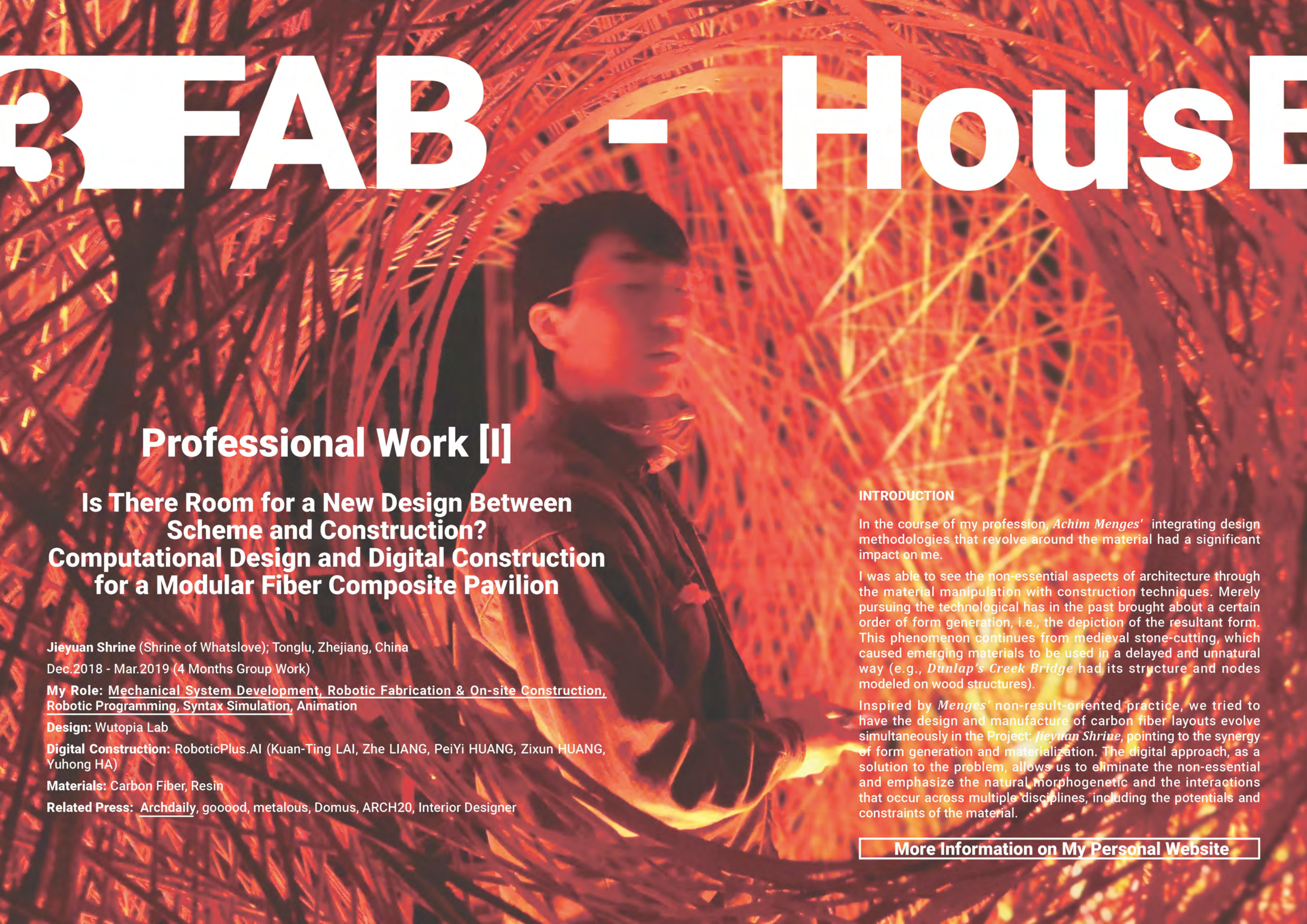


# 3FAB - HousE

## Professional Work [I]

### Is There Room for a New Design Between Scheme and Construction? Computational Design and Digital Construction for a Modular Fiber Composite Pavilion

**Jieyuan Shrine** (Shrine of Whatslove); Tonglu, Zhejiang, China

Dec.2018 - Mar.2019 (4 Months Group Work)

**My Role:** Mechanical System Development, Robotic Fabrication & On-site Construction, Robotic Programming, Syntax Simulation, Animation

**Design:** Wutopia Lab

**Digital Construction:** RoboticPlus.AI (Kuan-Ting LAI, Zhe LIANG, PeiYi HUANG, Zixun HUANG, Yuhong HA)

**Materials:** Carbon Fiber, Resin

**Related Press:** Archdaily, gooood, metalous, Domus, ARCH20, Interior Designer

**INTRODUCTION**

In the course of my profession, *Achim Menges'* integrating design methodologies that revolve around the material had a significant impact on me.

I was able to see the non-essential aspects of architecture through the material manipulation with construction techniques. Merely pursuing the technological has in the past brought about a certain order of form generation, i.e., the depiction of the resultant form. This phenomenon continues from medieval stone-cutting, which caused emerging materials to be used in a delayed and unnatural way (e.g., *Dunlap's Creek Bridge* had its structure and nodes modeled on wood structures).

Inspired by *Menges'* non-result-oriented practice, we tried to have the design and manufacture of carbon fiber layouts evolve simultaneously in the Project: *Jieyuan Shrine*, pointing to the synergy of form generation and materialization. The digital approach, as a solution to the problem, allows us to eliminate the non-essential and emphasize the natural morphogenetic and the interactions that occur across multiple disciplines, including the potentials and constraints of the material.

More Information on My Personal Website

A <u>TECHNICAL SYSTEM</u> UNDER <u>SEPERATE DESIGN CRITERIA</u>

**Our Project [1]:** Jieyuan Shrine

Digital Construction: RoboticPlus.AI (Kuan Ting LAI, Zhe LIANG, PeiYi HUANG, Zixun HUANG, Yuhong LIA)

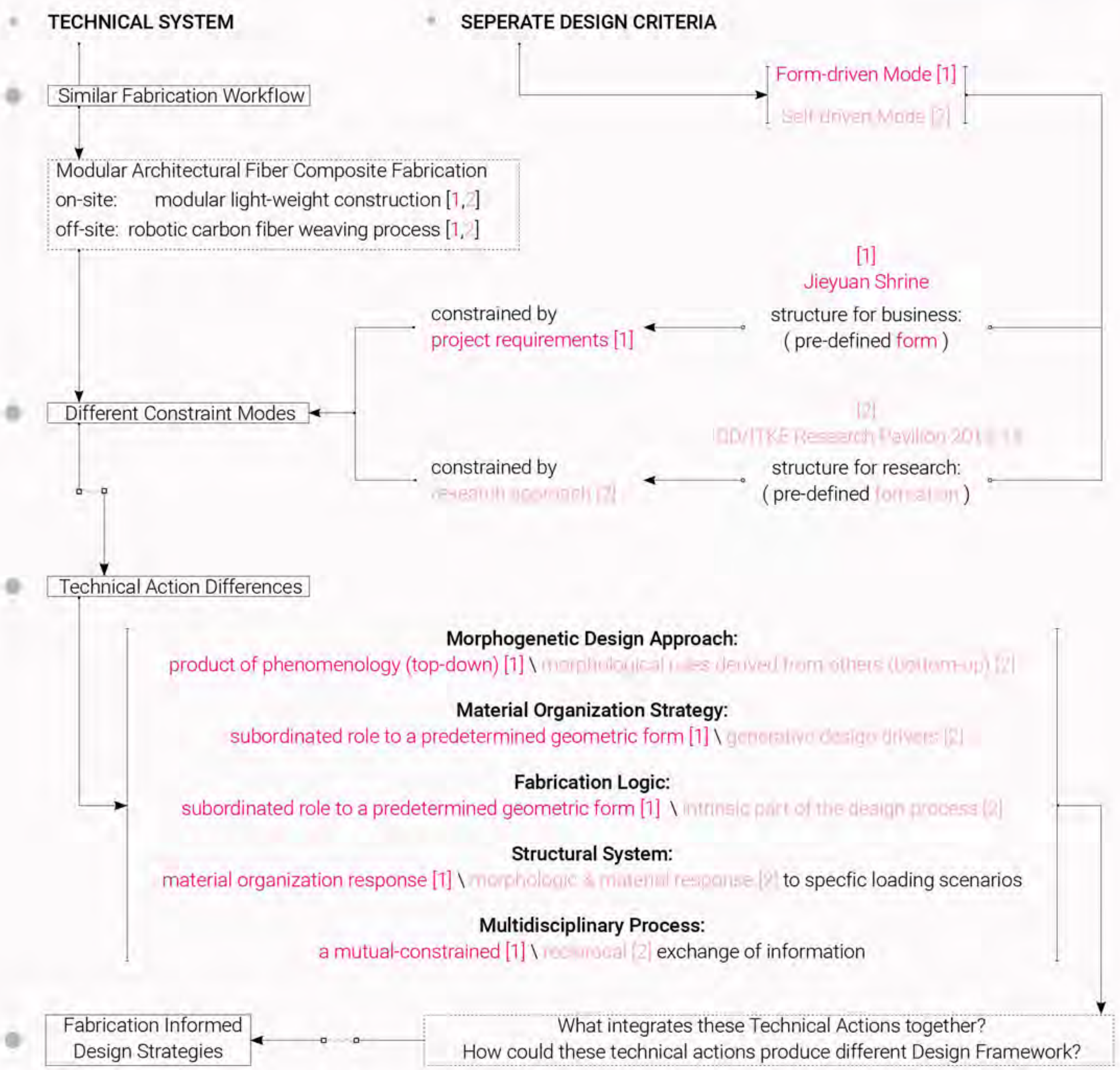
The shrine is more a visual image of a red line than a physical space, whose role is to arouse discussion on what's love in modern life and how to intervene in the rural construction.


**Menges' Project [2]:** ICD/ITKE Research Pavilion 2013-14

(Comparison Program)

Digital Construction: ICD/ITKE, WiSe 2012 - SoSe2013, WiSe 2013

" ... architectural pavilions whose role is to optimize material usage and weight, provide new architectural qualities and structuralsystems, and therefore understand natural systemson a deeper functional and methodological level." (Knippers and Speck, 2012)



**Reference:**

1. Dörstelmann, M., Knippers, J., Menges, A., Parascho, S., Prado, M., & Schwinn, T. (2015). ICD/ITKE Research Pavilion 2013-14: Modular Coreless Filament Winding Based on Beetle Elytra. Architectural Design, 85(5).

2. Dörstelmann, M., Prado, M., Parascho, S., Knippers, J., & Menges, A. (2014). Integrative computational design methodologies for modular architectural fiber composite morphologies.

3. Knippers, J and Speck, T 2012, 'Design and construction principles in nature and architecture', Bioinspiration & Biomimetics, 7, pp. 1-10

4. Yunis, L., Kyjánek, O., Dörstelmann, M., Prado, M., Schwinn, T., & Menges, A. (2014). Bio-inspired and fabrication-informed design strategies for modular fibrous structures in architecture


## FOREWORD

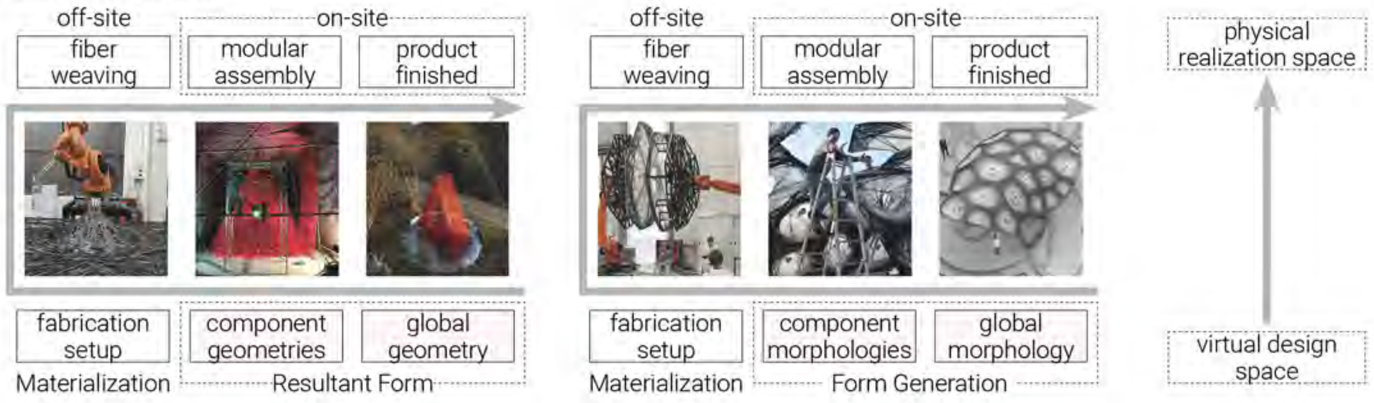
***By comparing our project to Menges' pavilion, I discovered that computational systems can reveal the intrinsic or extrinsic constraints of the design process.***

Architectural projects are usually constrained by contradictory intrinsic and extrinsic criteria, which are interrelated and integrated as ***constraint mode*** informing the development of the whole project. Several developments in material, fabrication and computation have given designers the opportunity to transfer existing constraints into ***active design drivers***.

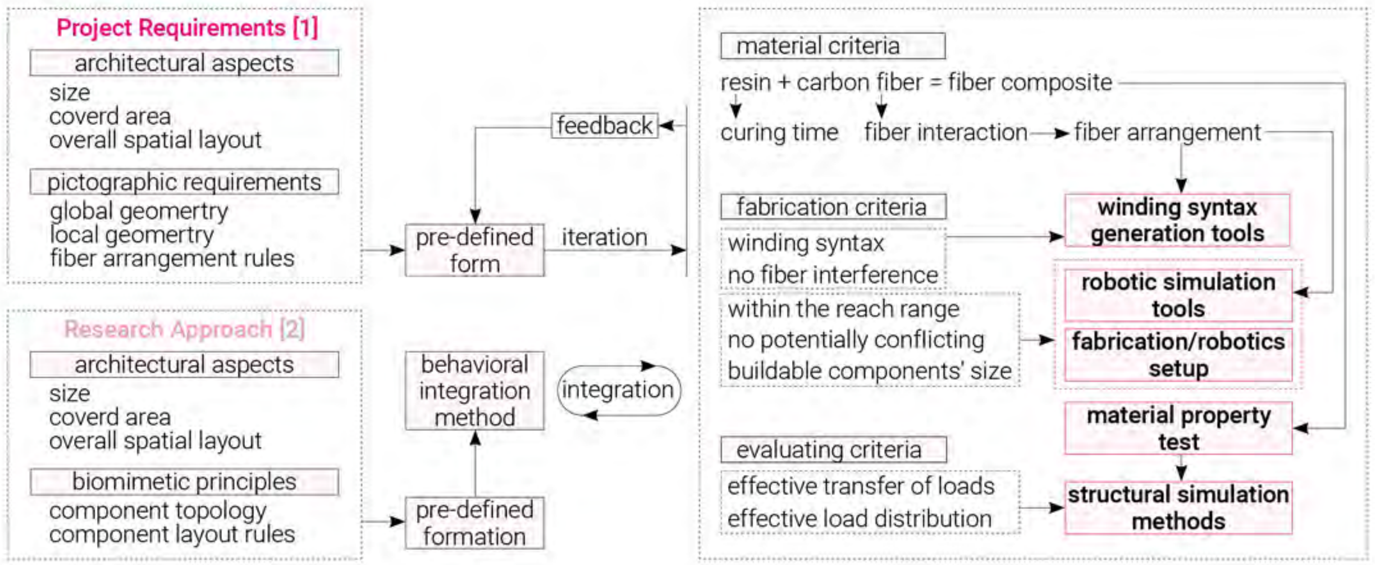
This chapter, taking Modular Architectural Fiber Composite Fabrication (***MAFCF***) as an example, compares the constraint mode in two cases distinguished by whether initial design intensions (***extrinsic part***) informed by process constraints (***intrinsic part***) such as material and fabrication.

This chapter shows differences in technical actions of the same construction system, i.e. MAFCF, under these two constraint modes, and shows how design computation organizes instrinsic and extrinsic constraints and synthesizes differentiated technical actions into a similar ***design framework*** which equips designers with the tools to negotiate complex interrelationships and to carry out ***materalization*** tasks from virtual design space to physical realization space.

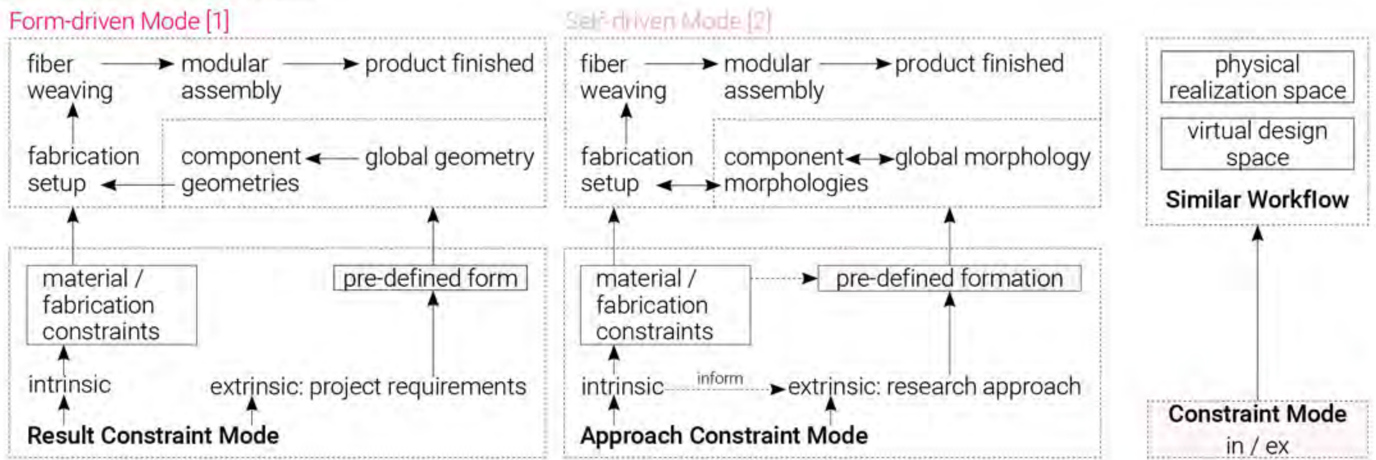
<u>01 MAFCF Workflow</u>

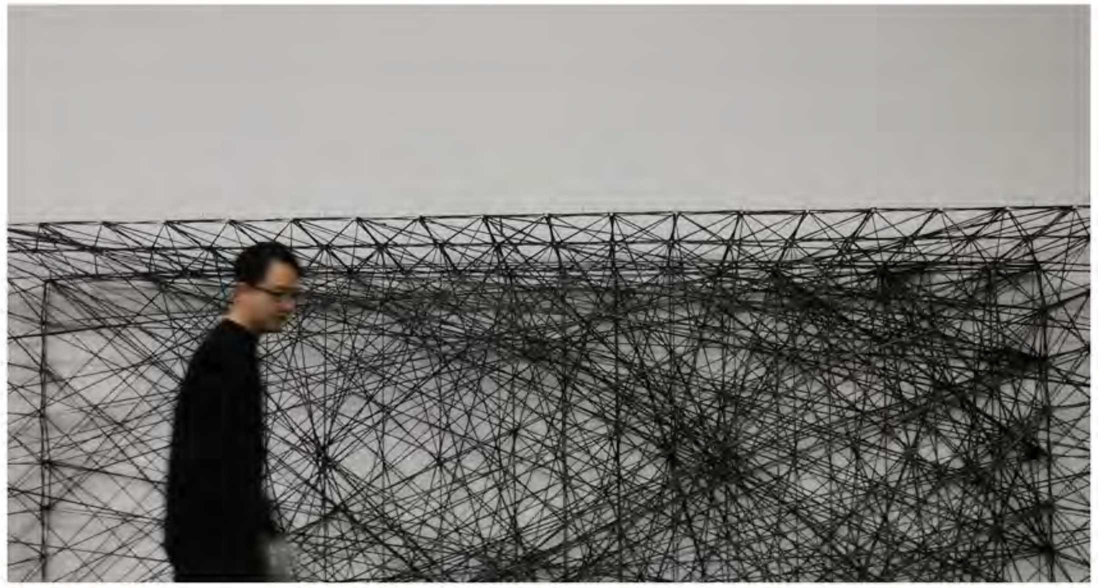



<u>02 From Design to Fabrication</u>




<u>03 Different Constraint Modes</u>

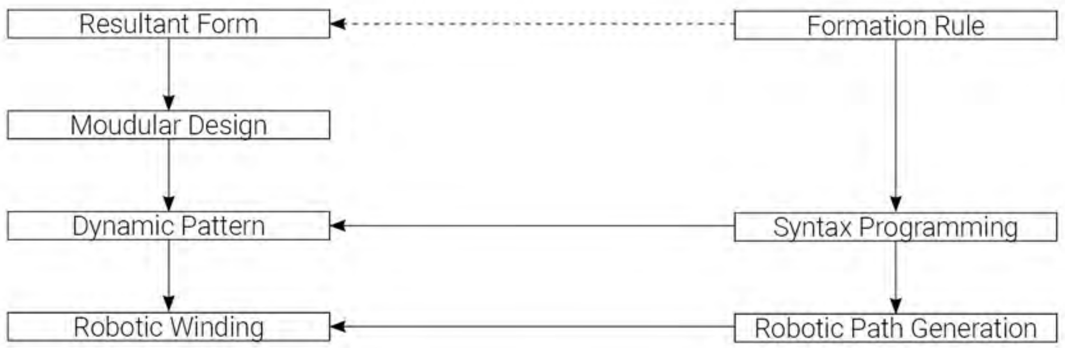




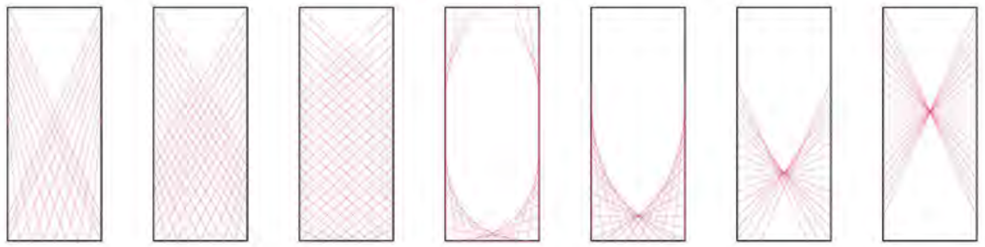
## 04 Computational Design Workflow

Is there room for a new design between scheme and construction? The geometry and volume of the knotted shrine is predefined, but how the pavilion is built is defined by us. There is still a lot of design space in between: if modularity is chosen because of transportation constraints, how many modules will it be disassembled into? How thick would each module be, and how many layers would it be divided into? What is the pattern of the carbon fiber inside the module, and how is the pattern woven?

In less than 3 months and with less than 5 people, we were able to redesign and build the entire pavilion. This was made possible by the explosive potential of combining computational design with digital construction.

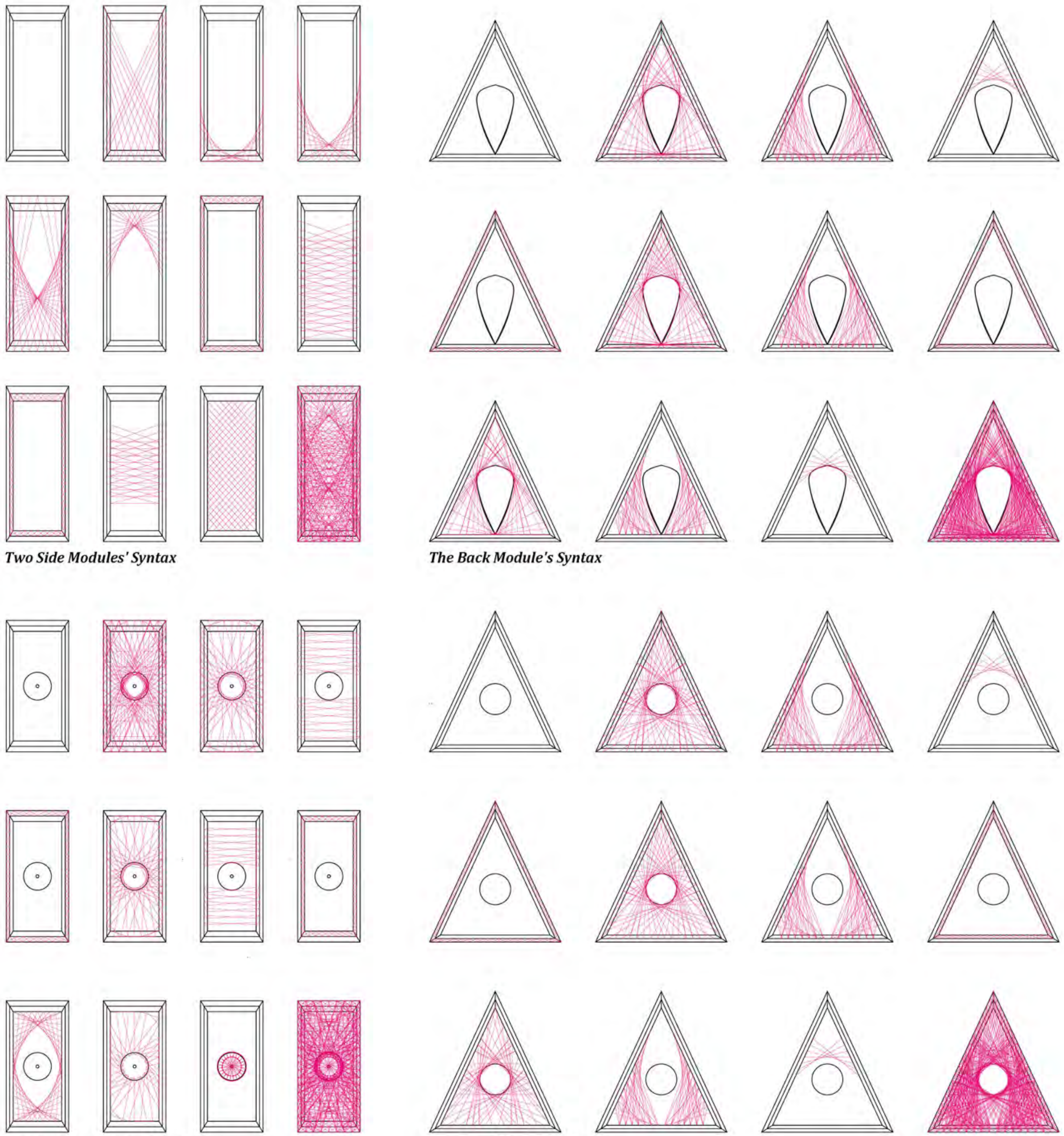



## 05 Syntax Simulation: Carbon-fiber Layout Generation



To ensure a certain structural thickness, each module consists of 3 layers of carbon fiber woven layers. The layout of the carbon fibers on the woven layers is controlled by specific parameters to ensure the final project effect (e.g. from the bottom up, the density of carbon fiber distribution decreases). The figure above shows the variation of the same woven cell with different parameters. The figure on the right shows the breakdown of the final woven layers for the five modules.

## 06 Syntax Simulation Results: Carbon-fiber Layouts

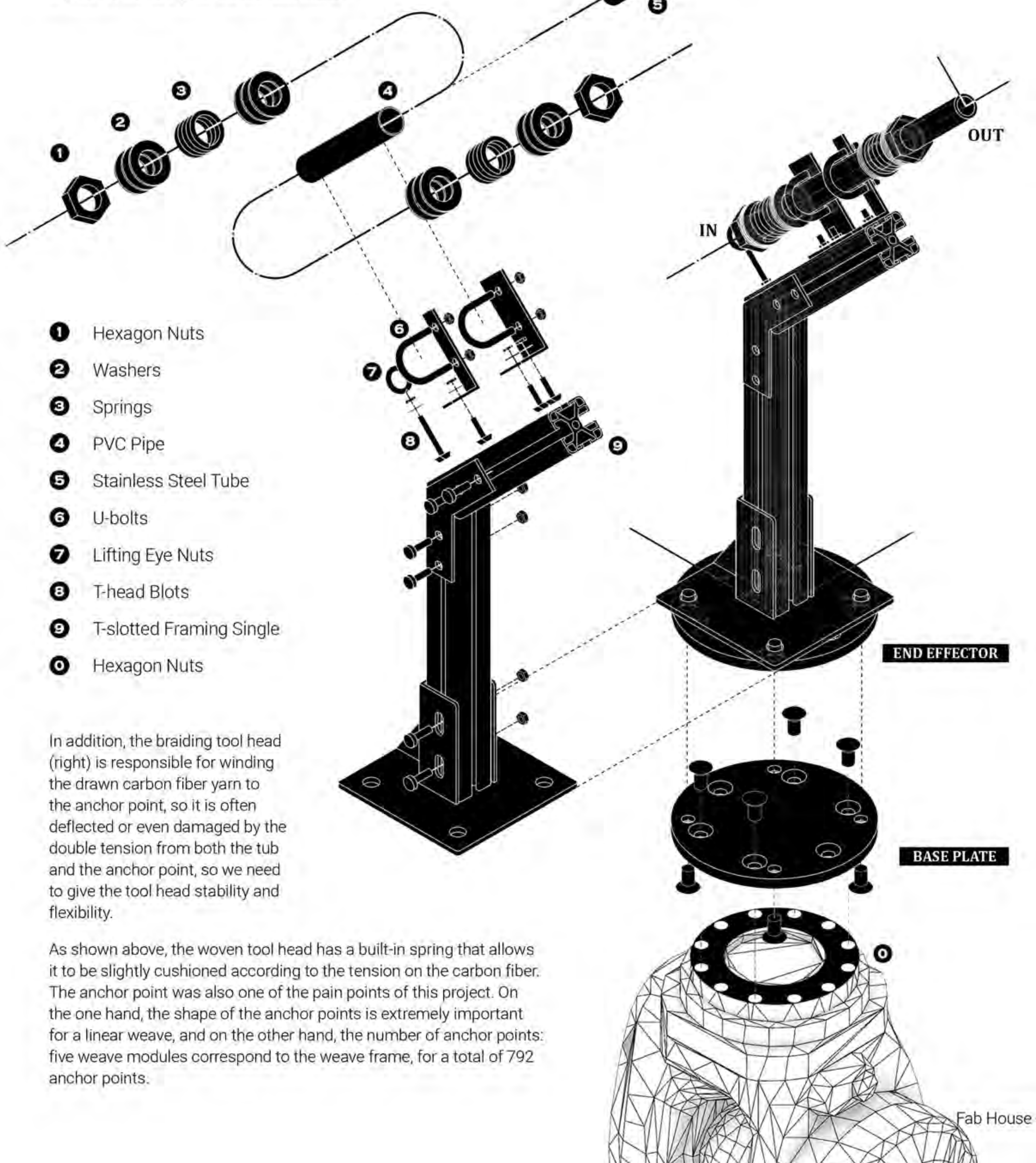


## MECHANICAL DESIGN | *This section introduces the weaving system part of the mechanical design, which consists of the end effector of the robot arm, the frame anchor points and the resin bath.*

### 07 Weaving System & End Effector

In fact, the design, fabrication, installation and commissioning of the complete winding system (carbon fiber yarn frame, resin tub, tool head, anchor points, braiding frame) took almost 70% of the time for this digitally built project.

During the carbon fiber weaving process, it is extremely important to control the tension, too much or too little tension may bring devastating consequences of carbon fiber pilling or even breaking. Therefore, controlling the friction and the angle of the passing thread became a very important chapter in the design of the tub and frame.




1. Hexagon Nuts
2. Washers
3. Springs
4. PVC Pipe
5. Stainless Steel Tube
6. U-bolts
7. Lifting Eye Nuts
8. T-head Blots
9. T-slotted Framing Single
0. Hexagon Nuts

In addition, the braiding tool head (right) is responsible for winding the drawn carbon fiber yarn to the anchor point, so it is often deflected or even damaged by the double tension from both the tub and the anchor point, so we need to give the tool head stability and flexibility.

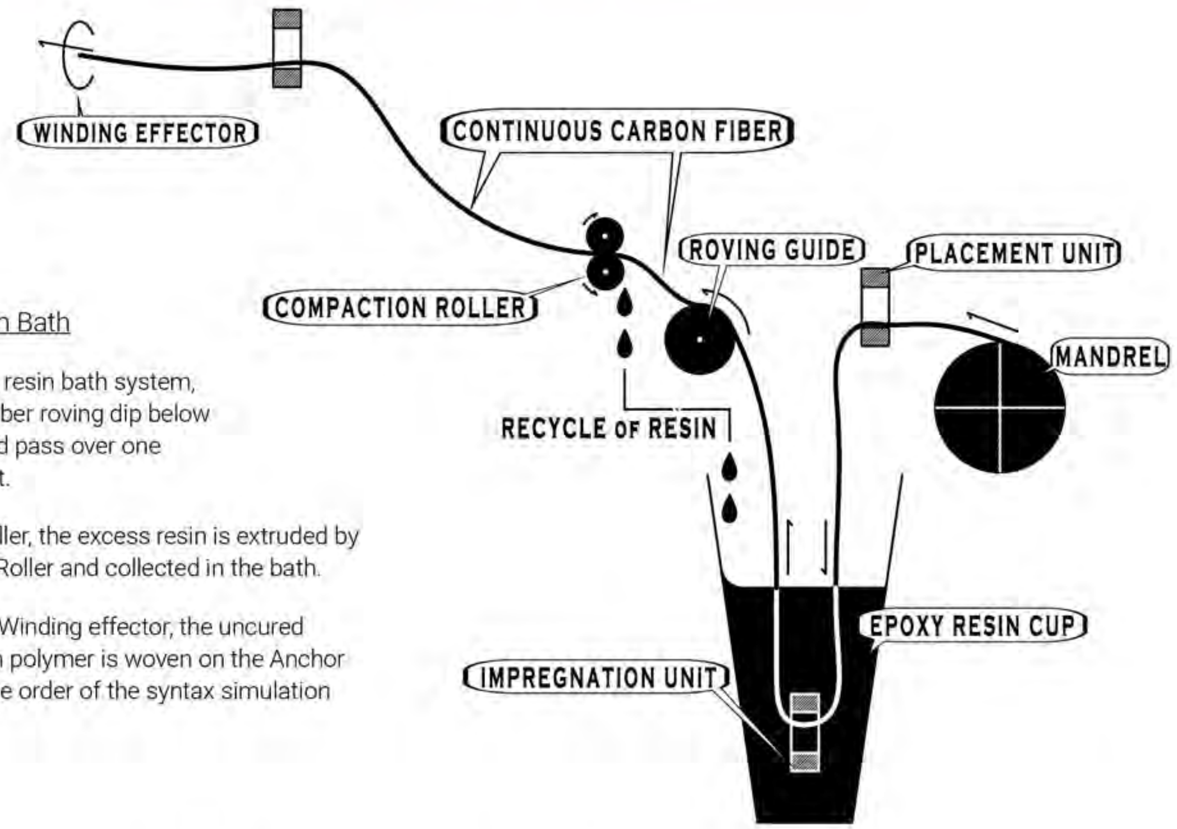
As shown above, the woven tool head has a built-in spring that allows it to be slightly cushioned according to the tension on the carbon fiber. The anchor point was also one of the pain points of this project. On the one hand, the shape of the anchor points is extremely important for a linear weave, and on the other hand, the number of anchor points: five weave modules correspond to the weave frame, for a total of 792 anchor points.

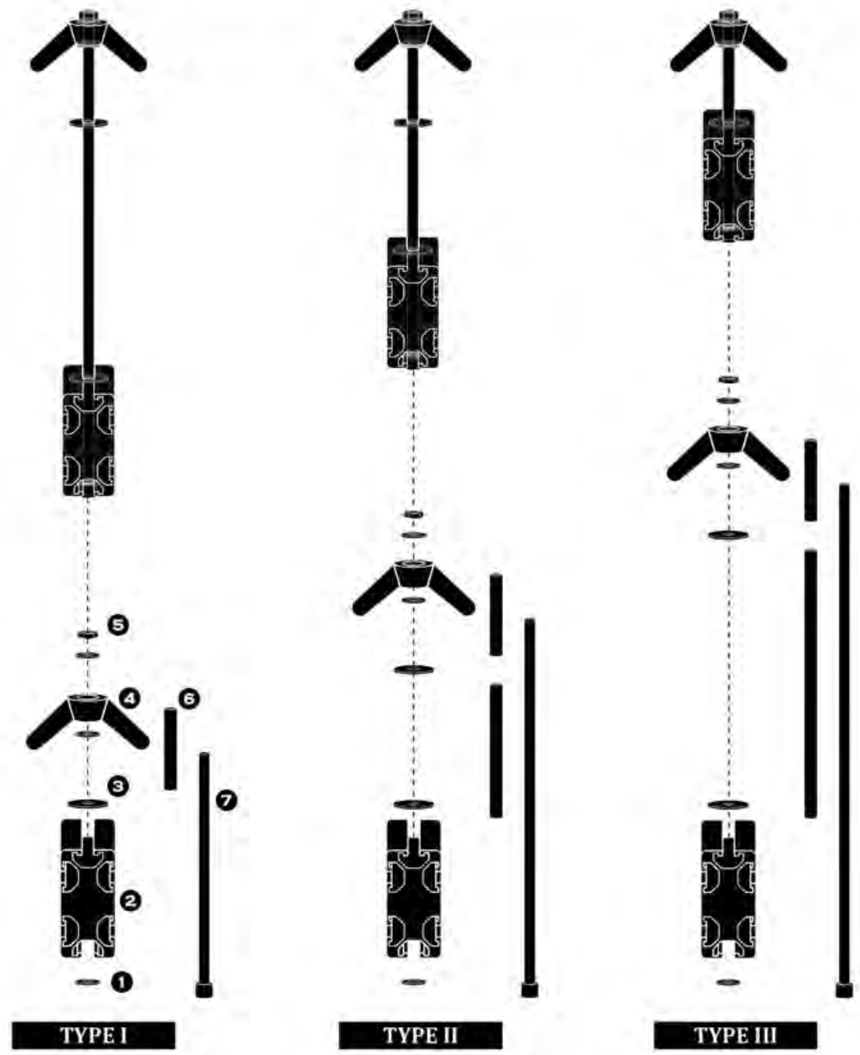
### 08 A Dip-type Resin Bath

1) In the Dip-type resin bath system, the 24K carbon fiber roving dip below the resin level and pass over one impregnation unit.

2) Guided by a roller, the excess resin is extruded by the Compaction Roller and collected in the bath.

3) Finally, after a Winding effector, the uncured carbon fiber resin polymer is woven on the Anchor of the frame in the order of the syntax simulation



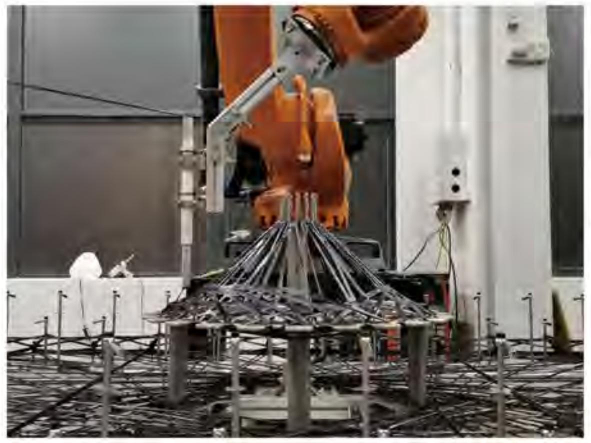

### 09 Anchor Points

However, the anchor points themselves are homogeneous and portable; at the same time, they are all composed of standard parts, which means that the components of the anchor points themselves are all directly recyclable.

1. Washers
2. T-slotted Framing Double
3. Round Washers
4. Wing Nuts
5. Cap Nuts
6. Stainless Stell Capillary Tube
7. Long Socket Head Cap Screws

## MECHANICAL SYSTEM

***This section shows how the whole weaving system works and how the 8 types of paths are woven. I have created an animation to visually show the process, which may help you to reduce your reading time.***



10 Robotic Winding

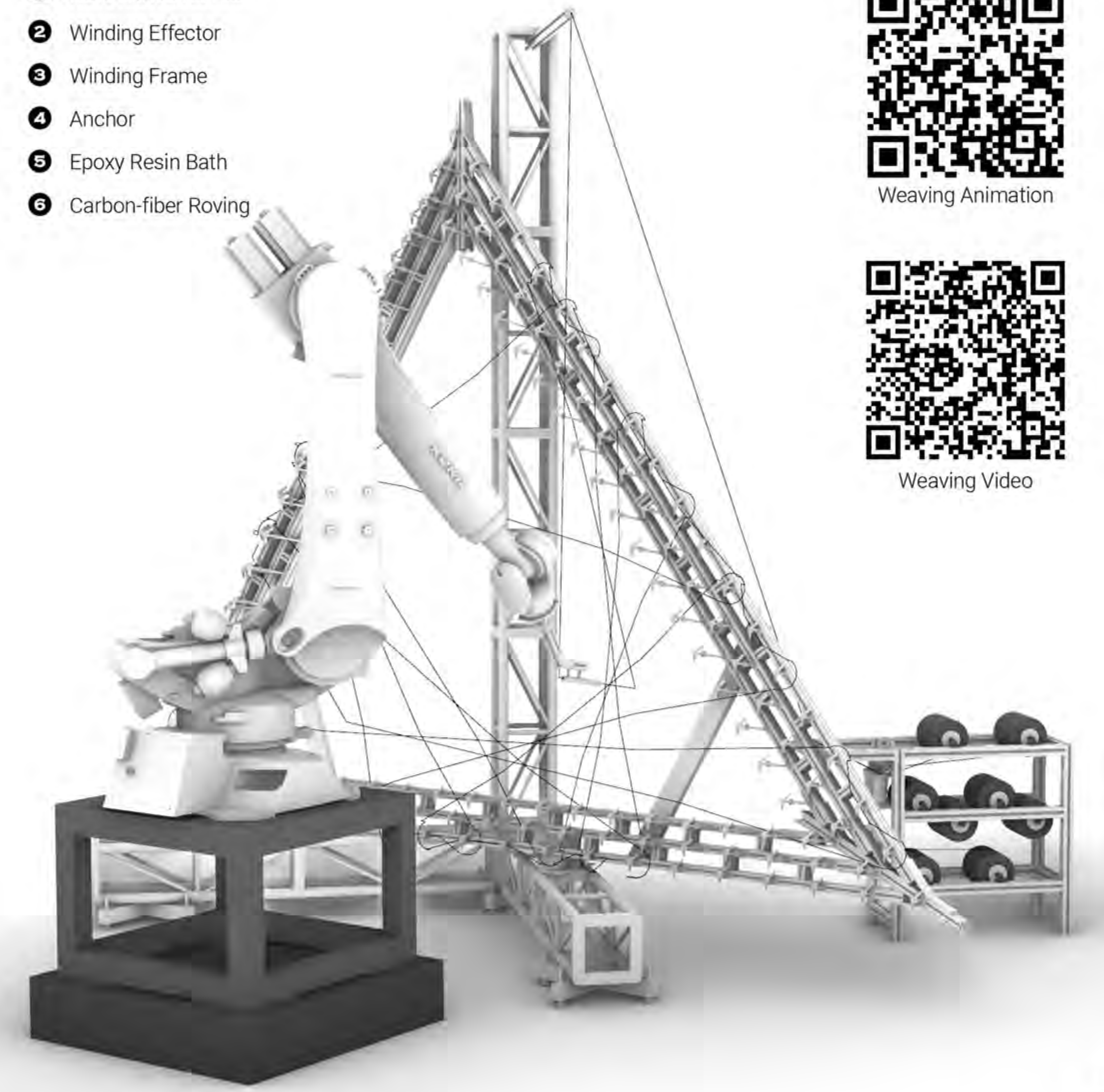
Using the above-mentioned weaving tools, resin bath and anchor points we developed, and with the programmability of the KUKA robot arm, we designed a complete automated weaving method to translate the weaving syntax simulation in 3D digital space into material space.

The photos on the right, from left to right, are: the carbon fiber yarn frame and the resin bath; the robot arm is weaving the module at the bottom of the Pavilion; and the anchor points in the motion camera view on the end effector.

In addition, I was responsible for programming the robot arm for the side modules in this part. The paths of the robotic arm movements are automatically generated by the GH program using the pattern derived from the syntax simulation as input. This is one of the advantages of combining computational design and digital construction as well.

11 Robotic Winding System

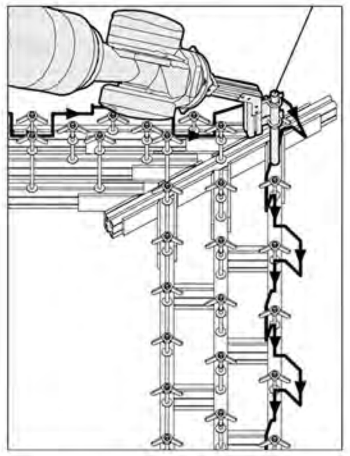
1. KUKA KR90 R3100
2. Winding Effector
3. Winding Frame
4. Anchor
5. Epoxy Resin Bath
6. Carbon-fiber Roving



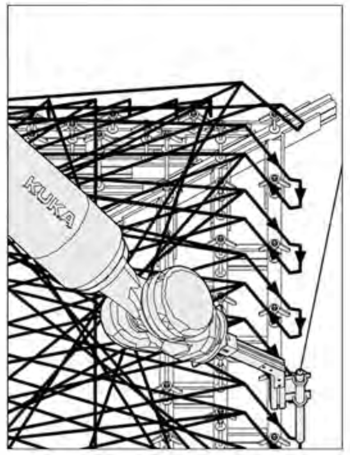
Weaving Animation

Weaving Video

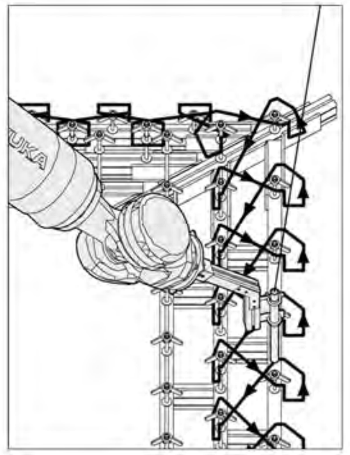
12 Robotic Winding Process



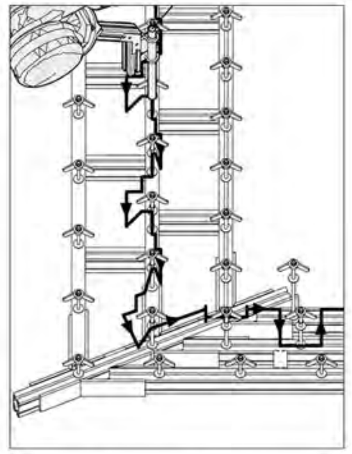
The sequence of the anchor point I is circumscribed by the S-shaped trajectory for two weeks to form a figure-shaped bundling as a frame structure of the edging hall.



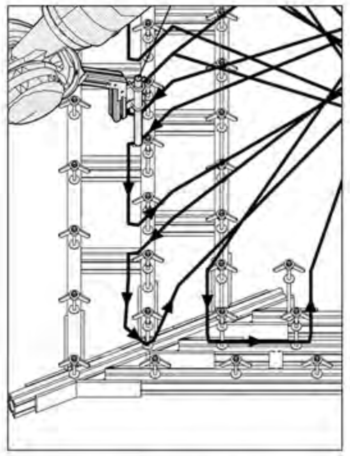
The uncured carbon fiber composite material is anchored to the anchor point I through a bag-shaped path to form a pattern of the outer surface surface layer of the rim.



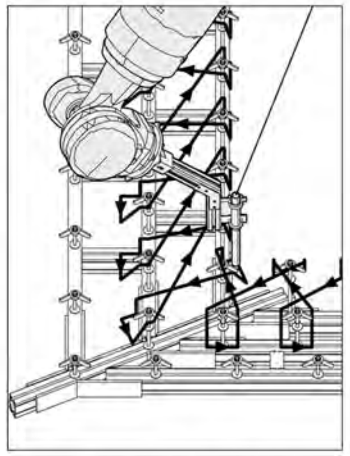
The 8-point type trajectory alternates the sequence of the anchor point I and the anchor point II to play a pulling effect on the woven structure.



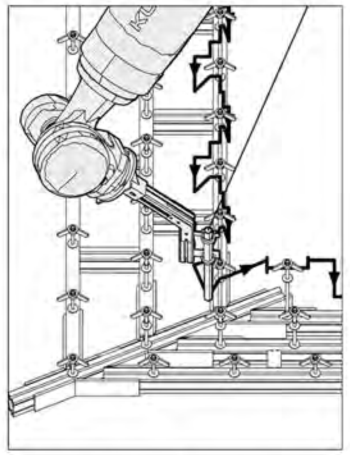
The anchor point II sequence is circumscribed by the S-shaped trajectory for two weeks to form a figure-eight type of tying as a frame structure of the rim.



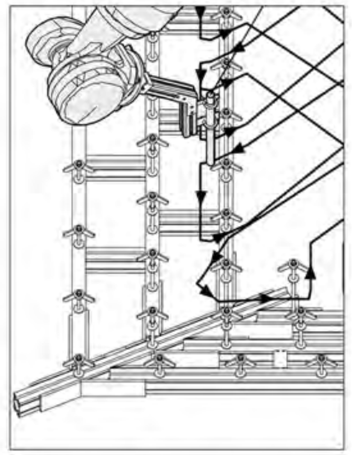
The uncured carbon fiber composite is anchored to the anchor point II by a pocket-shaped path to form a module intermediate layer pattern.



The anchor point II and the anchor point III sequence are alternately bypassed by the 8-shaped trajectory, and the braided structure is pulled.

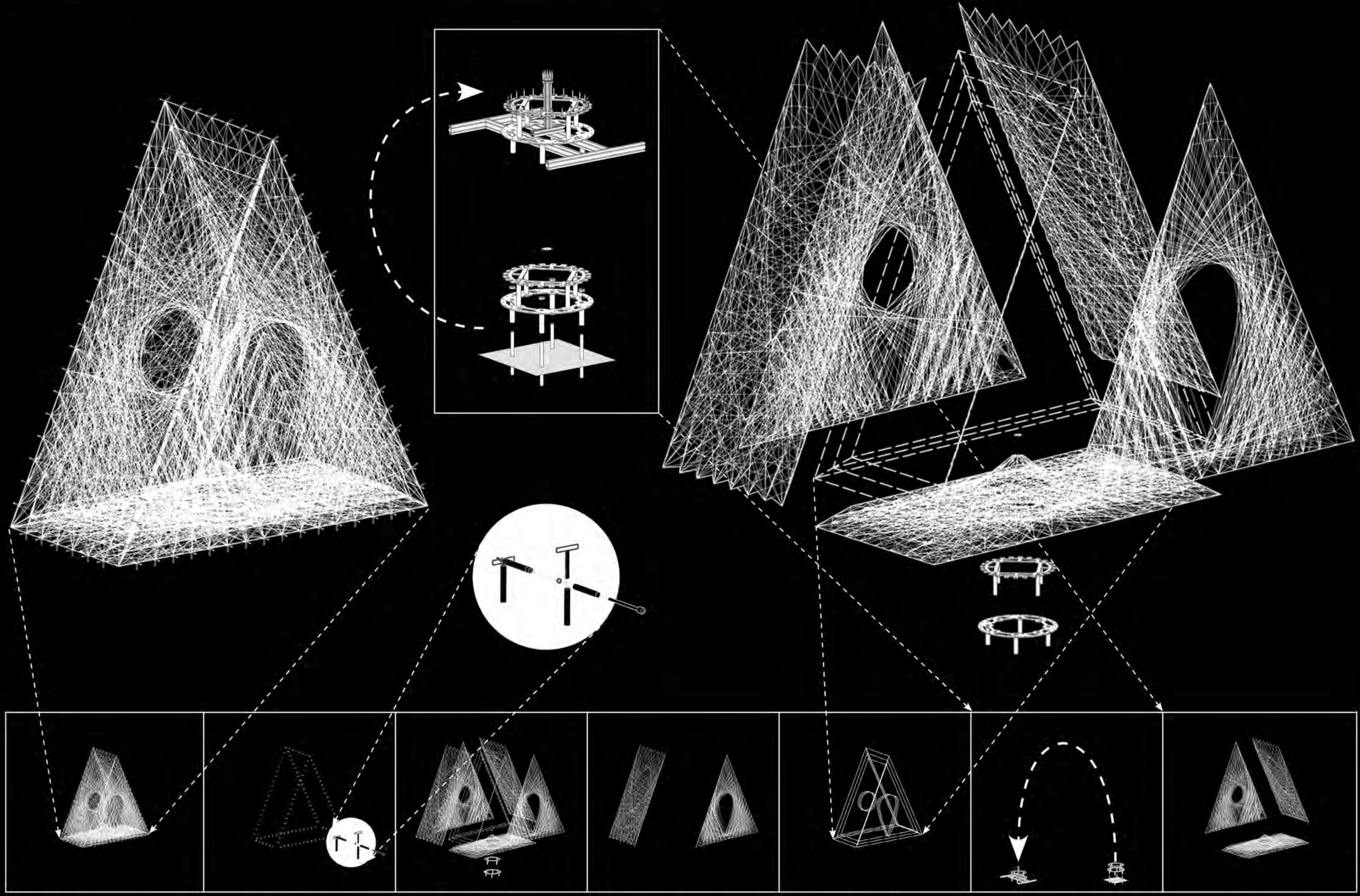


The anchor point III sequence is circumscribed by the S-shaped trajectory for two weeks to form a figure-eight tying as a frame structure of the rim.



The carbon fiber composite material is anchored to the anchor point III by a bag-shaped path to form a pattern of the inner surface layer of the rim.

## ASSEMBLY INSTRUCTION | *The pavilion consists of five modules, which are joined by tiny metal connectors. The entire pavilion is connected to the foundation by a central metal base.*

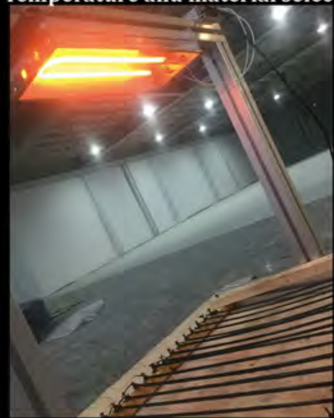


1) Pavilion Resultant Form   2) Metal Connectors   3) Explosive diagram   4) Modules   5) Frame   6) Metal base assembly   7) Modules

## WORKFLOW RECORD

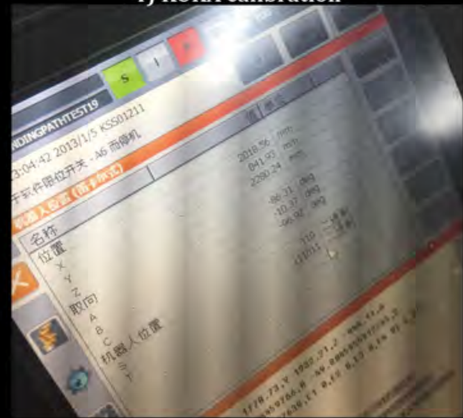
1) Material strength testing

2) Temperature and material selection



3) Frame positioning and erection

4) KUKA calibration

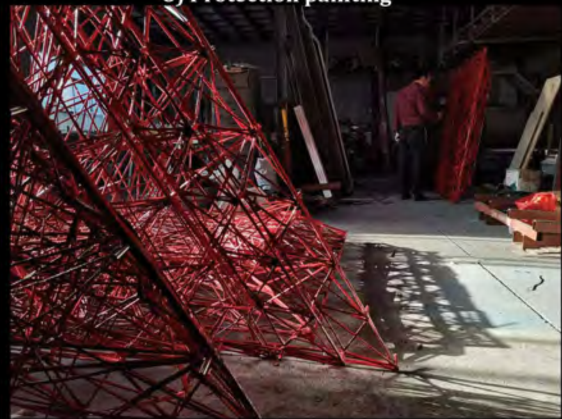


5) Robotic weaving

6) Baking and curing

7) Module trial assembly

8) Protection painting



9) Transportation

10) On-site assembly