清華大學深圳国际研究生院
Tsinghua Shenzhen International Graduate School

Co-intelligent Assemblies Design Studio

离散设计与智能装配展

Tsinghua Shenzhen International Graduate School
Institute for Future Human Habitats

Discrete design offers a participatory framework for collective production, placing at the centre the design of open-ended tectonic systems that encapsulate knowledge.

——*Jose Sanchez*

离散设计为集体生产提供了一个参与性框架，以概括知识的开放式构造系统的设计为中心。

——何塞·桑切斯

Co−intelligent Assemblies Design Studio
离散建筑与智能装配展

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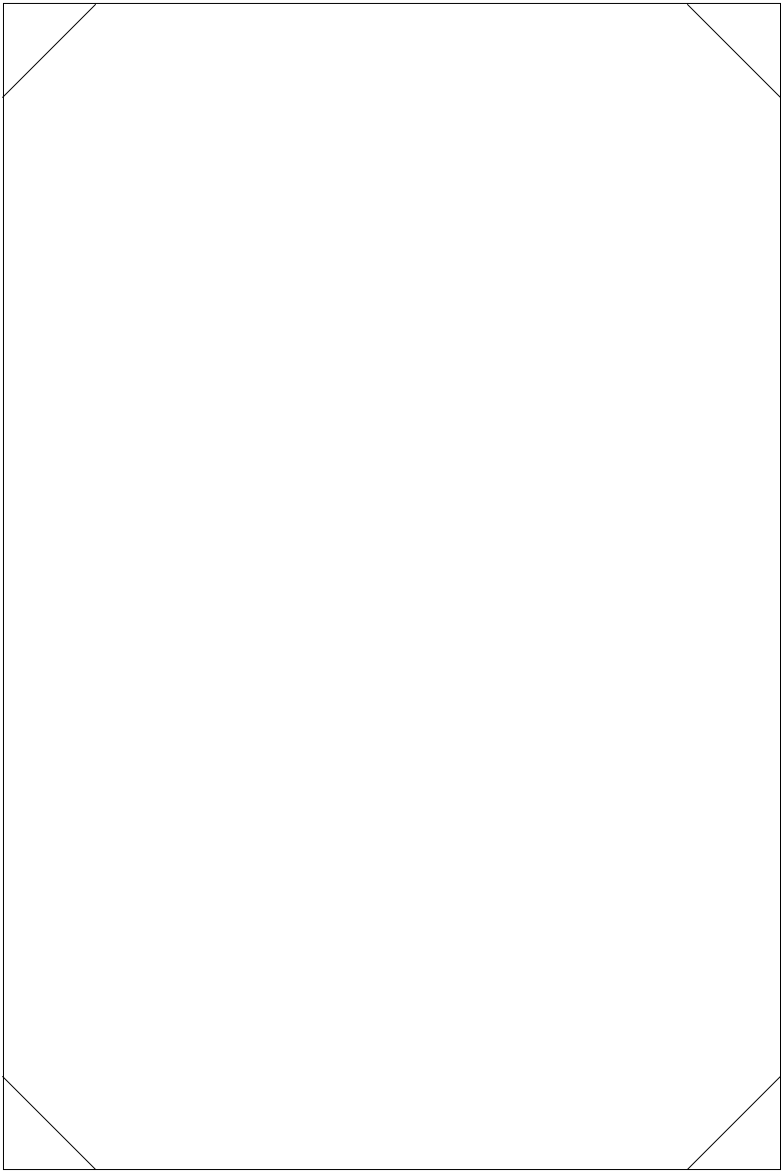

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简介

挑战

在无处不在的计算时代，人工智能的出现也影响着建筑、工程、施工和运营（AECO）等方面，成为工业 4.0 革命的一部分。新开发的智能装配方法、机器人生产和先进的数字化制造技术需要建筑设计师的高度重视，尤其是在设计阶段，数字化生产方式会影响设计流程与方法。然而，严格的数字化流程有时会忽视人的创造技能、工艺能力、作者身份和创造力。因此，" 协同智能装配 " 研究了如何在设计计算和人工智能的支持下，将人类设计师在设计和生产过程中的创造力、智慧和技能运用到一个连贯的设计工作流程中。通过将制造和装配设计方法、遗传算法和规则驱动的组合空间聚合策略整合到一个数字工作流程中，设计师可以根据非传统的设计方法扩展设计空间探索，并获得不可预见的结果。将机器提供的自下而上的生成技术与人类设计师探索的自上而下的直观设计意图相结合，可以为建筑空间的创建奠定坚实的基础。

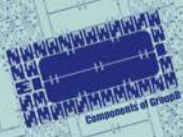
建筑空间可以通过部件套件系统来定义、生产和交付吗？如果模块化部件包是一种产品，那么利用模块化部件的建筑空间是否也是一种产品？部件如何组合在一起，又如何形成一个坚固的组合体，从而创造出一种空间品质？

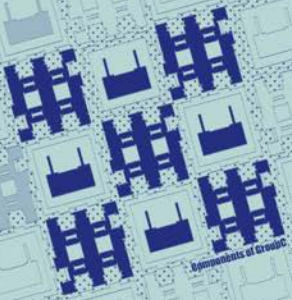
Introduction

Challenge

The advent of artificial intelligence in the era of ubiquitous computation also influences the disciplines of architecture, engineering, construction, and operation (AECO) as a part of revolutionizing Industry 4.0. The newly developed intelligent methods of assembly, robotic production, and advanced digital fabrication techniques require serious attention from designers, even in the early design stages. The digital production process affects the product's design itself. However, strictly digital processes sometimes neglect human creative skills, craft abilities, authorship, and creativity. Therefore, "Co-intelligent Assemblies" investigates how we can employ human designers' creativity, intelligence, and skills in design and production processes with the support of design computation and artificial intelligence into one coherent design workflow. By incorporating the Design for Manufacture and Assembly method, genetic algorithms, and rules-driven combinatorial spatial aggregation strategies in one digital workflow, designers can extend design space exploration with unforeseen outcomes based on unconventional design approaches. Combining bottom-up generative techniques provided by a machine with intuitive top-down design intents explored by a human designer yields a robust foundation upon which the architectural space can be created.

Can architectural space be defined, produced, and delivered through a kit-of-parts system? If the modular kit-of-part is a product, is architectural space utilizing modular parts a product, too? How do parts fit together, and how can they make a solid assembly, creating a spatial quality?


Components of Ground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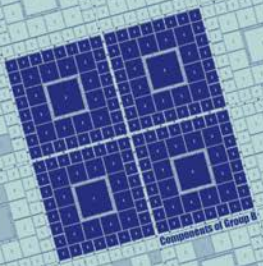
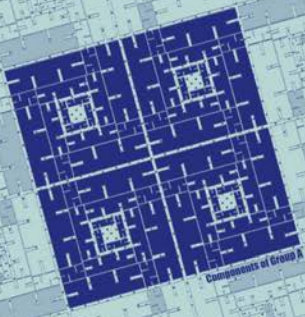
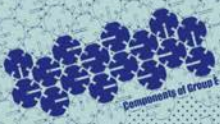
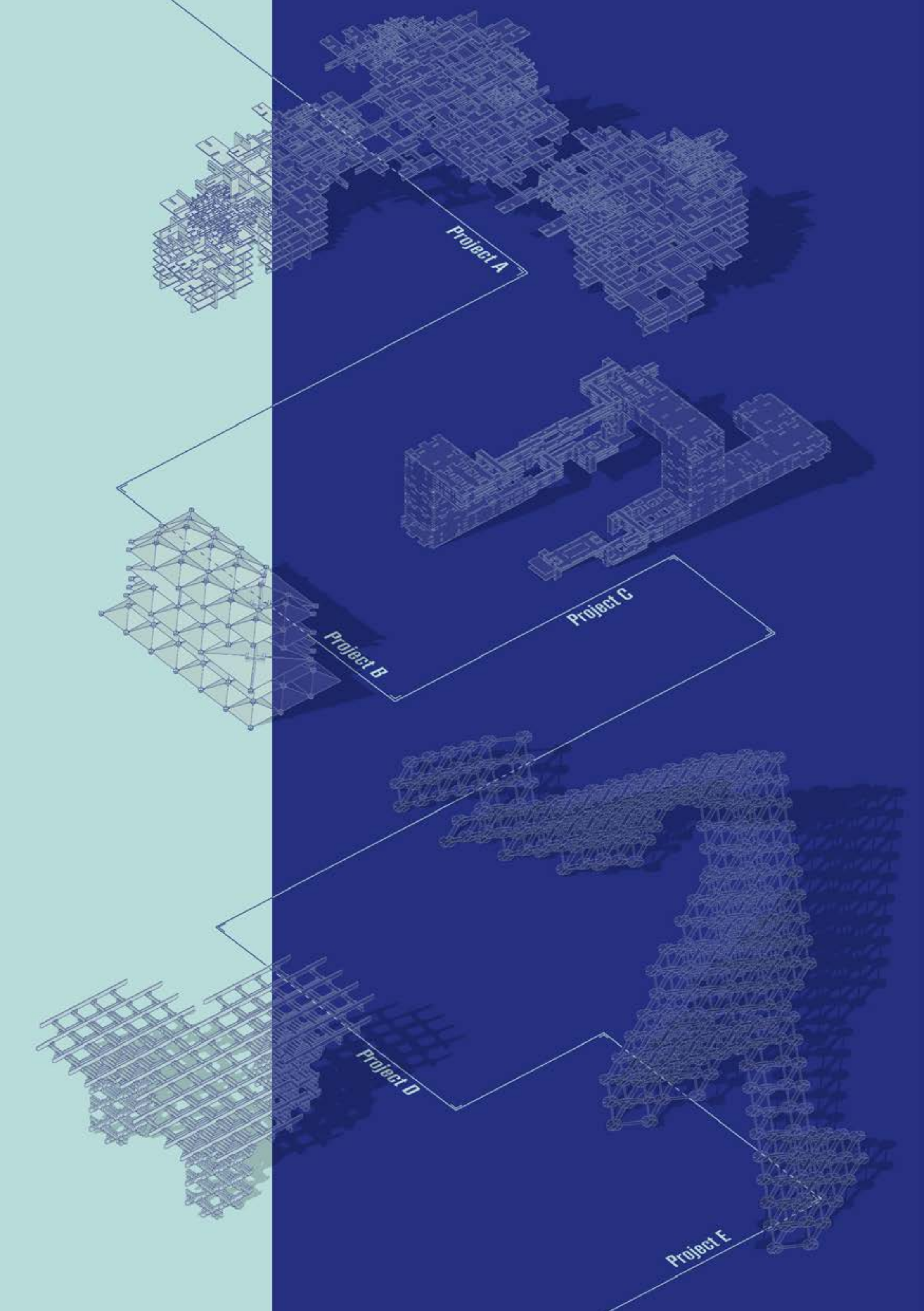
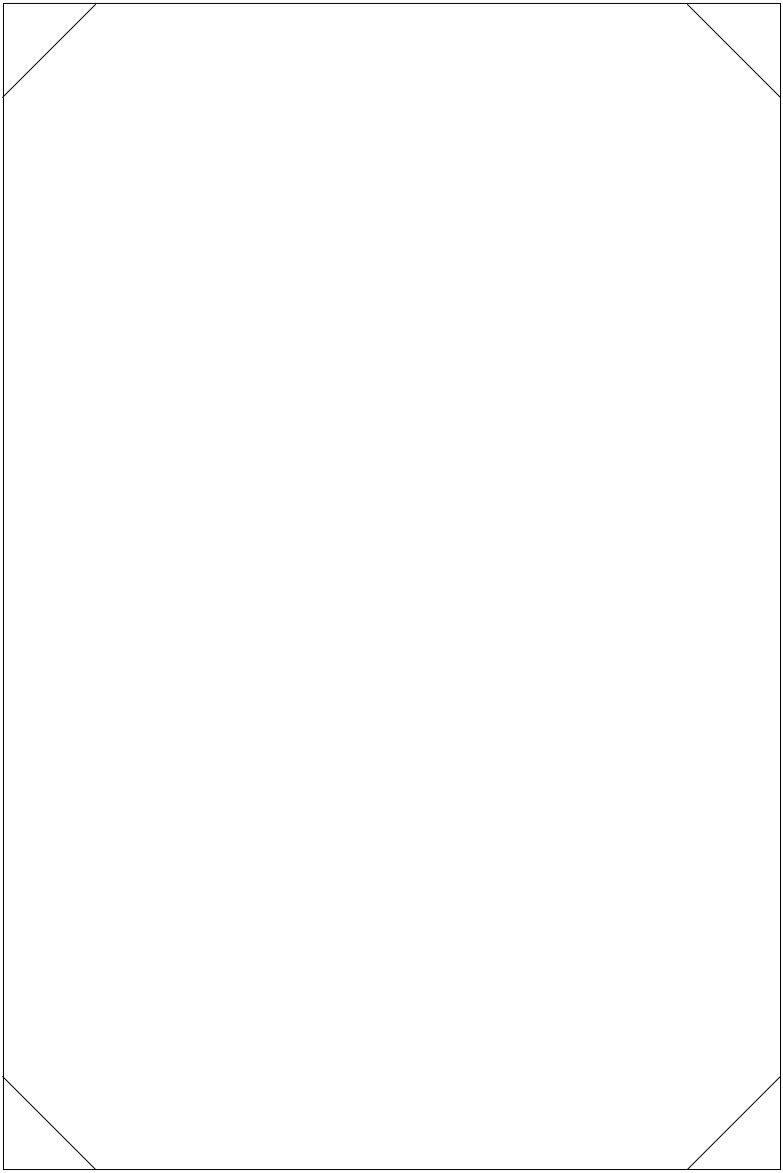

Components of Group B


Components of Group A


Components of Group E


Project A
Project B
Project C
Project D
Project E

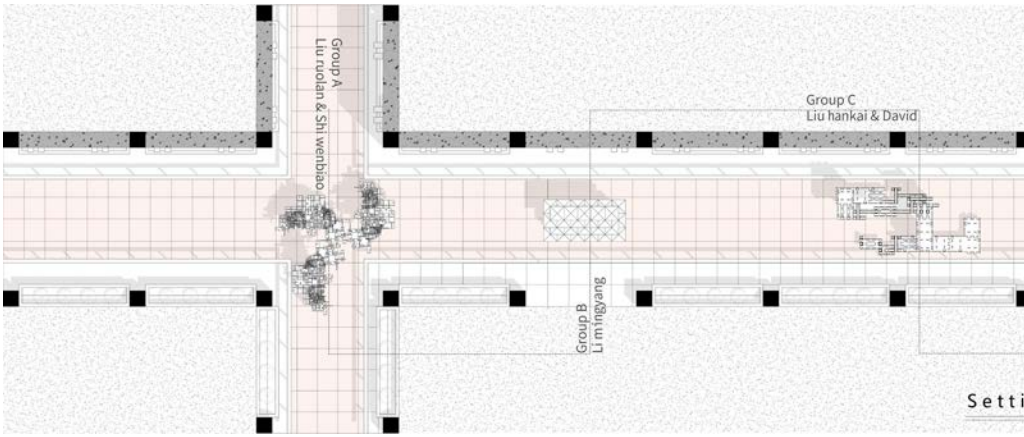


项目介绍

设计工作室项目：
面向制造和装配的设计

设计专题 I-- 清华大学未来人居研究院 2023/2024 年秋季学期的设计工作室，题为 " 协同智能装配 "，探索了制造与装配设计方法（DfMA）的生产和原型设计在建筑创造中的潜力。设计目标是创建一个独特的组装组件整体（随机模式或规则模式）代表空间干预，并作为清华大学深圳国际研究生院（SIGS）校园内学生的社交空间（例如，封闭空间、休憩区、城市家具、导航墙或现有空间或环境的抽象衔接）。

在本课程中，学生们学习了各种计算设计和数字制作技术，按照离散建筑的范式，根据预先设计的组件套件生成空间配置。建筑空间是由积木模块即离散组件（部件套件）定义和构建，通过子组件很容易集成到整体中。这种系统的优势在于提供一个直观的概念，让人了解各部分是如何组合在一起的，从而在单个部分和由这些部分组成的整体之间建立了一种耐人寻味的关系。学生们通过尝试包括人工智能及遗传算法的计算方法研究了逻辑和部件组织，探索了部件与整体的关系，以及部件在设计过程中如何产生更广泛的影响。他们在设计过程中还遵循将单个部件组装成整体的离散性原则，重点关注木工制品、联锁机制和所使用建筑材料的结构特性等方面，并在设计过程中为其设计决策提供依据。

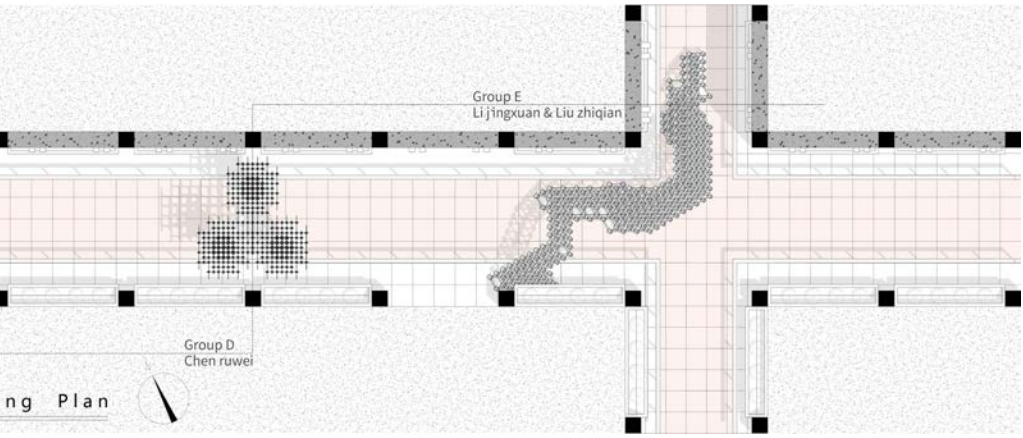


Project Description

Design Studio Projects: Design for Manufacture and Assembly

The Design Topics I – the design studio Fall term 2023/2024 at the Institute of Future Human Habitats Tsinghua SIGS titled “Co-intelligent Assemblies” explored the potential of Design for Manufacture and Assembly method (DfMA) of production and prototyping for spatial architectural scenarios creation. The design objective was to create a unique aggregation of the assembled components into wholes (either in a stochastic mode or in a regular way), representing spatial intervention and serving as a social space for students in the Tsinghua SIGS campus (e.g., enclosed space, sitting areas, urban furniture, navigation wall or an abstract articulation of the existing space or environment).

The students were introduced to various computational design and digital production techniques to generate spatial configurations based on predesigned components as kits of parts, following the paradigm of discrete architecture. The architectural spaces are defined and built out of the building blocks – discrete components (kit-of-parts), easily integrated into the wholes through sub-assemblies. The advantage of such systems is that they bring an intuitive notion and understanding of how parts fit together, creating an intriguing relationship between the individual part and the whole, which is formed of these parts. The students investigated the logic and component organization computationally, including the application of AI, specifically genetic algorithms, exploring the part-to-whole relationship and how parts are involved in the design process with wider consequences (spatial, relational, or environmental).

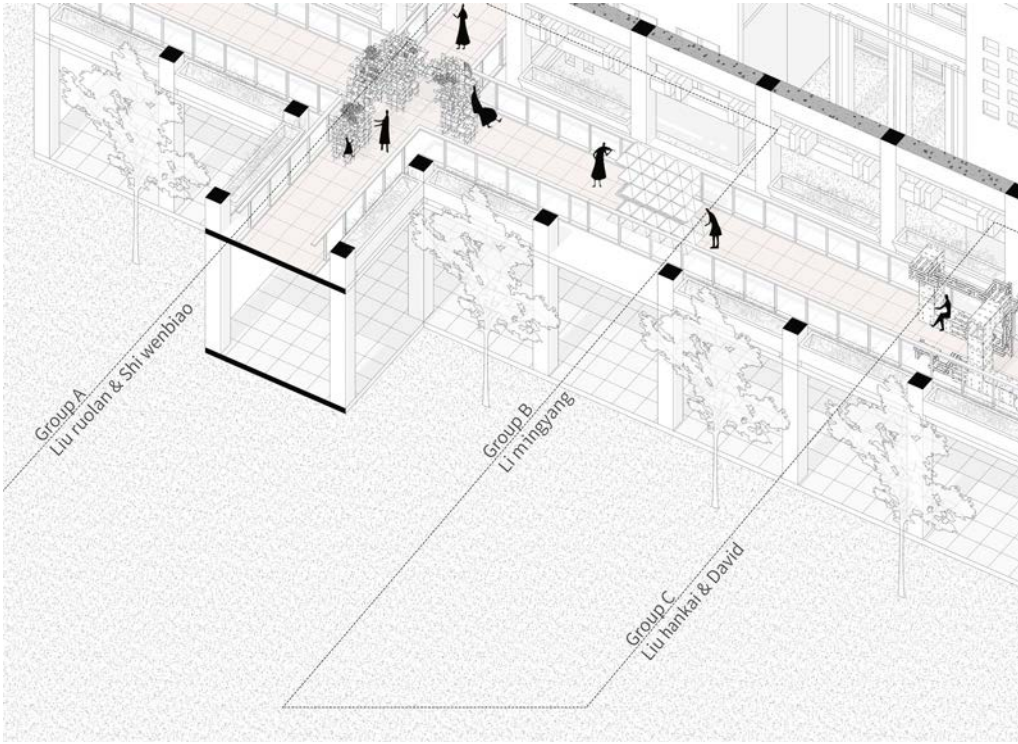


设计工作室项目：
面向制造和装配的设计

设计成果集中于从设计到生产的过程，阐明了安装在清华 SIGS 校园内的拟议干预措施的空间和结构质量。设计过程结合了生成方案的计算随机方法和更直观的设计师自上而下的方法。设计师兼施工总承包商积极参与生产过程，与承包商协商设计意图，与实际操作类似。这是在学术环境中应用真实世界的生产条件，为未来的建筑师进入行业做好准备。

通过结构性能、可交付性、可施工性、空间属性、生产效率以及与现有环境相关的整体体积表达，对干预措施进行了评估。这些建筑干预措施探讨了如何使设计到生产的过程更加高效、经济，并提供美观的空间效果。

在清华 SIGS 校园展出的 "Co-intelligent Assemblies " 浓缩了人类设计师如何利用计算设计方法与机器智能协同工作的理念。如果我们把两种智能结合成一个连贯、统一的工作流程，或许能为解决建筑行业目前面临的挑战做出贡献。

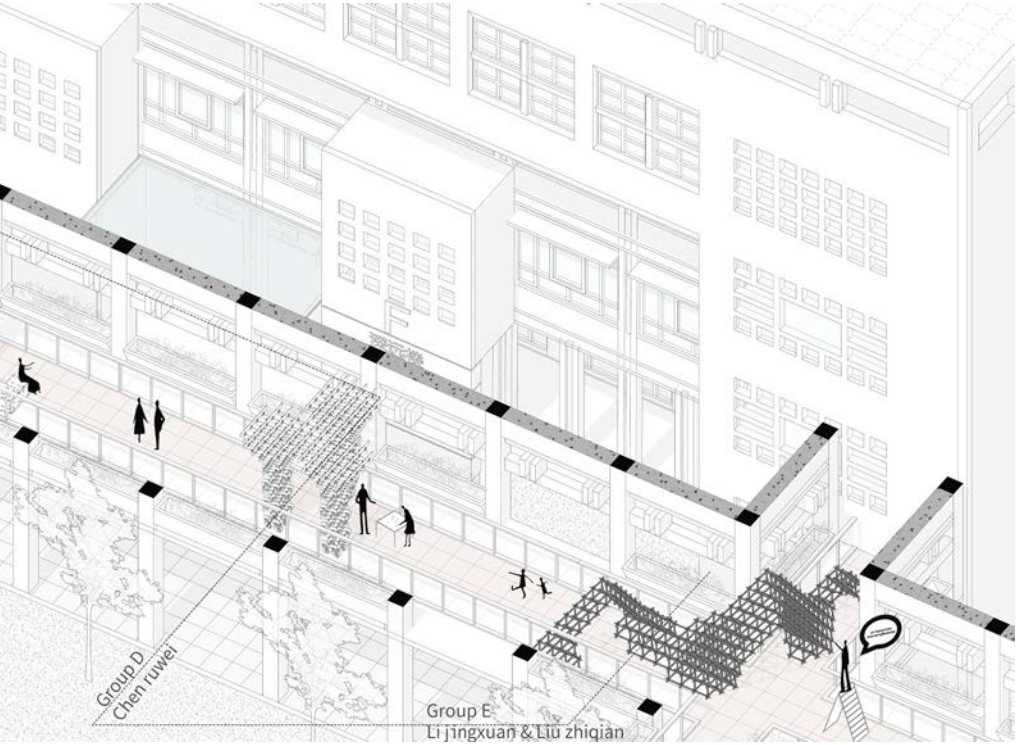


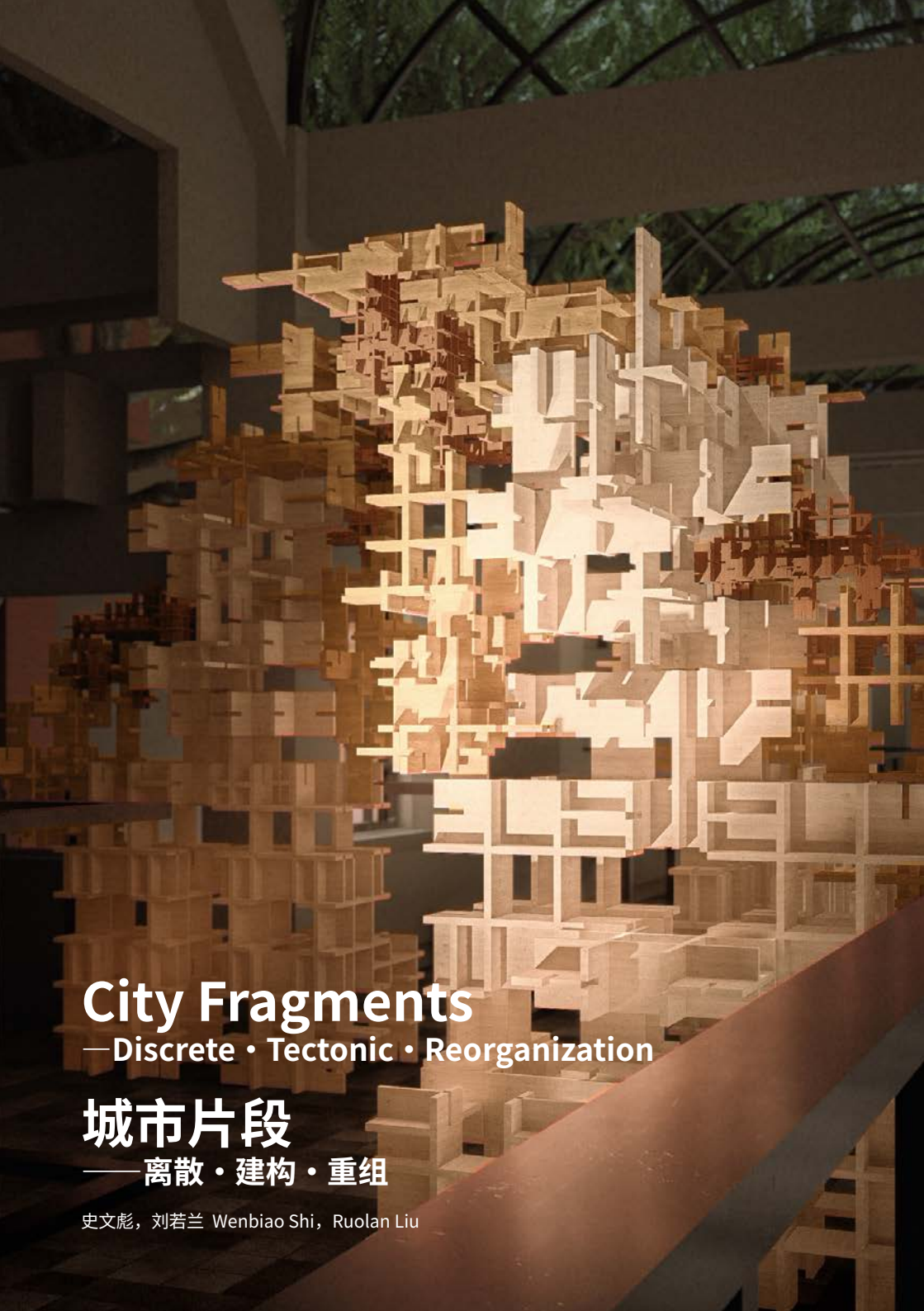
Design Studio Projects:
Design for Manufacture and Assembly

Following the principle of discreteness of the individual parts assembled into the wholes, they also focused on aspects of joinery, interlocking mechanisms, and structural properties of the building material they used, informing their design decisions during the process.

The design deliverables concentrated on design to production processes, articulating spatial and structural qualities of proposed interventions installed within the Tsinghua SIGS campus. The design process combined the computational stochastic method of generating scenarios and a more intuitive designer's top-down approach. The designers-master-builders actively participated in the production process, negotiating their design intent with the contractor, similar to the actual practice. This was an application of real-world production conditions in the academic environment, preparing future architects for the industry.

The interventions were evaluated through structural performance, deliverability, constructability, spatial attributes, production efficiency, and overall volumetric expression concerning the existing environment. The build interventions explore how the design-to-production process can be more efficient and affordable, delivering aesthetically pleasing spatial outcomes.



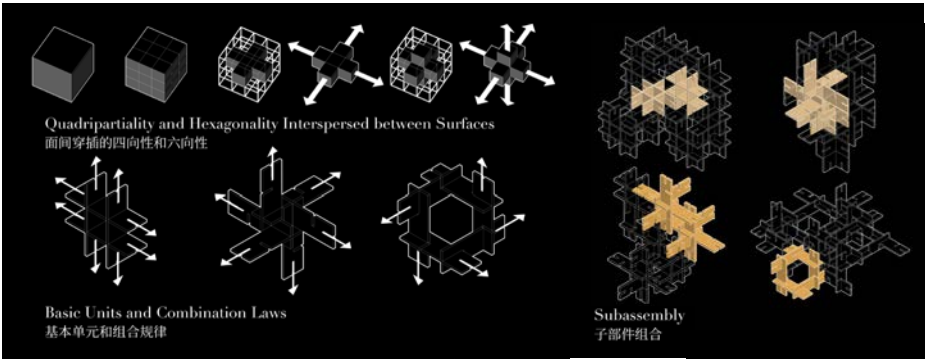


City Fragments
—Discrete · Tectonic · Reorganization

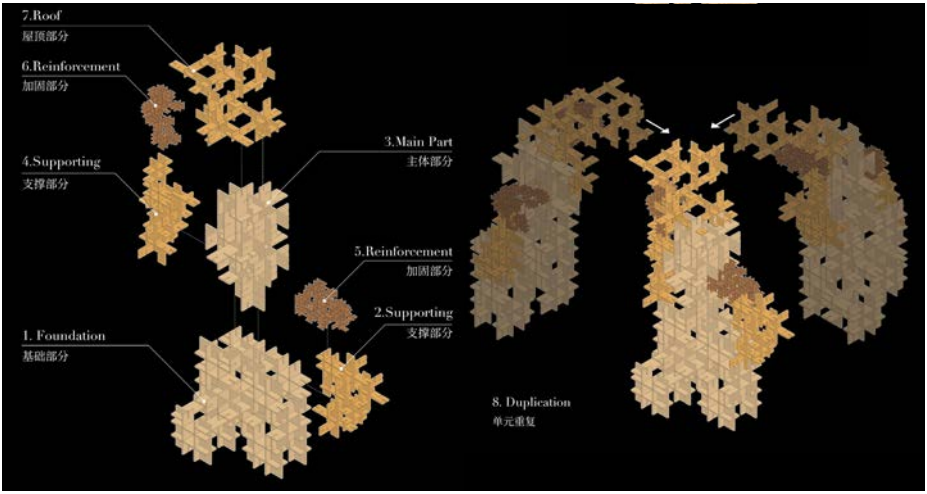
城市片段
——离散 · 建构 · 重组

史文彪，刘若兰 Wenbiao Shi，Ruolan Liu

Connection 丨 组合



Basic Units 单元组合

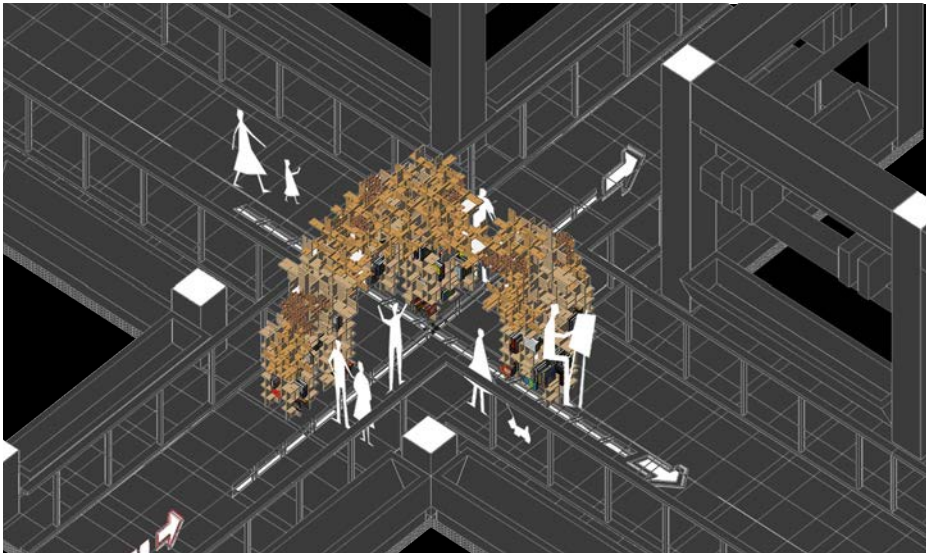


Sequence 搭建次序

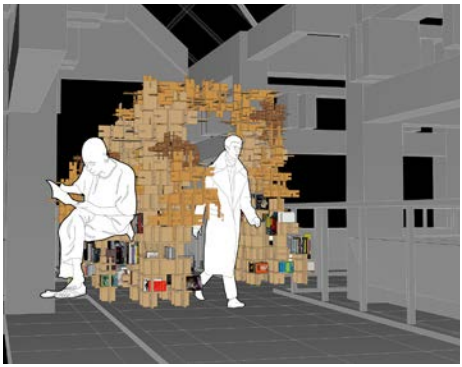
通过离散化设计探索木材片间穿插的四向性和六向性，完成足尺模型读书角的实体搭建，进而将其视为可生长的单元，通过数字算法设置参数与规则探索城市尺度的形态重组。

We explored the quadri-partiality and hexagonality of interspersed surfaces through a discrete design approach to complete the entity construction of a 1:1-scale model of reading corners. Subsequently, we consider it a growing unit, utilizing digital algorithms to set parameters and rules to explore morphological organization and re-organization of volumes at the urban scale.

Spatial | 空间



Circulation 流线



Scenario 场景

基础、支撑、屋顶和加固部分结合成一个单元，三个单元旋转构建出一个完整空间。不同高度对应不同的行为方式——停留、坐下或穿越，为校园提供了开放的交流与阅读场所。

The foundation, support, roof, and reinforcement parts are combined into a single unit, and three identical units rotate to construct a complete space. Different heights correspond to different modes of behavior—staying, sitting, or passing by, providing open spaces for people on the campus to communicate and interact.

Generation | 生长

找到“元部件”代表可以通过规则的设计来创造多种可能性，一切取决于规模。参考自然界的“分形”概念，并通过数字算法操控参数的变化性，在本次搭建方案的环境当中进行适应化生长。

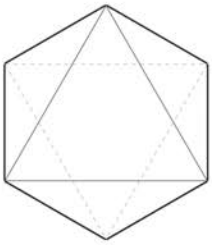
"Elemental components" symbolize diverse possibilities through rule-based design, influenced by the scale. Inspired by the natural concept of "fractals," the construction plan adapts and grows within its environment through the manipulation of parameters using digital algorithms.

PLATONIC PLANT WALL

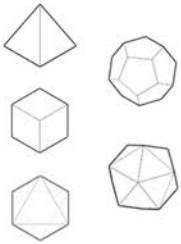
柏拉图景观墙 李明阳，LI MINGYANG

用柏拉图几何体正八面体作为基本单元，使用离散算法与结构核验算法，为学校走廊空缺的花池创造一面临时景观墙。

Using the Platonic geometry of the ortho-octahedron as the basic unit, a discrete algorithm with a structural kernel algorithm was used to create a temporary landscape wall for a vacant flower pool in a school corridor.

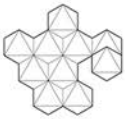


PLATONIC GEOMETRY 柏拉图几何体



柏拉图几何体，即每一面都是全等正多边形，每个顶点都是相同数目的正多边形的公共顶点。因此柏拉图几何体如正方体一般，可以作为完美的离散单元。柏拉图几何体共有五种，在此选用形体更丰富，又不至于太过复杂的正八面体。使用柏拉图几何体作为离散单元，可以带来以下规则：

Platonic geometry, i.e. each side is a congruent square polygon and each vertex is the common vertex of the same number of square polygons. Thus Platonic geometries, like squares, can be used as perfect discrete units. There are five types of Platonic geometries, but here we have chosen the ortho-octahedron, which is richer in form, but not too complex. The use of Platonic geometry as a discrete unit leads to the following rules:



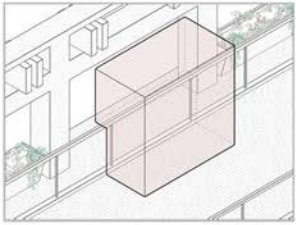
边对边连续无限扩张。
Edge-to-edge continuous infinite expansion.

数个单元可以组合成更大的单元。
Several units can be combined to form larger units.

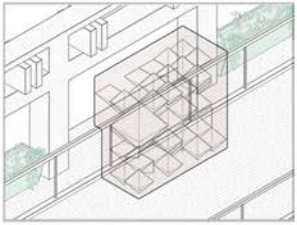
一个单元可以切分成数个小单元。
One unit can be cut into several smaller units.

GENERATION PROCESS 生成过程

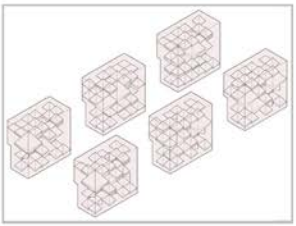
走廊柱间有花池，但部分柱间花池空缺。
There are planters between the columns, but some of the planters between the columns are vacant.



设置一面景观植物墙填补花池间的空缺。
Set up a wall of landscaping plants to fill in the gaps between the planters.

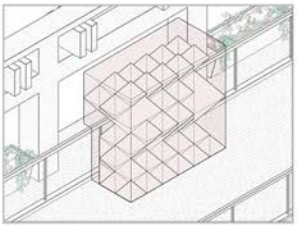


用离散算法使单元充满设定的边界。
A discrete algorithm is used to fill the cell with set boundaries.



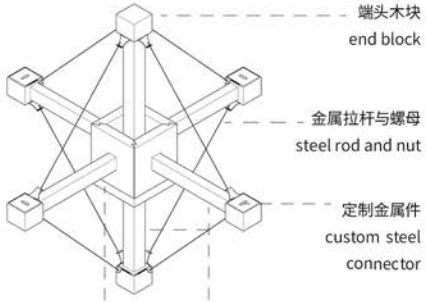
用算法产生多种备用方案。
Algorithms are used to generate multiple alternate scenarios.

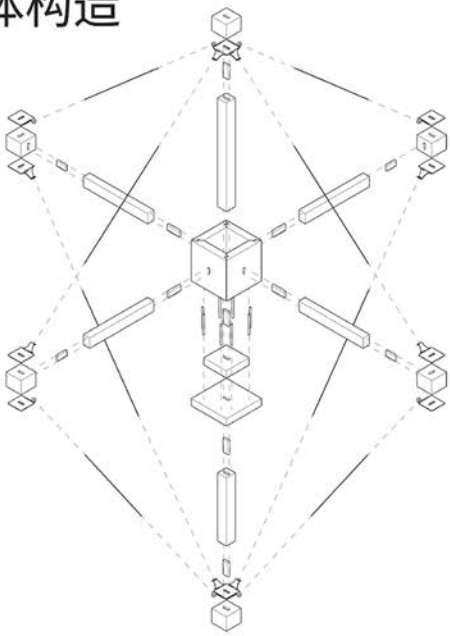
用Karamba 3D进行结构验算，排除不可行的方案。
Structural checks were performed with Karamba 3D to rule out infeasible solutions.

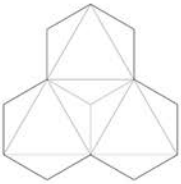


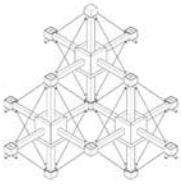
再手动修改，使最后的方案受力合理，又具备八面体的特点。
Then manually modified so that the final solution has reasonable forces and the characteristics of an octahedron.

UNIT STRUCTURE 单体构造









一个八面体单元由中心的木制结构和金属拉杆构成。由于木梁受重力下坠，以及多个单体组合会产生斜面，所以由金属拉杆提供拉力和支撑力。端头木块连接木结构与拉杆的同时，还负责连接各个单体。

An octahedral unit consists of a wooden structure in the center and steel rods. Tension and support is provided by the rods due to the fall of the wooden beams by gravity and the fact that the combination of multiple monoliths creates an inclined surface. The end blocks connect the wooden structure to the rods while also connecting the individual monoliths.

木榫将各个部分连接起来。由于拉杆提供拉力，所以木榫不会被拔出。中心木盒切斜边再组装起来，用蚊钉和胶水与底板连接，木榫还会将定制金属片连接起来。使结构看起来干净单纯。

The dowels join the sections together. The dowels won't pull out because the tie rods provide tension. The center wood box is cut beveled and reassembled, attached to the baseboard with mosquito nails and glue, and the dowels also attach custom metal pieces. It gives the structure a clean and simple look.

THREE SYSTEMS 三套系统

内核：装置主要的呈现部分。此装置中呈现的内容是植物，与周围花池产生联系。

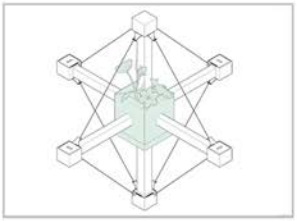
Content: the main presentation part of the installation. The content presented in this installation is plants which connects with surrounding flower pool.

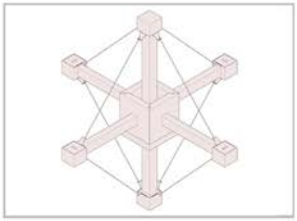
结构：轻质灵活的临时结构，单元易于生长，还可以分成更小的部分来适应周围环境。

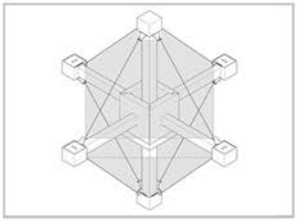
Structure: Lightweight and flexible temporary structure, units are easy to grow and can also be cut into smaller sections to fit the surroundings.

表皮：不同表皮适应不同环境。此装置表面悬挂了金属网格，连接栏杆的金属网。

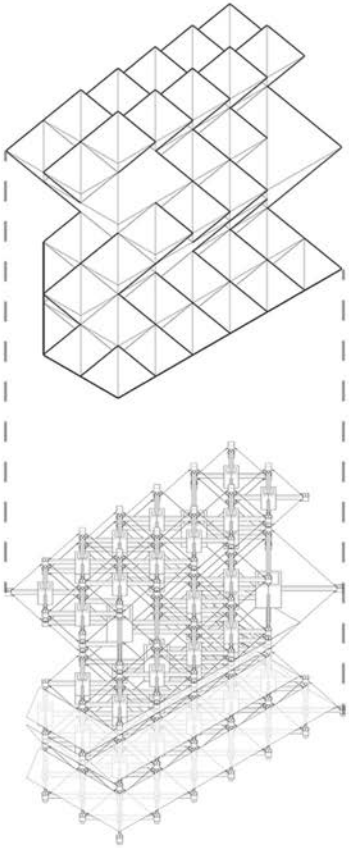
Skin: different skins adapt to different environments. This unit has a metal mesh hanging from the surface and a metal mesh attached to the railing.

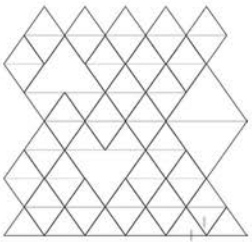






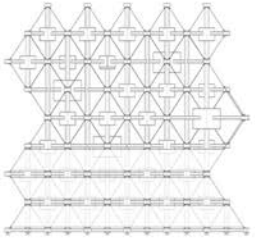
INTEGRAL CONSTRUCTION 整体构造

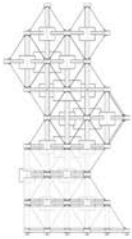




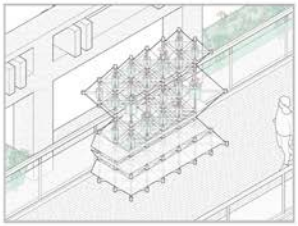
南立面
south elevation
半个单元
half unit
普通单元
common unit

西立面
west elevation
1/4单元
1/4 unit
大单元
big unit

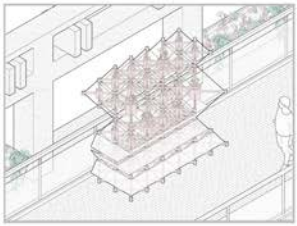




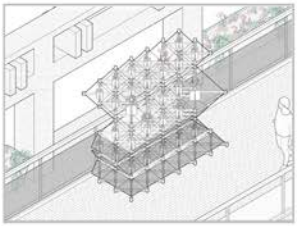
半个单元形成一层坚固的基底，大单元拥有更大的核心容纳更多植物。1/4单元填补缝隙，使装置平稳地贴到栏杆上。
Half units form a solid foundation, and big unit has a larger core to accommodate more plants. 1/4 units fill the gaps so that the device fits against the railing.



一个个架空的大小不一的花池，连起两侧的花池。
Elevated flower pools of various sizes connect to planters on either side.



轻质稳定的临时结构，适应周边环境，易于搭建与拆卸。
Lightweight and stable temporary structure that adapts to the surrounding environment and is easy to erect and dismantle.



底部三层的拉杆悬挂起金属网格，与原本的栏杆产生对话。
The bottom three tiers of rods suspend metal mesh that creates a dialog with the original railing.

KITS^2
羅生^2

何大衛，刘瀚锴 | David HE, Hankai LIU

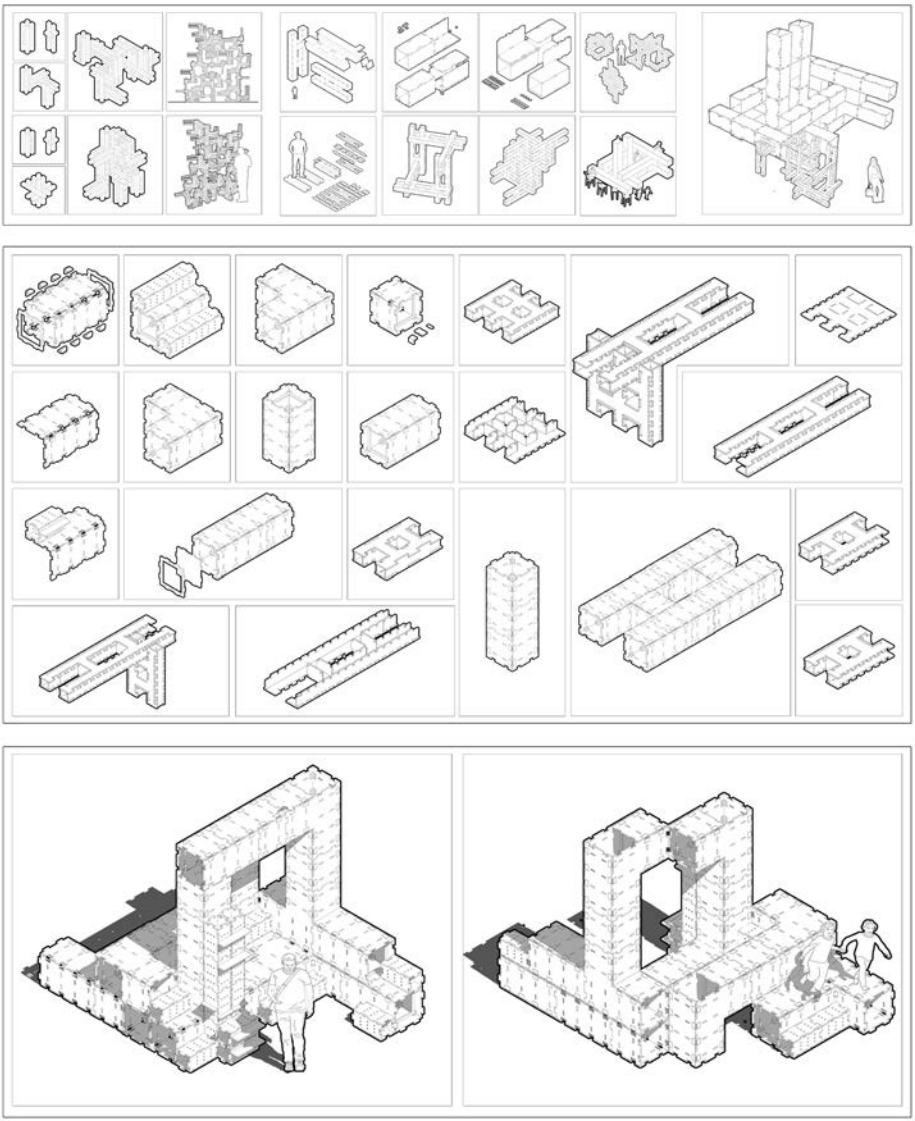
簡介

壹生貳，
貳生叁，
叁生萬物。
多方向的接入可能，不同規模的尺寸搭配，
從而羅生出無限形態。

Introduction

There was one, that of the divine law.
After one come two, after two come three,
then there were all things.
Modular connection methods and cross-scale compatibility, gave rise to the potential of infinite forms.

derivation | 衍生



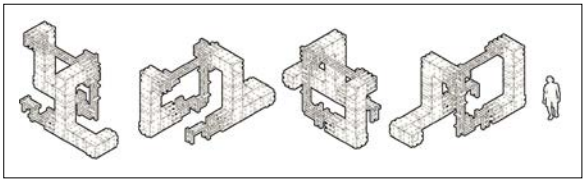
derivative iterations | 衍生迭代

在多向結合與跨尺寸兼容的組合拼接下不斷進行推敲，最終獲得豐富的形態可能。

The combination of multi-directional joints and components across multiple scales resulted in constant iterations, exploring the morphological possibilities of the assembly.

軸側圖

axonometric drawing

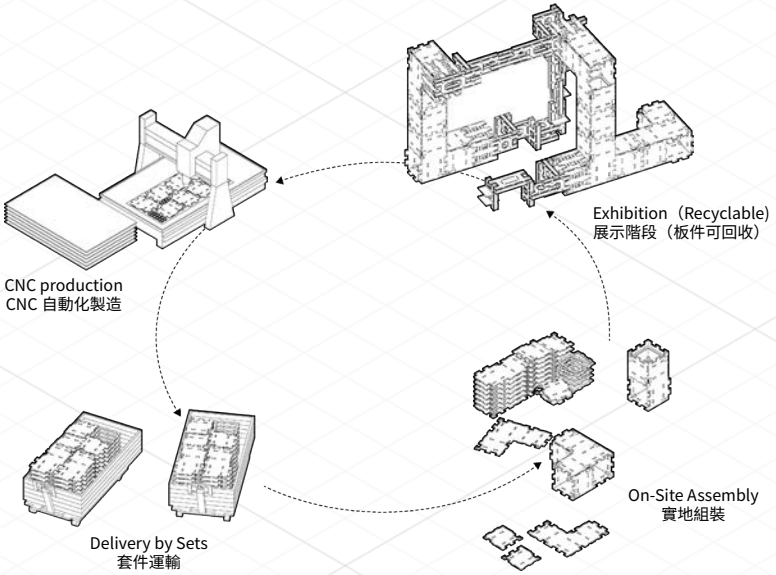


kit of kits ｜模塊化工具集

cycle of discrete | 離散化建造

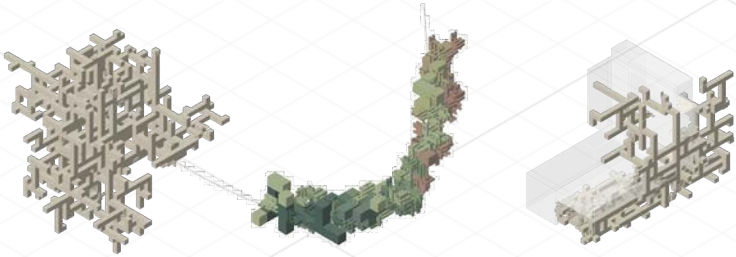
設計在使用參數化方法輔助的基礎上生成，且絕大部分的製造流程都將在工廠內完成，以成套板件的形式運抵建造地。如此模塊化的單元極大程度上縮短了實地建造周期。

The assembly is generated with the aid of parametric design methods, while most of the production process were completed prior to the delivery to site. The Kit-of-Parts paradigm may drastically shorten the time for on-site construction.



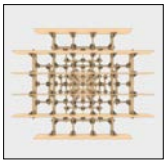
在利用參數化進行體塊生成時，有三種不同的聚合邏輯可供選擇，僅需用鼠標點擊操作即可自動生成符合各種場地條件的體塊，並可利用 Galapagos 自動進行進一步的空間優化。

The parametric design methods provided opportunities for three types of aggregation methods, which can be quickly switched with a mouse click. Forms may be easily generated based on the input parameters, and automatically optimized with Galapagos.



Kung Reborn
古拱今生

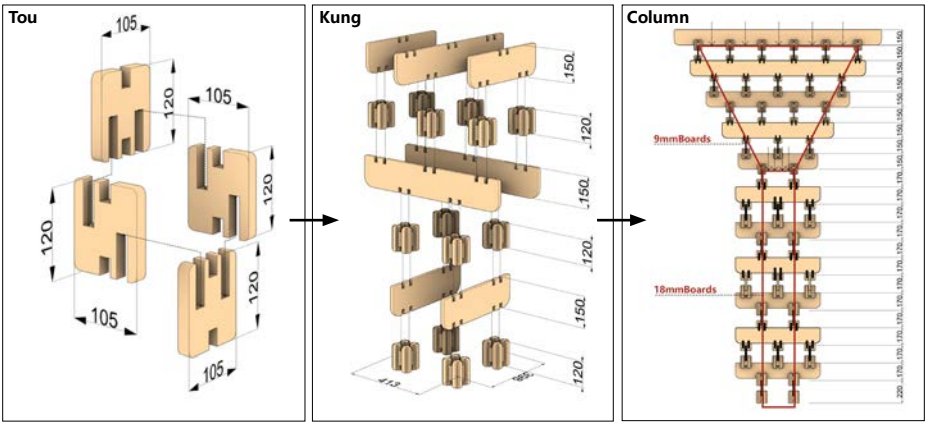
陈汝薇 Ruwei Chen



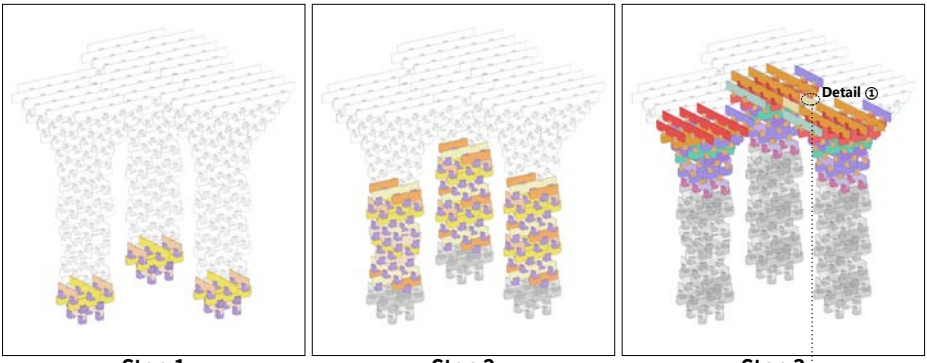
本方案汲取中国传统古建筑斗拱支撑逻辑，“斗”与“拱”相承、“柱”与“柱”相连，形成一套有机系统，构成新中式画卷。

This concept gracefully weaves the essence of traditional Chinese architecture, where the interlocking of "Tou" and "Kung" supports a logic that binds "column" to "column", crafting an organic system that paints a new Chinese landscape.

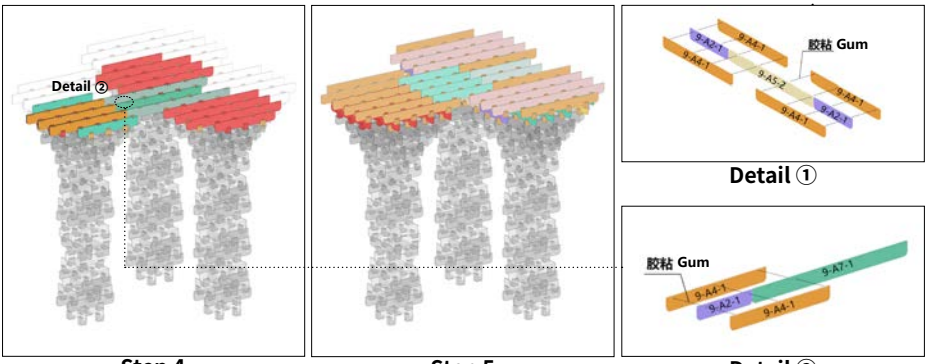
Assembly Process | 搭建过程



Assembly of Tou | Assembly of Kung | Structural Prototype



Step 1 | Step 2 | Step 3



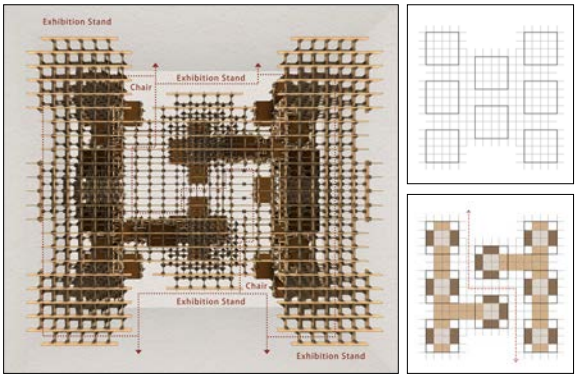
Step 4 | Step 5 | Detail ① | Detail ②

New Year Scenario 丨新年

方案由中国传统古建筑斗拱转译而来，并形成拱廊形态。传统文韵味与新年场景融合，带来一种穿越古今的沉浸体验。

The design draws inspiration from the traditional Chinese architectural structure of Tou-Kung, forming an archway. The integration of traditional cultural charm with the festive New Year ambiance creates an immersive experience that transcends the boundaries of time.

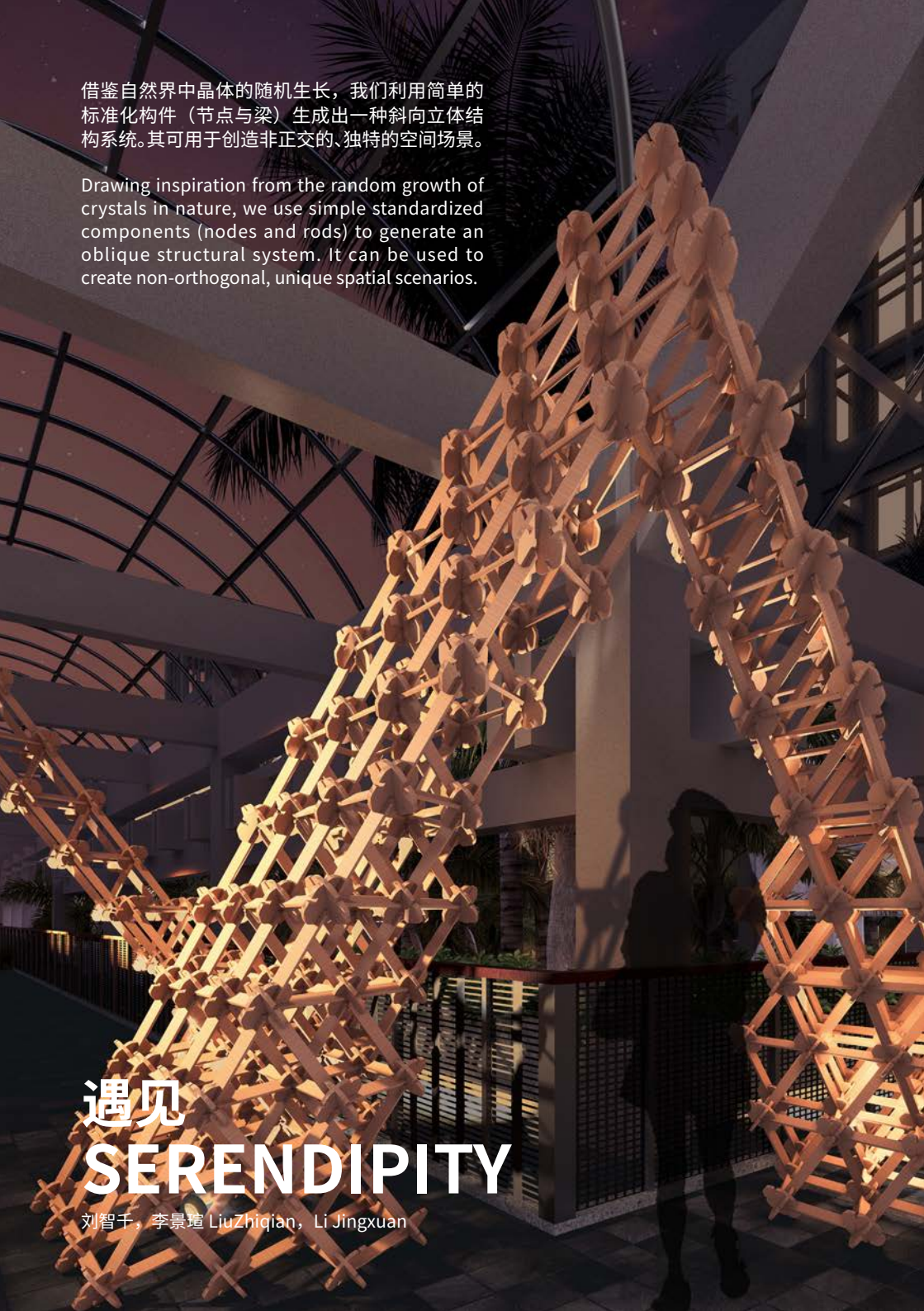
Exhibition Hall | 展厅



Exhibition hall functions and streamline organization

由斗拱层叠而成的“柱”可以继续拓展出更大的空间。本方案展示了八根“柱”搭建的展厅，展厅座椅、展架均通过插接关系与“柱”相连，形成有机整体。

The "columns" formed by the overlapping of Tou-Kung can be further expanded to create larger spaces. This design showcases an exhibition hall constructed with eight of these "columns," where the seating and exhibition stand are connected to the "columns" through interlocking relationships, forming an organic and cohesive whole.



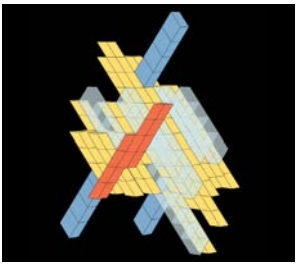
借鉴自然界中晶体的随机生长，我们利用简单的标准化构件（节点与梁）生成出一种斜向立体结构系统。其可用于创造非正交的、独特的空间场景。

Drawing inspiration from the random growth of crystals in nature, we use simple standardized components (nodes and rods) to generate an oblique structural system. It can be used to create non-orthogonal, unique spatial scenarios.

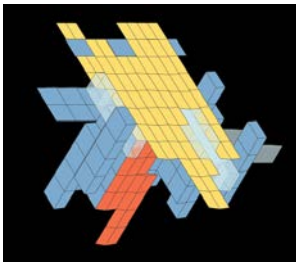
遇见
SERENDIPITY

刘智千，李景璇 LiuZhiqian，Li Jingxuan

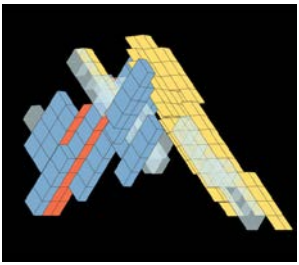
Cell Generation | 形体生成



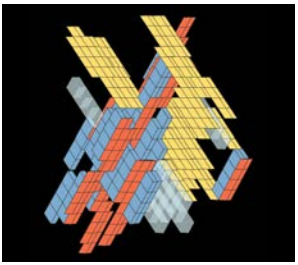
N = 50 Case 1



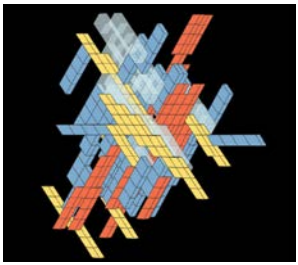
N = 50 Case 2



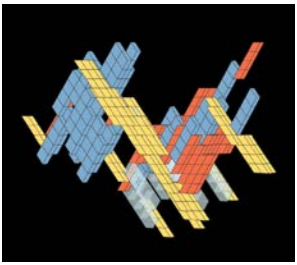
N = 50 Case 3



N = 100 Case 1

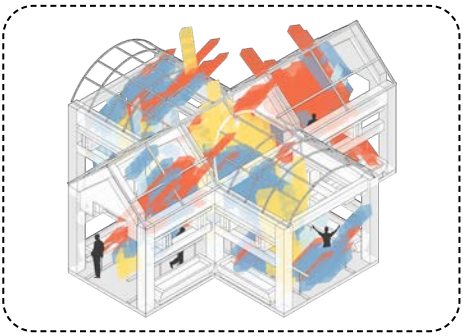


N = 100 Case 2



N = 100 Case 3

Habitation | 人居环境



Corridor Junction 十字路口

晶胞在走廊十字路口的6个位置上随机生长、蔓延、相遇、融合，形成了一个独特的休息空间。

The unit cells grow, spread, encounter and merge in a random manner from six positions in the corridor, eventually forming a unique resting space.

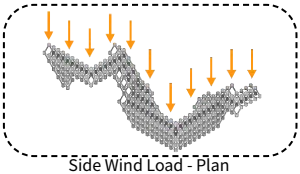
Human Scale 人体尺度

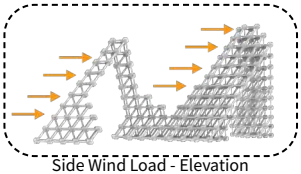
通过人流生成的人行空间干扰原始休息空间，以满足人的尺度要求，并提升使用者的体验。

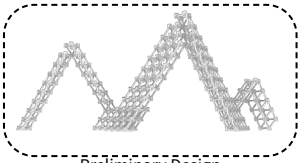
By subtracting the original structure from the space formed by circulation, the design can conform to human scale and enhance the experience of interaction with it.

Optimization | 结构优化

The structural analysis process includes four steps: 1. transforming the design into equivalent beams and supports; 2. defining beams and supports in Karamba 3D; 3. setting beam sections and material properties; 4. specifying the direction and magnitude of side wind. The diagrams show the utilization and displacement in the original and optimized designs.

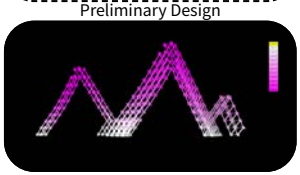

Side Wind Load - Plan

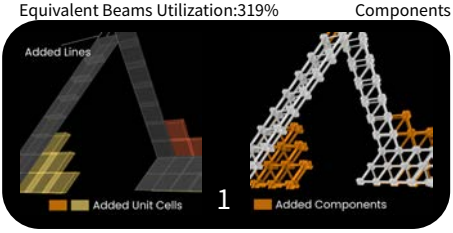

Side Wind Load - Elevation

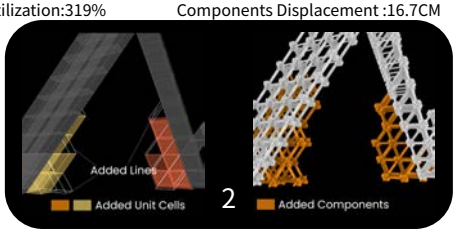

Preliminary Design

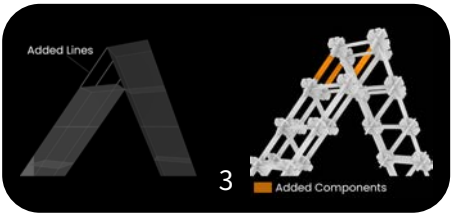

Equivalent Beams Utilization:319%

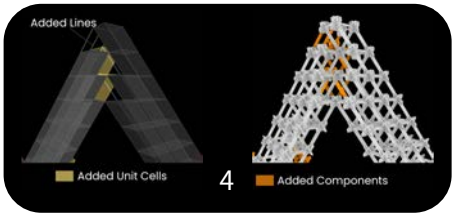

Components Utilization:319%

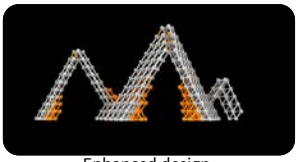

Components Displacement :16.7CM



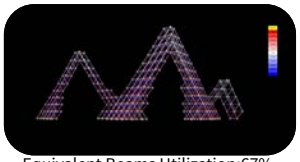


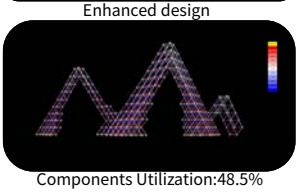


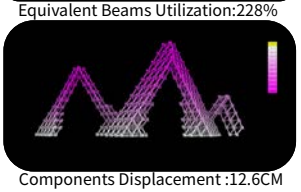


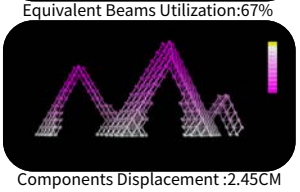

Enhanced design


Equivalent Beams Utilization:228%

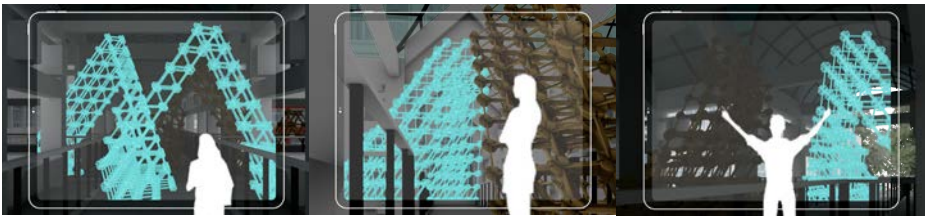

Equivalent Beams Utilization:67%


Components Utilization:48.5%


Components Displacement :12.6CM


Components Displacement :2.45CM

AR View | 增强现实辅助建造

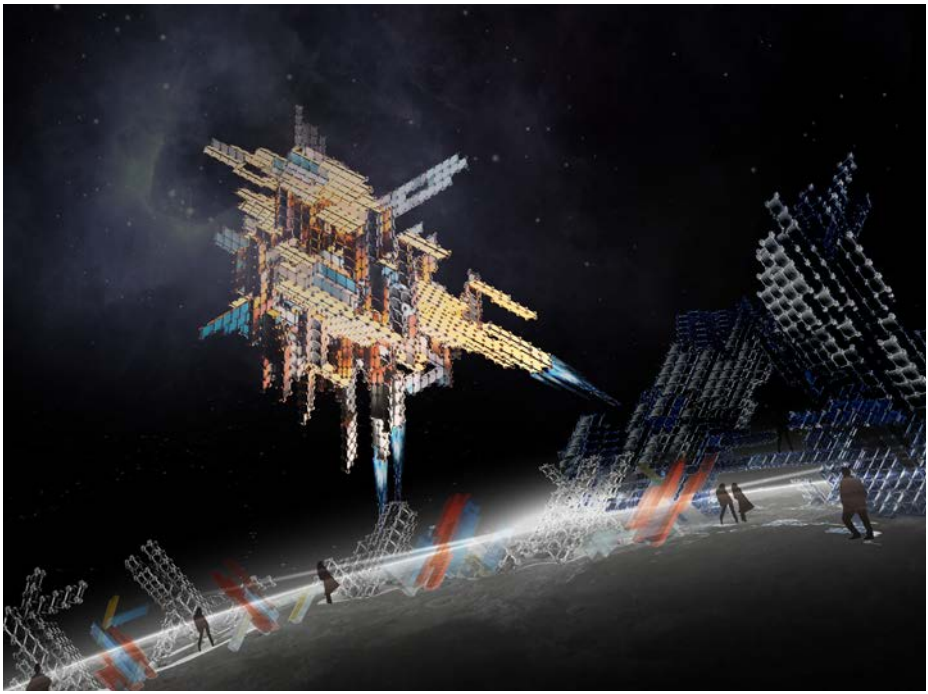


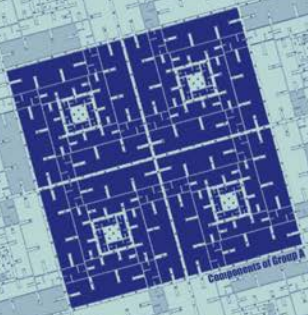
Phantom　　Spire　　Opposition

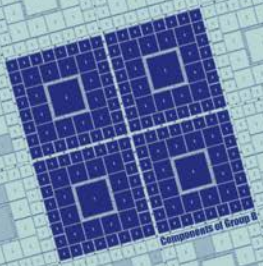
Maximum Scenario | 场景

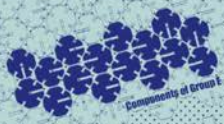
通过使用更强的材料、扩大组件尺寸并增加数量，构件可以建造模块化的城市建筑或航天器。而且，这些结构可以灵活地拆卸和重新组装，以满足多样化的太空生活需求。

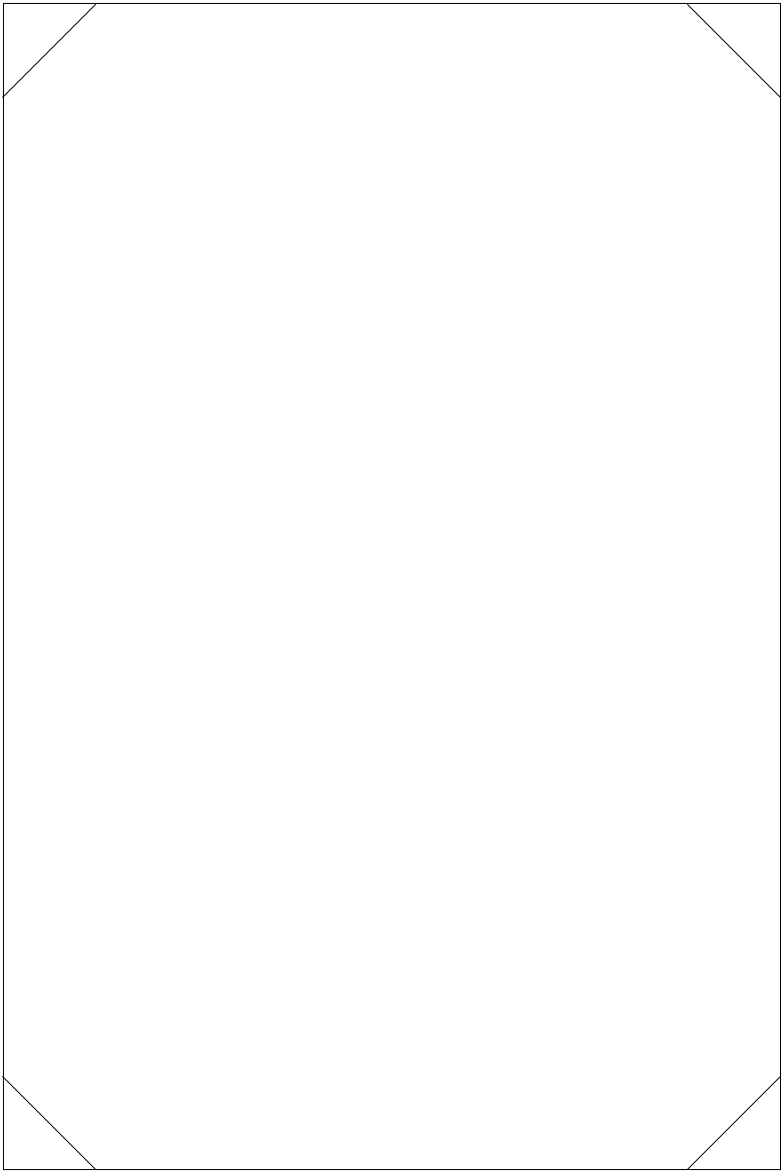
Modular space cities or spacecraft can be created by using stronger materials and increasing the amount and the scale of the components. These structures allow flexible disassembly and reassembly to meet a variety of space life needs.




Components of Group A


Components of Group B


Components of Group E



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