PhD WIP Presentation - RMIT PRS Europe 2023

AI-powered Prefabricated Timber System

AI Integration and Data Synthesis in Architectural Design with Prefabricated Timber Systems

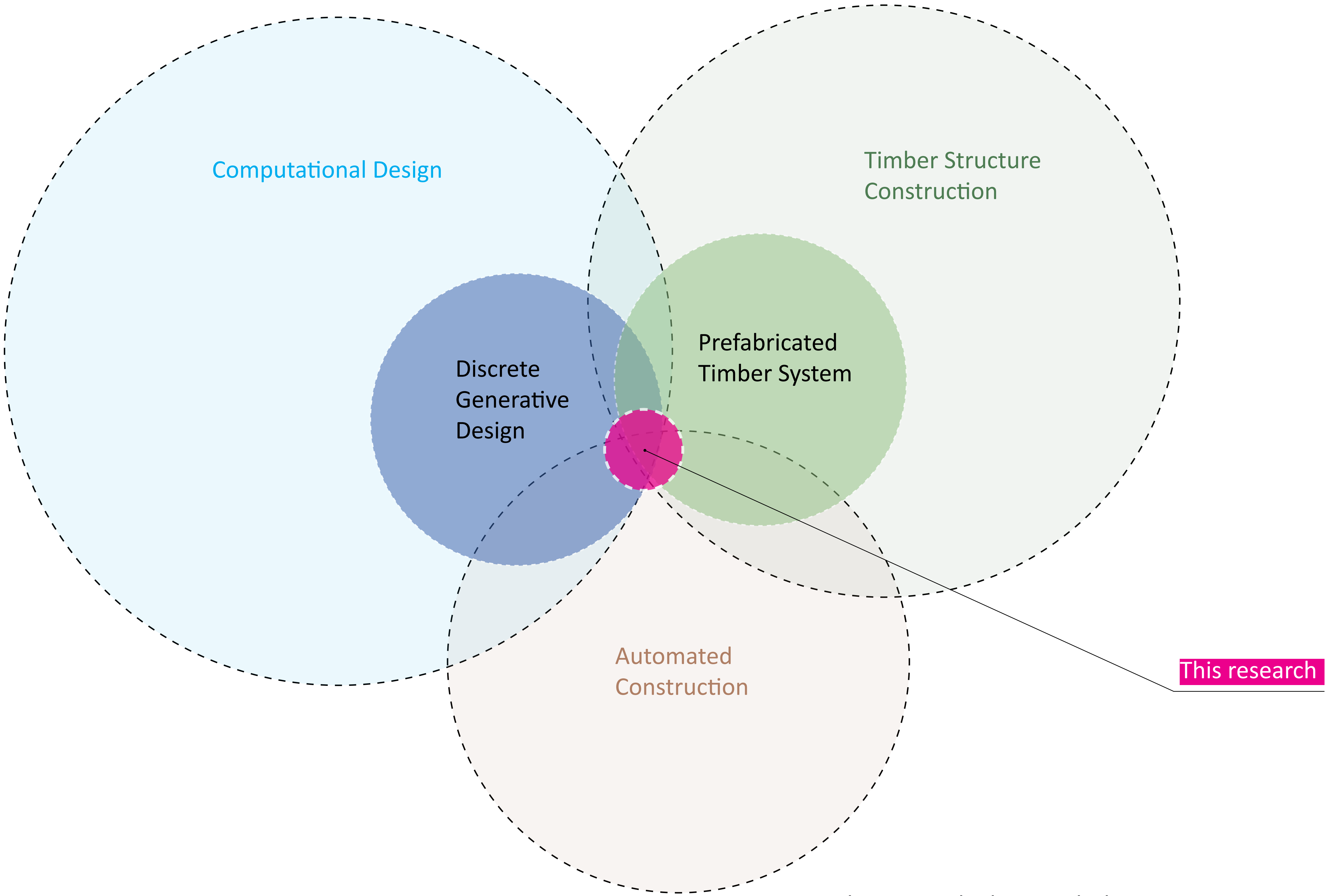
Ningzhu wang

Primary Supervisor (RMIT): Alisa Andrasek
Associate Supervisor (TuDelft): Henriette Bier

Image source:

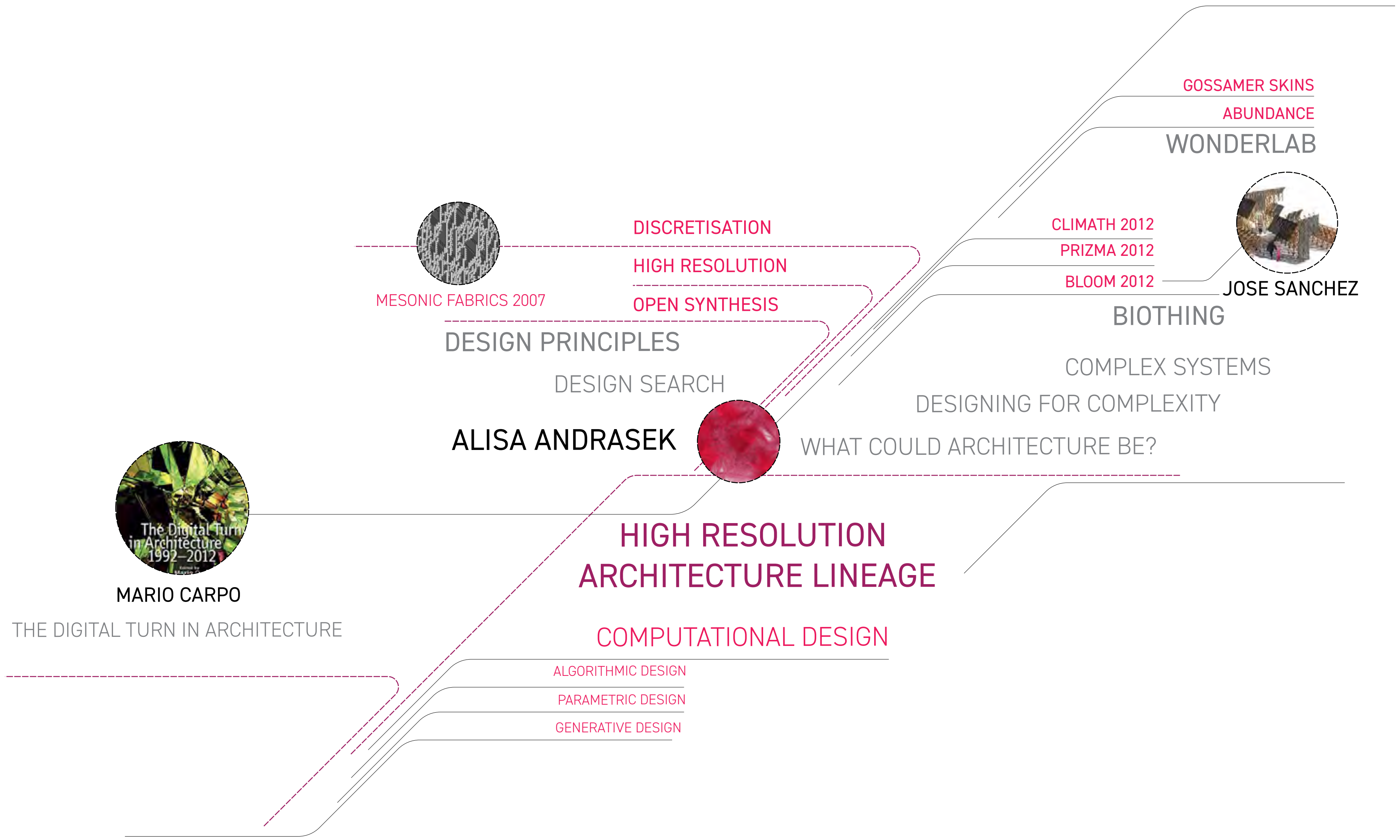
Top: https://www.ricedesignalliance.org/event/mass-tim-
ber-tour-series-san-jacinto-college-classroom-building

This research aims to establish an innovative workflow to enhance the architectural design based on prefabricated timber structural systems, thereby making a substantial contribution to the advancement of novel architectural construction solutions.

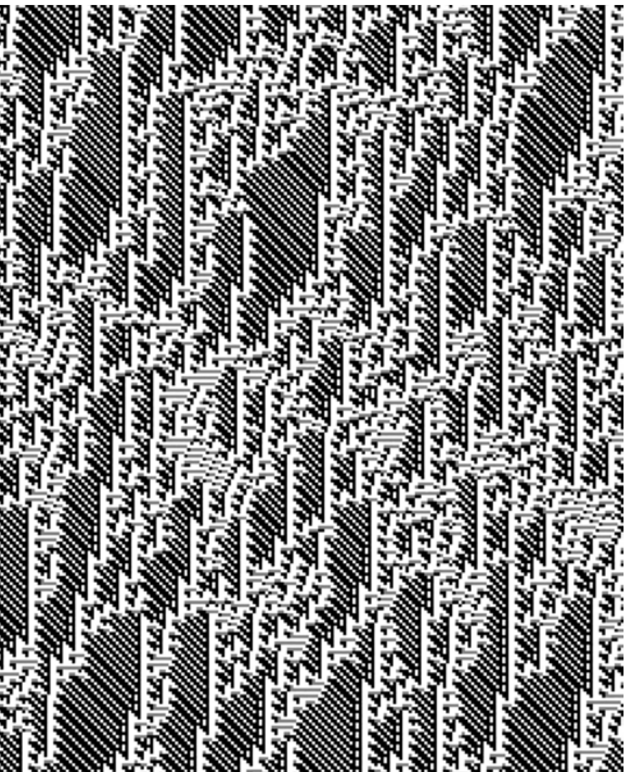


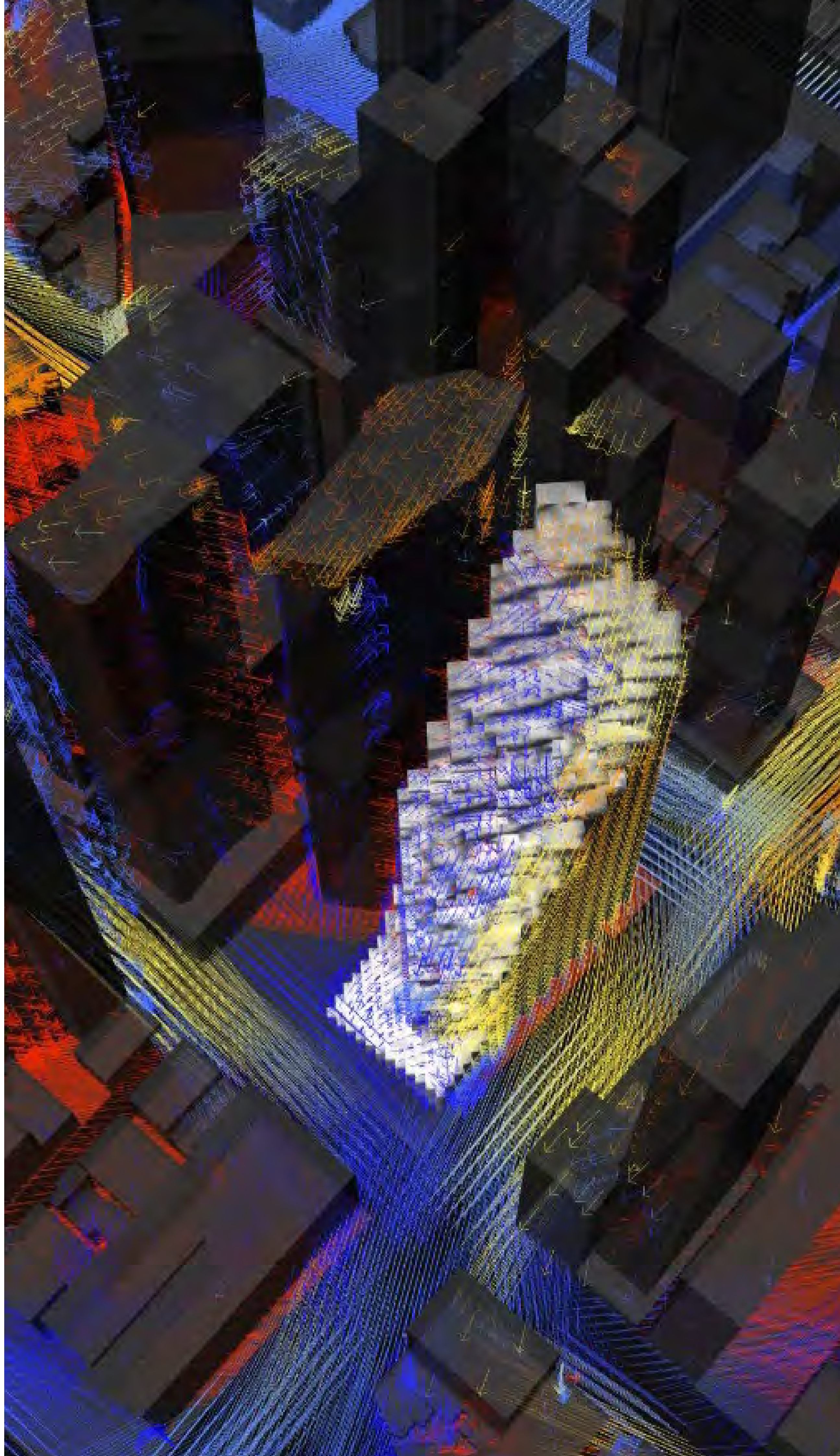
This research aligns with the generative practice research mode as outlined in the Practice Research Symposium (PRS) model at RMIT University.

This research is situated within a lineage of practice that emphasizes high-resolution architecture, generative design methodology, discrete design systems, prefabricated timber systems, and automated construction.

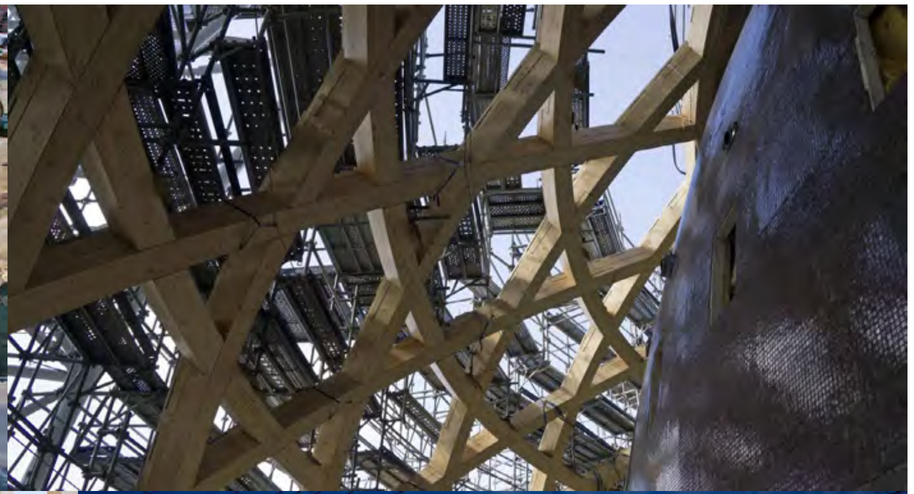


Source: the Complex City Research Framework established by Alisa Andrasek and her design practice Biothing, as well as academic work from prior research conducted at the Architectural Association (AA), Columbia University, and Wonderlab UCL Bartlett.





Community of Practice - Industry




PRACTICE IN TIMBER CONSTRUCTION:

- Kivi Sotamaa
- Kengo Kuma
- Shigeru Ban
- Fabian Scheurer & Design-to-Production
- Martin Self & xylotek
- The FCBA technological institute
- AIT Austrian Institute of Technology
- Egoin Wood Group
- ECTP Innovative Built Environment

ORGANIZATIONS

- Built by Nature

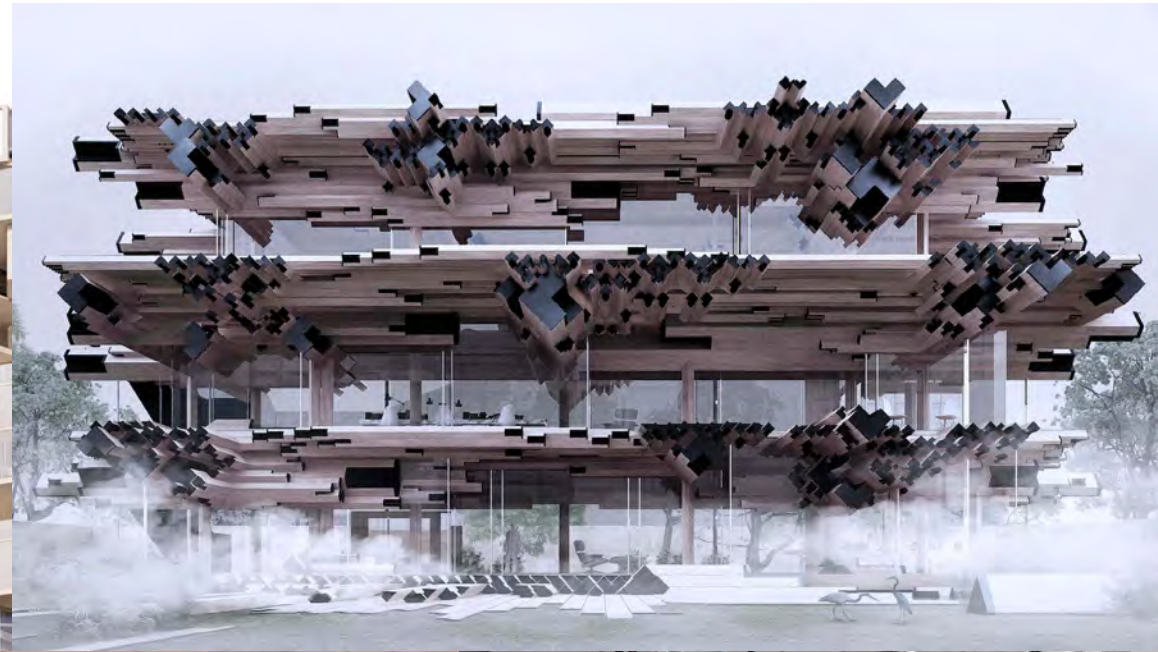
Community of Practice - Research

DISCRETE DESIGN

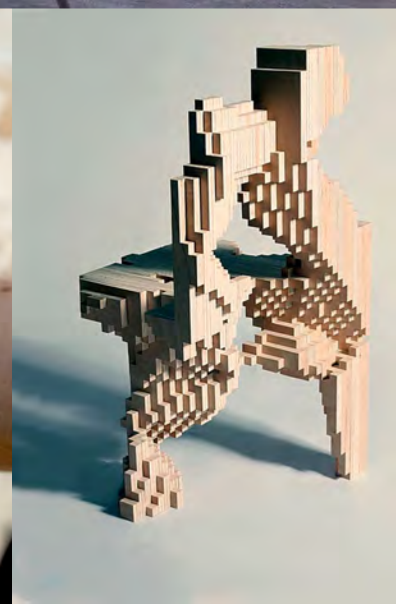
- Alisa Andrasek & AIARCH
- Gramazio Kohler Research (ETH Zürich)
- EZCT Architecture & Design Research
- Gilles Retsin

TIMBER CONSTRUCTION

- Achim Menges (ICD)
- Philippe Block(ETH Zürich)
- Philip F. Yuan (Tongji University)
- Raccoon (NCKU)
- Jan Knippers
- IGARASHI Laboratory (University of Tokyo)
- Jorge M Branco (University of Minho)






Challenges:

1. Repetition of standard design for prefab systems
2. High costs of customized timber structures
3. Thinking in trades and disjointed workflow
4. Workflow discourage the architect's creativity

Opportunities:

1. Development Prefab timber system and automated construction
2. Development of technologies of data and AI
3. Increasing computing power
4. Awareness of sustainable development in society

Background - Timber System in Construction Industry - Large Scale

- Sou Fujimoto

Bottom: https://www.dezeen.com/2023/10/03/construction-expo-2025-osaka-master-plan-sou-fujimoto/?li_source=base&li_medium=bottom_block_1

Stories Amsterdam - Olaf Gipser Architects

https://www.dezeen.com/2022/10/19/olaf-gipser-architects-stories-housing-amsterdam/

Background - Timber System in Construction Industry - Large Scale

CREE System - CREE Buildings Austria

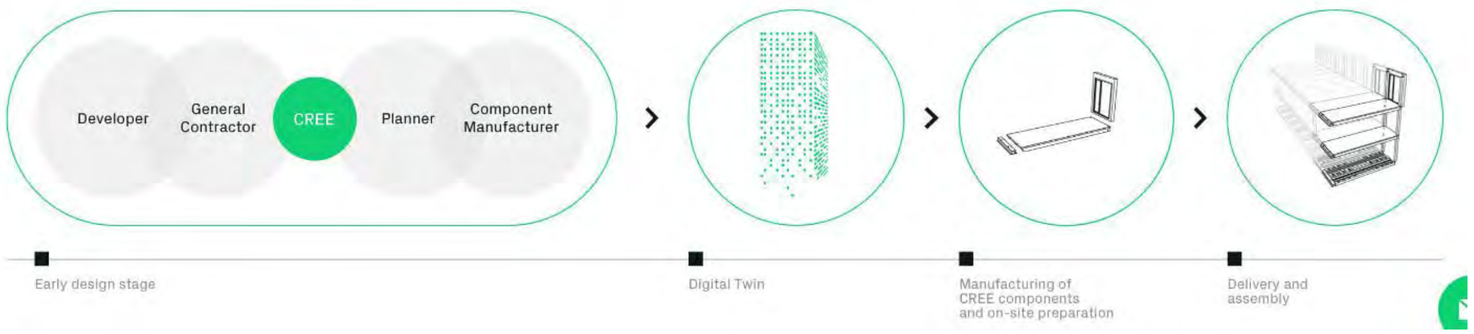
Start now with the CREE Process

CREE Process | Conventional Process

Early engagement of CREE in the design-and-build process, plus early involvement of all stakeholders, leads to real efficiency.

Potential savings

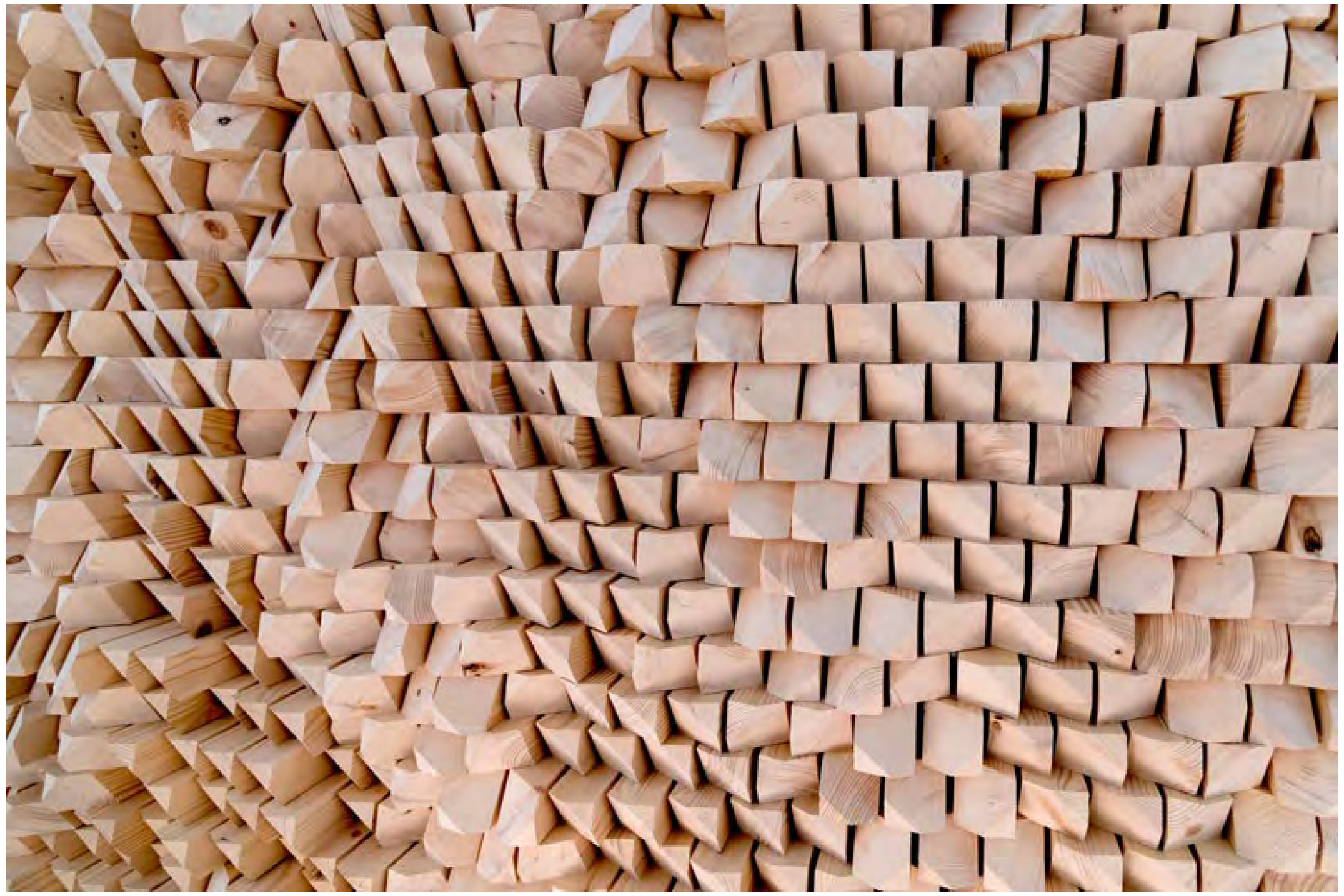
Cost	Transport	Material	Time	CO2
25%	30%	40%	50%	50%

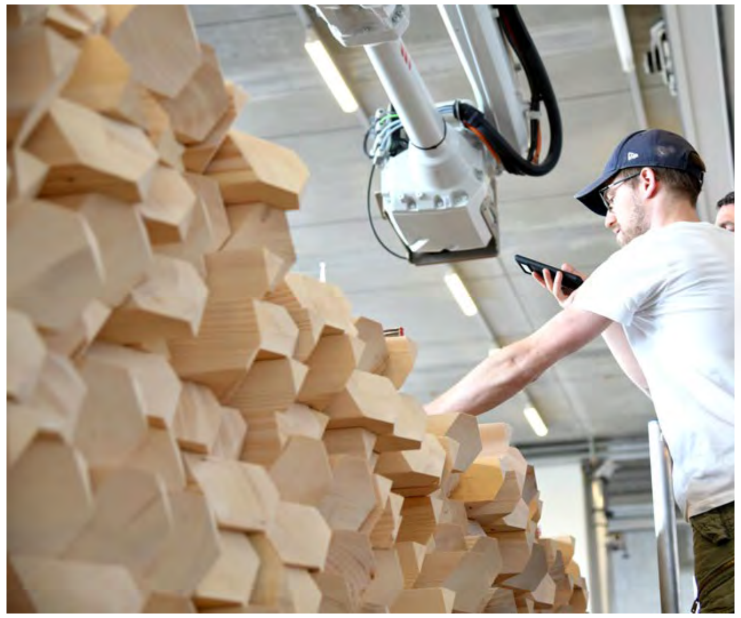


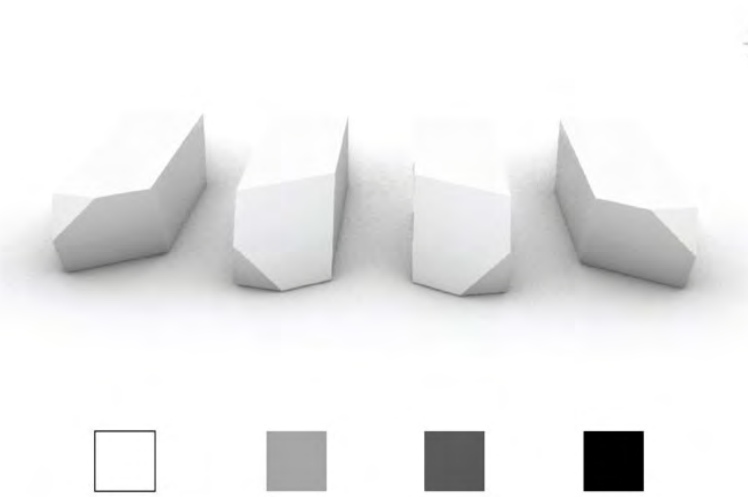
Source: https://www.creebuildings.com/system

Background - Timber System Research - Small Scale

Gramazio Kohler Research, ETH Zurich







Aichi Triennale, Japan, 2022

Robotic Assembly of Modular Multi-storey Timber-only Frame Structures
Using Traditional Wood Joinery

Touch Wood, Zentrum Architektur Zurich Bellerive (ZAZ), 2022

Augmented Acoustics
The project Augmented Acoustics combines computational design with an innovative augmented fabrication system. In addition, it is possible to define additional parameters, such as the degree of acoustic diffusion, the custom pattern image.

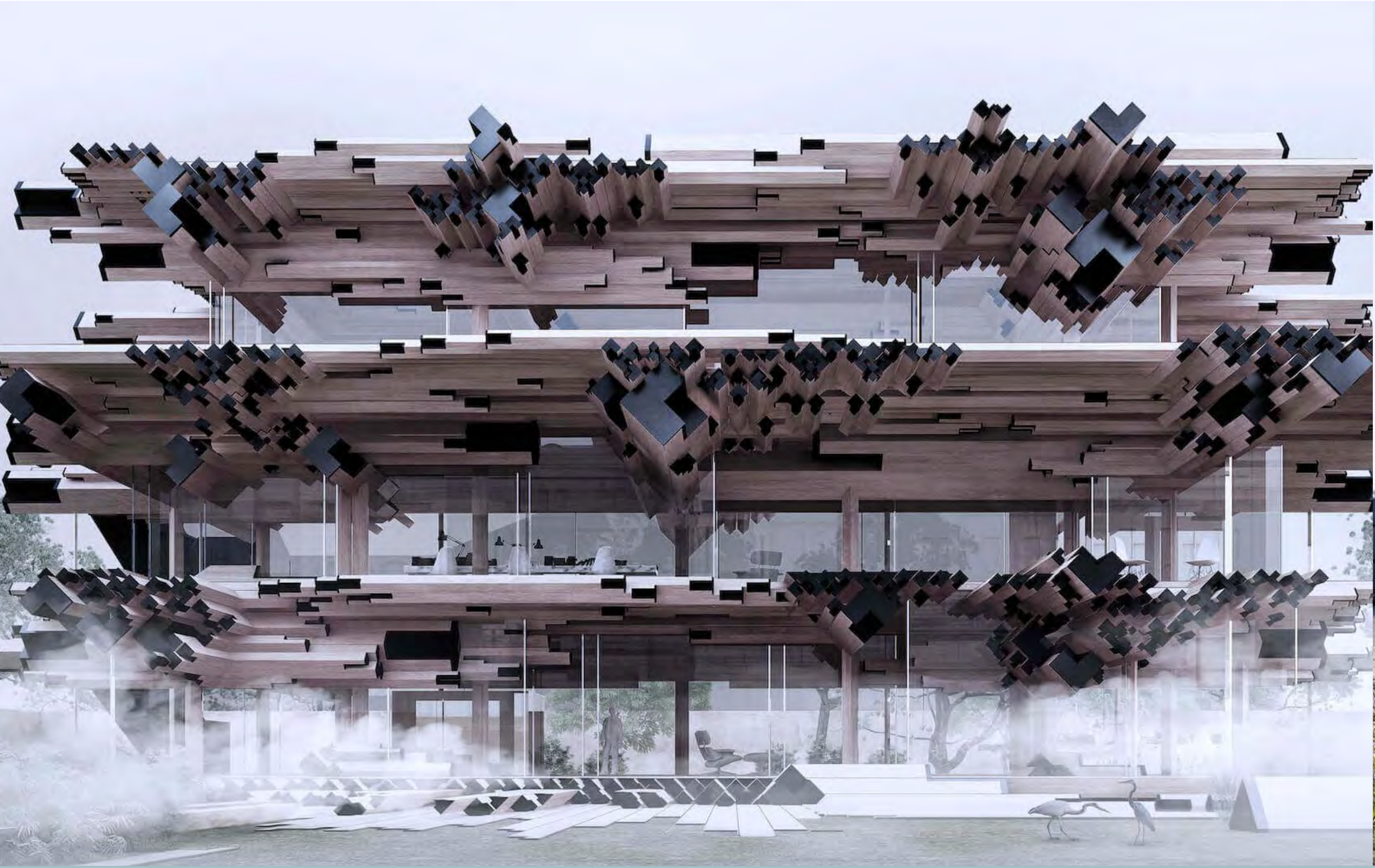
Background - Timber System in Construction Industry - Small Scale

Kivi Sotamaa - Sotamaa Builds Finland

CLT timber Prefab house with **Bespoke Design (5 stages -> 58 steps)**

Prefab houses with CLT timber with **Existing Standard Design**

Literature Review - The Gaps in the Current Industry



?

→

How to scale it up?

Working business model + New aesthetics --> Bigger social impact

Research Questions:

1. **How does the AI assist the design workflow in mass-customized pre-fabricated timber structures?**

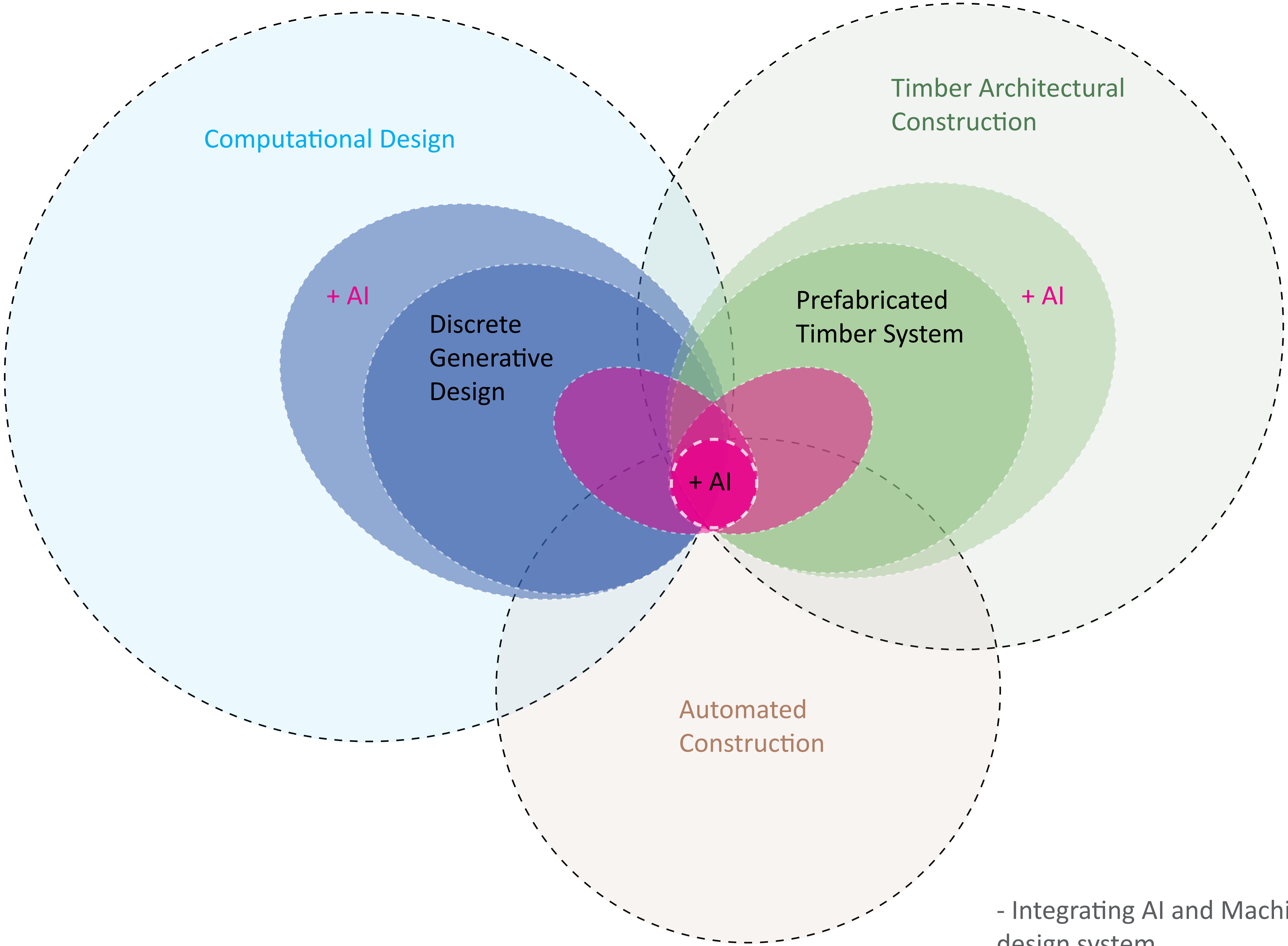
2. **How does this workflow generate new combinatorics in the discrete timber architectural design in a data-rich environment?**

3. **How does this workflow leverage the power of advanced computational capabilities and the simulation tools to create high-resolution and design-rich architectural designs?**

Keywords:

Combinatorial Design / Architectural Design Synthesis / Machine Learning / Prefabricated Timber Structure / Discrete Design / Artificial Intelligence /

The Goals of This Research

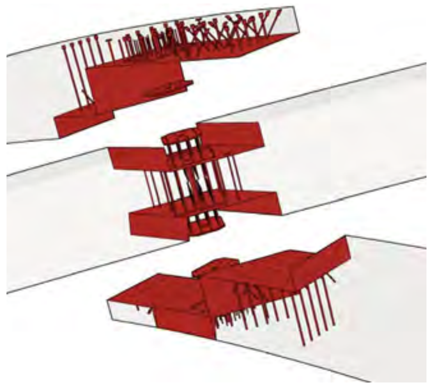


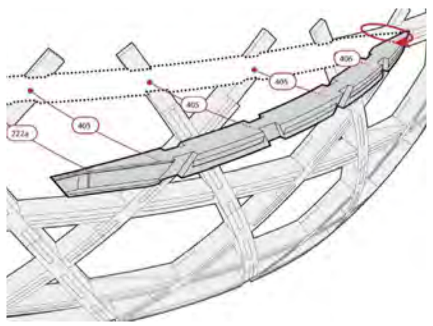
- Integrating AI and Machine Learning in the discrete prefab timber design system.

- This research will leverage the power of advanced computational capabilities in mass-customized timber architecture applications.

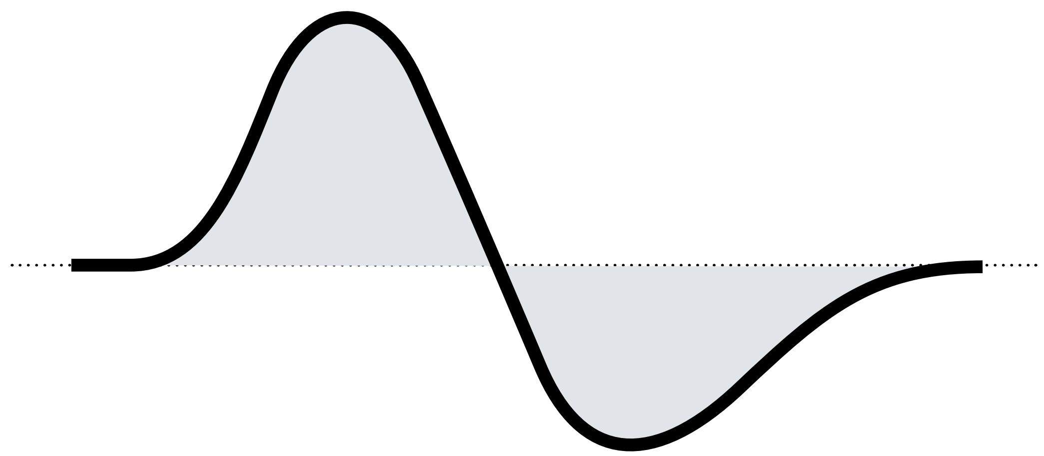
- Providing new possibilities in the timber architectural design.

Continuous Design





Discrete Design



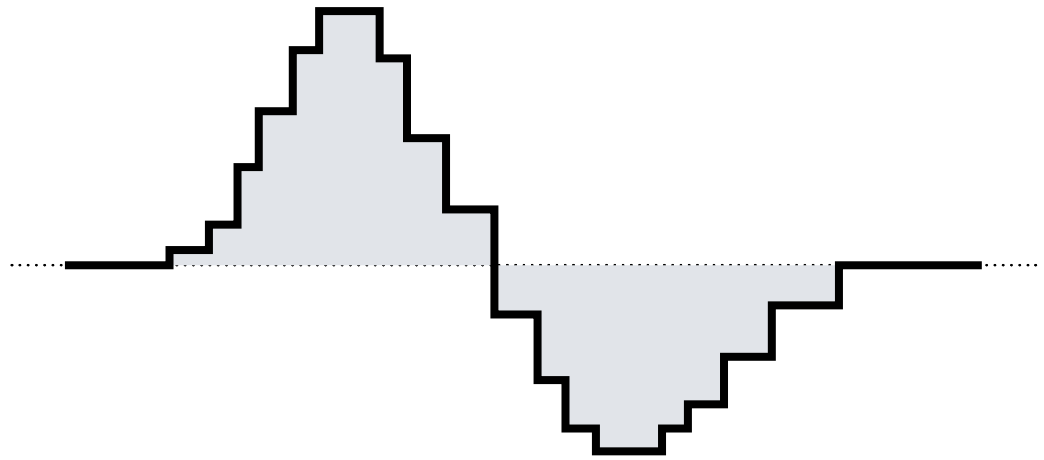
CONTINUOUS

- Highly customized elements and joints

+ Any free form

- Mathematic abstraction

- High Construction cost



DISCRETE

+ Standard parts and joints

- The repetitive look

+ Computational logic

+ Lower Construction cost

DISCRETE DESIGN

Parts

Combinatory

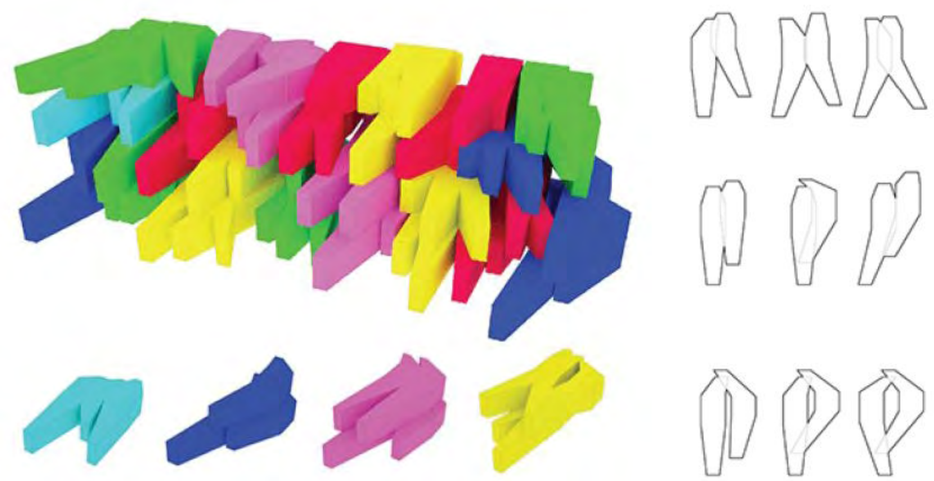


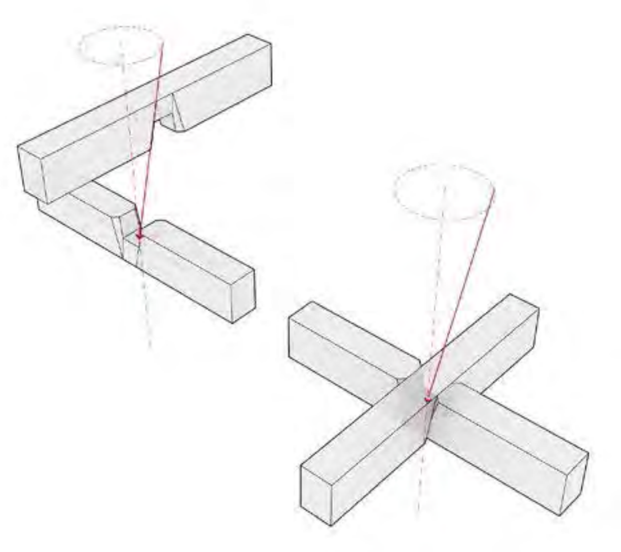
Image sources: Complex City Research Framework, RMIT & Biothing, Alisa Andrasek, 2012

COMBINATORY

↓

JOINTS

Key factors of combinatorial design in the discrete timber architectural system

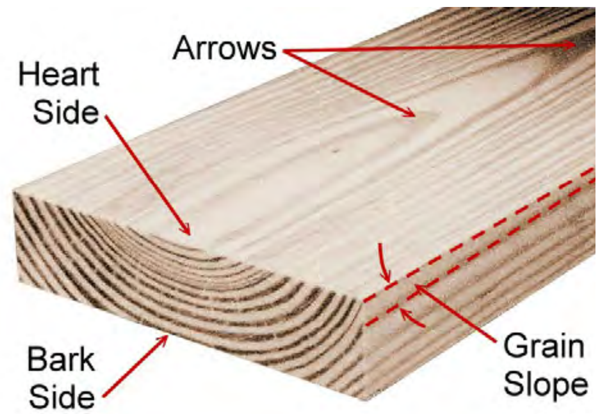


Joints Type

- Vector Math
- Aesthetics

Manufacture / Assembly Method / Computation

- 3-axis CNC / 6-axis robotic milling
- Automated/Manual assembly



Material Attributes

- Anisotropic material
- Wood type and species
- Dry-wooden/metal/gluing joint

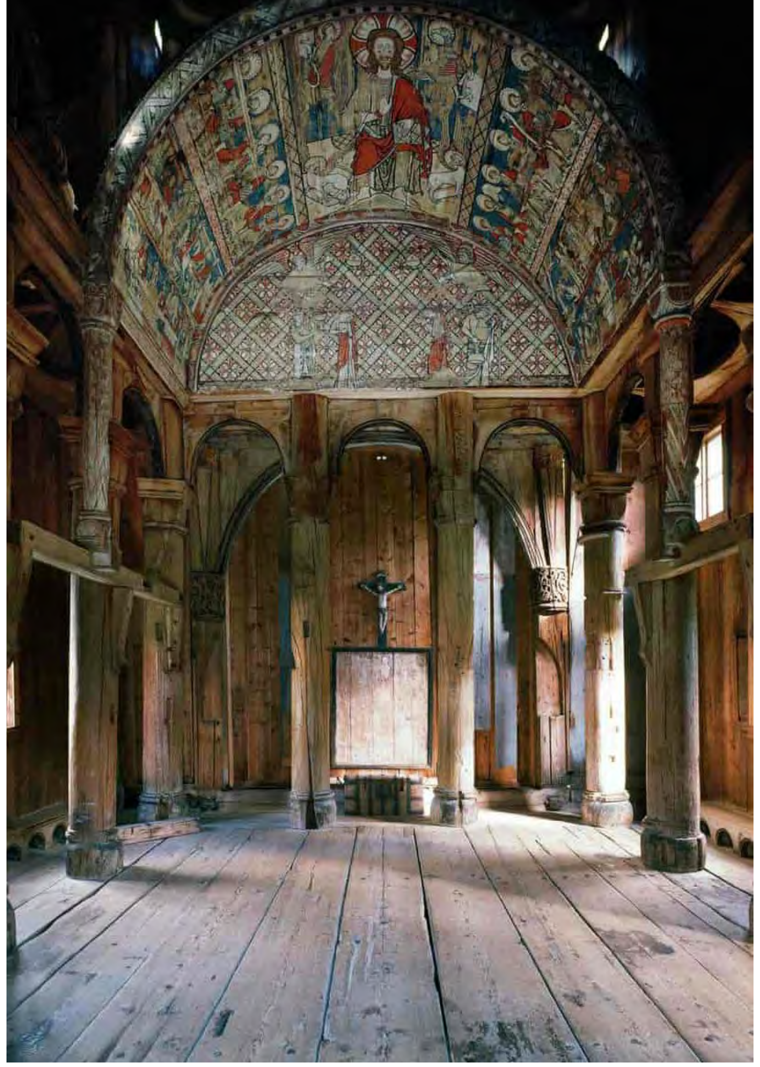
Costs / Time

- Computation is cheaper
- Material is expensive

Research Plan - Searching the simulation platform

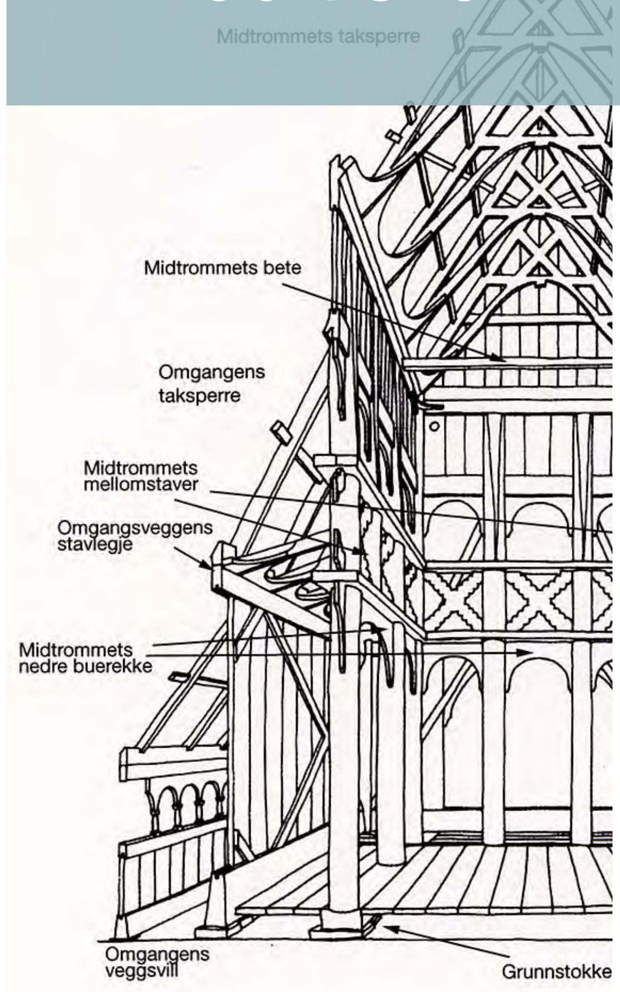
ESSENTIAL CRITERIA:

- Complex 3D modelling
- Generative design processes
- Capabilities of integrate with AI and machine learning
- Parallel computing
- Architectural performance simulations and analysis



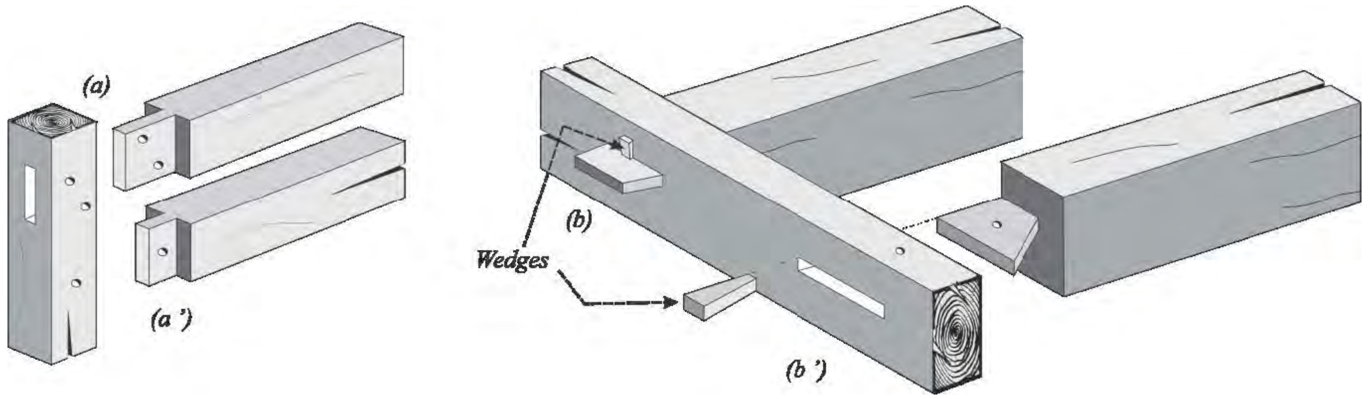
Traditional Timber Joints - Asia

Traditional Timber Joints - Europe

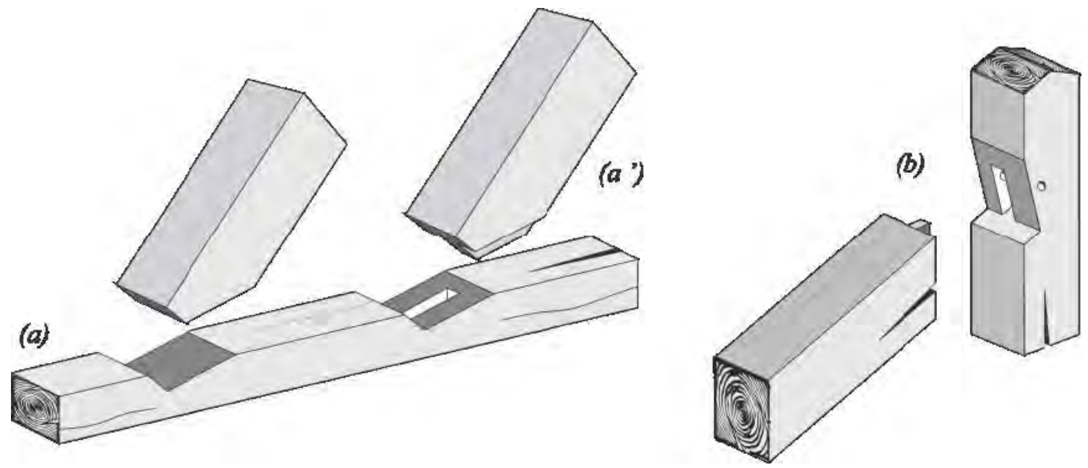


Research Plan - Establishing Dataset of Joints

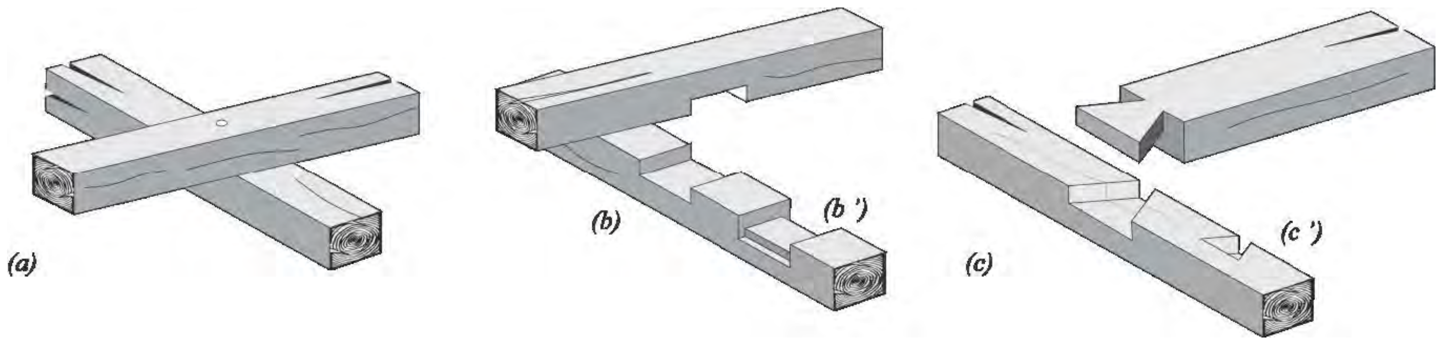
Traditional Carpentry Joints - 4 main types



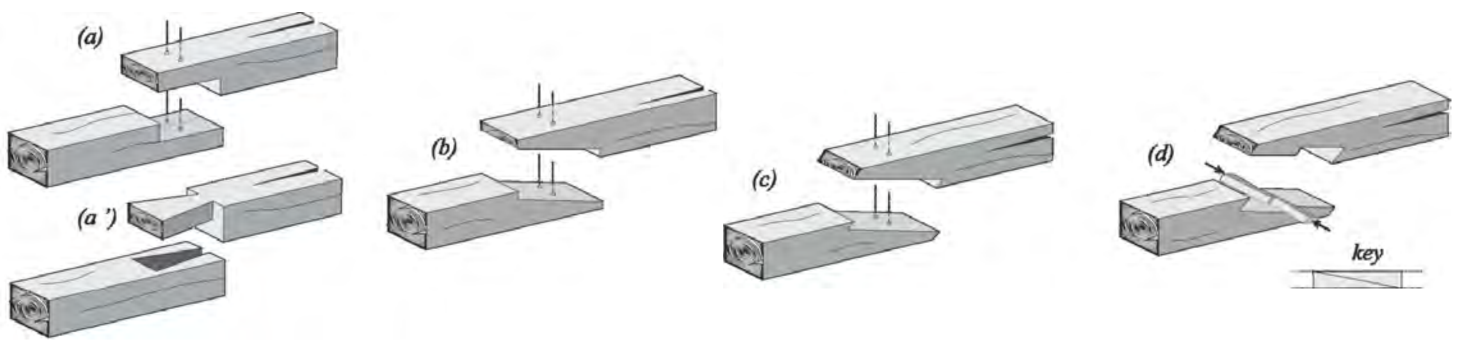
1. Tenon and Mortise Joints



3. Notched Joints



2. Lap Joints

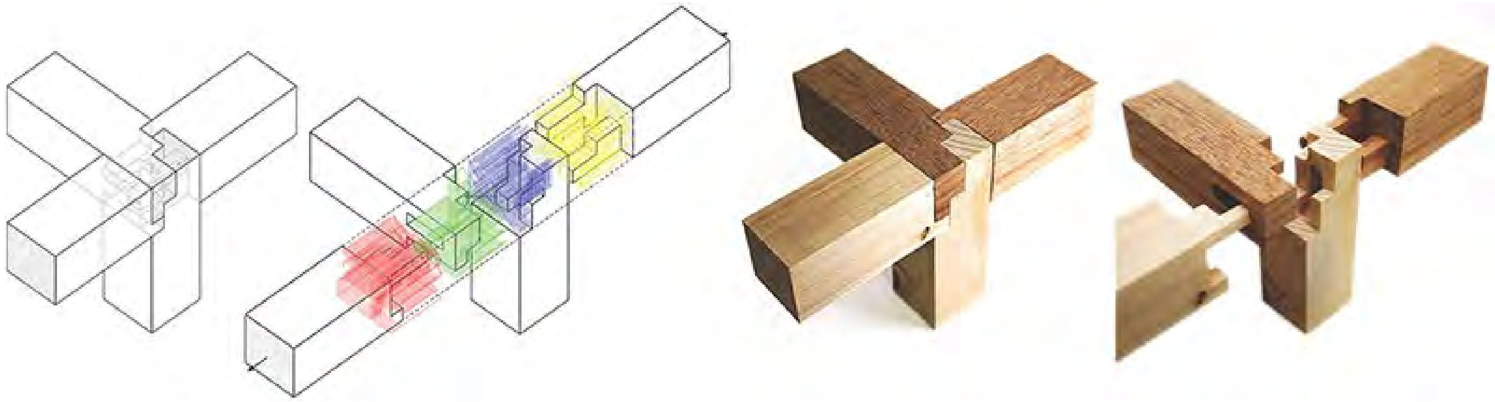


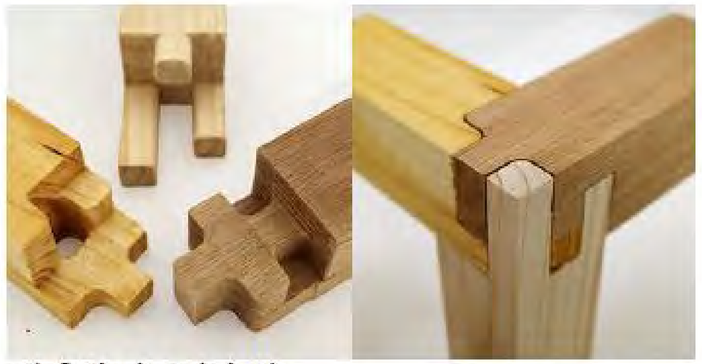
4. Scarf Joints

Branco, J. M., & Descamps, T. (2015). Analysis and strengthening of carpentry joints. Construction and Building Materials, 97, 34–47. https://doi.org/10.1016/j.conbuild-mat.2015.05.089

Research Plan - Establishing Dataset of Joints

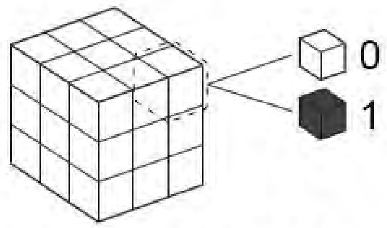
Interactive Design and Fabrication - User Interface Research Group - IGARASHI Laboratory/University of Tokyo (2020)



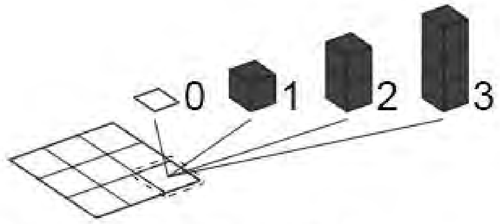


a) 3-timber joint*

b) 4-timber joint*



27^{27} = 134 217 728

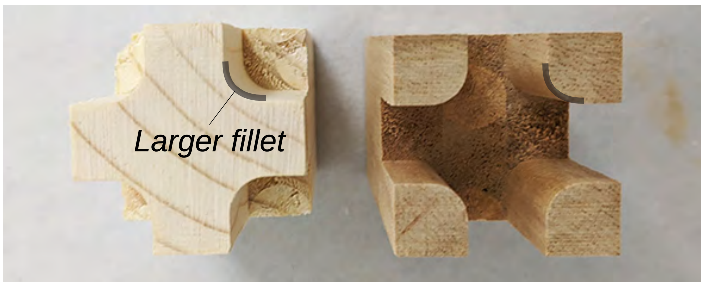


4^9 = 262 114 (ours)

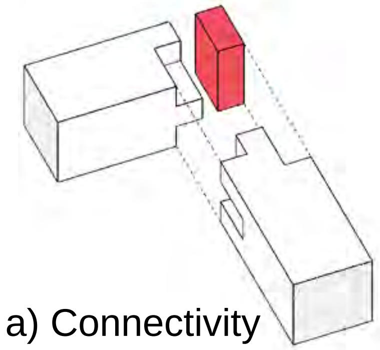
a) 2×2×2

b) 5×5×5

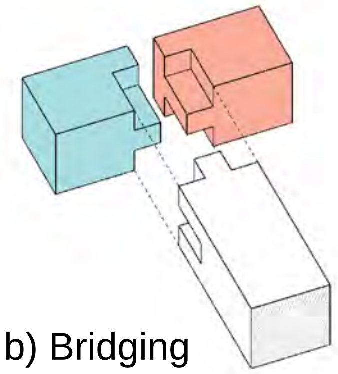
a) Mill bit: Ø 6 mm



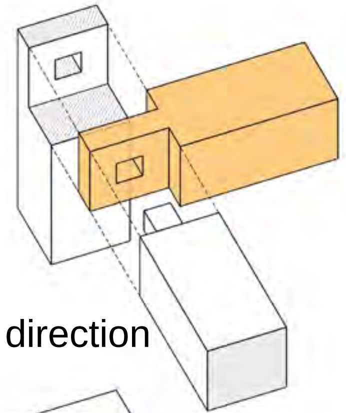
b) Mill bit: Ø 10 mm



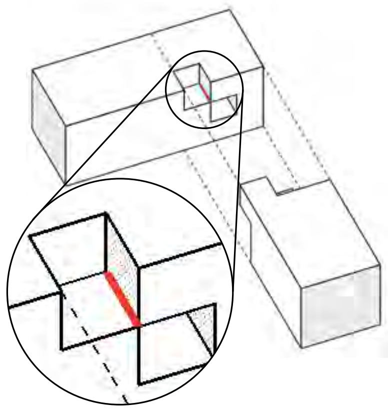
a) Connectivity



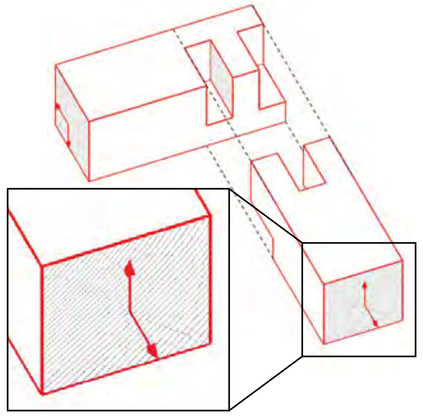
b) Bridging



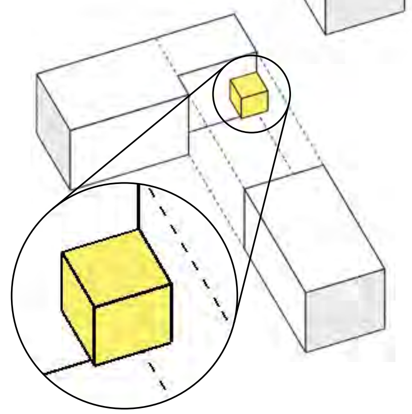
c) Milling direction



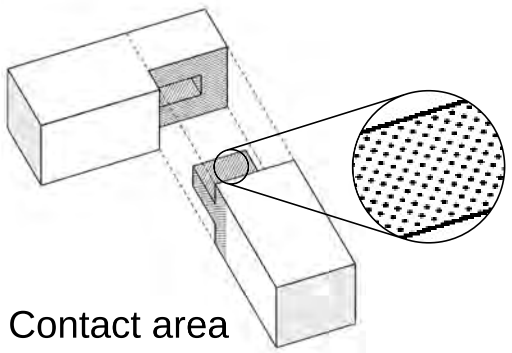
d) Checkerboard



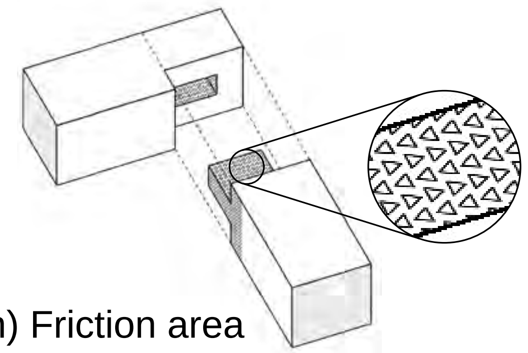
e) Slidability



f) Durability



g) Contact area



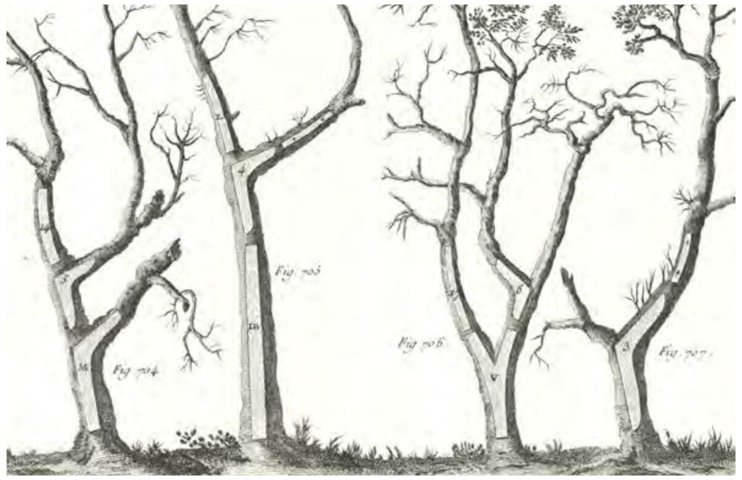
h) Friction area

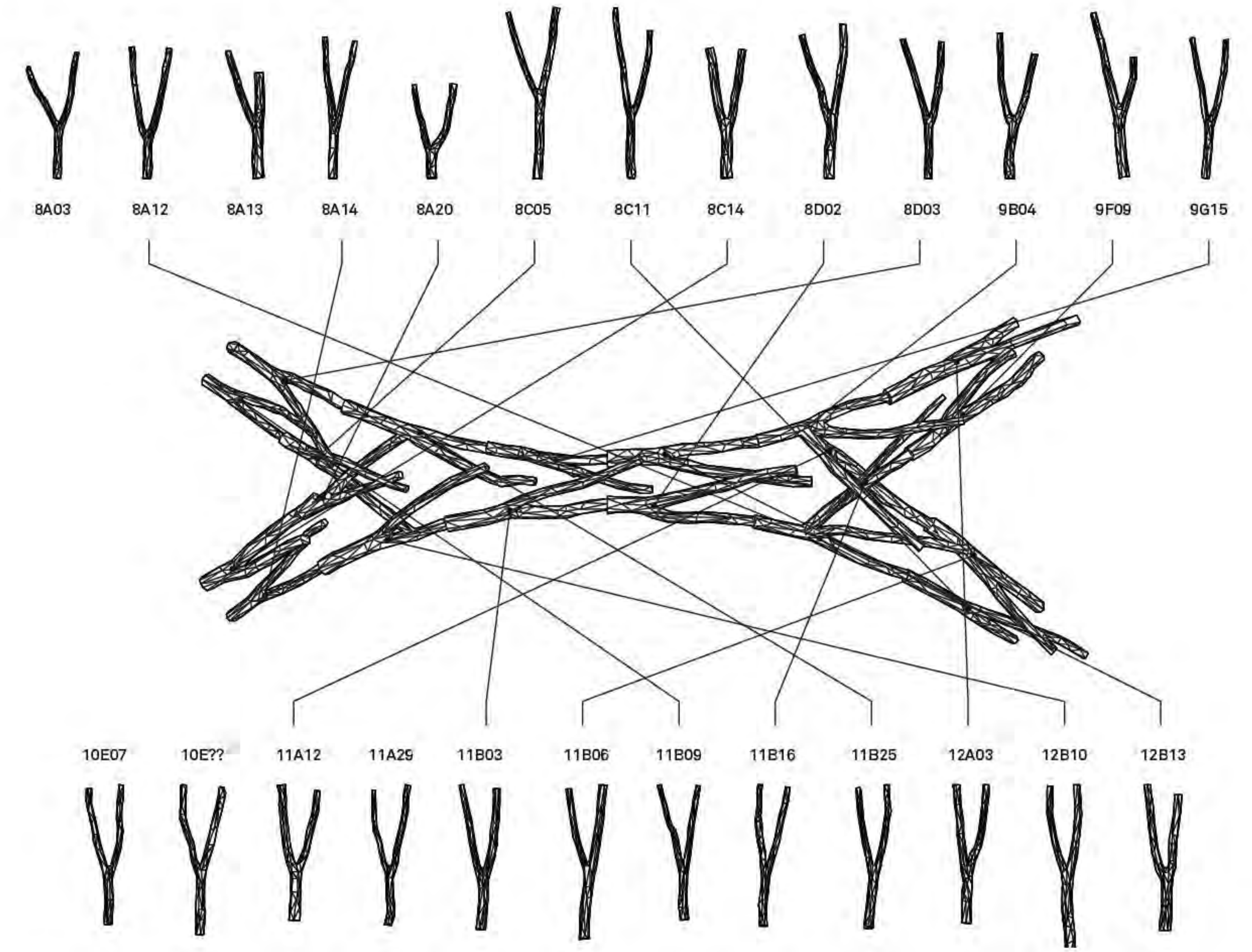
The system is implemented as a tool for designing a single wood joint for connecting timbers with rectangular sections. The system was based in a 3D grid of voxels space. The joints were evaluated by 8 performance metrics.
In the case of one 3 × 3 × 3 resolution joint between 2 timbers, the number of possible designs are 134 million. Searching through all the possibilities took 30 min. If it is 3- to 6-timber joint took 3–9 hours.(Considered as lightweight feedback, not with Finite Element Analysis(FEA))

Interactive Design and Fabrication of Wood Joints
Maria Larsson, Hironori Yoshida, Nobuyuki Umetani, and Takeo Igarashi
The University of Tokyo

Research Plan - Combinatorics Exploration with AI Searching

Wood Chip Barn, AA Design+Make (2016)



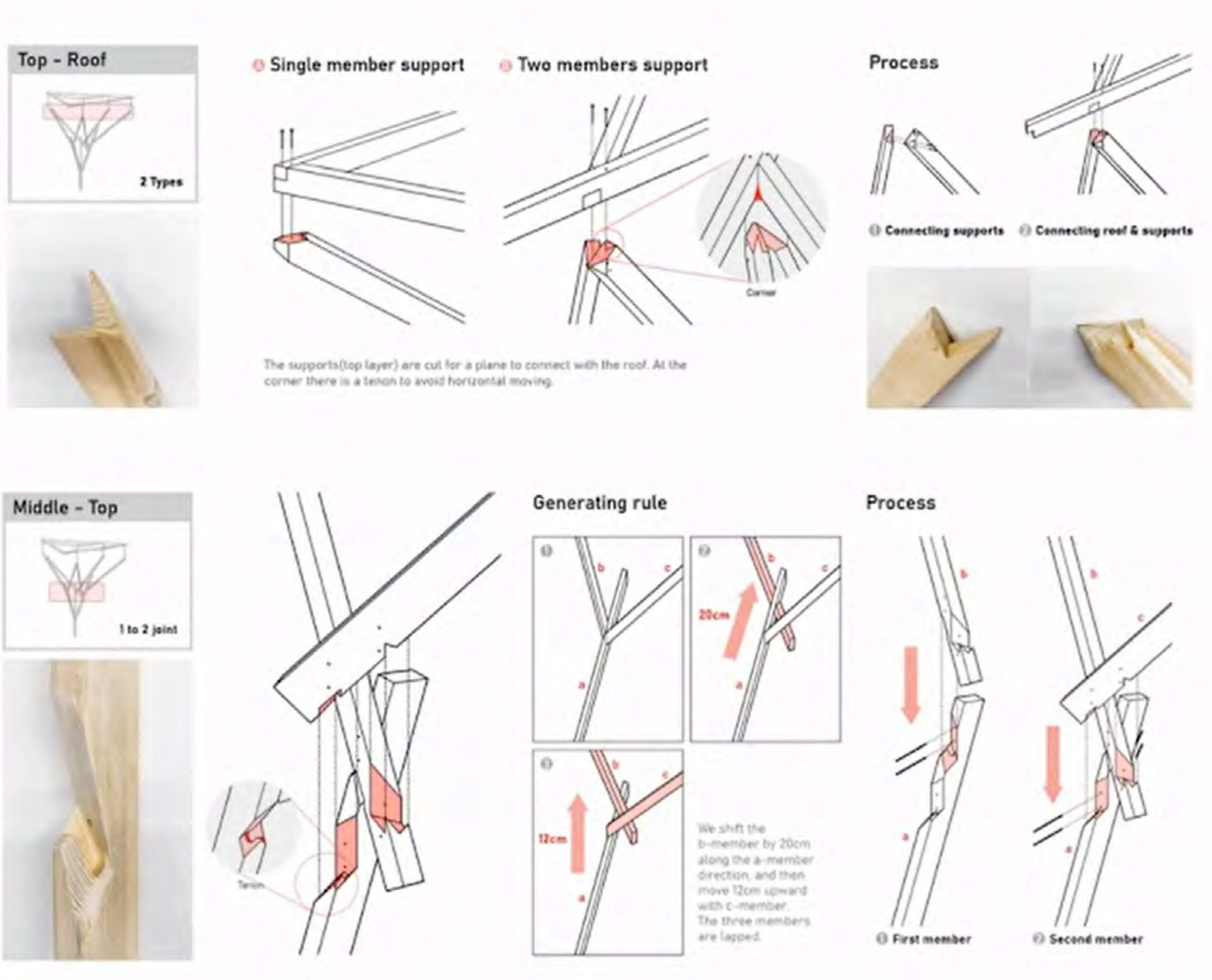


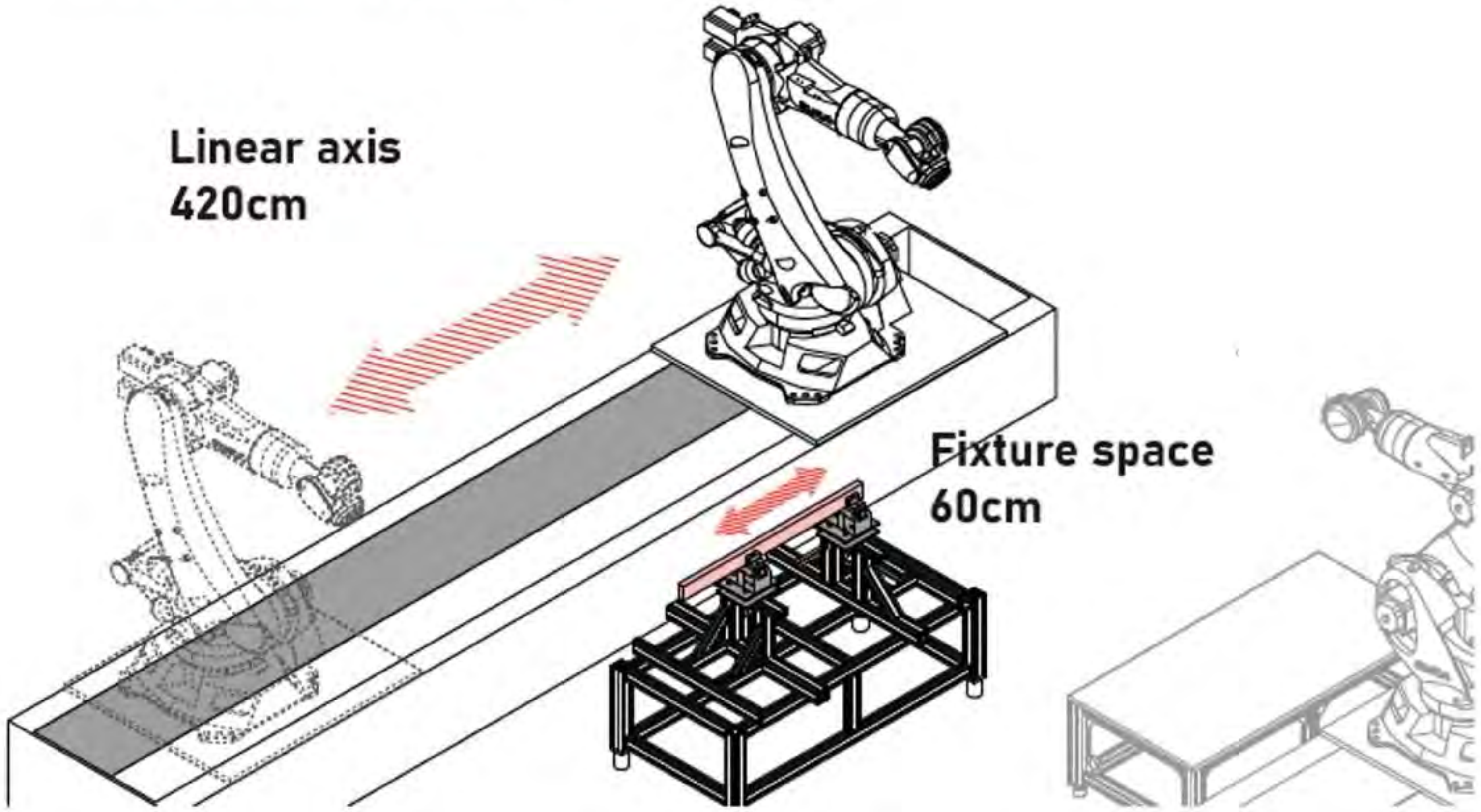
Wood Chip Barn, AA Design+Make, 2016

Design & Make Students: Mohaimeen Islam, Zachary Mollica, Sahil Shah, Swetha Vegesana, Yung-Chen Yang
Tutors: Toby Burgess, Charley Brentnall, Martin Self, Emmanuel Vercruysse

The application of 3D-scanning, metaheuristic evolutionary optimization of the placement of each discrete component within a structurally determined arch, and customized robotic fabrication are presented as enabling an alternative conception of material form in which inherent irregular geometries are actively exploited by non-standard technologies.

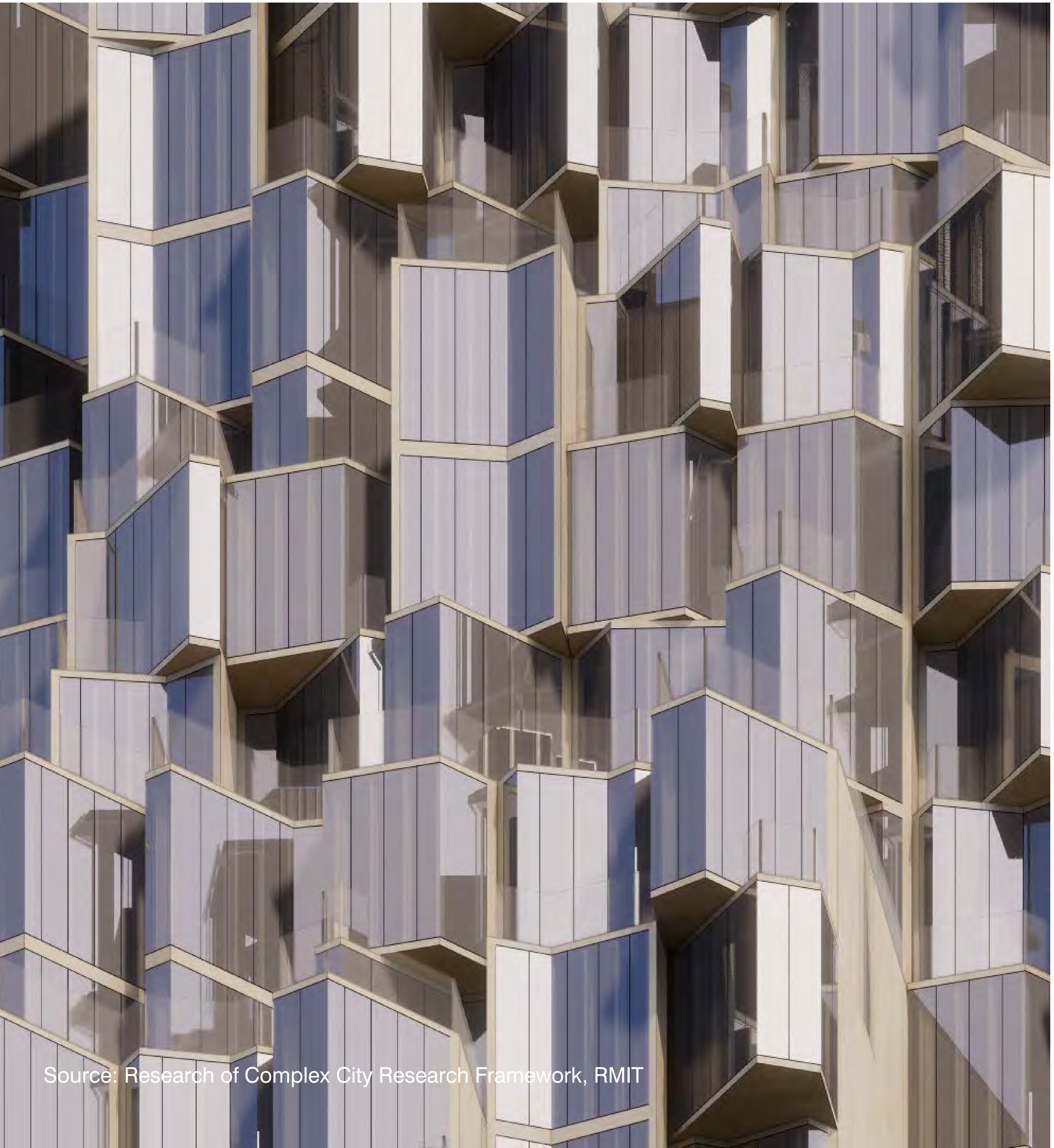
Research Plan - Combinatorics Exploration with AI Validation





Source: Interlace Forest, Raccoon, College of Planning and Design NCKU, 2022

Research Plan - Design Exploration and Prototyping

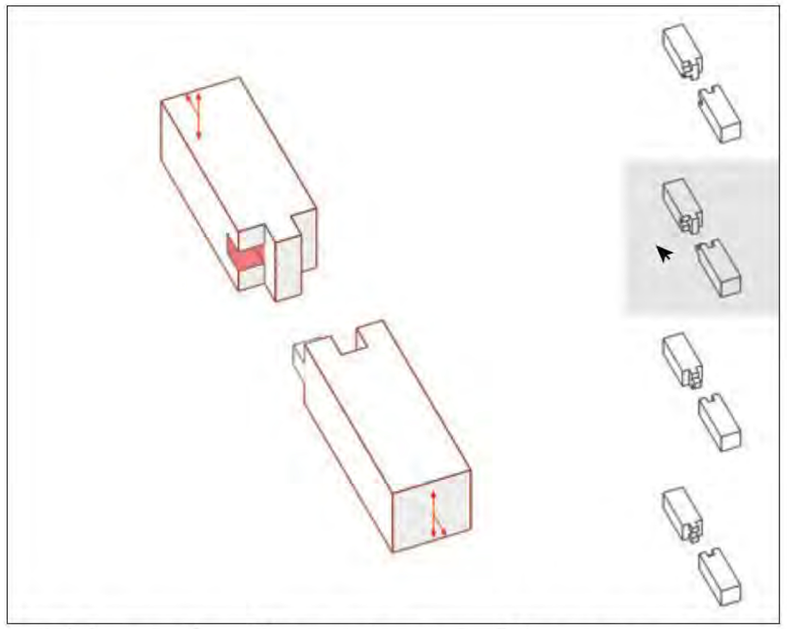


Source: Research of Complex City Research Framework, RMIT

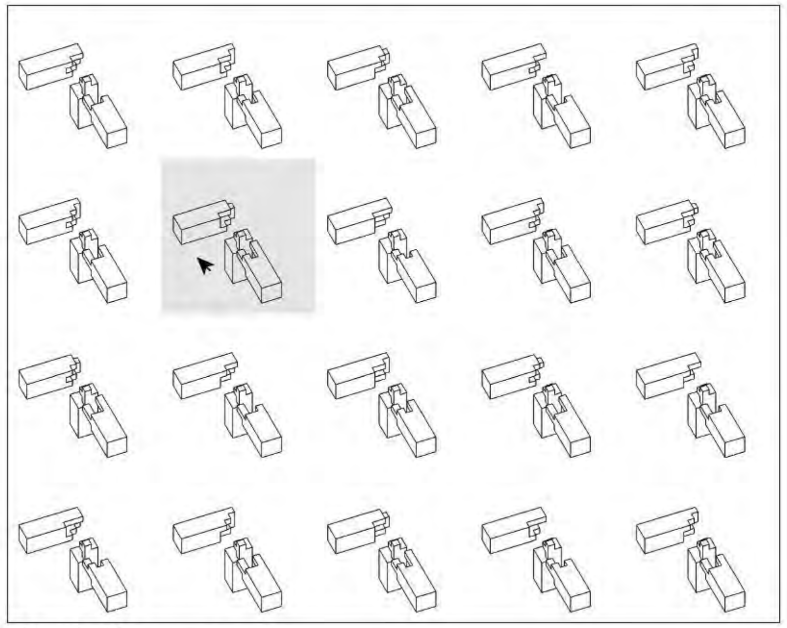
MACHINE LEARNING + JOINT SEARCH
+DISCRETE PARTS
// MORE POSSIBILITIES

- Explore innovative combinatorial possibilities of discrete timber components through various vector fields and the joint dataset.

Research Plan - User Interface with Assistance of Visual Feedback

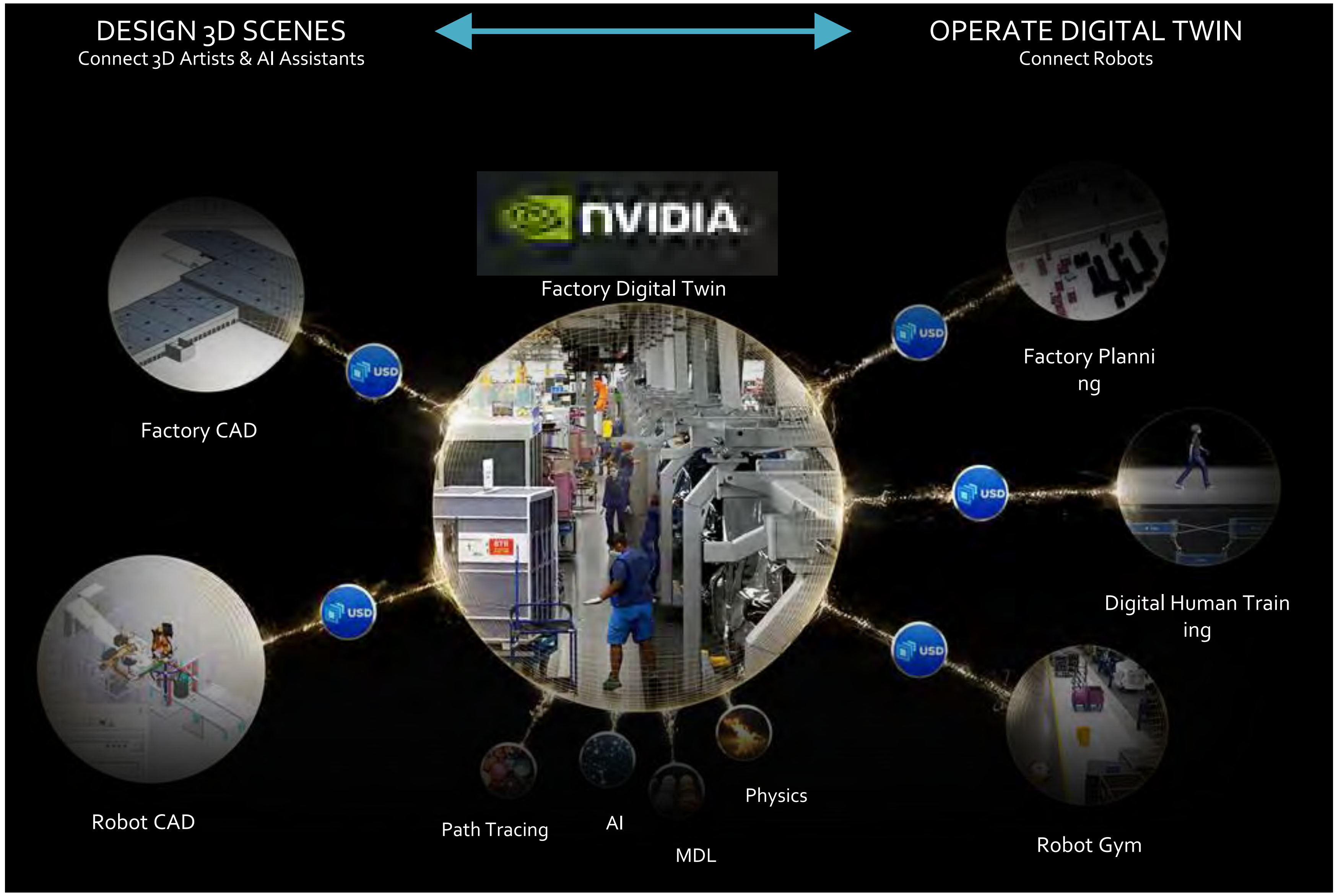


a) Manual editing mode with suggestions



b) Gallery mode

Source (upper images): User Interface Research Group - IGARASHI Laboratory/University of Tokyo



INTERFACE

The aim of the interface is to create a visual aid that assists designers and engineers in efficiently interacting with the design system. In this process, the integrated AI will provide a collection of valid design solutions based on the designer's intentions.

By shortening the design validation process, it encourages designers' creativity and fosters more exploration. Simultaneously, it efficiently synthesizes design data, bridging the gap between various fields of expertise in the prefabricated timber design system.

Preliminary Bibliography

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THEORY

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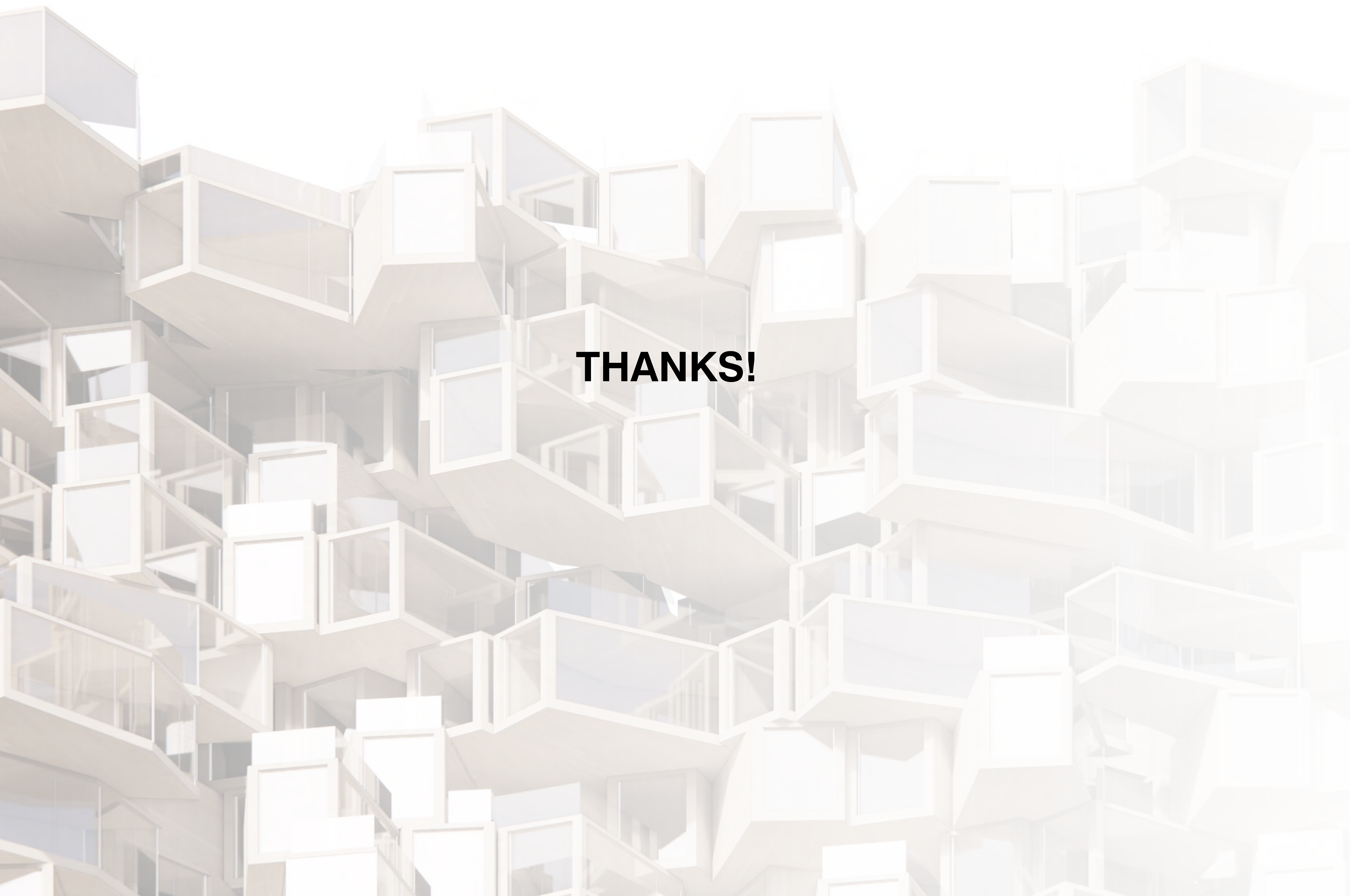

THANKS!