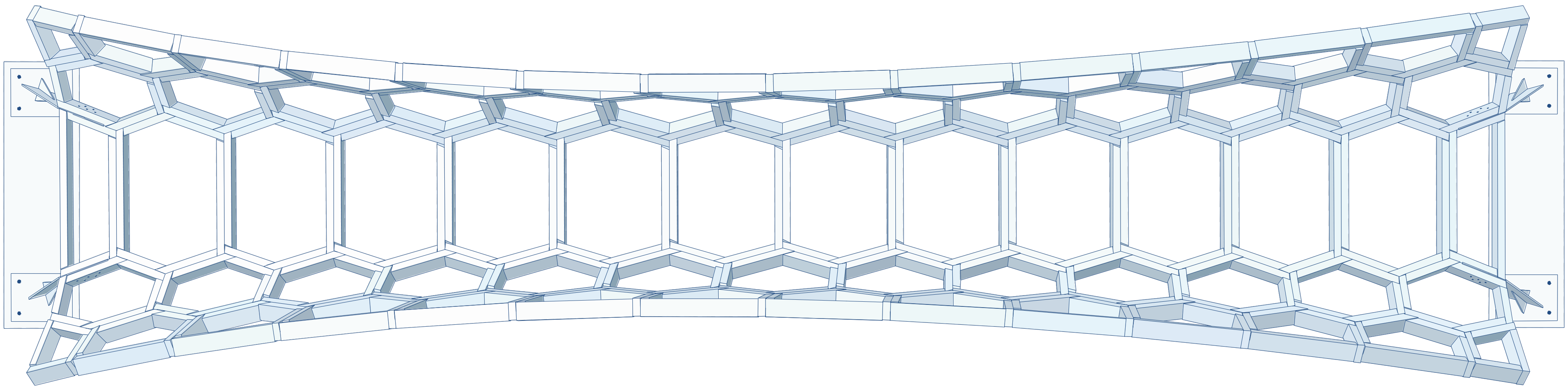
THE VEIN OF FALLEN LEAVES

: Trail Pioneering Project of Digital Twins Tectonics



NCKU | Dept. of Arch | RAC-Coon | RATs | 2023

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国立成功大學建築學系數位智造工坊

落葉之脈: 數位雙生構築之溪徑開拓計畫

The Vein of Fallen Leaves:
Trail Pioneering Project of Digital Twins Tectonics

沈揚庭 著作
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PREFACE

We are delighted to present this portfolio, providing a comprehensive account of the design and fabrication projects accomplished with the invaluable assistance of industrial robots. As the manager of Raccoon, it is our privilege to share the insights and achievements of our fourth successful timber structure, expertly crafted with the aid of these advanced machines.

Contained within these pages are the fruits of our endeavors in robotic fabrication, culminating in the impressive construction of a timber bridge. Our approach revolves around a strong emphasis on practical learning, as we firmly believe that tackling real construction challenges offers unparalleled opportunities for growth and innovation. This guiding philosophy has formed the foundation of our fruitful partnership with students, fostering an environment where knowledge and skills are collectively honed within this dynamic field.

The success of this project is largely attributable to the dedication and efforts of the students involved. Their commitment and boundless enthusiasm have been instrumental in pushing the boundaries of what is achievable through robotic fabrication. Their work has played a pivotal role in verifying the feasibility of our cutting-edge robotic fabrication techniques and has significantly contributed to the advancement of this promising area of research.

Throughout the years, our unwavering focus has centered on lightweight timber structures, underpinned by principles of sustainability and efficiency. Through multiple iterations, we have continually refined our methodologies, with each project serving as a decisive step forward in exploring the boundless capabilities of industrial robots in the realm of architecture. As we gaze ahead, our determination remains resolute as we forge ahead in developing automation and smart construction technologies.

We extend an invitation to all readers to delve into the following chapters with the hope that the contents presented herein will ignite inspiration among architects, engineers, and researchers. The potential of industrial robots in architectural design is vast, and we are committed to continuously pushing the boundaries of what is possible, contributing to a future where automation and intelligence harmoniously reshape the landscape of construction.

Chia-Ching Yen
Manager and Lead Developer at Working Space Raccoon

CONTENTS

INTRODUCTION

WHO WE ARE

RAC-Coon | Smart Construction Workshop
founded in Sep. 2020 @NCKU

RATs | Robotic Arm Tectonics Studio
founded in Feb. 2021 by Shen, Yang-Ting

Working Space RAC-Coon is an innovative research and teaching space within the College of Planning and Design NCKU. It is a Higher Education Sprout Project-funded project and opened on 4th, April 2020.

RAC-Coon aims to innovate architectural research, developing intelligent construction automation by integrating robots into construction, and eventually improve the technique and quality of construction in Taiwan. The workspace is equipped with two large-scale robots on the rails collaboration, which also forms the logo of the working space.

The purpose of the establishment of the Robotic Arm Tectonic Studio (RATs) is to cultivate interdisciplinary talents who will lead the upgrading and transformation of Taiwan's architecture in the future, and reconstruct the paradigm of architectural education with the value "Design for build."

RATs (Robotic Arm Tectonics Studio) symbolizes the core value of "Design-based, Technology-based, and Construction-based." RATs means a Taiwanese saying that the son of a mouse will make a hole, and it symbolizes the spirit of that the architect creates space.

RAC-Coon
Robot Aided Creation and Construction
成 大 數 位 智 造 工 坊

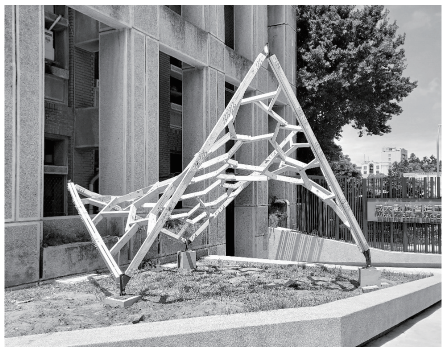
Robotic Arm Tectonics Studio

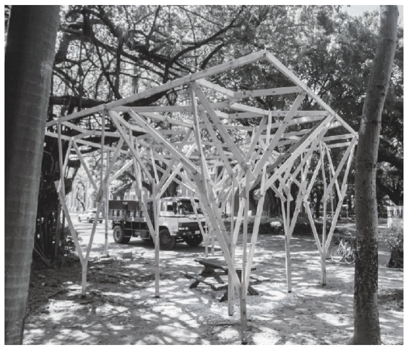
WHAT WE PURSUE

FULL SCALE TECTONICS

- We can change the world
- Design for build
- Robots Tectonics
- Robotic Timber Frame Structure
- Build a pavilion in real world

RATs focuses on the concept of "Design for Build." Under this promise, RATs introduces robots to aid the construction of architectural components, which could ultimately merge architectural design with intelligent construction.
The best proof of architecture is implementation. What RATs pursue is to build a pavilion that marks a milestone for the development of intelligent construction. It will be different from the usual design methods that start from space and function but start from the truth to materials and honest display of the construction.
Full scale, tectonic, multidisciplinary, robots: all these factors will be integrated with the concept of Design for Build. The pavilion will embrace the complexity of customization, bringing more possibility to design and construction.





WHAT WE HAVE

Robot
- KUKA KR300 Robot *2
- HIWIN RA620 *2

End Effector
- Hot Wire Cutter
- Spindle Miller
- Pneumatic Gripper
- Interchangeable Woodworking Tools
- Metal Bending
- Metal Welding

TECHNOLOGY-EMPOWERED DESIGN

Integration of robots make technology a complementary addon
to the design process.

RATs' robot construction course uses lumber as the main construction material. The robot is equipped with a spindle, which makes it a 5-axis CNC milling machine. Along with various woodworking techniques, including drilling, milling, and cutting, the lumber could be

RATs hopes to turn the constraints into a challenge of design and construction, believing that feasible construction methods will eventually emerge from them.

WHAT WE LEARN

SMART CONSTRUCTION

- Design for Build
- BIM- Building Information Modeling
- Parametric Design for Smart Construction
- Visualized Coding for Robot Control
- Grasshopper PRC

Instruction Objectives

① The relationship between material and structure :

We use southern pine as the primary building material for the pavilion. Thus, we must consider the properties of lumber when designing the pavilion which will be built. Its structural performance, structural behavior, and joinery design are all crucial factors.

② Computational design thinking and fabrication :

The design workflow must consider the feasibility of fabrication. The following abilities are therefore required by this process :
a. Building Information Modeling
b. Parametrical design process
c. Robot fabrication simulation

③ Skill training programs :

Continuing from the above, the course will include :
a. Building information model training
b. Parametric design training
c. Robot operation training
It is the goal that we can integrate the three into a design project empowered by technical capabilities.

④ Teamwork :

In this design, each group member will first make individual design proposals, so as to cultivate the communication and sharing in the group. In the end, a single work will be selected for 1:1 real construction. The teamwork is emphasized to complete the work within a limited time.

PROPOSALS

At the first stage of this studio, every group member makes a proposal for the final 1:1 construction.

Liao, Chen-Chia
Bridge 10

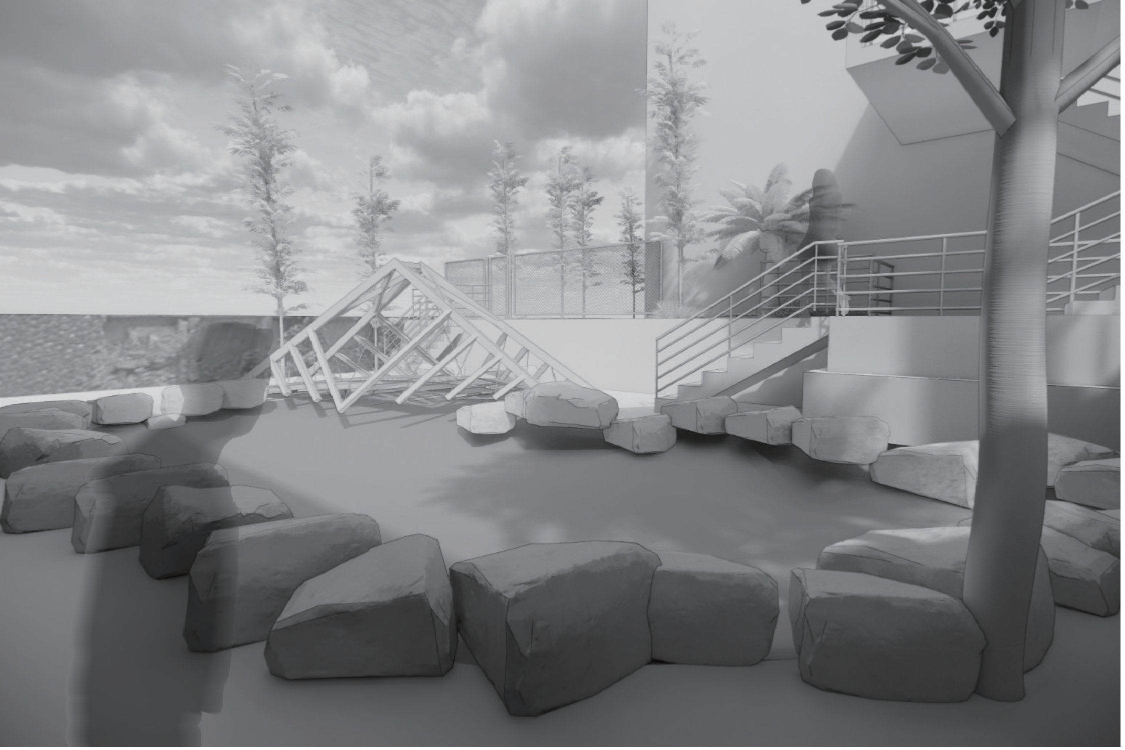
Pan, Zhong-Yu
Voyage Bridge

Hung, Huai-Yun
V V Bridge

Tsao, Yung-Hsing
First Quarter Bridge

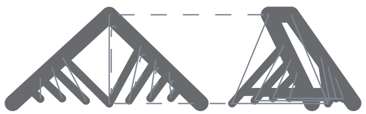
Tai, Huai-An
Veins of Leaves

Ho, Pei-En
The Weave Bridge



BRIDGE 10

NCKU ARCH Dep. Chen-Chia, Liao

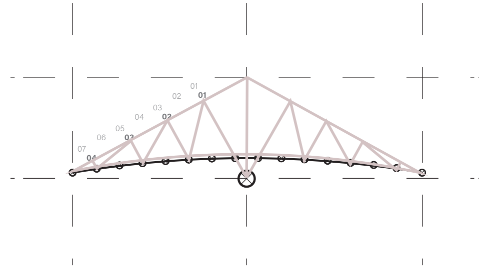


INTRODUCTION

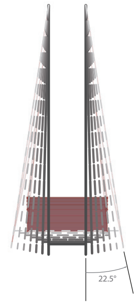
My design stems from a structural concept. The lightweight and delicate nature of tensile structures greatly captivate me. With the application of machine-assisted manufacturing techniques, I believe this concept can be realized. Simultaneously, the texture of the environment cannot be overlooked, so I have established a parameter-generated design model with versatility. Consequently, the entire structural system can evolve in harmony with what I perceive as fitting with the environment. To eliminate overly subjective notions resulting from personal value judgments, I simply want to name it "Bridge 10." This represents the tenth version throughout my design development process.

PARAMETRIC DESIGN

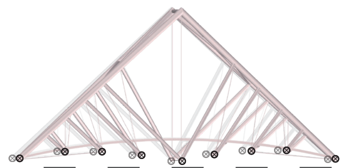
01.
timber quantity
addition



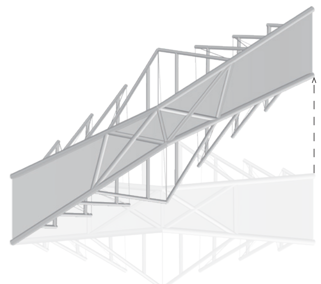
02.
BOTH FLANK
FLOATING ROTATE



03.
ELEVATION SHIFT



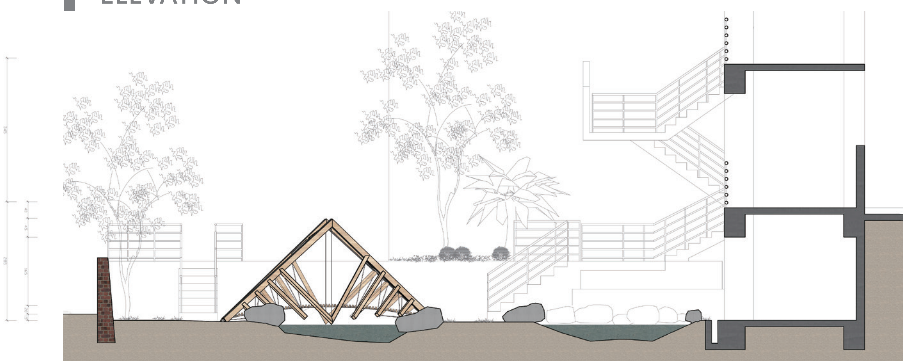
04.
PLAN SHIFT



SITE PLAN

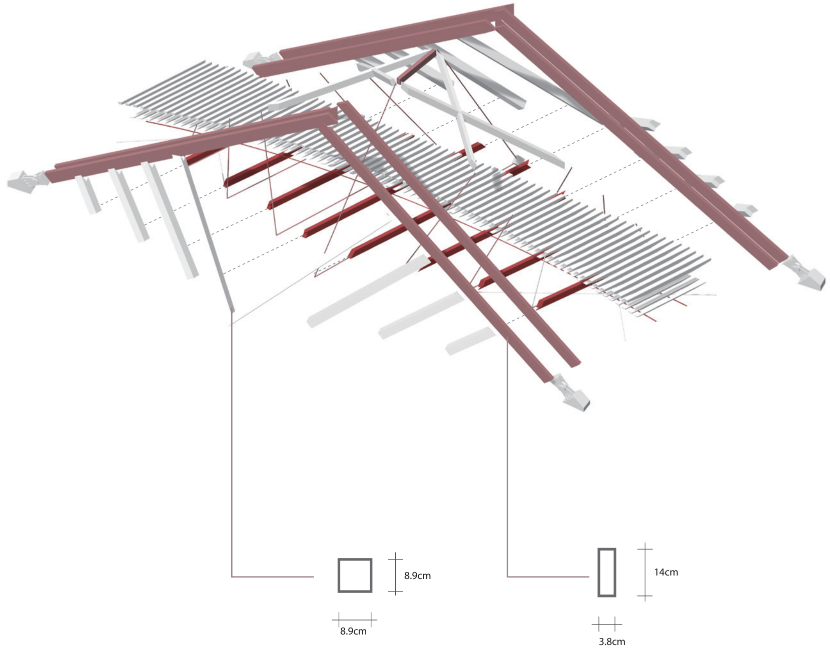
I try to extend site context according to the special circulation walking down the stairs right above the site, and put my bridge design to cross the pond. After the bridge design, I hope the tiles could be replaced to guide people walking through the path and minimum interfering the enviroment.

ELEVATION



The height of the bridge is limited within the height of one floor, so that the view of the landscape can be extended.

STRUCTURE

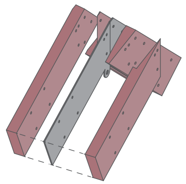


Through the precision machining of the mechanical arm, the wood is tightly bonded, and the internal force of the bridge is finally transmitted back to the main structure of 2X6 through the suspension cable. In order to ensure that the straight wood is compressed and will not buckle, the 4X4 wood is selected. Finally, the tread is combined with tension steel cables and pre-cut wood.

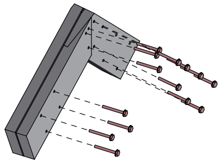
JOINT COMPONENT

I have chosen the most complex node as the subject of a local experiment. This node will bear the weight of the entire bridge as well as the live load, and it is also one of the joints with the highest number of timber connections. I will attempt to assemble it with the most extreme angular parameters to ensure that the most complicated component in the fabrication process can be produced.

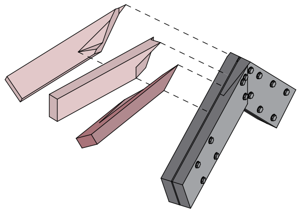
They are composed through the following six steps:



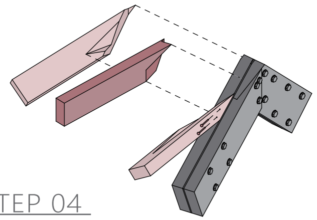
STEP 01
PREFABRICATED TIMBERS



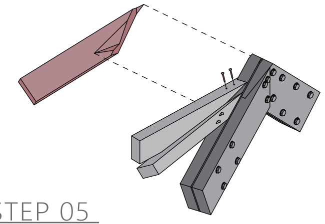
STEP 02
SHEAR BOLT COMBINATION



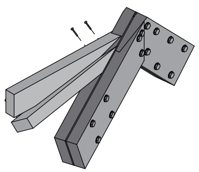
STEP 03
PREFABRICATED BEAMS



STEP 04
SHEAR THREAD COMBINATION

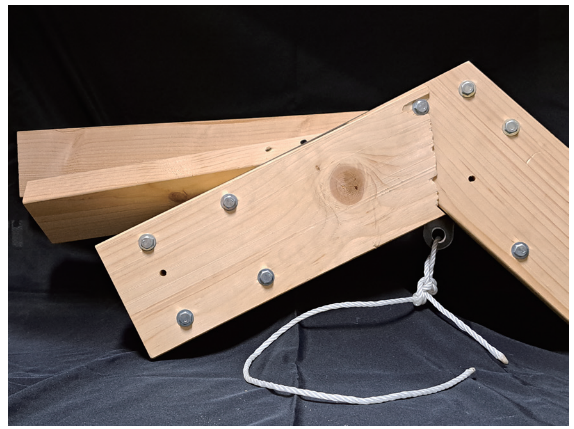


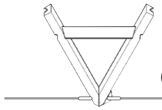
STEP 05
INSTALLING MAIN GIRDER



STEP 06
FINISH REST OF THE PART

MODEL

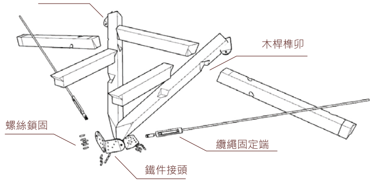




空中絲路

OYAGE BRIDGE

NCKU ARCH Dep. Zhong-Yu, Pan



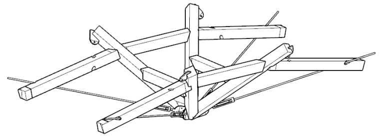
INTRODUCTION

My concept for a structural bridge stems from my admiration for the force of gravity. The bridge not only supports its own weight but also carries the weight of people, enabling them to cross over obstacles and reach the other side of the bridge. I am fascinated by the research conducted on structural behavior and the creation of efficient and precise bridges using elements like beams and trusses. Therefore, my structural bridge is inspired by the concept of "anti-gravity" in terms of its design. By analyzing the tension and compression forces on structural members, I propose using cables instead of tension members and 4x4 wooden beams for compression members in my design.

PARAMETRIC DESIGN

GRASSHOPPER: COMPRESSION AND TENSION OF ARCH BRIDGE

Step1

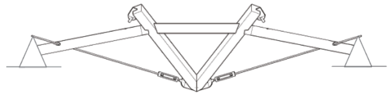


Unit

Unit ideas

I aim to use cables as tension members to reduce the overall weight of the bridge. I intend to conduct research and develop unit models based on the thinking pattern of spatial trusses.

Step2

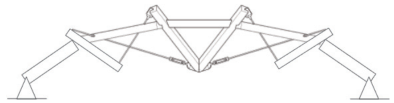


Unit=1

Structure

I intend to break free from the traditional form of spatial trusses and deconstruct the uniqueness of the bridge structure into components of the truss. I will design by intertwining cables and wooden beams together at certain points.

Step3

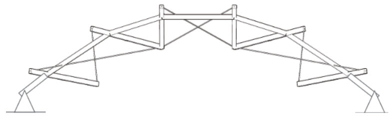


Unit=3

Parametric

With the unit and structure determined, I will proceed with parametric design, adjusting the number of units and the individual angles of each unit.

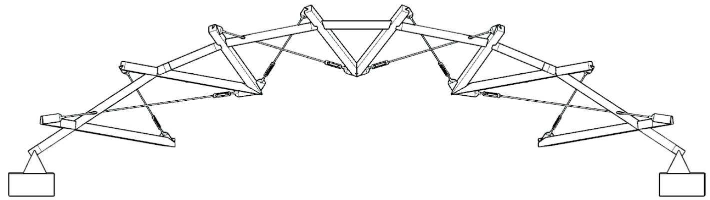
Step4



Unit=5

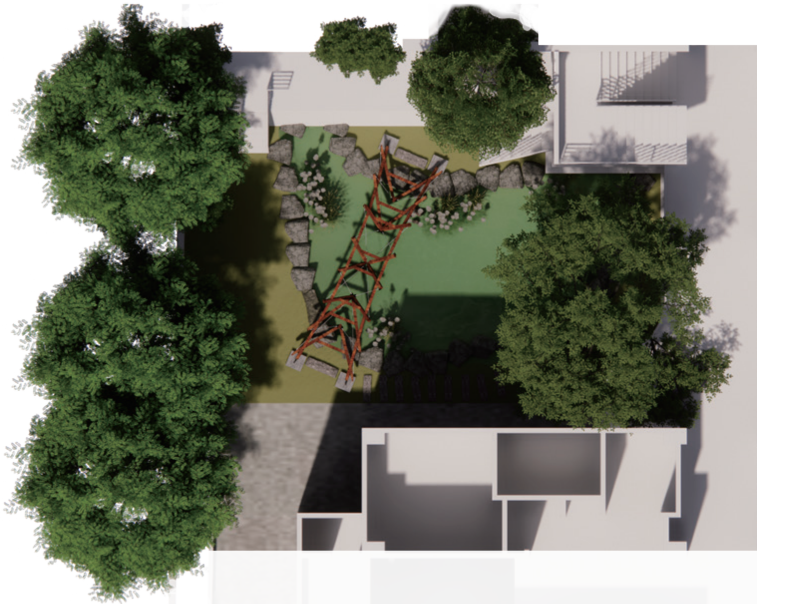
Site

In the end, I will adjust parameters such as the span, number of units and other factors based on the existing conditions of the site. This adjustment aims to achieve proportionality and harmony while considering material constraints and limitations, as well as ensuring construction efficiency.



Final

SITE PLAN

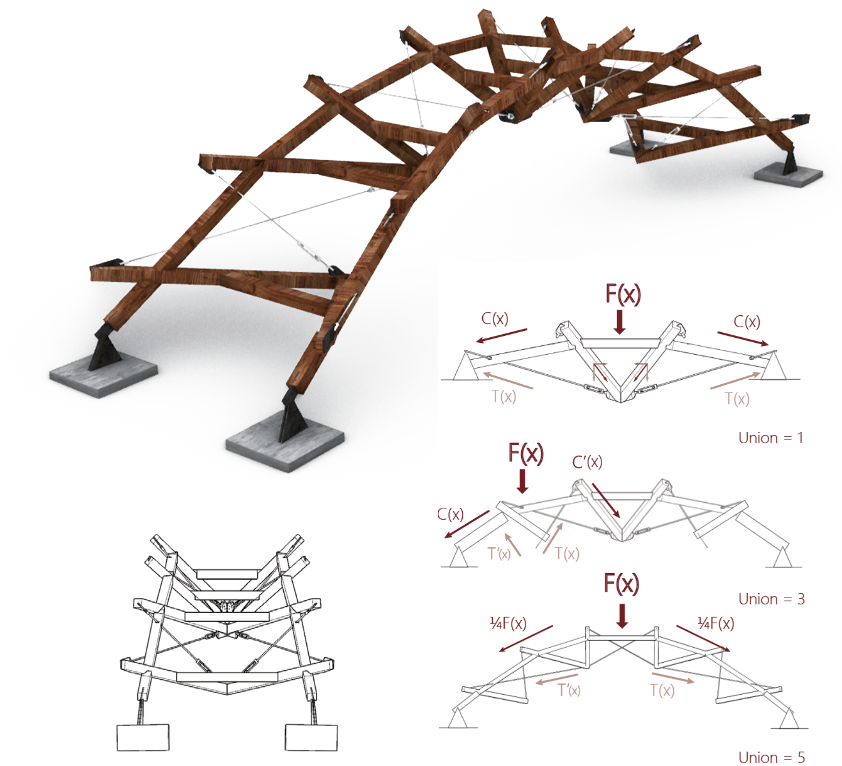


I have placed the bridge between two nodes on the site: one is a continuous pathway near a staircase, and the other is a significant intersection point. The positioning of the bridge not only affects the continuity of the pedestrian flow but also takes into consideration the space required for construction.

ELEVATION

From the elevation drawing, it can be seen that the overall structure of the bridge appears relatively lightweight due to the material properties of the cables.

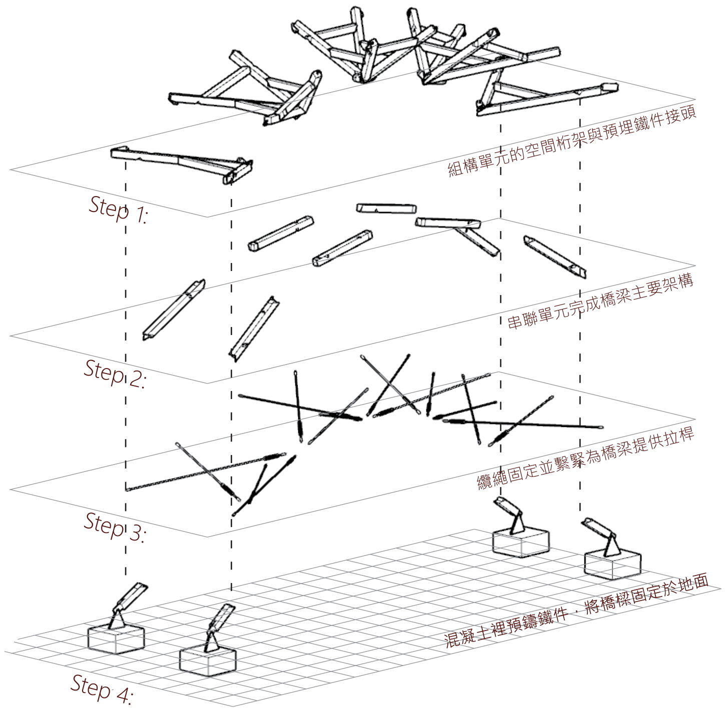
STRUCTURE

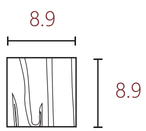


my design begins with studying the structural behavior of individual units. The compression and tension members are interconnected, and four wooden beams are used to spread them apart, achieving a state of force balance. This unit structure, resembling a spatial truss, is then multiplied towards both ends based on a cardinal number, ultimately forming an arch bridge.

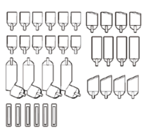
The primary load-bearing mechanics rely on the continuous main arches, while the cables are responsible for supporting the weight of people walking on the bridge. The tension members transmit the forces back to the main arches, which, in turn, transfer the forces to the foundation. The outward forces resulting from the load are absorbed by the concrete pedestals.

JOINT COMPONENT





4 X 4
Pine Tember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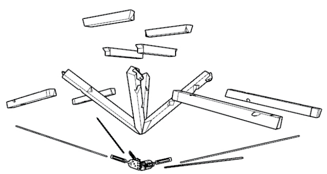
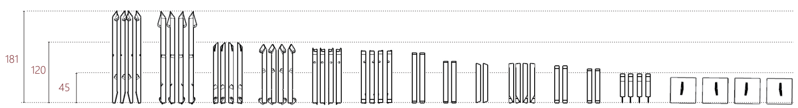




MODEL

Structural Test Model

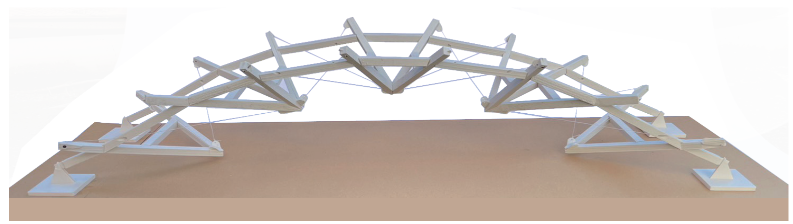
After testing, the stability of the structural behavior, the mechanical balance between compression members and tension cables, and the overall stability of the bridge structure have been verified. However, the outward forces resulting from the load still need to be stabilized through the foundation.

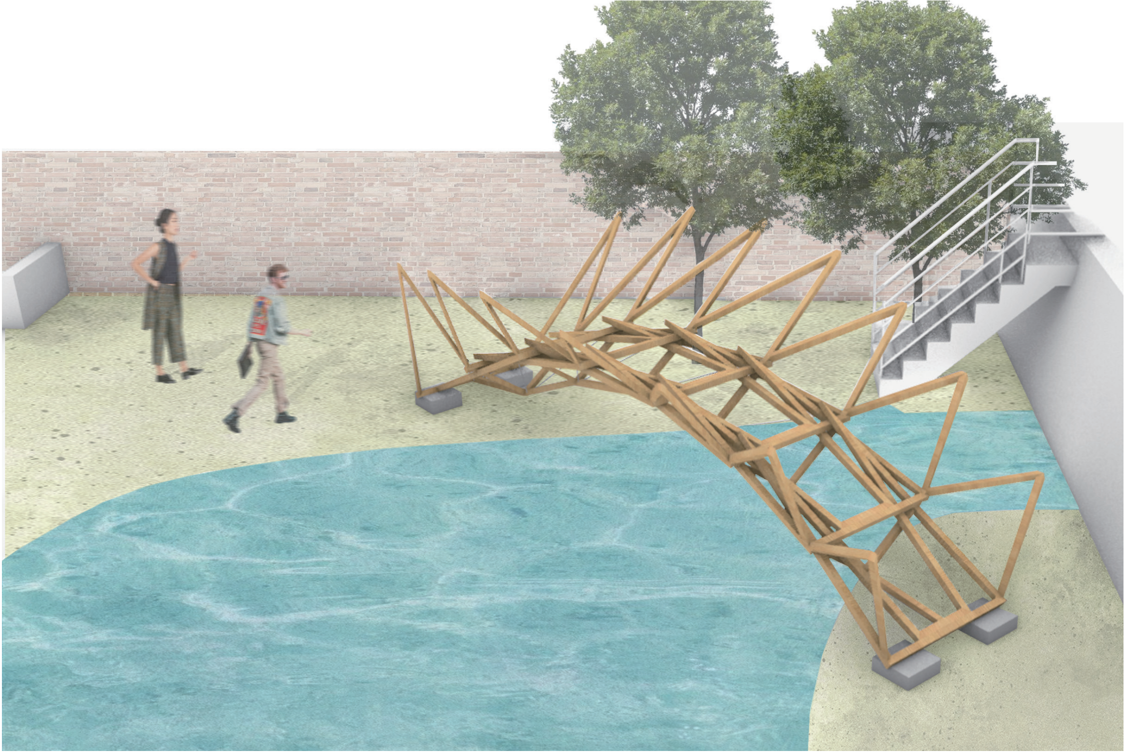
1:1 Detailed joint

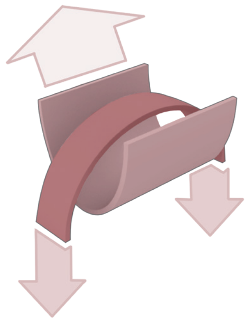
Due to the truss-like structure system, the joints must accommodate the connection of elements from eight different directions. To achieve this, I have decided to use iron components as the medium to join all the elements together. These iron components help control the direction of the elements and stabilize the joint structure. Additionally, the weight of the iron components adds further stability to the mechanical balance of compression and tension members.

1:10 Voyage bridge Model

The V-shaped structure seems to support the weight of the bridge with just two main arches, creating a sense of structural uncertainty, as if the bridge is leaping forward. The interweaving pattern of cables appears like a decorative totem, but it actually plays a crucial role in stabilizing the bridge.







V V BRIDGE

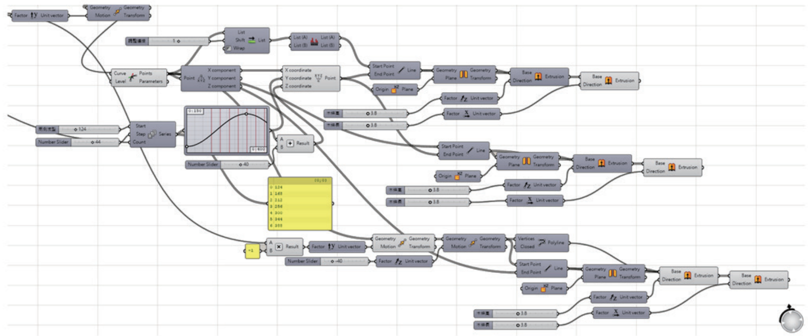
NCKU ARCH Dep.   Huai-Yun, Hung

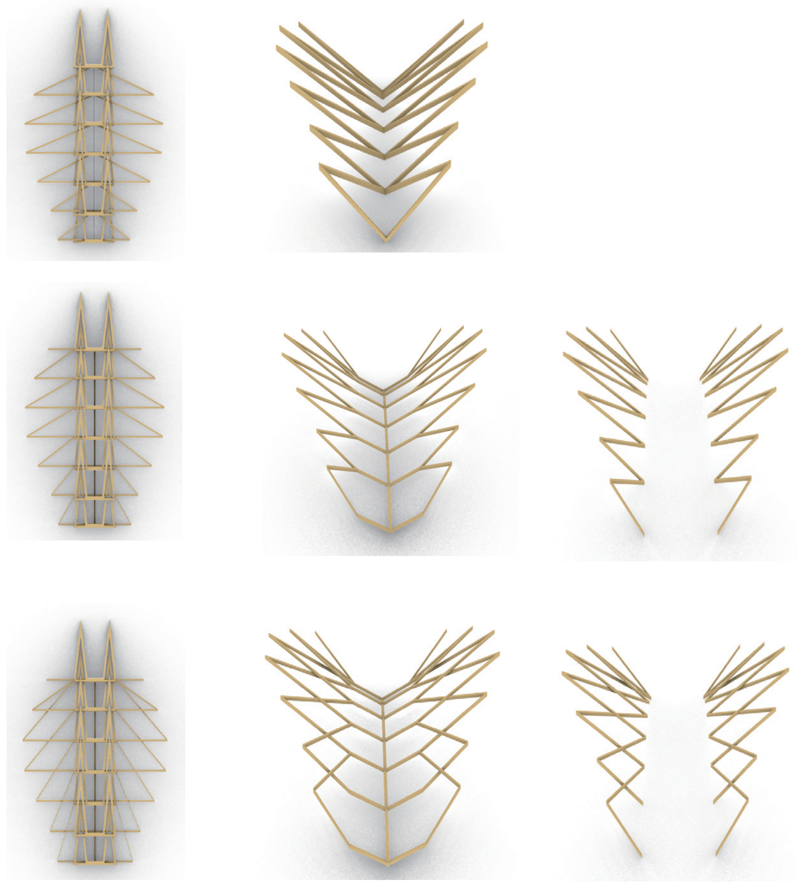
INTRODUCTION

Using the self-supporting structure of the Da Vinci Bridge as the main bridge structure, a downward curve is created. At the same time, the space truss is used to create a secondary system, which serves as the main beam and handrail below, and an upward curve is generated at the same time, forming a bridge where the two systems are embedded.

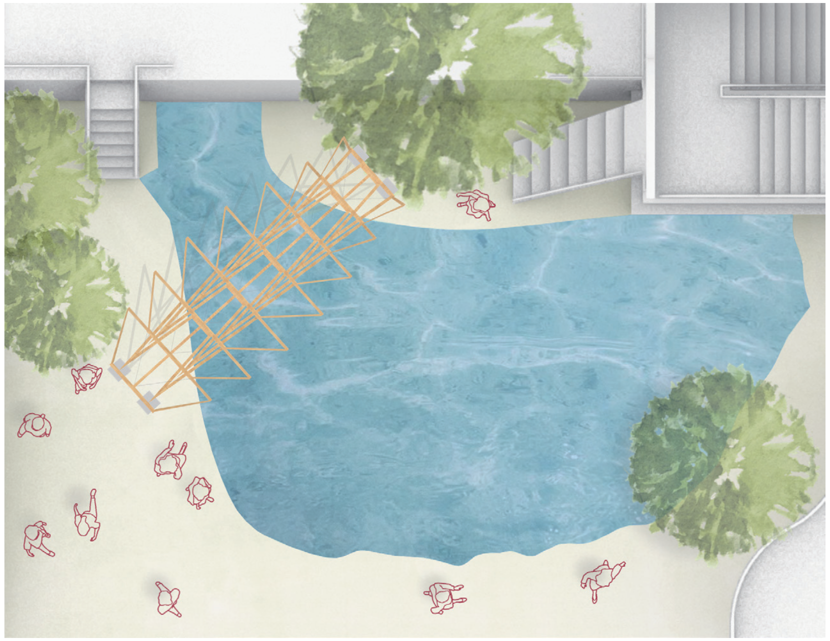
Double V-shaped units form the bridge , and the handrails on both sides are also connected by V-shaped, echoing the characteristics of the flow of people in the site.

PARAMETRIC DESIGN



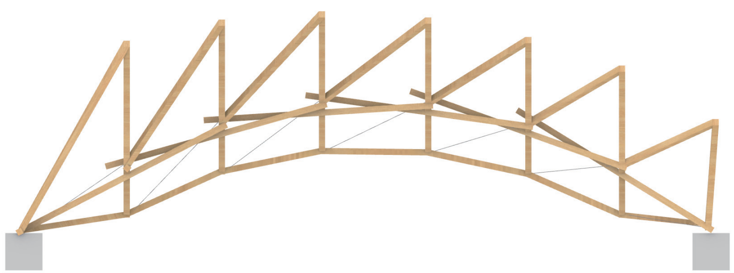


SITE PLAN

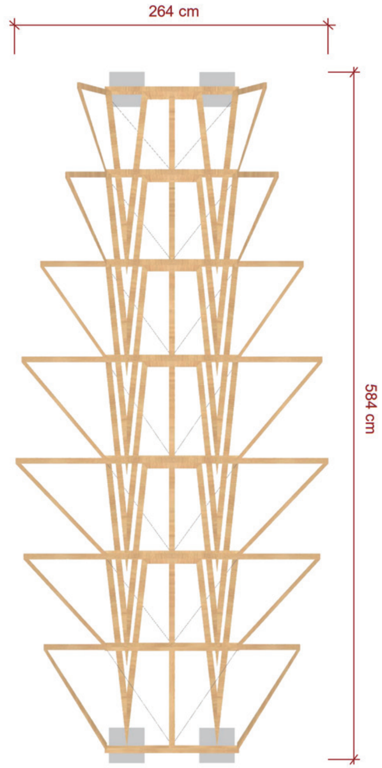


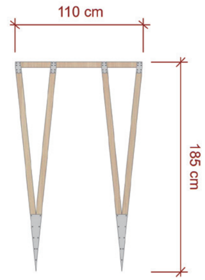
The northern hinterland of the site is small, with few people staying, while the southern hinterland of the site is large, connecting studios and Science And Technology Buildings, and the circulation is large. Therefore, the handrails gradually widen from the plane from north to south to echo the characteristics of the site's circulation.

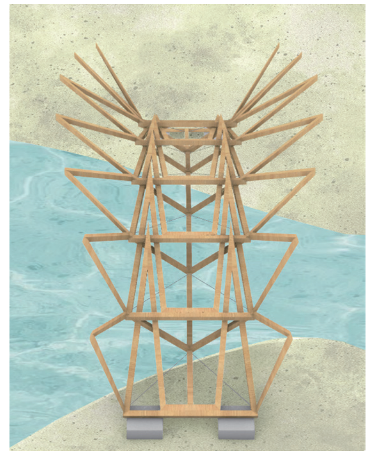
ELEVATION

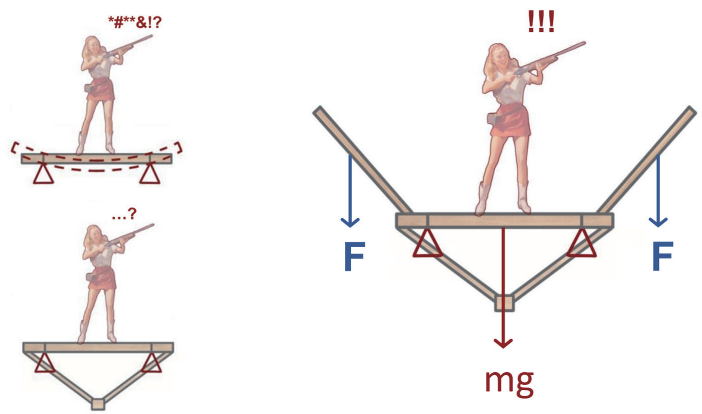


STRUCTURE

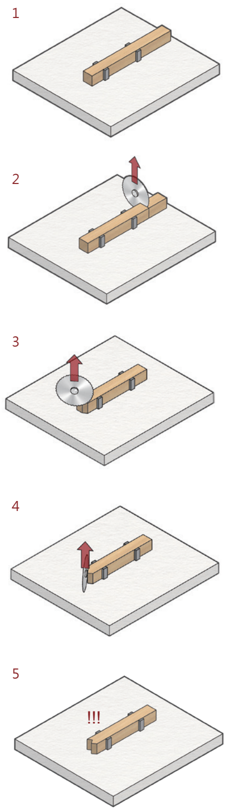




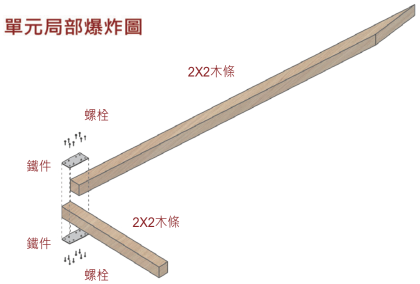


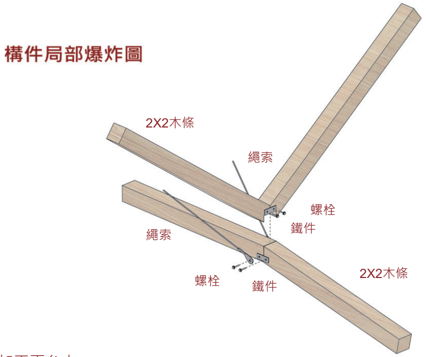


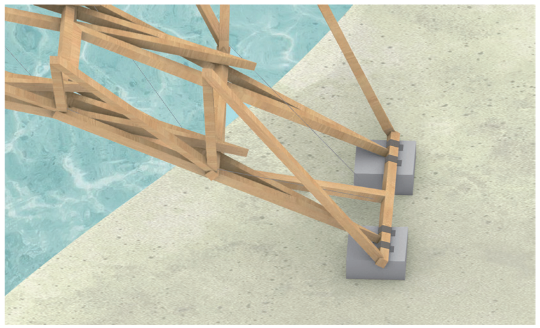
JOINT COMPONENT

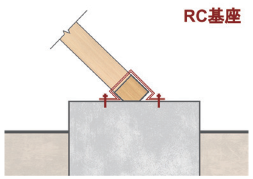


2x2木條固定於加工平台上
以機械手臂控制鋸片裁切

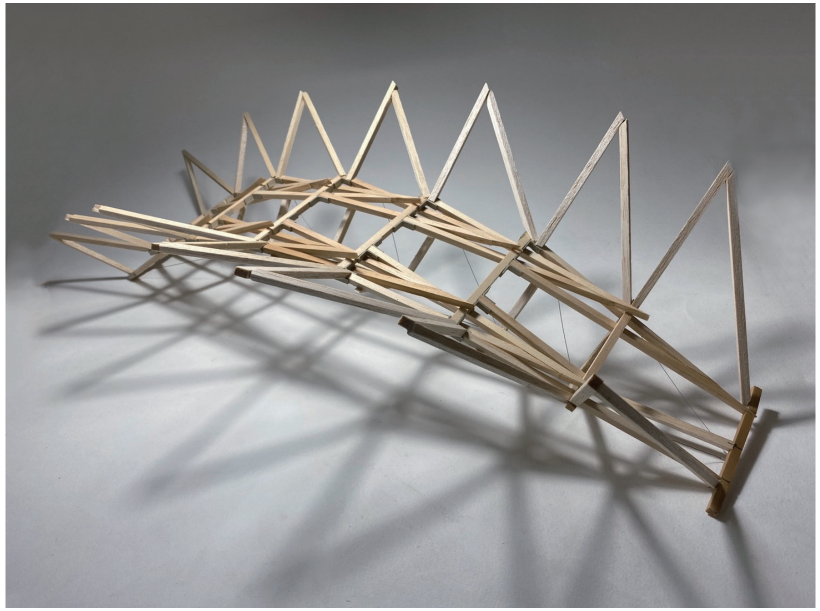


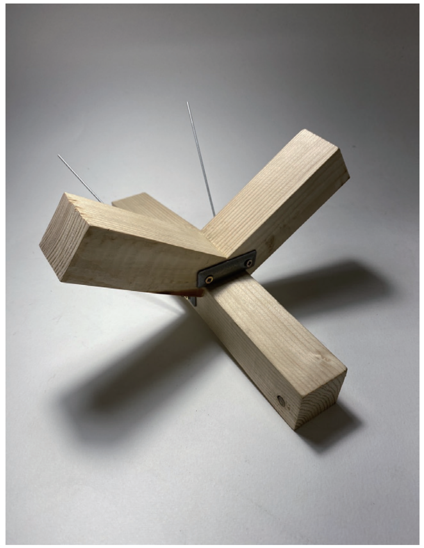


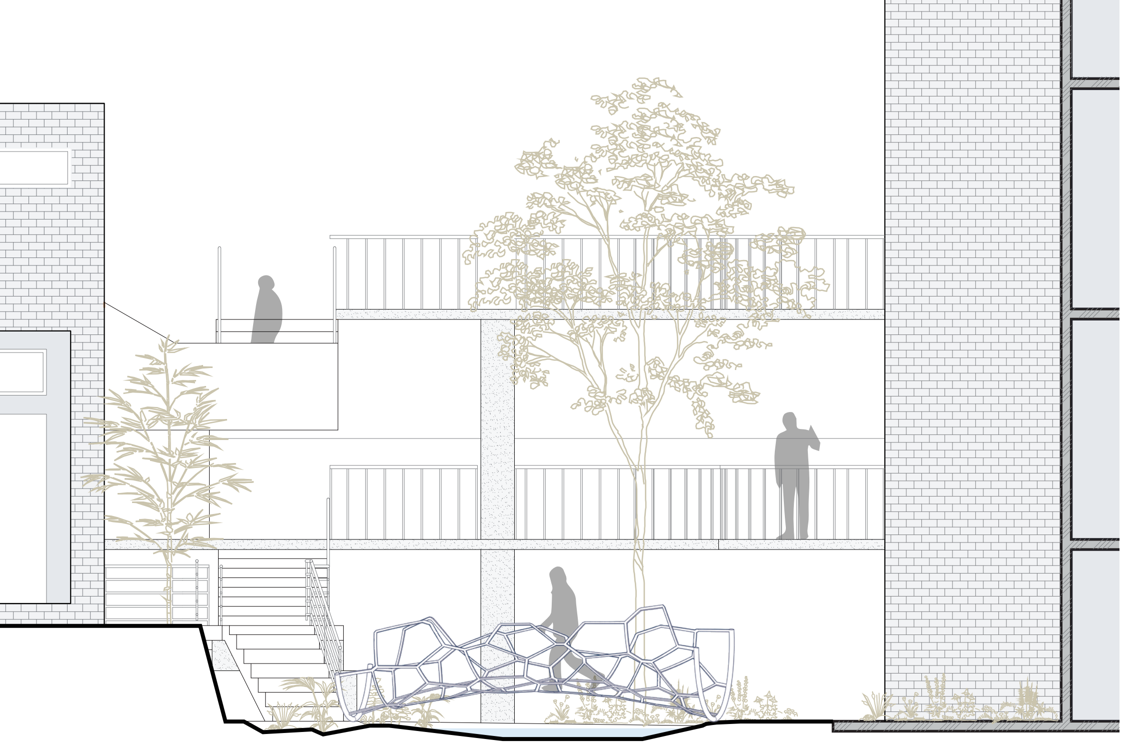




MODEL

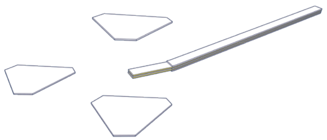






First Quarter Bridge

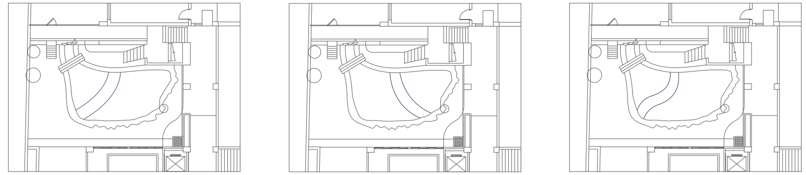
NCKU ARCH Dep.   Yung-Hsing, Tsao

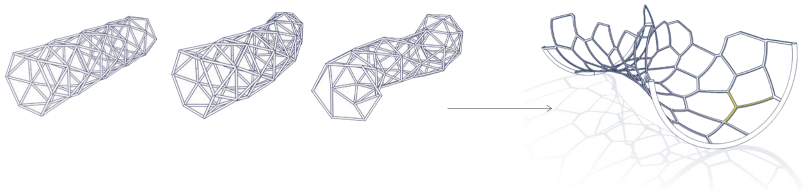


INTRODUCTION

My design concept is inspired by the Green River Wood Bridge in Taichung. I researched its complete enclosure and multidirectional wooden structural design principles. Since the cylindrical structure would be too large for our site, I cut it half and transform it into a form resembling a suspension bridge. I also incorporated the Voronoi pattern to enhance the walking experience. Furthermore, I studied deeply in creating curved wooden and explored how to achieve multidimensional non-planar connections. The cylindrical shape, which was the divided in half following the Voronoi pattern, naturally created a railing and ensured a seamless appearance that is both aesthetically pleasing and safe.

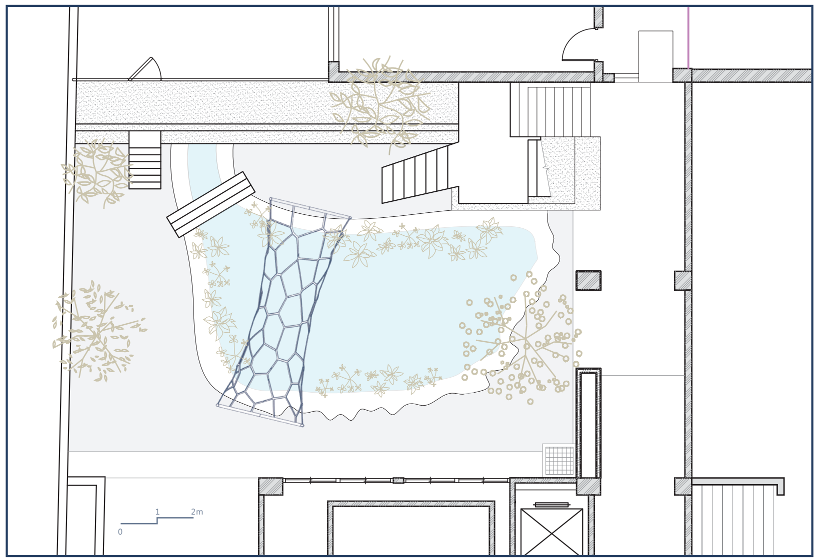
DEVELOPMENT PROCESS



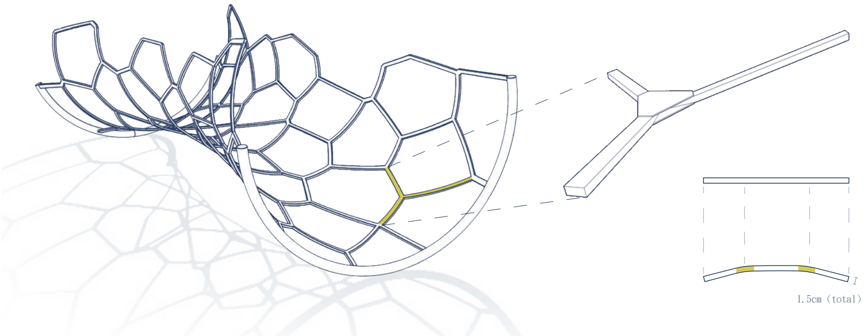


SITE PLAN

The length of bridge is 6 meters in total, with a wider width on both ends and a narrower width in the middle.
The circular diameter at both ends is 2.5 meters, and the middle section of the bridge has a circular diameter of 1.5 meters.



STRUCTURE DEVELOPMENT



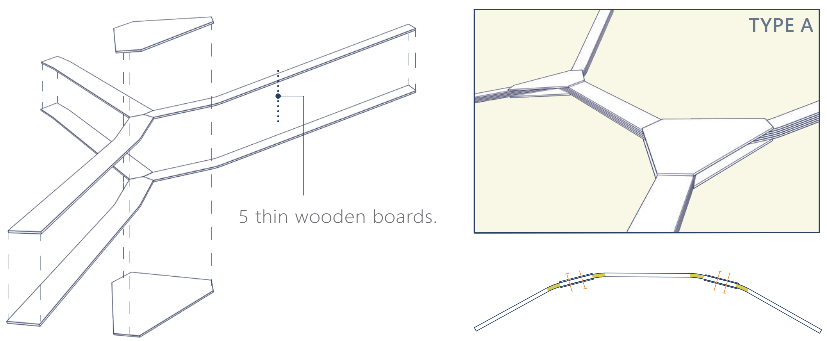
Calculate the curvature of each timber.

↓

Glueing several layers of thin wooden boards together to fix their shape.

↓

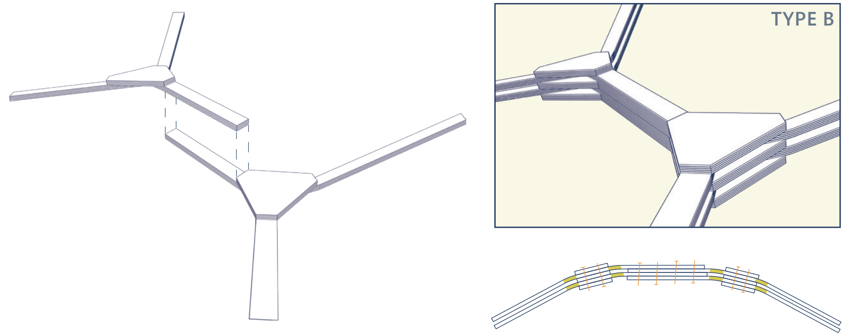
Connect several (3 or 4) wooden timbers at their intersection points with thin wooden boards to match the joint angles.



Glue and bend five thin wooden boards as a unit, then sandwich them with one wooden board on top and one on the bottom, and secure them together with bolts.

↓

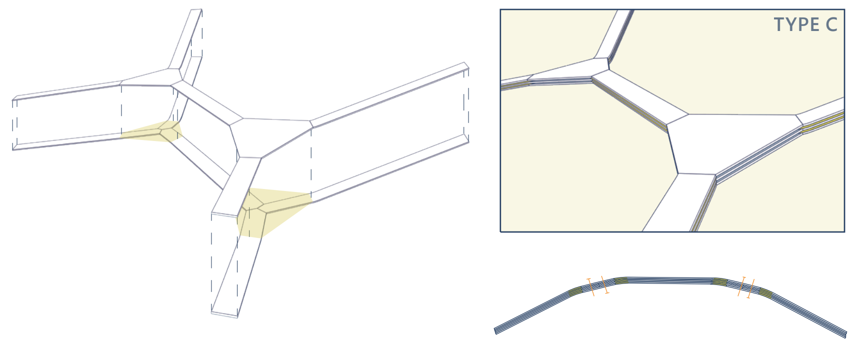
The joint area is weaker in strength.



The wooden boards and beams at the joints are grouped into units of five, staggered and overlapped.
When two units are joined together, there are four wooden beams overlapping, making the overall structure more stable.

↓

It is more wasteful of materials and overall too thick and heavy.

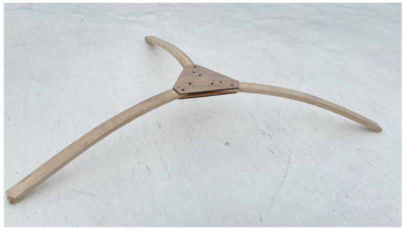


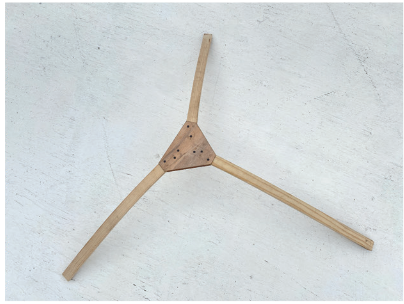
The wooden boards and beams at the joints are overlapped and staggered, resulting in two forms of wooden beams: the yellow beams in the upper illustration extend to meet at the center of the joint, while the other layers are flush with the edges of the central wooden board, allowing them to remain in the same plane.

↓

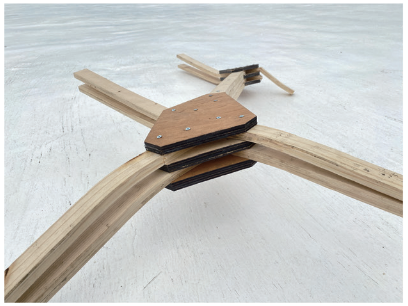
Ensure the strength of the joints and the beams themselves while keeping the overall structure lightweight and slim.

MODEL

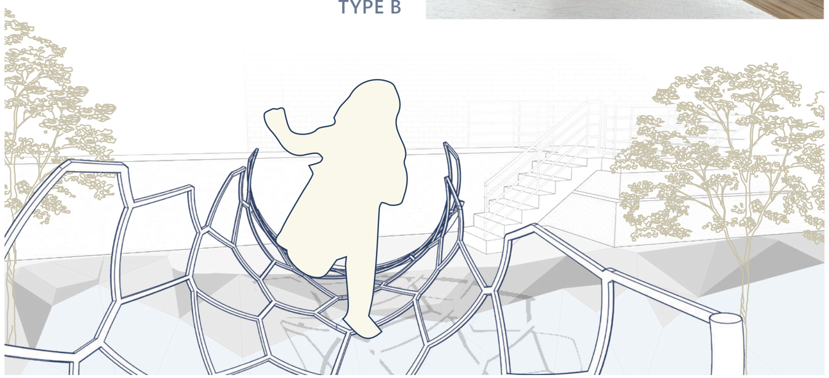




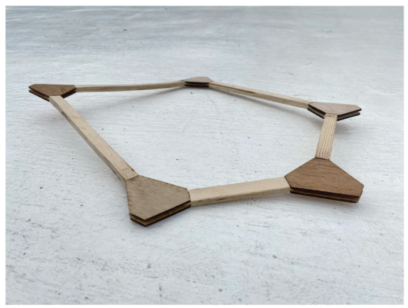
TYPE A

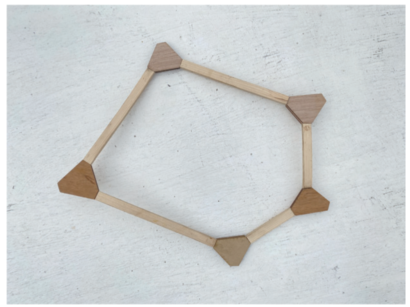


TYPE B



TYPE C





Veins of Leaves

NCKU ARCH Dep. Huai-An, Tai

INTRODUCTION

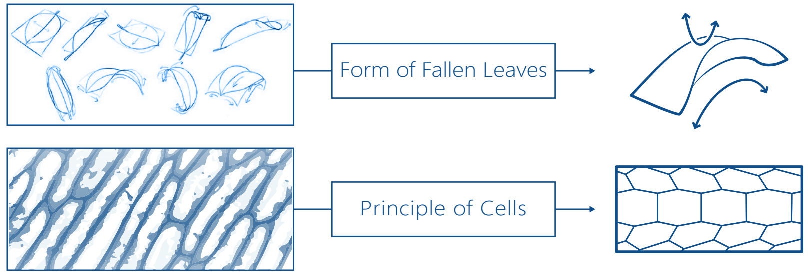
"Veins of Leaves" is the name I have bestowed upon this robot fabricated bridge, which encapsulates the intended aesthetic concept for the design.

Leveraging robotic arm machining is crucial in this design to fabricate bridge components. Hence, I prioritize incorporating current timber processing techniques.

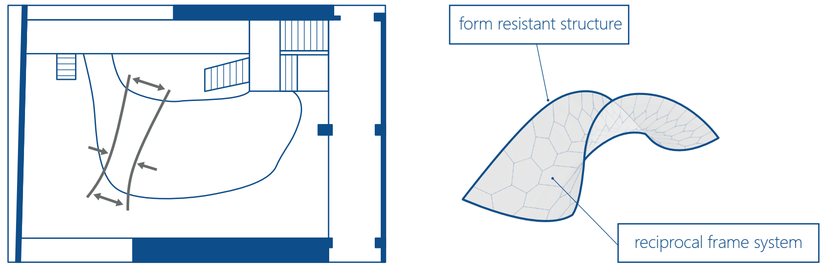
Given the site's proximity to a constructed wetland, I begin by drawing inspiration from natural forms, specifically the intricate curves of falling leaves and vein growth, resulting in a refreshing bridge structure.

Following this generative logic, this timber bridge "Veins of Leaves" evolved and came into existence.

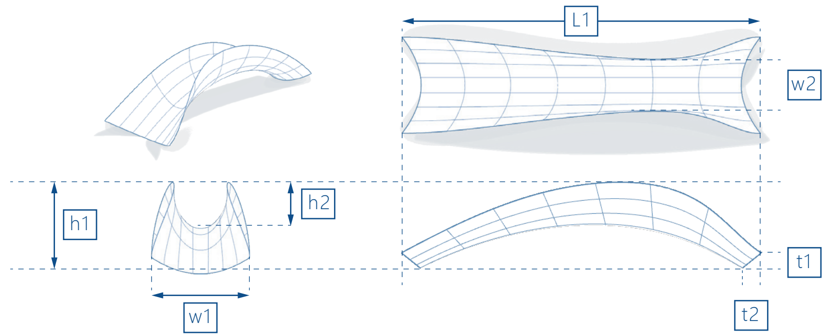
FORM GENERATING



Due to the narrow space of the site, I have chosen to widen both side of the bridge to alleviate the sense of confinement. To not only serve a structural purpose but also avoid aquatic vegetation below, the bridge deck arches upward.

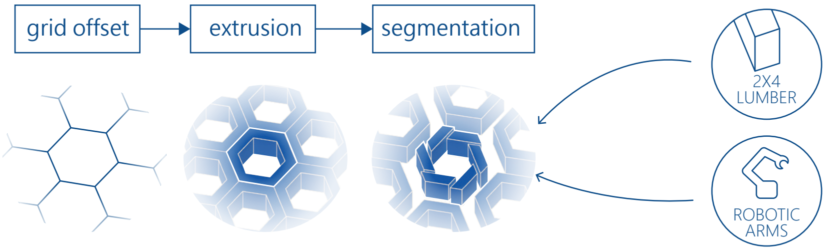


PARAMETER SETTINGS



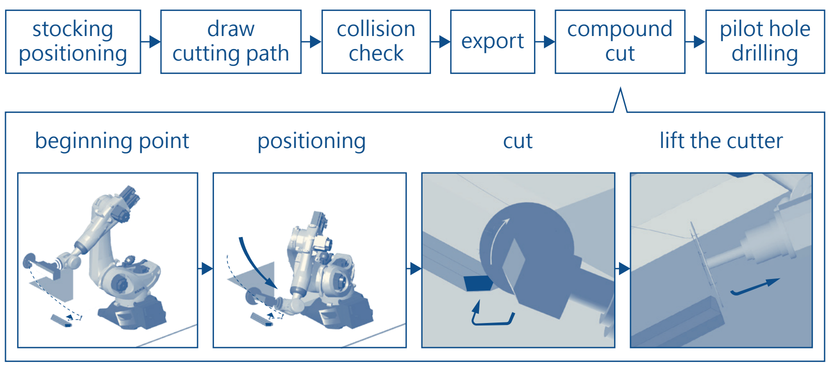
TECTONICS

The curved surface has been dissected into unit frameworks, which are further deconstructed into individual members. It was during this phase that I discovered the potential of integrating and utilizing robotic arms for the fabrication of this reciprocal frame bridge structure.

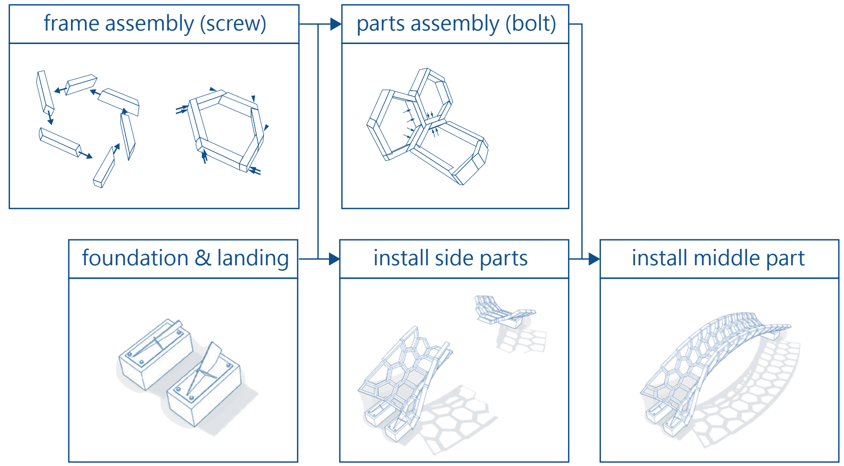


FABRICATION

Using a robotic arm as a manufacturing tool, we need to produce 344 members to construct this wooden bridge. To ensure the safety of the arm during the manufacturing process, it is necessary to simulate it using KUKAprc and Grasshopper before importing the files, in order to prevent collisions. Then, the arm will proceed to fabricate 344 unique customized components. These are the challenges and breakthroughs involved in this machining task.

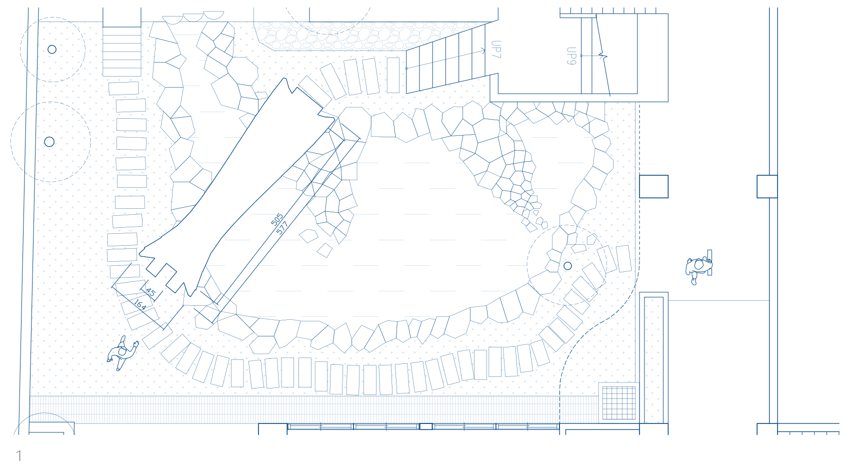


CONSTRUCTION

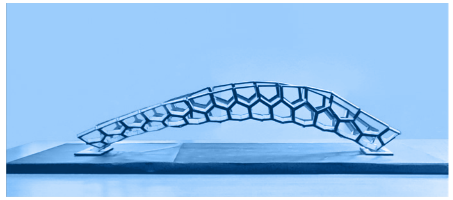


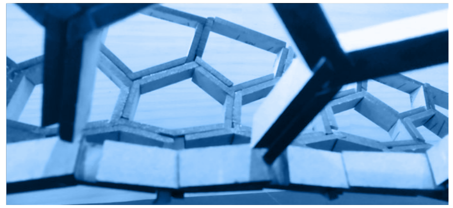
Due to the precise angles between the members, it is easy to assemble the framework by fastening the members with screws. Additionally, the presence of bolt hole allows for frame alignment and tightening, facilitating the assembly of the framework. After the foundation is cast, the assembly process can proceed from both sides of the bridge towards the center, completing the construction of the bridge.

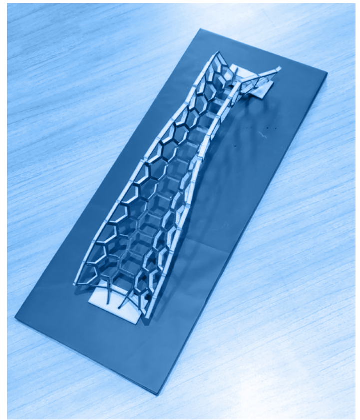
PLAN



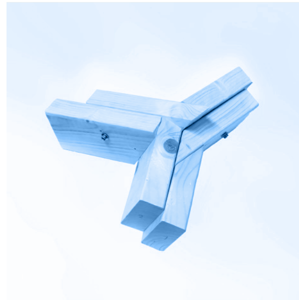
3D RENDERING

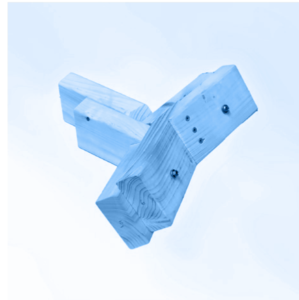


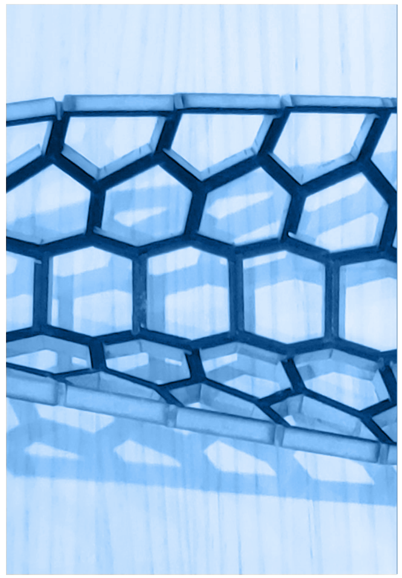




MODEL

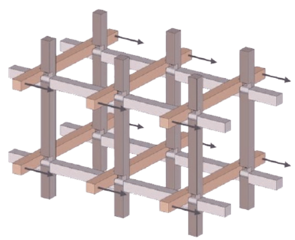






THE WEAVE BRIDGE

NCKU ARCH Dep.   Pei-En, Ho



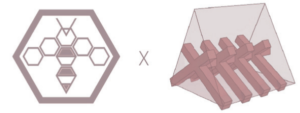
INTRODUCTION

My research begins with the details. While searching for cases, I have been consistently fascinated by the clean joints found in pure wooden structures like the one shown in the right image. Therefore, I started studying three-dimensional joinery, hoping to extend and develop a structurally sound bridge based on multidimensional joinery. The most important aspect is to use only wooden components and ensure that there are no excess materials at the joints. Additionally, I will further explore the possibilities of extending outward from individual units and utilizing variations in angles to create different shapes.

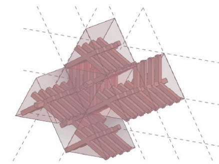
PARAMETRIC DESIGN

GRASSHOPPER: FROM DISCRETE DESIGN TO WASP

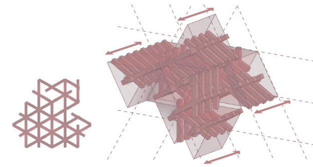
00.
ORIGINAL UNIT:
TRIANGLE & MEMBER



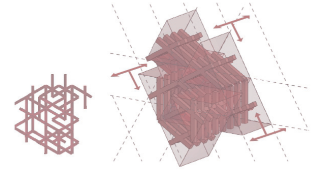
01.
TWO-DIMENSIONAL
AGGREGATION

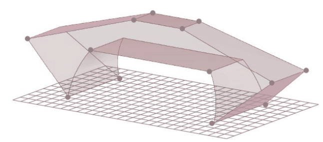


02.
THREE-DIMENSIONAL
AGGREGATION

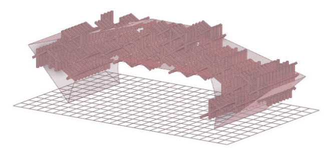


03.
MULTIDIMENSIONAL
AGGREGATION

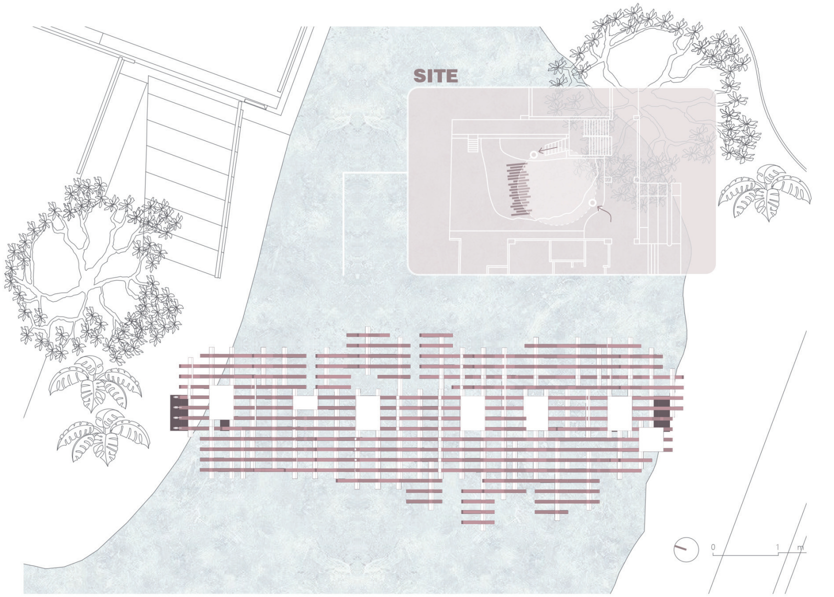




04.
FINAL:
BRIDGE SHAPE CONSTRAINTS

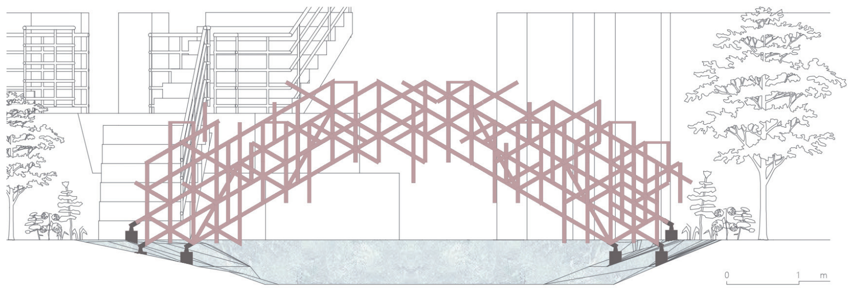


SITE PLAN



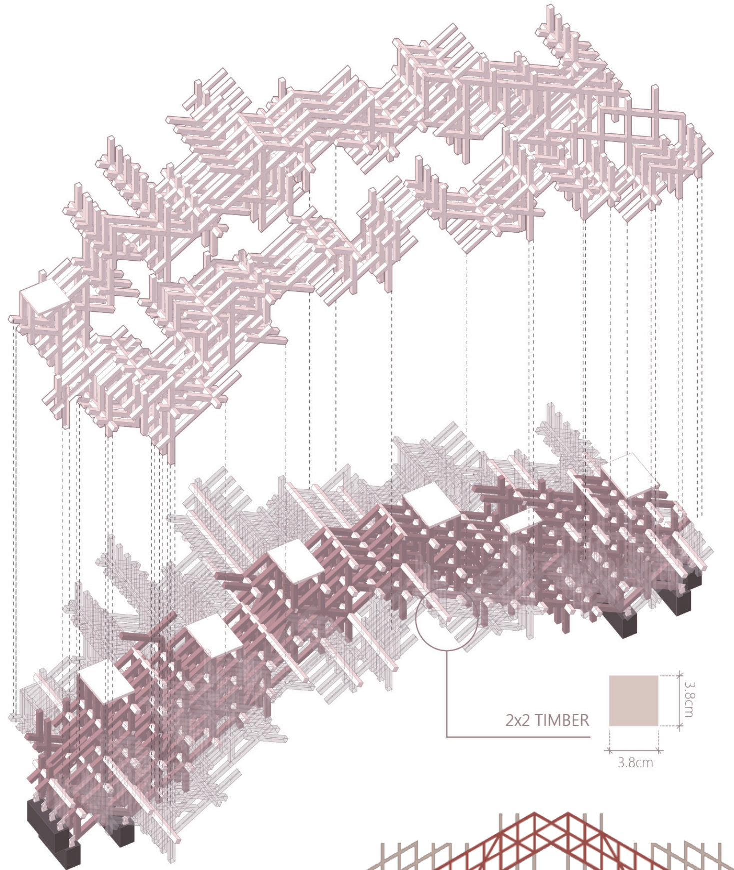
I connect the circulation nodes of the ecological pond with circles, and I place my bridge according to the direction, creating a new circulation loop for the entire ecological pond.

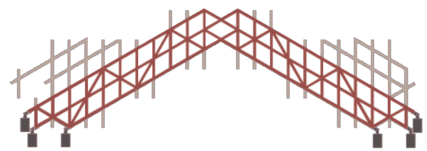
ELEVATION



The outcome of the design is like weaving, where from the small units and individual threads, a complete bridge structure is woven.

STRUCTURE



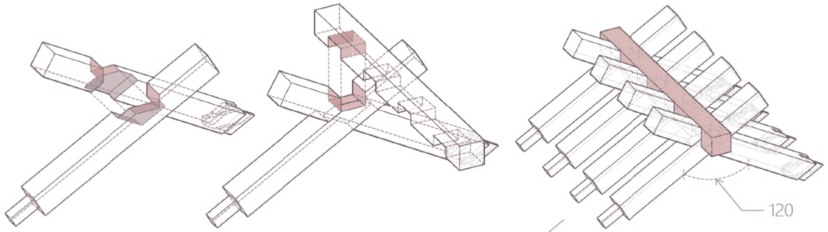


With this random process, it is inevitable that there will be issues with discontinuous force transmission paths. My approach is to first allow the small units to form a stable and continuous framework before fitting them back into the original bridge design constraints to generate a main structural component similar to a truss. The other units then grow along this main structure. The entire bridge consists of both the main structural component and additional decorative elements attached to it.

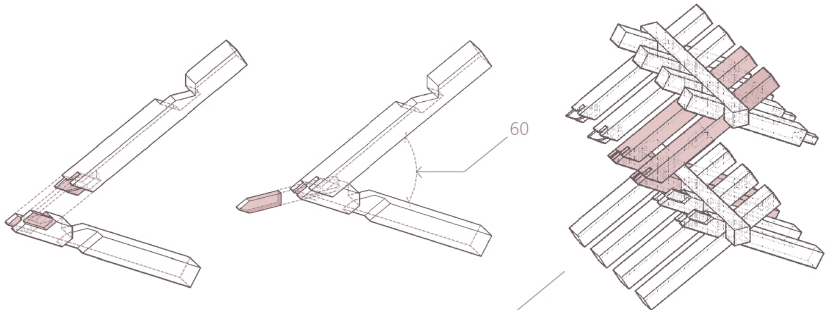
JOINT COMPONENT

The angles formed by connecting triangles are 120 degrees, 60 degrees, and 180 degrees.

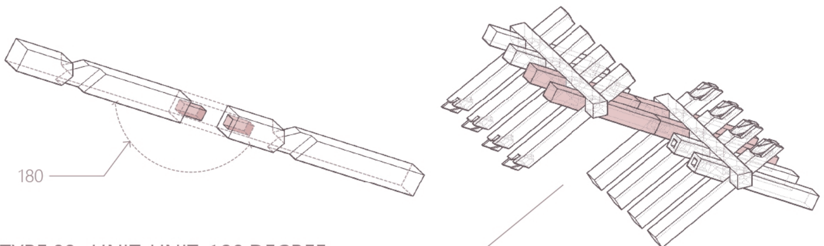
They are composed of the following three types of joinery:



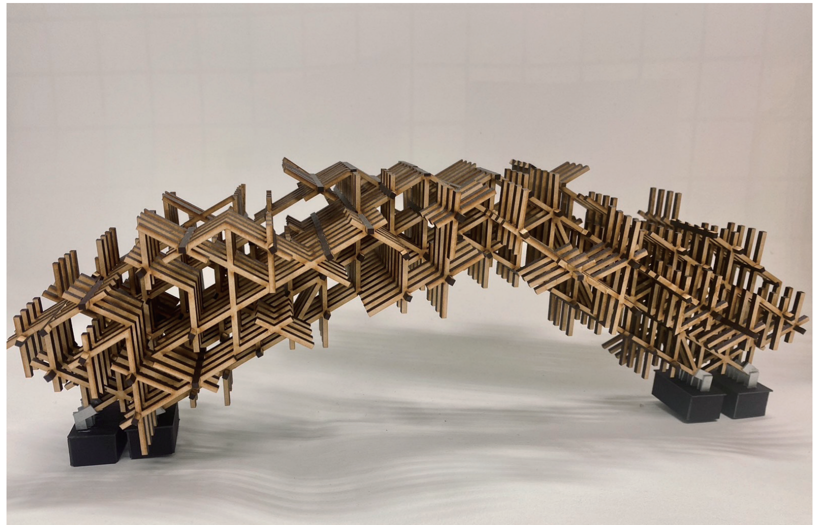
TYPE 01. MEMBER-MEMBER: 120 DEGREE



TYPE 02. UNIT-UNIT: 60 DEGREE



TYPE 03. UNIT-UNIT: 180 DEGREE



MODEL

PROJECT DEVELOPMENT

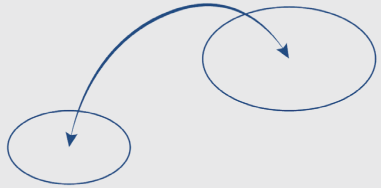
THE VEIN OF
FALLEN LEAVES

SITE

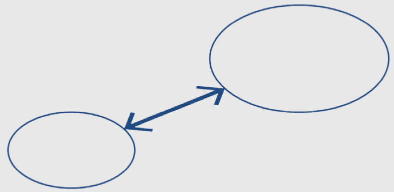
SITE STATUS

The designated site for this project is a constructed wetland located between the buildings of the Department of Architecture at National Cheng Kung University. This ecological artificial wetland, designed by Professor Lin Hsien-Te of the Department of Architecture, serves as a green space situated between the two main buildings. On its left and right sides, it connects the student studios and the architectural service core.

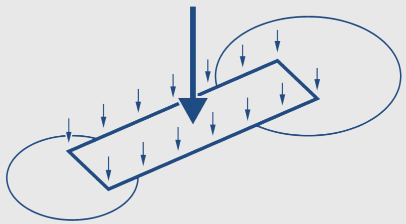
CHALLENGES



The challenge with this site lies in its partial nature, as it is not a complete open space, but rather a pond with construction support only available on the two sides of the pond's banks. Therefore, the objective of this project is to construct a bridge that spans across the water, connecting the two sides of the open space and creating a new pathway for activities.

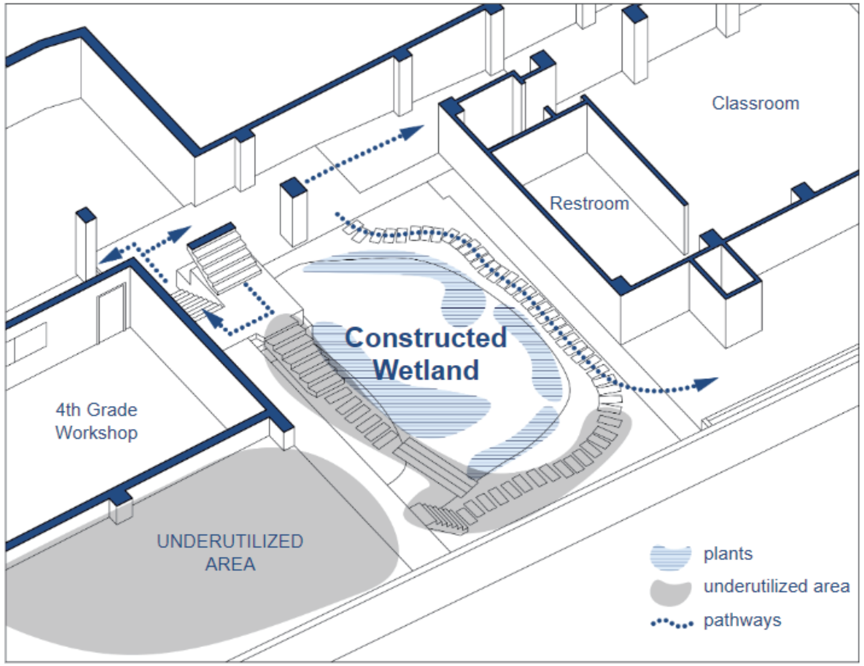


The challenge in this design lies in the pond's total width, which falls within the range of 5 to 7 meters. Creating an appropriate structure to meet the spatial requirements of the site while spanning such a distance is a significant challenge.



Moreover, the bridge structure must adhere to certain characteristics. Apart from supporting its own weight, it should also provide additional load-bearing capacity to accommodate pedestrian traffic. In other words, besides the aesthetic design, structural considerations must also be taken into account.

SITE ANALYSIS

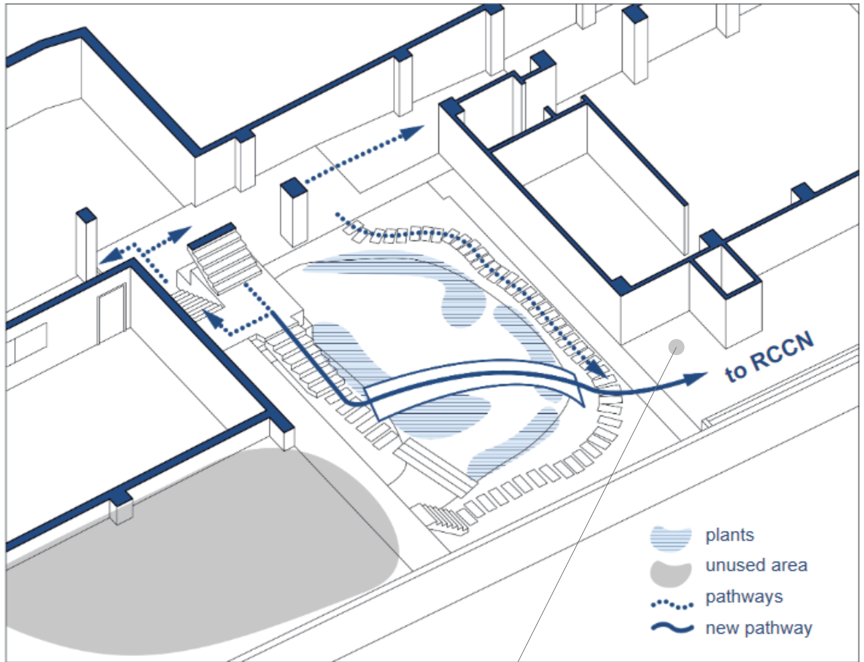



Tall Aquatic Plants


Lack of Landing Area

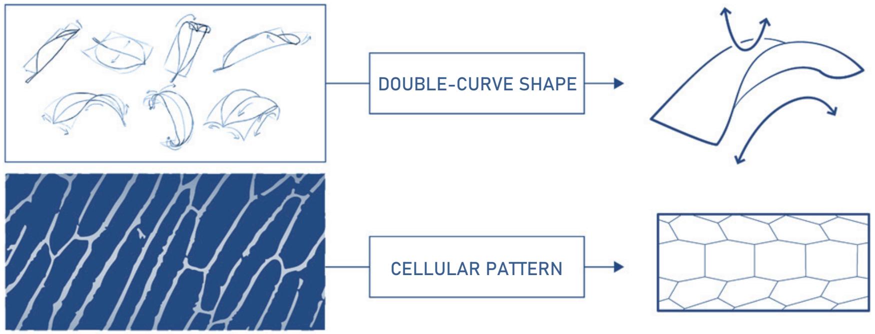

Underutilized Pathways

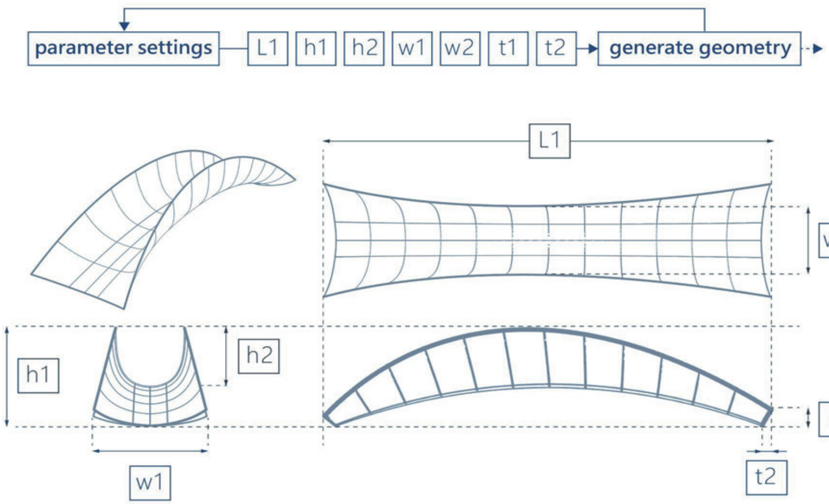
Regarding the current condition of the site, there are several underutilized grey areas that have not been fully utilized. The usage of existing pathways is relatively low, and these fragmented grey areas restrict the available space for any structure on the site. Furthermore, the most distinctive feature of the ecological pond lies in the abundant planting of tall aquatic vegetation, creating a diverse and lush appearance within the ecosystem pond.



After thorough analysis and deliberation, we have decided to replace the existing low-usage pathways with a new bridge structure to create a functional passageway. The new pathway will serve as the primary axis connecting the Department of Architecture building and RAC-Coon Workshop, spanning over the ecological pond. Taking into consideration the aquatic plants within the pond, we have opted for an arch bridge design to preserve the natural growth space for the aquatic plants. The intention behind choosing an arch bridge is to allow the water plants to retain their original habitat.

DESIGN PROCESS



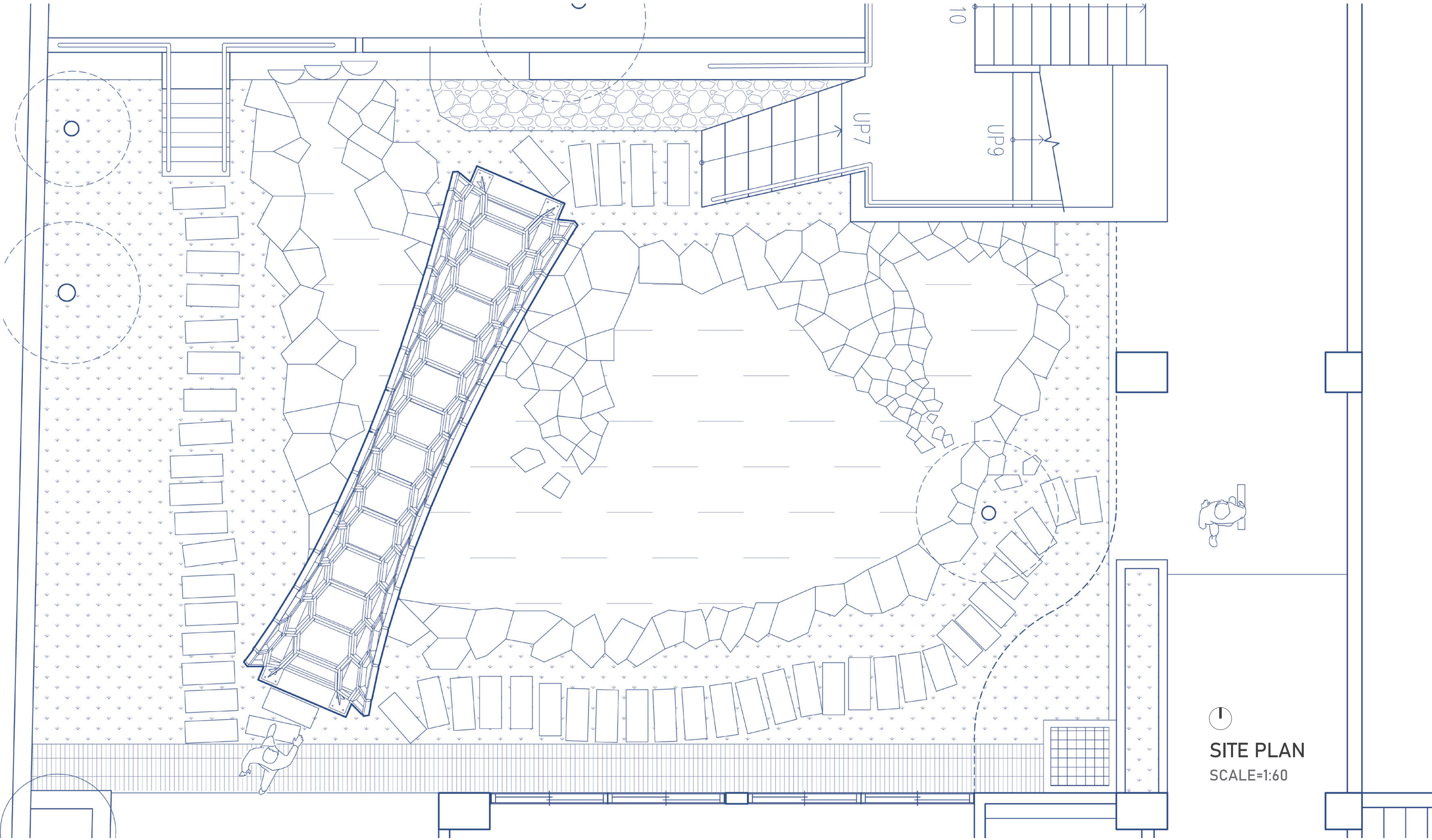


BRIDGE IMAGE

The concept was inspired by the natural textures of the constructed wetland, taking the imagery of falling leaves as its starting point. It evolved into the most primitive form of a hyperbolic paraboloid shape. The patterns on the curved surface were derived from the cellular structure, where hexagonal geometric shapes were parametrically designed and applied to the surface. This artwork embodies the essence of "Veins of Fallen Leaves."

FORM GENERATION

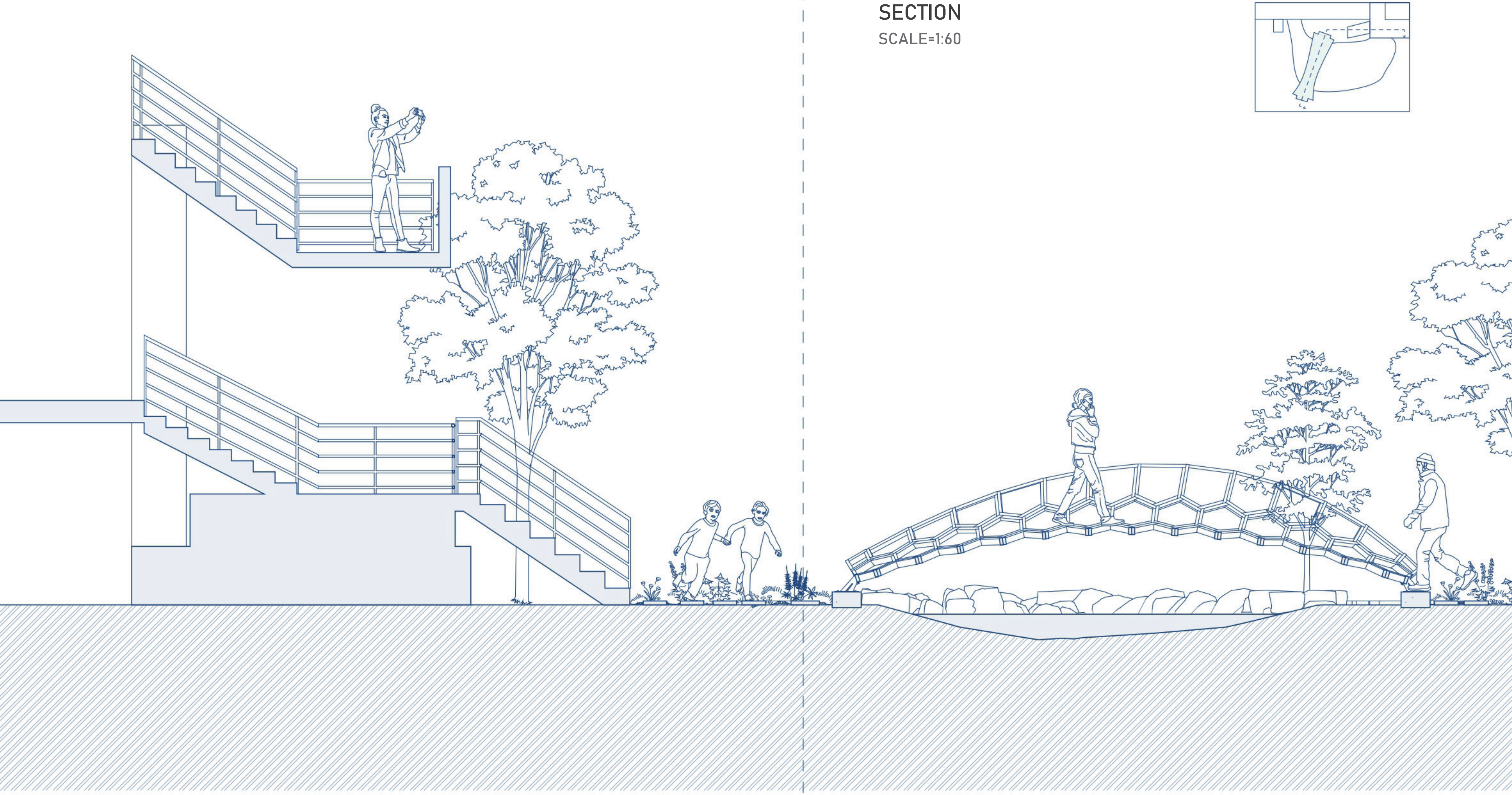
During the form-generating process, we opted for Rhinoceros Grasshopper as a parametric design tool to generate our bridge. Through digital assistance, we input given variable parameters, namely L1, h1, h2, w1, w2, t1, and t2, to control the bridge's length, height, width, and curvature. By leveraging computer calculations, we achieve the final outcome, allowing for flexible adjustments of the design to suit the site or specific requirements.



SITE PLAN

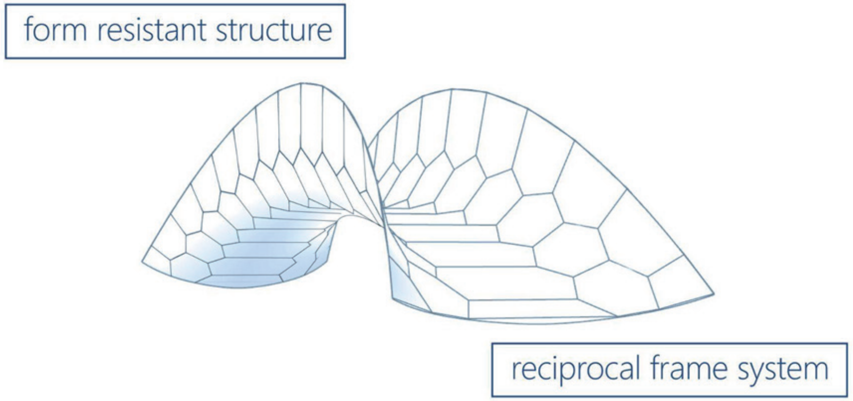
SCALE=1:60

SECTION
SCALE=1:60



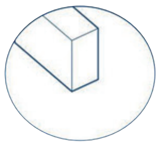
TECTONICS

FROM 2D TO 3D

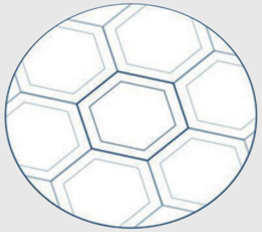


In simple terms, the final design outcome is a composite structure composed of hexagonal patterns applied to a hyperbolic paraboloid surface. It inherits the inherent form-resistant characteristics of the hyperbolic paraboloid, remaining a non-developable surface when rigidly connected, providing structural stability.

Furthermore, we contemplated the appropriate detailing and joining methods to imbue it with a reciprocal frame system's structural behavior. By utilizing the interaction forces between each unit, we aimed to enhance the overall stability of the bridge.

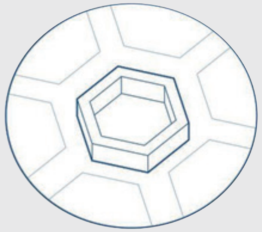


The physical bridge structure is constructed using 2x4 lumber , with a cross-section length of approximately 8.9 cm and a width of about 3.8 cm.



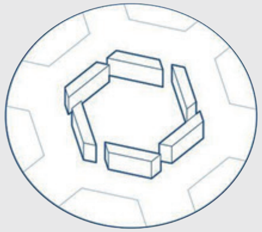
GRID OFFSET

The hexagonal grid is first offset inward by the width of the wooden material (i.e., 3.8 centimeters) to create a surface-like hexagonal outer frame between the lines.



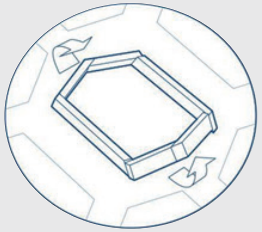
EXTRUSION

The formed surface is then extruded downward by the thickness of the wooden material (i.e., 8.9 centimeters), creating a solid hexagonal outer frame.



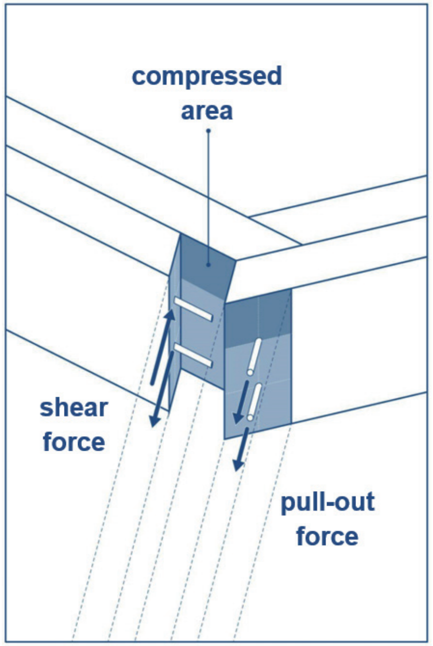
SEGMENTATION

The hexagonal outer frame is divided into six members in a counterclockwise direction, allowing each member to be manufactured from a single 2x4 wooden piece.



3D ADJUSTMENT

By utilizing the rotational angles between the members, we create unique angular relationships to meet the aesthetic requirements of the parametric bridge design. With the assistance of robotic arms during manufacturing, we can precisely define the absolute cutting angles for each member and determine their relative positions, constructing the three-dimensional hexagonal framework.

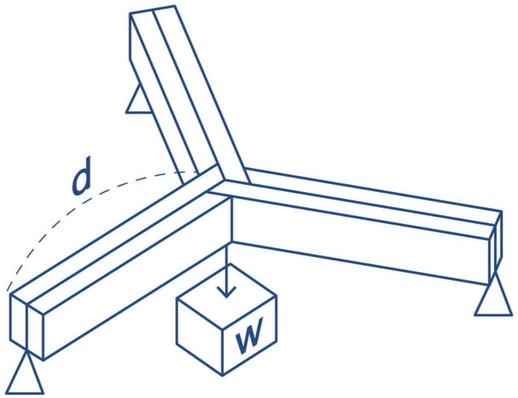


STRUCTURAL TEST

The jointing system in this design goes beyond the conventional bolted connections typically used for transmitting forces. It predominantly relies on the interaction of surfaces coming into contact to resist and transmit forces, creating a mechanism of force transfer. However, this kind of structural behavior is not explicitly defined within the scope of wood structural design codes and regulations, resulting in several uncertainties during structural analysis.

Max. Bending Moment : 1300 kg-cm
Required Load Bearing : 80 kg
Safety Factor : 0.5
Final Load : 150 kg (deformation 5cm)

Then we decided to conduct specific structural tests on the jointing units. The objective is to calculate the overall bridge's load-bearing capacity based on the behavior of individual joints, thus reviewing and ensuring the bridge's stability.

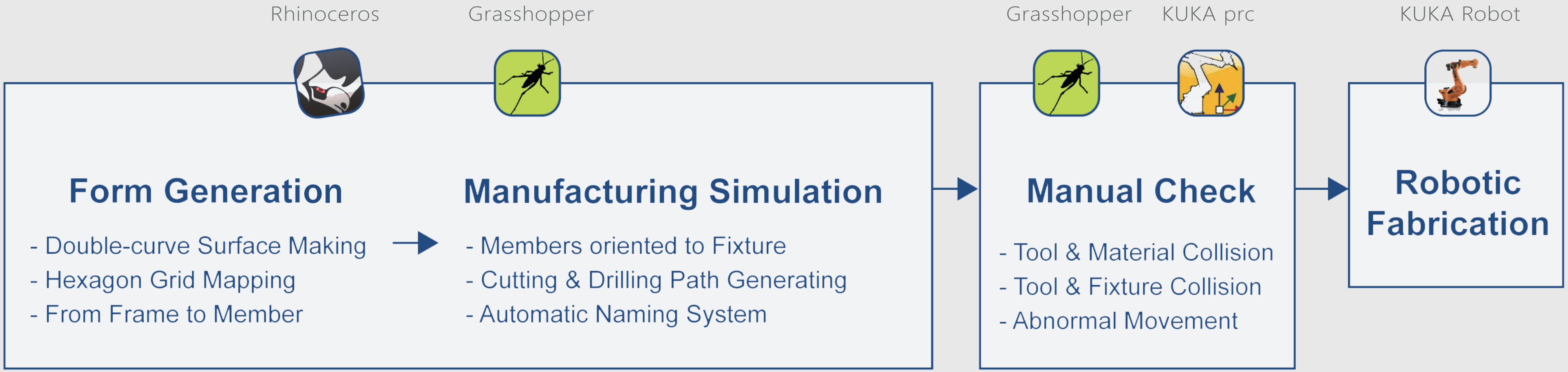


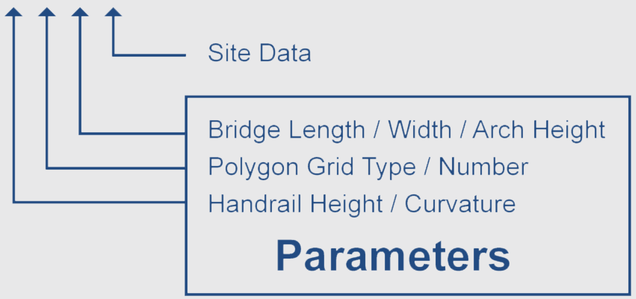
During the testing process, we first created a 1:1 scale model of the joint and extended the three-dimensional members to increase the moment arms. Each member was fixed on three sides, and a load was applied at the center joint until structural failure occured.

The final experimental results showed that the test model withstood a total load of 150 kilograms before deforming by 5 centimeters. Through calculations, we confirmed that the entire bridge structure's bending moment and live load capacity remained within a safe range. The joint demonstrated a semi-rigid connection, contributing to a stable structural behavior.

PARAMETERS

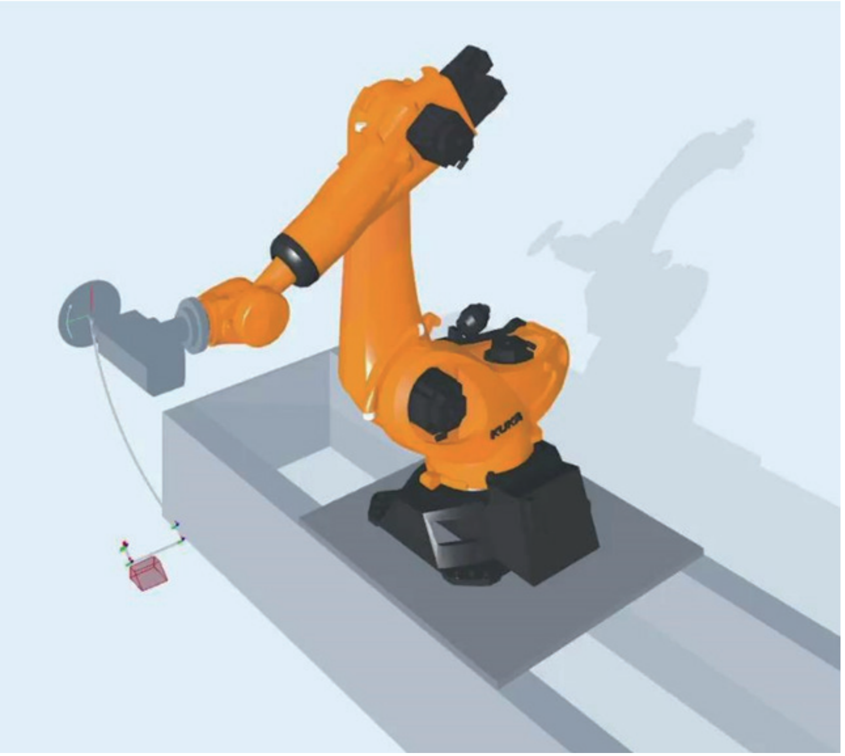
PARAMETRIC DESIGN WORKFLOW





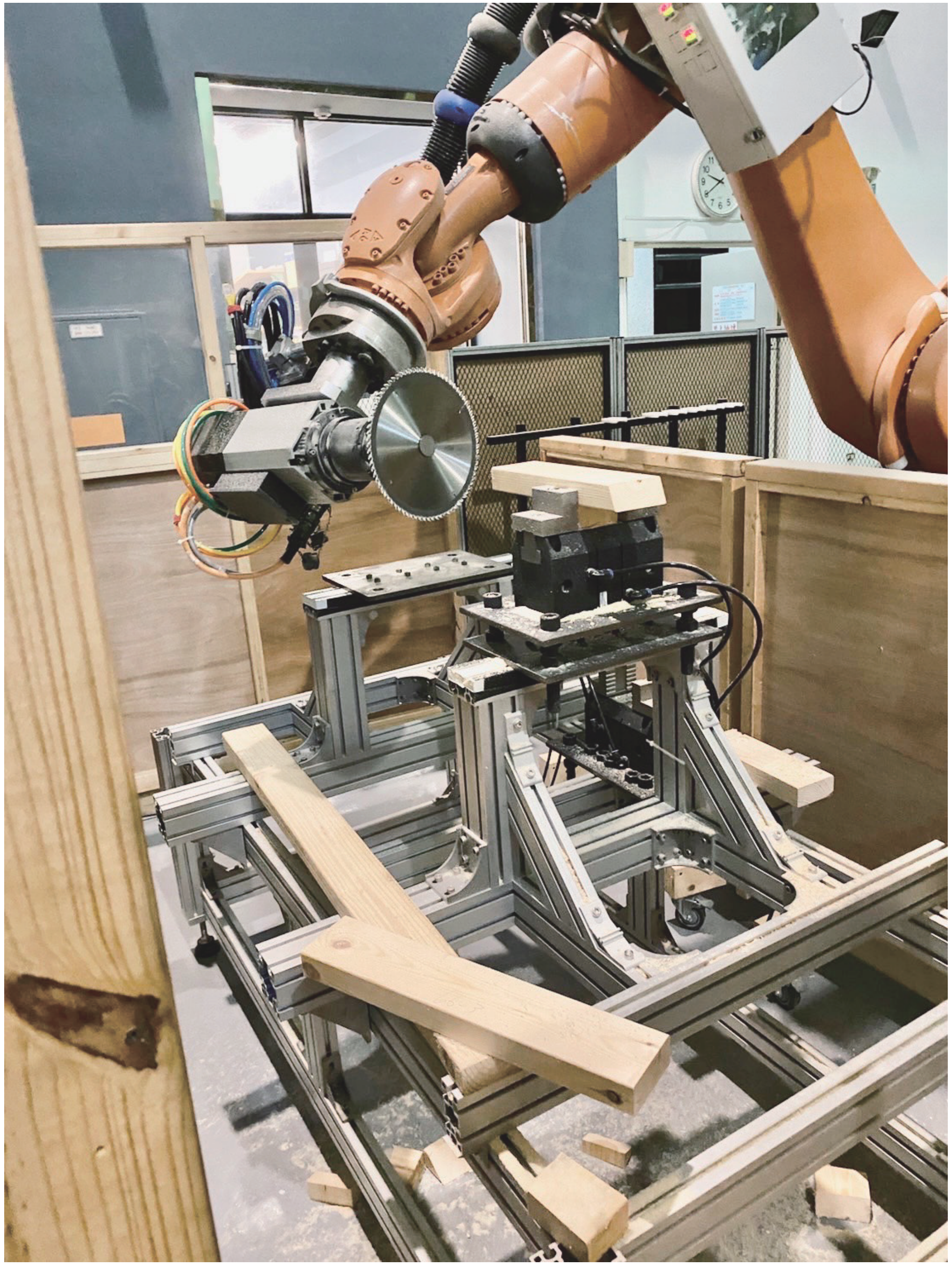
The entire parametric design process is divided into three major parts. The first part involves the generation of the bridge structure's design. The second part entails simulating the manufacturing process. The third part involves manual adjustments before finally proceeding to the stage of robotic arm fabrication.

ROBOT SIMULATION

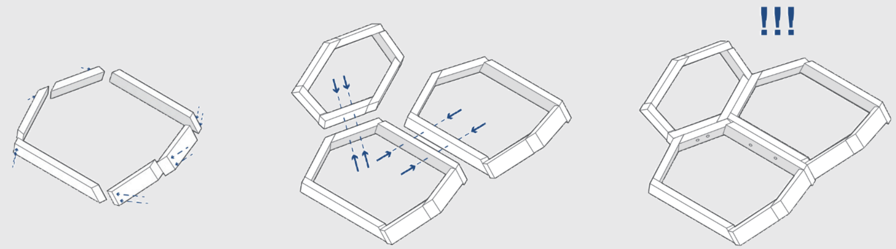


PRC in Grasshopper

During the robotic simulation process, we used Grasshopper to simulate the operations of cutting and drilling paths performed by the robotic arm, correcting the issue we found in the simulation by fine-tuning the parameters.



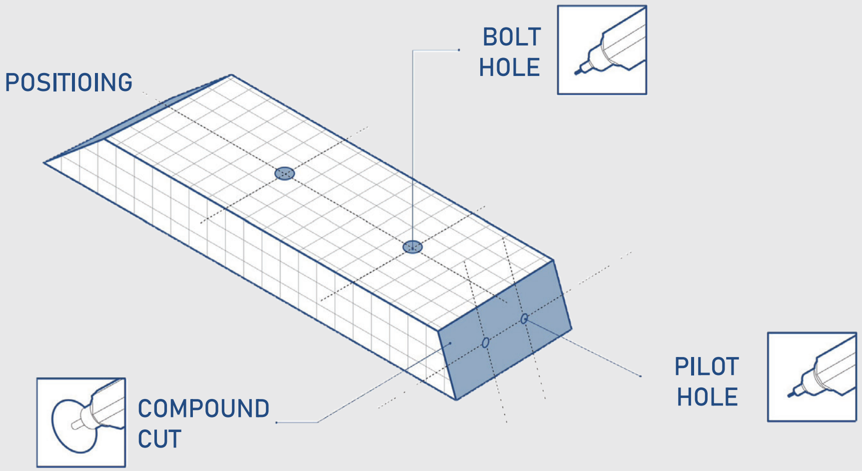
FABRICATION



Members to Units | Units to Clusters | Clusters to the whole

FABRICATION CHALLENGES

372 MEMBERS



1.  **COMPOUND CUT**

The bridge comprises a total of 372 members, whose cross-sectional angles vary from member to member. Moreover, the cutting angles for each cross-section are compound cuts in 3D dimensions, making it challenging to execute manually on a flat plane. Therefore, we utilized the robotic arm with a circular saw for direct positioning and cutting, allowing digital assistance for manufacturing the intricate cutting angles.

2.  **PILOT HOLE**

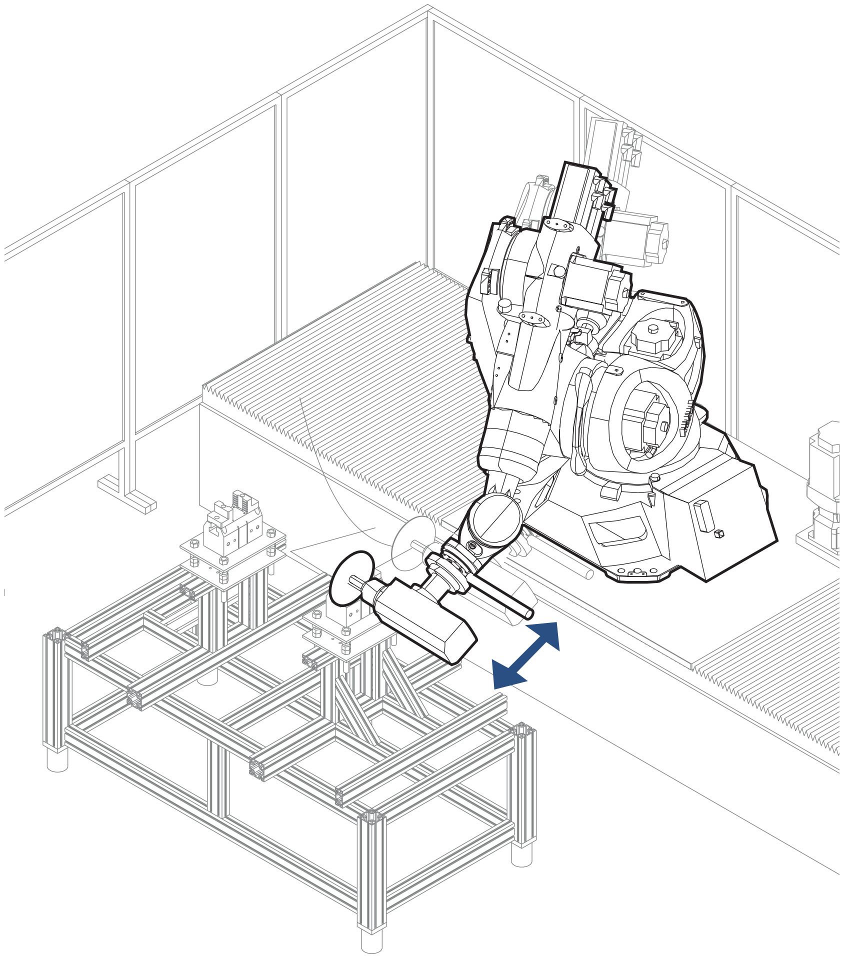
In addition to using the robotic arm for precise plane definition, we also conducted pre-drilling on the cutting surfaces to ensure the accuracy of member positioning during the assembly process. This pre-drilling aided in the precise alignment between the members.

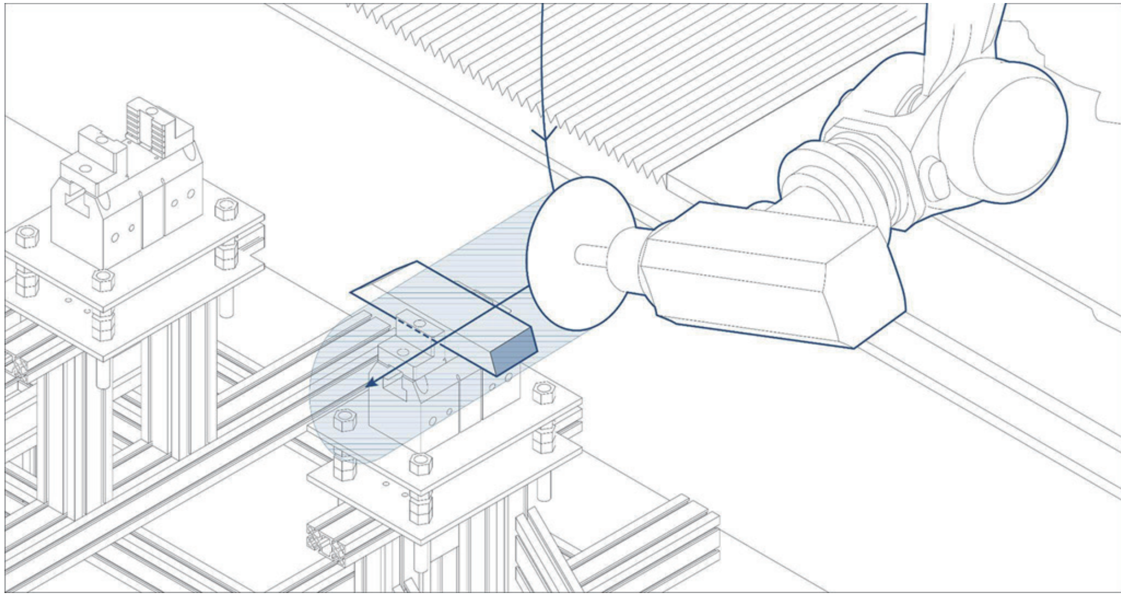
3.  **BOLT HOLE**

Between each unit, we pre-determined the bolt positions for the joints and used the robotic arm to drill bolt holes at fixed intervals on the members. This ensured that the two units could maintain accuracy when joining together.

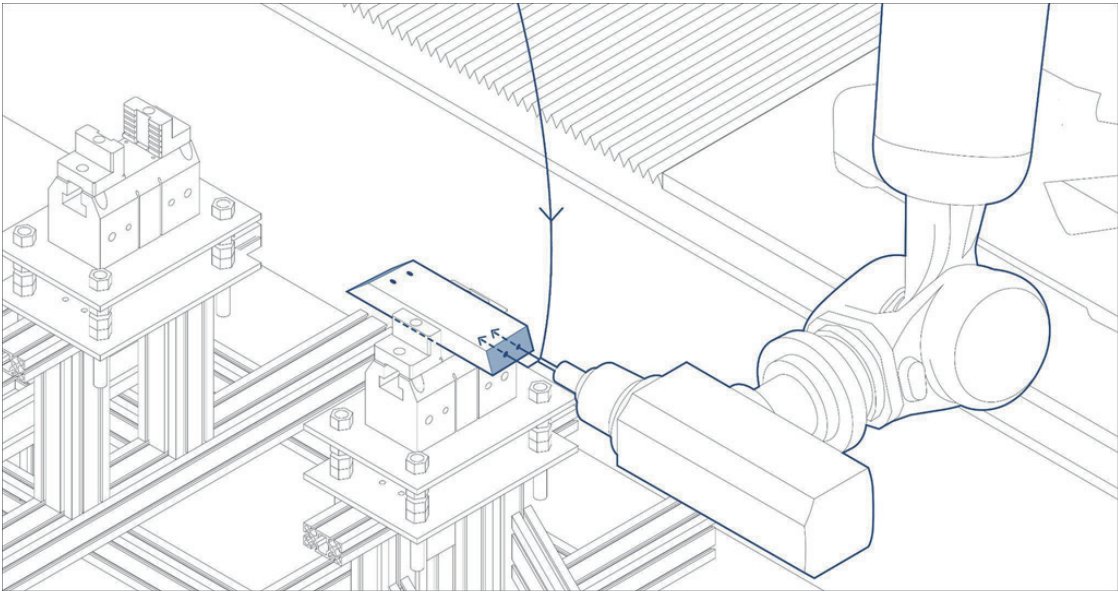
FABRICATION SEQUENCE

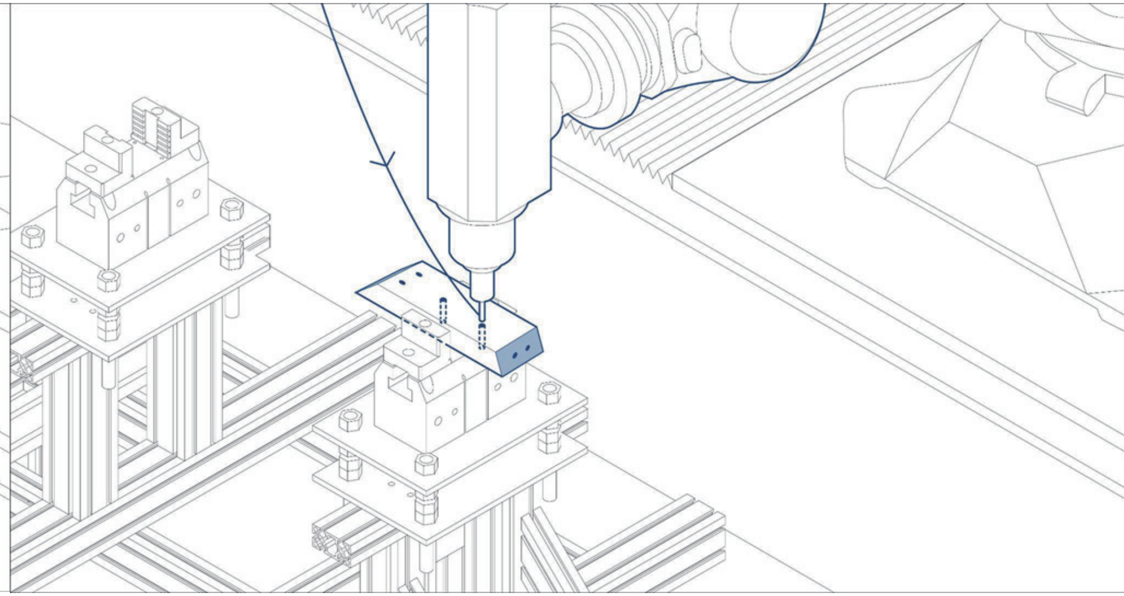
During the fabrication process, we chose to fix lumbers onto the fixture and fabricated with movable tools installed on the robotic arm.





STEP 01.
CIRCULAR SAW CUTTING



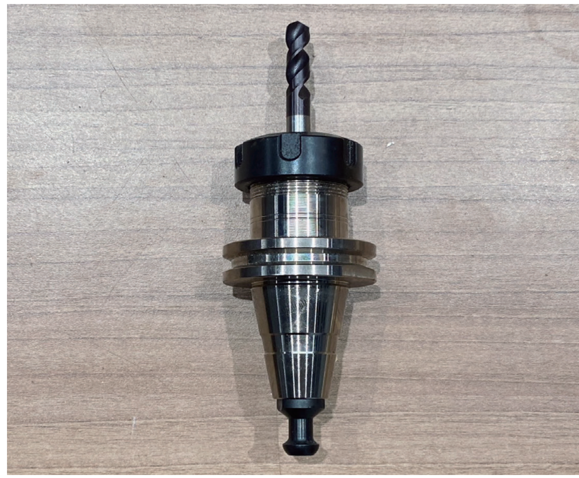


STEP 02.
PILOT HOLE DRILLING

Using a 3mm drill bit.

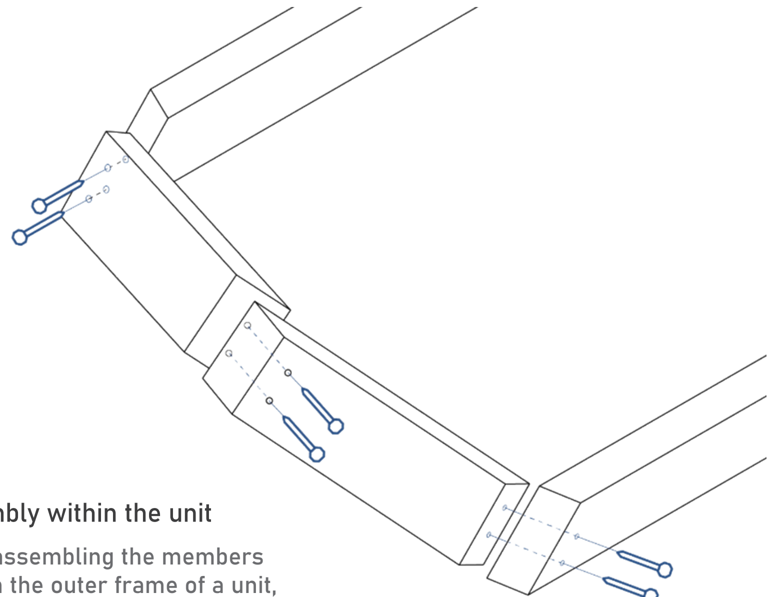
STEP 03.
BOLT HOLE DRILLING

Using a 8mm drill bit.



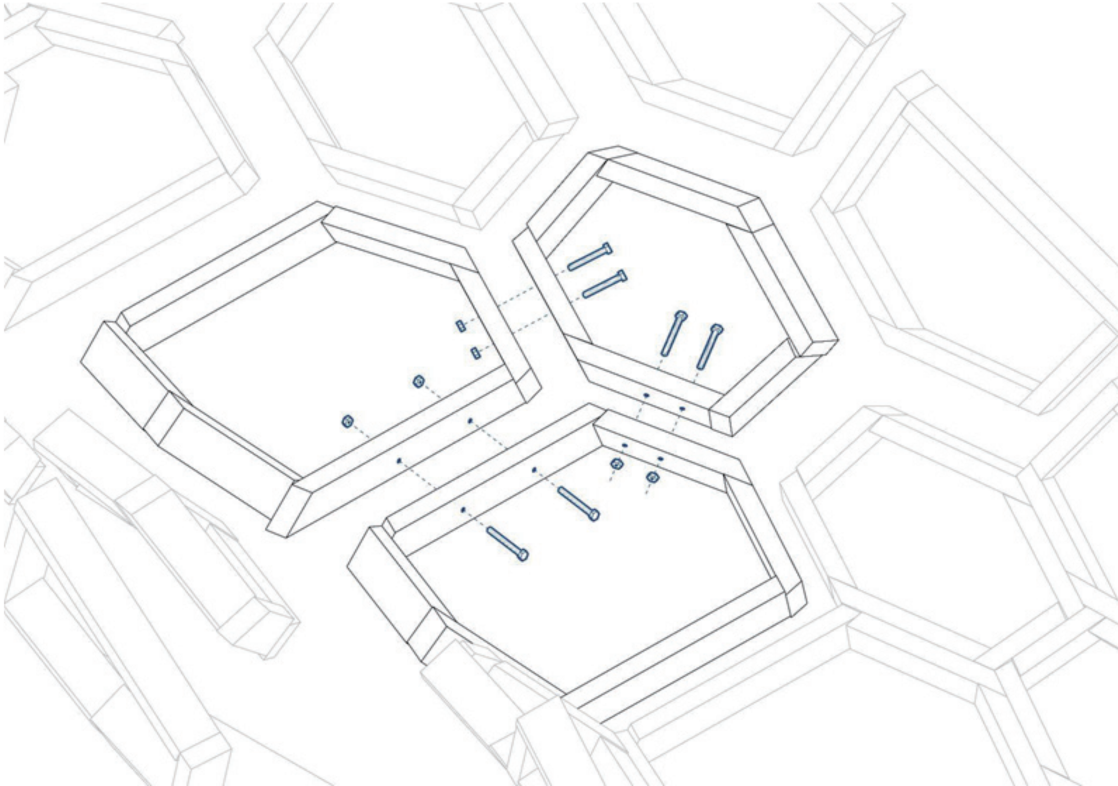
DETAIL OF JOINERY

After cutting the lumber into the final members, the assembly process can be divided into two steps. First, the members are assembled to form the hexagonal outer frame of a single unit. Then, the units are interconnected and locked together to create a larger overall framework.



Assembly within the unit

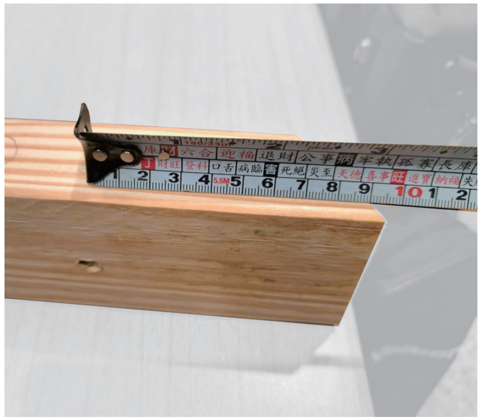
When assembling the members to form the outer frame of a unit, we use 3mm screws to align and join cut surfaces.



Assembly between the units.

Between the unit frames, we use two 8mm bolts to align and join the flat surfaces together.

Apply 1st layer before frame assembly & 2nd layer after frame assembly



MANUAL VERIFICATION

Due to the different special cutting angles of each member and the relative rotational relationships during assembly, precise cutting and drilling positioning are crucial. After processing each member, we conduct manual inspections to ensure that the robotic arm's results match the initial design intent. Through the inspections, we found that the errors in the robotic arm's processing are within ±2mm, which is considered highly accurate compared to manual cutting.

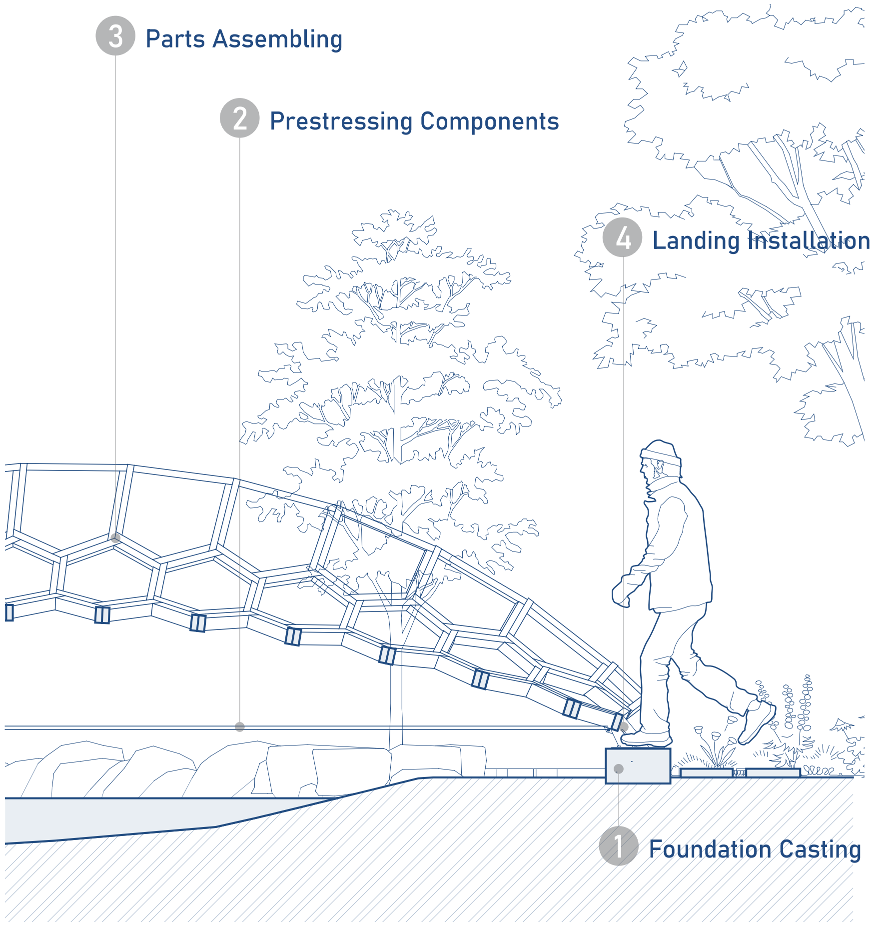
WOOD FINISHING

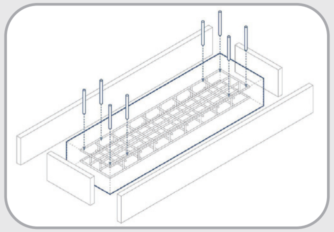
As the site is located near the pond, the impact of humid and moist conditions on wood preservation is also a significant consideration. To enhance the wood's water resistance, we applied Jing oil as an outer coating for the lumber.

CONSTRUCTION

CONSTRUCTION SEQUENCE

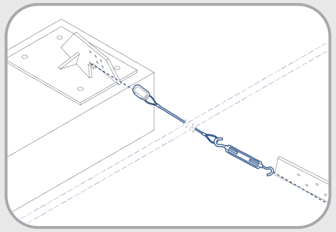
The assembly of the entire bridge can be divided into four main parts: foundation casting, prestressing components, parts assembling and landing installation. They are arranged in the following construction assembly sequence.





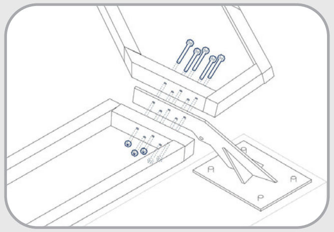
1 Foundation Casting

To withstand approximately 200 kilograms of its own weight and the expected live load it will bear.



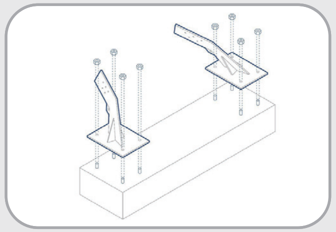
2 Prestressing Components

Using the tensile strength of steel cables to assist the foundation in resisting outward forces.



3 Parts Assembling

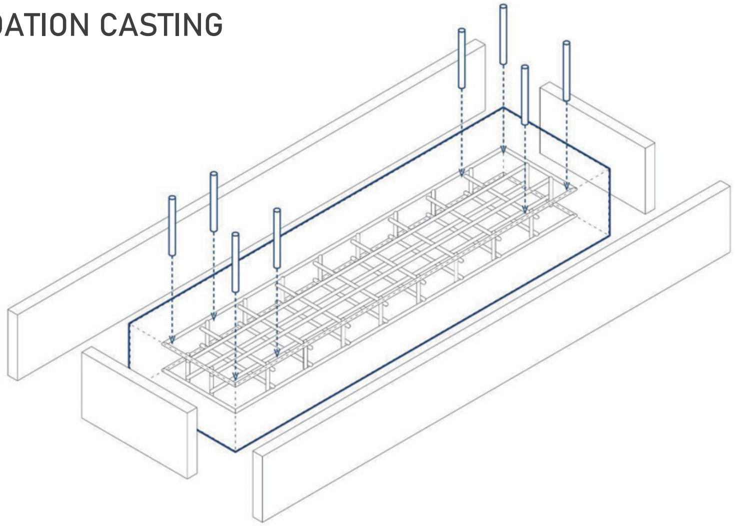
The construction sequence is influenced by the structural behavior, which also determines the locations where errors are absorbed.



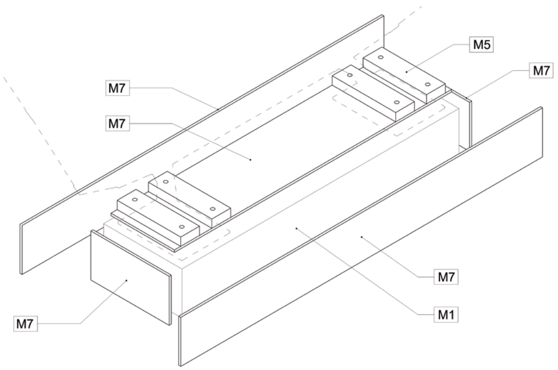
4 Landing Installation

Transferring the bridge's load to the foundation while accommodating construction errors.

FOUNDATION CASTING



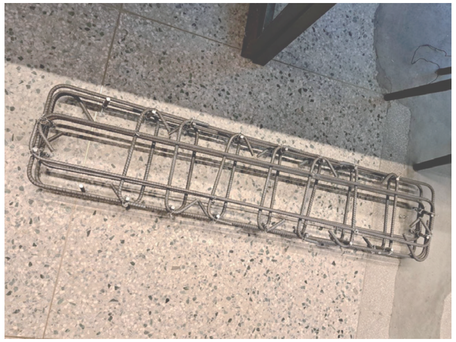
The arch-shaped design of the bridge results in significant outward thrust on both sides when bearing its self-weight and external live loads. Therefore, we have chosen to use the weight of concrete foundations on both sides to resist the outward forces while providing a medium for the bridge to transfer its load to the ground.



M1 Concrete
M2 8mm Steel Plate
M3 d16 Base Bolt
M4 M8 Bolt
M5 2X4 Wood Timber
M6 #3 Rebar
M7 1cm Board

The foundations are made of concrete, with overall dimensions of 131*37*20cm. They are internally reinforced with a dual-layer, bidirectional steel cage. Four anchor bolts are connect to a steel plate, and two plates to each foundation.


Construction Setting Out

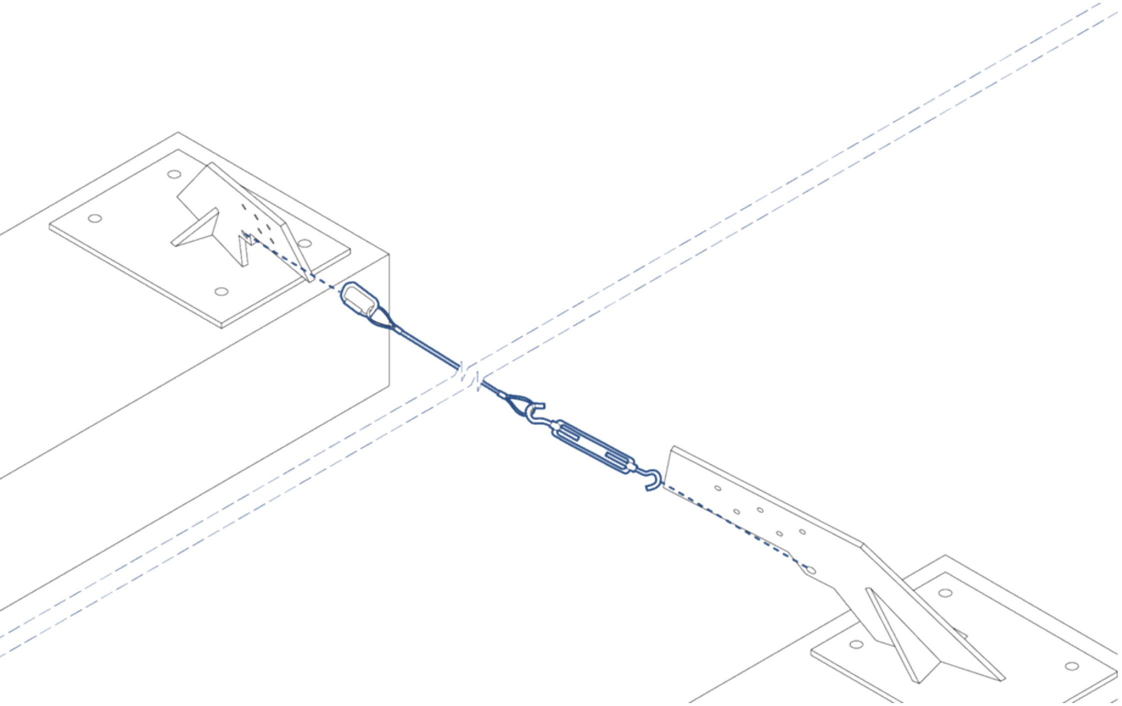


Reinforcement

Concrete Formwork


Foundation Casting

PRESTRESSING COMPONENTS

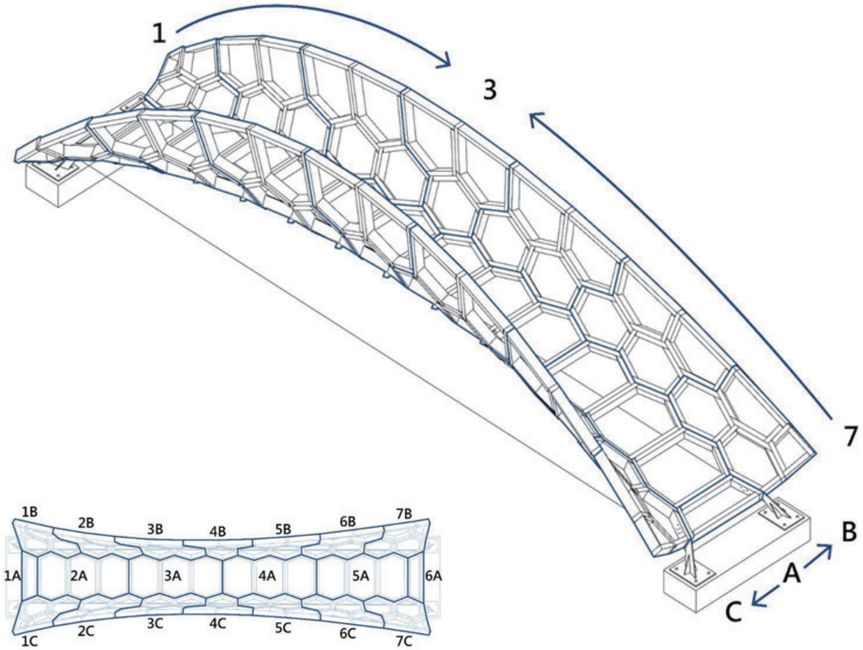


CABLE & TURNBUCKLE

Due to the limited space available for grounding at the site, relying solely on the weight of concrete foundations to withstand the outward thrust caused by the load is insufficient. Therefore, considering the structural constraints, we designed a system connecting the two sides of the bridge using cable and turnbuckles, which utilize the tensile strength of steel cables to share the outward force borne by the foundations. This approach significantly reduces the required weight of the foundations.

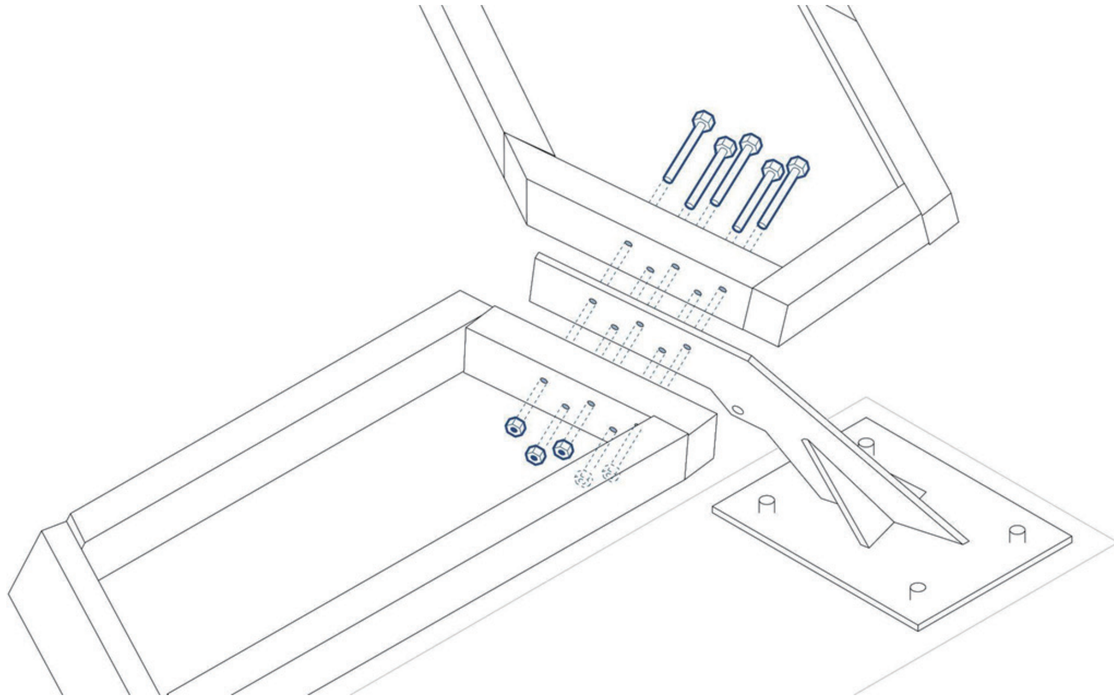
CABLE INSTALLATION

PARTS ASSEMBLING



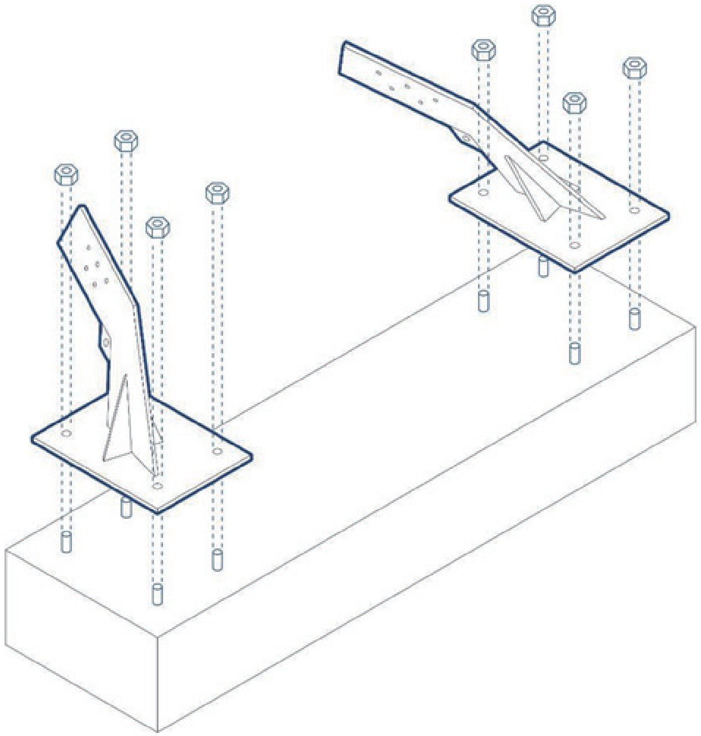
A to B+C & 7+1 to 3

Considering construction feasibility, we divided the entire bridge into 20 segments, including the central section, two side handrail areas, and the terminal units connected to the steel plates. Each segment consists of 3-4 units, which are assembled in the factory first and then assembled once again on-site. This division also allows for easier disassembly of the bridge if needed in the future. The assembly sequence starts with Segment A, where the central framework is assembled first, followed by the sequential assembly of the two sides.



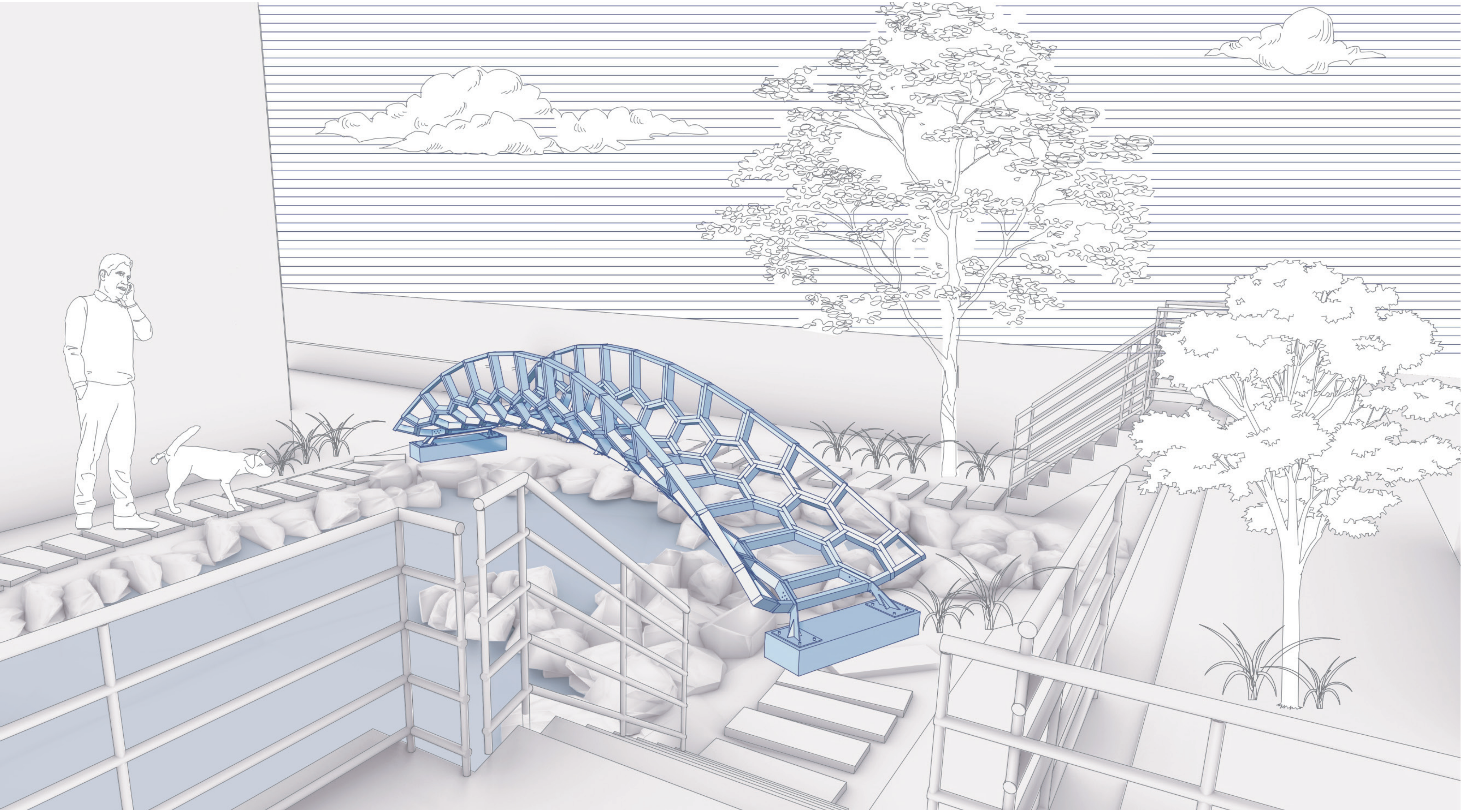
On-site Assembly

LANDING INSTALLATION

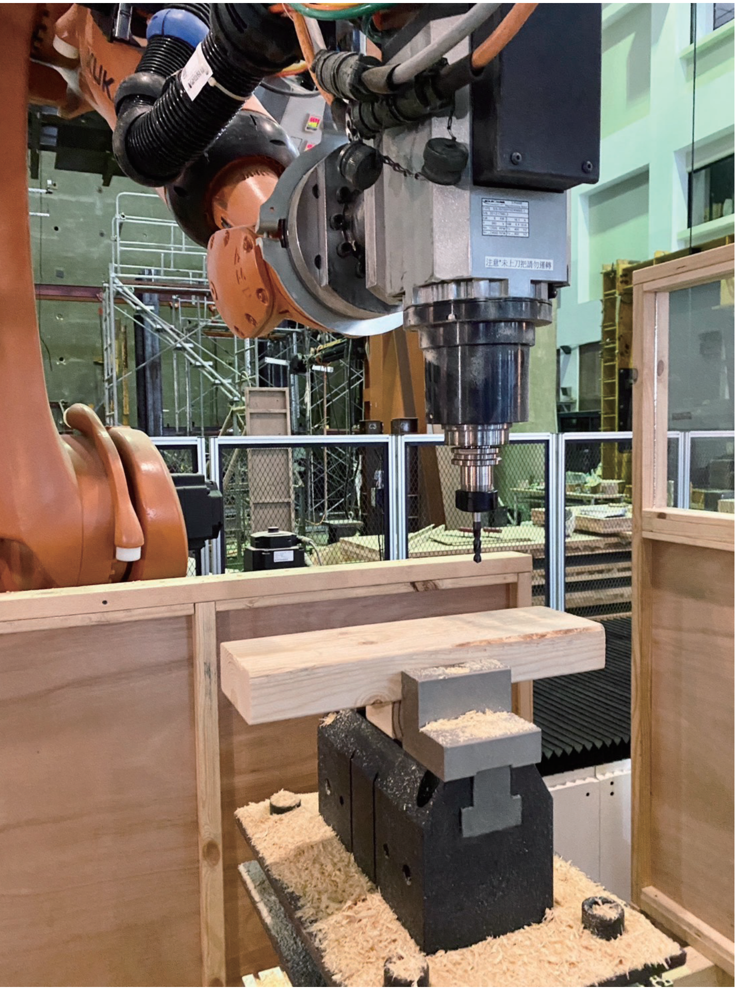


Angle Positioning & Welding

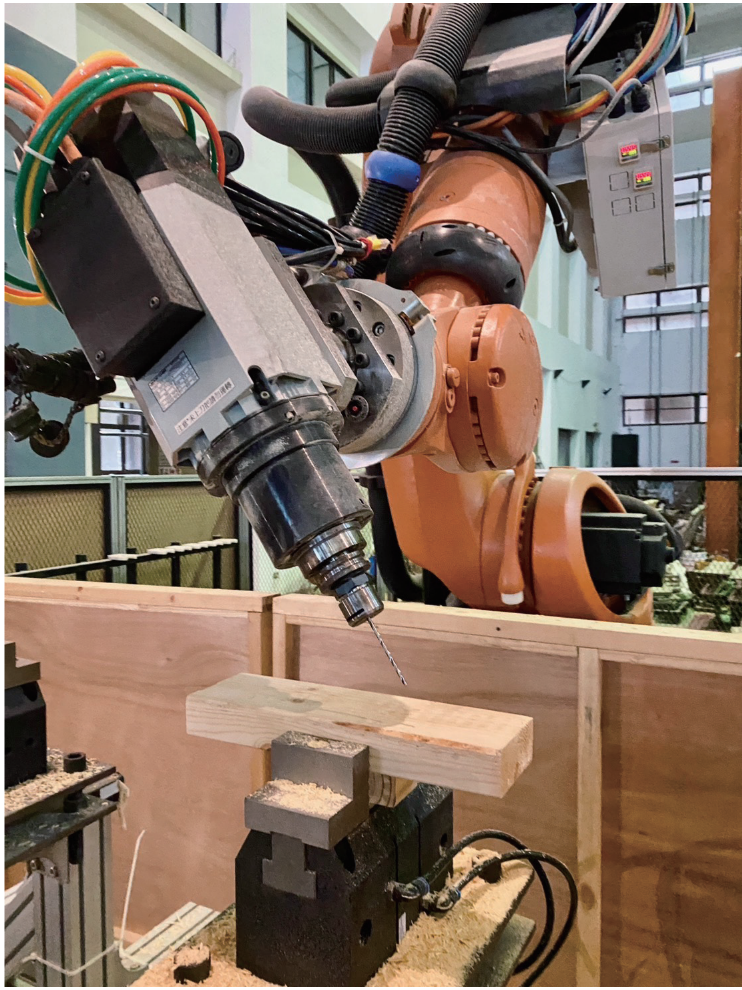
At the junction between the units and the foundations, steel plates are used for connection through welding. The steel plates are fastened to the wooden structure with bolts and secured to the concrete foundations using anchor bolts. Considering on-site construction tolerance, we have chosen to weld the steel plates at the end of the construction sequence, intending to absorb any discrepancies in the entire bridge structure.



WORK

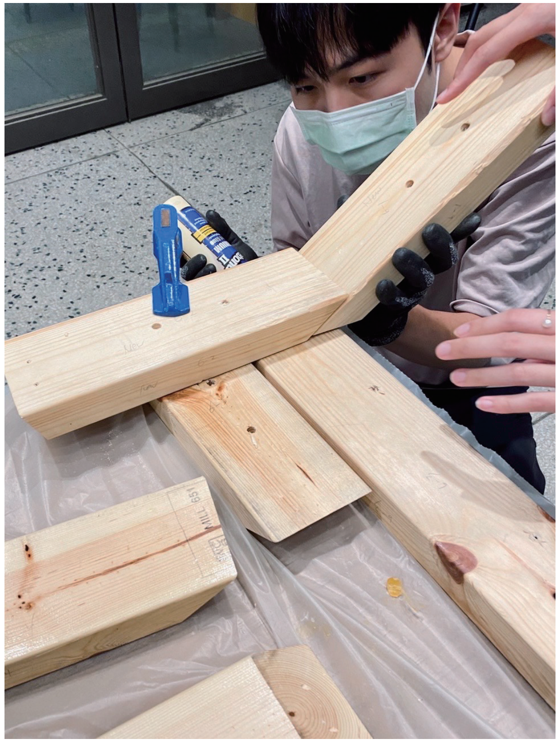


PRE-FABRICATION



UNIT PRE-ASSEMBLY

CONCRETE PRE-MIX



ON SITE CONSTRUCTION


OUTCOME

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