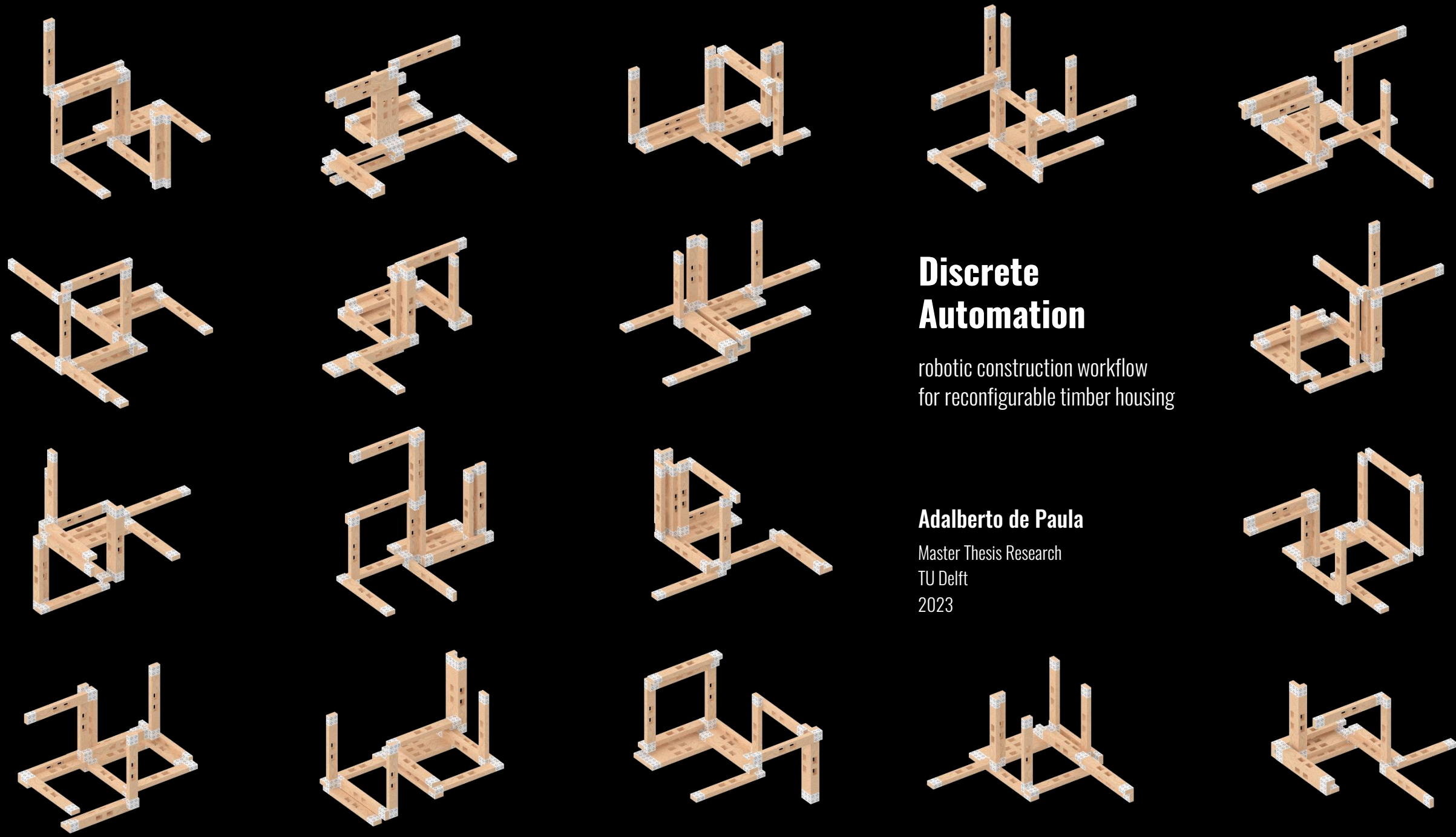


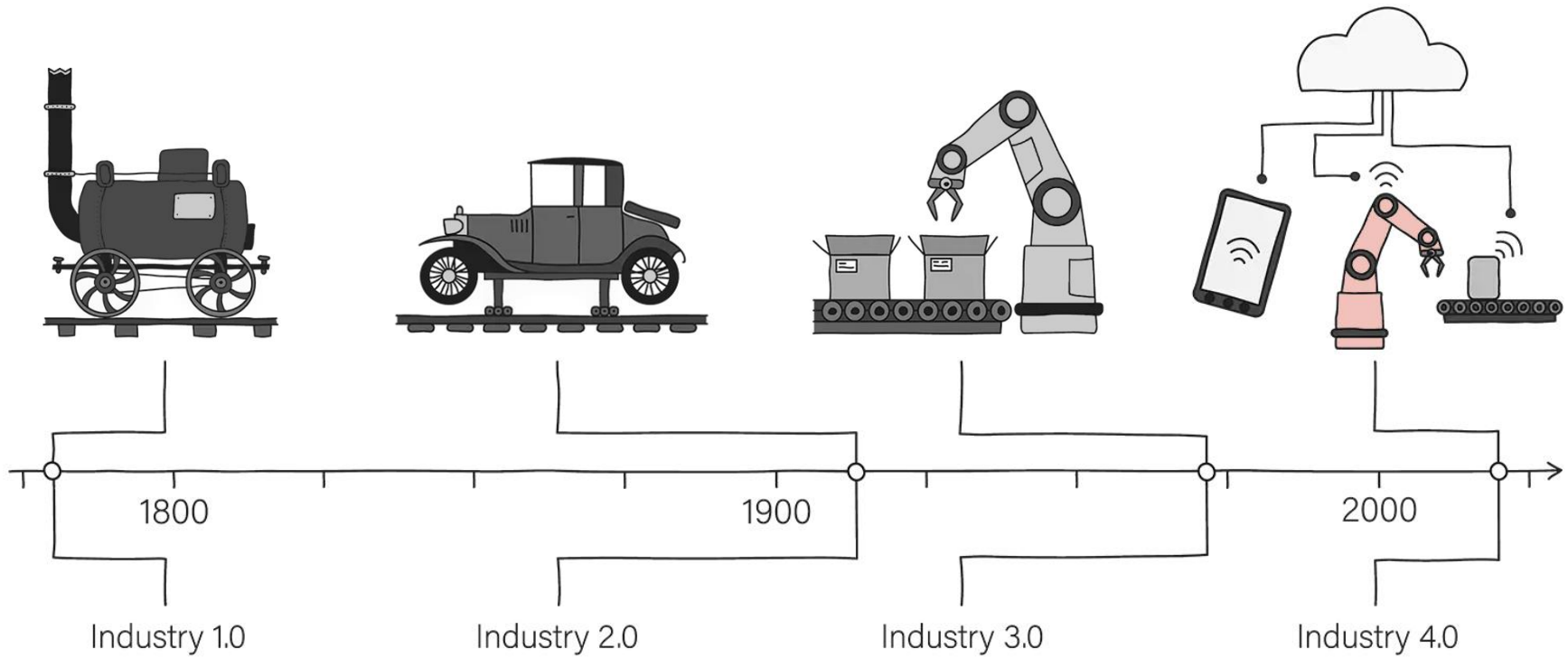
Discrete Automation

robotic construction workflow
for reconfigurable timber housing

Adalberto de Paula

Master Thesis Research
TU Delft
2023

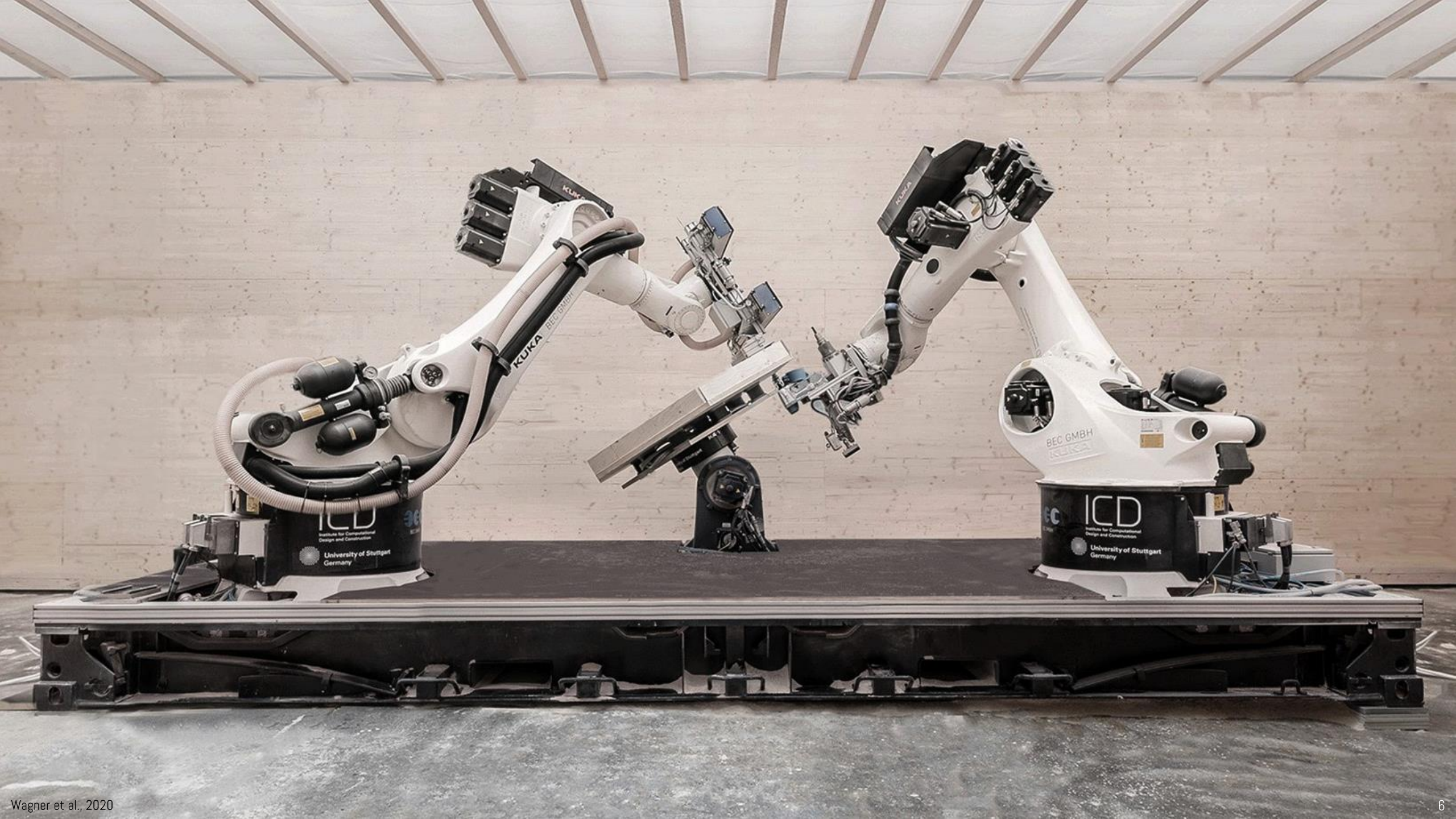
work less,
work everyone,
automate everything,
produce what is necessary,
redistribute everything.



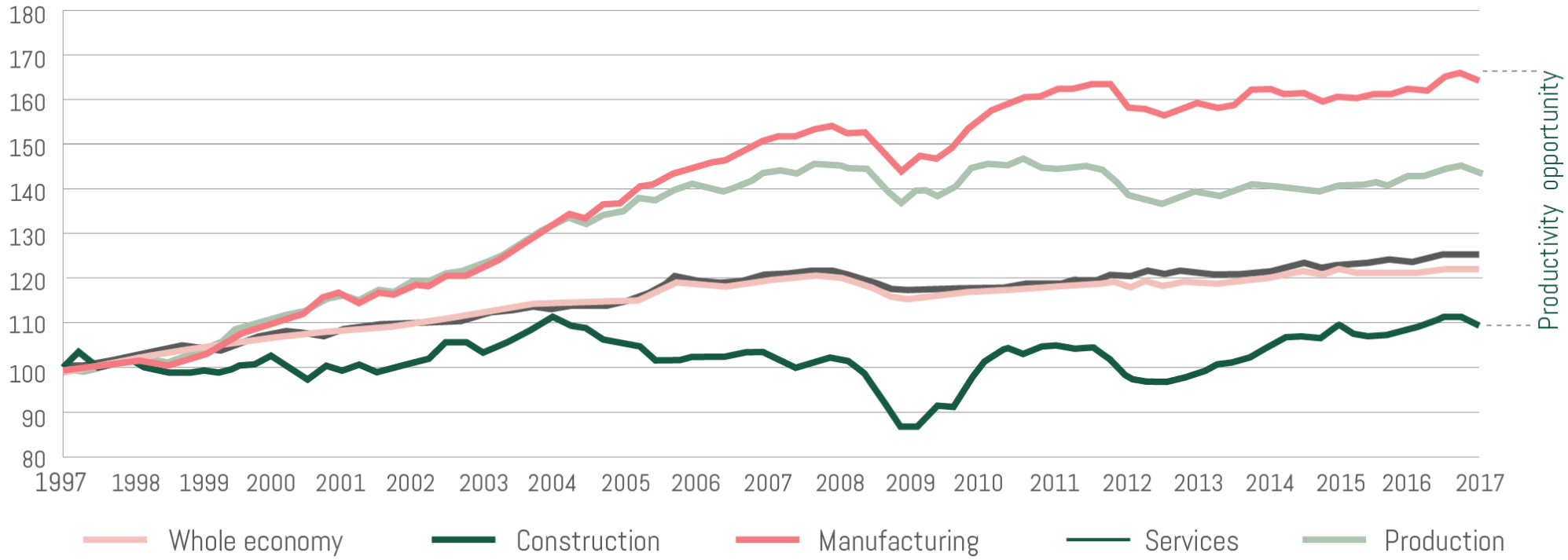
Adapted from Simio Forward Thinking, 2023

Fabricate book, 2011, p. 173, Fig. 5

Bau des RLC Alain Herzog / EPFL 2010



Wagner et al., 2020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1997
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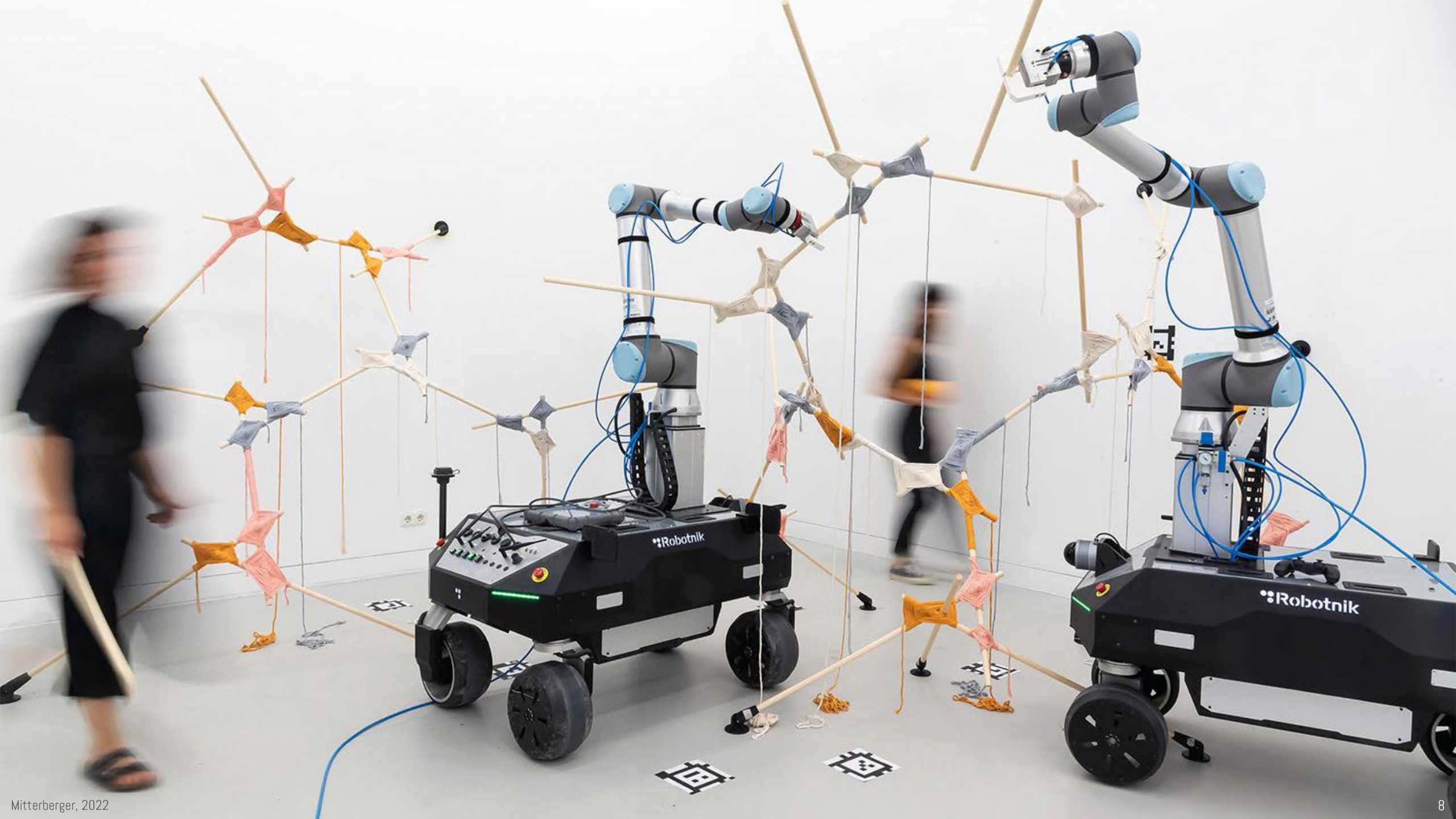
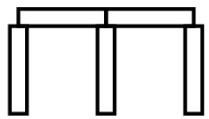
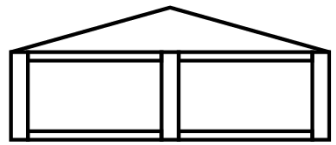
2011
2012
2013
2014
2015
2016
2017
Productivity opportunity
Whole economy
Construction
Manufacturing
Services
Production

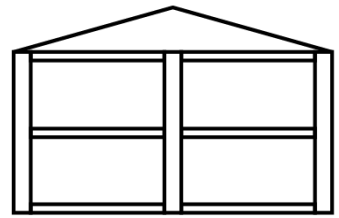

Robotnik
Robotnik



really old

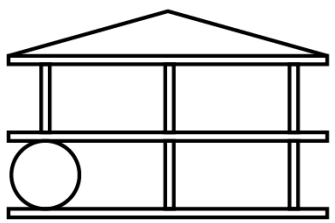


< 1000 BC

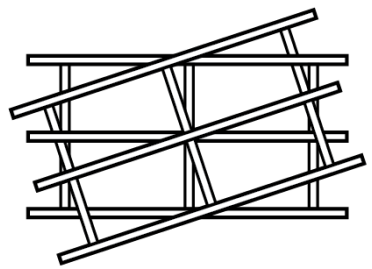


1000 BC - 1920

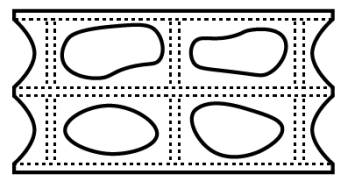
1920 - 1970



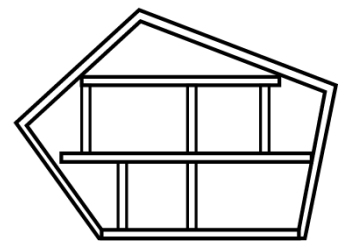
1970 - 1990



1990 - 2000

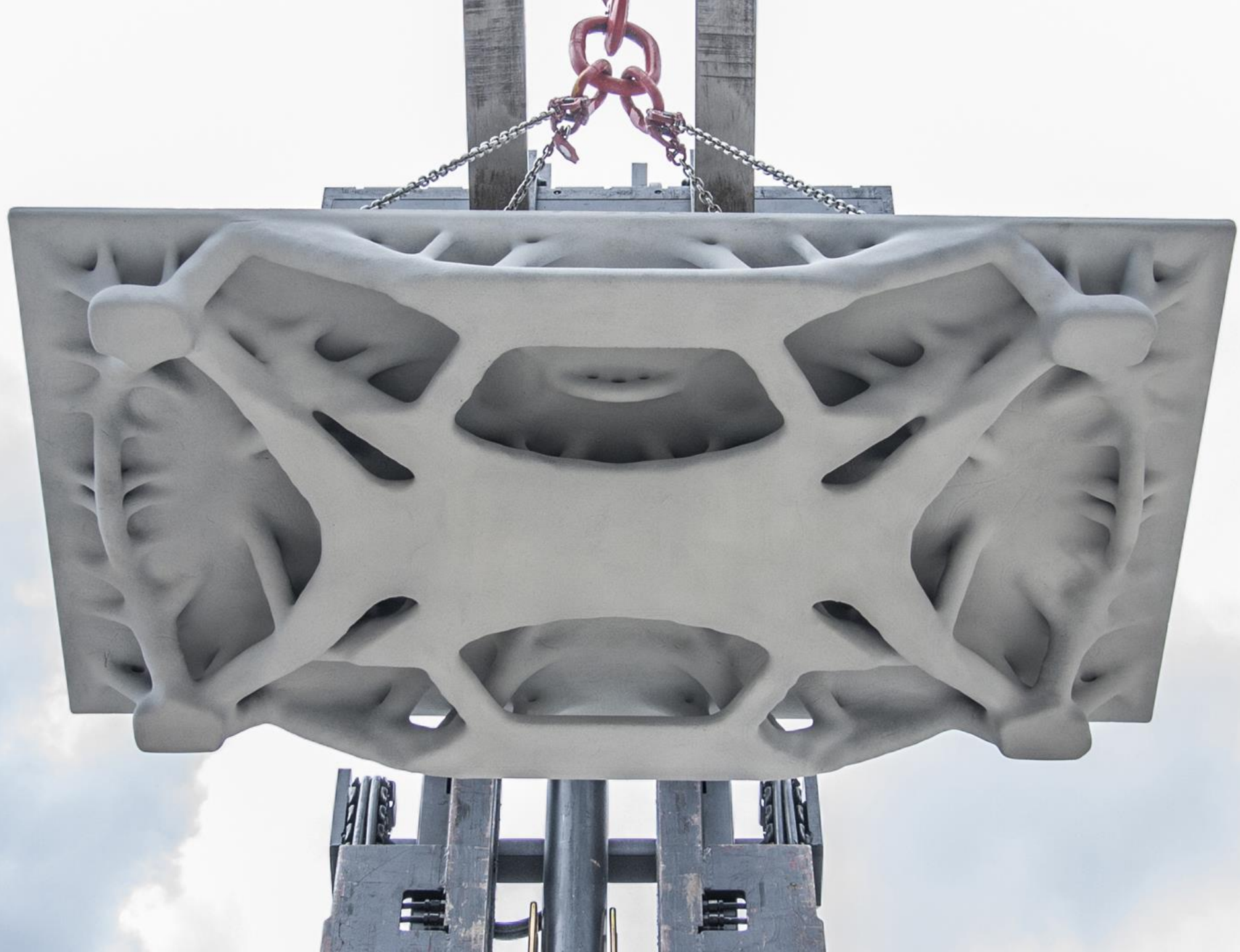


2000 - 2008



2008 - today

Zaha Hadid Architects, 2011

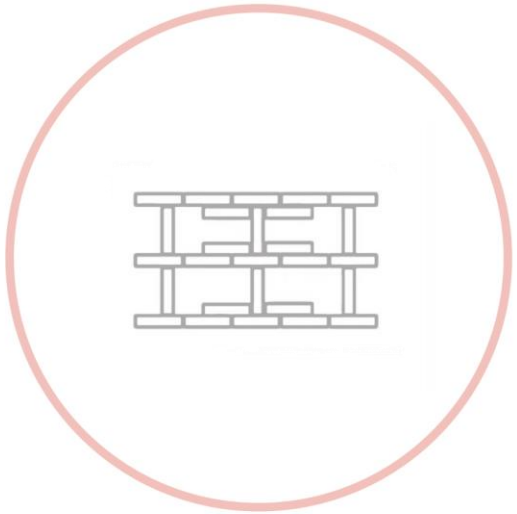


Automation

Human-Robot Collaboration

Automated workflow

Increase of productivity



Discrete design

Discrete architecture thinking

Reconfigurability

Mass customization

Circularity

Design-for-disassembly

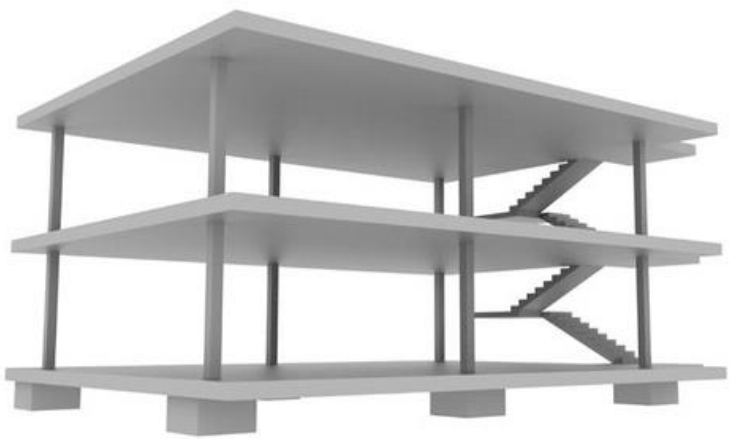
Design for future reuse

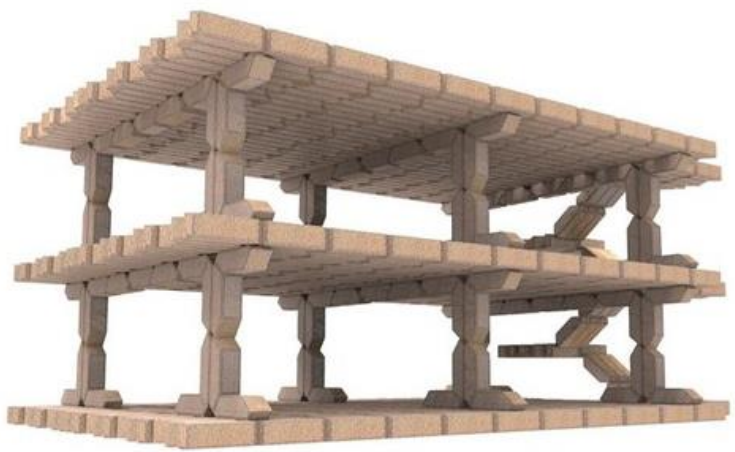
Low-carbon biomaterial

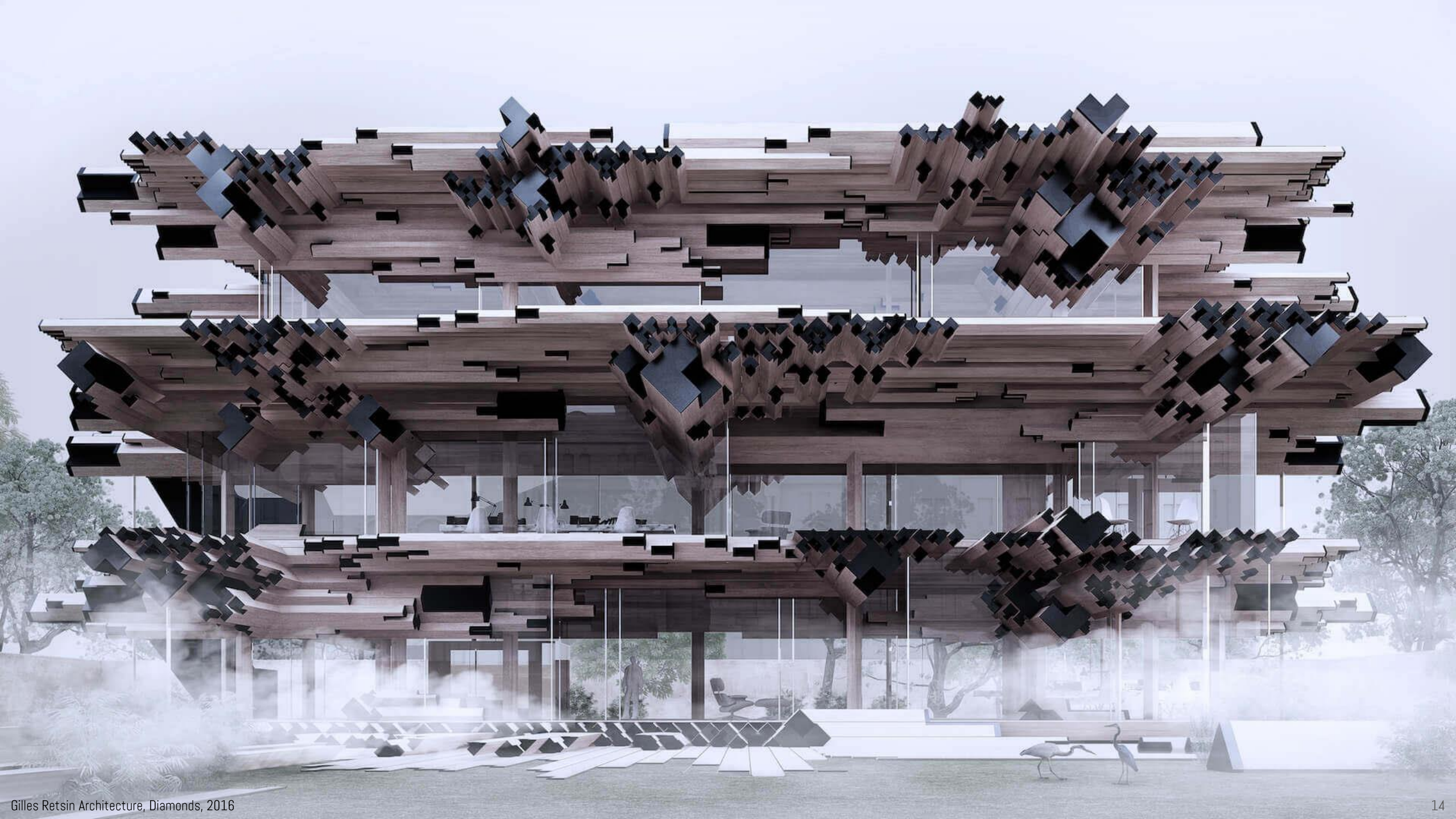
Scalable production model for affordability

Column Floor Stair

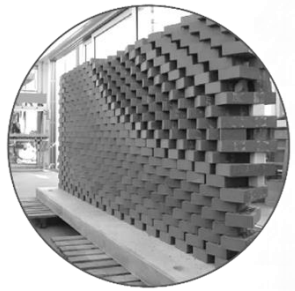
"Column" "Floor" "Stair"







Gilles Retsin Architecture, Diamonds, 2016



solid blocks

hollow blocks

solid-bar blocks

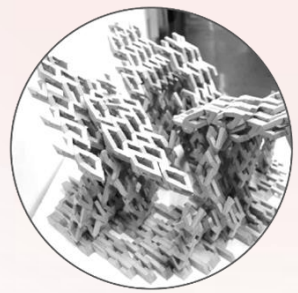
hollow-bar blocks

solid plates

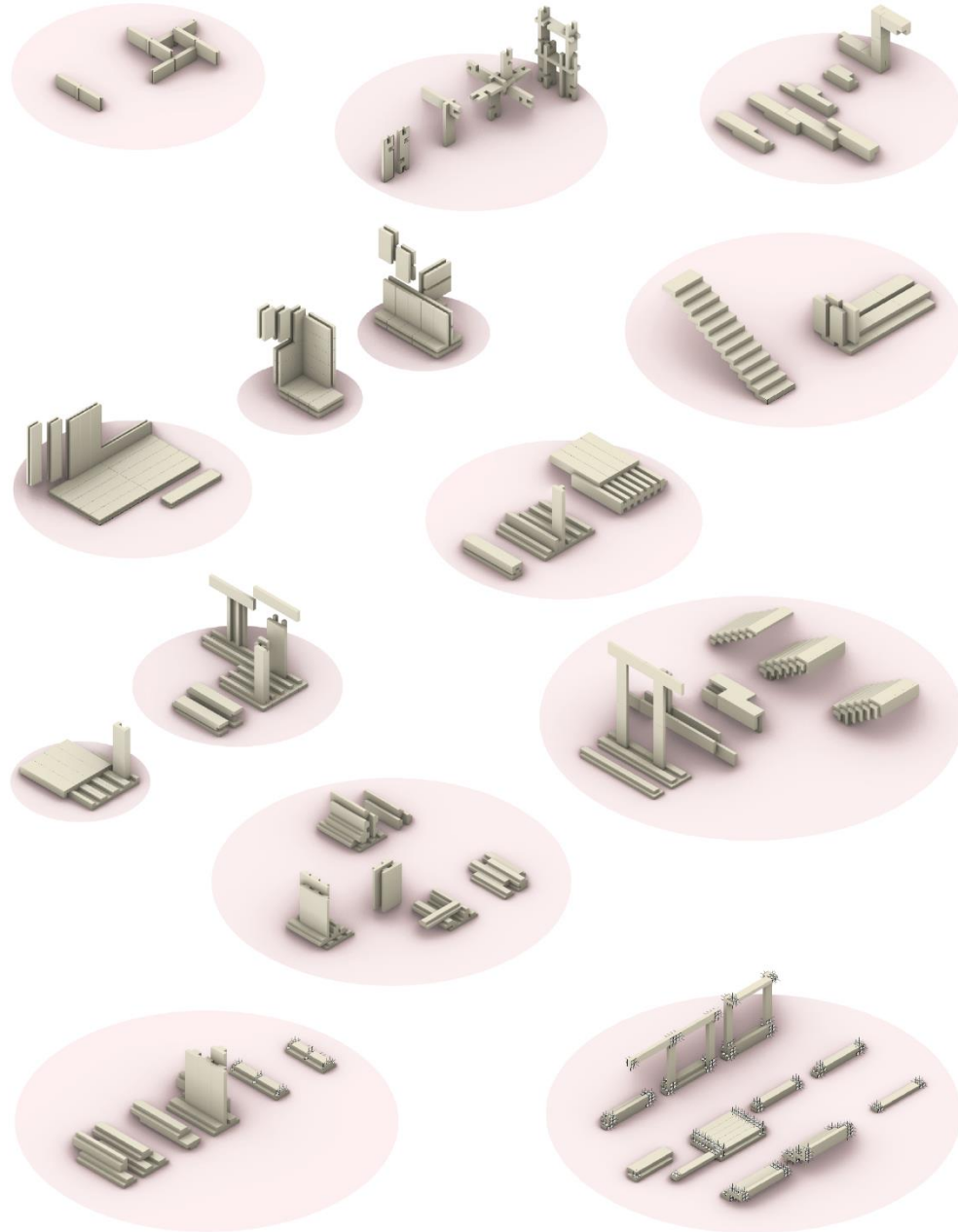
hollow plates

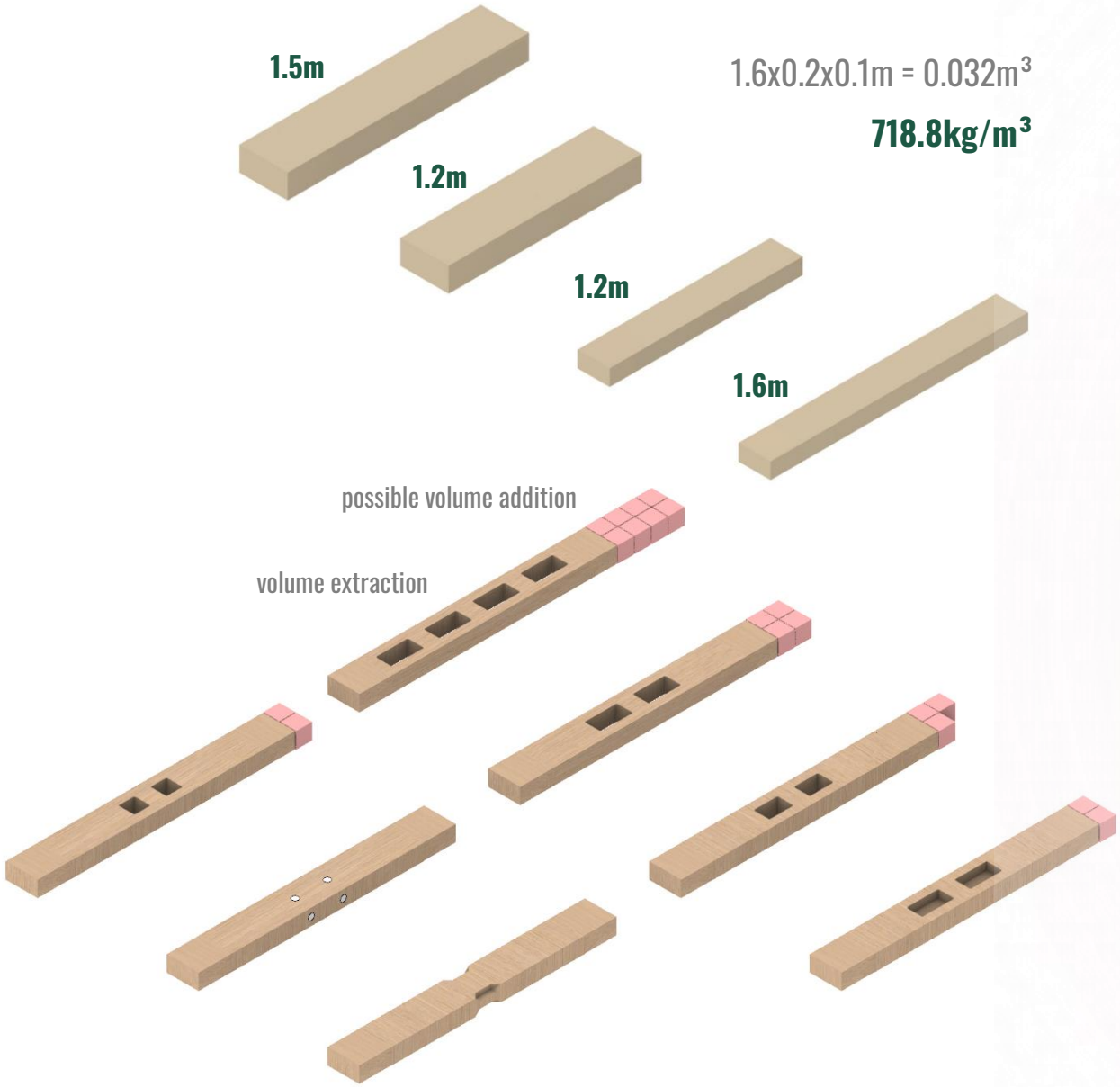
orthogonal beams

shape-specific beams



complex blocks



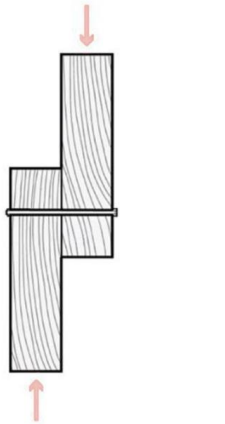


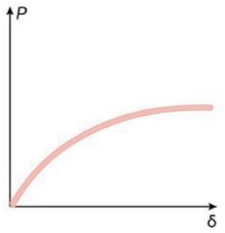
1.6x0.2x0.1m = 0.032m³

718.8kg/m³


Railway Sleeper
100x200x2400mm

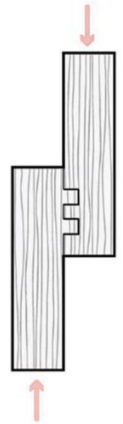
Shear resistance and assembly self-alignment features

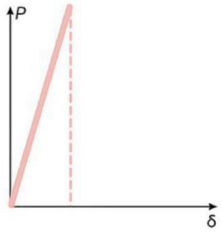




A

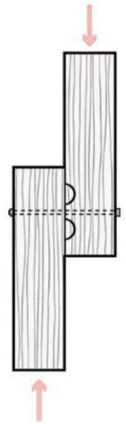
Traditional bolted connection

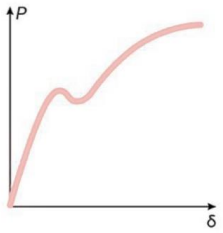




B

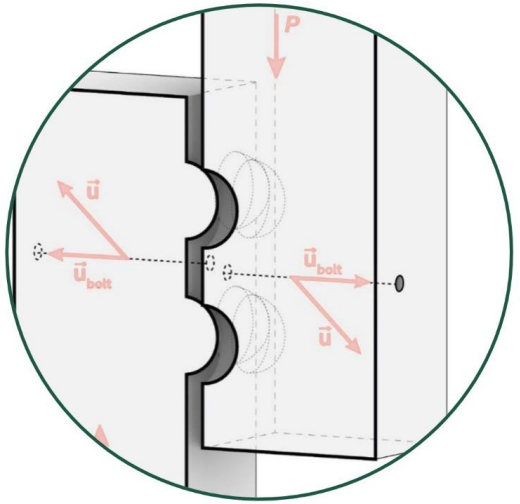
Finger joint connection

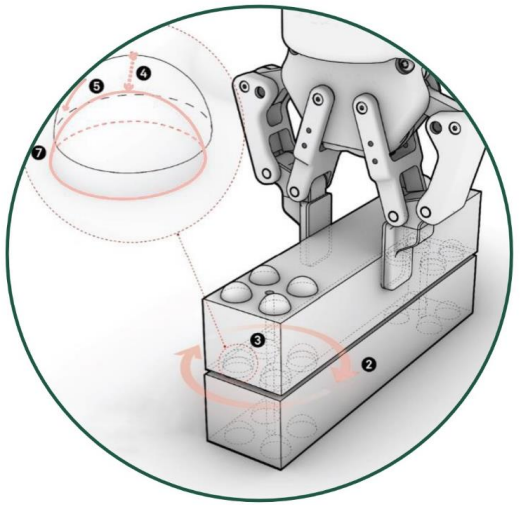




C

New connection proposed in this study



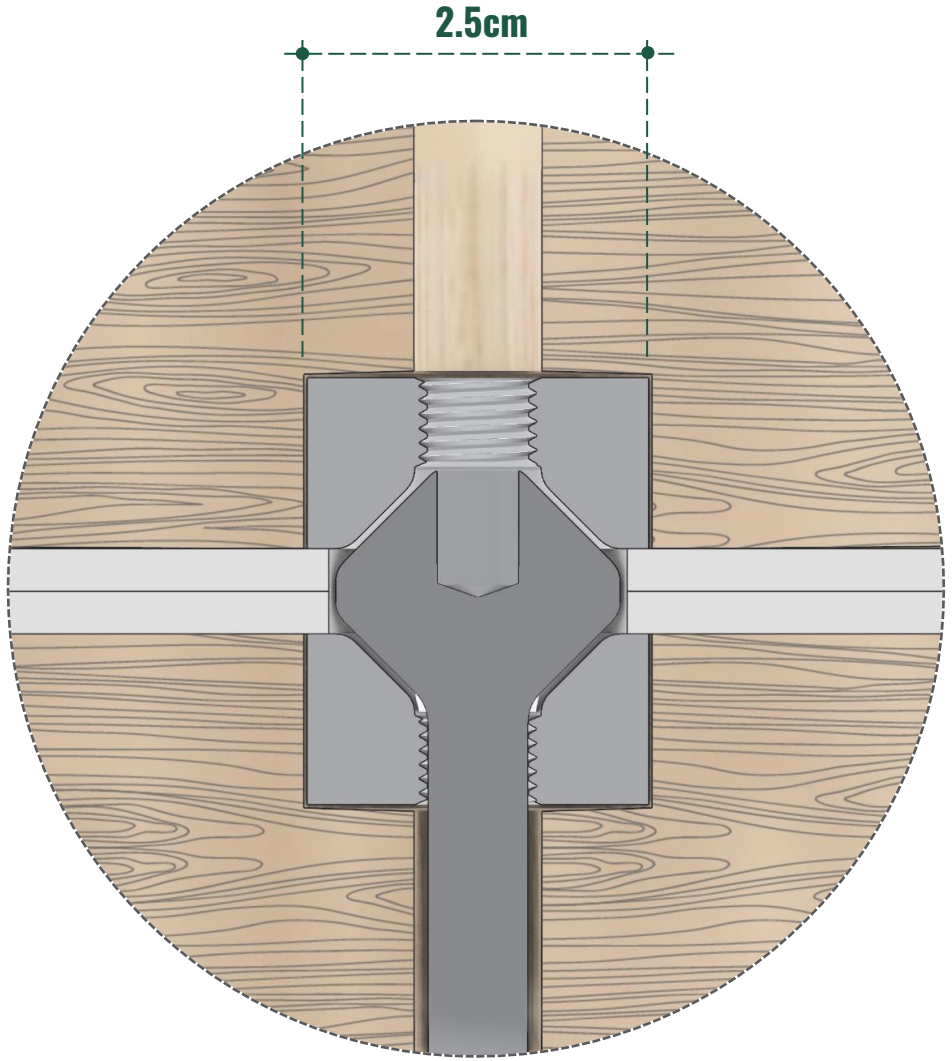


Hansen et al., 2021

Bolts and nut design

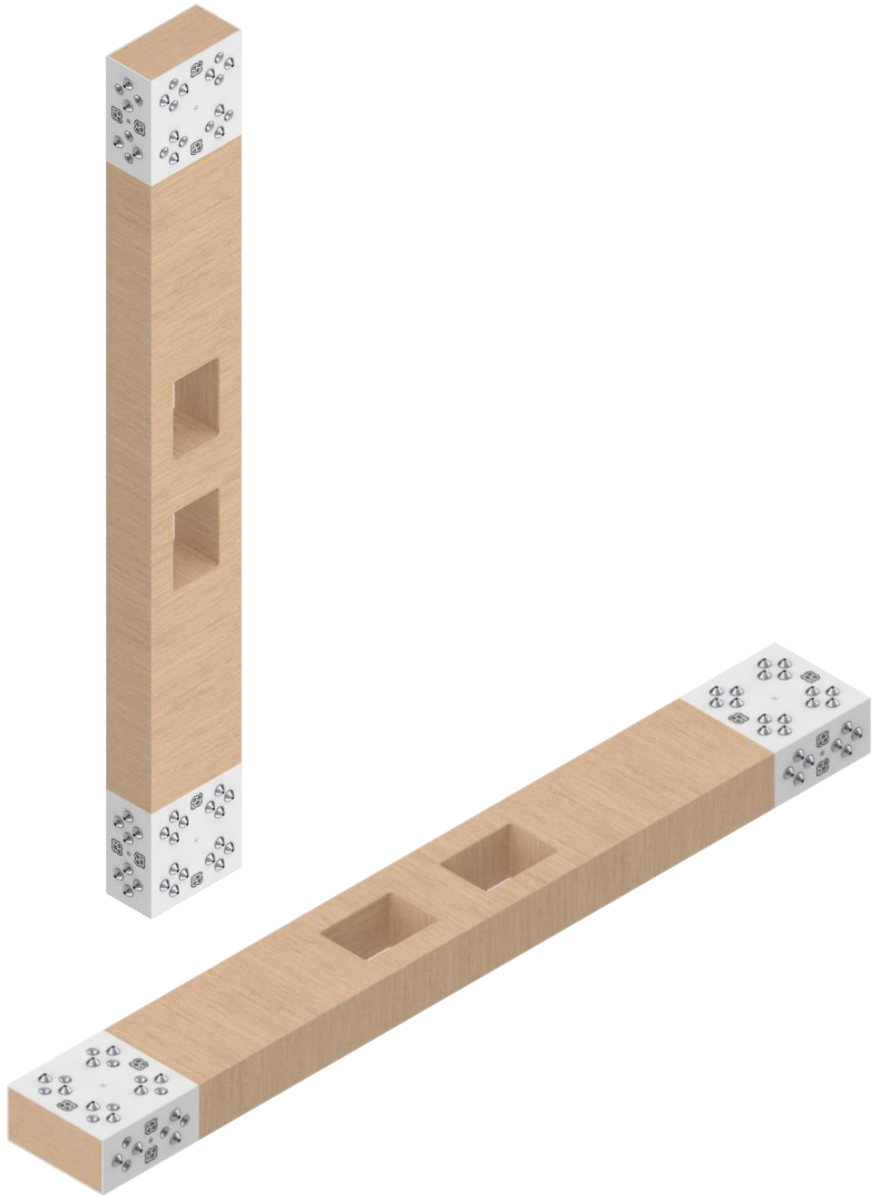
20cm

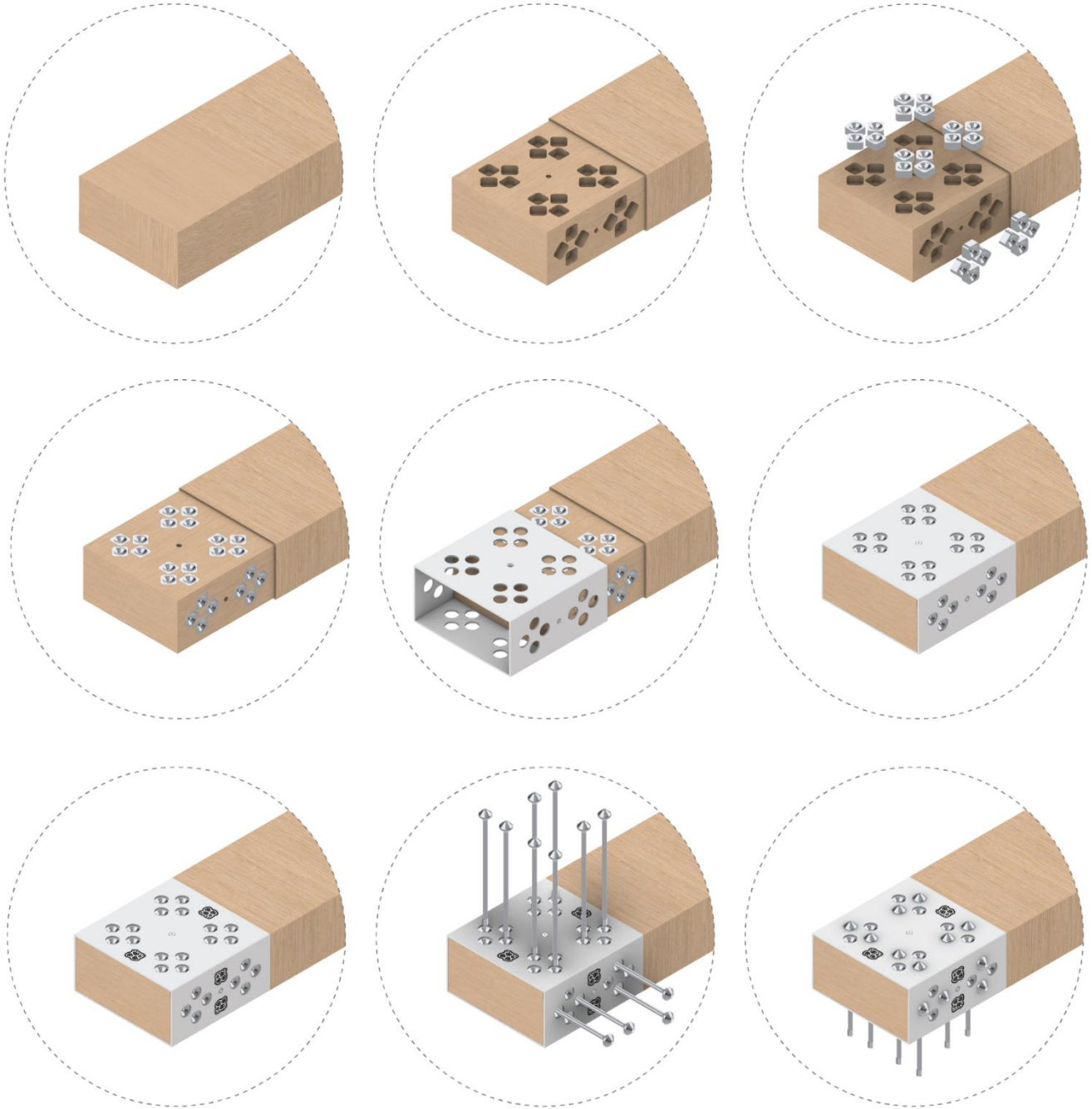
30cm

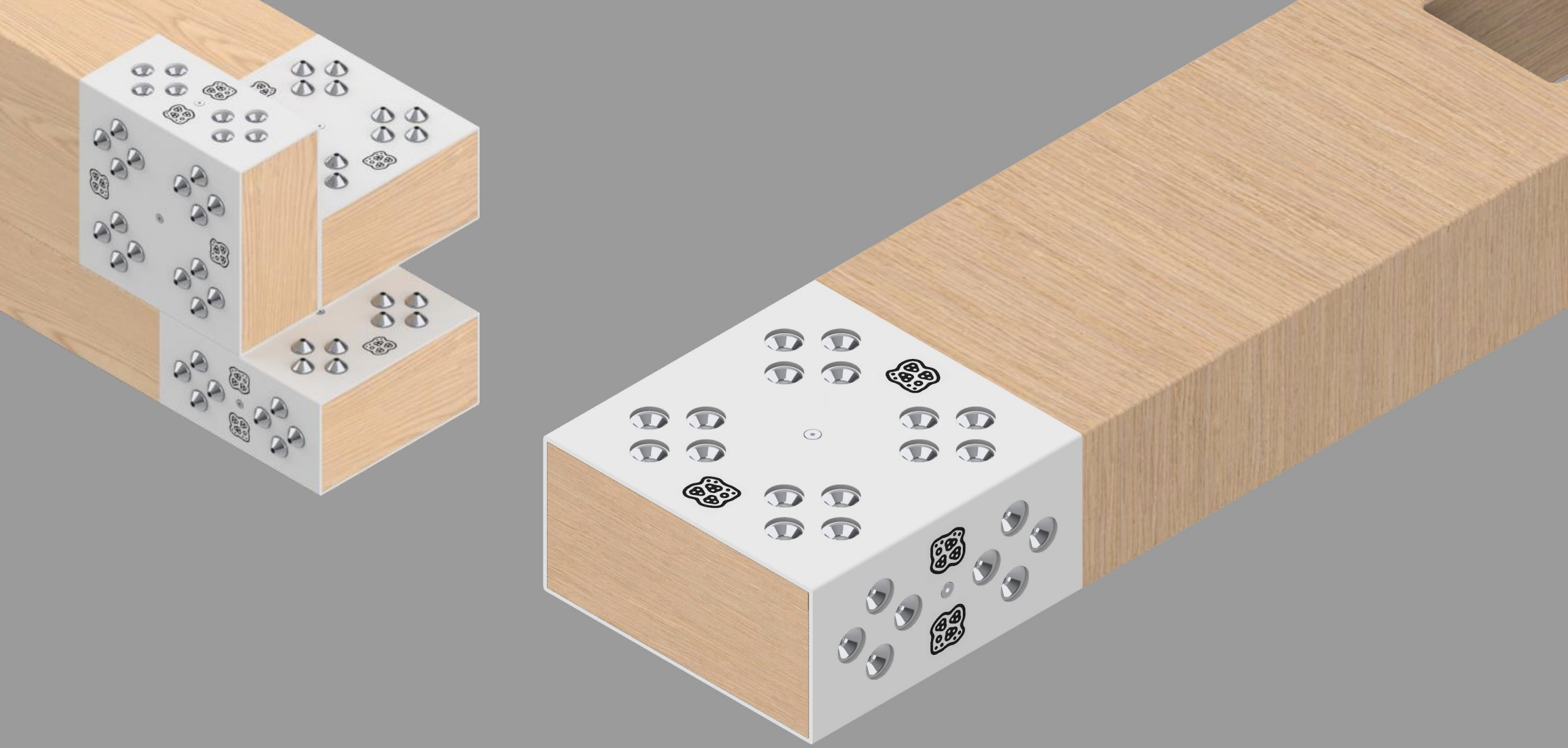


Bolt Connection

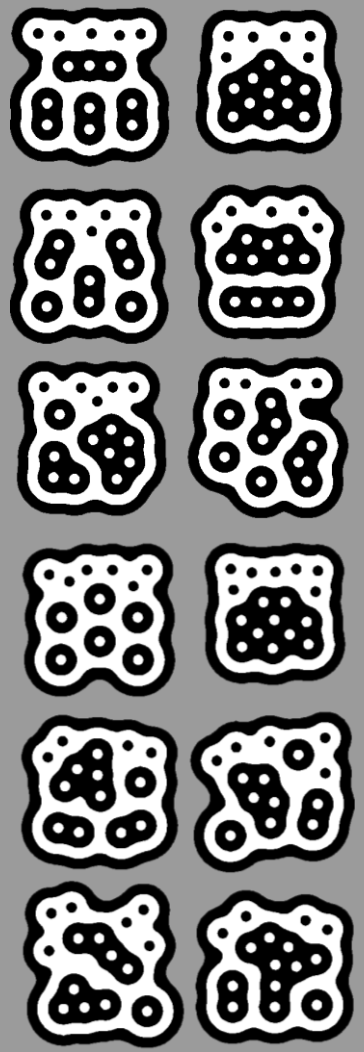
Connection assembly

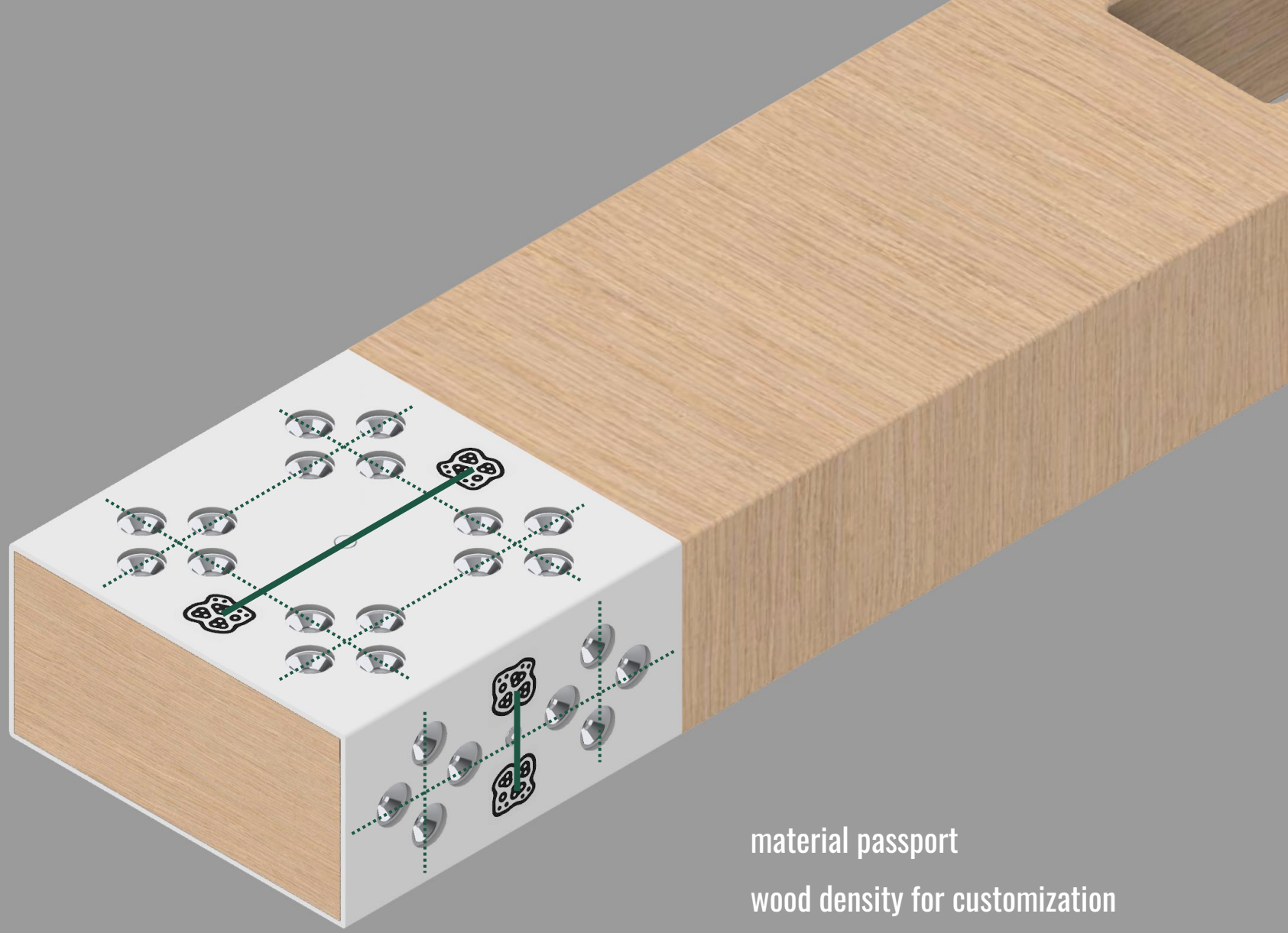






Fiducial code identification





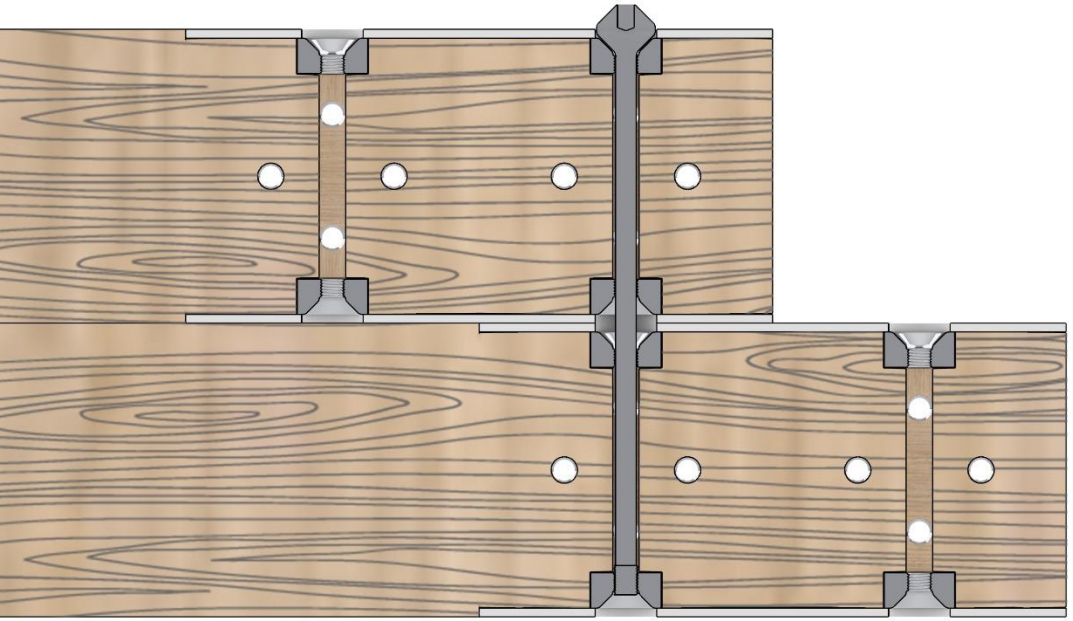
material passport

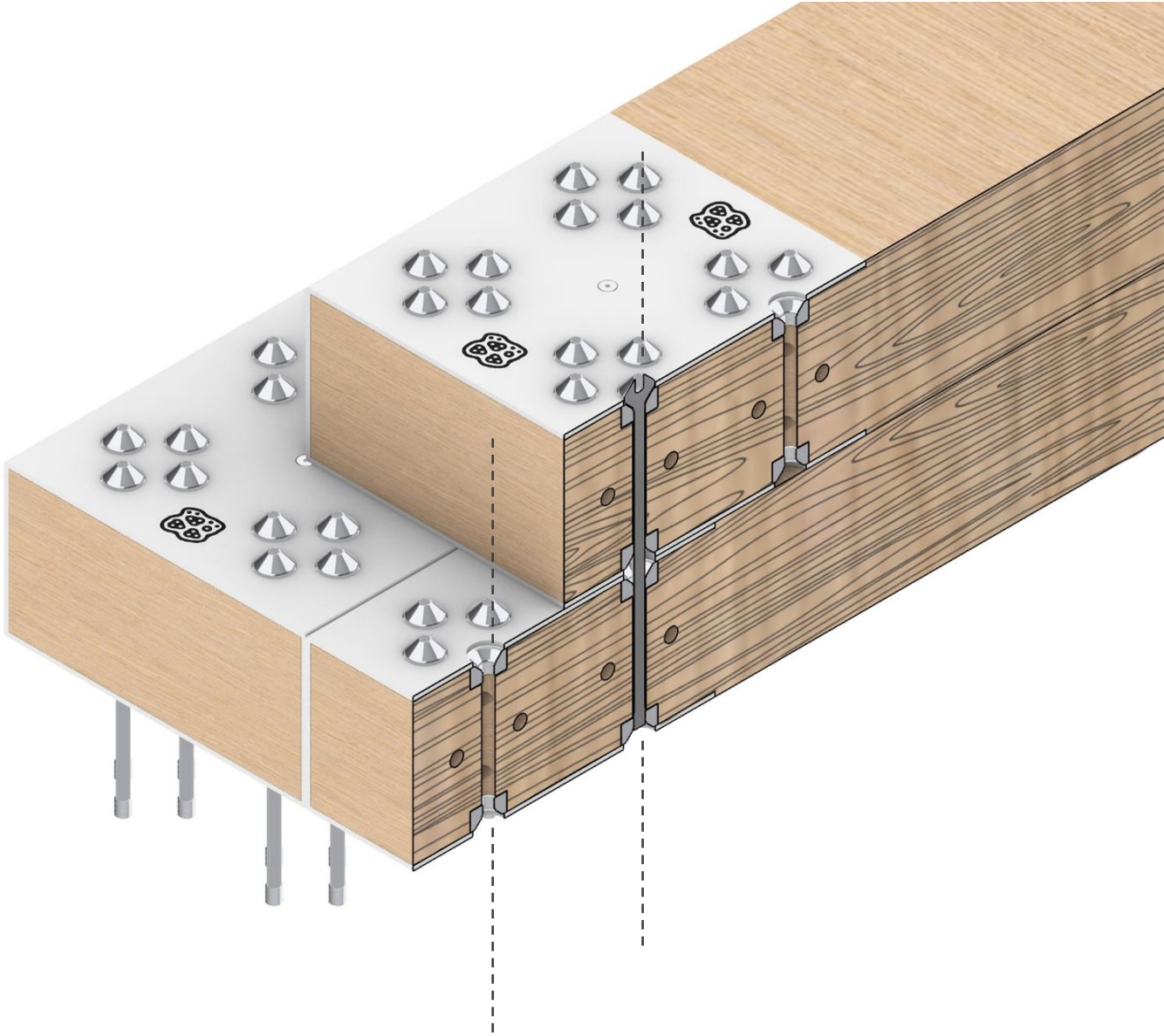
wood density for customization

surface recognition by code distances

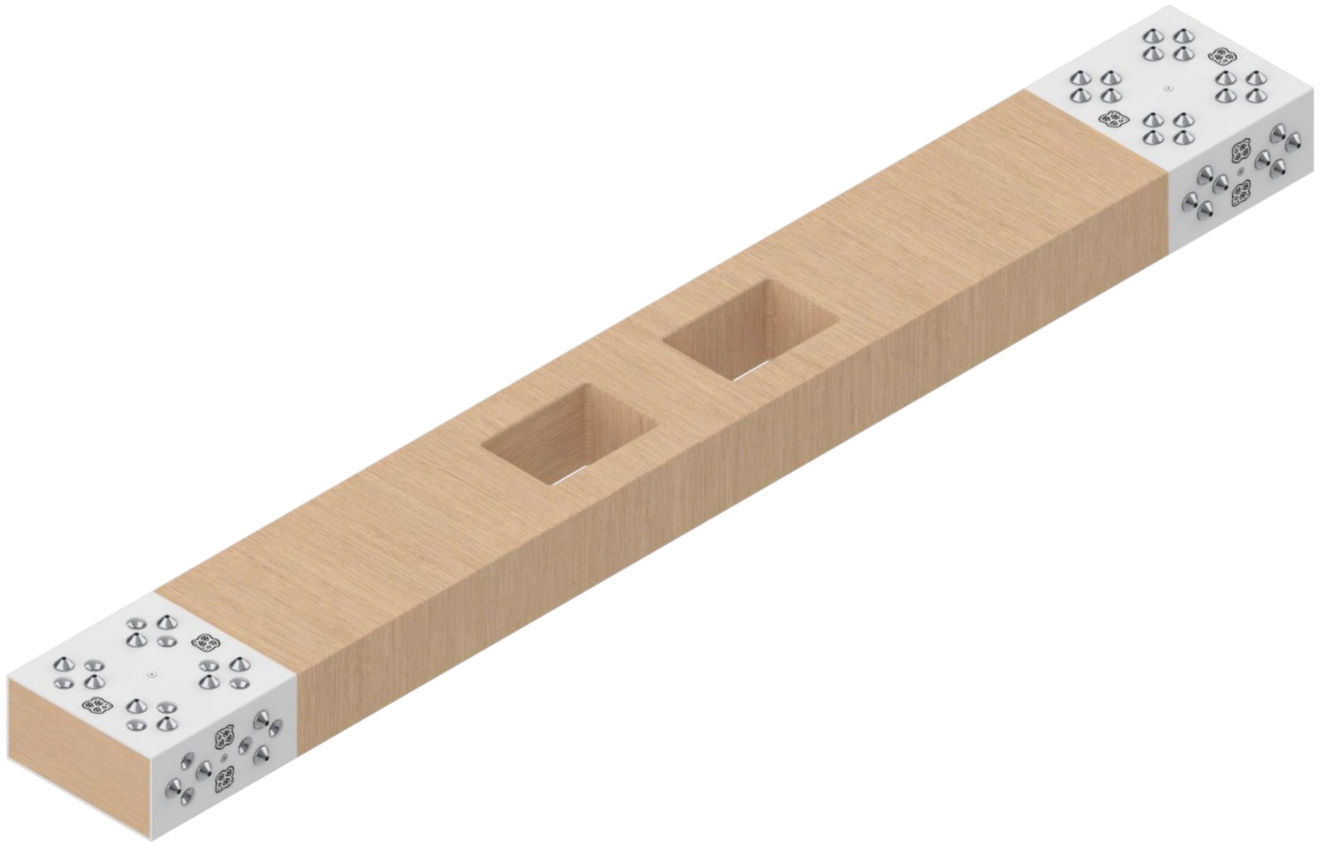
computer vision calibration

Connection fixation

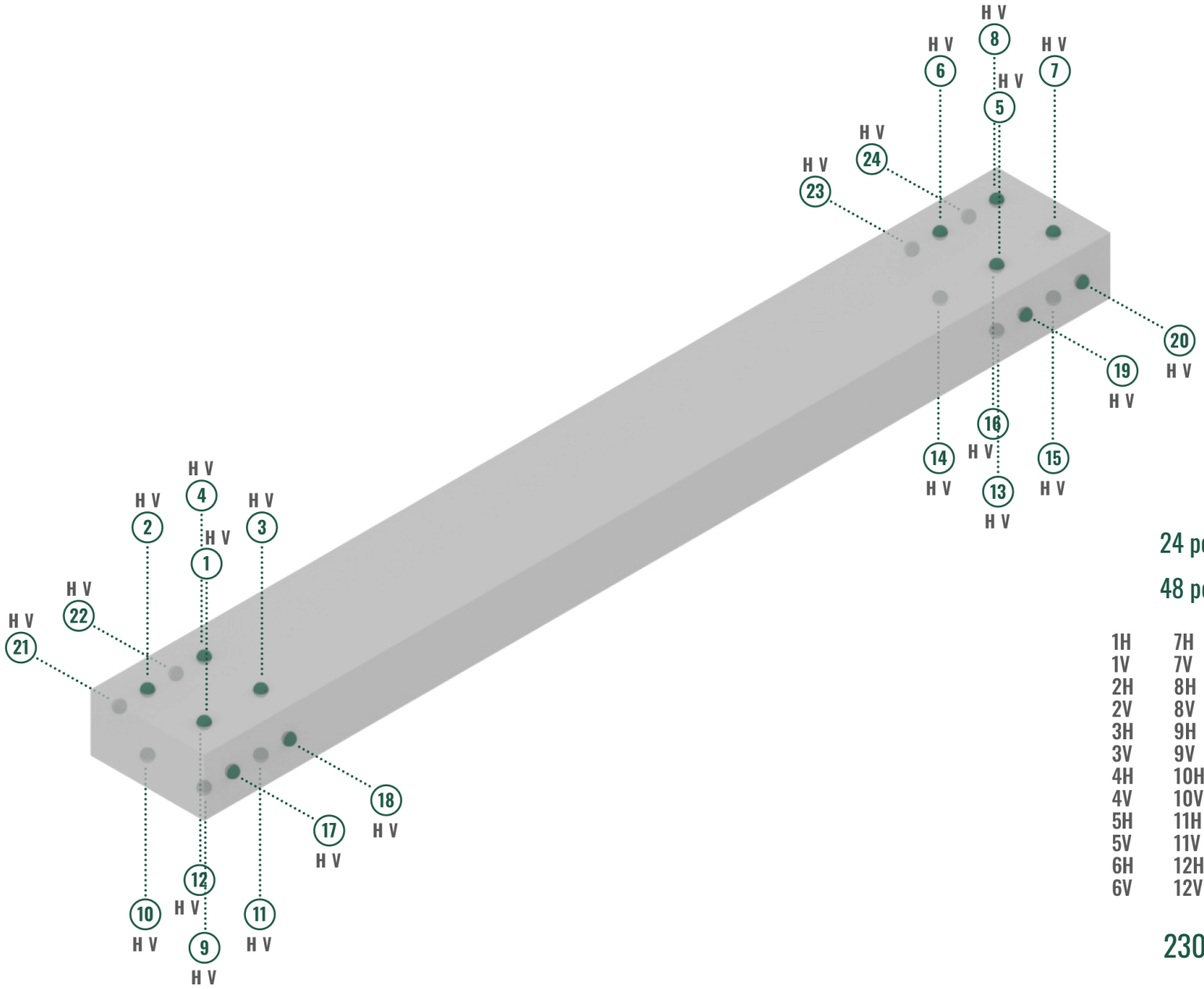




The discrete element



Combinatorial rules



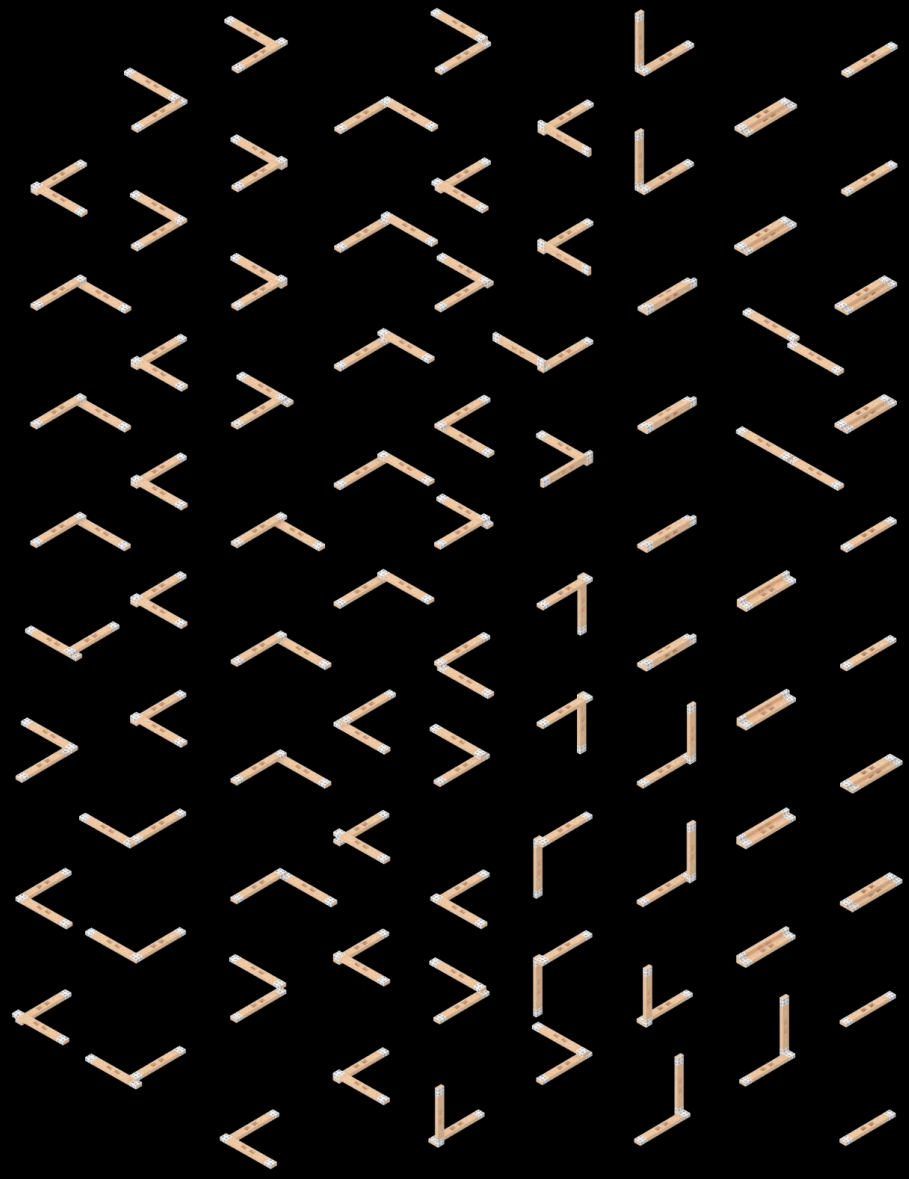
24 points

48 points ids

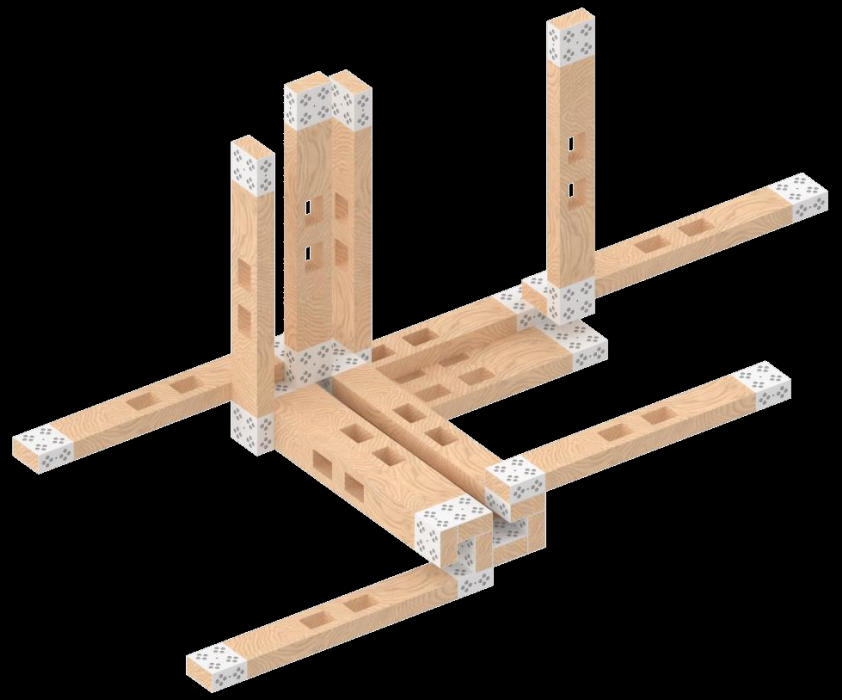
1H	7H	13H	19H
1V	7V	13V	19V
2H	8H	14H	20H
2V	8V	14V	20V
3H	9H	15H	21H
3V	9V	15V	21V
4H	10H	16H	22H
4V	10V	16V	22V
5H	11H	17H	23H
5V	11V	17V	23V
6H	12H	18H	24H
6V	12V	18V	24V

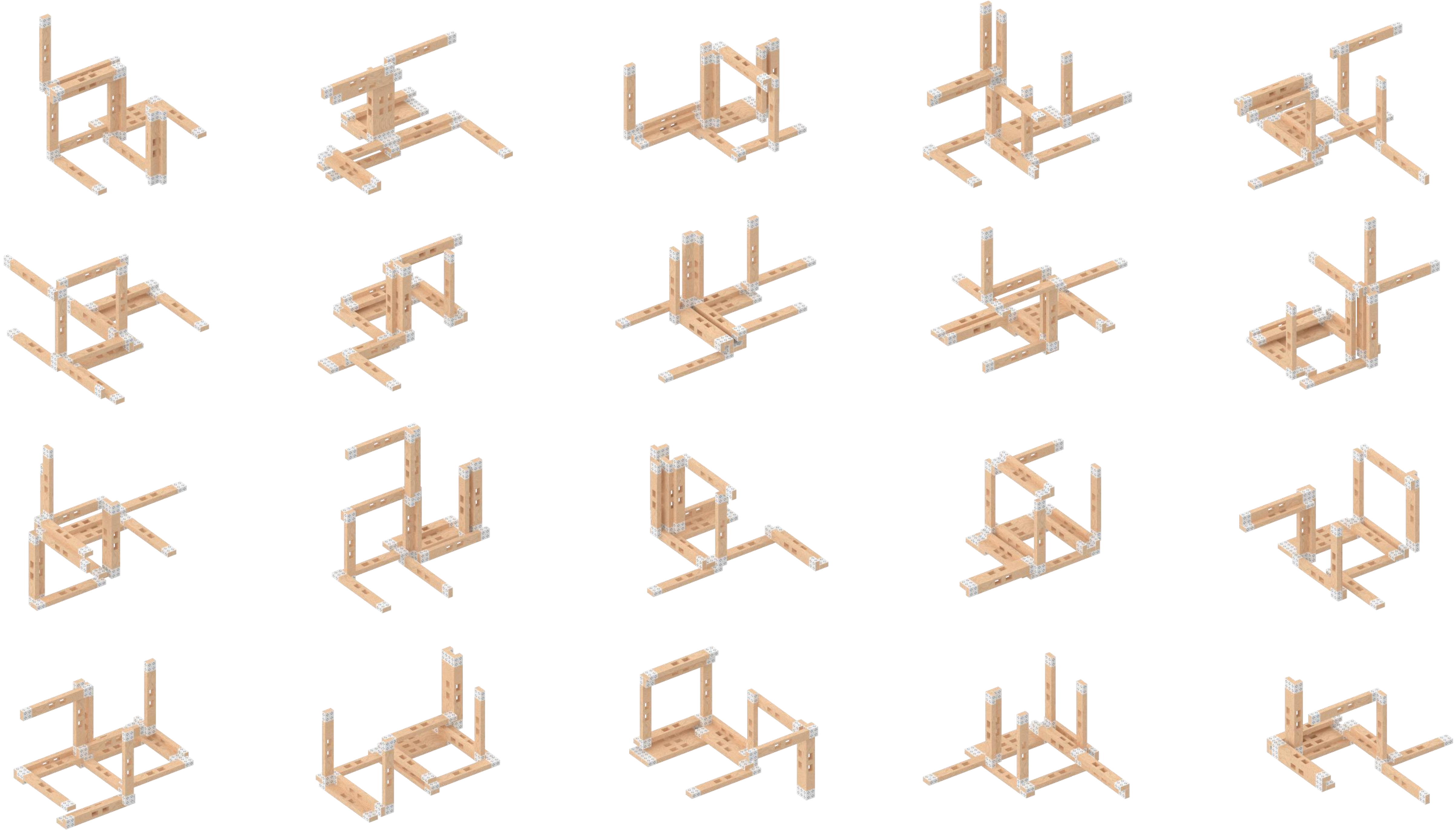
2304 rules

84 combinatorial rules

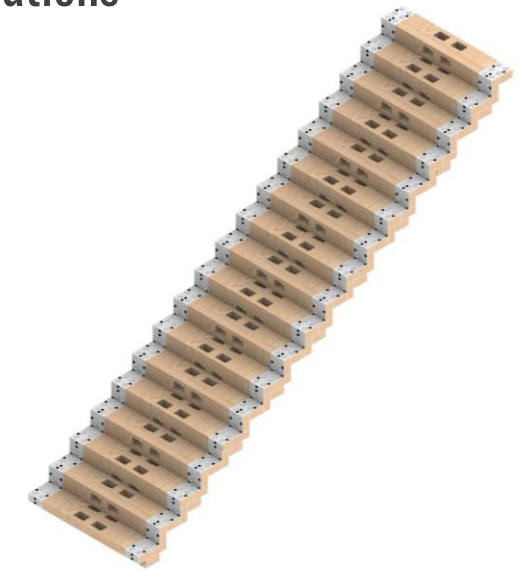


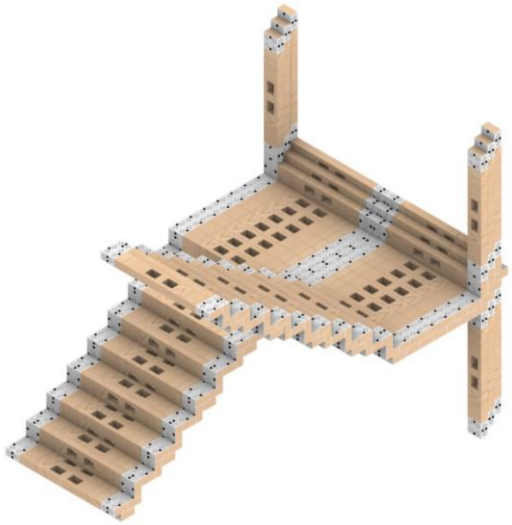
aggregation rules iterations

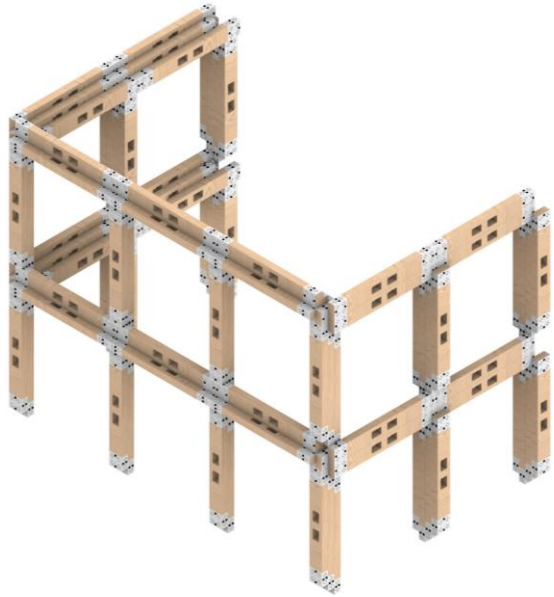


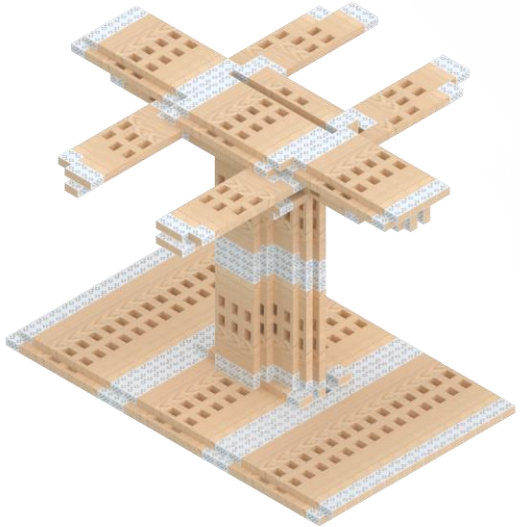


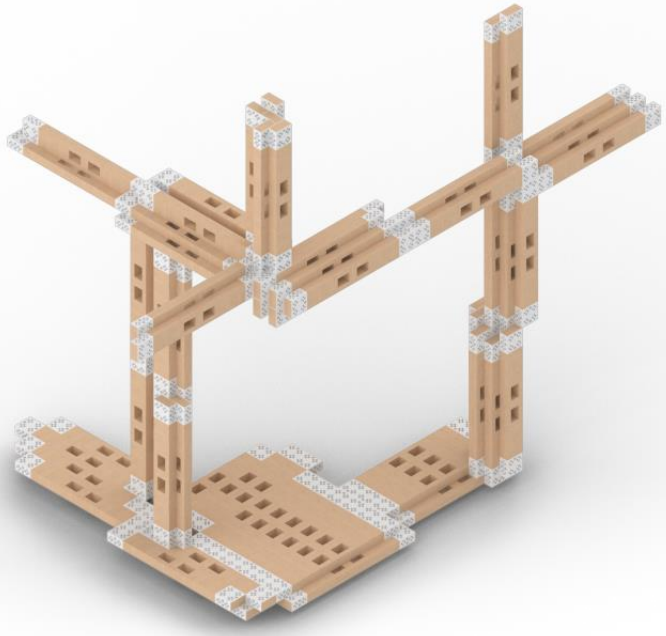
Aggregations

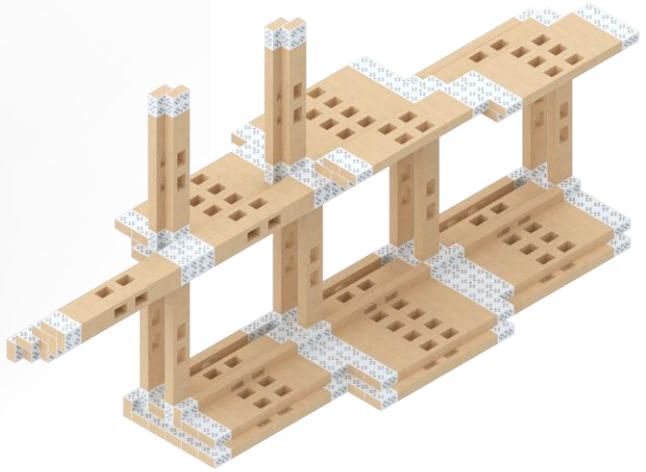


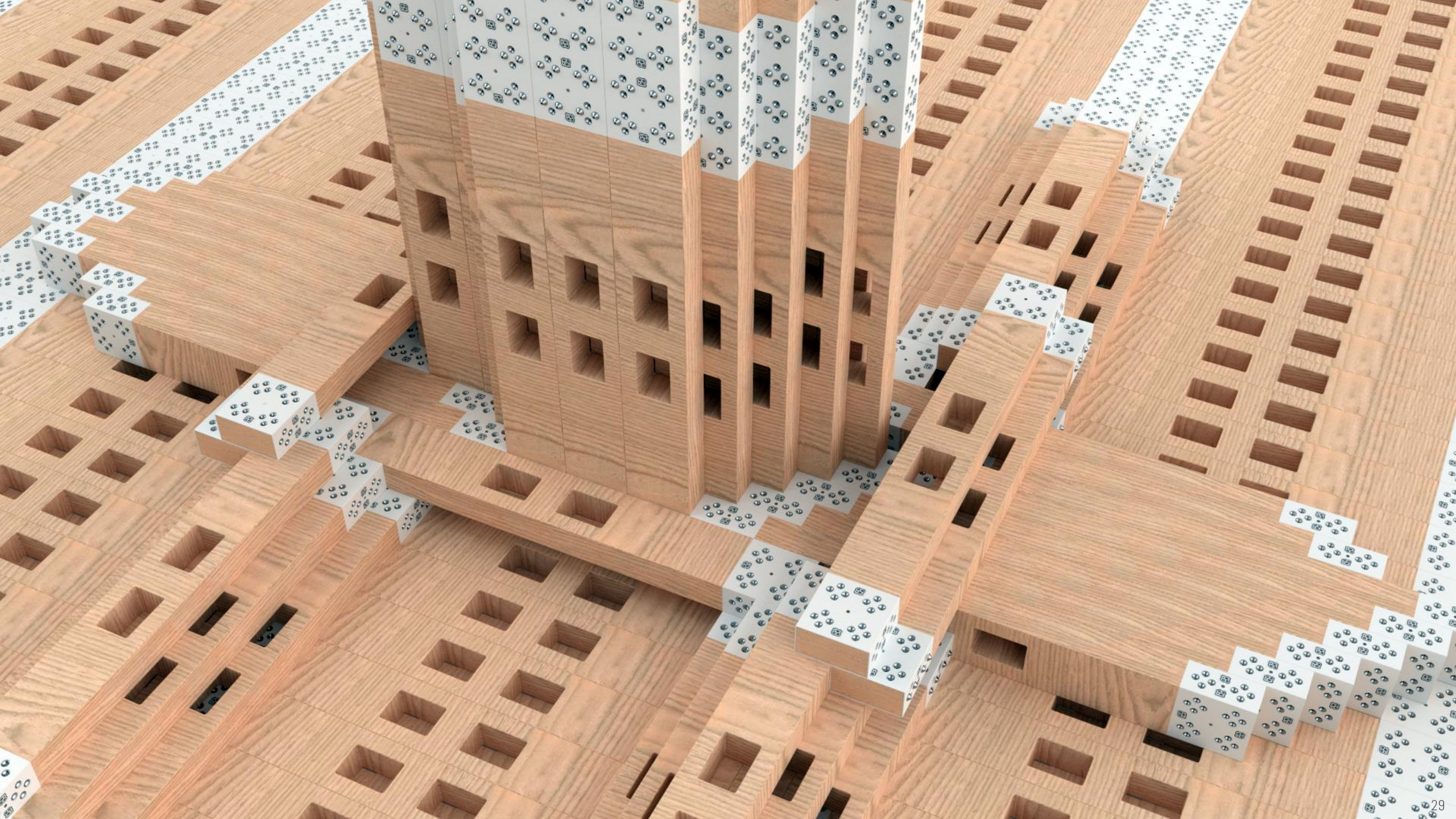






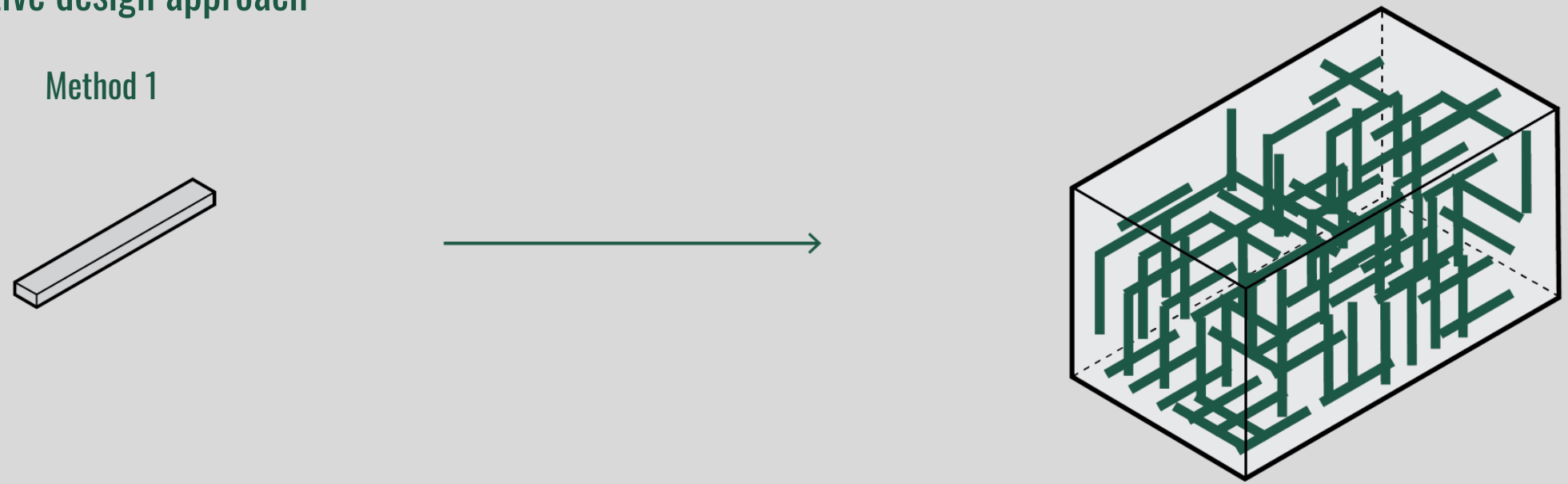




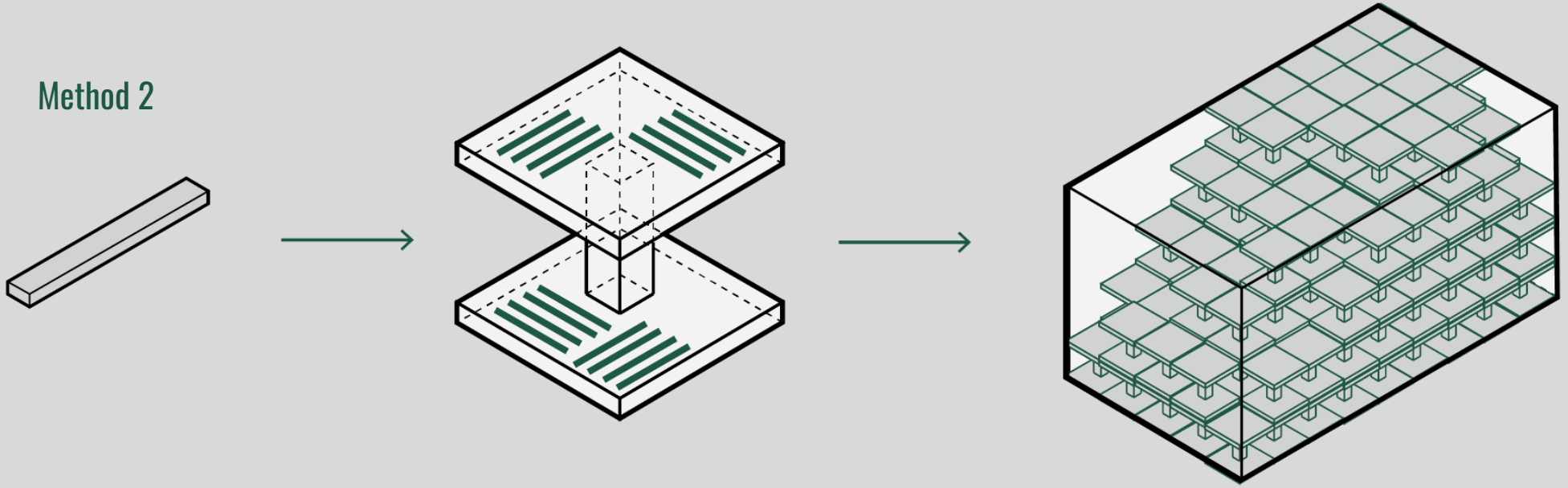


Generative design approach

Method 1

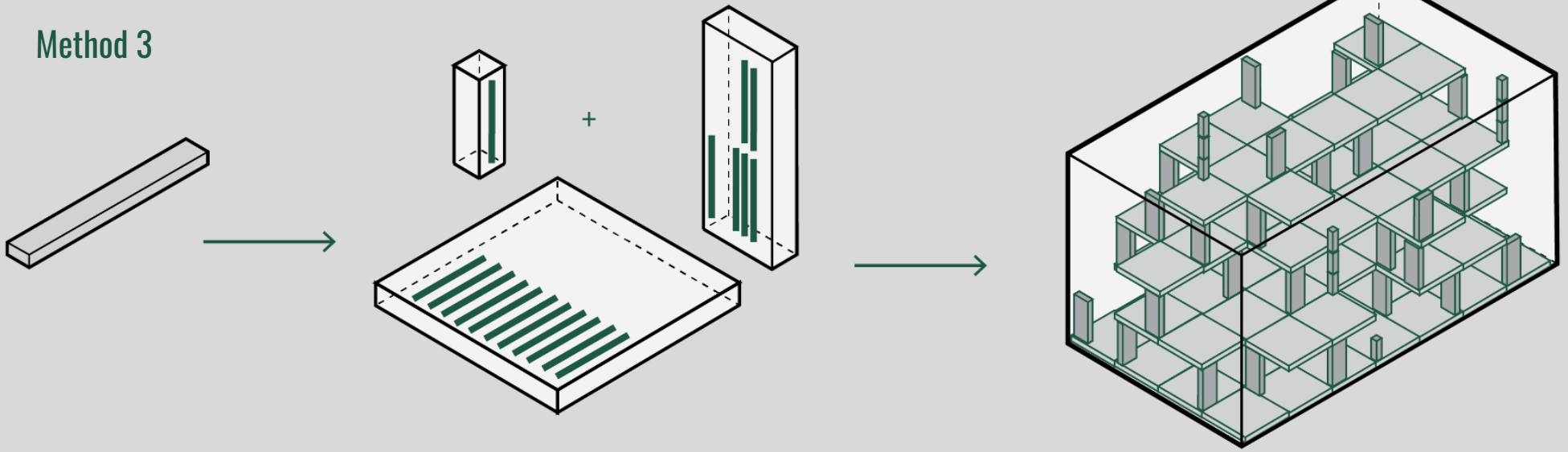


Method 2

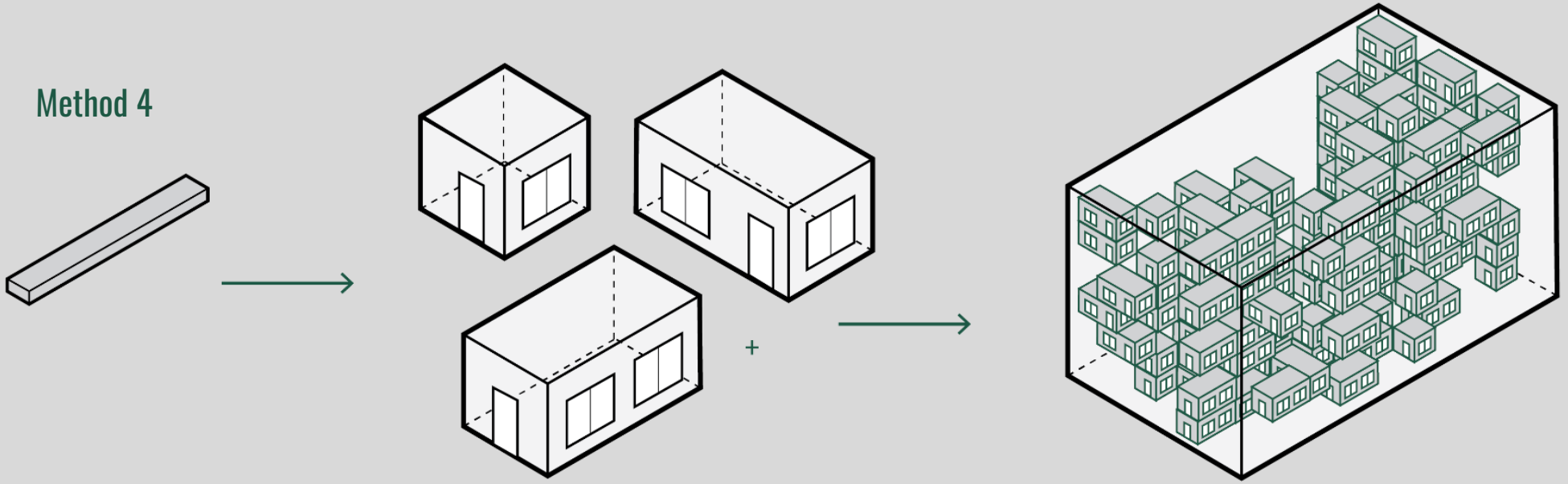


Generative design approach

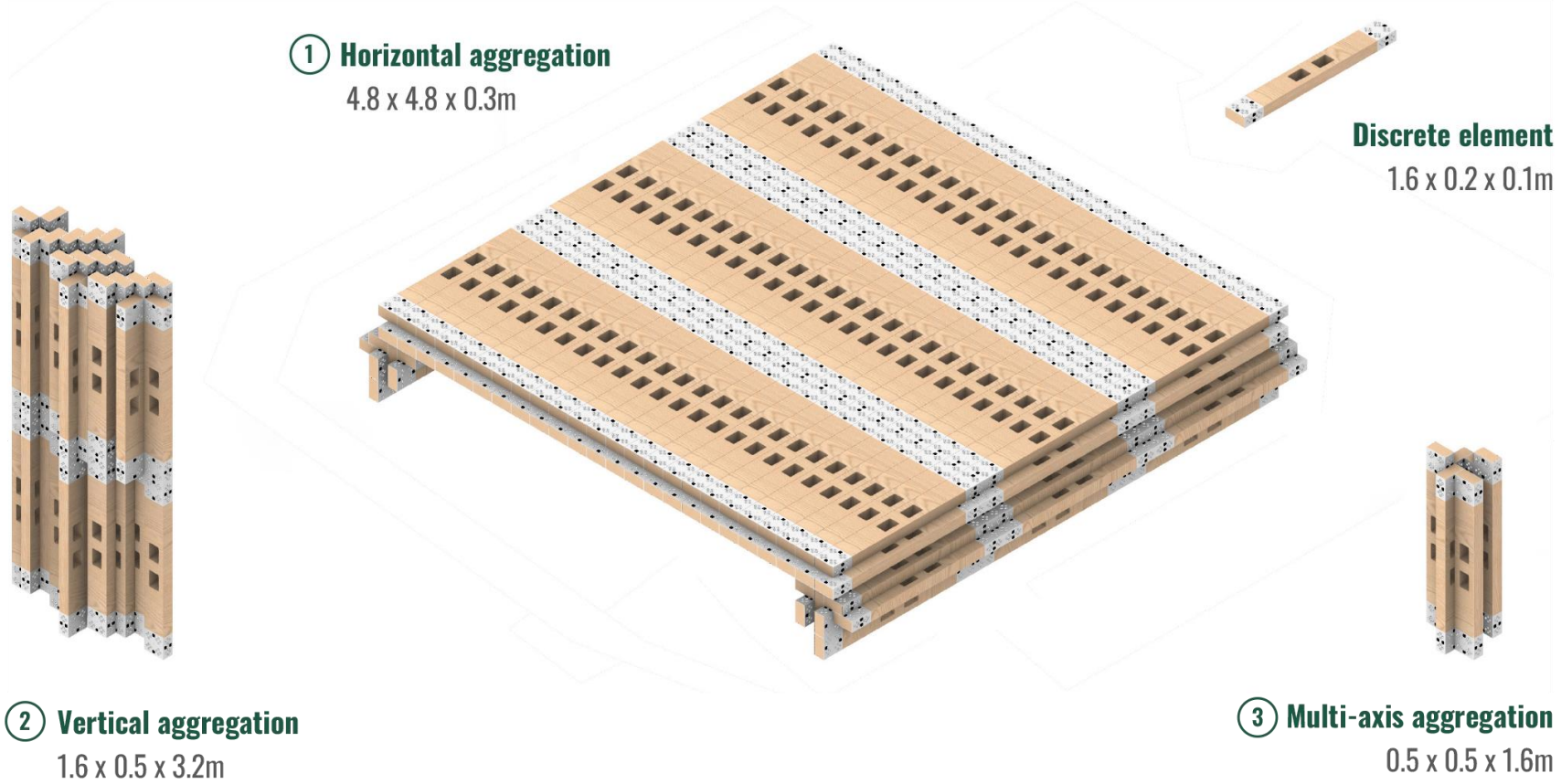
Method 3



Method 4



Aggregation components

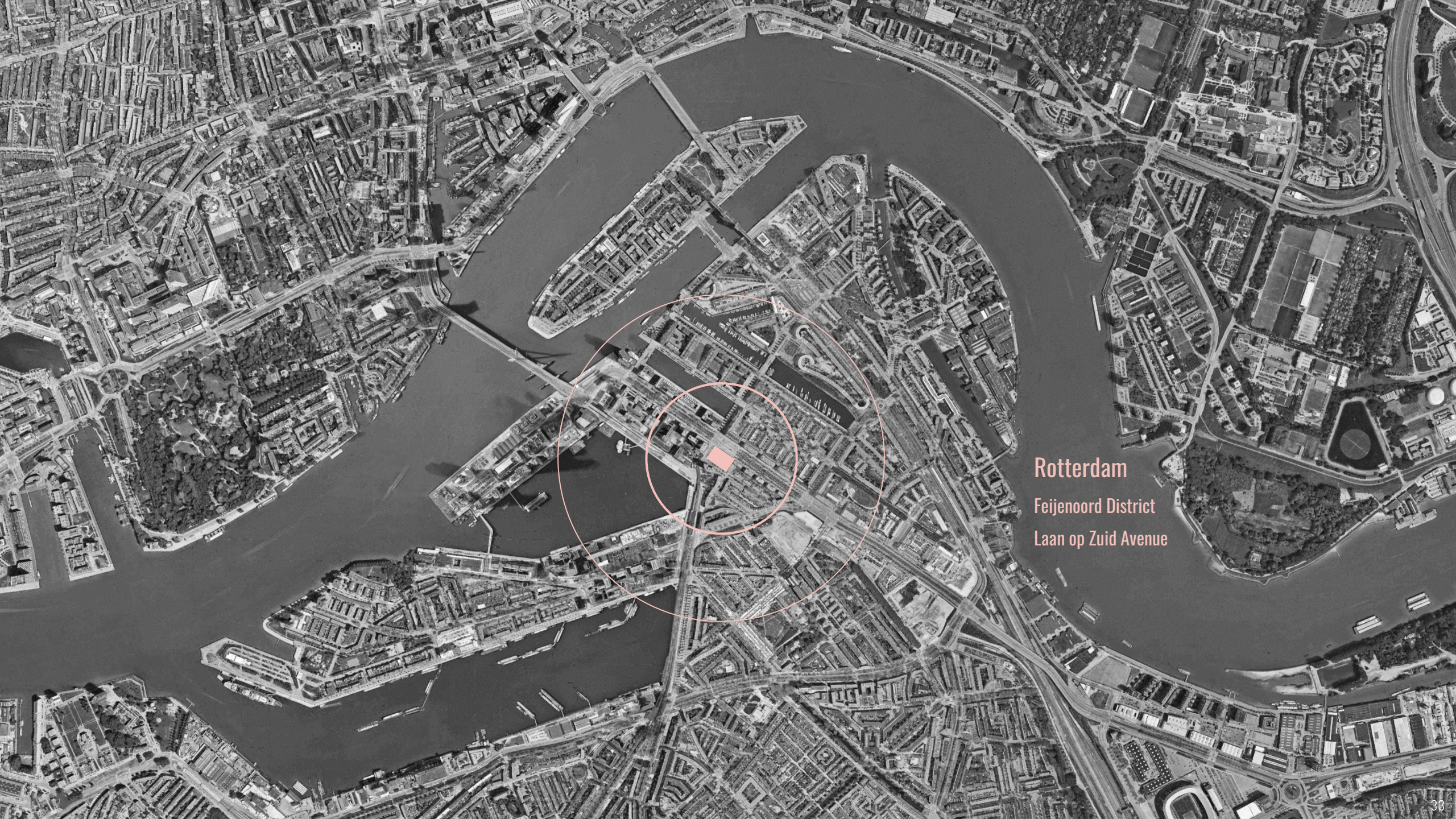


① **Horizontal aggregation**
4.8 x 4.8 x 0.3m

Discrete element
1.6 x 0.2 x 0.1m

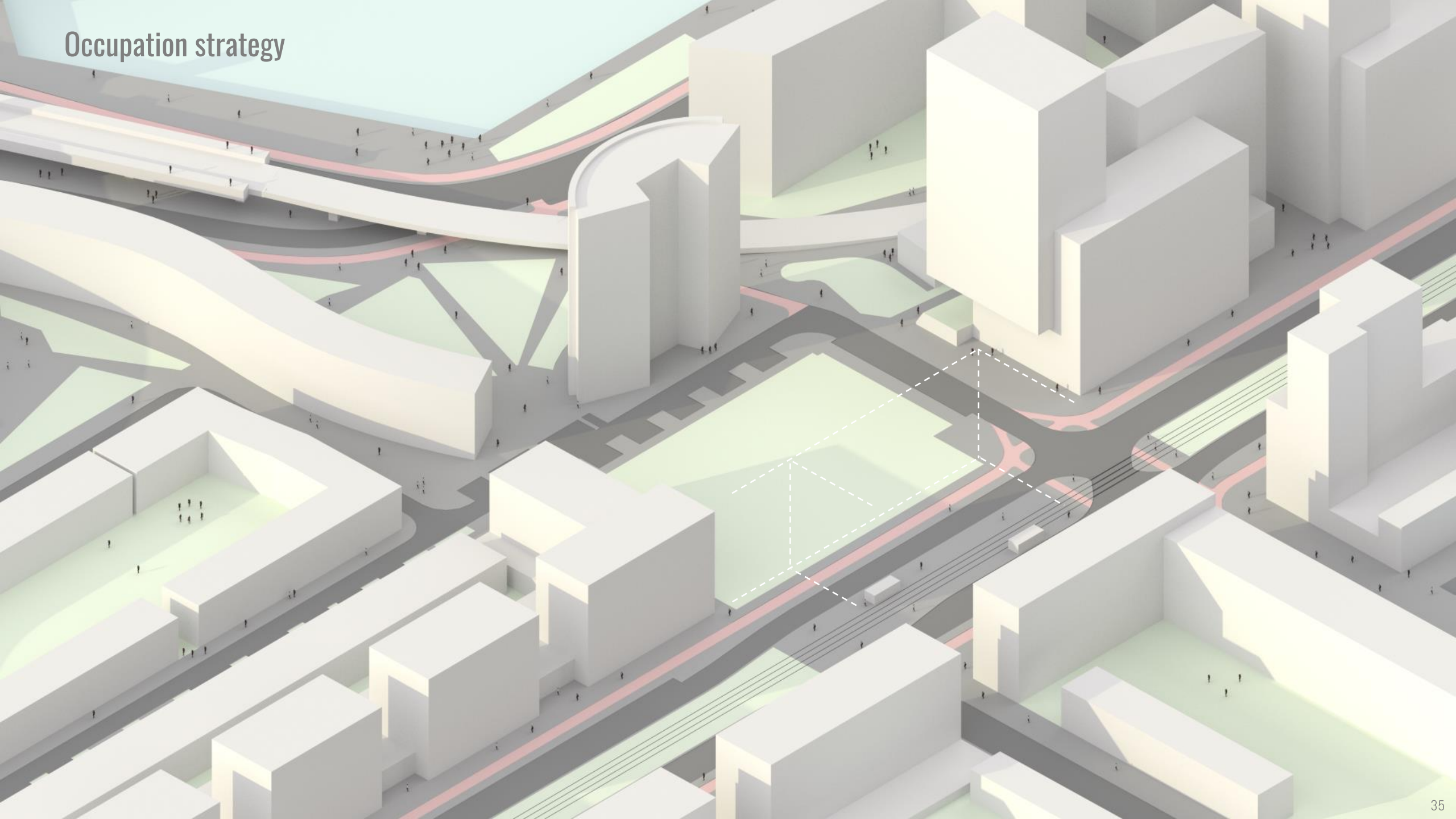
② **Vertical aggregation**
1.6 x 0.5 x 3.2m

③ **Multi-axis aggregation**
0.5 x 0.5 x 1.6m

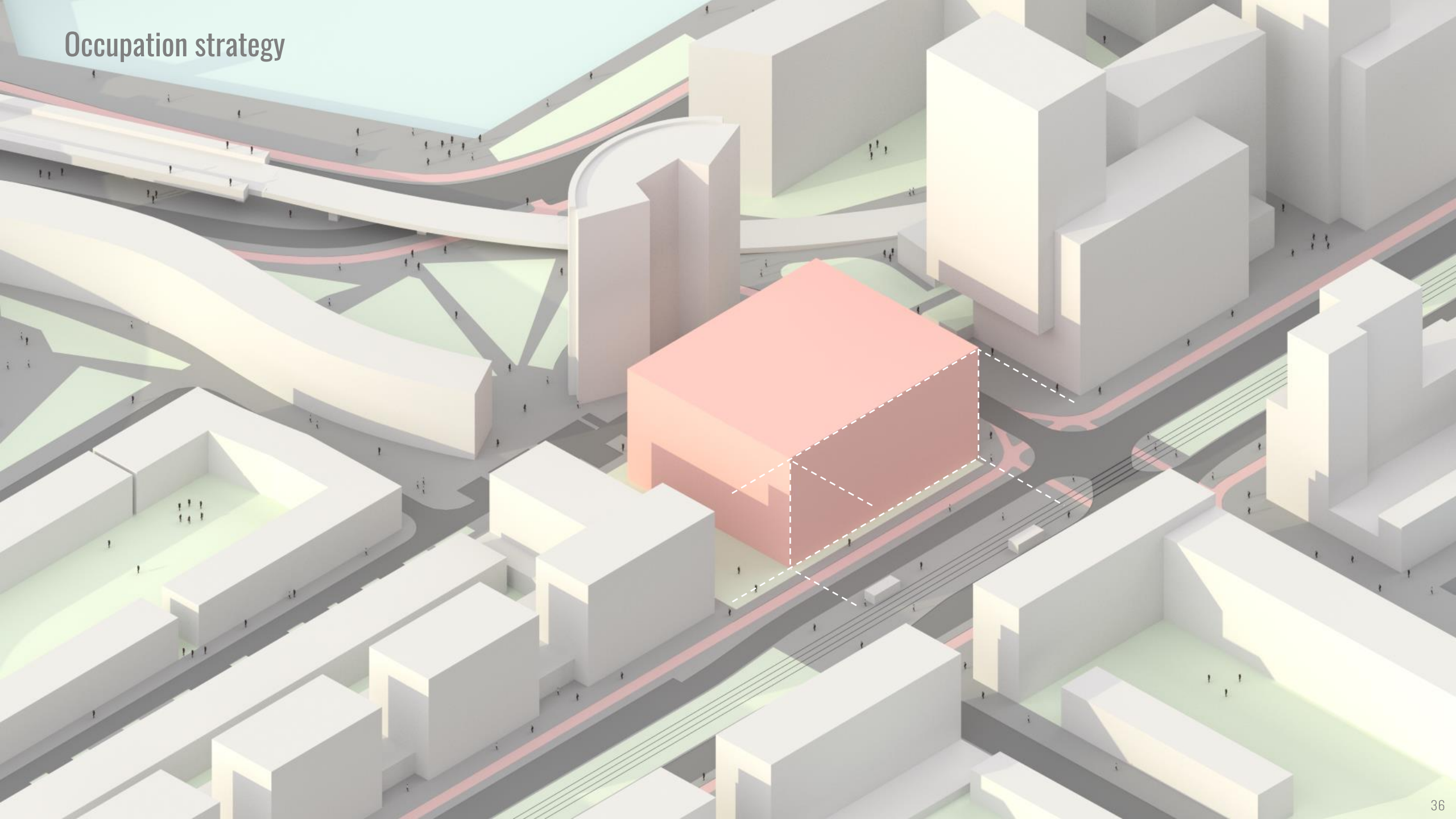

Rotterdam
Feijenoord District
Laan op Zuid Avenue


50m
80m

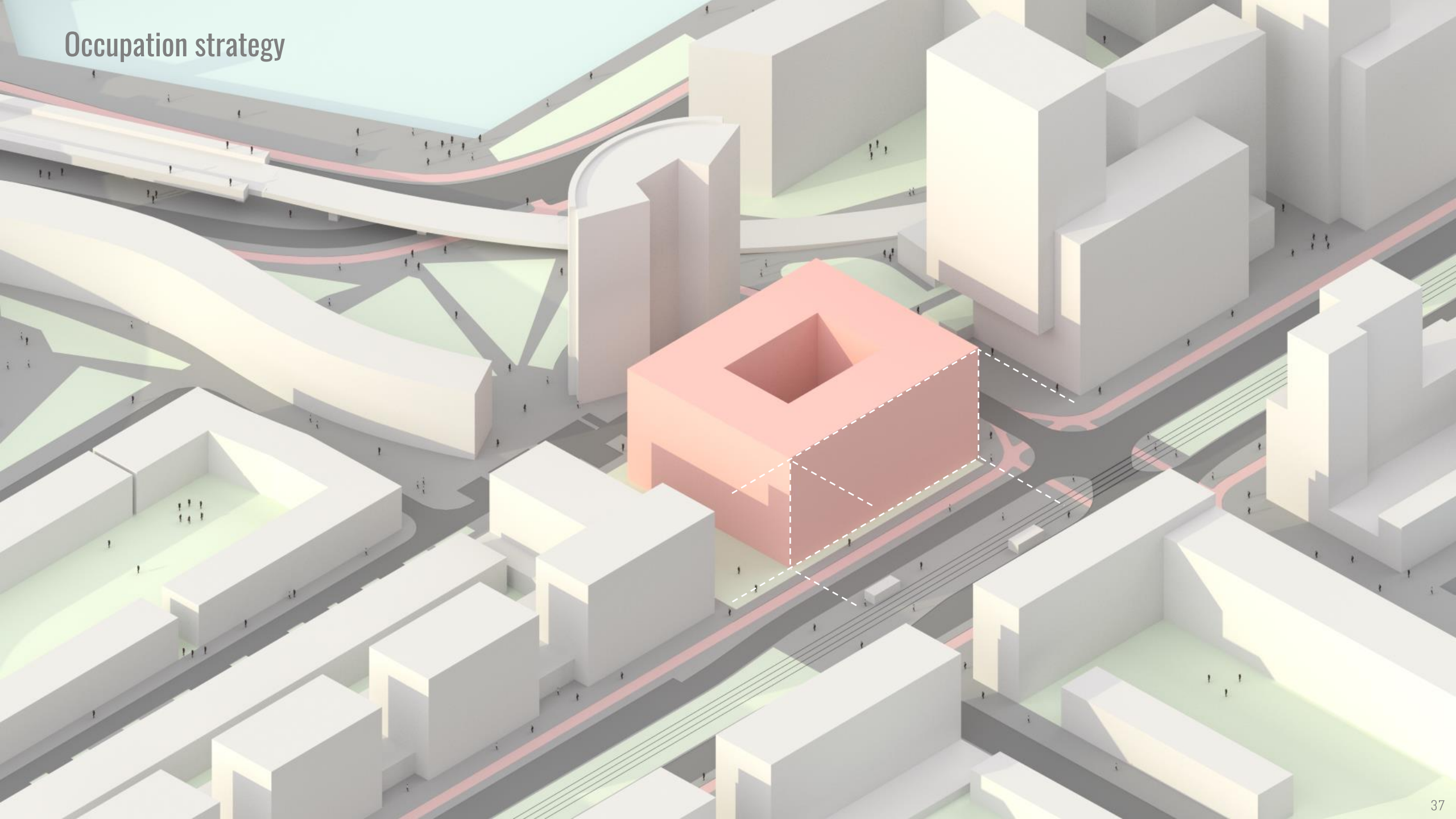
Occupation strategy



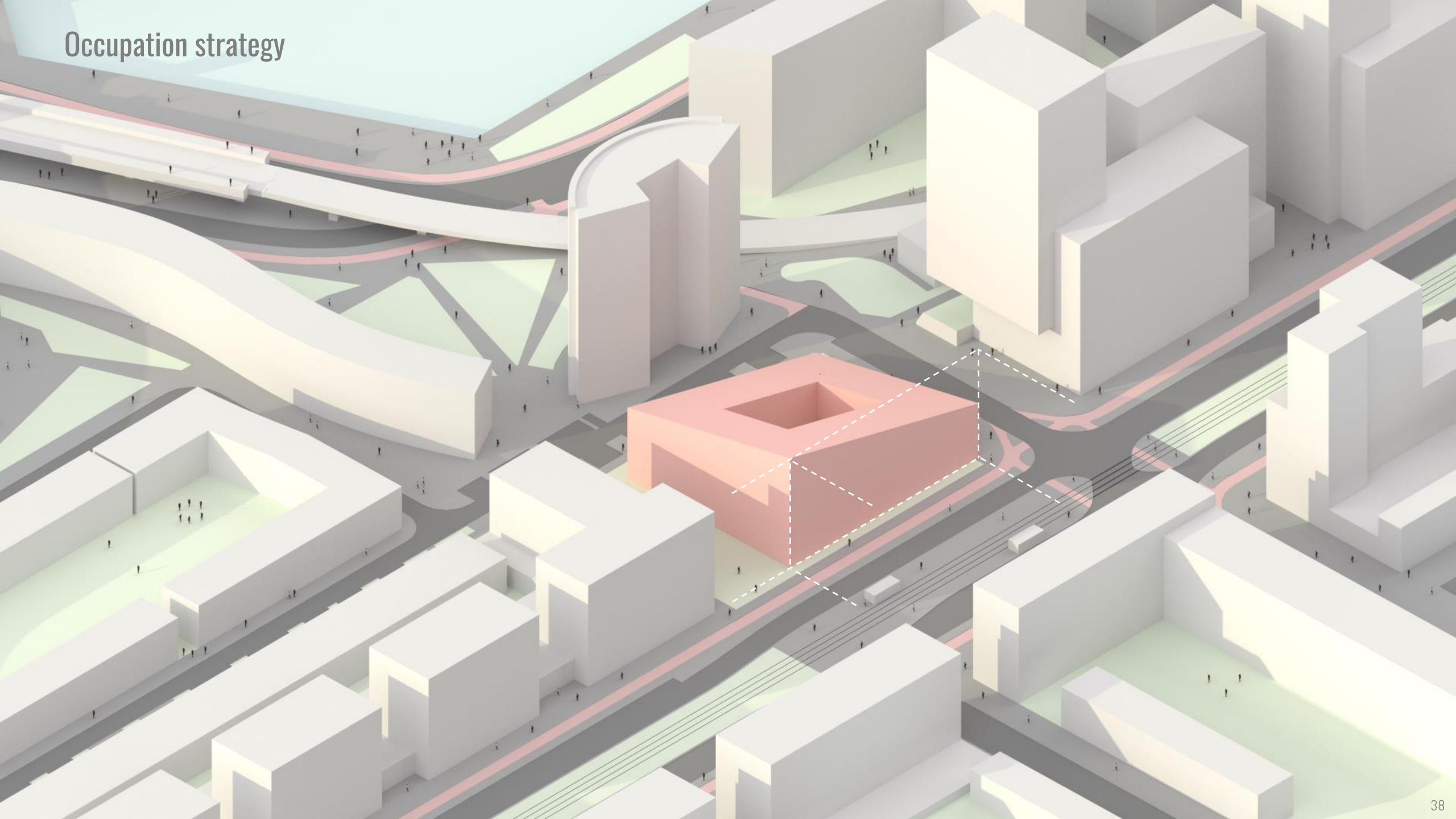
Occupation strategy



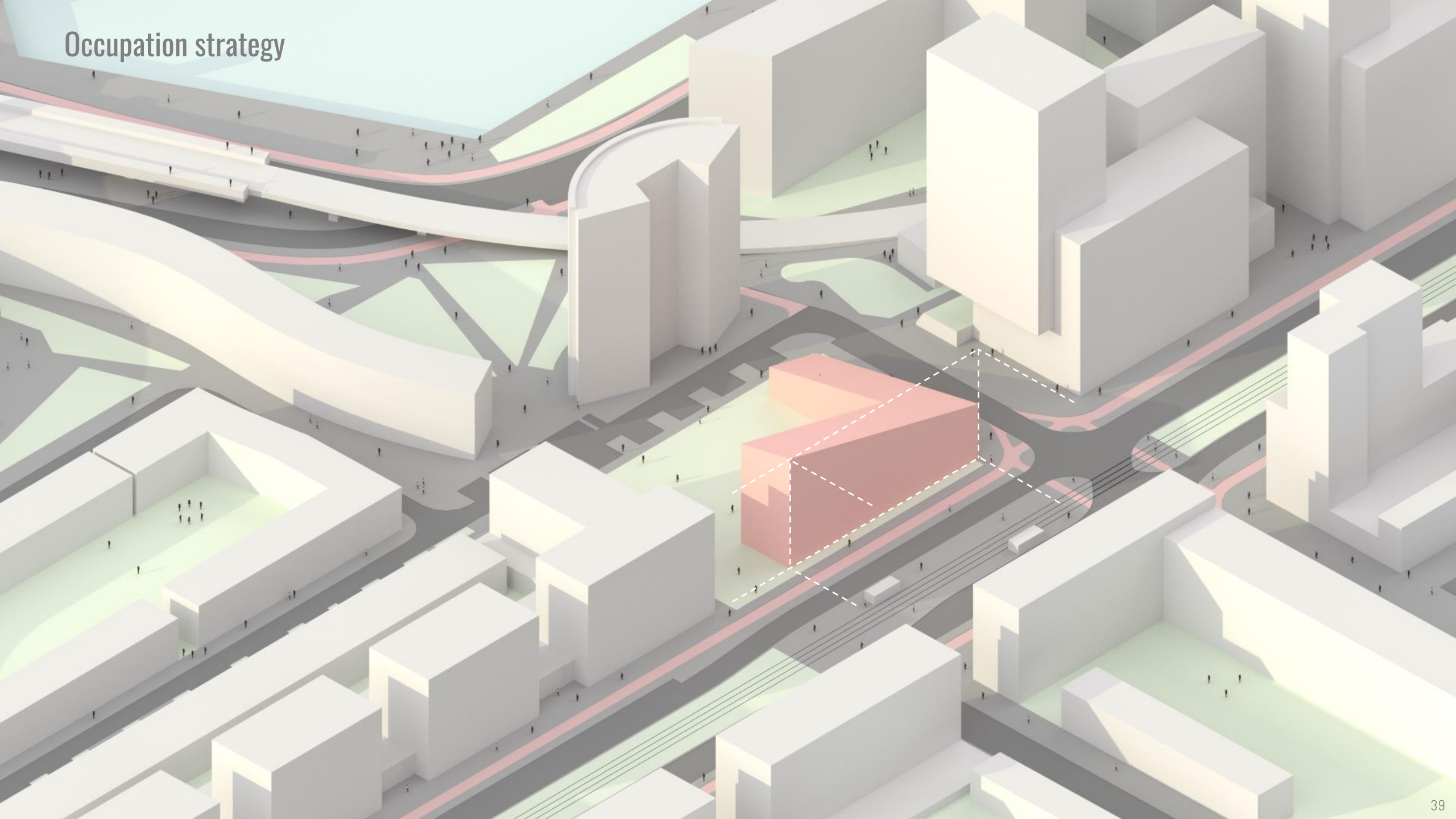
Occupation strategy



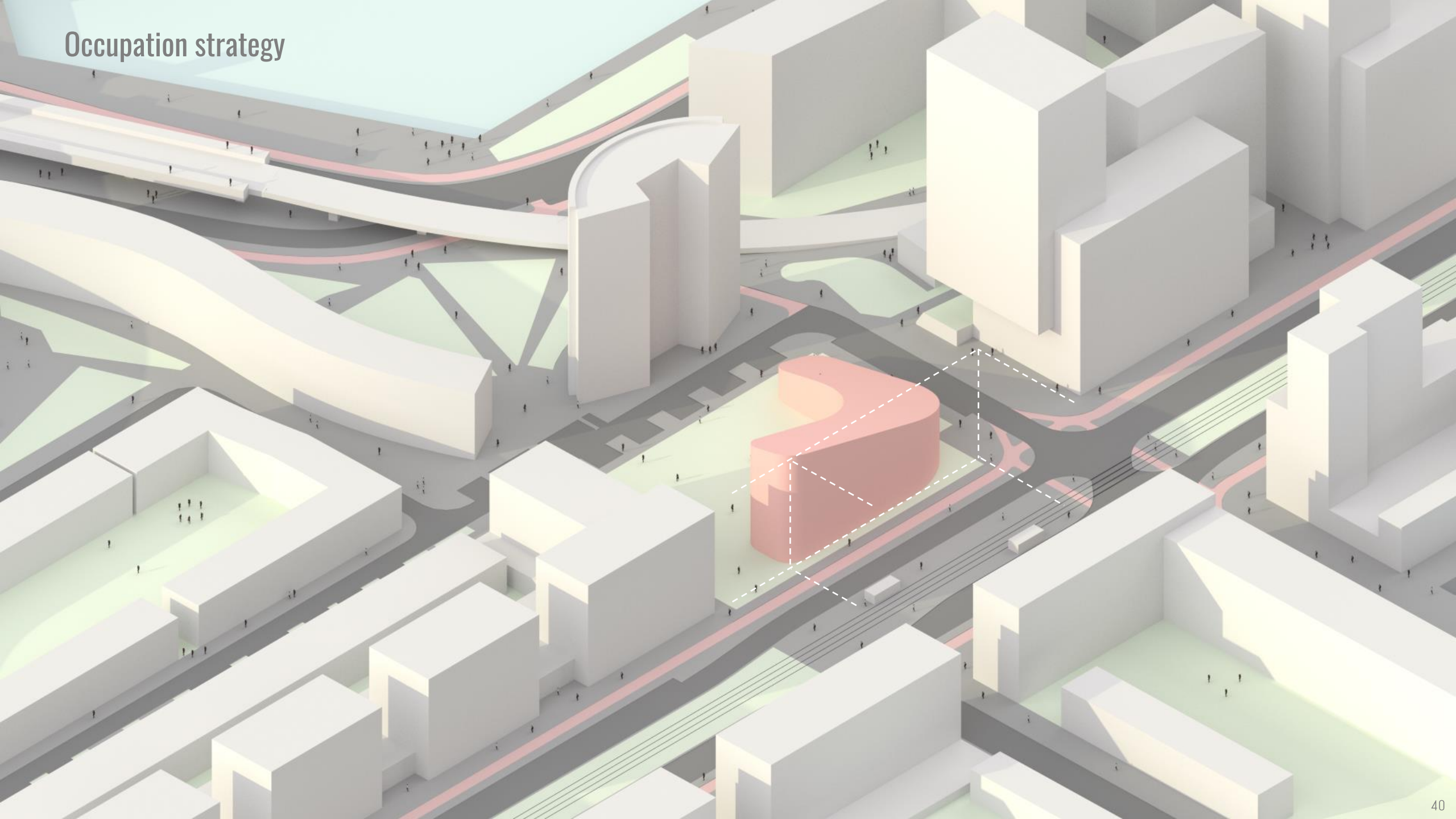
Occupation strategy



Occupation strategy



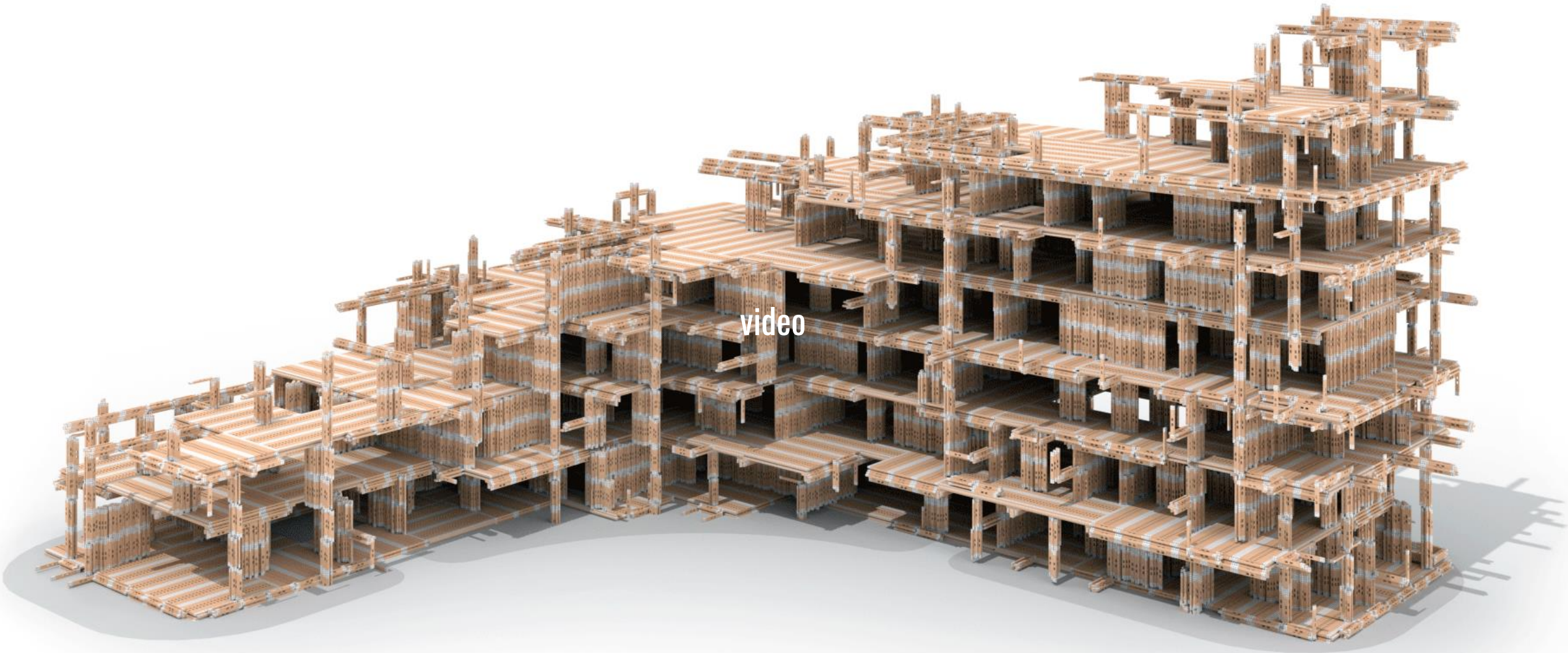
Occupation strategy



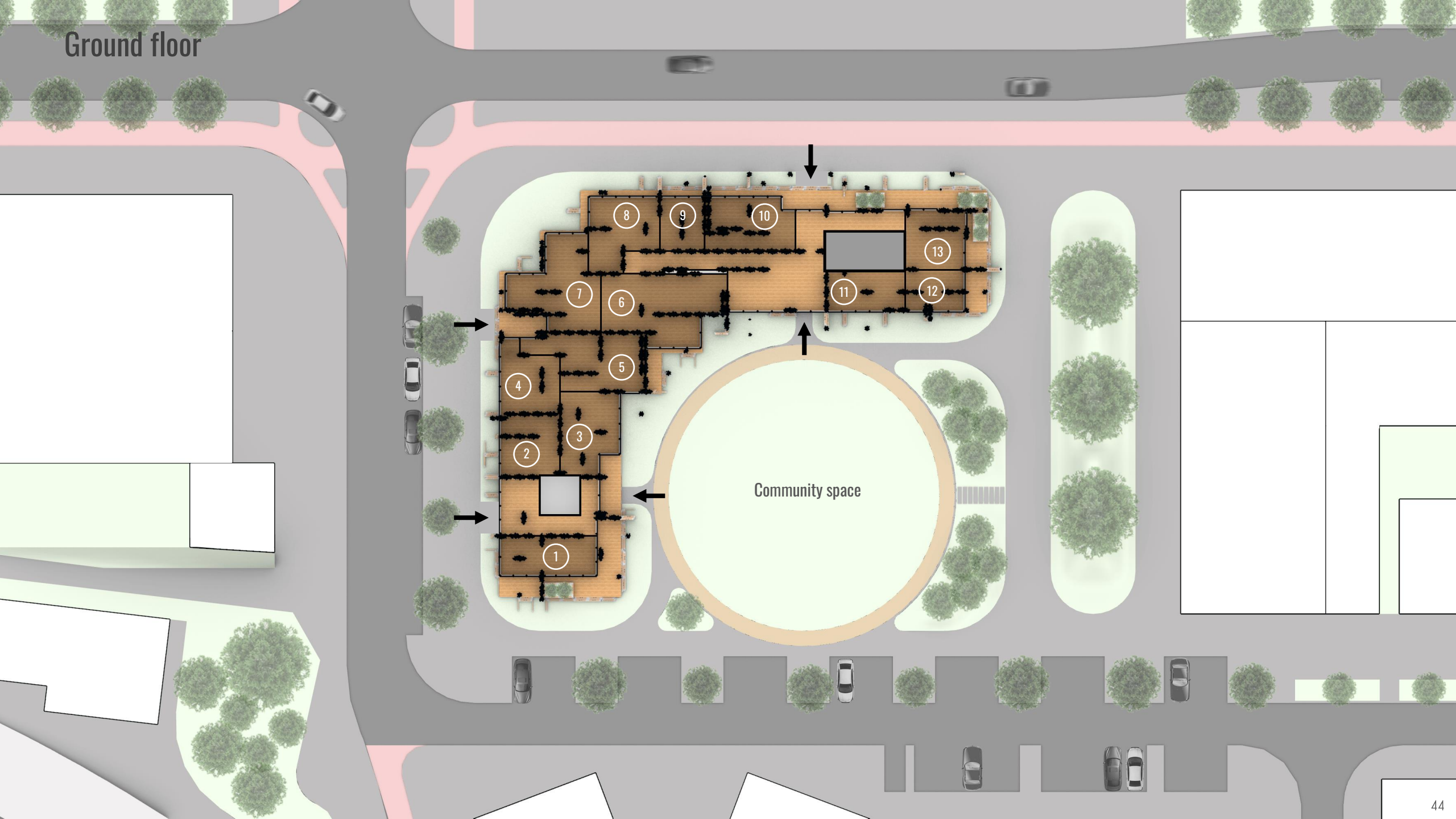
Occupation strategy

Occupation strategy

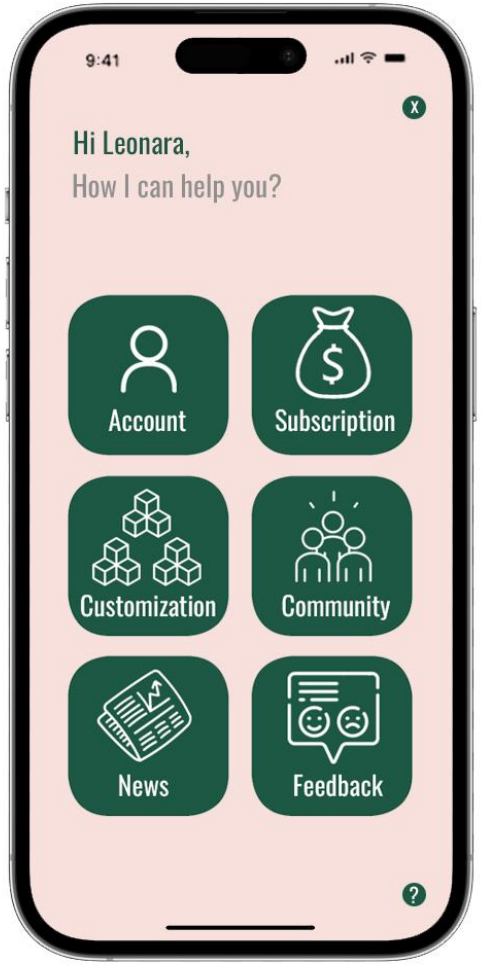
Open-end building configurations

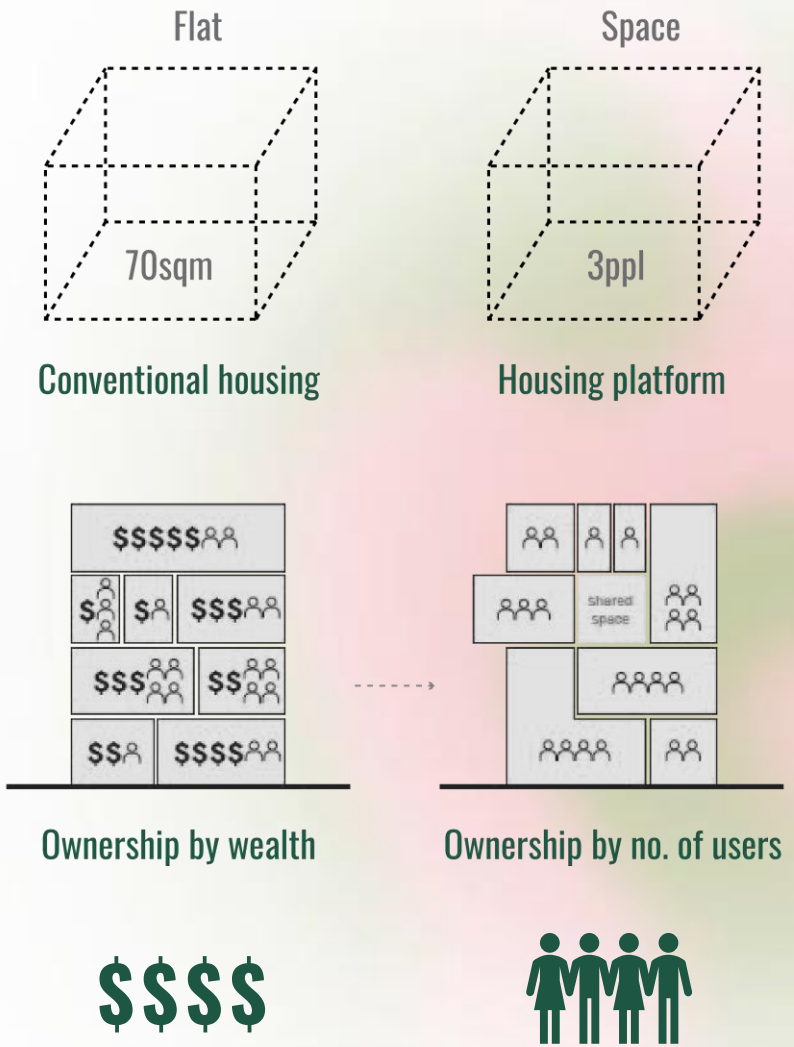


Ground floor



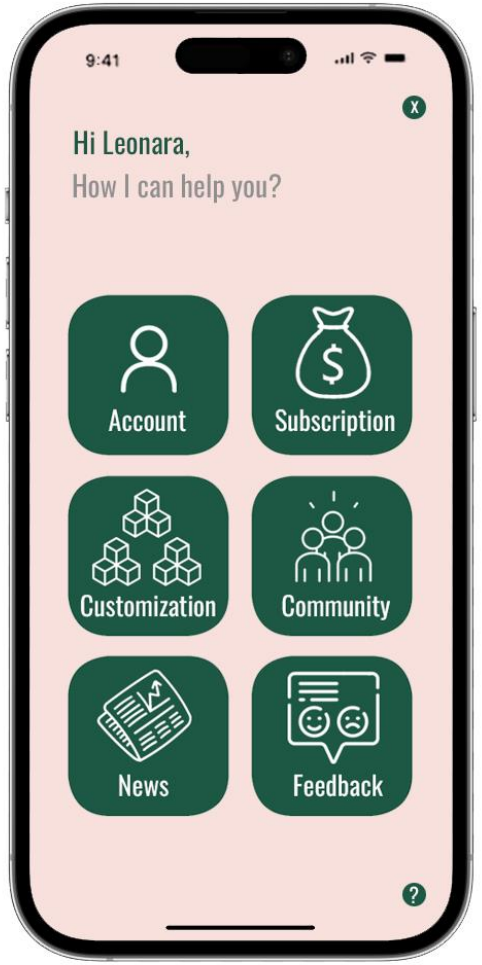
Housing platform's interface app for users





Cheng et al. (2020).

Housing platform’s interface app for users



Recognize Humans as a variable element.

Adaptability through reconfiguration.

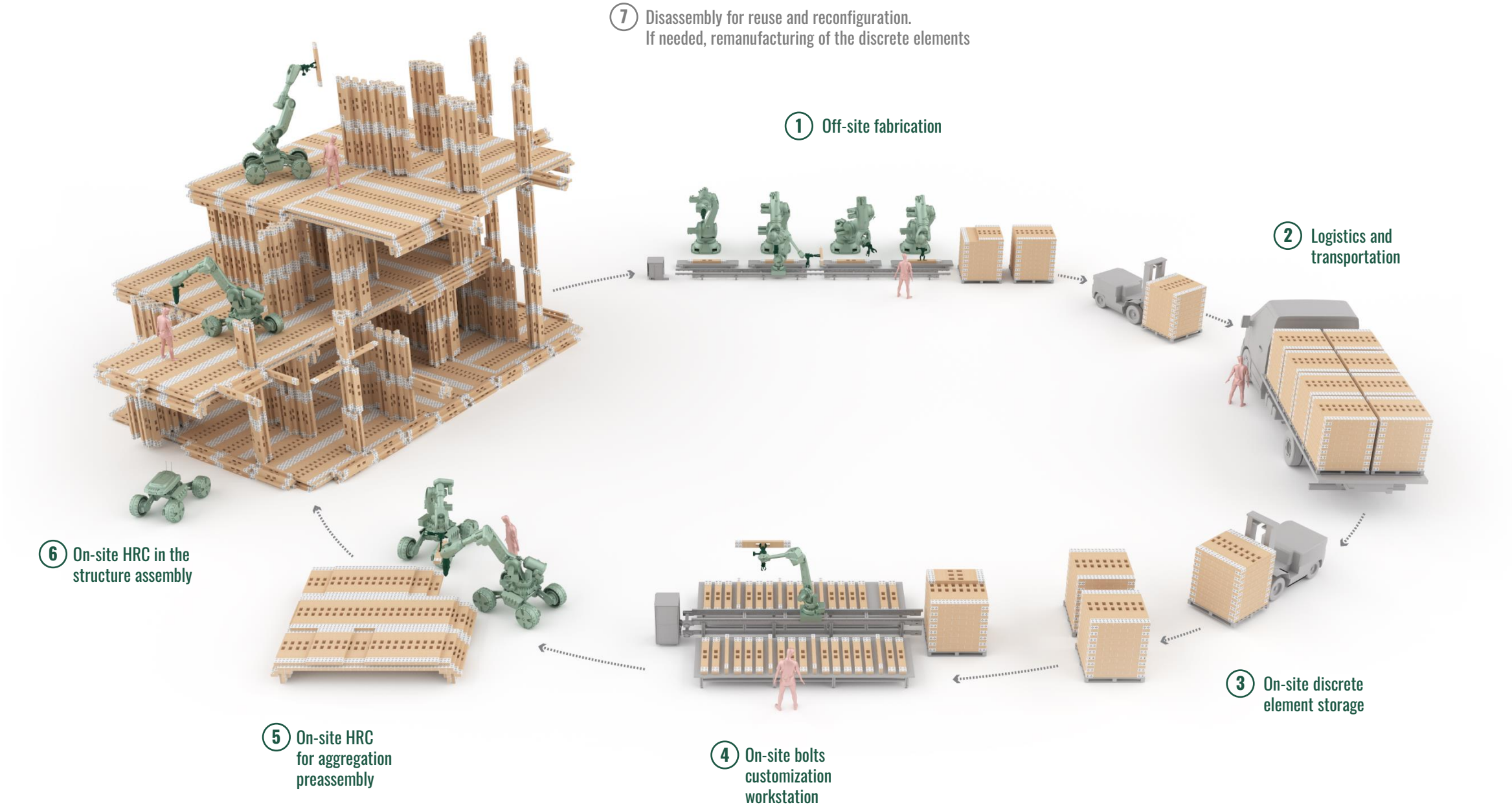
Changing ownership notion.

User-centric approach.

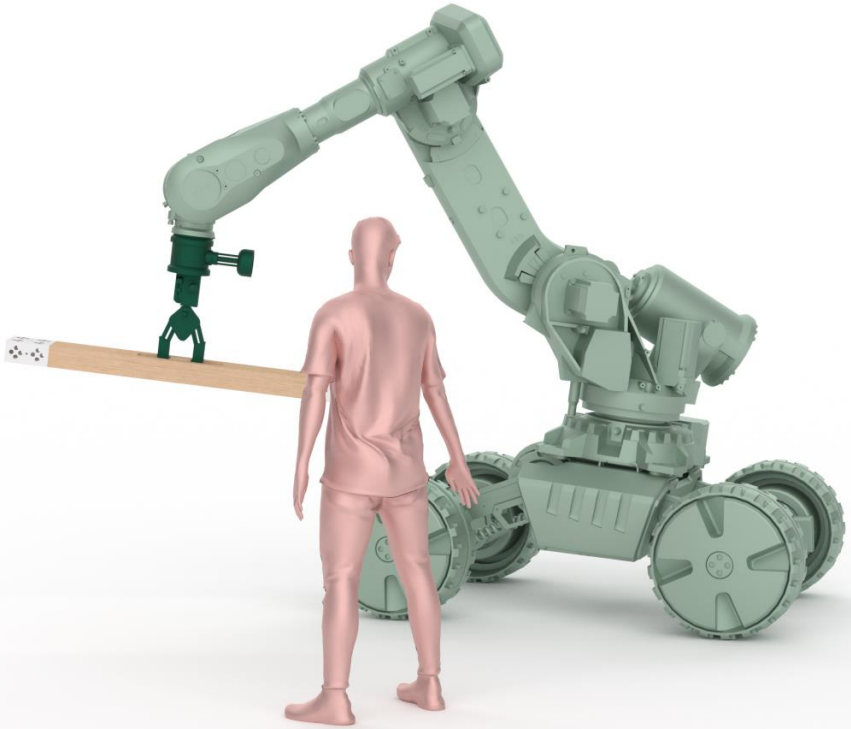
Cheng et al. (2020).

Cheng et al. (2020).

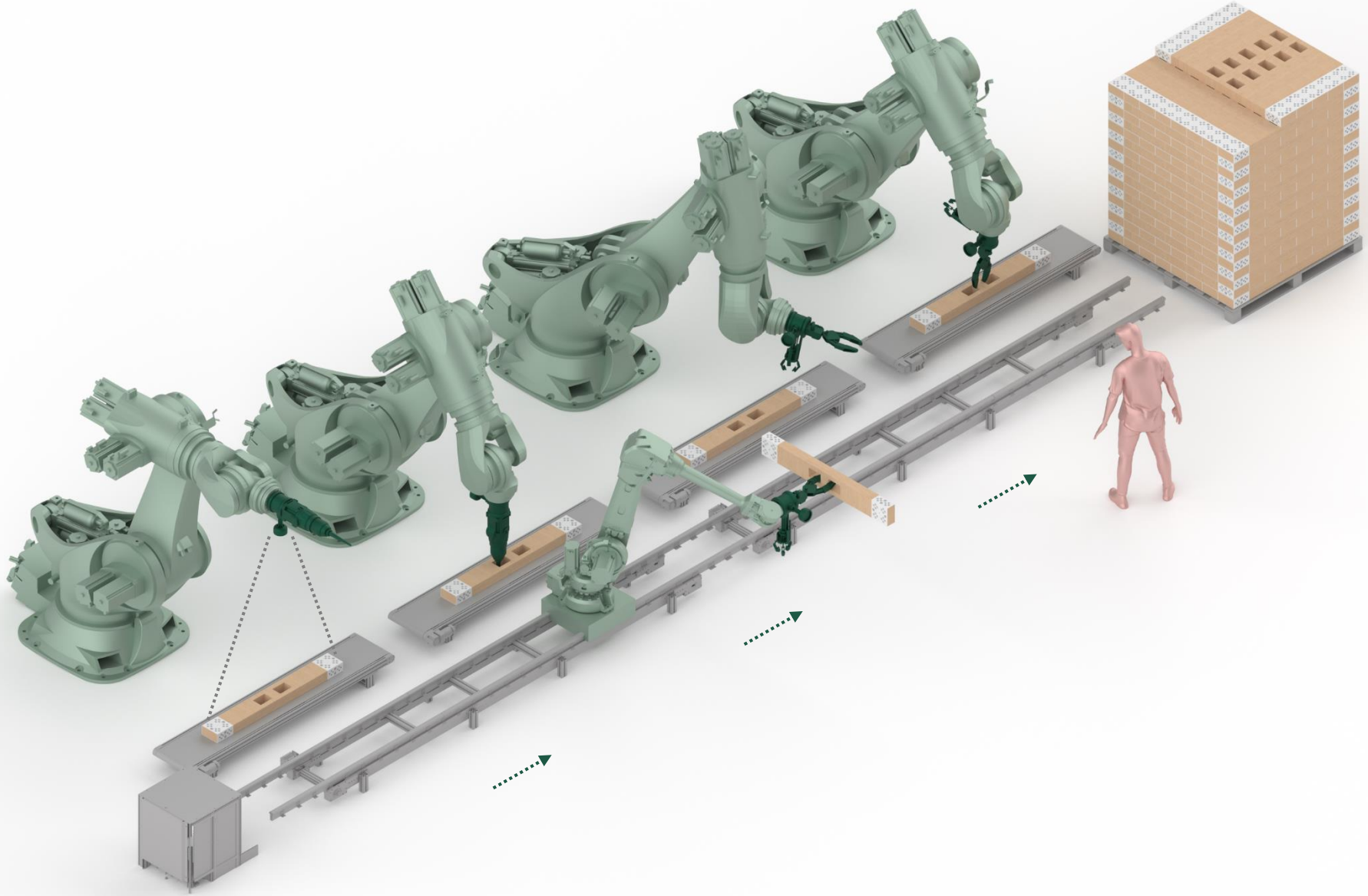
Design-to-build workflow



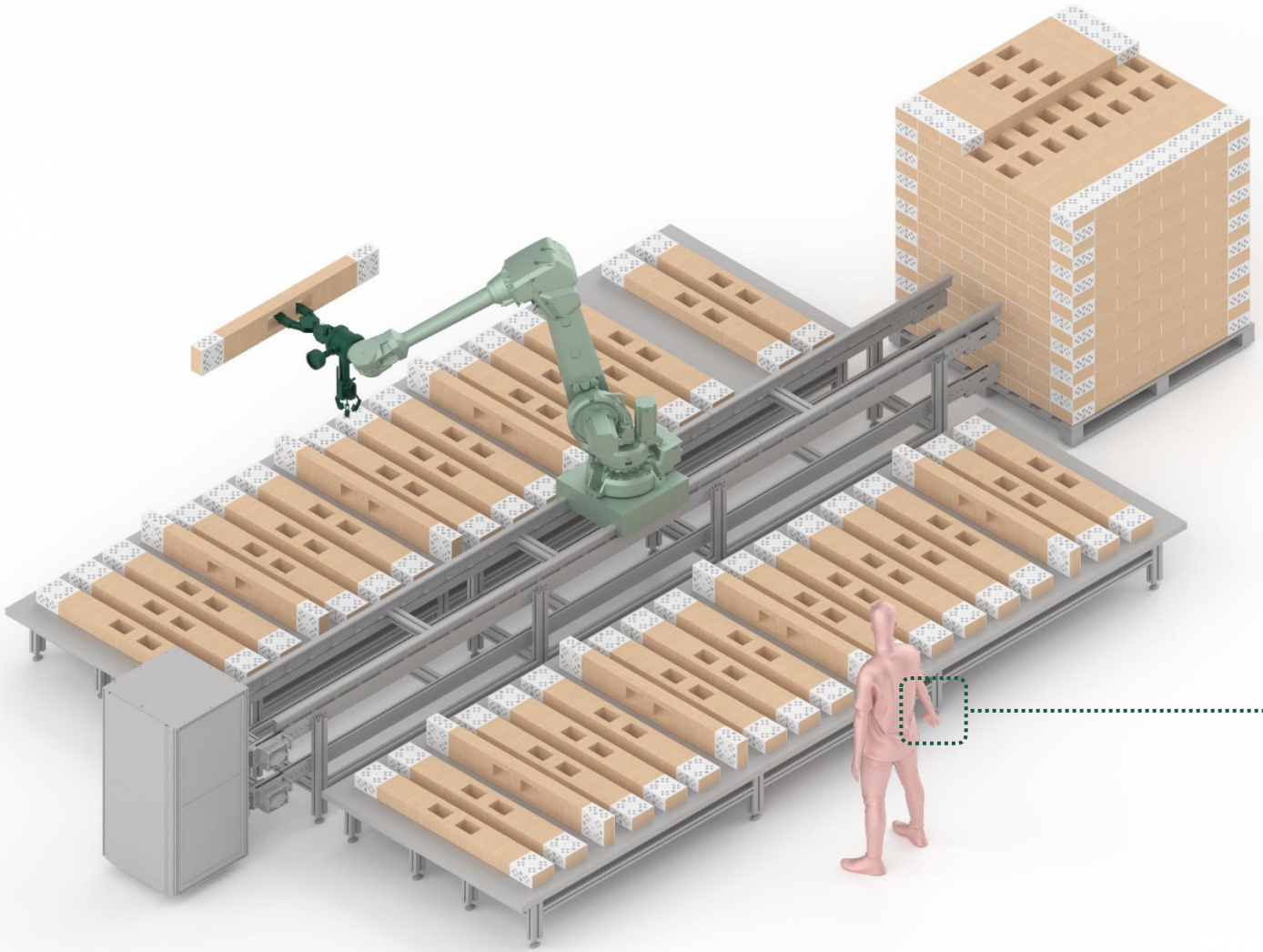
Robot awareness and human as assembly's tolerance



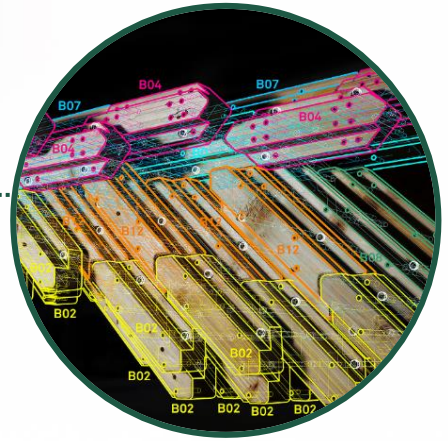
Off-site prefabrication



Customization workstation

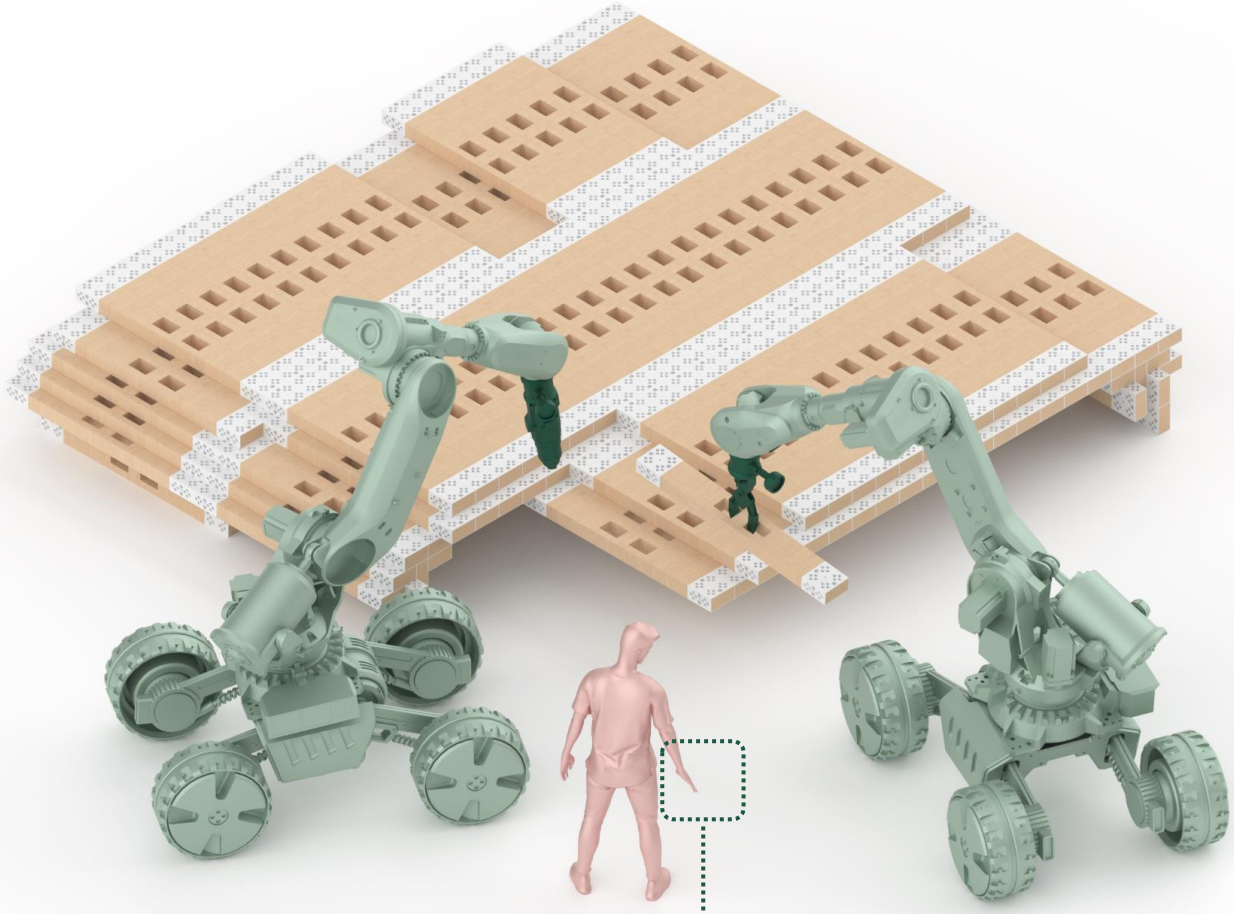


Augmented reality



Kunic et al., 2021b

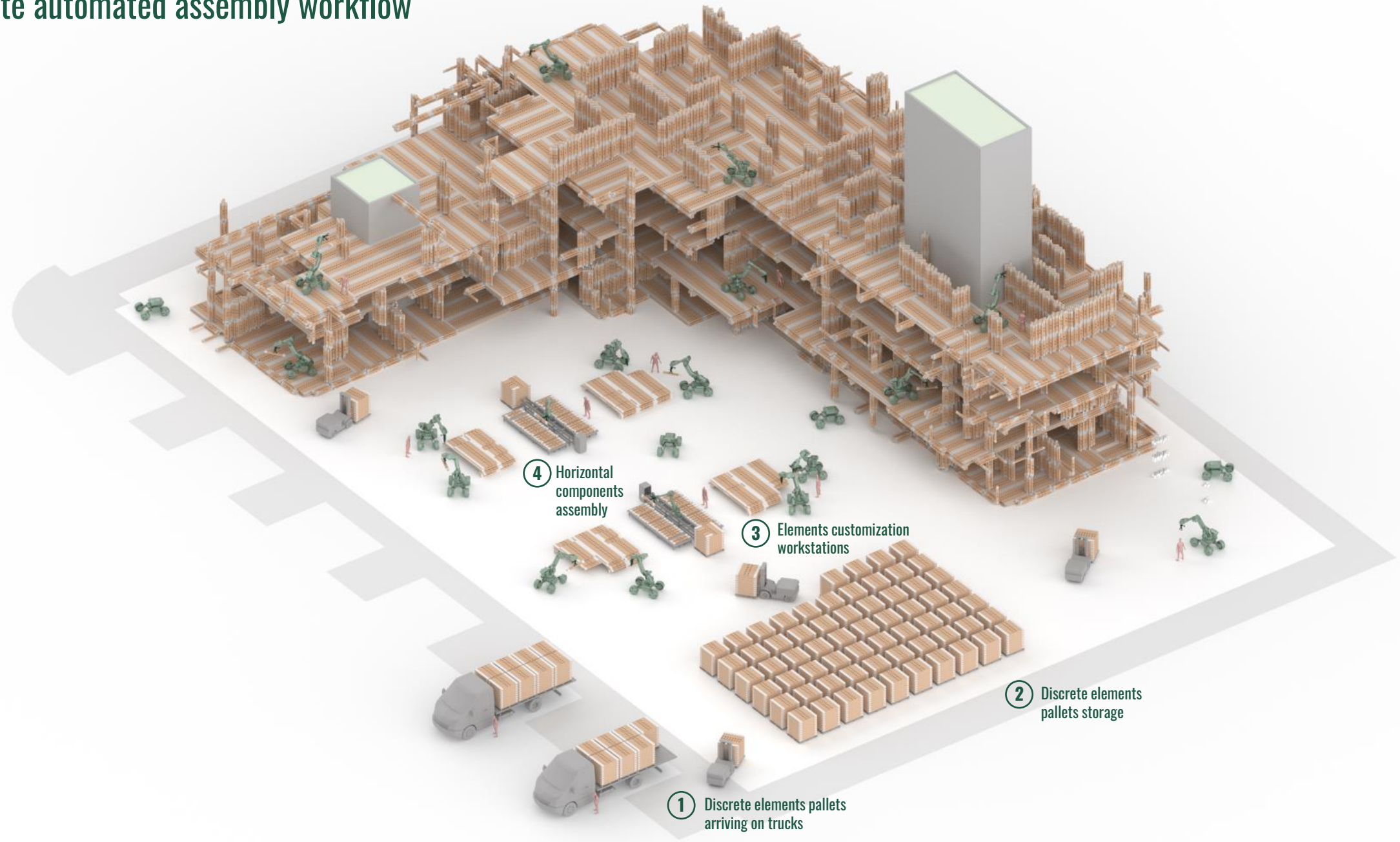
On-site HRC pre-assembling on the ground



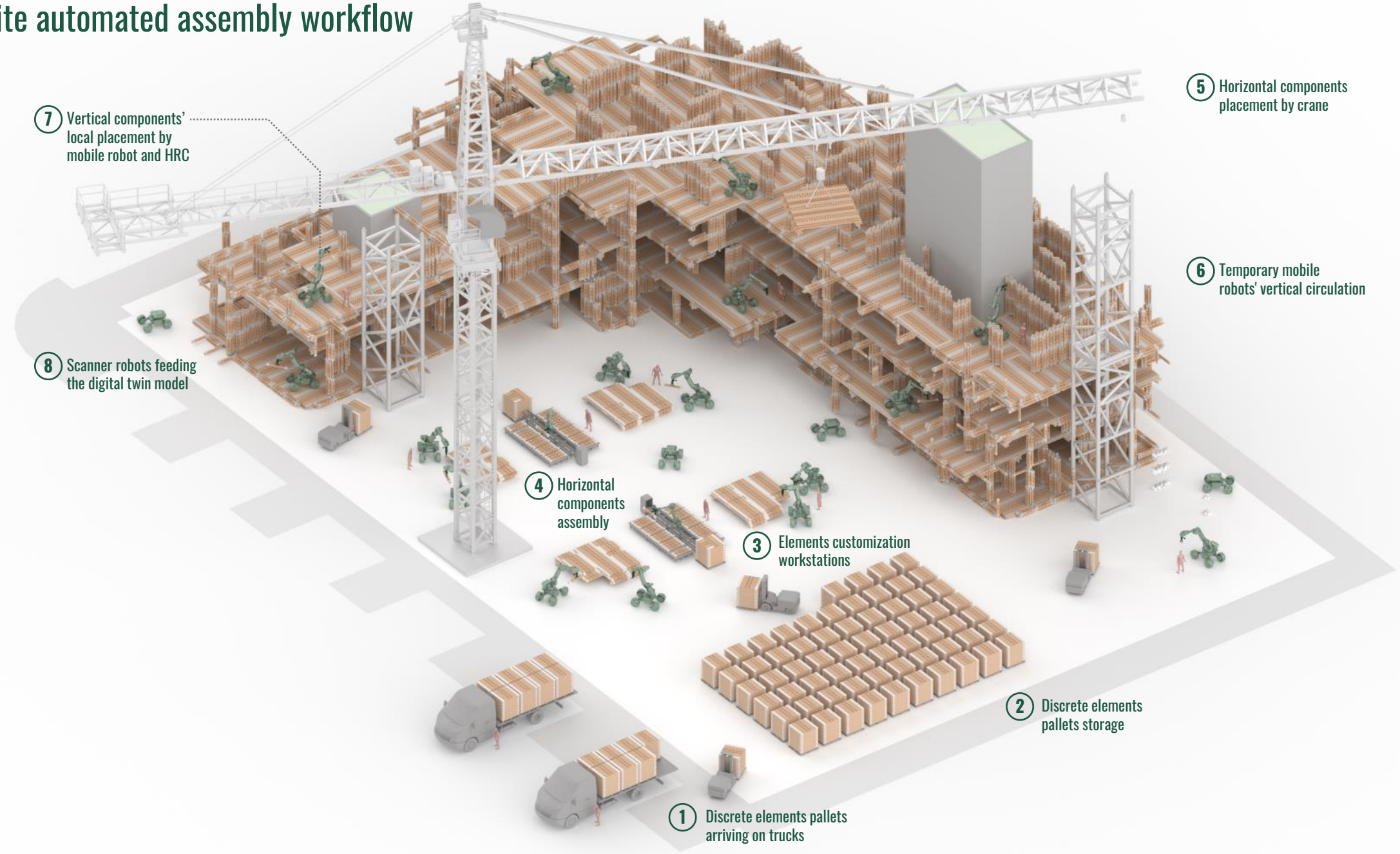
Nordbo Mimic Kit

Universal Robots, 2023

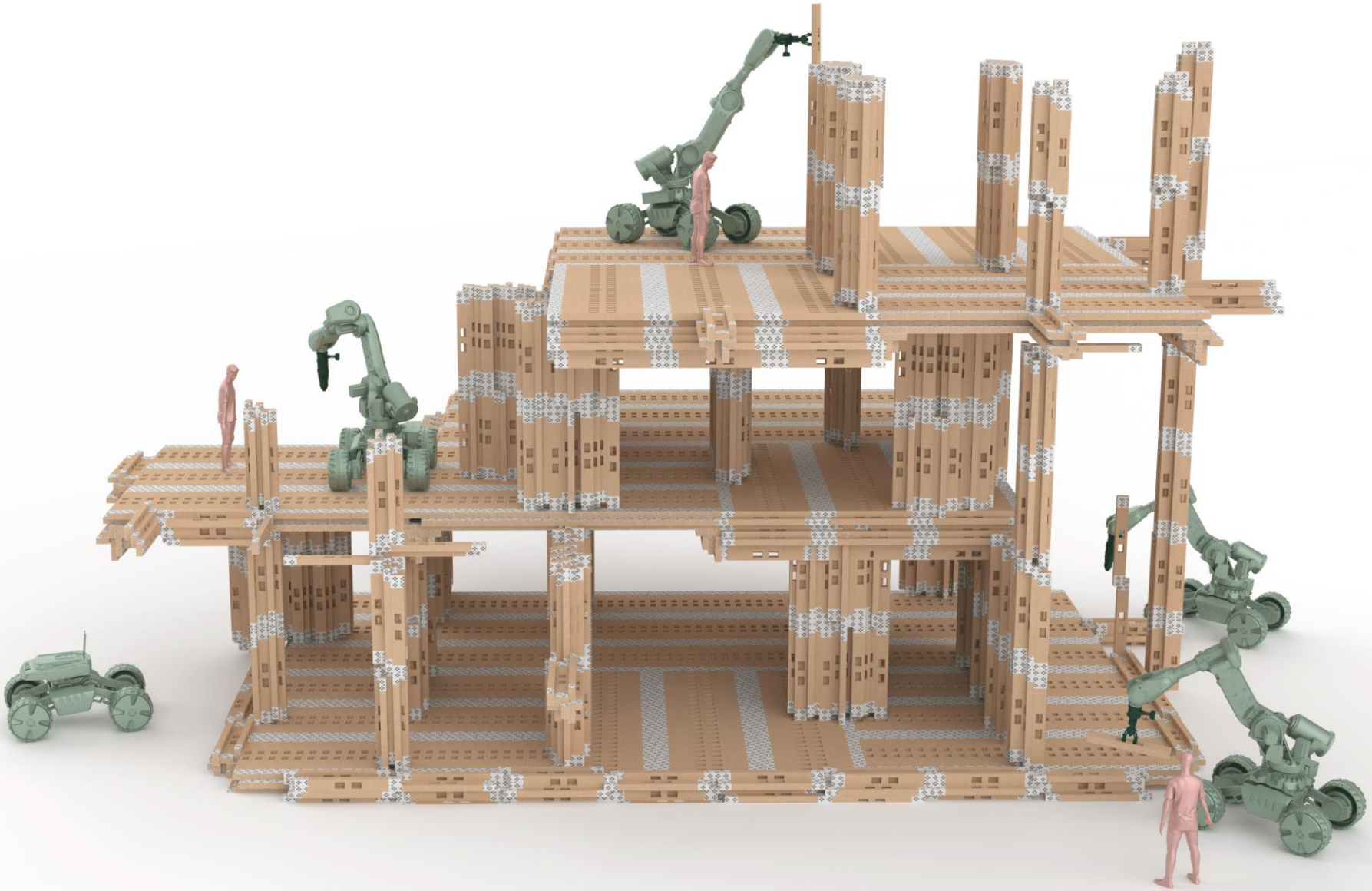
On-site automated assembly workflow

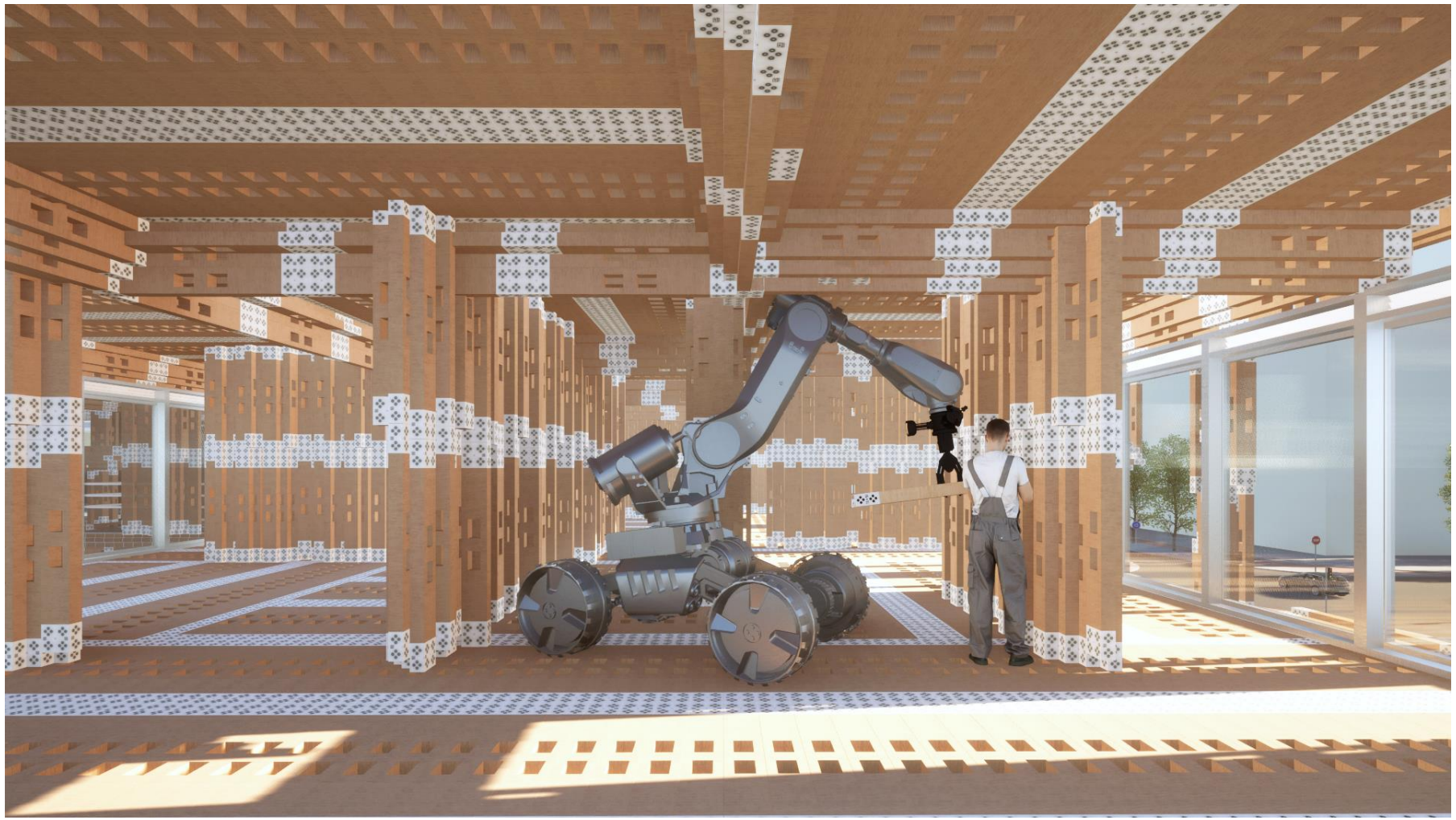


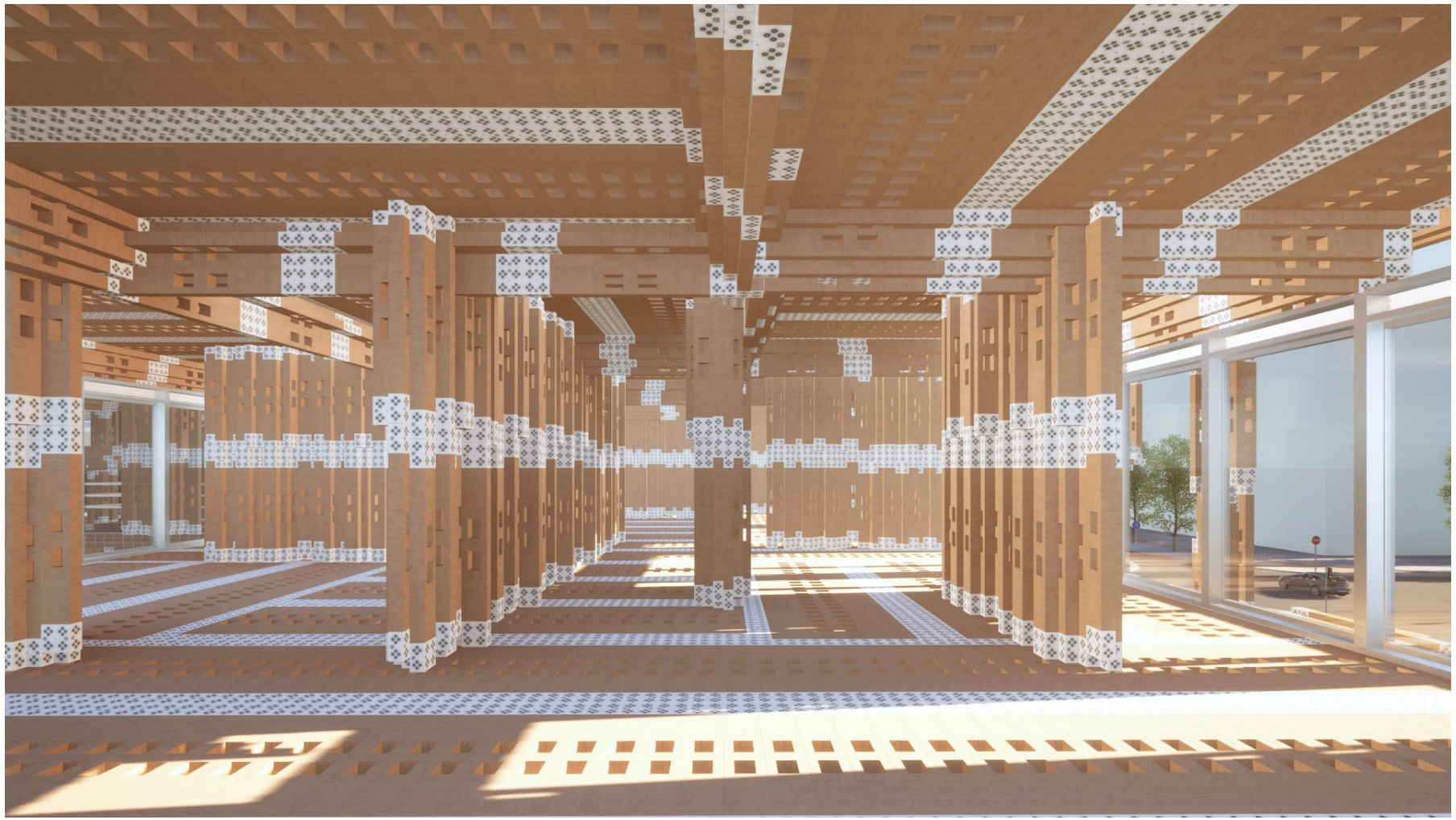
On-site automated assembly workflow



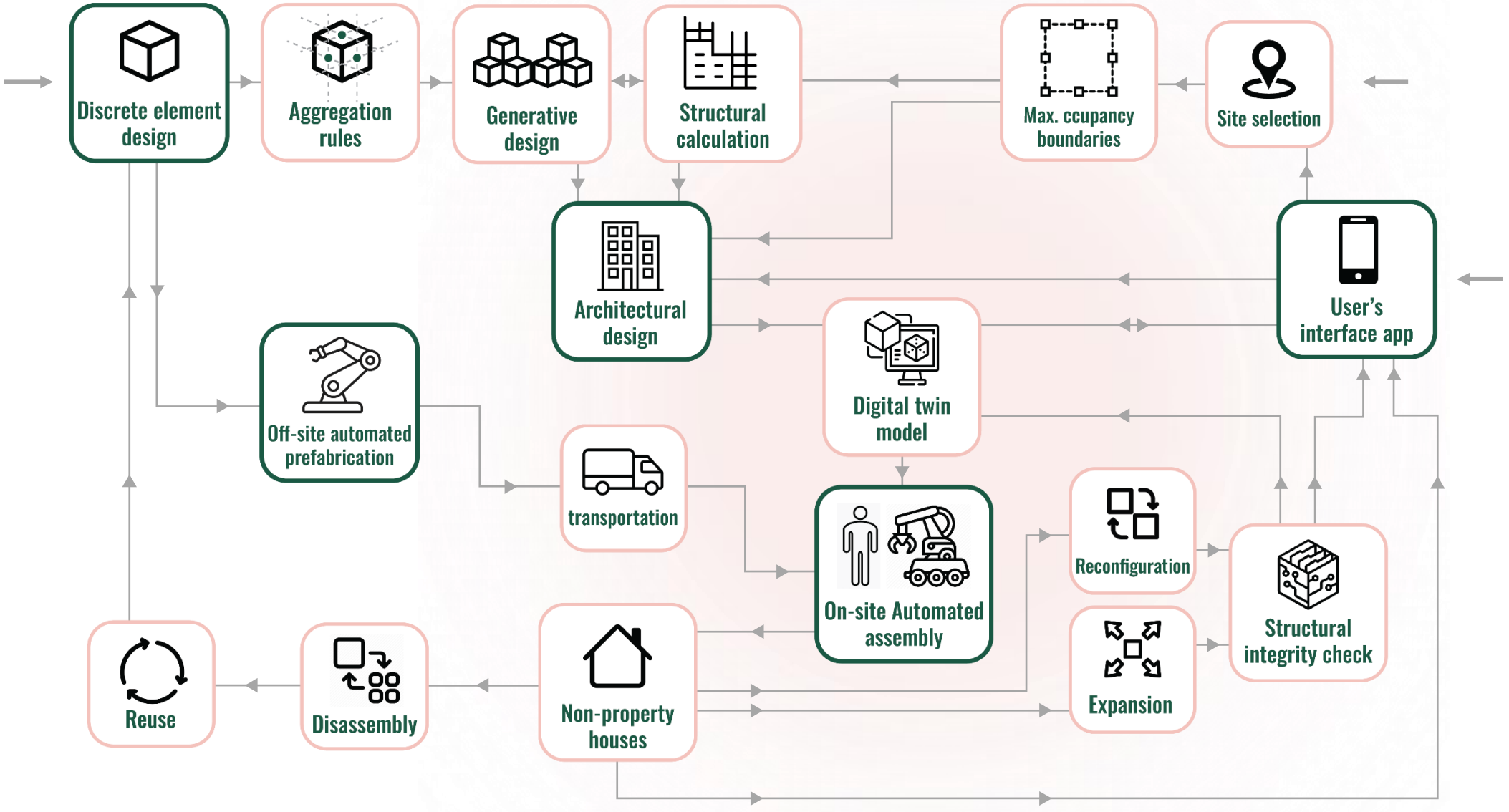
Reconfiguration







Automated workflow overview



1:1

3 pieces

1:5

16 pieces

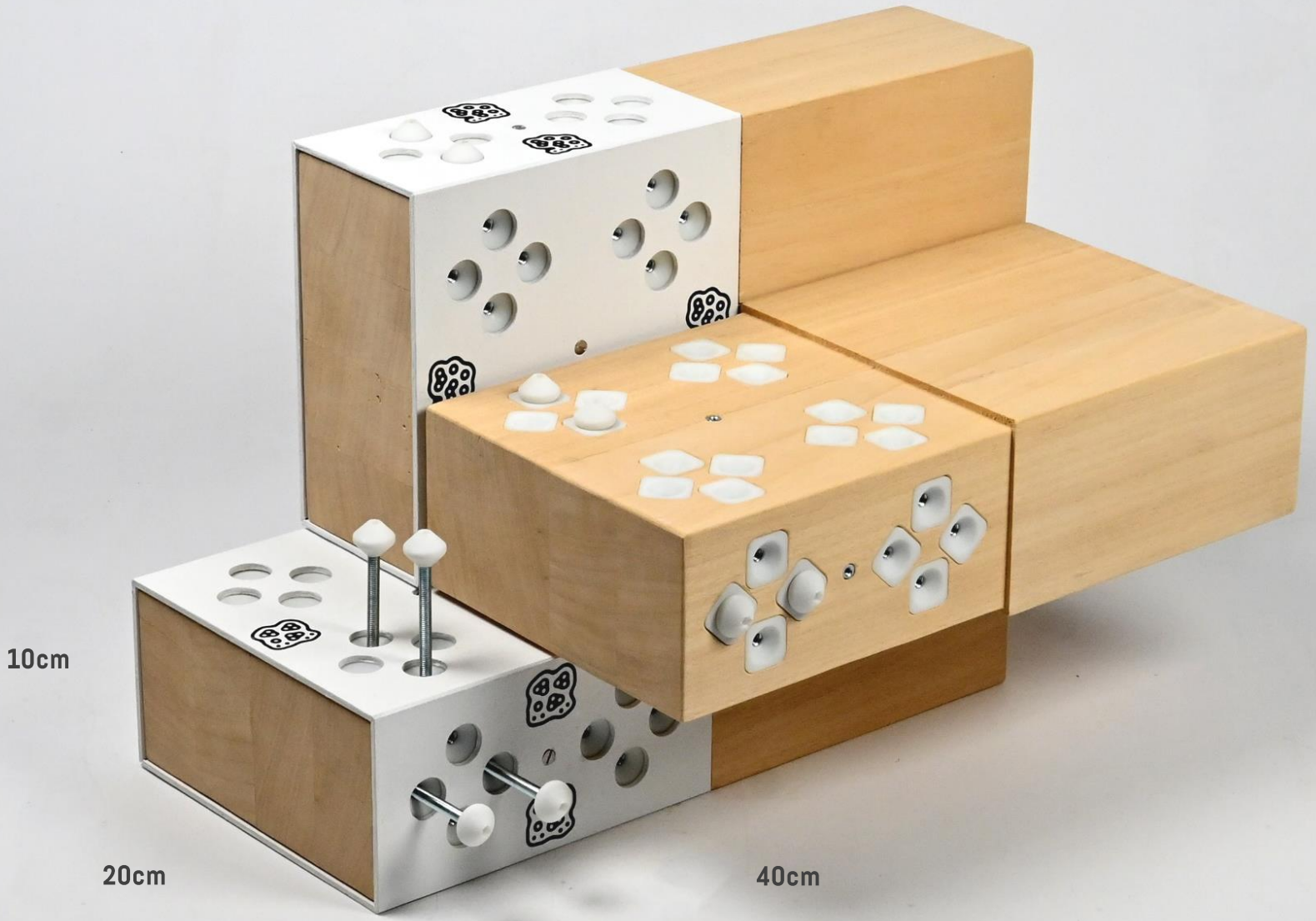
1:10

150 pieces

1:1 Prototype

3 pieces

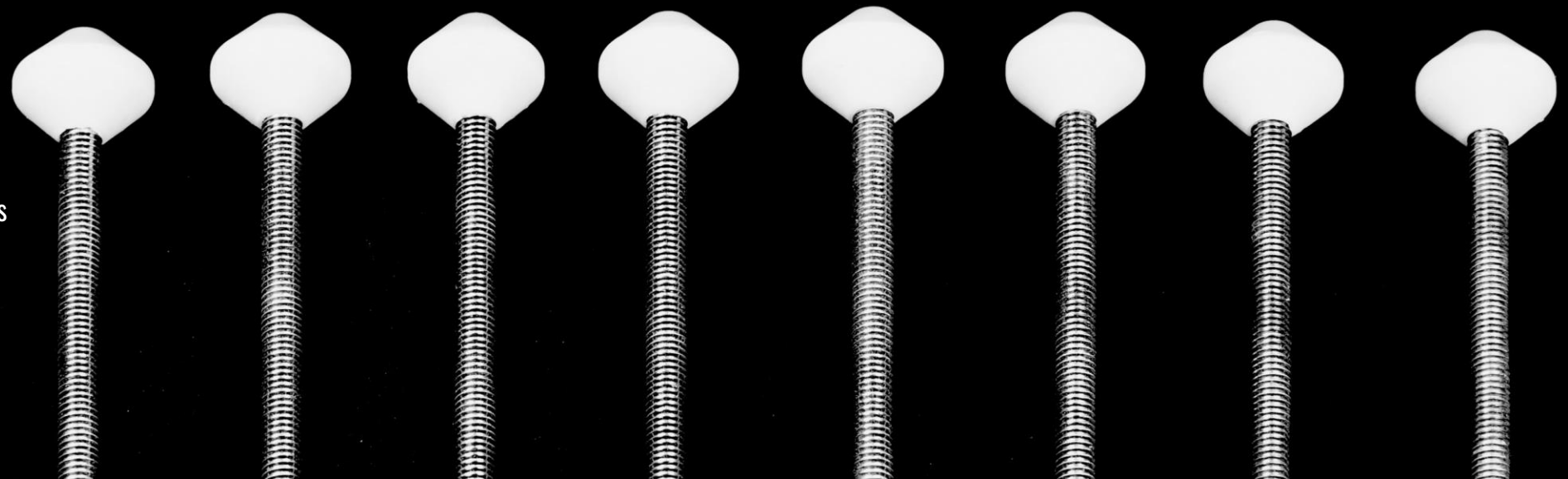
real connection
bolts in the right dimension



1:1 Prototype precision testing

1:1 Prototype parts

M6 threads



1:1 Prototype procedures

1:1 Prototype parts

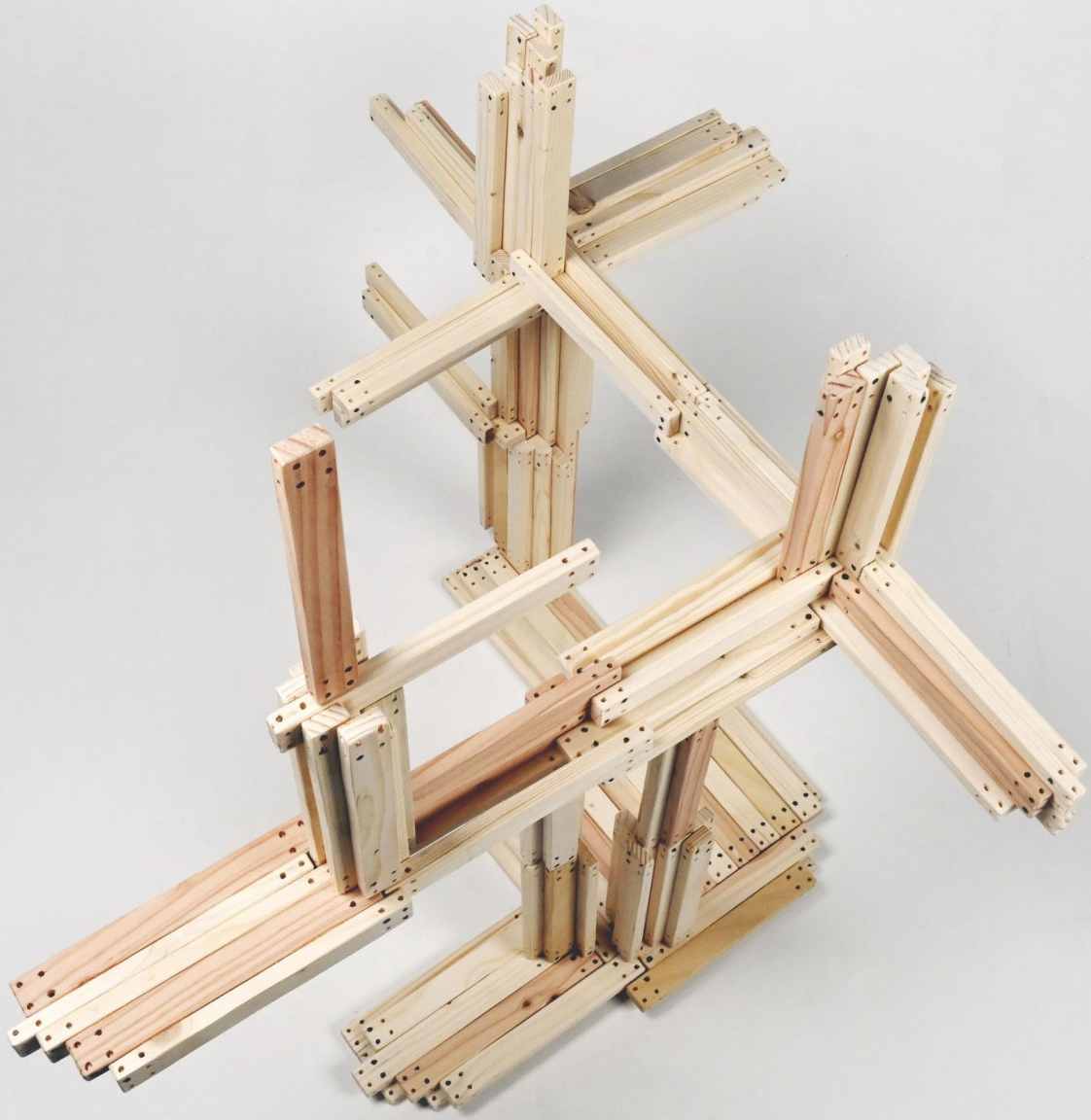
1:1 Prototype configurations

1:10 Prototype

150 pieces

element in a larger quantity
assignment of a function

1:10 Prototype



Basalt Columns in Iceland (CarSiceland, n.d.).

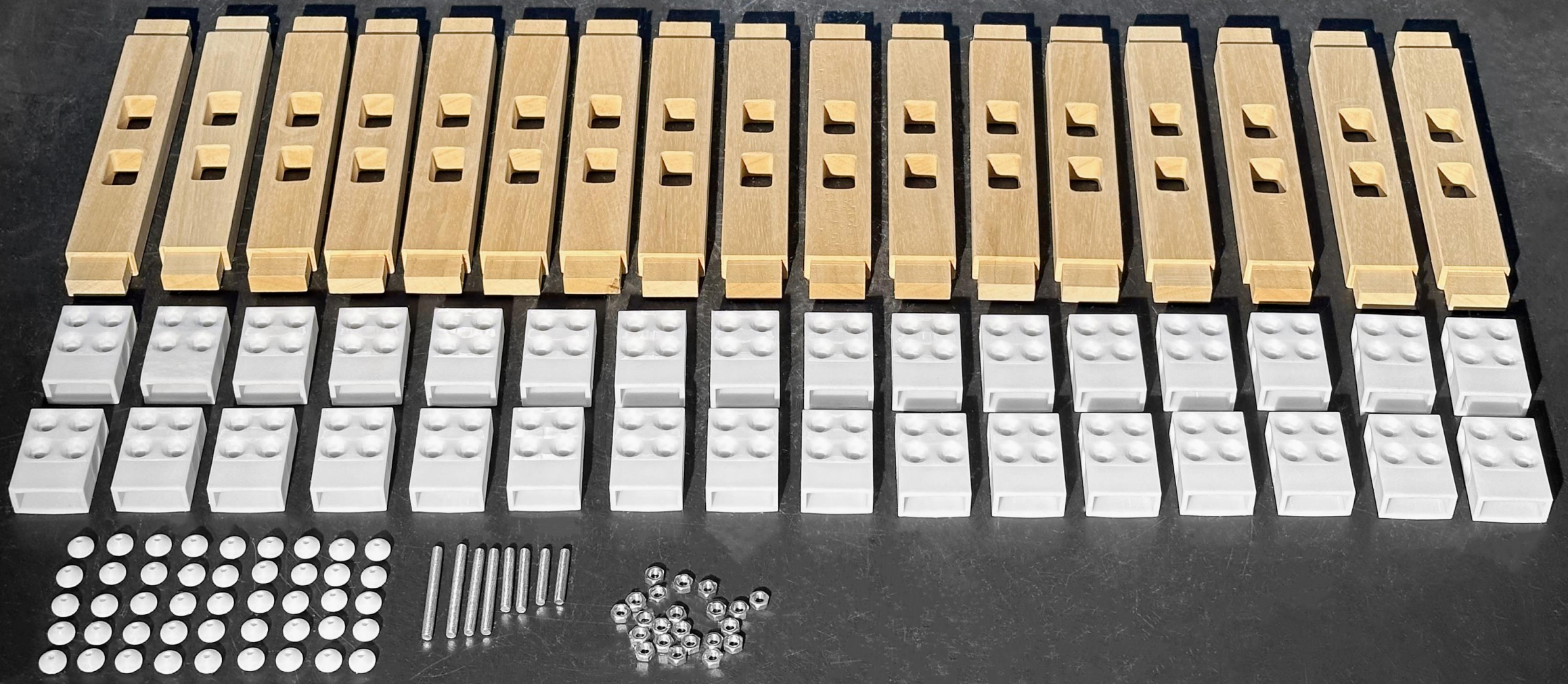
1:5 Prototype

16 pieces

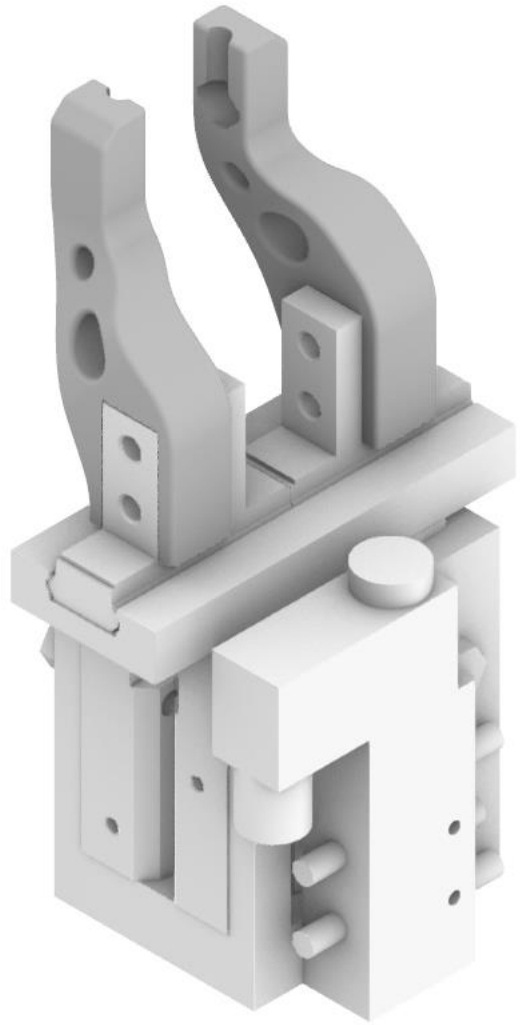
robotic workflow
human-robot collaboration
discrete self-alignment

1:5 Prototype discrete element

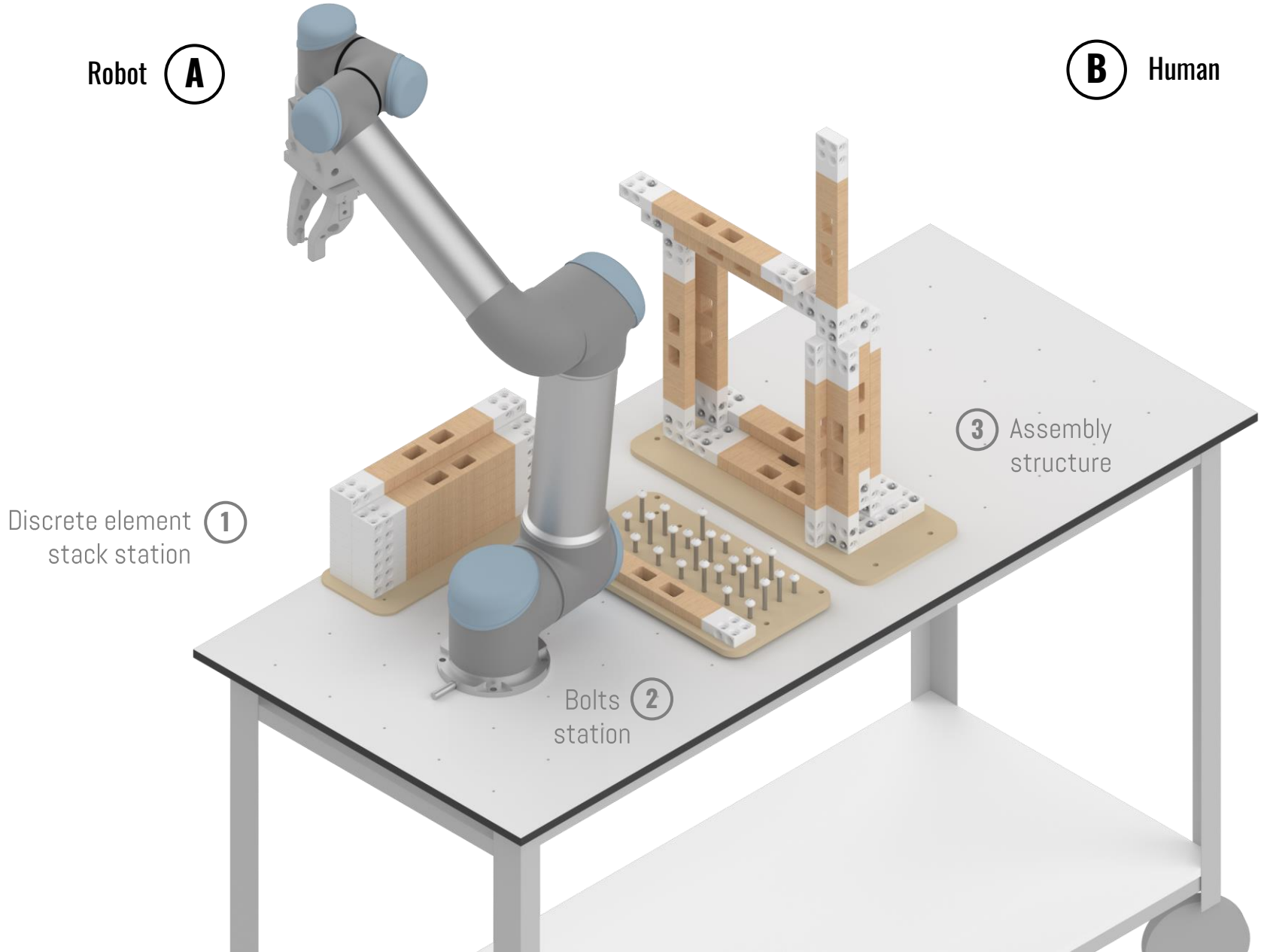
1:5 Prototype parts



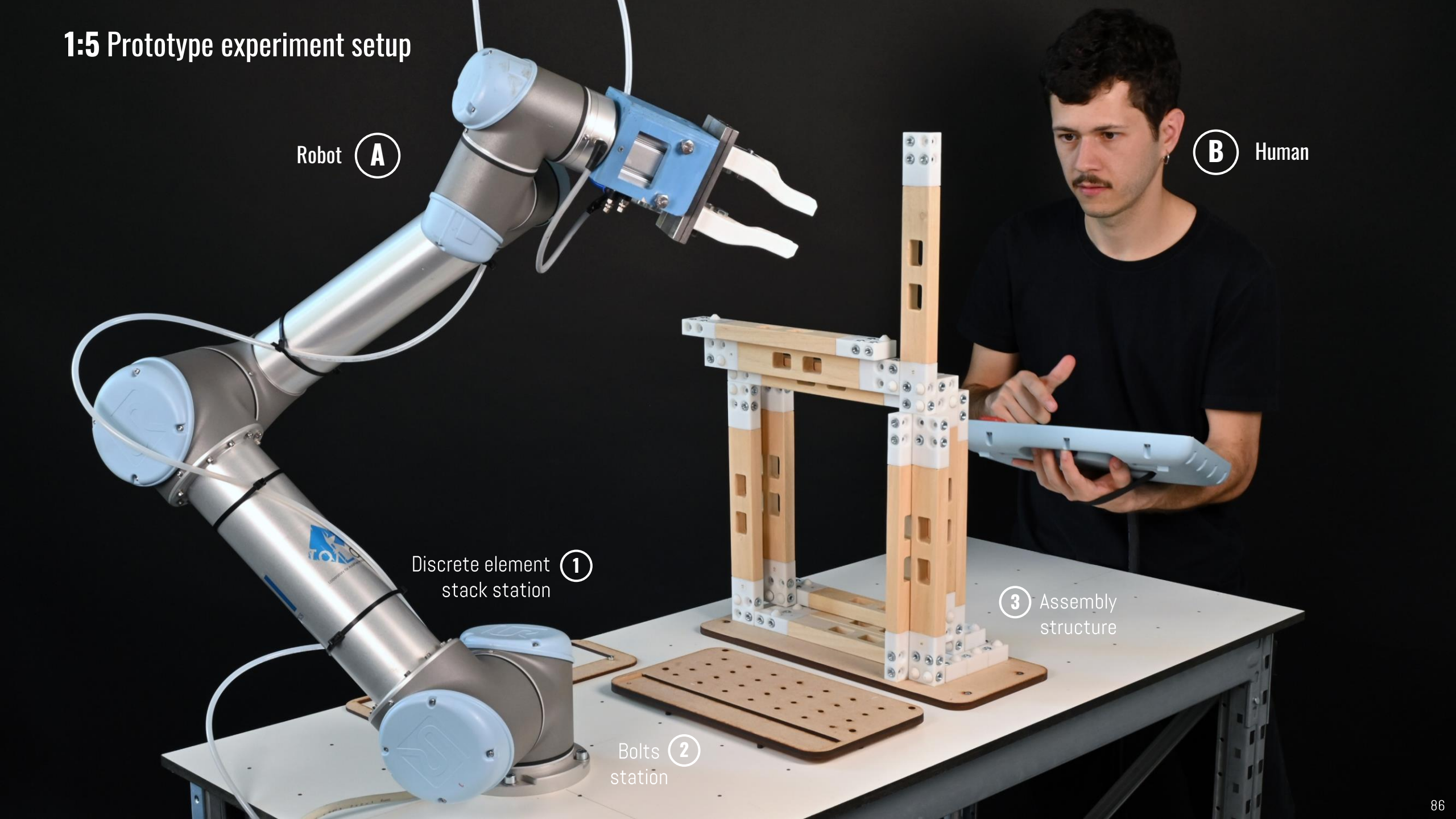
1:5 Prototype end effector design



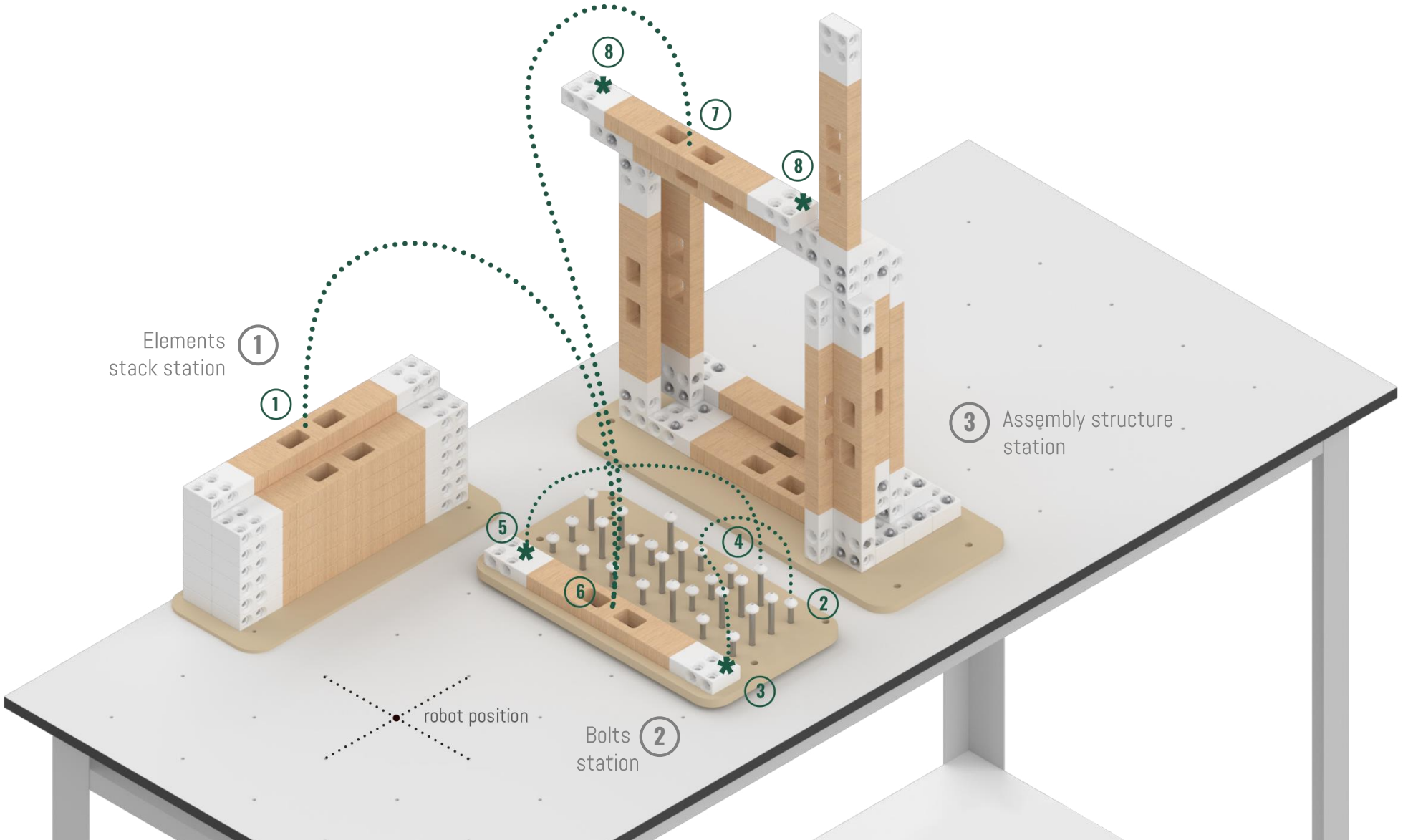
1:5 Prototype experiment setup



1:5 Prototype experiment setup

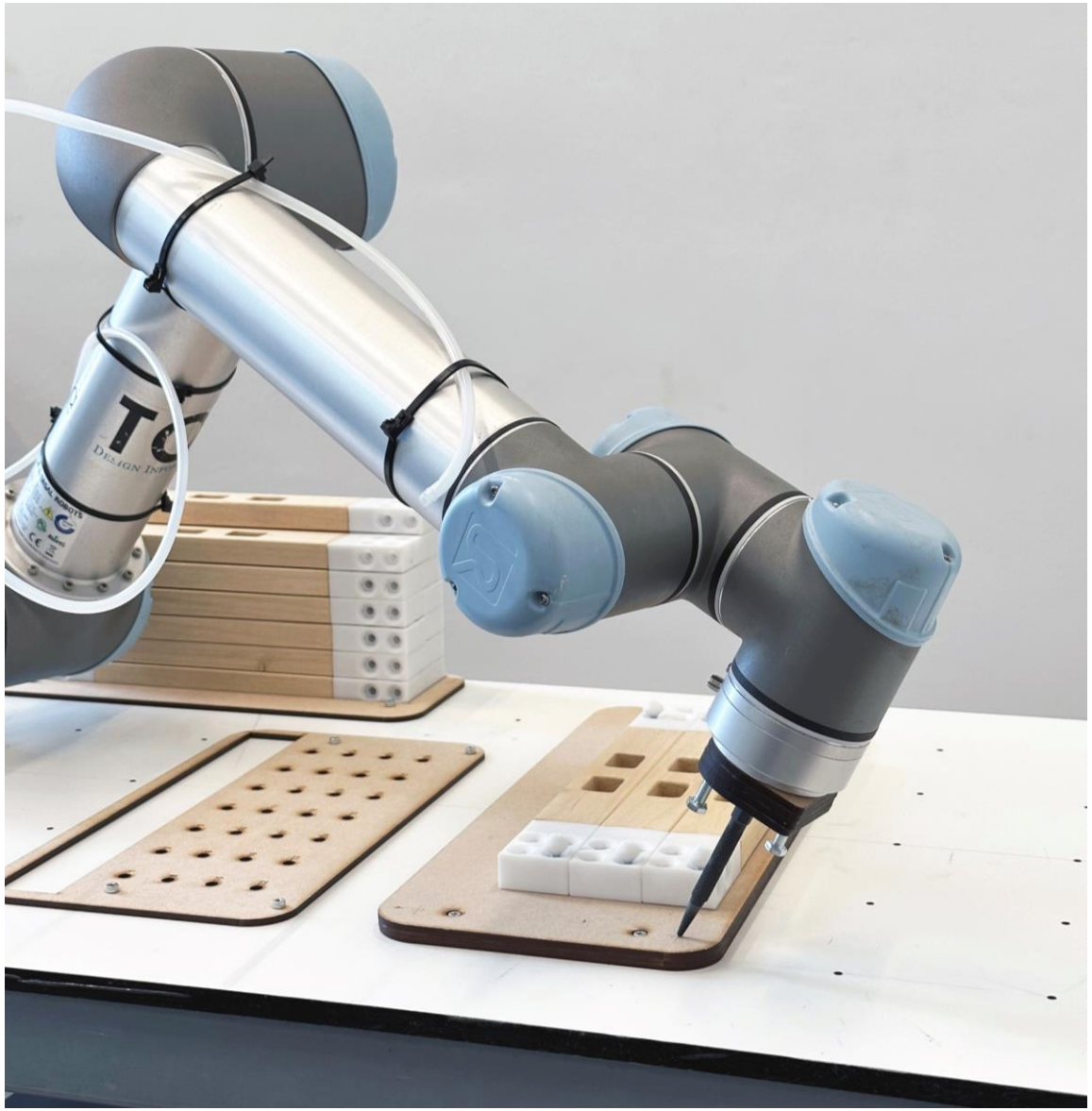


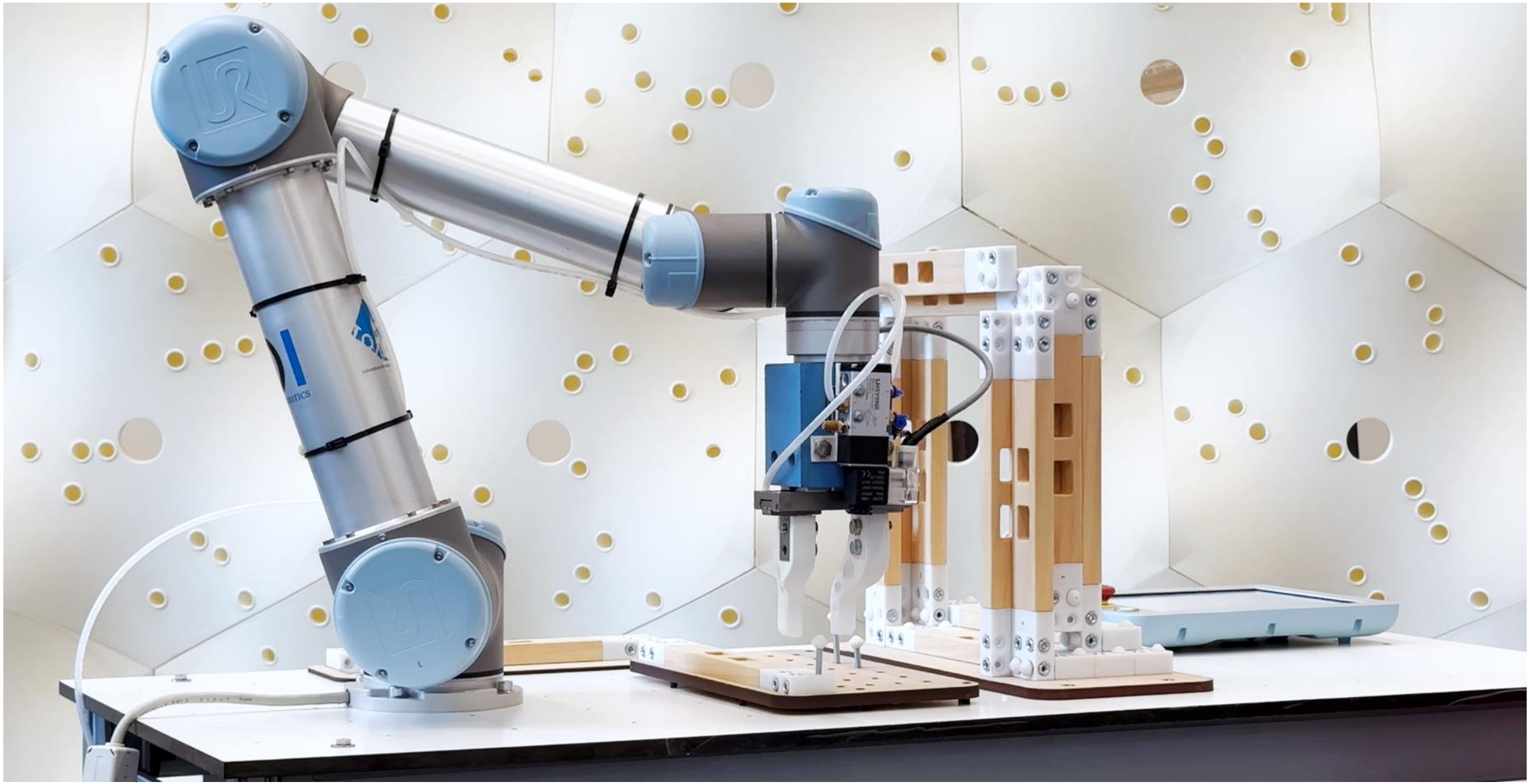
1:5 Prototype movements

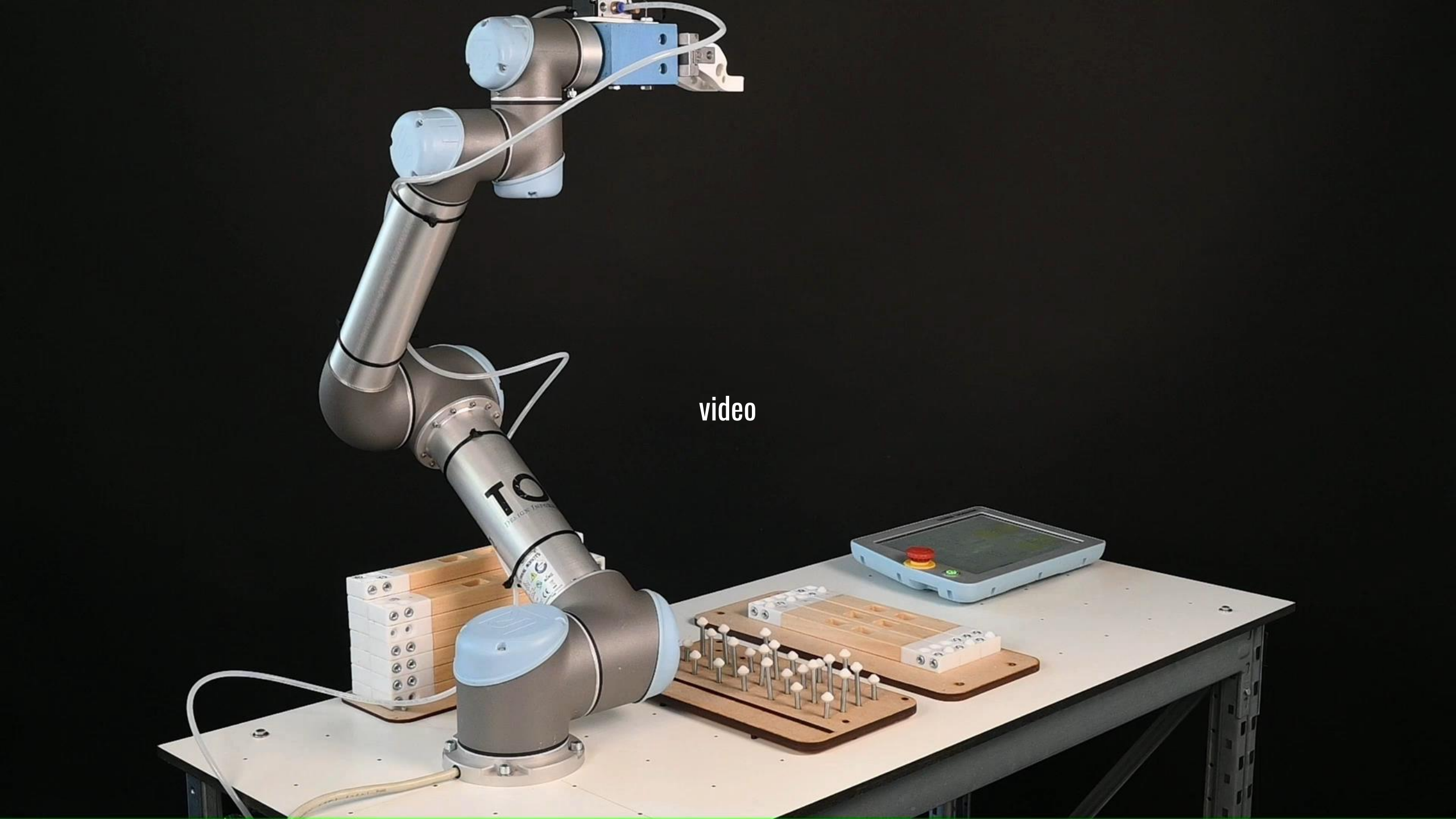


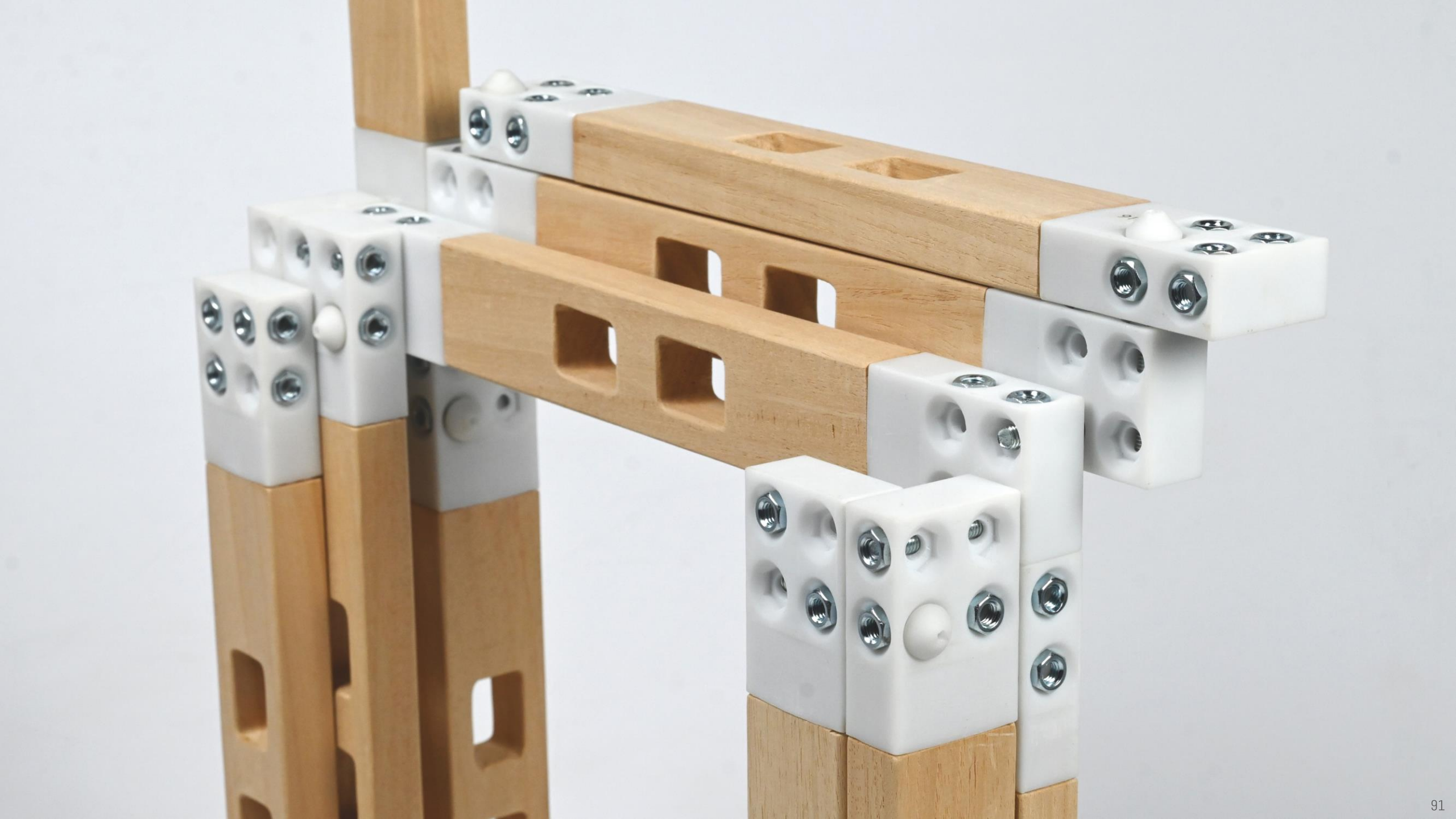
Elements stack station
Bolts station
Assembly structure station

0	Stack approach **arrival** point
1	Discrete element **pick-up** point
2	Stack approach **departure** point
3	Element preparation approach **arrival** point
4	Element preparation **place** point
5	Element preparation approach **departure** point
6	1st bolt approach **arrival** point
7	1st bolt **pick-up** point
8	1st bolt approach **departure** point
9	1st bolt placement approach **arrival** point
10	1st bolt **placement** point
11	1st bolt placement approach **departure** point
12	2nd bolt approach **arrival** point
13	2nd bolt **pick-up** point
14	2nd bolt approach **departure** point
15	2nd bolt placement approach **arrival** point
16	2nd bolt **placement** point
17	2nd bolt placement approach **departure** point
18	Element preparation approach **arrival** point
19	Element preparation **pick-up** point
20	Element preparation approach **departure** point
21	Customized **transition** point
22	Final placement approach **arrival** point
23	Final **placement** point
24	Final placement approach **departure** point
25	Customized **transition** point






video



Further developments

- Automated disassembly
- Topology optimization
- Aggregation rules from structural calculations
- Structural calculation
- Mechanical properties tests
- Self-alignment of the bolts in a 1:1 scale
- Tolerances improvements
- Robot sensing and awareness
- Real-time validation feedback
- Digital twin model platform
- Real-time structural analysis for reconfiguration
- Alternative assembly methods
- Robot design
- Insulation
- Financial impact
- 45 degrees connections
- Other lengths of elements

It is about time.

The systems of change.

The adaptable architecture.

The circular.


thank you

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