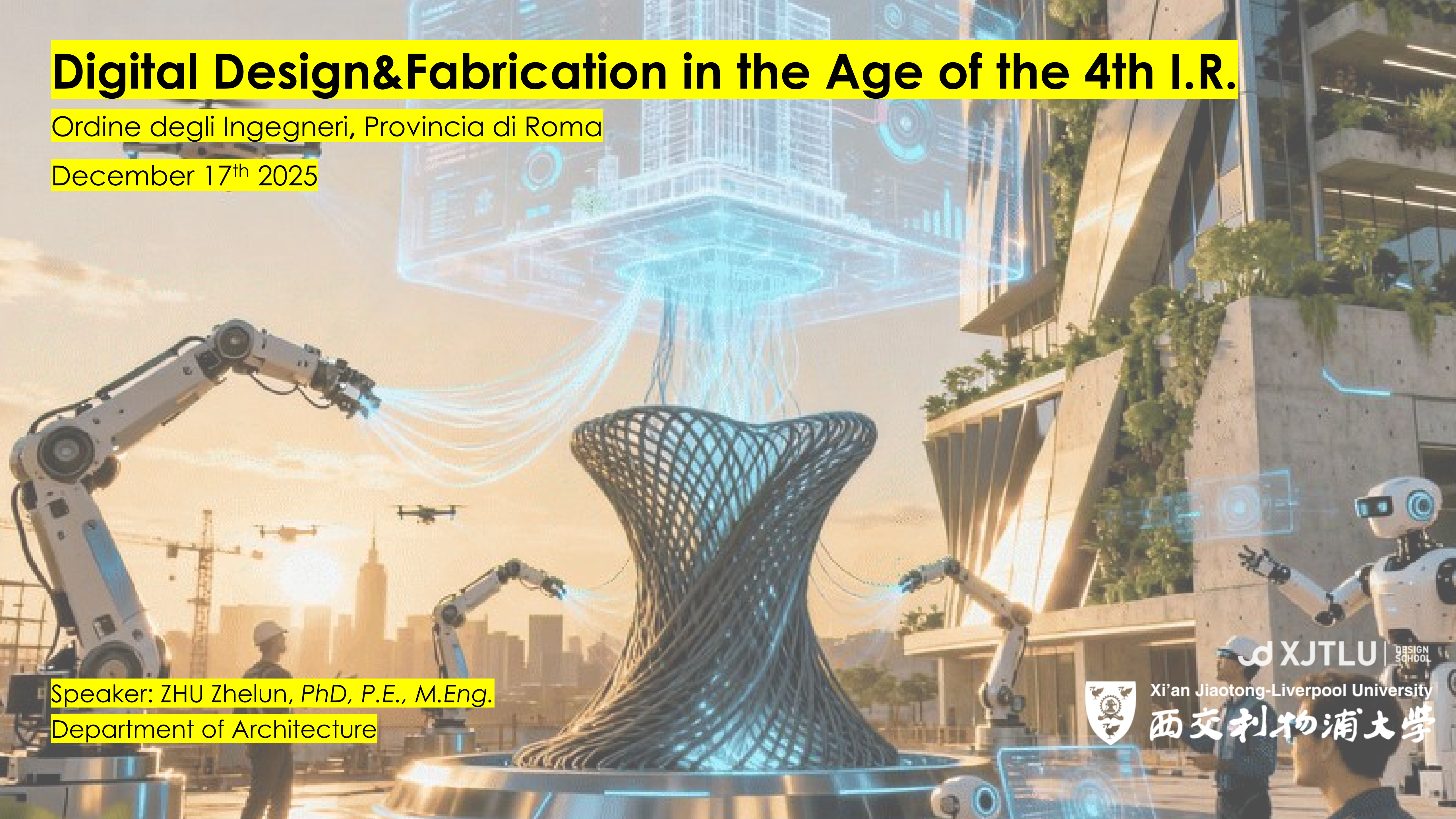
Digital Design&Fabrication in the Age of the 4th I.R.

Ordine degli Ingegneri, Provincia di Roma

December 17th 2025



Speaker: ZHU Zhelun, *PhD, P.E., M.Eng.*
Department of Architecture

XJTLU | DESIGN SCHOOL
Xi’an Jiaotong-Liverpool University
西交利物浦大学

朱哲伦 ZHU Zhelun, *PhD, P.E., M.Eng.*

Department of Architecture, Design School

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- PhD from Sapienza University of Rome
- Visiting scholar at Inst. AAA, Southeast University (Nanjing, China)
- Visiting scholar at Texas A&M University (Texas, USA)
- Aerospace Committee, Engineers Association of Rome
- Space Habitat Committee, International Astronautical Federation
- Polar Zone Architecture, Chinese Architects Association

LinkedIn

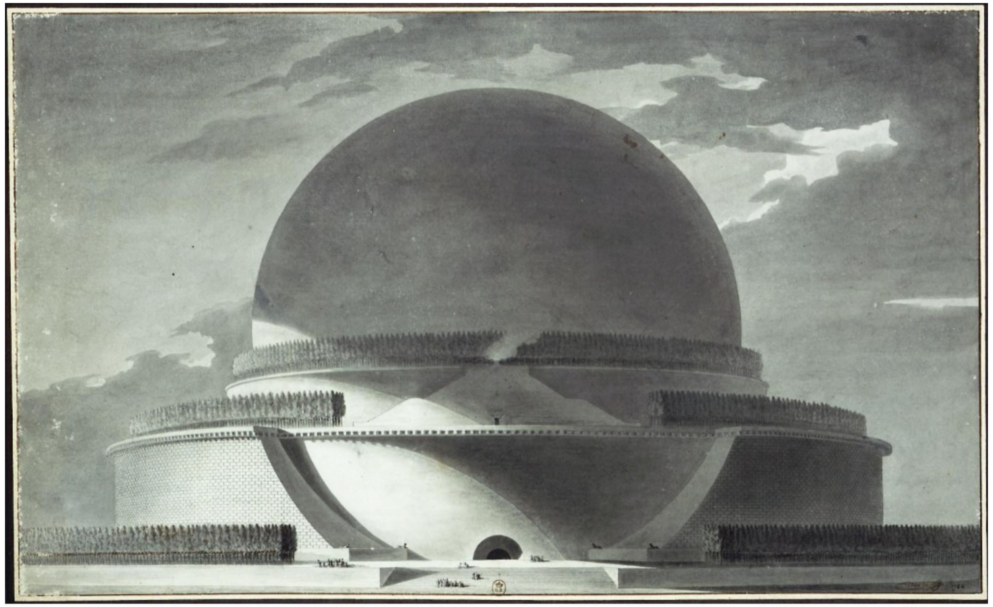
18th Century
First
industrial revolution

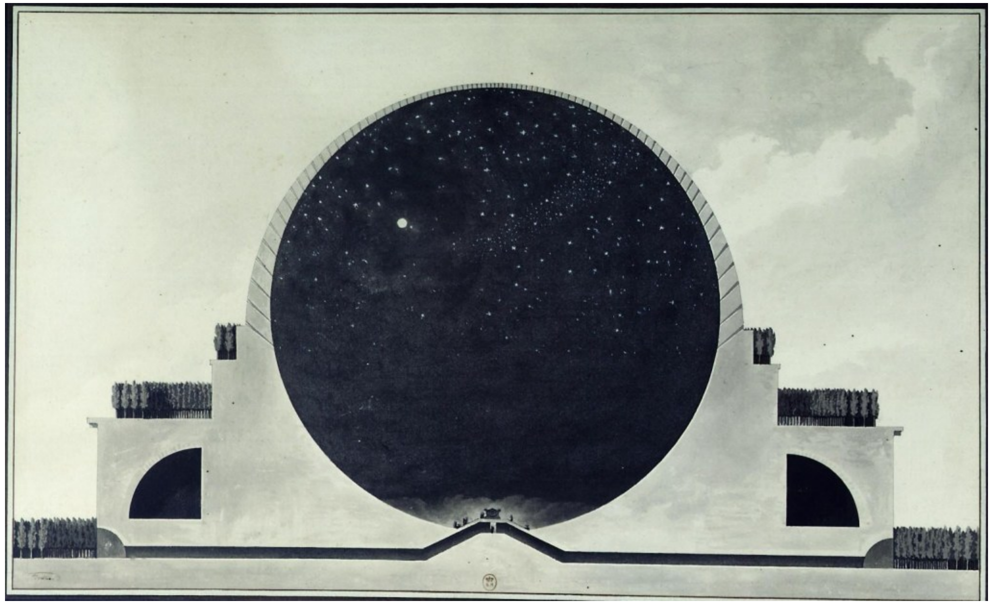
19th Century
Second
industrial revolution

20th Century
Third
industrial revolution

21st Century
Fouth
industrial revolution

Stream power
Mechanisation





Cenotaph for Newton (1780s)
É.-L. Boullée

18th Century

First
industrial revolution

19th Century

Second
industrial revolution

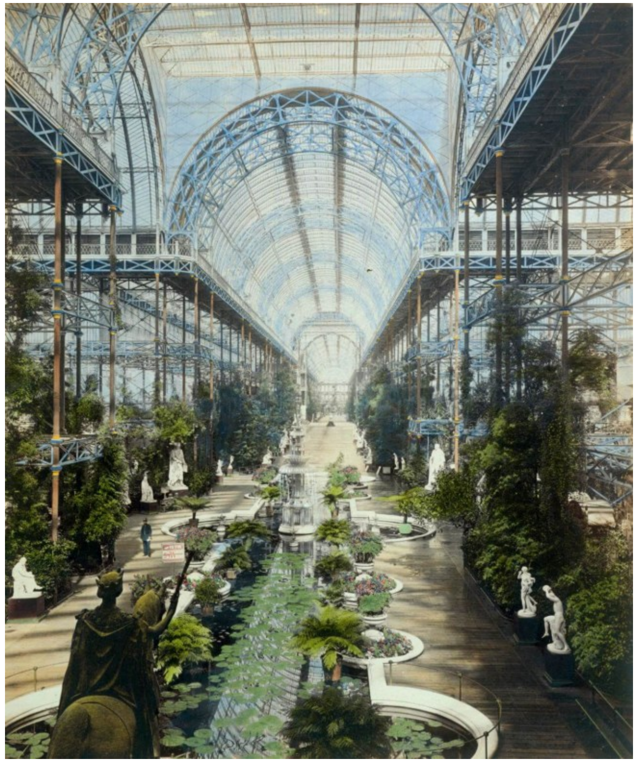
Assembly line
Electric power
Mass production

20th Century

Third
industrial revolution

21st Century

Fouth
industrial revolution



Crystal Palace (1850s)
J. Paxton

18th Century

First
industrial revolution

19th Century

Second
industrial revolution

20th Century

Third
industrial revolution

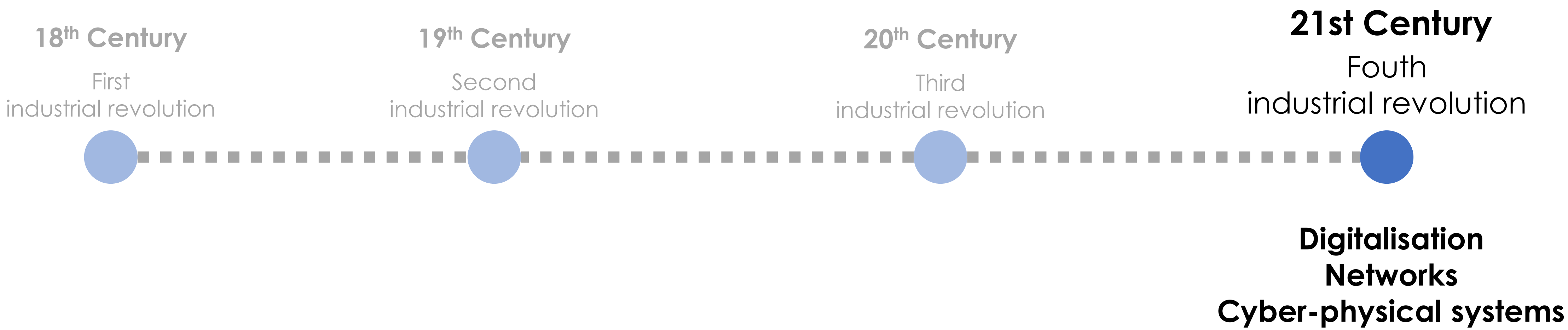
21st Century

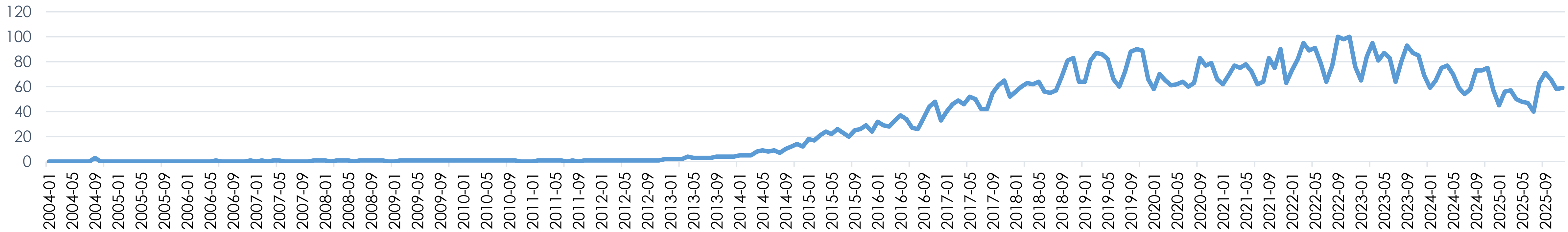
Fouth
industrial revolution

Automation
Electronics

Guggenheim Museum
Bilbao (1990s)
F. Gehry

HSBC Building (1980s)
N. Foster, O. Arup



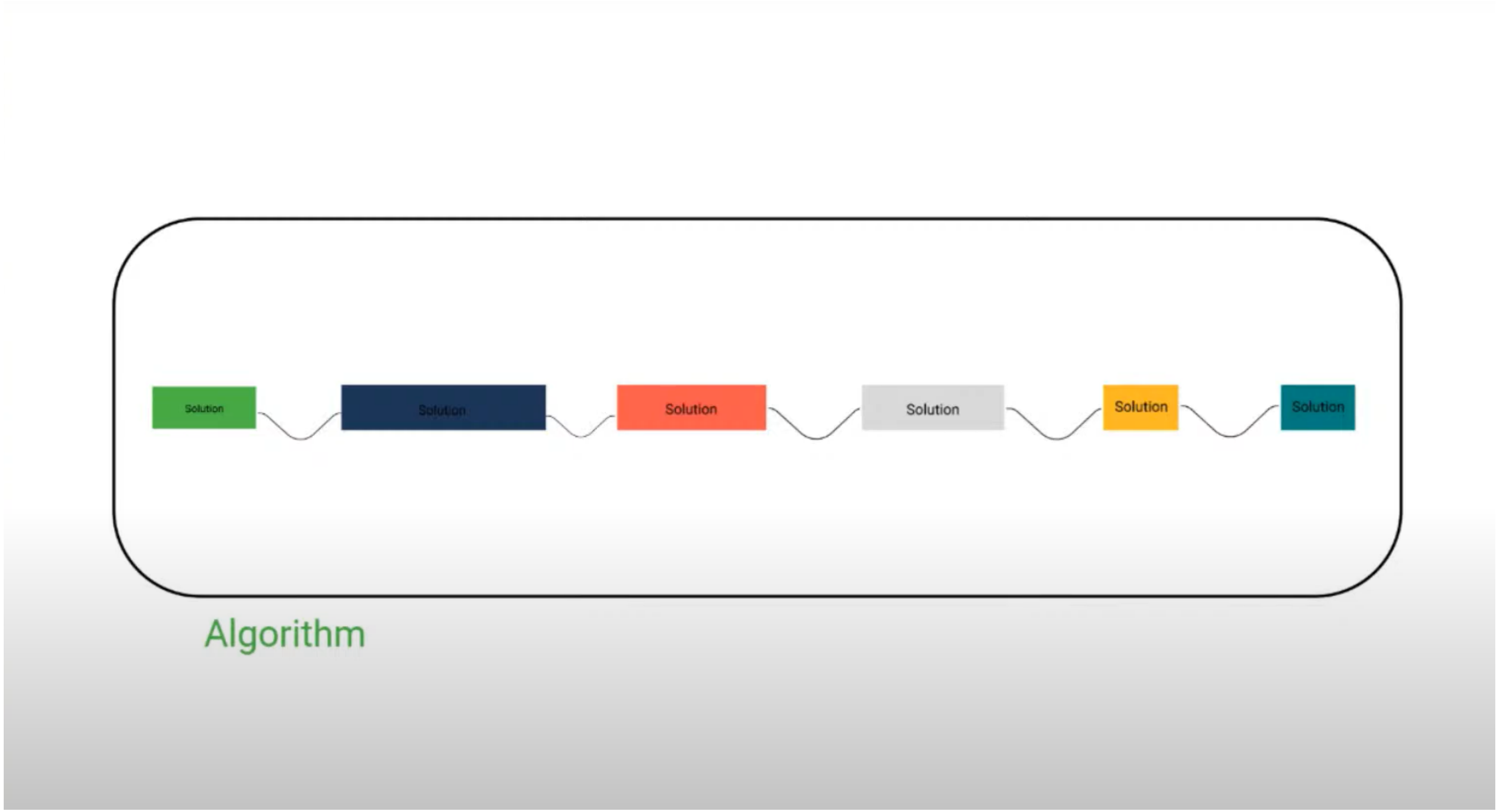


Worldwide interest trend of the topic "Fourth Industrial Revolution" since 2004 (Source: Google Trends).

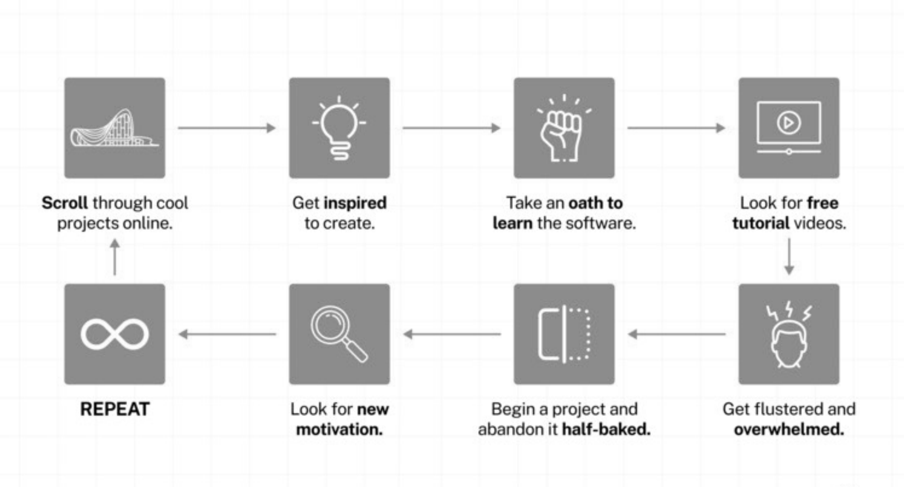
Digital Design in AEC

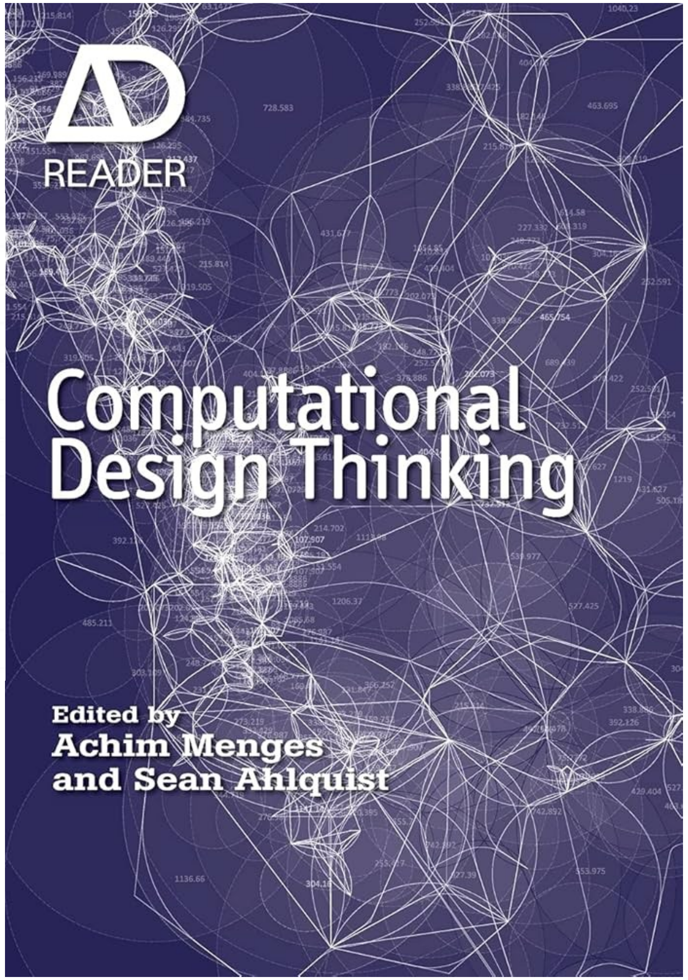
Digital Design involves softwares, tools, and applications process data with the help of algorithms and parameters to propose solutions. With the use of computational technology, every input is translated into a computer-coded language for generating models and analysing reports. By entering data, the machine can repeat tasks a desired number of times and generate a favourable outcome.

Digital Design in AEC



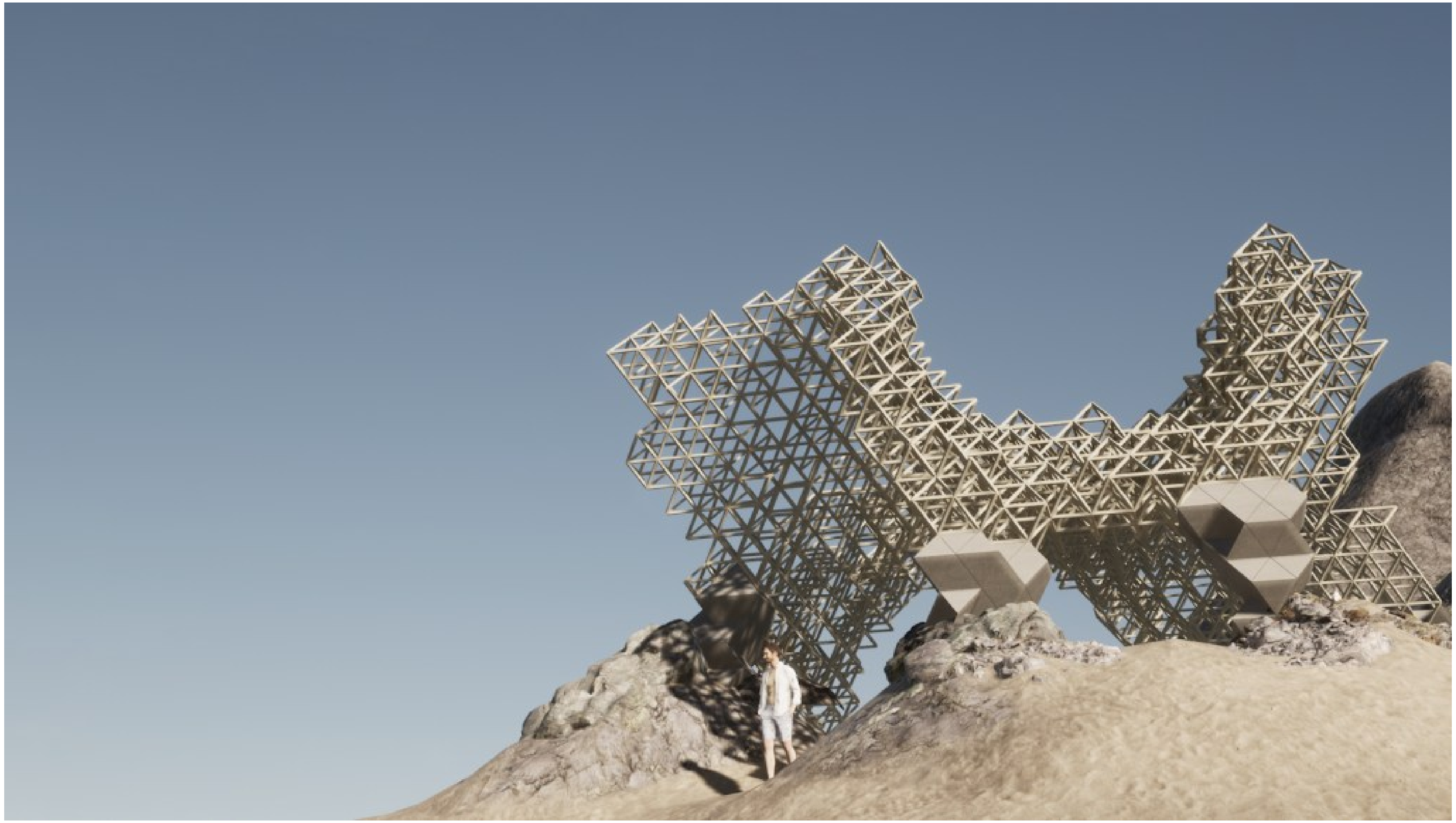
The current transition from Computer Aided Design (CAD) to Computational Design in architecture represents **a profound shift in design thinking and methods**. Representation is being replaced by simulation, and the crafting of objects is moving towards the generation of integrated systems through designer-authored computational processes. While there is a particular history of such an approach in architecture, its relative newness requires the continued progression of novel modes of design thinking for the architect of the 21st century. This AD Reader establishes a foundation for such thinking. It includes multifaceted reflections and speculations on the profound influence of computational paradigms on architecture. It presents relevant principles from the domains of mathematics and computer science, developmental and evolutionary biology, system science and philosophy, establishing a discourse for computational design thinking in architecture. Rather than a merely technical approach, the book will discuss essential intellectual concepts that are fundamental not only for a discourse on computational design but also for its practice.





MODULAR WOOD PAVILLION
Iaac

The system development process started with inspiration from the natural world. **Slime mold – a single cellular organism renowned for its ability to find the most optimal route to find the source of food was an initial driver of the design**. During the development of the project initial ideas shifted towards a wooden, modular system which could be assembled and disassembled with ease. Timber planks of the same size would allow anyone to use and build the system



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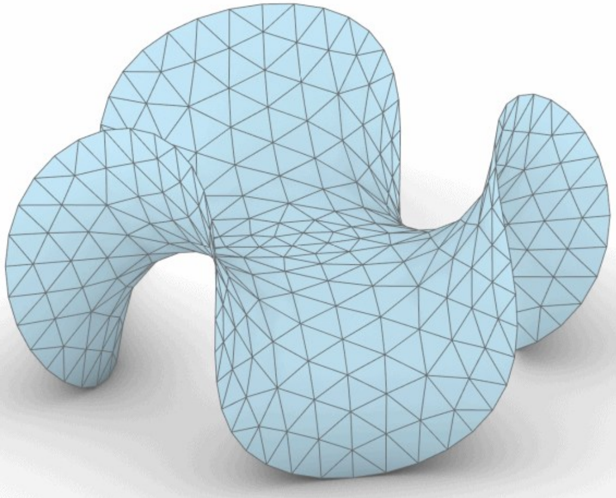

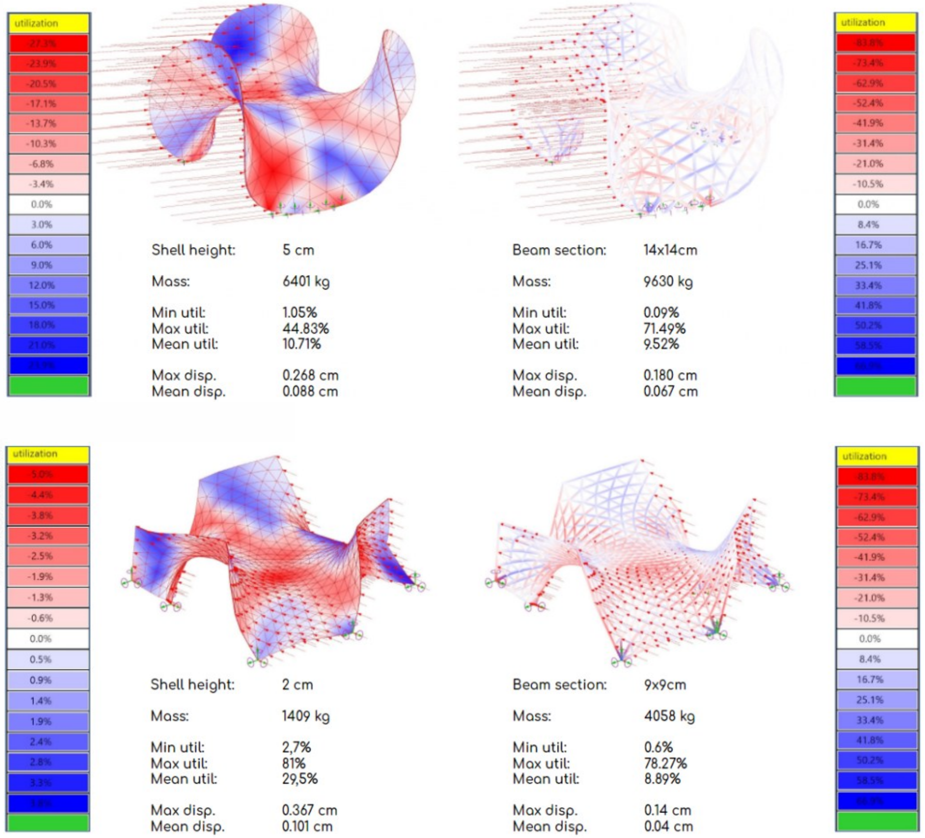

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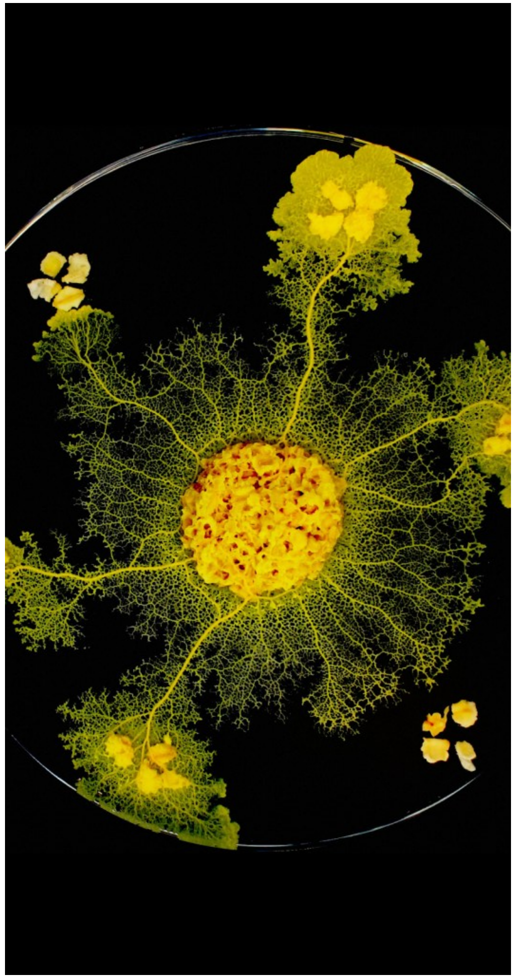

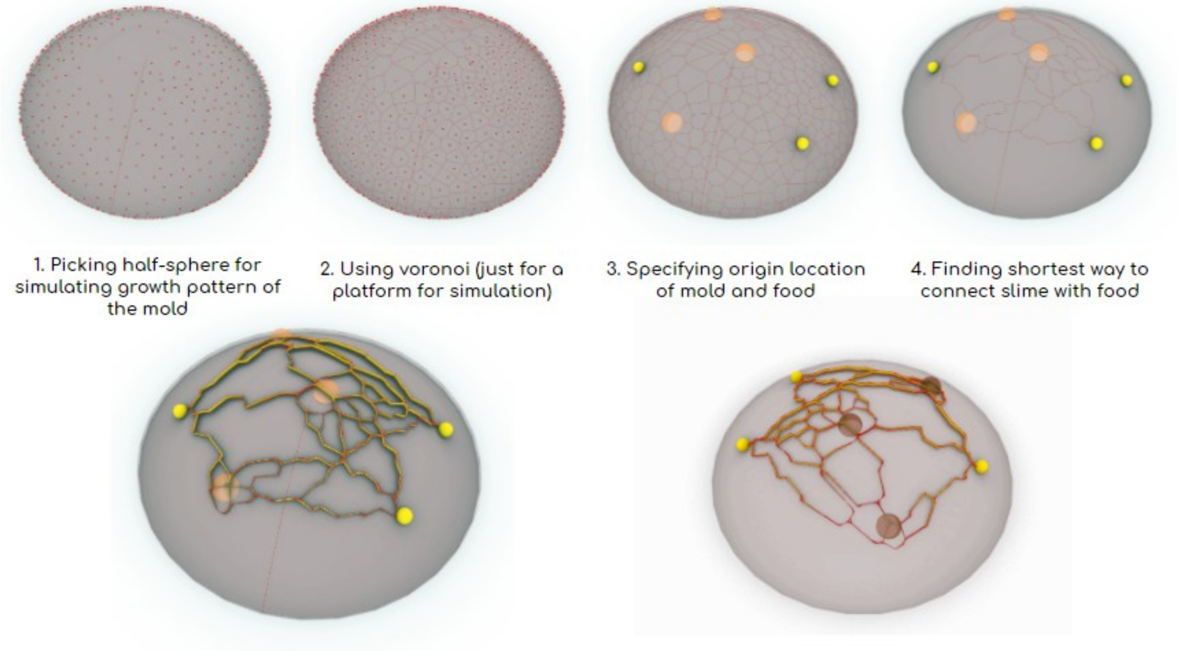

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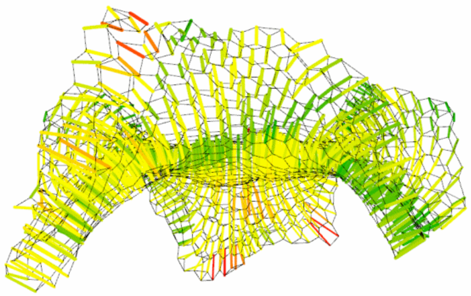

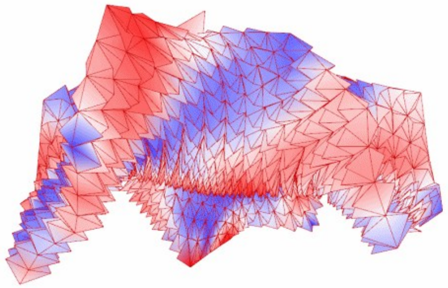

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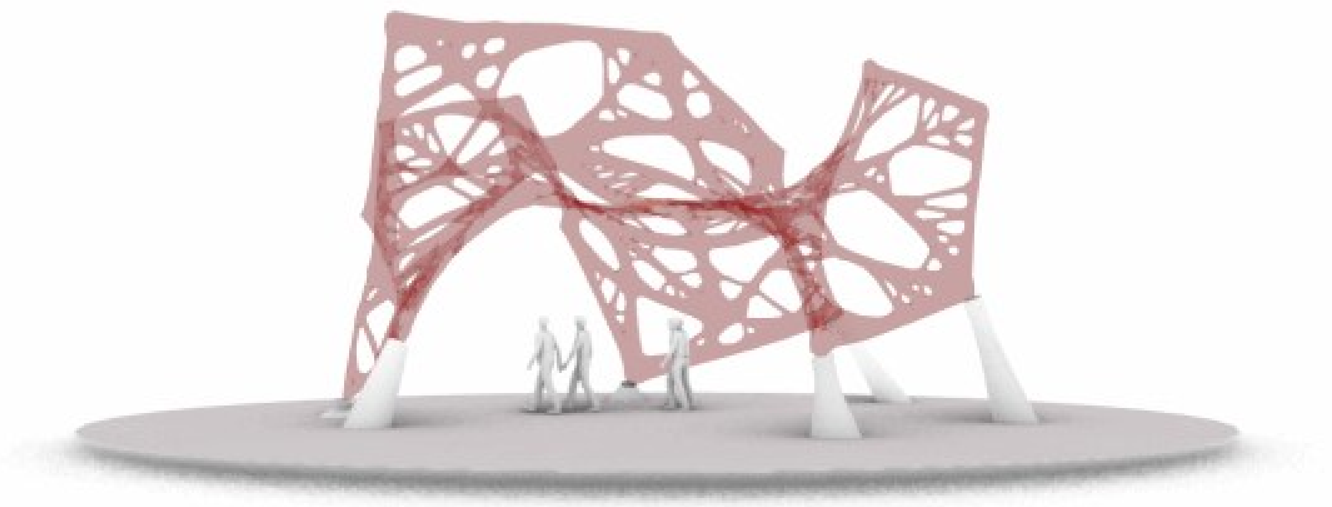

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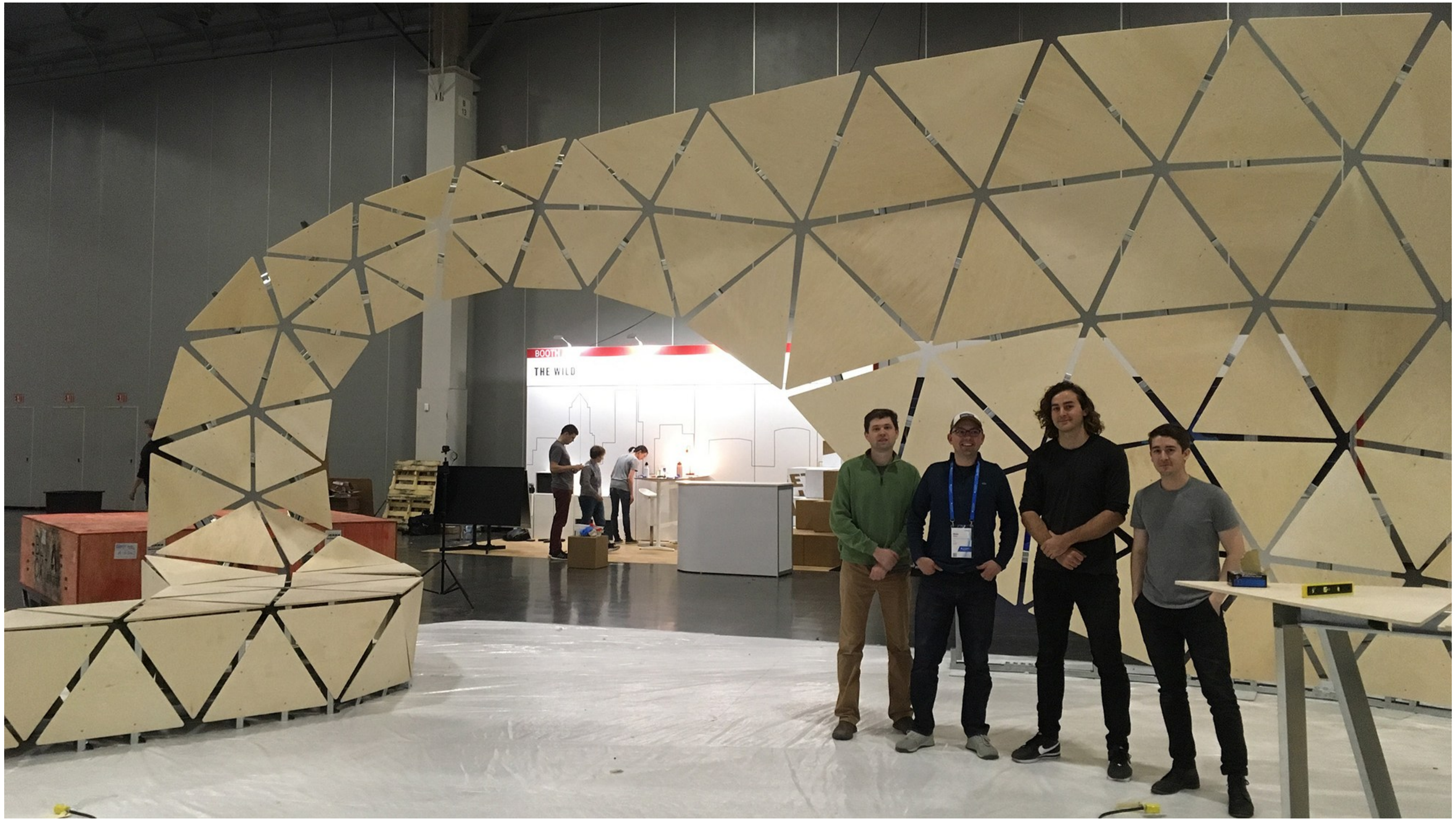
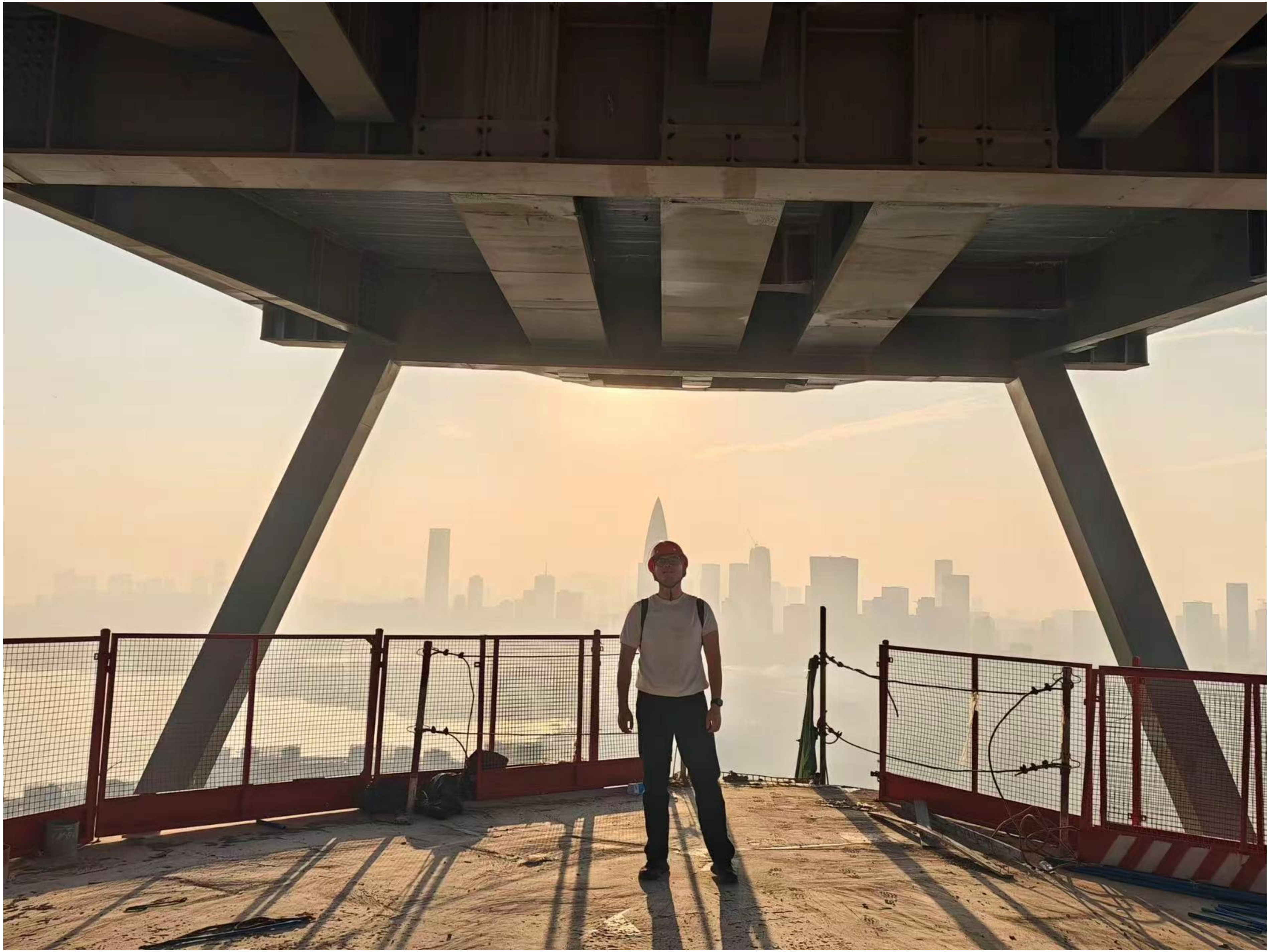
Dynamo Pavilion
Autodesk's AEC Generative
Design Team

Designed by Autodesk and pre-fabricated by BLOX, the Dynamo Ribbon was a research project that allowed the team to develop new workflows that integrate design, analysis, fabrication, and construction. The team was challenged to go from concept to completion in under three months, with the additional constraint of only two days on site in Las Vegas to build the structure.

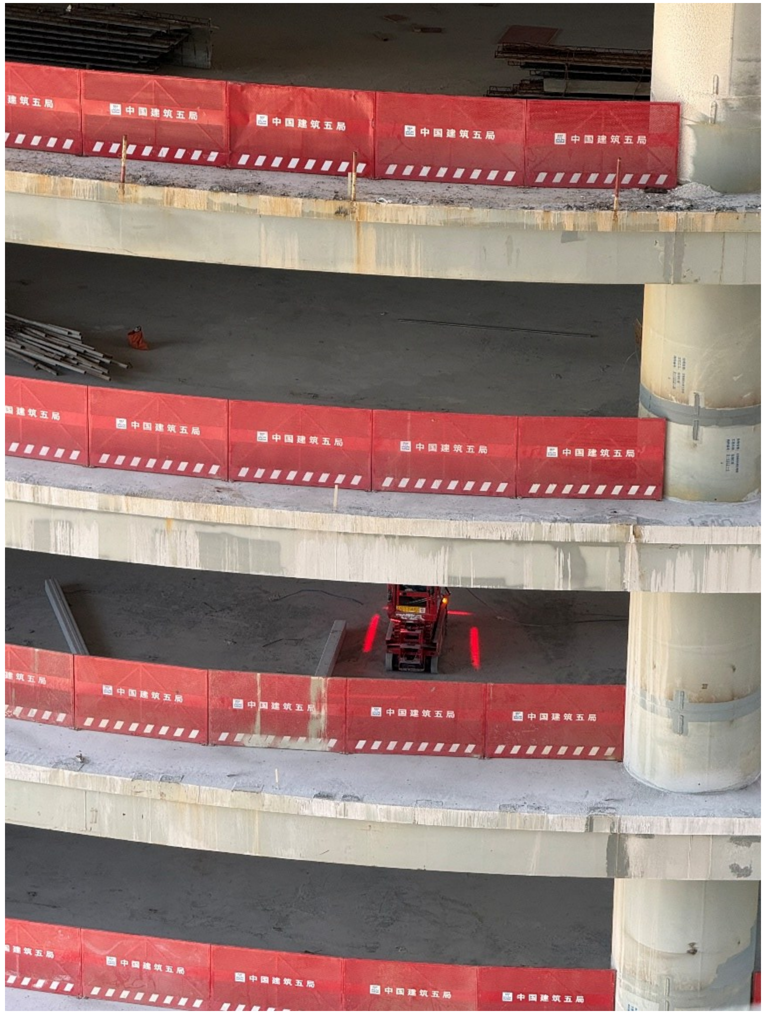





OPPO 国际总部大厦
OPPO International Headquarters
MOCAUP
当代艺术与
城市规划馆


中国建筑五局
深投控
SZBA-UCD

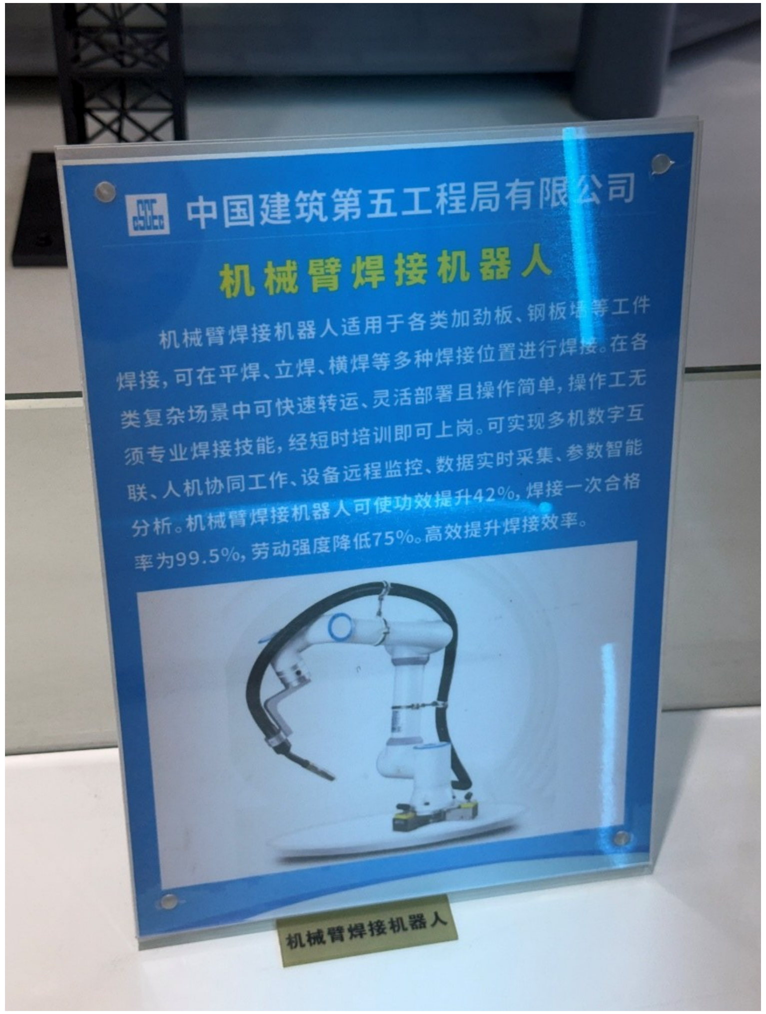

中国建筑第五工程局有限公司
智能钢筋绑扎机器人
智能钢筋绑扎机器人旨在替代传统人工完成平面钢筋的绑扎工作。通过自动化操作，显著提高施工效率和绑扎质量，同时降低了人力成本和安全风险。其模块化设计和灵活性使其能够适应不同的施工场景。该设备采用了独特的移动结构设计，包括凹形轮和长圆轮的组合，能够胜任0-40cm钢筋间距的作业需求，同时搭配起落式滑轨平移系统，确保作业精准性。机器人还集成了多传感器感知系统，可对作业环境进行全面感知，并通过智能控制终端解析数据、优化操作。此外，搭载的UI交互界面支持多种控制方式，为用户提供了便捷的操作体验。这款机器人不仅降低了工人的劳动强度，还提升了施工现场的安全性，是推动建筑行业技术升级和产业创新的重要助力。
钢筋绑扎机器人


中国建筑五局


中国建筑第五工程局有限公司
四盘地面抹光机器人
四盘地面抹光机器人采用非轮式底盘技术和智能运动算法，实现了无人自主运动和高精度施工。其设计通过先进的电池驱控平台，实现了施工过程的零碳排放。机器人结构小巧，机动灵活，操作便捷，同时具备出色的施工效果，抹光平整度偏差控制在5毫米以内，施工宽度可达1.4米，效率高达300-500平方米/小时，可显著节省人工成本60%以上。其刀盘直径为770毫米，专为混凝土终凝前的地面收光施工设计，广泛应用于停车场地坪、厂房地面、商用楼面及顶面等大面积施工场景。通过高效率和高精度的施工表现，这款机器人为现代建筑施工提供了智能化解决方案。
混凝土抹光机器人


中国建筑第五工程局有限公司
四轮激光地面整平机器人
四轮激光地面整平机器人采用智能激光找平算法和线控底盘技术，实现了无人自主运动与高精度施工。其设计结合了先进的电池驱控平台，确保施工过程零碳排放，同时具备小巧灵活的机身，操作简单，施工效果显著，地面平整度精确，密实均匀。该机器人可在混凝土浇筑后进行地面找平施工，施工效率高达400-600平方米/小时，激光探测精度可缩小至2 mm，测量高差控制在5 mm以内，可替代人工2至5人，显著节省劳务成本60%以上。设备适用于停车场地坪、厂房地面、商用楼面及顶面等大面积施工场景，凭借高效高精的表现，为建筑施工提供了智能化的解决方案，仅需完成8-10万平方米施工面积即可回收设备成本。
地面整平机器人


中国建筑第五工程局有限公司
智能移动巡检机器人
智能移动巡检机器人是一种专为云端工厂设计的高效巡检设备，集成了云轨系统、摄像头、便携充电站和AI边缘计算硬件。其主要应用于云端工厂的智能移动监控、安全管理和质量巡检，适应多种工业环境。机器人配备独立的云轨系统，悬挂在工厂挂架层内，可在N+1层操作空间中执行巡检任务。设备能够实时观察混凝土浇筑过程、模板硬化后的钢筋绑扎过程，以及施工现场的技术提升进展。通过结合视频画面和AI图像识别技术，它可以对穿戴反光衣、安全帽等安全行为进行自动监测，并识别人员跌倒等异常行为。此外，机器人支持移动监控、质量巡检以及远程视频管理，为工业环境中的高效管理和安全保障提供了智能化解决方案。
巡检机器人


中国建筑第五工程局有限公司
机械臂焊接机器人
机械臂焊接机器人适用于各类加劲板、钢板墙等工件焊接，可在平焊、立焊、横焊等多种焊接位置进行焊接。在各类复杂场景中可快速转运、灵活部署且操作简单，操作工无须专业焊接技能，经短时培训即可上岗。可实现多机数字互联、人机协同工作、设备远程监控、数据实时采集、参数智能分析。机械臂焊接机器人可使功效提升42%，焊接一次合格率为99.5%，劳动强度降低75%。高效提升焊接效率。
机械臂焊接机器人


中国建筑五局
中国建筑五局
DFMA

AIM: The future of lighting in social/outdoor spaces, residential, and working environment in ten-years framework

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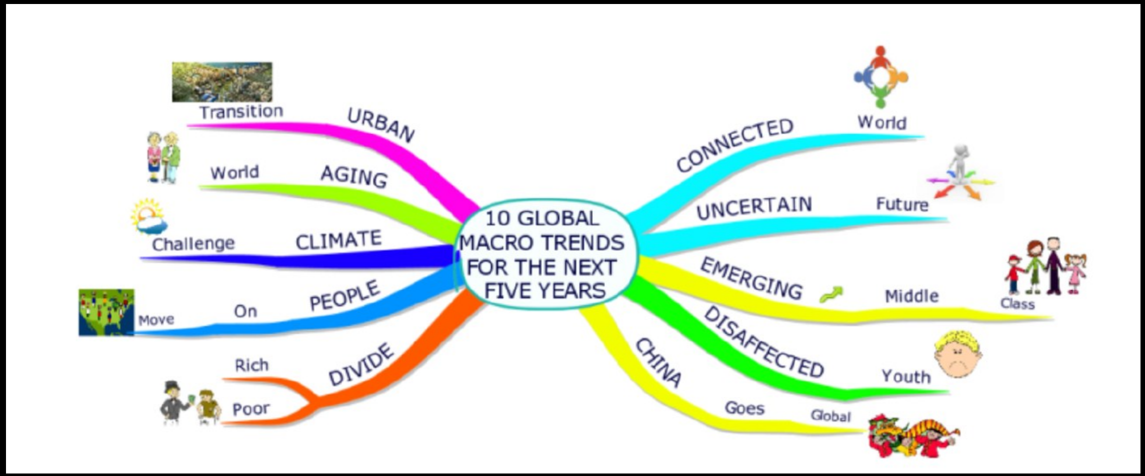
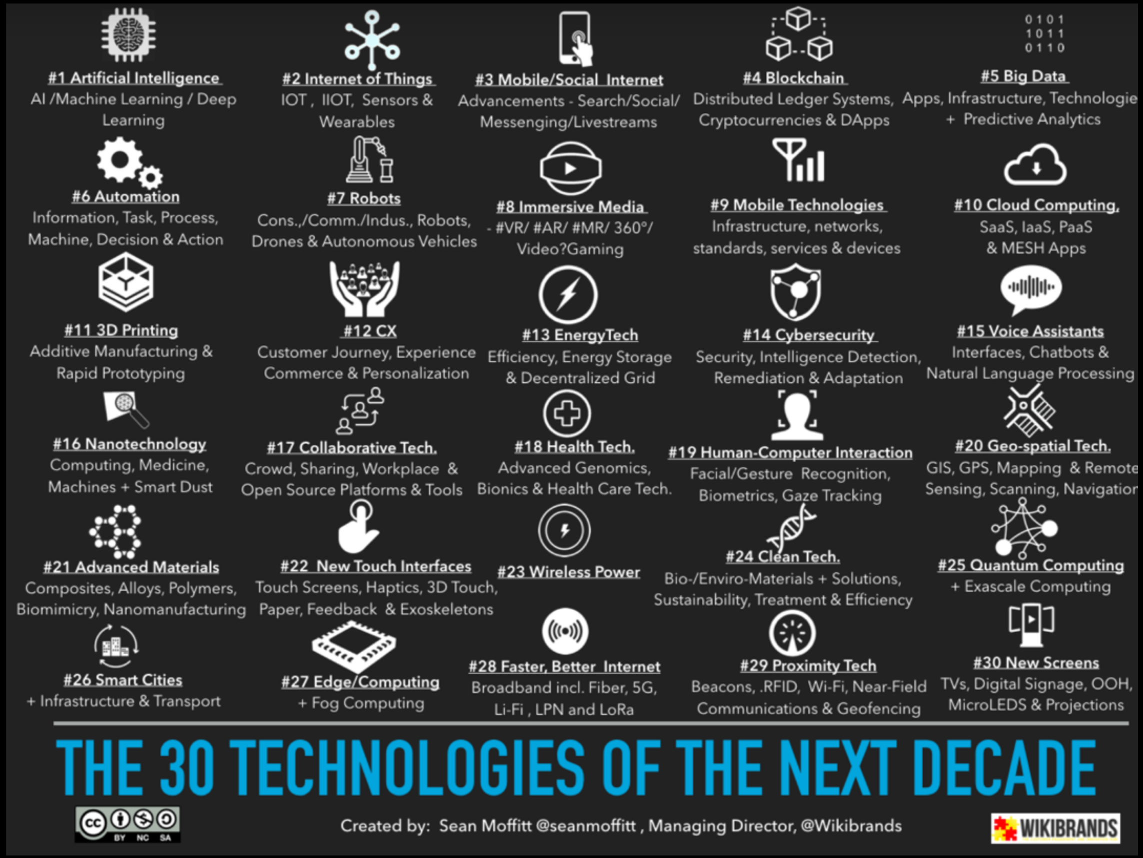
西交利物浦大學
iGuzzini
iDi Italian Design Icons
EASTANT COMMUNICATION & EVENTS
PromeAI

Formulate a "area of interest" to starting your trend research. Example : lifestyle activities



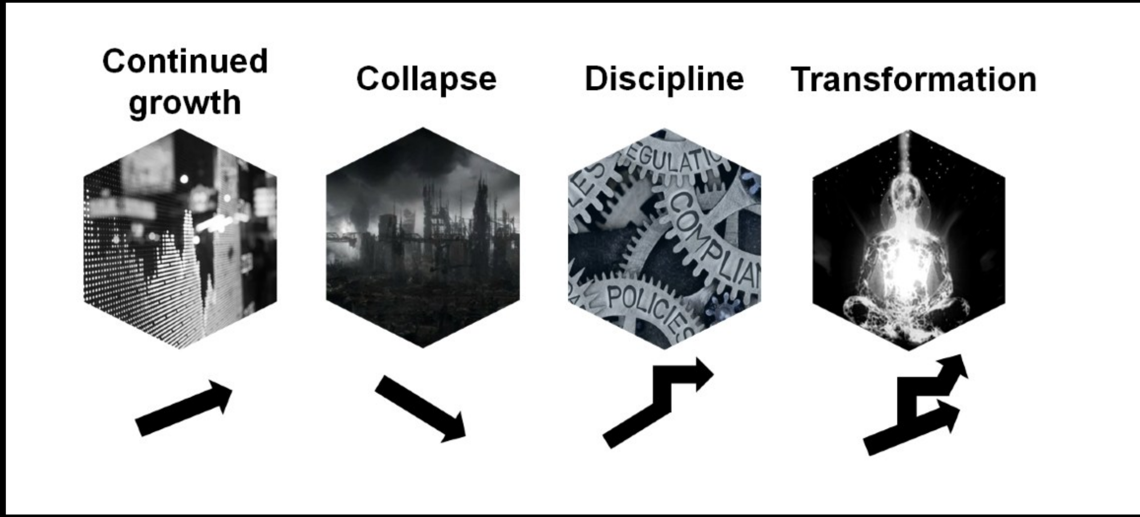
Run a research based on possible concrete trends and possible directions of the near future.



The world of 2034 – Time machine journey
What will you see when you will open the door in the 2034?

ACTIVITY INSTRUCTION:

Each participant draws one idea on a A3 paper and writes a catchy title coming from the previous analysis + sum up sentence.
Revise all the generated ideas in a shared session with peers' feedback.

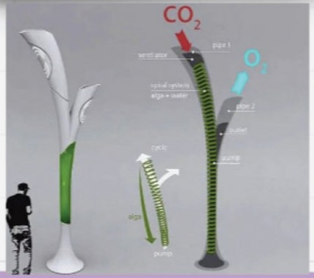


Background

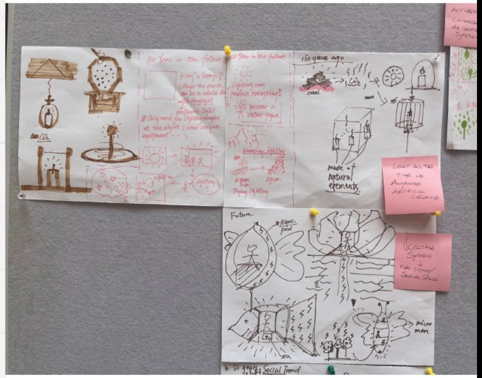
Continued growth:The world of the future is an extension and expansion of the present. Nature is becoming more and more important to us. Biophilic lighting is an innovative design philosophy that draws unceasing inspiration from the natural world to conceive lighting solutions that replicate natural light patterns, seamlessly integrate organic elements, and elevate overall wellbeing.

collapse:natural disasters,wars, plagues, famines, economic collapse, underpopulation or overpopulation

discipline:Man and nature coexist in harmony



transformation:The shift in biophilic design lighting combines the allure of nature with groundbreaking lighting solutions. It has the potential to revolutionize the way we perceive and experience spaces, as well as enhance their aesthetics and overall well-being and productivity.

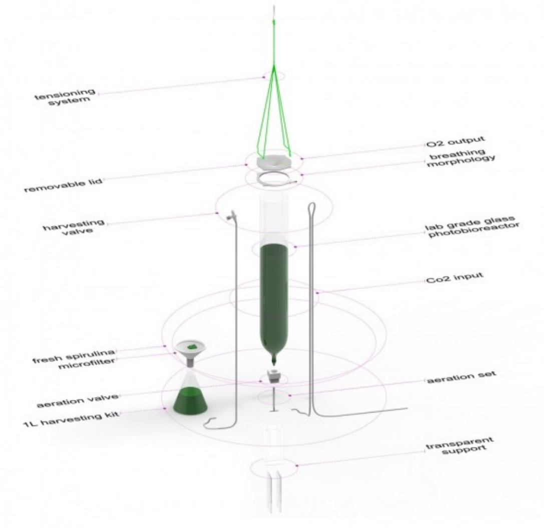


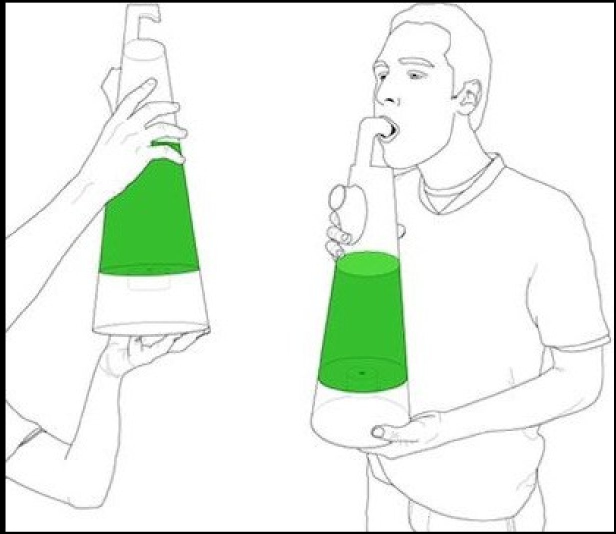
Imagine the future

The world of the future is an extension and expansion of the present. Nature is becoming more and more important to us.
Biophilic lighting is an innovative design philosophy that draws unceasing inspiration from the natural world to conceive lighting solutions that replicate natural light patterns, seamlessly integrate organic elements, and elevate overall wellbeing.

Research trend

French biochemist Pierre Calleja has spent several years working on a way to harness the microorganisms’ special abilities to help mitigate the global warming, threats to ecosystems and the need for renewables.
His solution comes in the shape of a cylindrical algae-powered lamp that requires no electricity and is thus completely self-sufficient, operating through a process wherein all the energy produced during photosynthesis is collected and stored in a battery that helps to power the light during the evenings.





https://www.smithsonianmag.com/innovation/can-an-algae-powered-lamp-quenchour-thirst-for-energy-3509307/

Digital Design in XJTLU

Design outcome

Digital Design in XJTLU

Design outcome





Digital Design in XJTLU

Design outcome

Digital Fabrication in XJTLU

ARC301_Architectural Technology
BEng Architecture Level 3
AY2526

AIM: Building a pavilion that combines digital design and fabrication within 10 weeks.

Leyuan Jiang (Module Coordinator): PVC Force-Responsive

Iasef Md Rian, PhD: 3D printing concrete

Yang Song, PhD: VR supported assembling

Zhelun Zhu, PhD: interlocking blocks using hotwires cut EPS panels

Digital Fabrication in XJTLU

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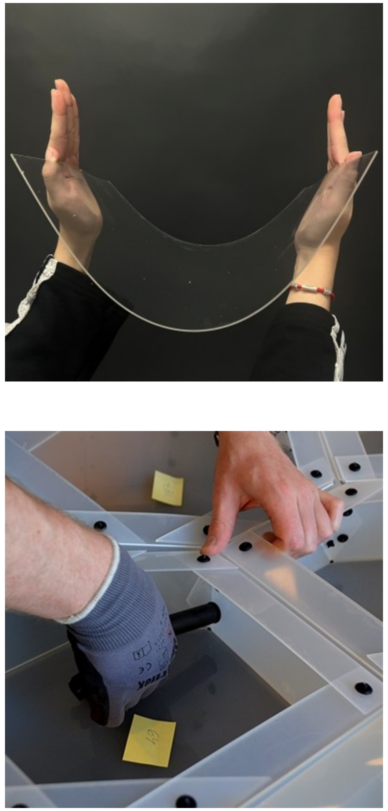
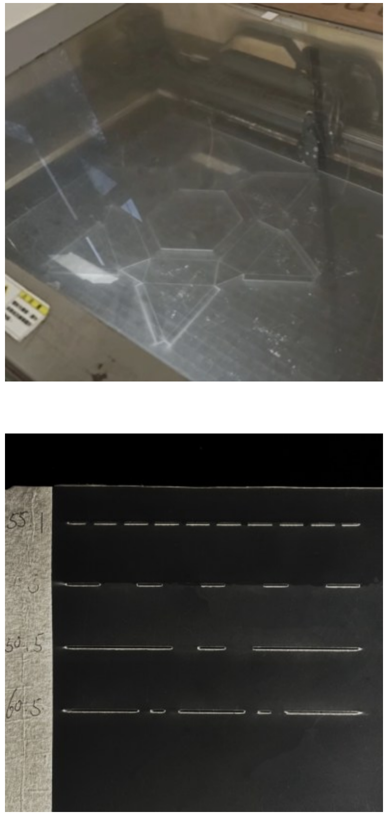
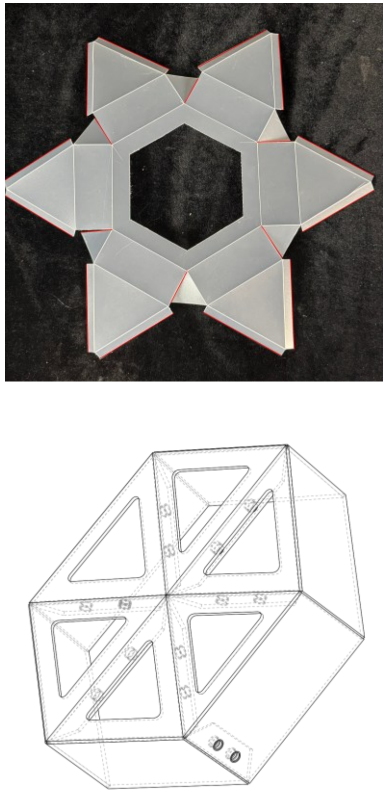


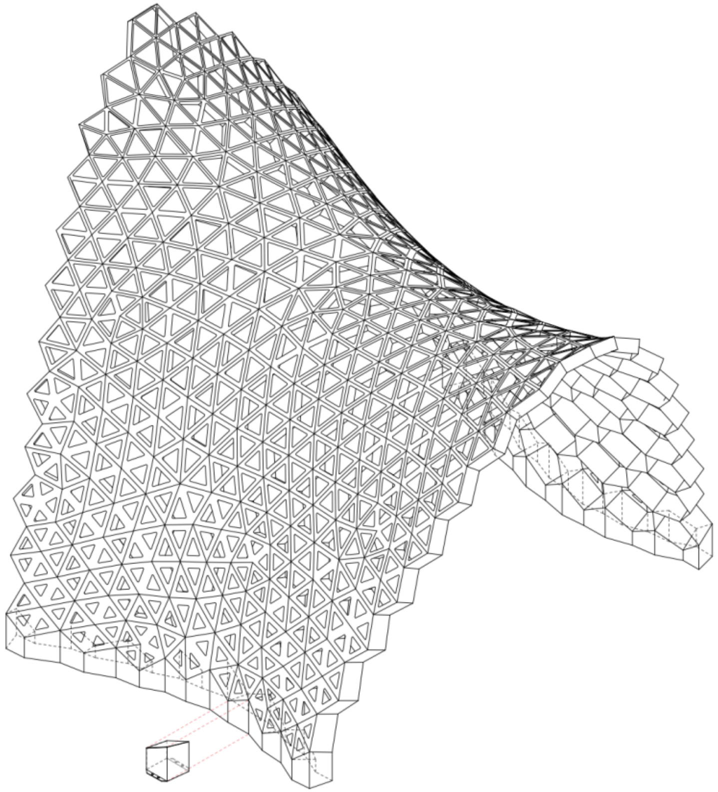
Construction strategy



Digital Fabrication process



Panel Development



Leyuan Jiang (Module Coordinator): PVC Force-Responsive

Digital Fabrication in XJTLU

Zhelun Zhu, PhD: interlocking blocks using hotwires cut EPS panels

ARC301_Architectural Technology
BEng Architecture Level 3
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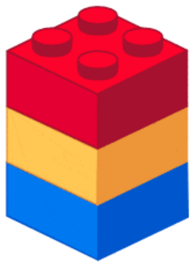
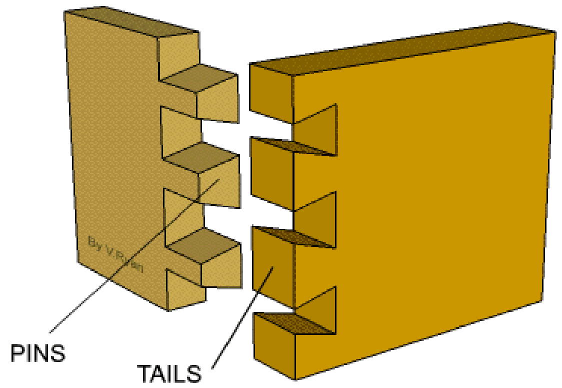
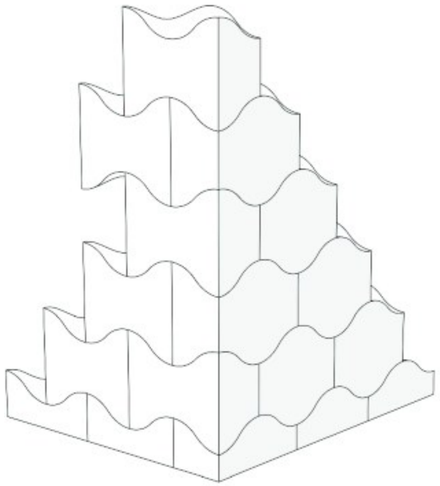
Interlocking bricks have three types of locking (jointing) methods:

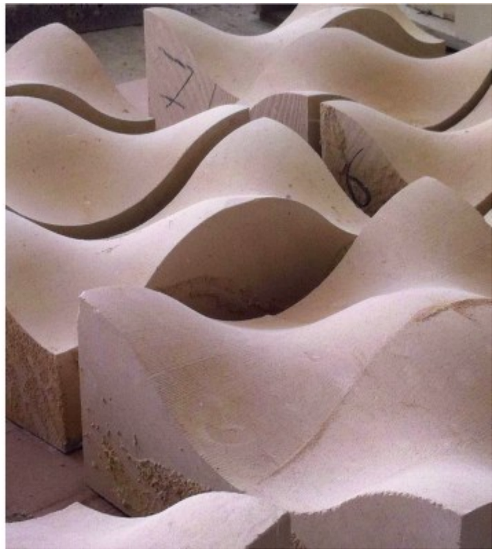
- Tongue and Groove (T&G),
- Protrusions and Depressions (P&D),
- Topological non-planar locking (osteomorphic brick)

The interlocking system restrict brick movements both perpendicular to the wall surface and along the wall









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Zhelun Zhu, PhD: interlocking blocks using hotwires cut EPS panels

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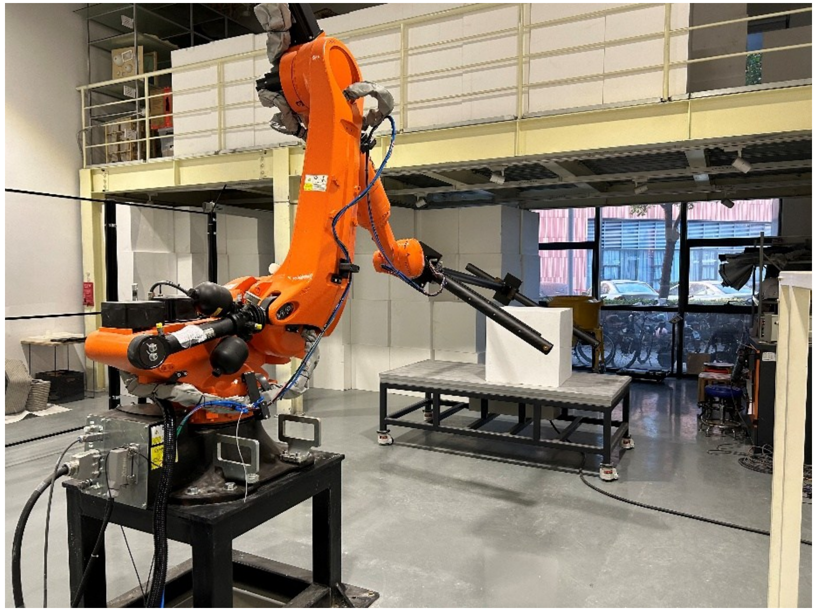

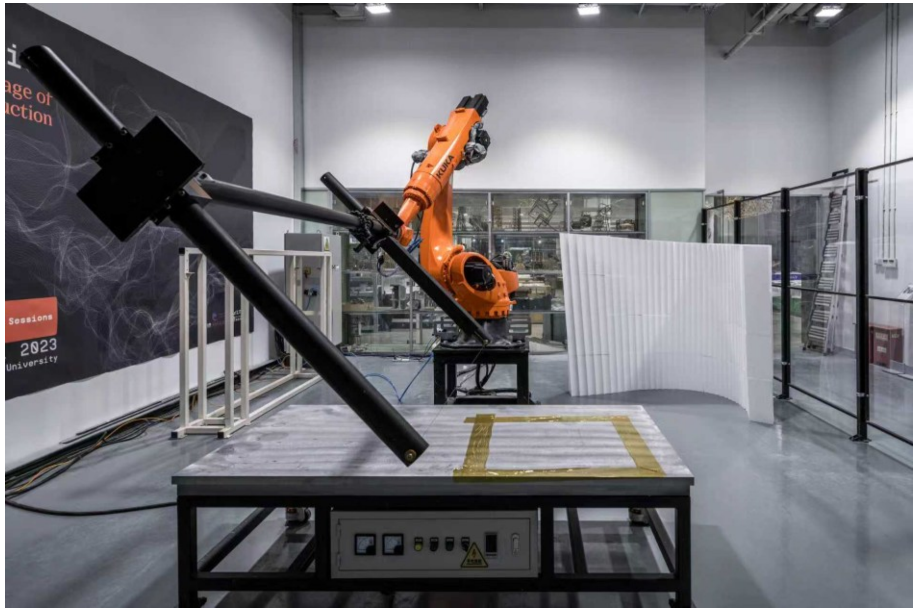

Equipment:
Six-axis robotic arm
Hot-wire equip size: 650 x 450 mm

Material:
EPS panel
Size_1000 x 600 x 600 mm
Density_ 20 kg/m³

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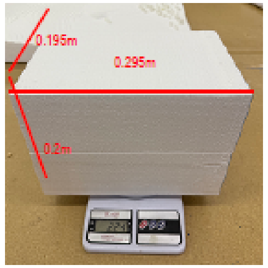
EPS is thermoplastic. After heating and foaming, each cubic decimeter has 3-6 million sealed bubbles, over 98% volume is air. This gives it many properties. EPS foam plastic deformation increases with loading time. It's rigid foam plastic. Under load, it shows viscoelasticity, a brittle-hard material trait. Its bending, compressive, and tensile strengths are proportional to apparent density.

密度 (kg/m³) (Density)	弹性模量 (Young's Modulus) (kN/cm²)	平面内剪切模量 (In-plane shear modulus) (kN/cm²)	横向剪切模量 (Transverse shear modulus) (kN/cm²)	比重 (Specific weight) (kN/m³)	泊松比 (μ) (Poisson's Ratio)
15	3~6	1.1~1.9	1.0~2.0	0.147	0.30~0.35
20	8~12	3.0~4.5	2.8~4.7	0.196	0.30~0.35
25	12~17	4.8~6.5	4.6~6.8	0.245	0.31~0.35
30	16~22	6.9~8.4	6.6~8.8	0.294	0.32~0.35
35	23~27	8.8~10.3	8.3~10.7	0.343	0.32~0.35
40	28~32	10.7~12.3	10.1~12.6	0.392	0.33~0.35

-Laboratory EPS Density Measurement

When studying the properties of EPS materials, since the obtained data are range values that vary with density, it is first necessary to measure the density of the EPS material in the laboratory to determine other physical parameters.



V = 0.295 m × 0.2 m × 0.195 m

ρ = M/V=0.224 kg / 0.011505 m³

Density: ρ ≈ 19.47 kg/m³

-EPS Physical Properties

Density:15 - 30 kg/m³
(Fablab Eps 19.47kg/m³)

Young's Modulus(KN/cm²): 0.00055 KN/cm²
(Young's modulus increases with density.)

Tensile Strength (KN/cm²):0.00055 KN/cm²

Poisson's Ratio: 0.1

In-plane shear modulus (KN/cm²): 0.00025 KN/cm²
(For isotropic materials, the in-plane and transverse shear moduli are the same.)

Transverse shear modulus (KN/cm²): 0.00025 KN/cm²
(Poisson's ratio ν ≈ 0.1, G = E / [2(1+ν)] ≈ E/2.2. Based on the aforementioned E = 5.5 MPa, G ≈ 2.5 MPa.)

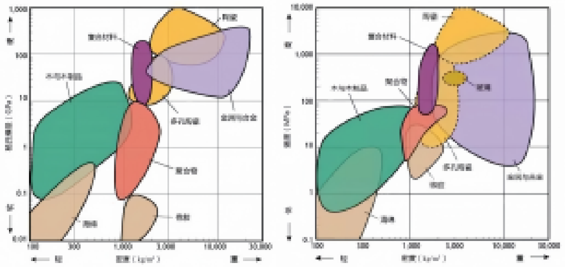
Specific weight (KN/m³): 0.1862 KN/m³
(Calculated from density. 19 kg/m³ × 9.80665 m/s² = 186.326 N/m³ ≈ 0.1862 KN/m³)

Coefficient of thermal expansion (1/℃): 0.00007 1/℃

Yield strength (KN/cm²):0.00006 KN/cm²

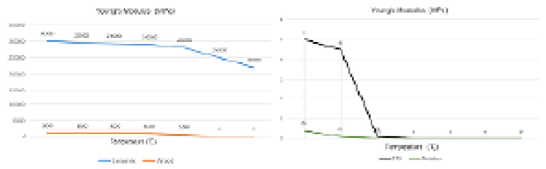
-Comparison of EPS Properties with Other Materials

This report focuses on the comparison of physical parameters that cause material deformation.

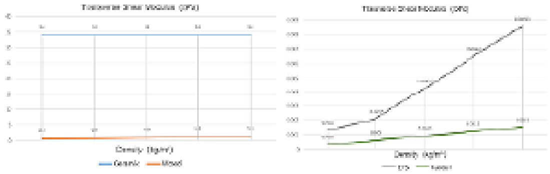


Select two materials with the same density but different Young's moduli, and two materials with different densities but the same strength. Compare these four materials.The other three materials compared with EPS are: rubber, wood and ceramics.

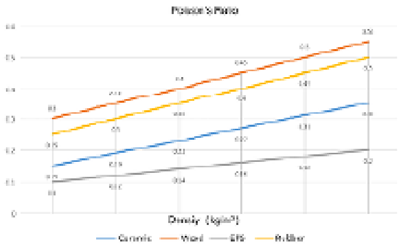
Young's Modulus(弹性模量)



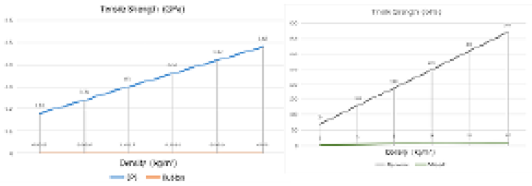
Transverse shear modulus（剪切模量）



Poisson's Ratio（泊松比）



Tensile Strength (拉伸模量)



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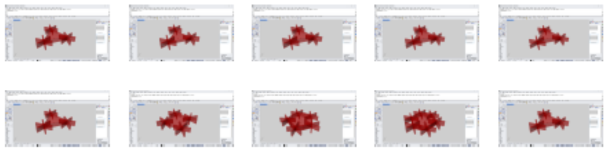
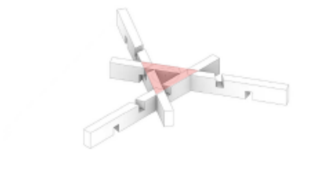
Brick Process

Regular brick transformation——cuboid

Irregular brick transformation——triangular

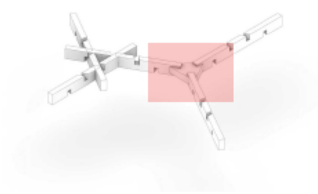


Grid pattern design



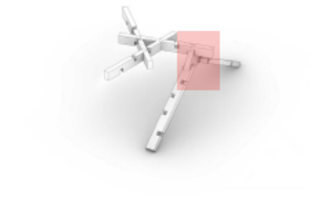
Step1
Angle 60°

Basic blocks are assembled into an equilateral triangle.



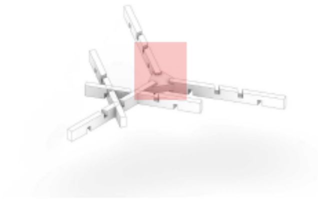
Type1
Direct embedding

Directly embed the triangular connector into
the base block.



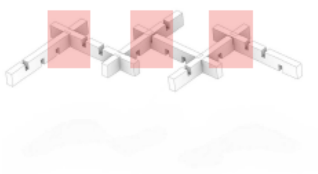
Type2
Angle 90°

Rotate the triangular connector 90 degrees.



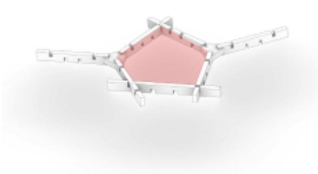
Type3
Dirction changed

Directly embed the triangular connector into
the base block degrees.



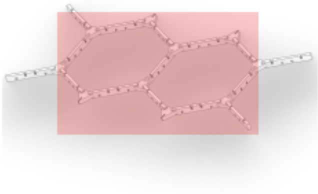
Step2
Angle 90°

The basic blocks are connected in a mutually perpendicular manner.



Type1
Angle 108°

The base blocks support each other in the form of a pentagon.



Type2
Basic Pentagon

Connect the two pentagons together.

Type3
Enhanced Pentagon

The center of the pentagon is further stabilized through triangles.

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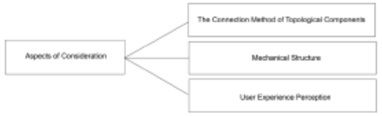
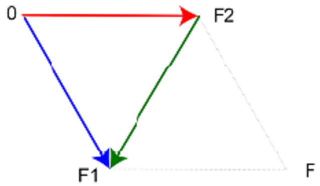
THE DESIGN LOGIC OF PAVILION FORM

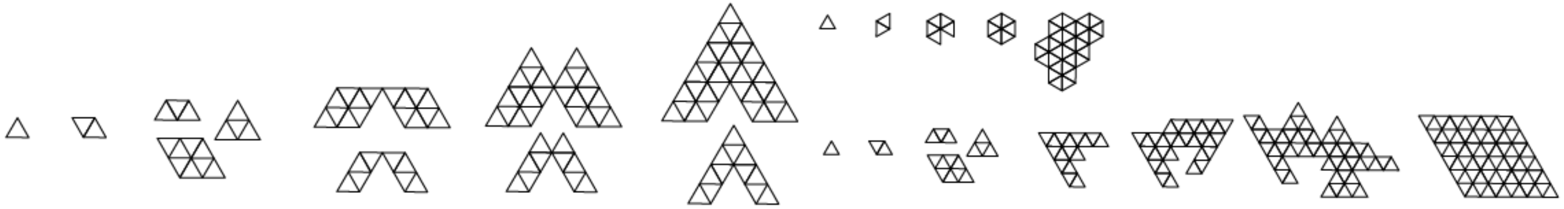
As the team responsible for designing the pavilion form, our primary considerations include the connection method of topological components, the mechanical structure, and the user experience perception, and we strive to achieve the balance and unity among them.



First, we established the parallelogram as the basic form. This simple theorem—the parallelogram law of forces—was one of the starting points for our creation.

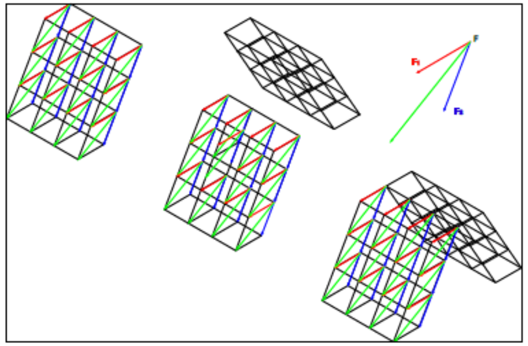


We carried out planar topology on the parallelogram and obtained various forms.

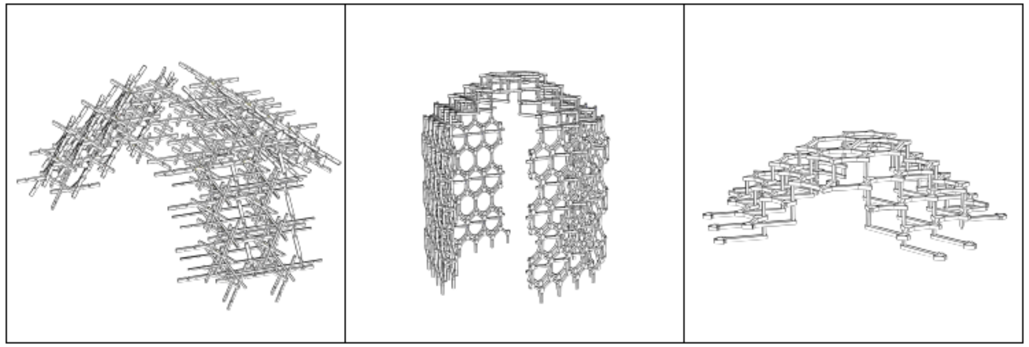


As the height, side lengths, and interior angles of the parallelogram change, this will affect the length, height, and width of the pavilion. The topological shapes derived will also change accordingly.

MECHANICAL CONSIDERATIONS



ATTEMPTS AT THE PAVILION CONFIGURATION



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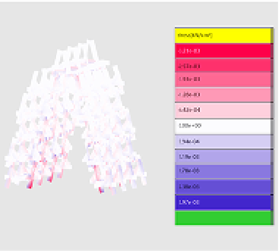
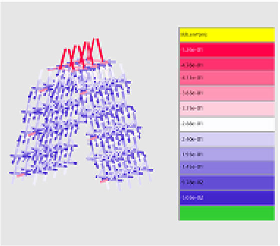
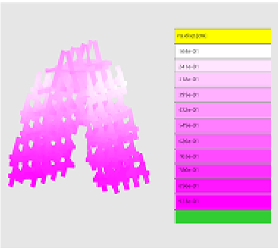
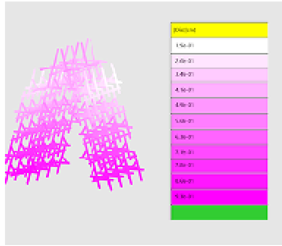
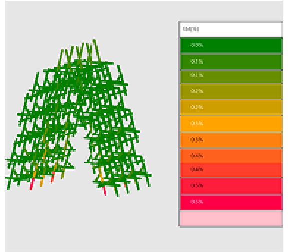
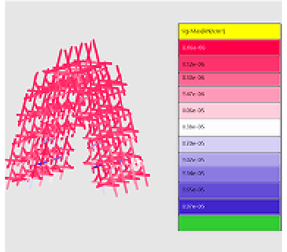
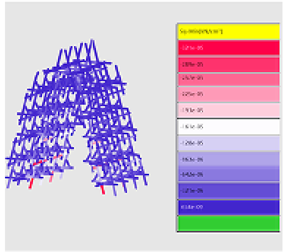
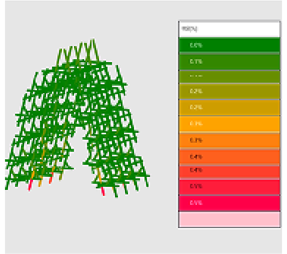
Karamba Analysis				
Name	Axial Stress	Buckling Length in Y Direction	Cross-Section Displacement	Mid-Axis Displacement
Formula	$\sigma = \frac{N}{A}$ σ: axial stress N: axial force A: cross-sectional area	$L_{cr,Y} = K_Y L$ $L_{cr,Y}$: buckling length in Y direction K_Y: effective length factor in Y direction L: actual member length	$\delta = \sqrt{u^2 + v^2 + w^2}$ δ: displacement magnitude (cm) u, v, w: displacements in X, Y, Z (cm)	$\delta_{mid} = \sqrt{u_{mid}^2 + v_{mid}^2 + w_{mid}^2}$ δ_{mid}: mid-axis displacement (cm) $u_{mid}, v_{mid}, w_{mid}$: mid-axis displacements (cm)

Karamba Analysis				
Name	Utilization in N Direction	SIG-MAX	SIG-MIN	Overall Displacement
Formula	$U\_N = \frac{6\sigma}{USL - LSL}$ U_N: Utilization-N (a dimensionless number). σ: (Sigma) The standard deviation of the process. USL: Upper Specification Limit. LSL: Lower Specification Limit.	$SIG\text{-}MAX = \min\left(\frac{\bar{X} - LSL}{\sigma}, \frac{USL - \bar{X}}{\sigma}\right)$ $SIG\text{-}MAX$: The capbility measure in term of sigma (higher is better) $\bar{X}$: (X-bar) The mean or average of the process. LSL: Lower Specification Limit. USL: Upper Specification Limit. σ: (Sigma) The standard deviation of the process.	$SIG\text{-}MIN = \max\left(\frac{\bar{X} - LSL}{\sigma}, \frac{USL - \bar{X}}{\sigma}\right)$ $SIG\text{-}MIN$: The capability measure in terms of sigma. $\bar{X}$: (X-bar) The mean or average of the process. LSL: Lower Specification Limit. USL: Upper Specification Limit. σ: (Sigma) The standard deviation of the process.	$\delta_{overall} = \sqrt{u_{tot}^2 + v_{tot}^2 + w_{tot}^2}$ $U_{overall}$: overall utilization Demand: combined applied effect Capacity: total allowable capacity

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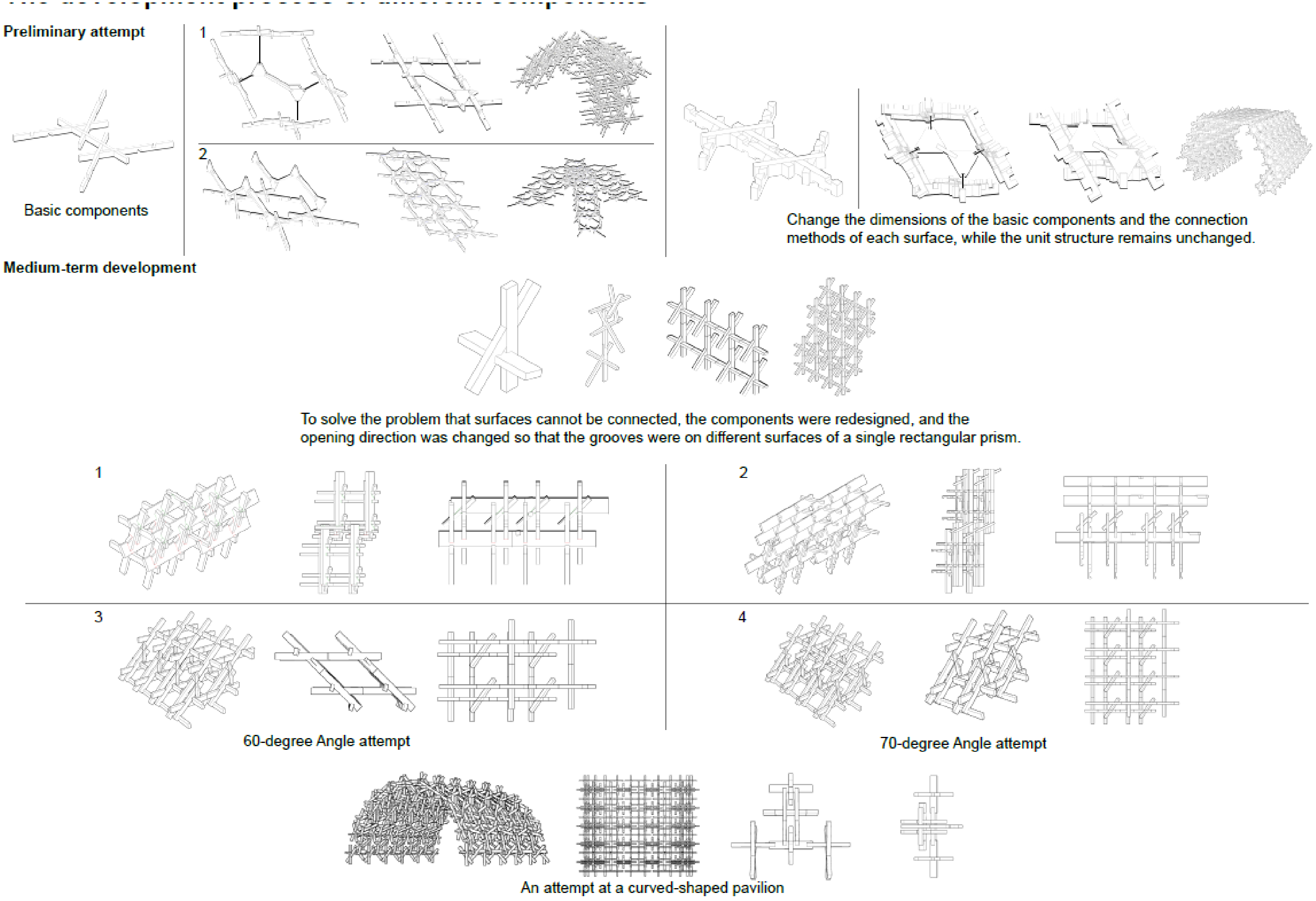
Zhelun Zhu, PhD: interlocking blocks using hotwires cut EPS panels



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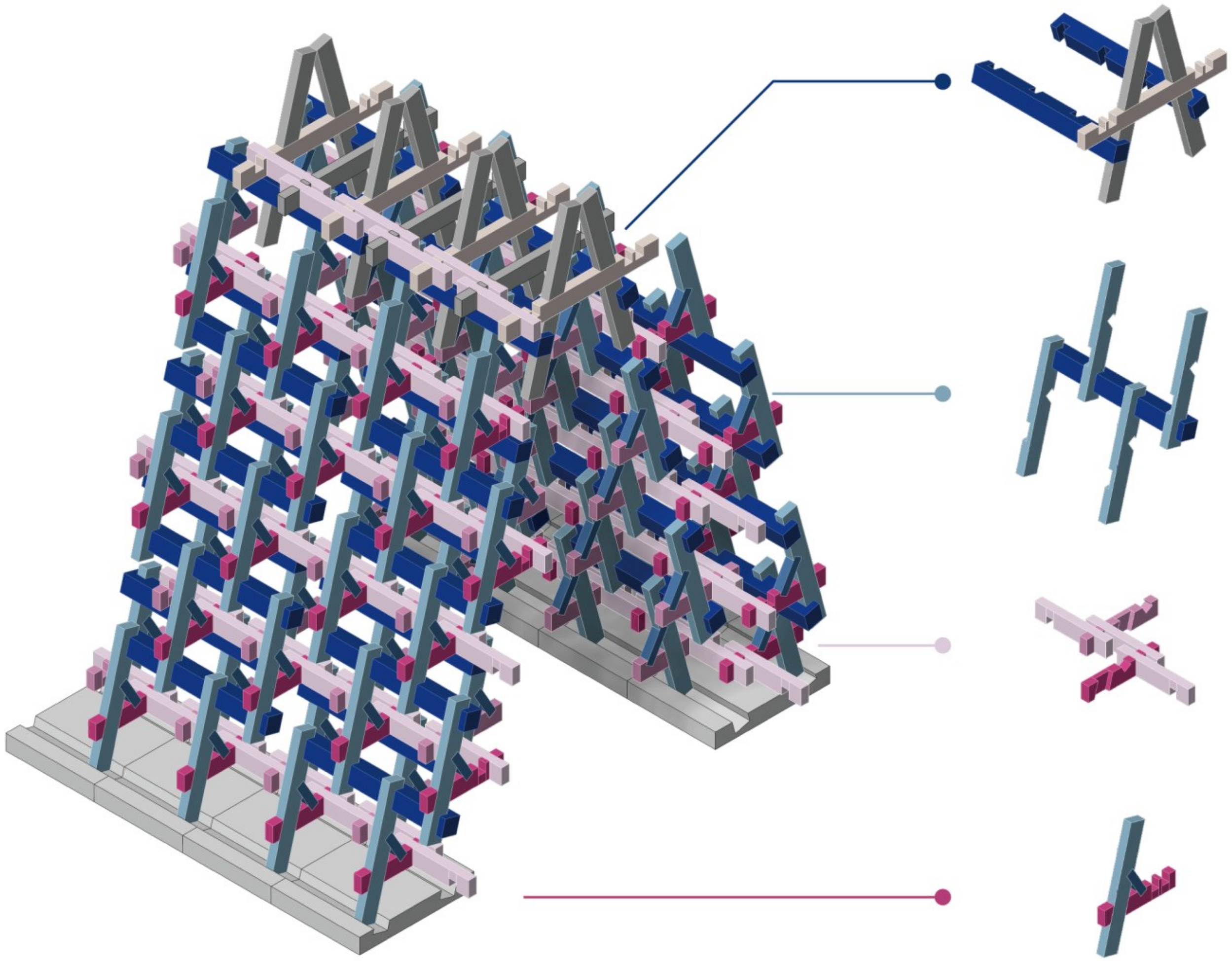
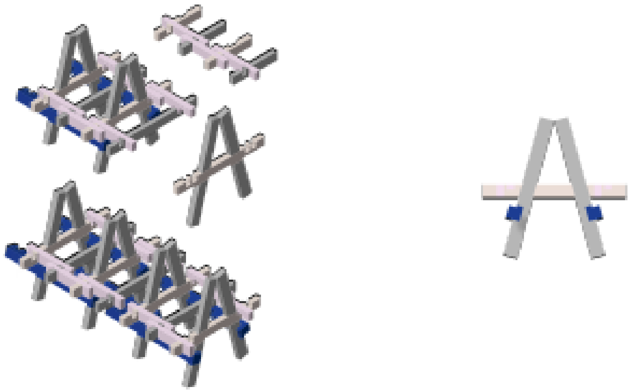
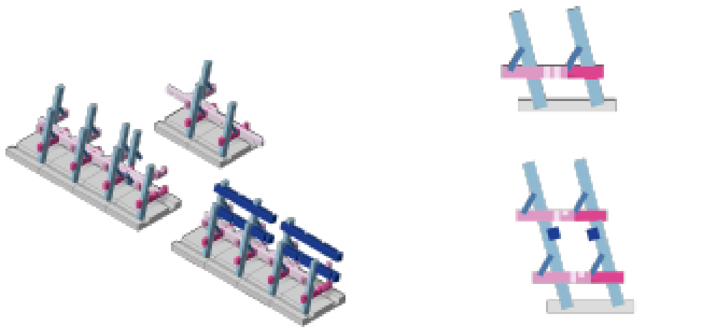
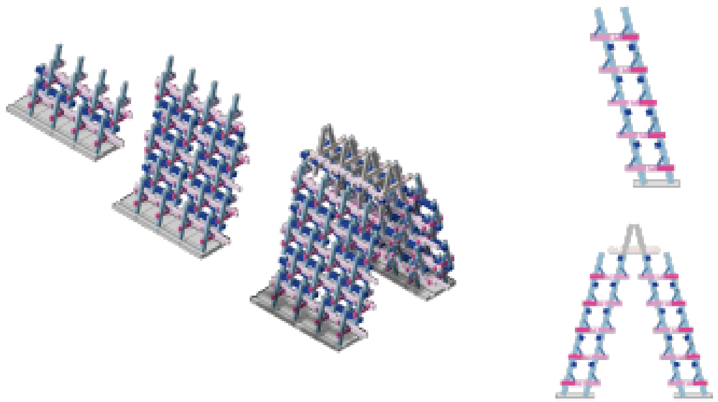




The top of the pavilion continues the lower part in a conical and cross extension



The bottom connection is repeated in a cross pattern, and the upward connection is maintained mainly by dark blue parts



The entire pavilion is divided into two parts, each of which is repeatedly ascended by the simplest triangular connection

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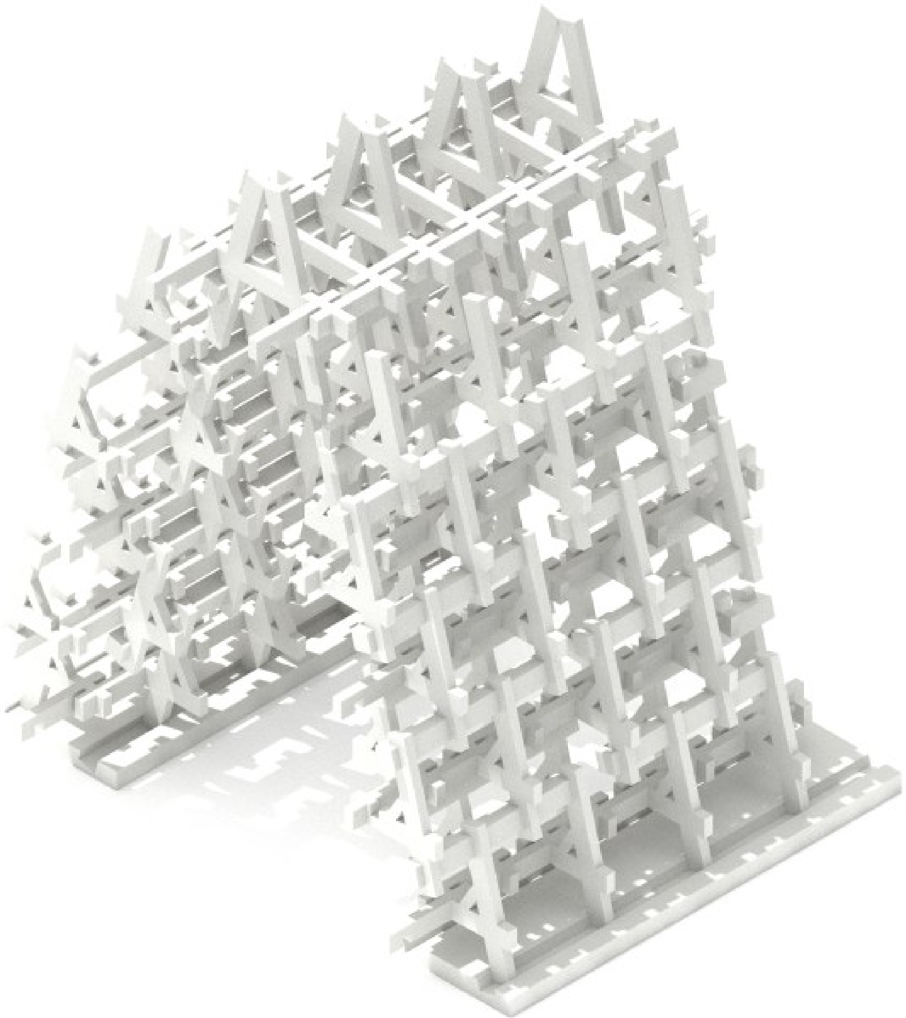

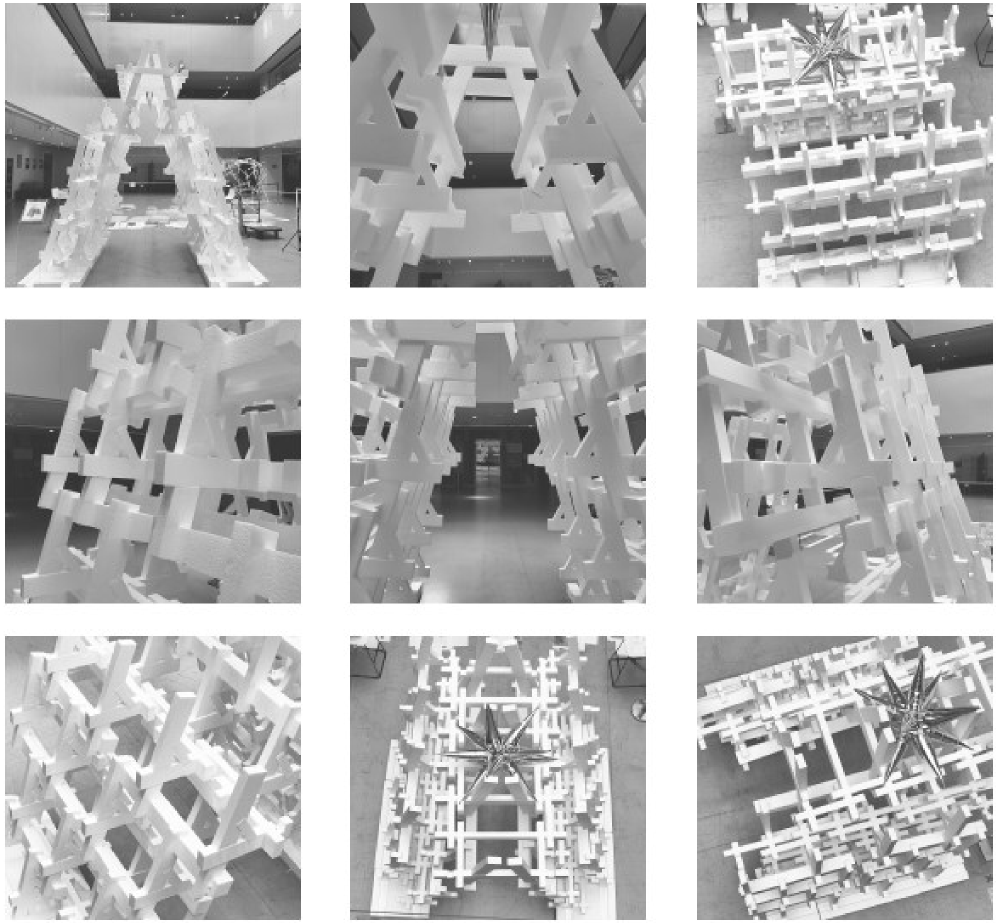

Because of the advantages of modular design, the structure of the pavilion is formed through continuous repetition from the smallest unit to the layer, so the total construction speed is about 6 hours in the end.

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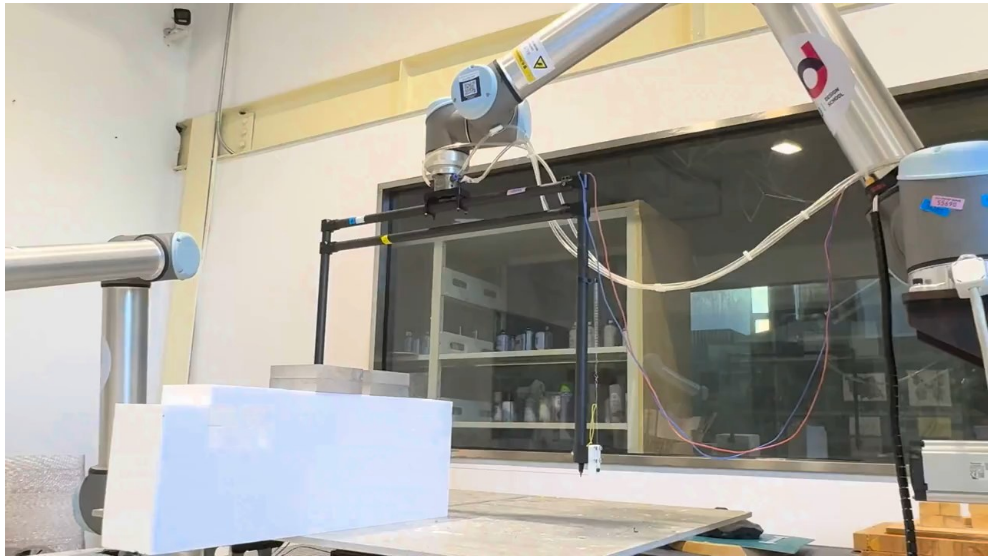

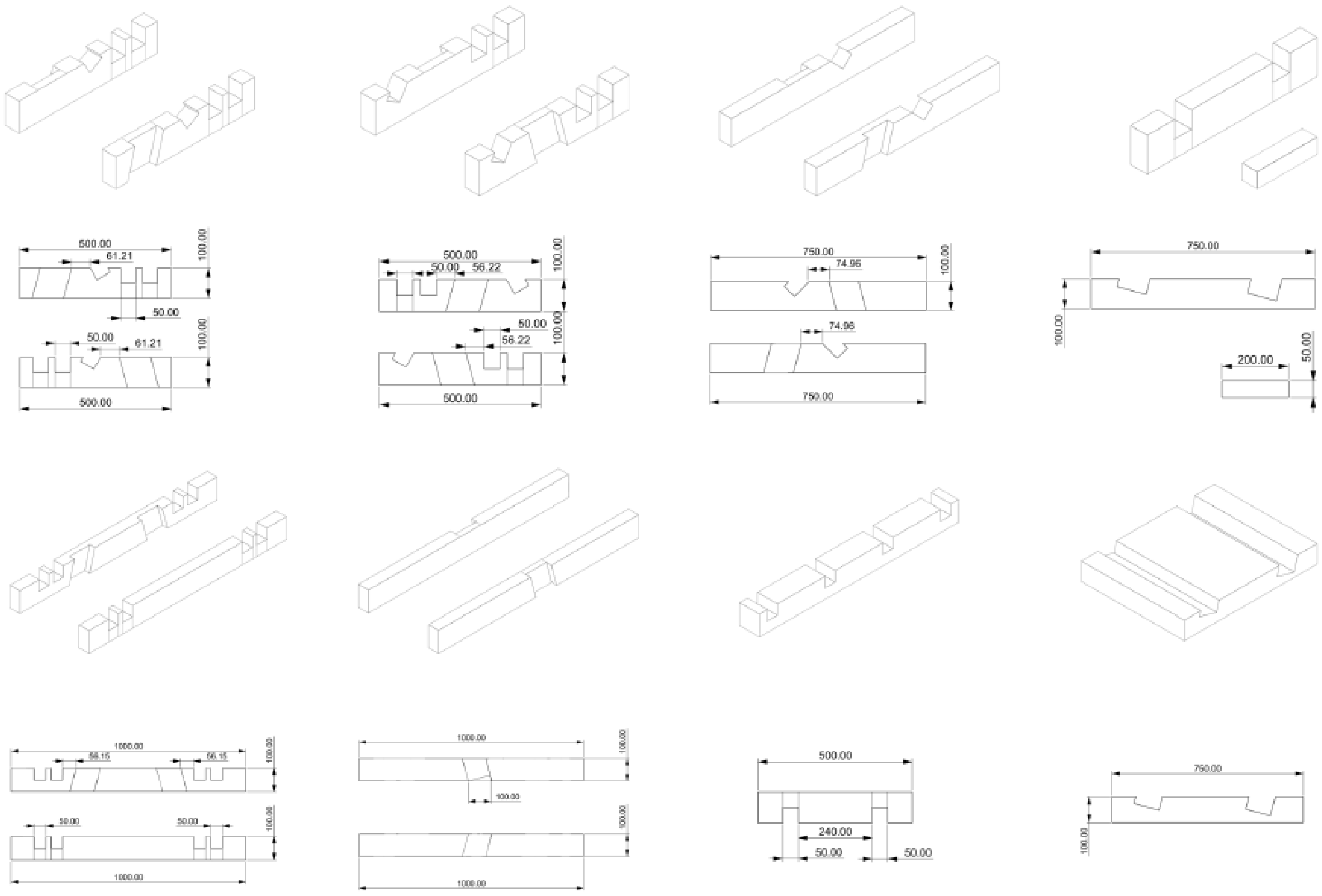

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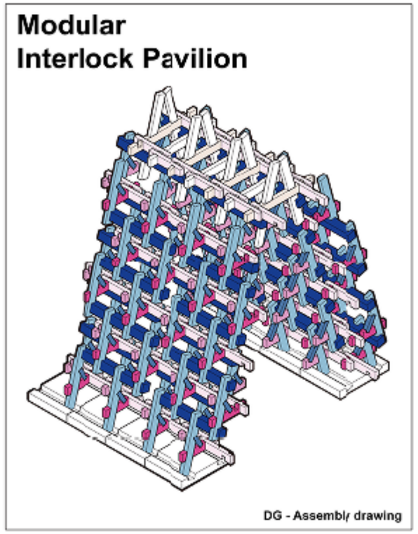

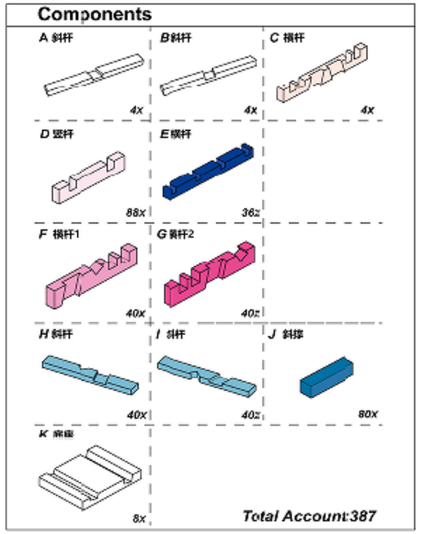

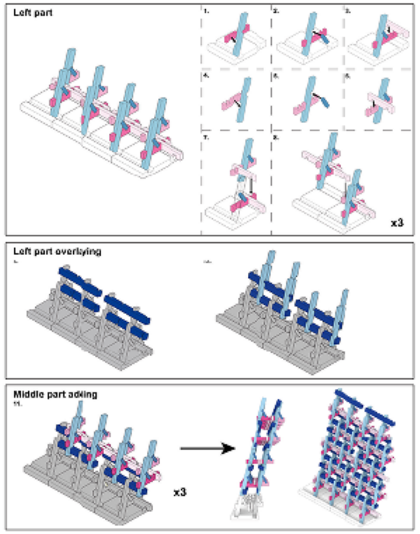

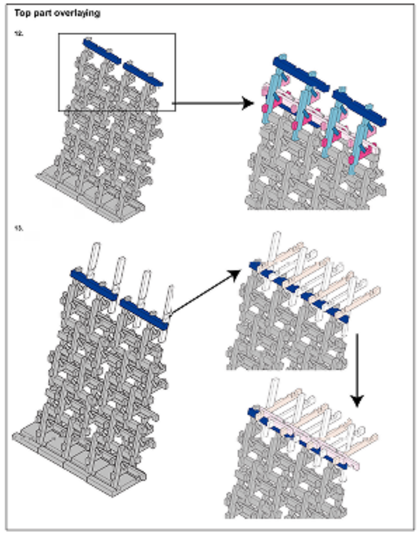

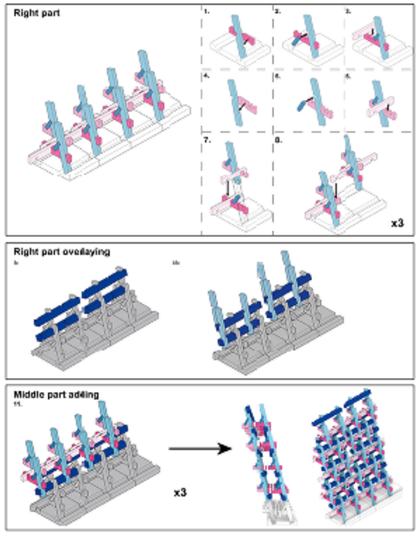

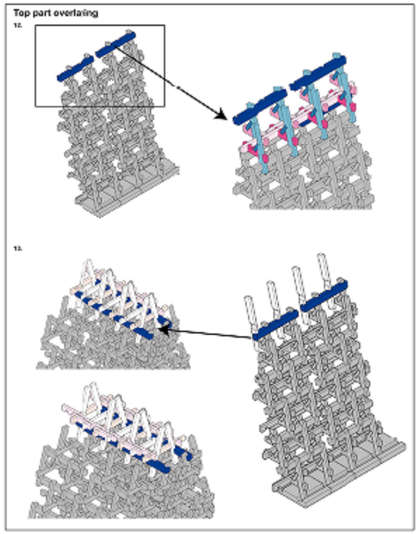

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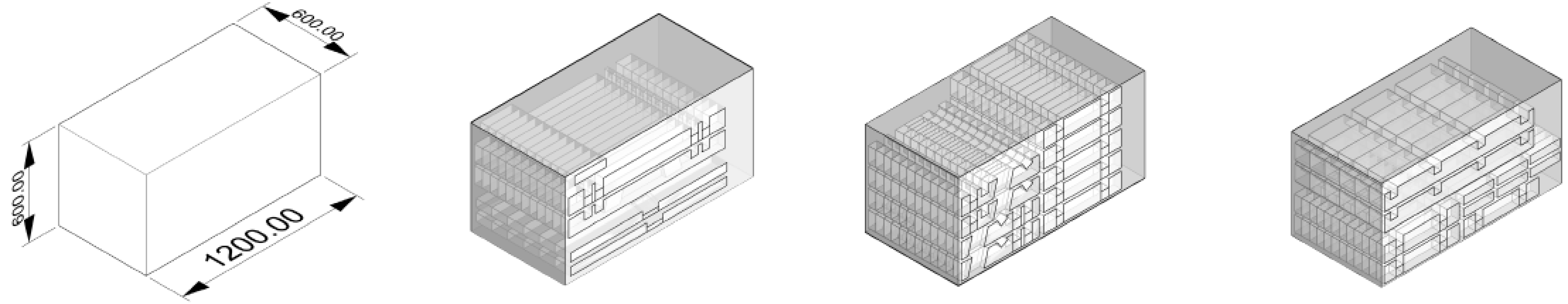
Initial Foam Size: 60*60*120 (cm)



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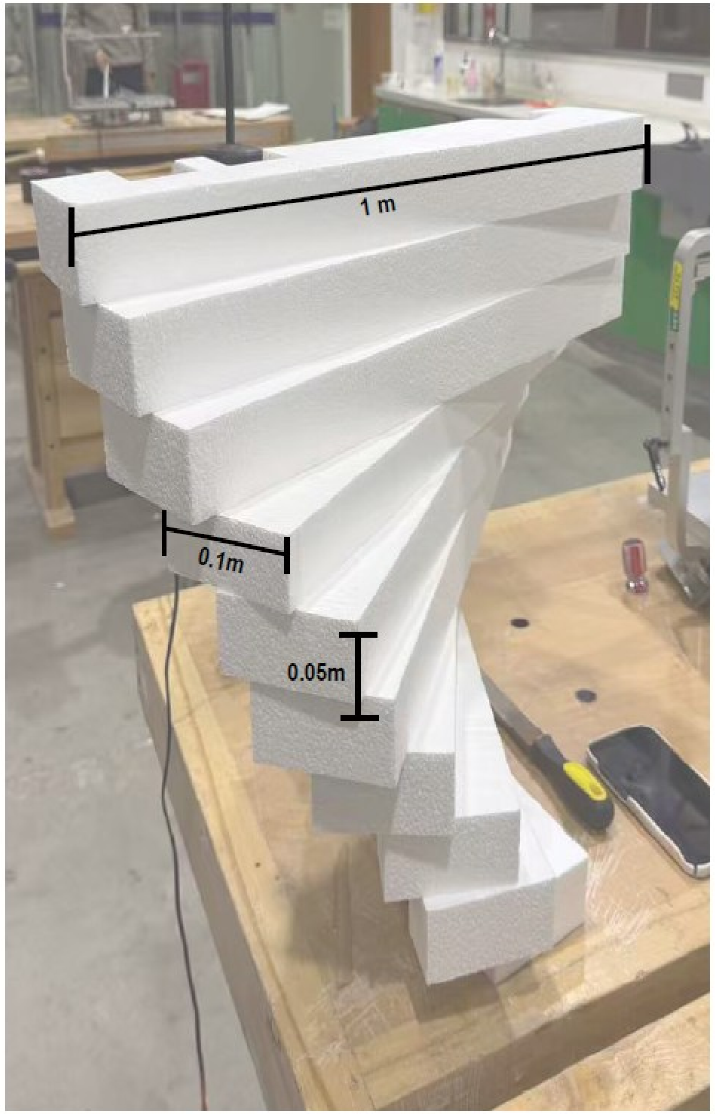
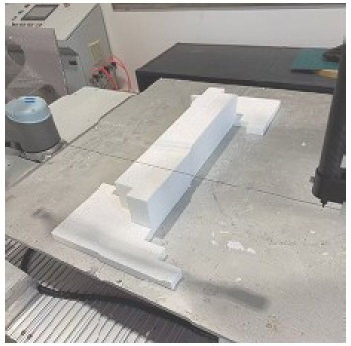


1. Standard Material = Cost Saving

Using 1 m × 0.1 m × 0.05 m EPS strips allows purchasing at standard industrial sizes,

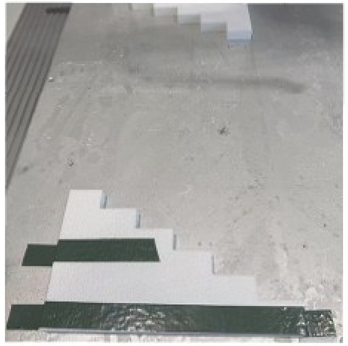
2. Less Cutting = Higher Efficiency

The slender section aligns with the robot's cutting reach, minimizing toolpath length,



3. Optimised Workflow = Time Saving

Lightweight strips are faster to load, position, and assemble, accelerating every step from fabrication to module installation.



Modular Interlock Pavilion

ARC301 Architectural Technology

Group D

“We stand on the brick of a technological revolution that will fundamentally alter the way we live, world, and related to one another. In its scale, scope and complexity, the transformation will be unlikely anything humankind has experienced before.”

- Klaus Schwab, World Economic Forum 2015

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