Structural performance of reversible discrete timber systems

MSc in Architecture, Urbanism and Building Sciences, Building Technology track at Technical University of Delft

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Delegate of the board of examiners: Ir. M.J. de Haas

Introduction

Context

World's first year-long breach of key 1.5C warming limit

8 February 2024

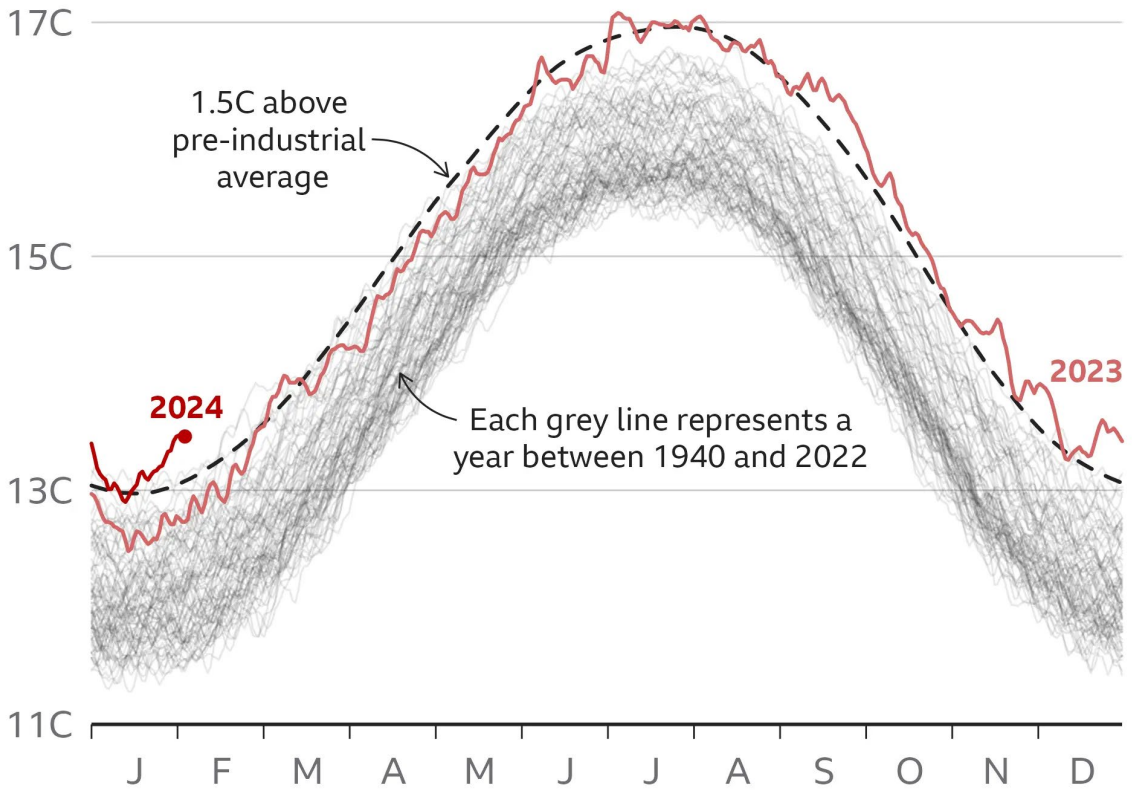
Share

By Mark Poynting, BBC News climate reporter

News article on World's first year-long breach of key 1.5C warming limit (Poynting, 2024)

Global temperatures remain at record levels

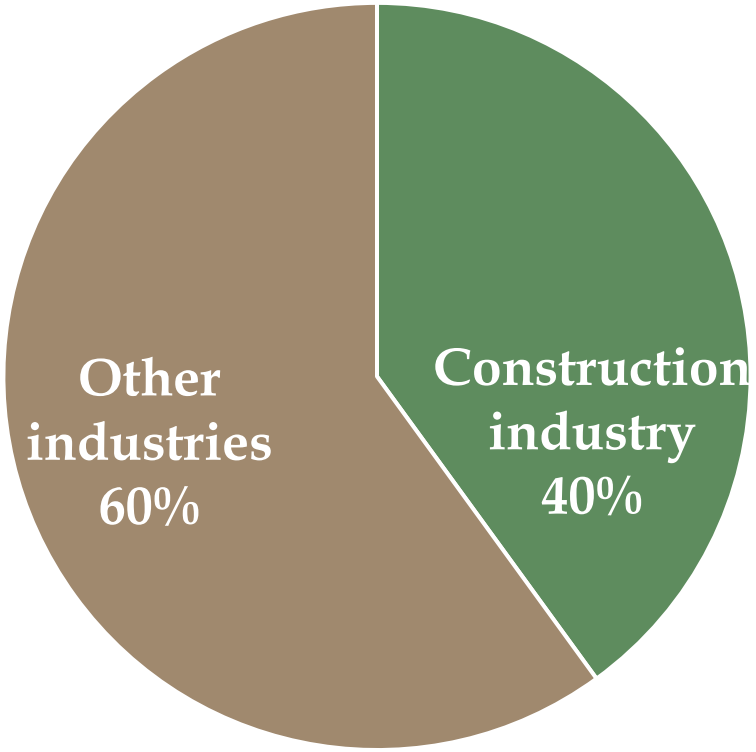
Daily global average air temperature, 1940-2024



Daily global surface air temperature by C3S-ECMWF (2024)

Context

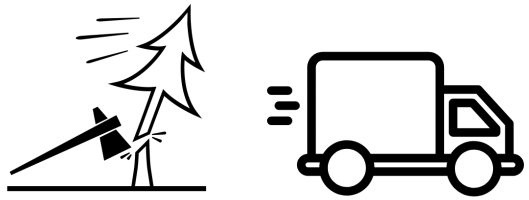
Greenhouse gas emissions of construction industry compared to the total (New Buildings Institute, 2023)



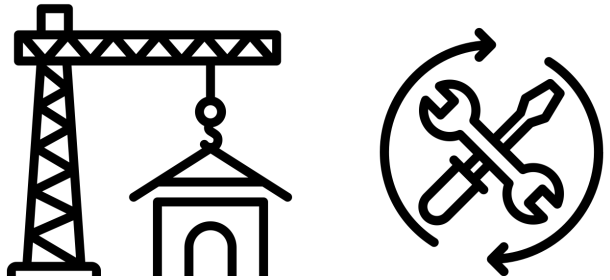
Problem statement

25% of the total construction industry emissions are **embodied carbon** emissions

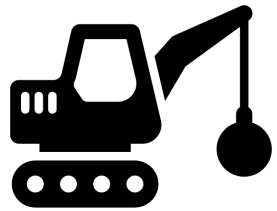
Harvest & Transport



Construction & Maintenance



Deconstruction/ demolishing



Problem statement

Lower embodied carbon materials

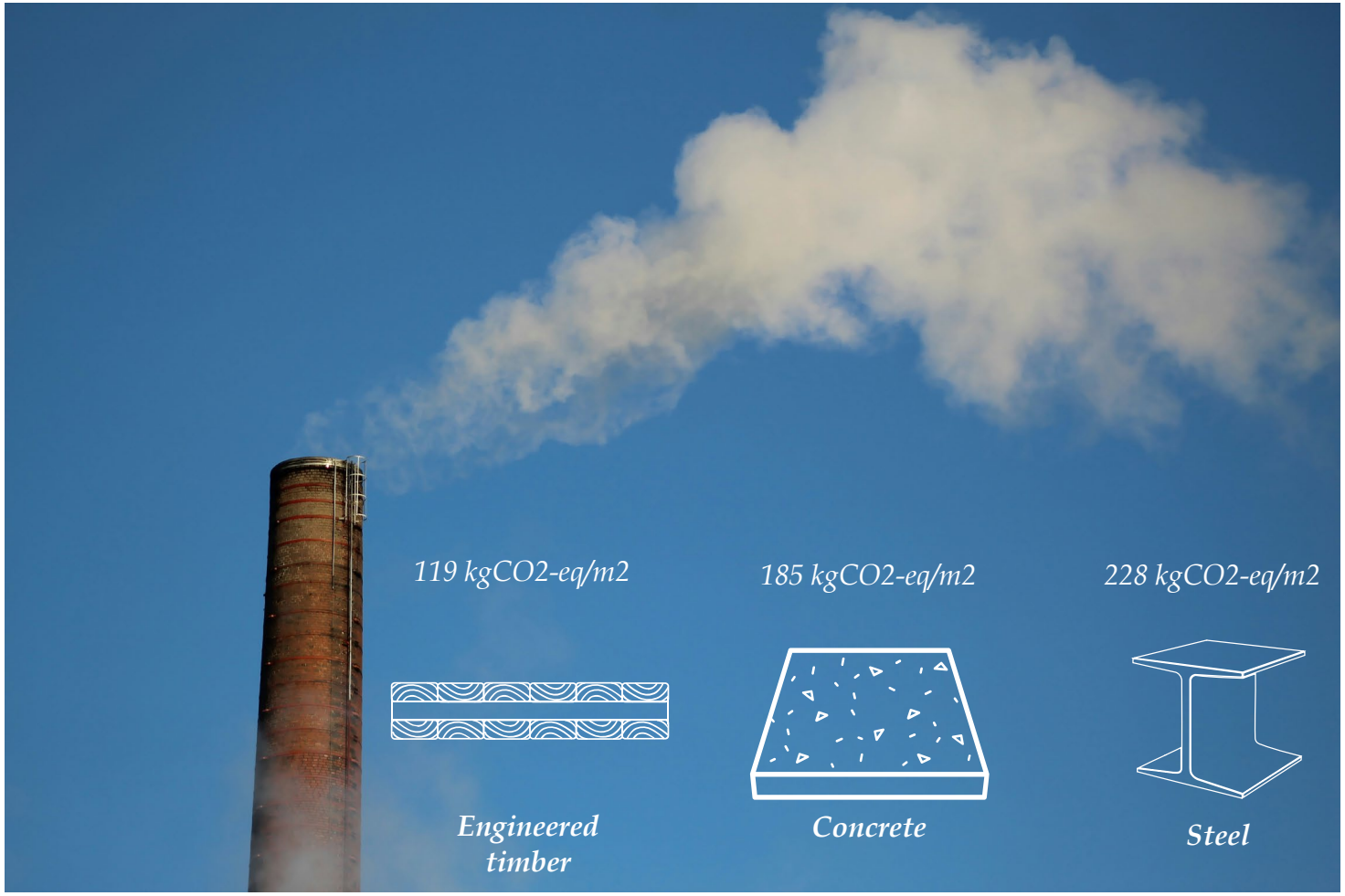
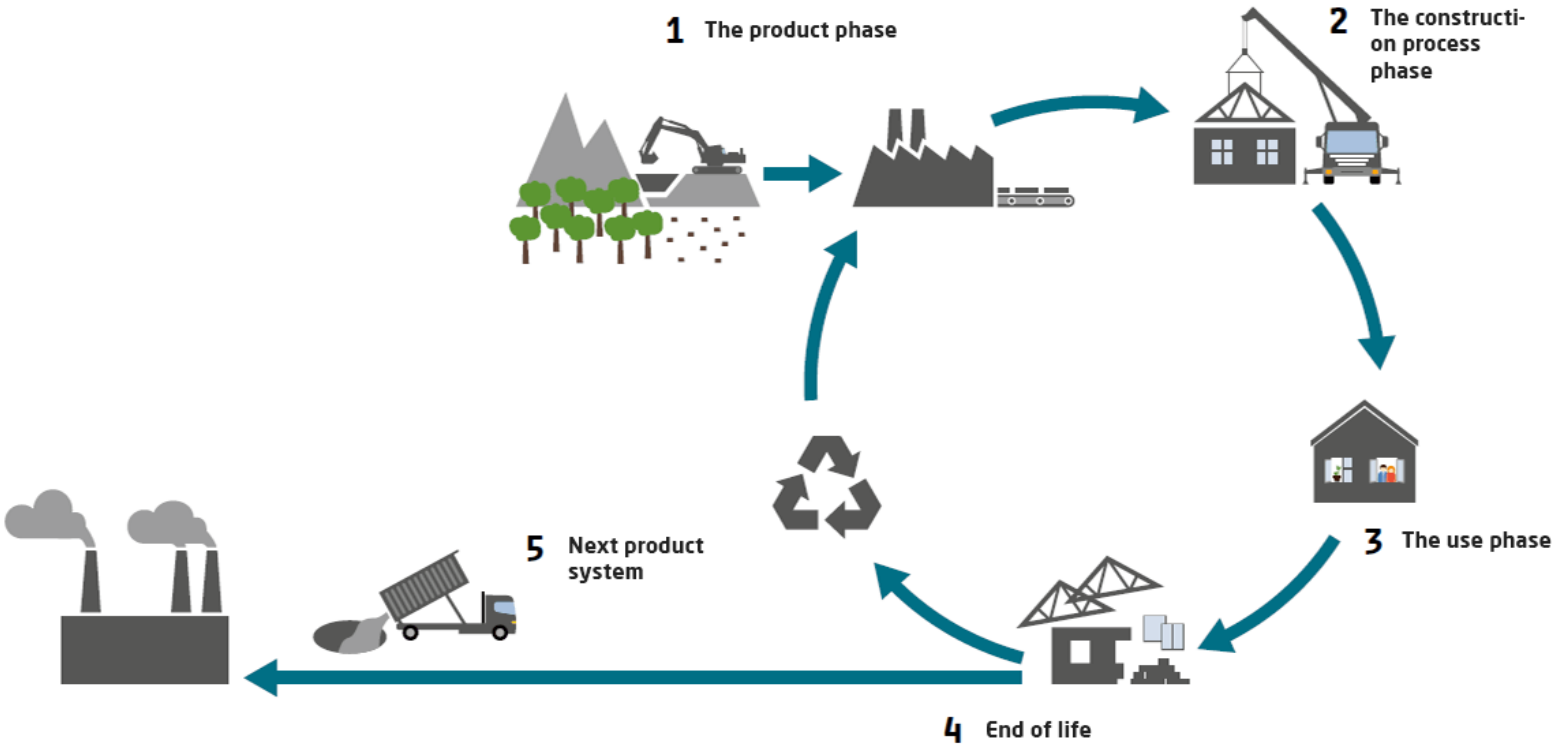


Photo by Anne Nygård on Unsplash

Problem statement

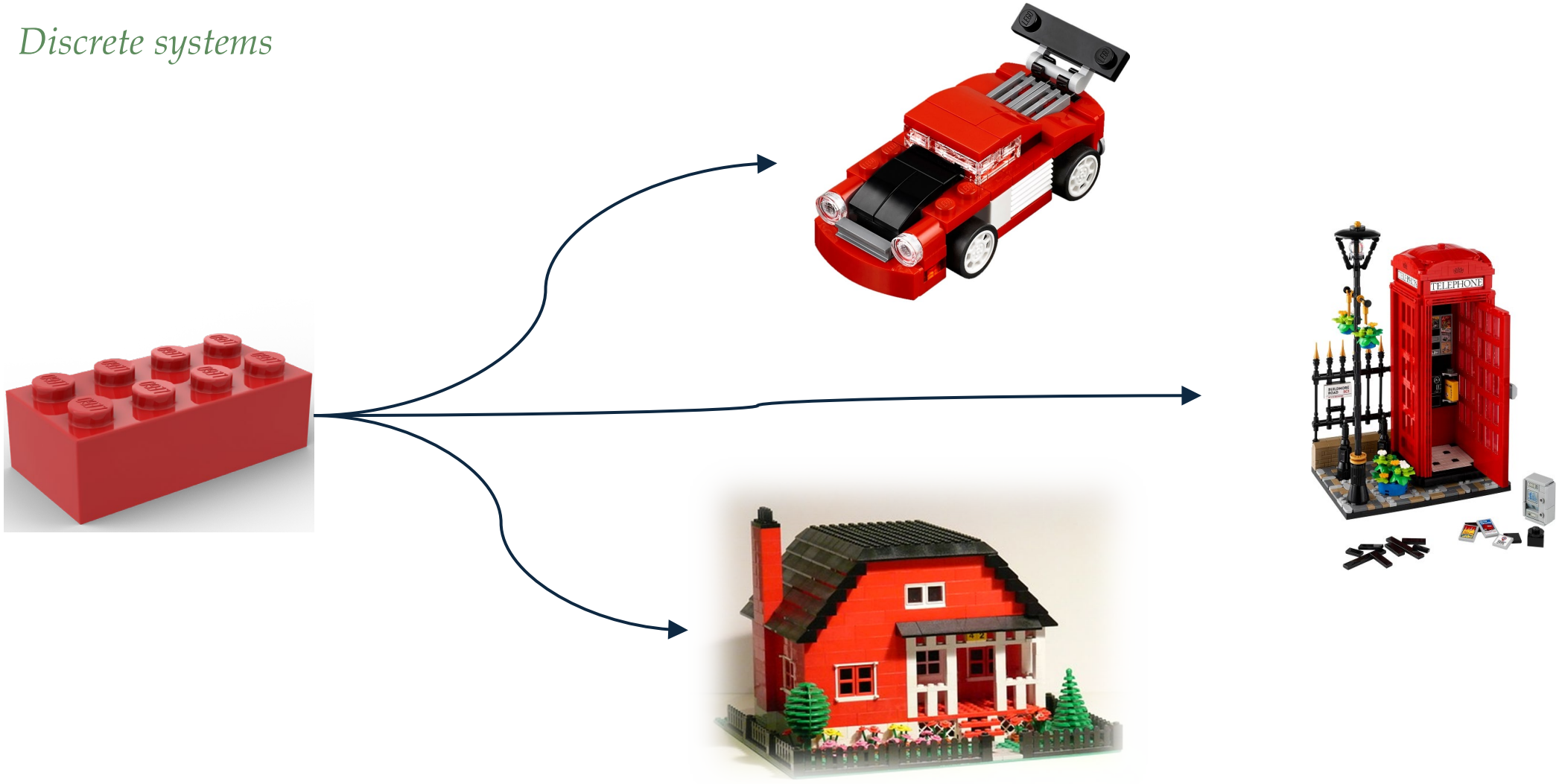
Design for Deconstruction and Reuse



Technosphere side of a butterfly diagram on circular timber buildings (Ottenhaus et al., 2023)

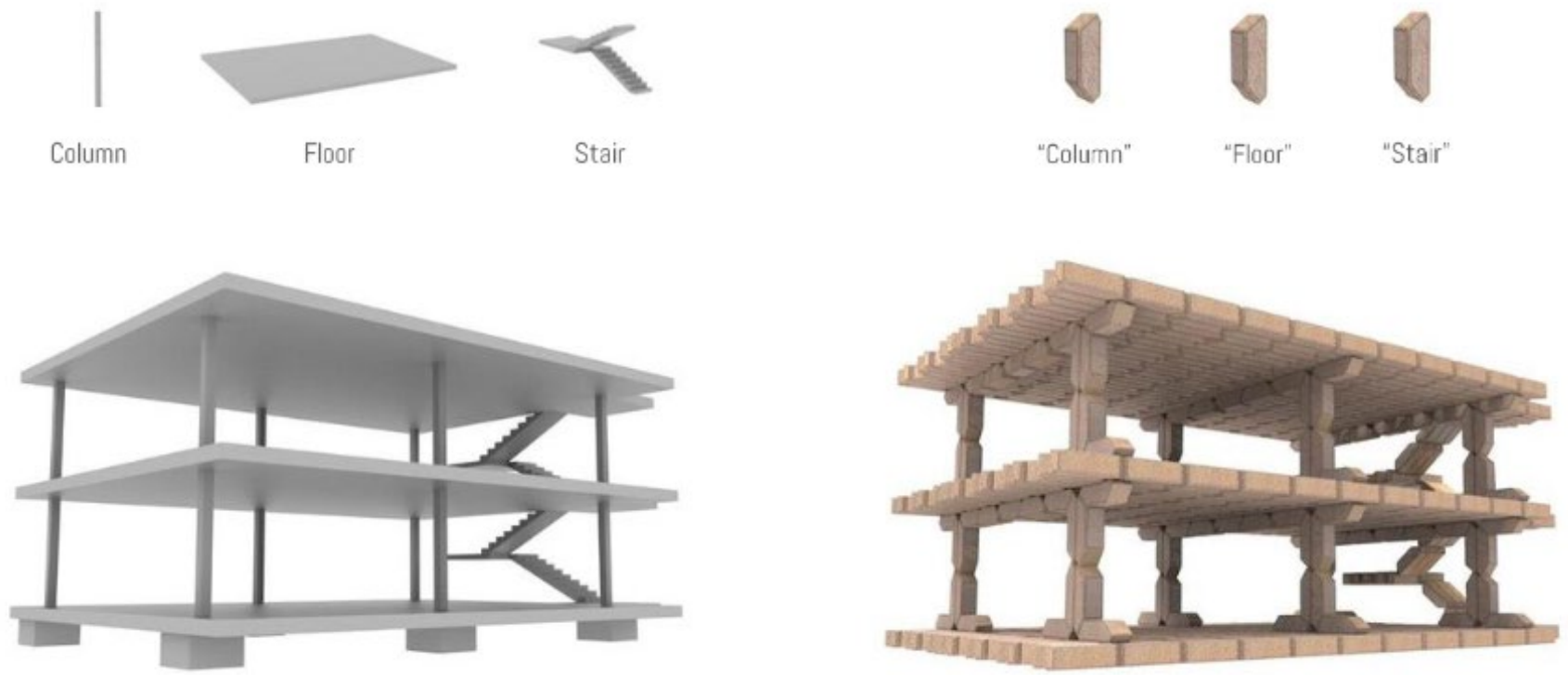
Problem statement

Discrete systems



Problem statement

Discrete systems



Conventional versus discrete building elements (Tedbury, 2017)

Problem statement

Discrete systems

Discrete system has **flexible use of elements** and
can be used with **reversible joints**

Problem statement

Research gap

Current discrete timber systems in **theoretical research**, **research prototypes**, and **small scale projects**

Research question

How can a reversible discrete timber system be a feasible alternative to conventional structural timber?

Important theory

Design for Deconstruction and Reuse

Joints

Easily accessible

Non-destructive disassembly

Complexity of the joints

Ease of assembly and disassembly

Minimal variation in joints

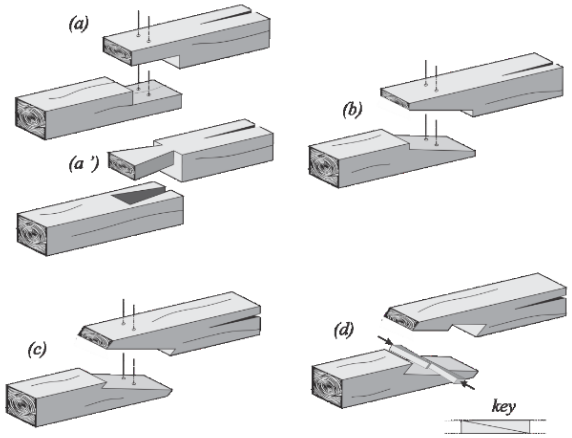
No use of adhesives and sealants

Nest we Grow by Kengo Kuma Architects (Shinkenchiku Sha, 2015)

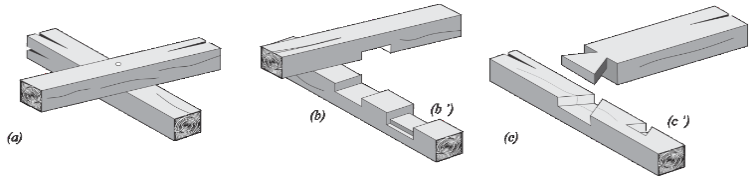
Connections in timber

Dry timber joints

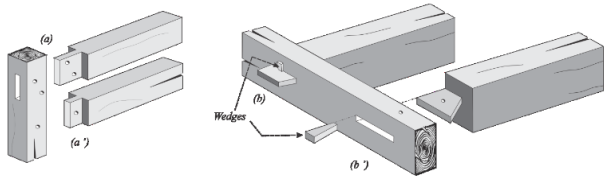
Scarf-joints



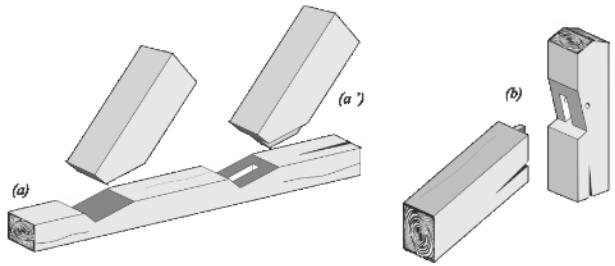
Lap-joints



Mortise and tenon joints



Notched joints



Categorized dry timber joints (Branco & Descamps, 2015)

Case study

Top-up apartement blocks

Housing shortage

The Netherlands faces the task to **build 981.000 houses** by 2030.

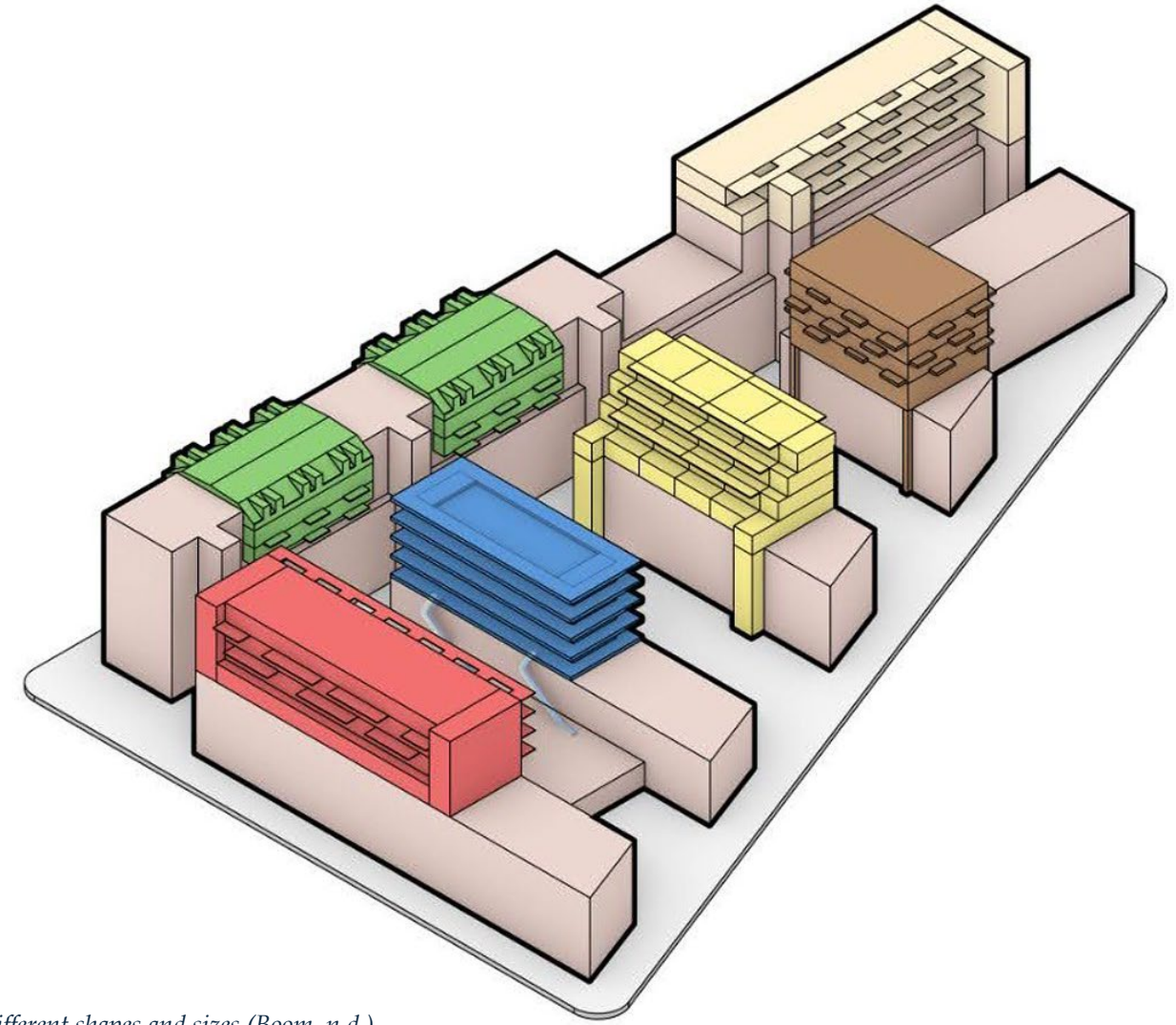
Top-up apartement blocks

Topping up on existing buildings

Top up design by Symbiotic Urban Movement TU Delft (SUM, n.d.)

Top-up apartement blocks

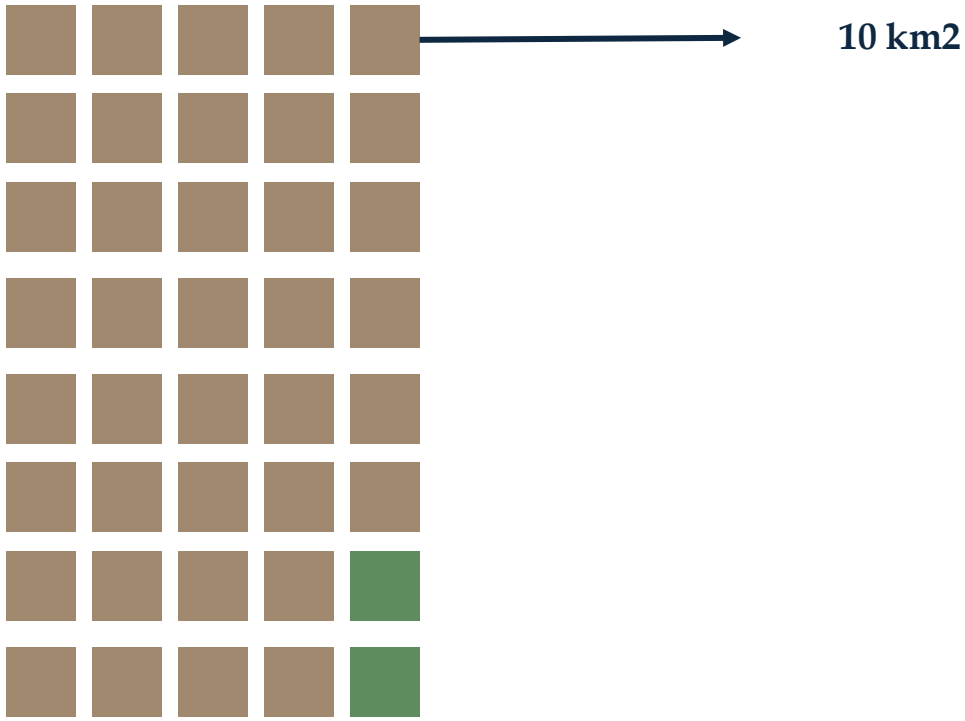
Topping up



Top-ups in different shapes and sizes (Boom, n.d.)

Top-up apartement blocks

Topping up - potential



= 10 km2 flat roof surface

= flat roof surface in the Netherlands

= flat roof surface in Rotterdam

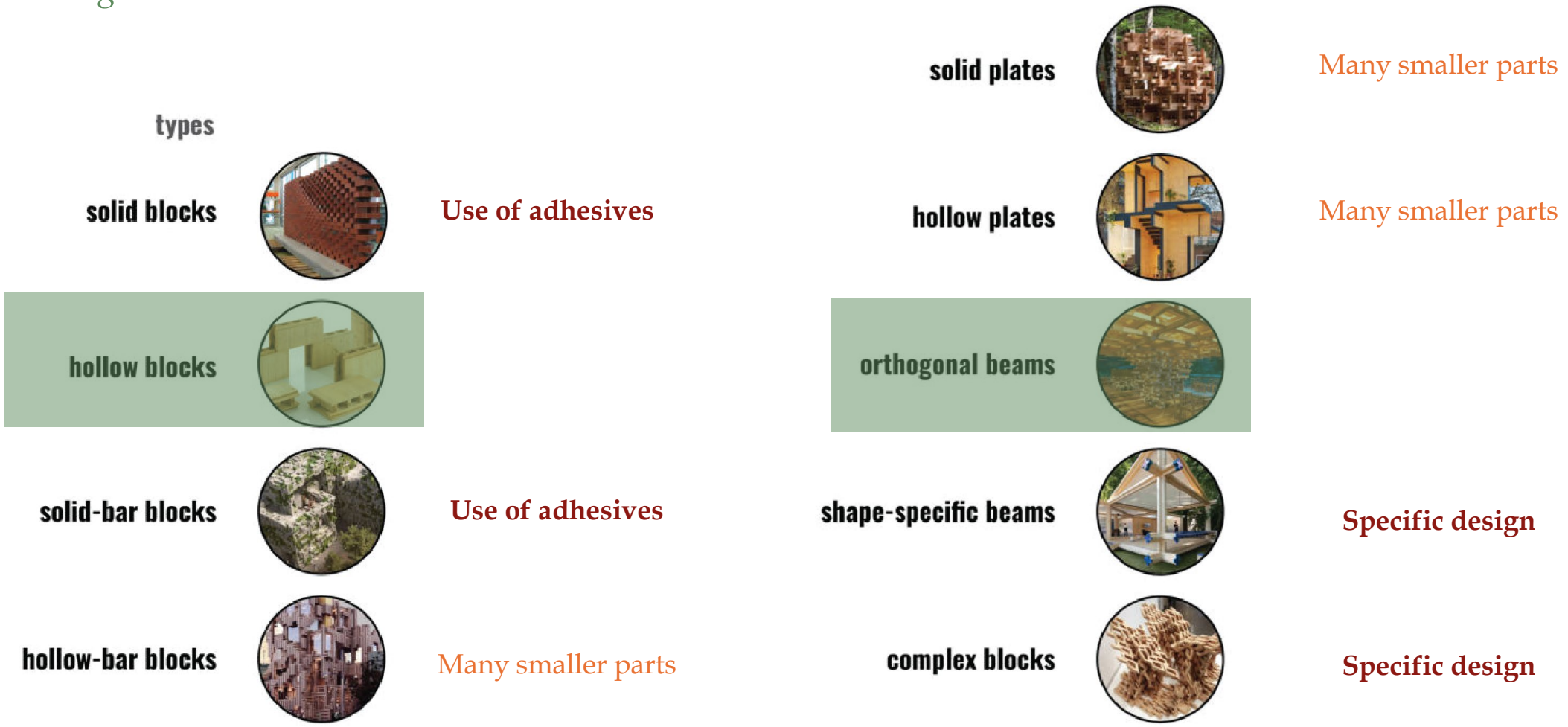
Top-up apartement blocks

Topping up – selected case

Discrete elements

Discrete elements to discrete systems

Existing discrete timber elements



Discrete element typology analysis (A. de Paula, 2023)

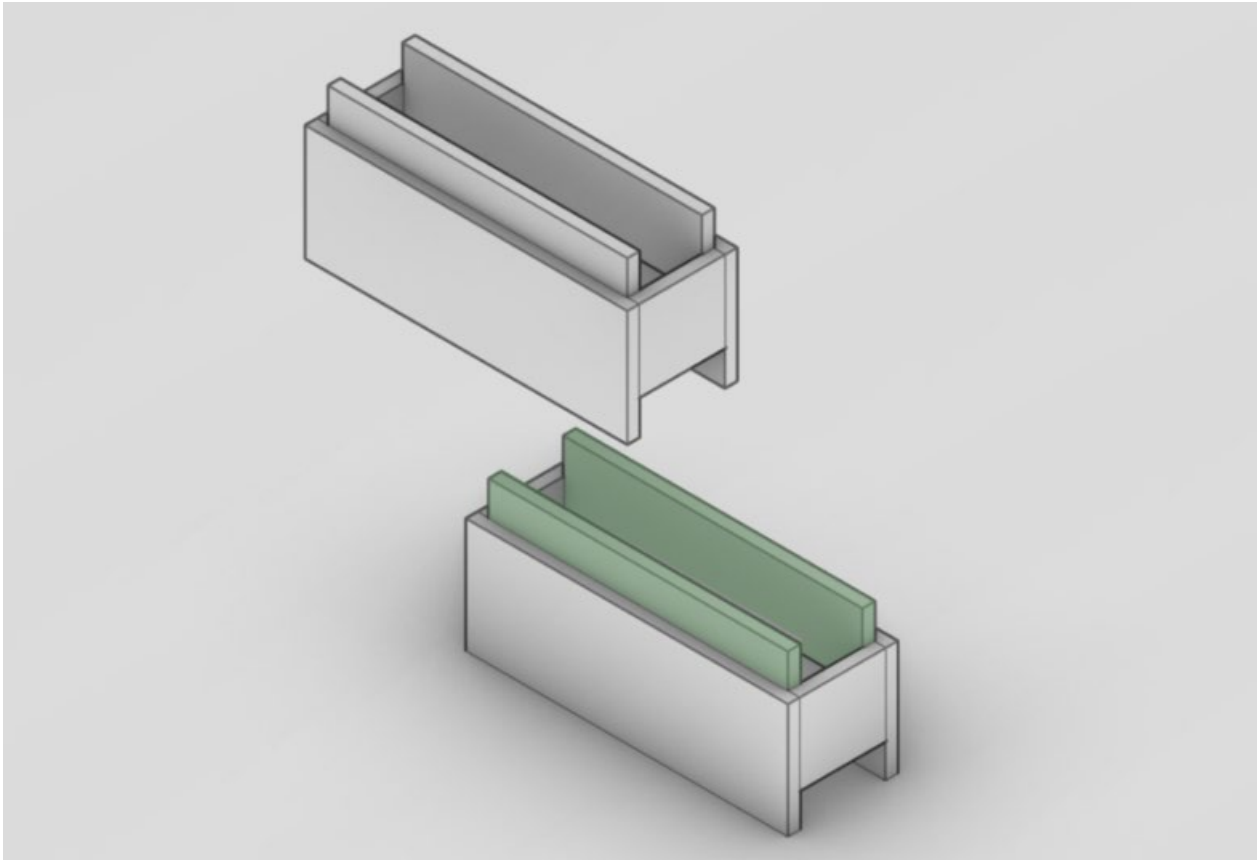
Discrete elements to discrete systems

Discrete timber elements

How do we **connect the discrete elements** in a discrete system?

Discrete elements to discrete systems

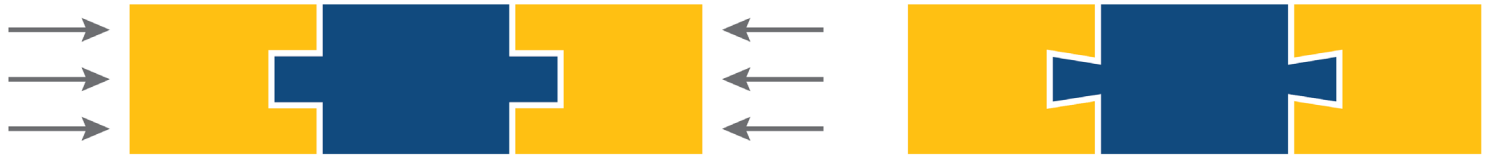
Hollow blocks



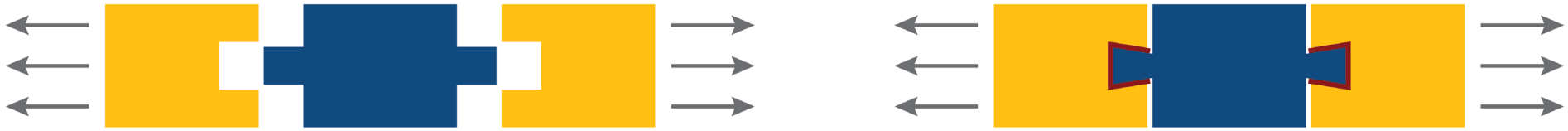
Topological interlocking with hollow blocks (own work, 2024)

Discrete elements to discrete systems

Hollow blocks



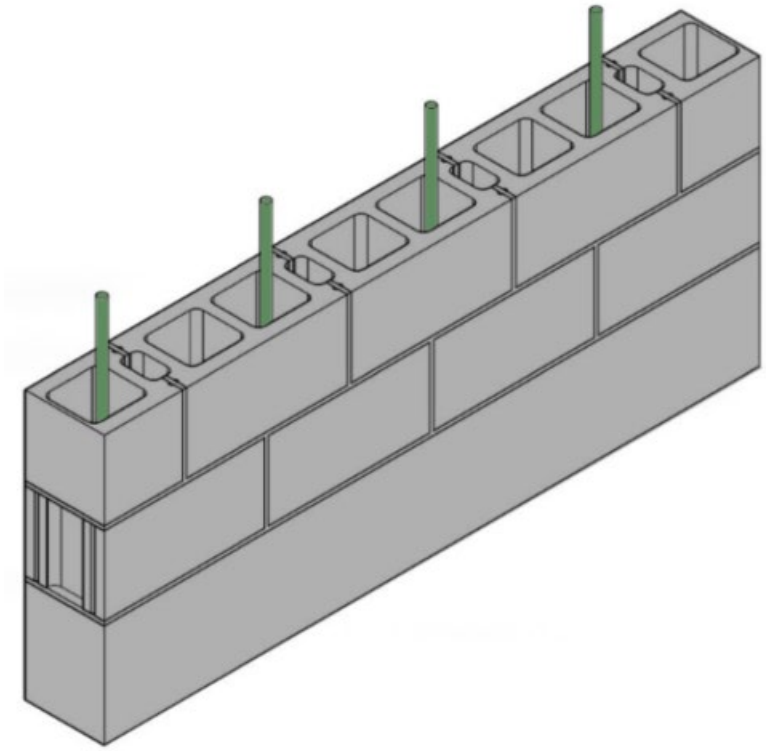
Conceptual examples of topological (left) and geometrical (right) interlocking (Estrin et al., 2021)



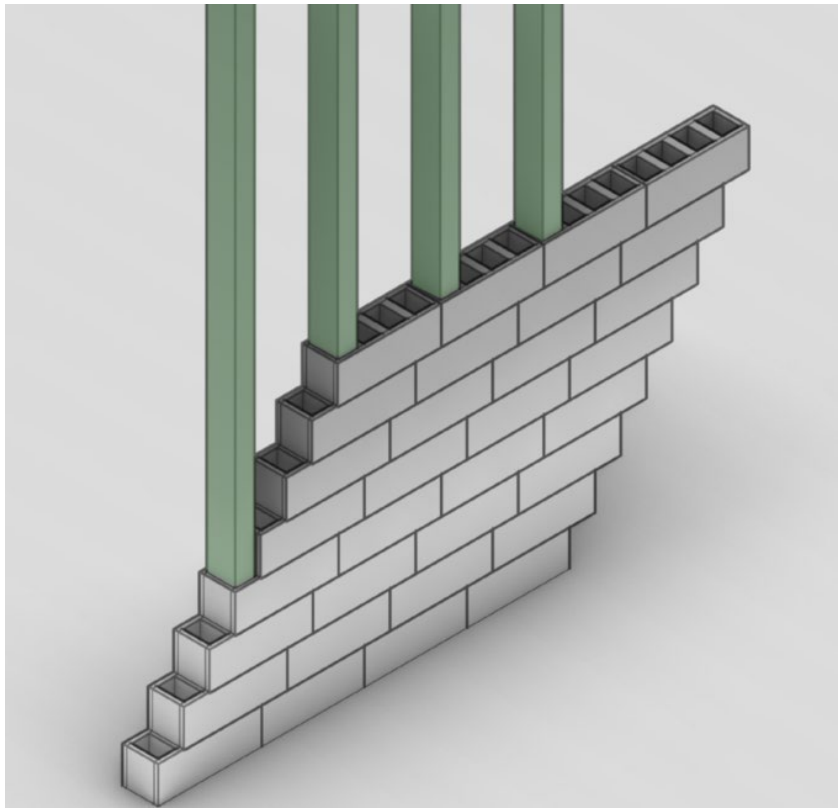
Conceptual examples of topological (left) and geometrical (right) interlocking when under tension (own work, 2024)

Discrete elements to discrete systems

Hollow blocks



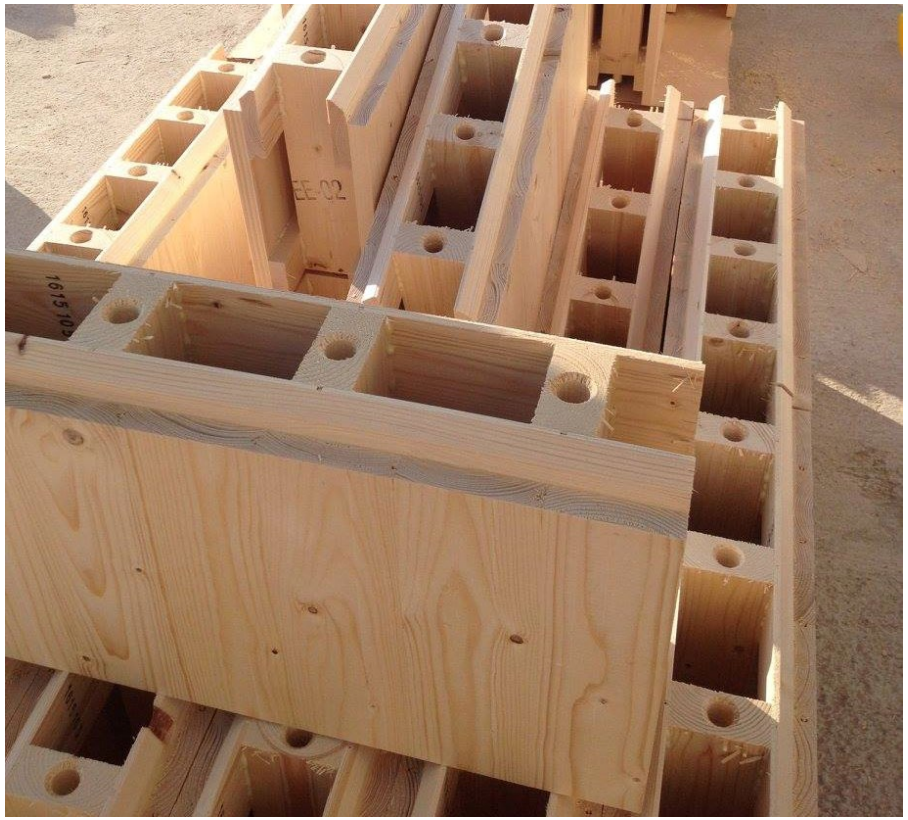
Hollow concrete blocks with rebar reinforcement (adapted from A.J.J. Sparling, 2015)



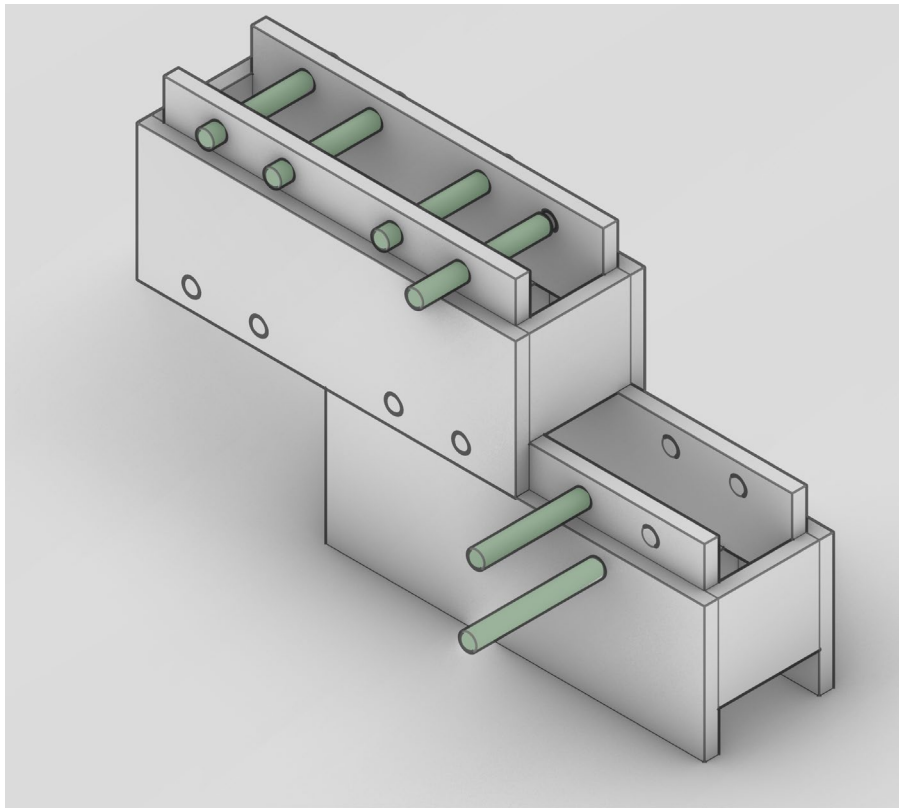
Vertical support elements in timber hollow blocks (own work, 2024)

Discrete elements to discrete systems

Hollow blocks



Steko building system (STEKO®, 2017)



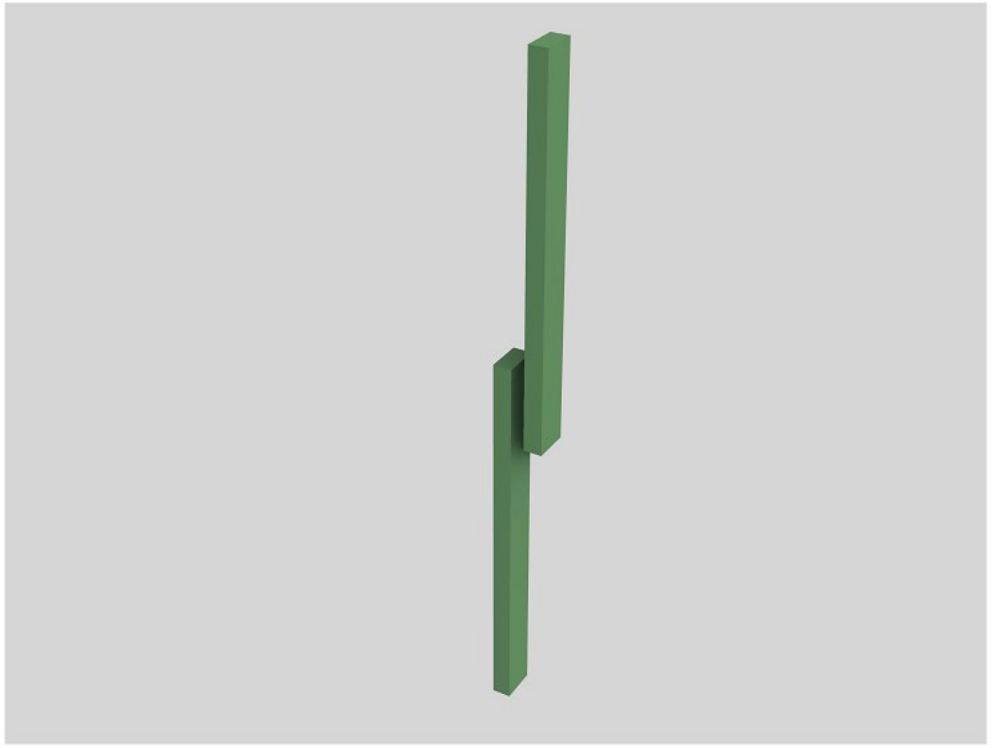
Horizontal dowels in hollow blocks (Own work, 2024)

Discrete elements to discrete systems

Hollow blocks

Discrete elements to discrete systems

Orthogonal beams

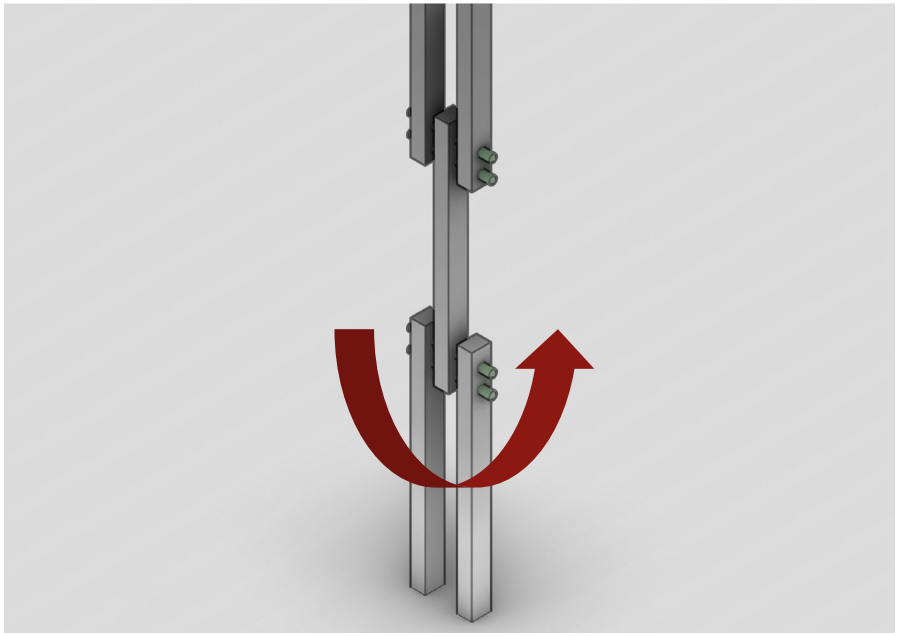


Placing orthogonal beams in the length direction (Own work, 2024)

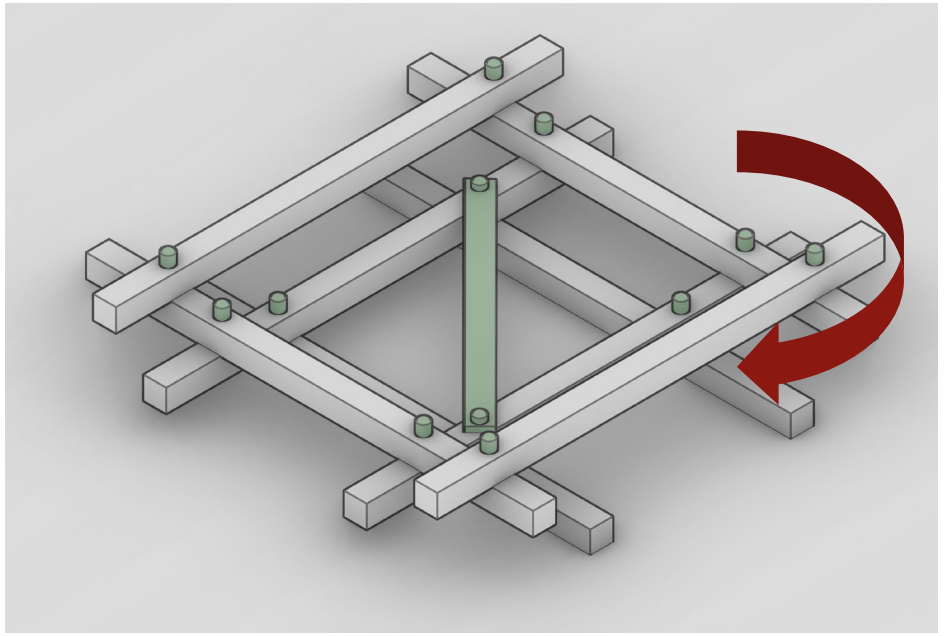
Placing orthogonal beams horizontally (Own work, 2024)

Discrete elements to discrete systems

Orthogonal beams



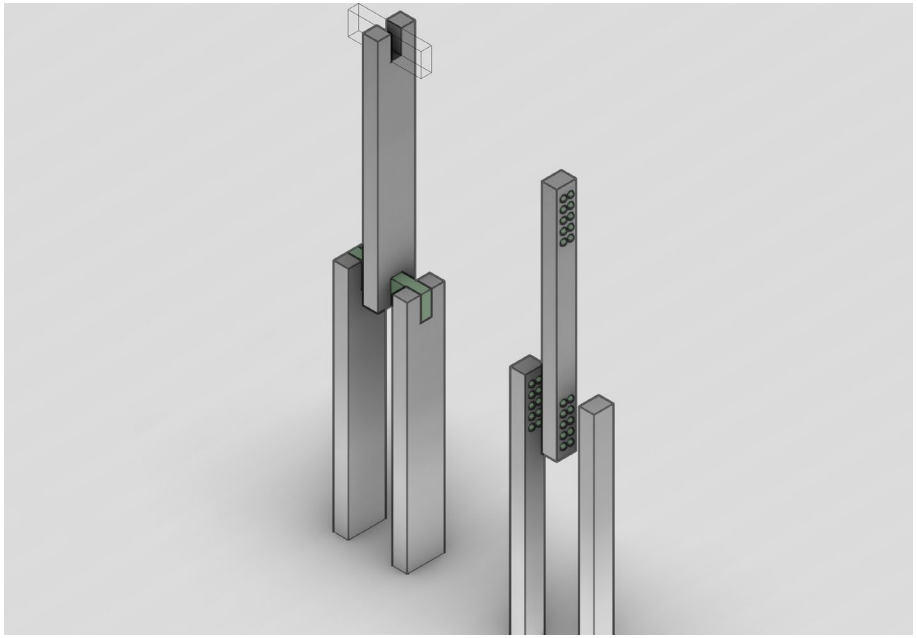
Placing orthogonal beams vertically with dowels for joints (Own work, 2024)



Placing orthogonal beams horizontally with dowels (Own work, 2024)

Discrete elements to discrete systems

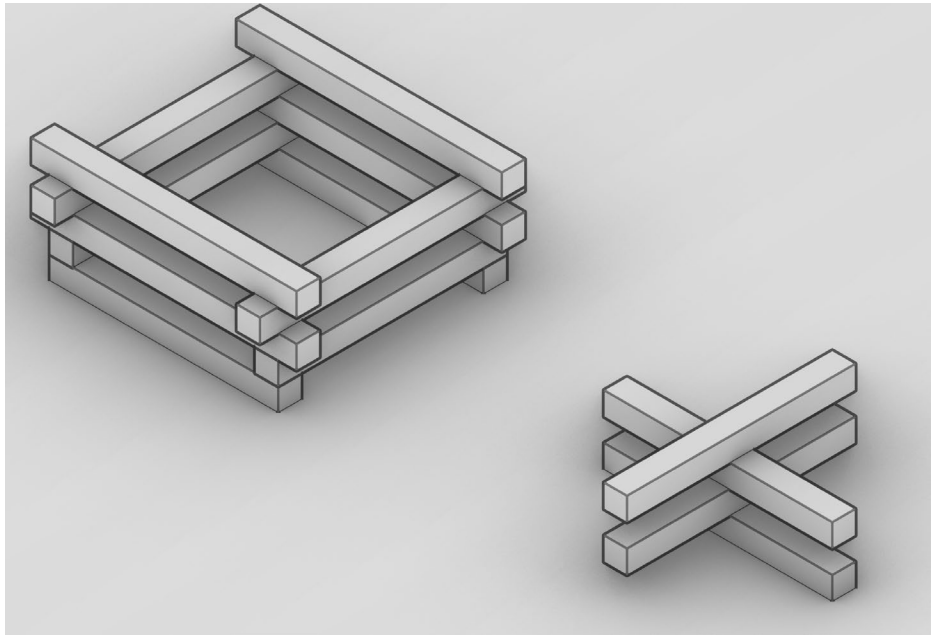
Orthogonal beams



Orthogonal beams geometric and topological interlocking (Own work, 2024)

Discrete elements to discrete systems

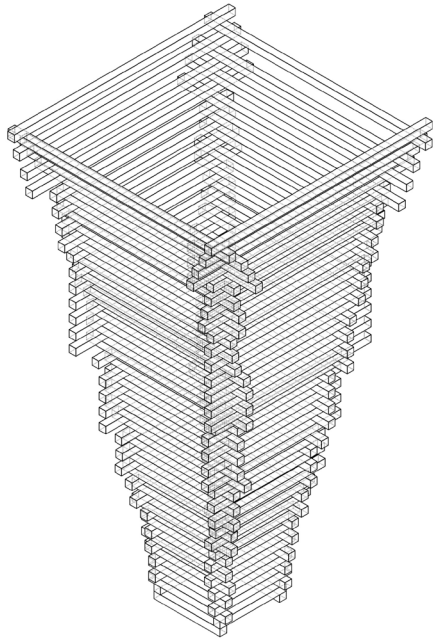
Orthogonal beams



Two ways of stacking orthogonal beams horizontally (Own work, 2024)

Discrete elements to discrete systems

Orthogonal beams

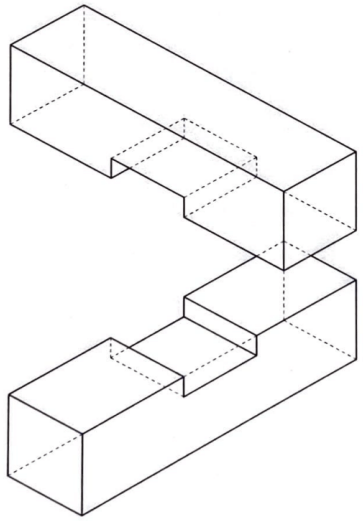


Discrete system column by horizontally stacking orthogonal beams (Own work, 2024)

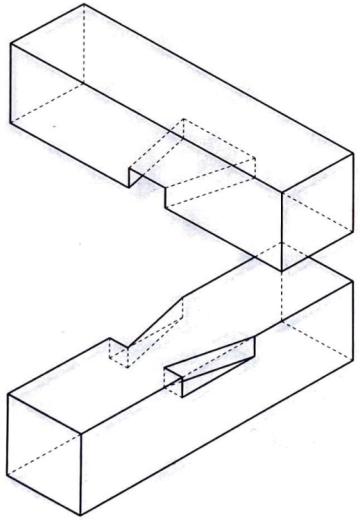
Mushroom columns in de Van Nelle factory (Tjasker, n.d.)

Discrete elements to discrete systems

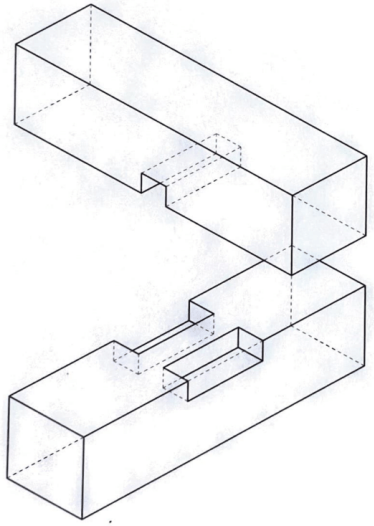
Ansys simulation tested joints



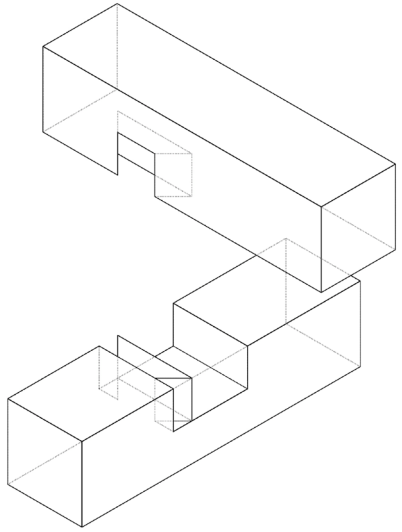
Simple square cog



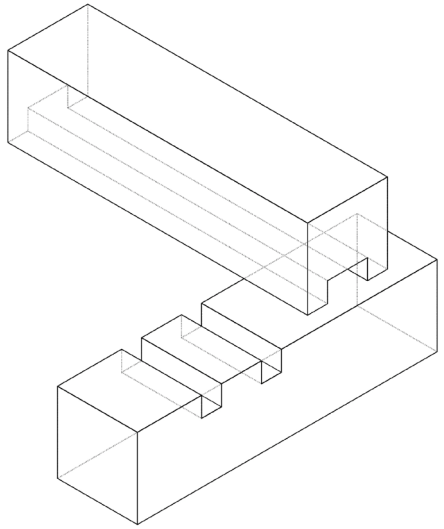
Dovetail cog



Double cog



Dovetail lap



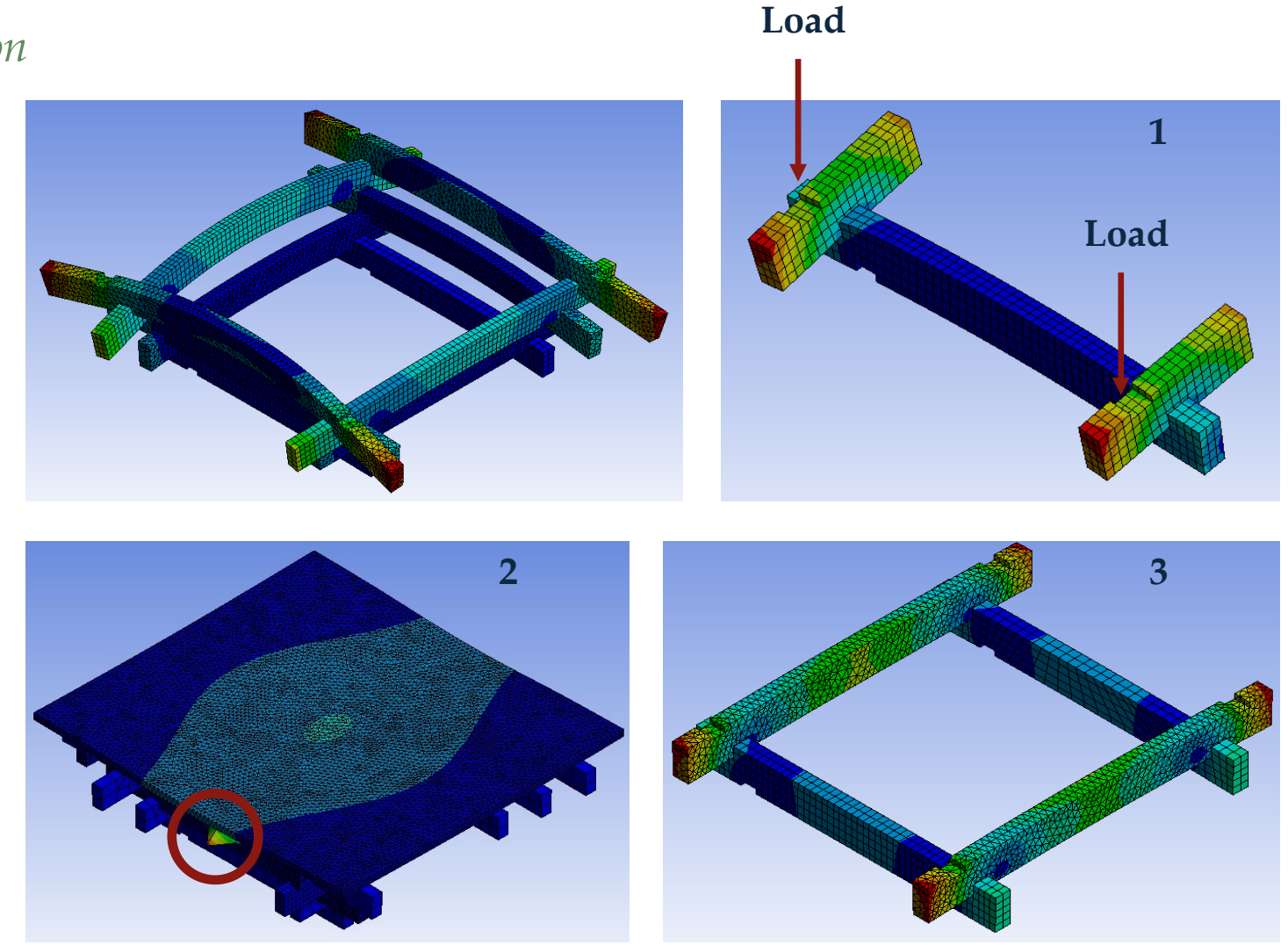
Inverse double cog

Simple square cog, dovetail cog, and double cog (Guenoun, 2019)

Dovetail lap and inverse double cog (own work, 2024)

Discrete elements to discrete systems

Ansys simulation



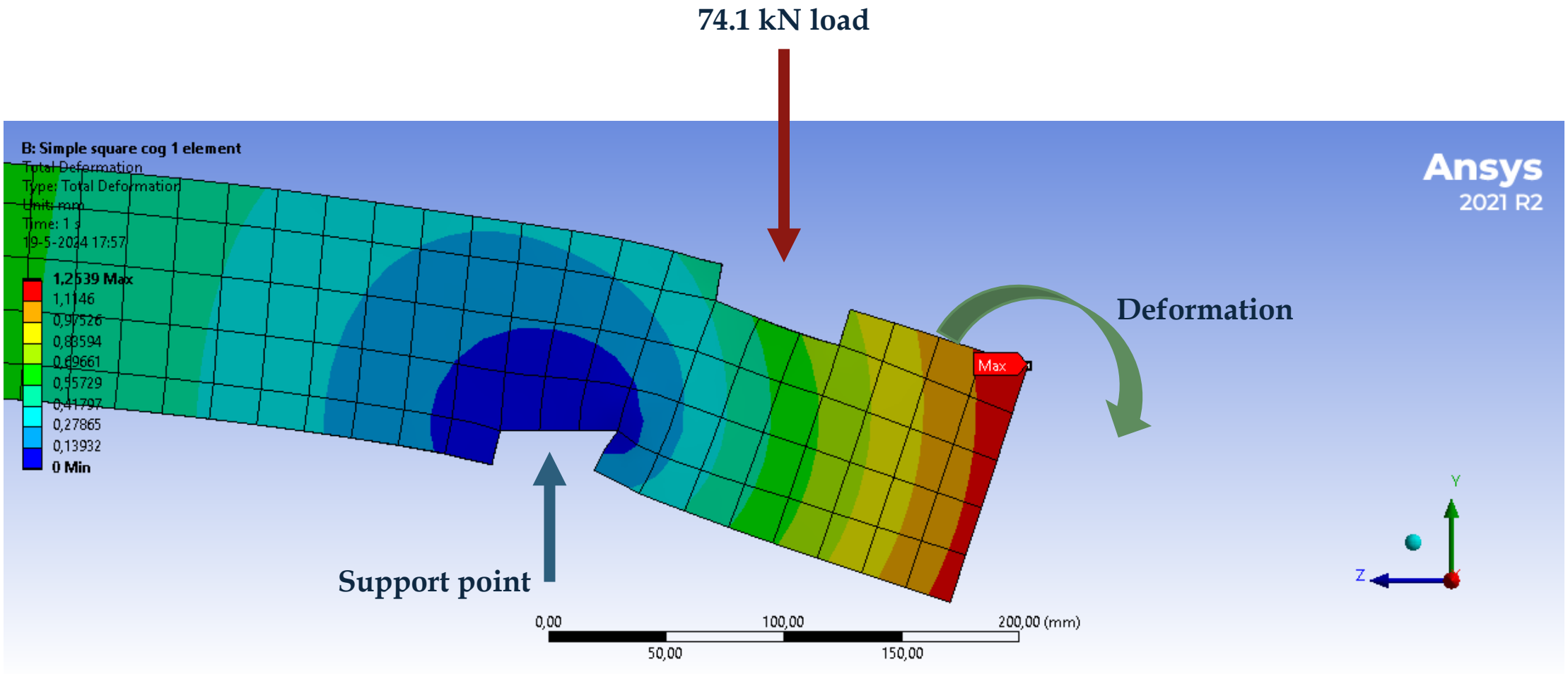
Ansys deformation simulation tests (own work, 2024)

Discrete elements to discrete systems

Which **forces** and **deformation** occur in the **connections**?

Discrete elements to discrete systems

Ansys simulation

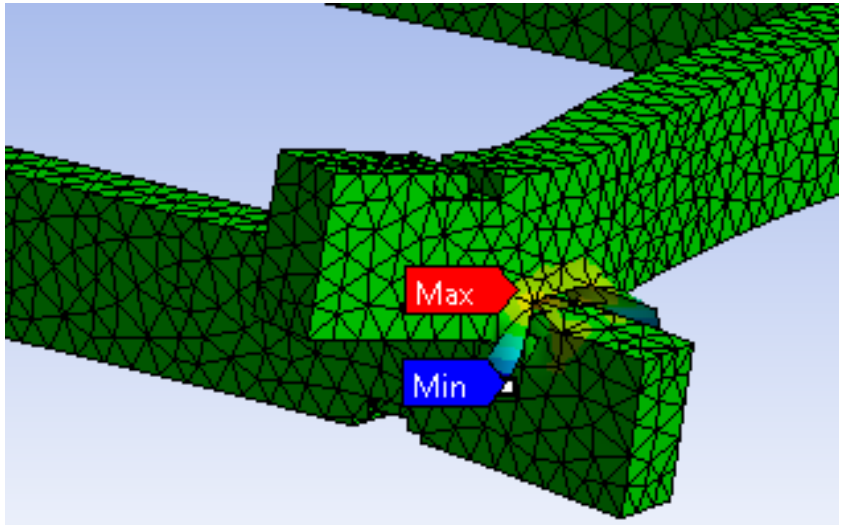


Simple square cog Ansys deformation simulation with one element (own work, 2024)

Discrete elements
Findings

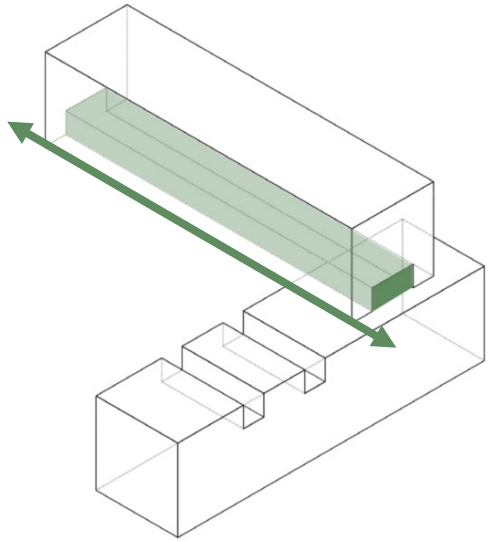
Discrete elements to discrete systems

Ansys simulation findings



Dovetail lap

Dovetail lap Ansys maximum principal stress simulation with two layers (own work, 2024)

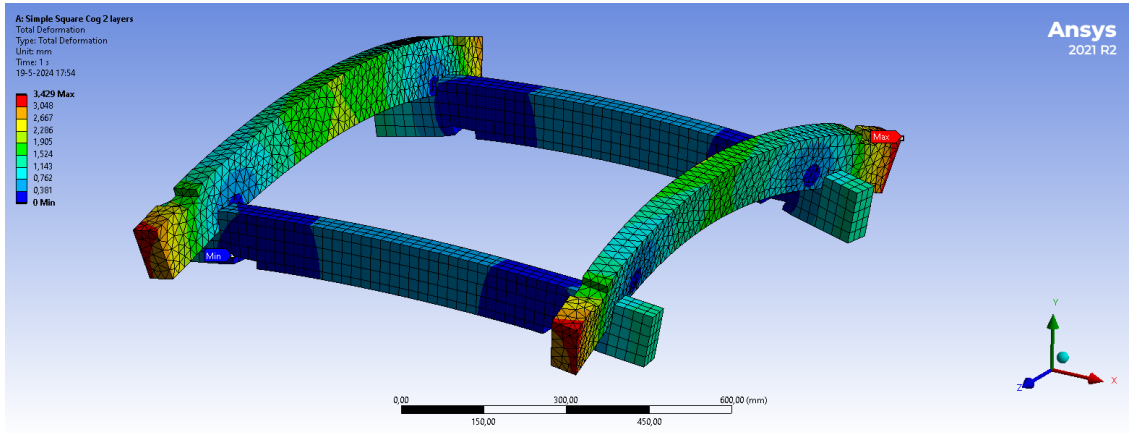


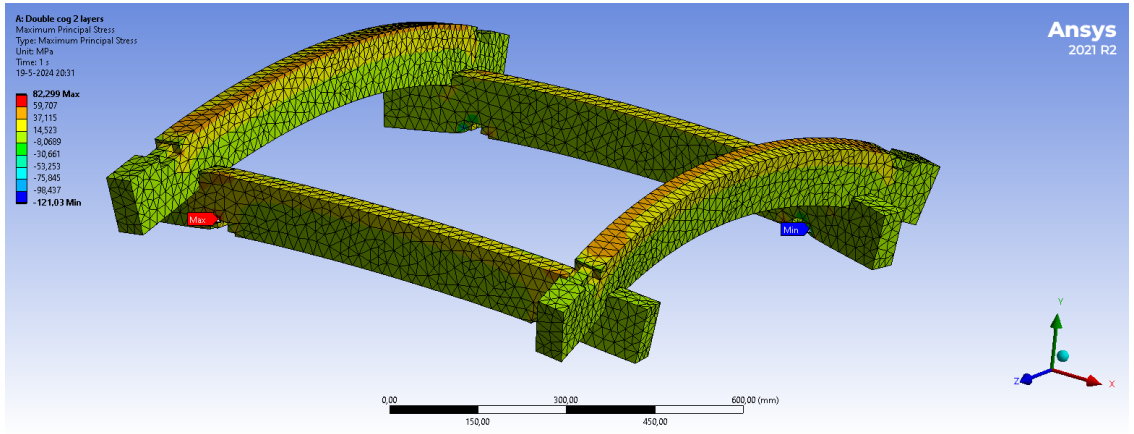
Inverse double cog

Inverse double cog sliding (own work, 2024)

Discrete elements to discrete systems

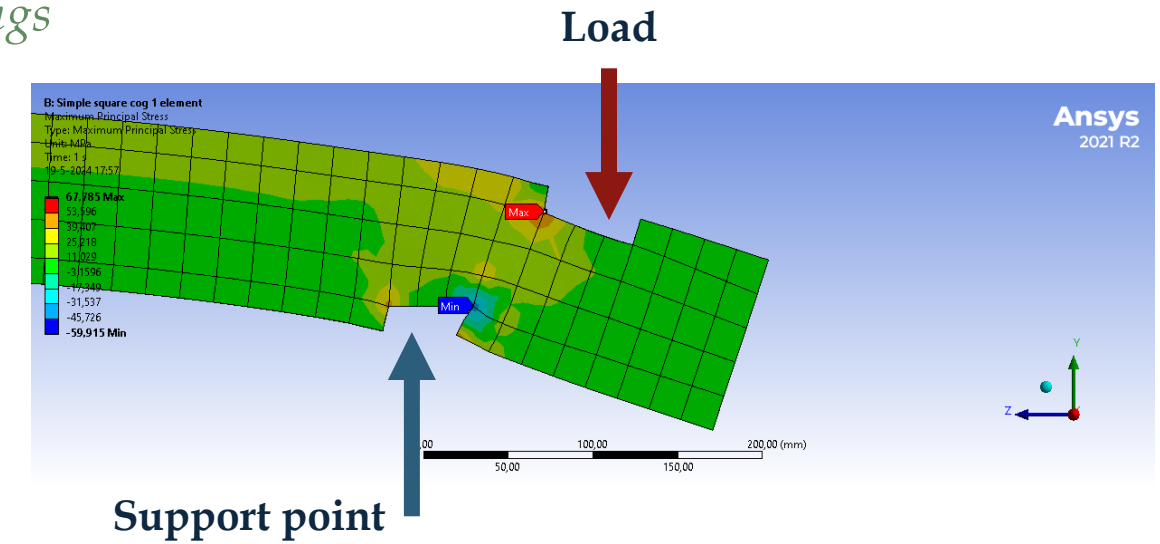
Ansys simulation findings

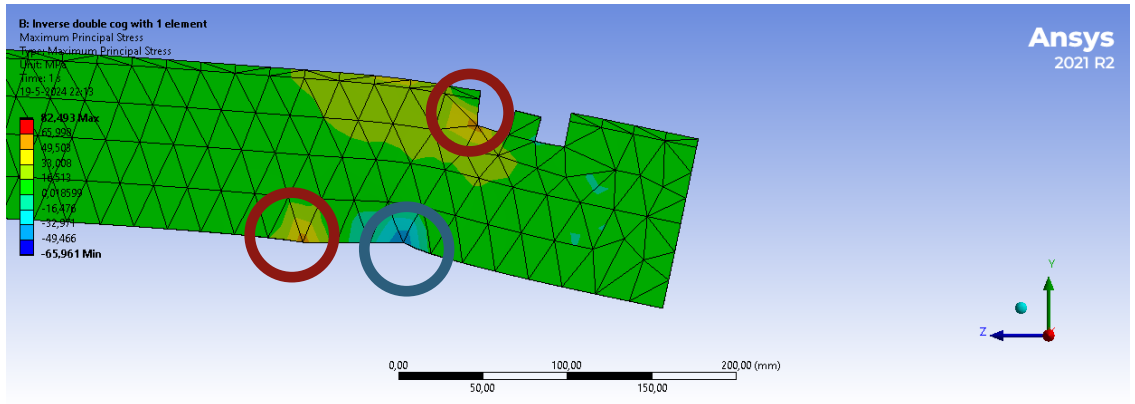




Discrete elements to discrete systems

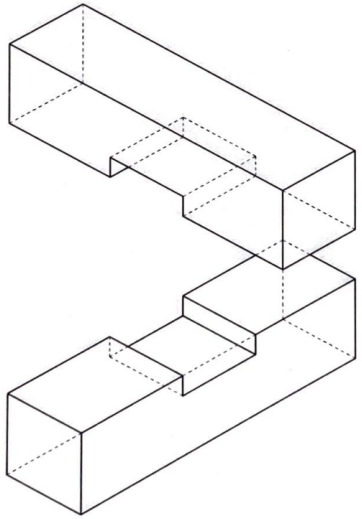
Ansys simulation findings





Discrete elements to discrete systems

Ansys simulation result

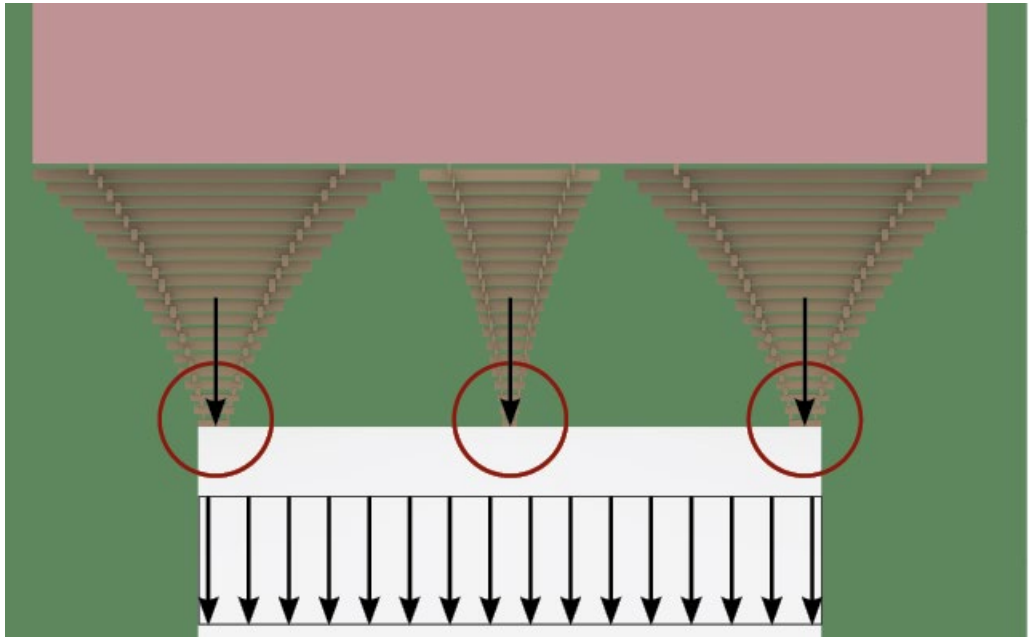


Simple square cog

Simple square cog, dovetail cog, and double cog (Guenoun, 2019)

Discrete elements to discrete systems

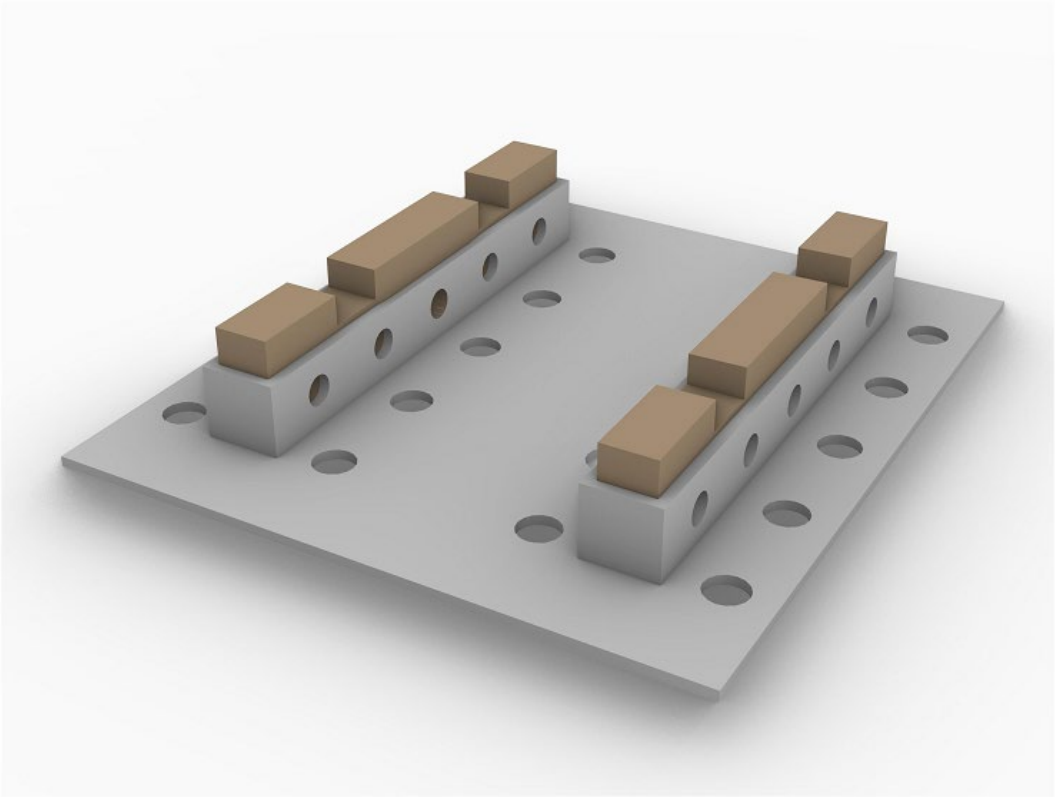
Load transferring



Side view of the discrete timber columns on the existing structure (own work, 2024)

Discrete elements to discrete systems

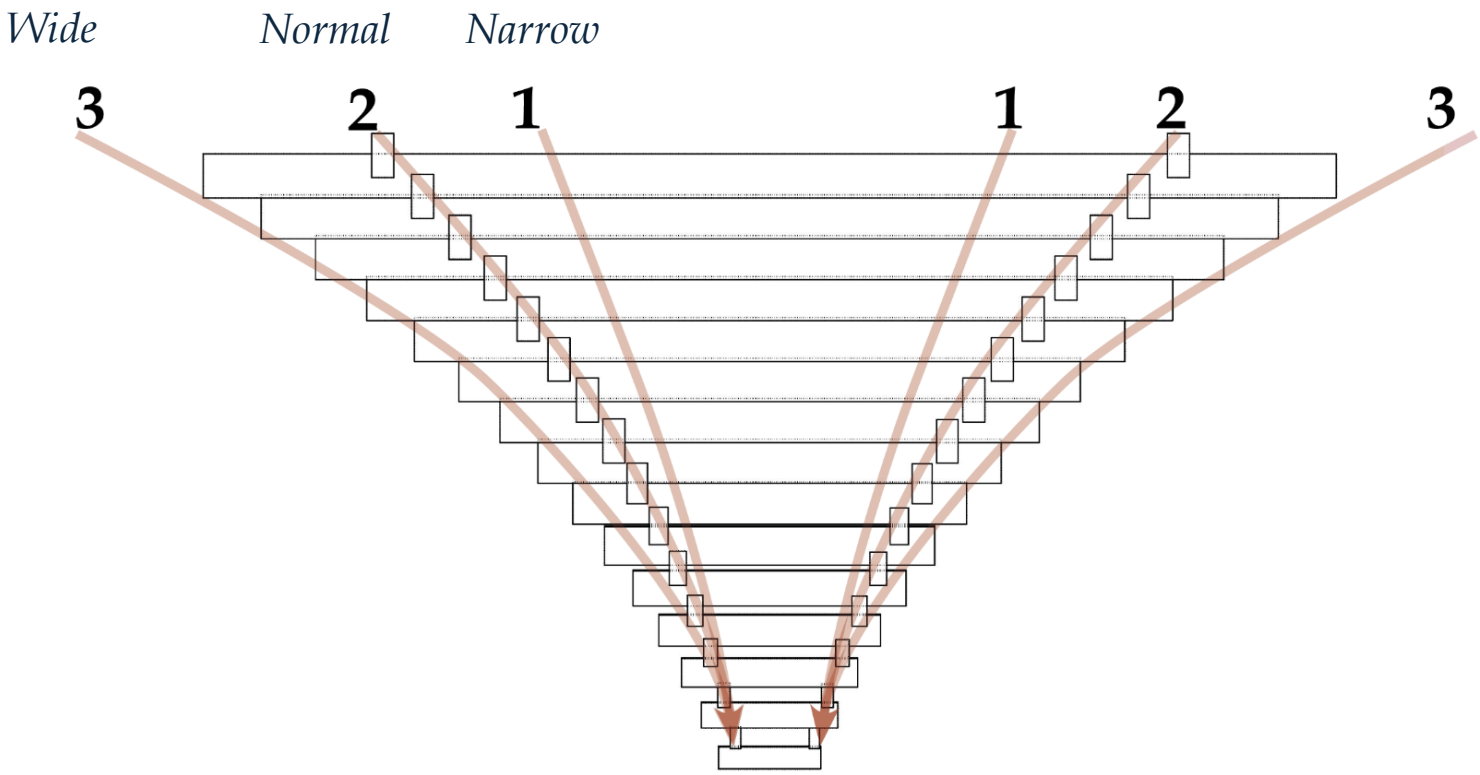
Load transferring



Custom steel bracket for discrete timber system (own work, 2024)

Aggregating discrete timber elements

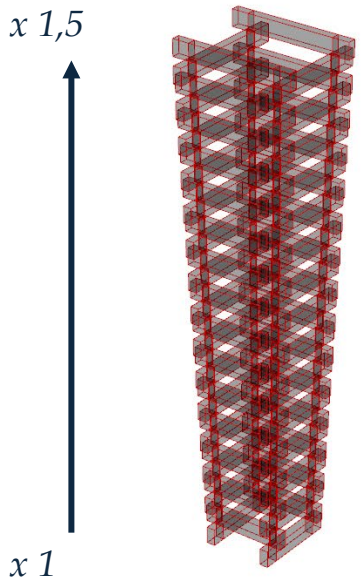
Aggregating discrete timber elements



Side view of a discrete system with lines for load paths (own work, 2024)

Aggregating discrete timber elements

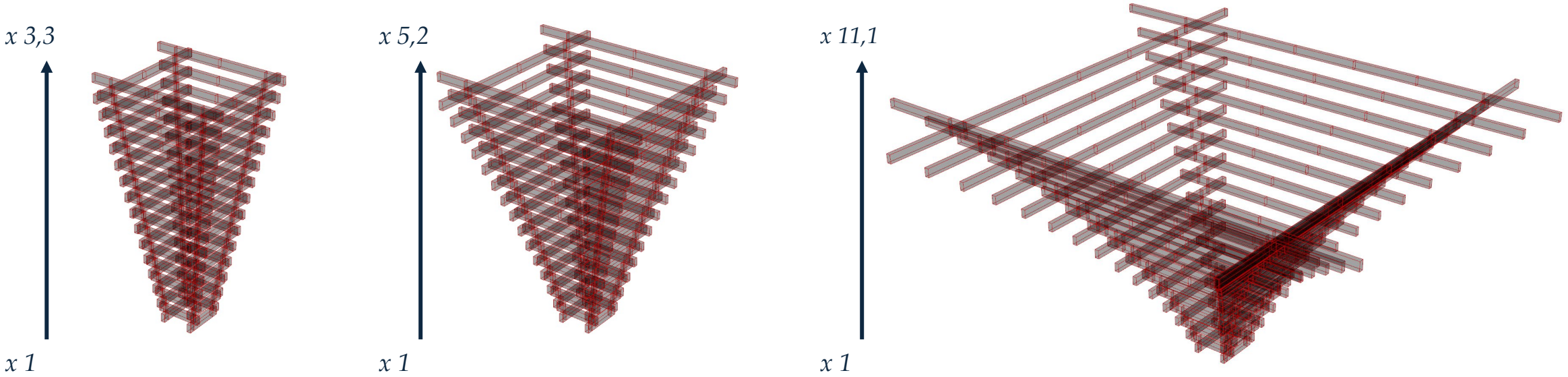
Baseline column



Cross section view of the baseline column (own work, 2024)

Aggregating discrete timber elements

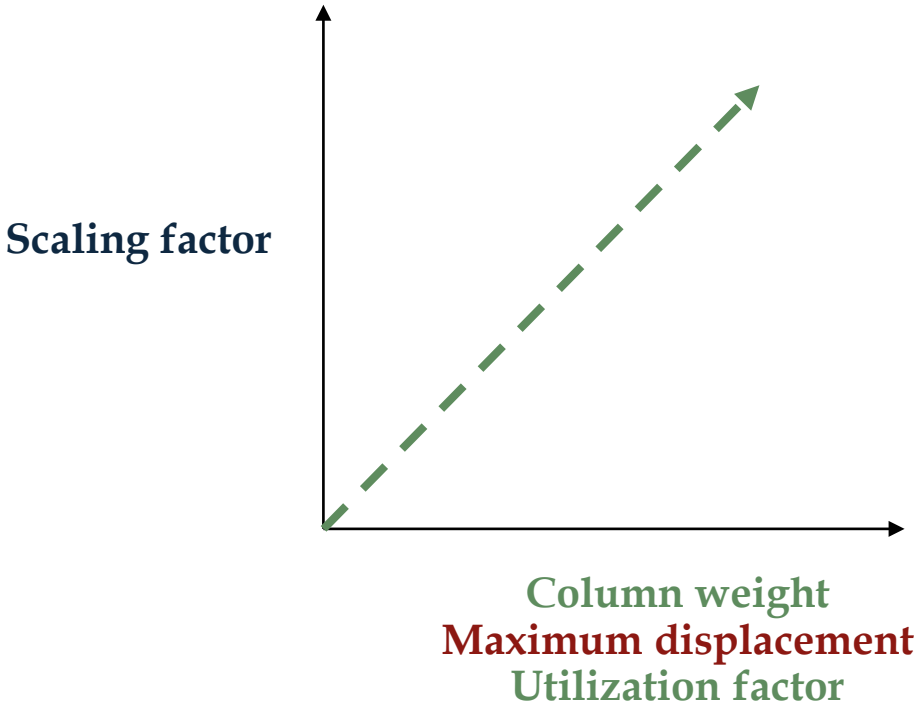
Narrow, normal and wide column



Cross section view of the narrow column (own work, 2024)
Cross section view of the normal column (own work, 2024)
Cross section view of the wide column (own work, 2024)

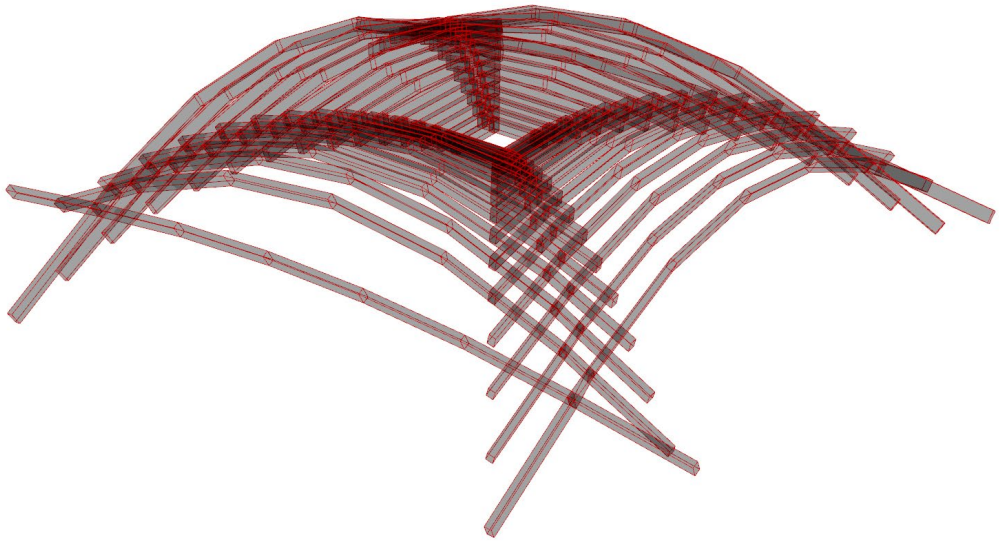
Aggregating discrete timber elements

Narrow, normal and wide column findings



Aggregating discrete timber elements

Findings



A **longer beam** with **identical characteristics** under the same loading **displaces more**.

Aggregating discrete timber elements

Additional simulations

Hardwood D30

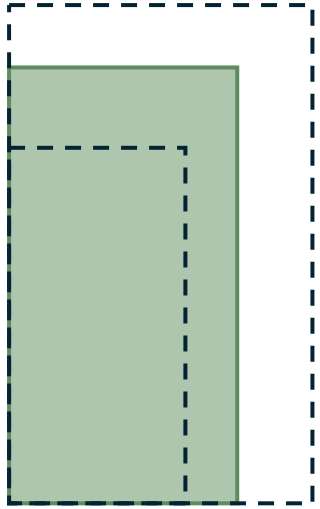
Softwood C24

Glulam GL28c

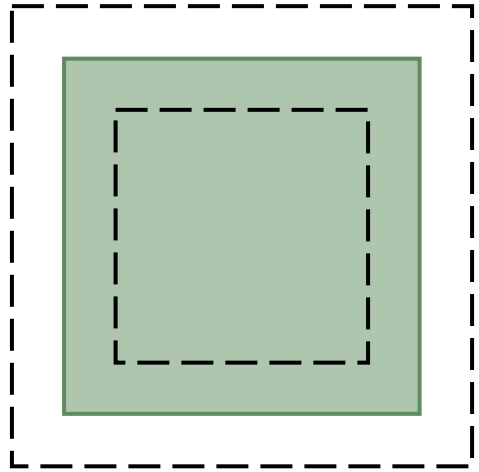
Glulam GL32c

Hardwood D65

Material and/or strength grade of material



Cross section of the elements



Dimensions of the column base

**Results are compared to the wide column*

Aggregating discrete timber elements

Additional simulations - material

Material

Hardwood D30

Softwood C24

Glulam GL28c

Glulam GL32c

Hardwood D65

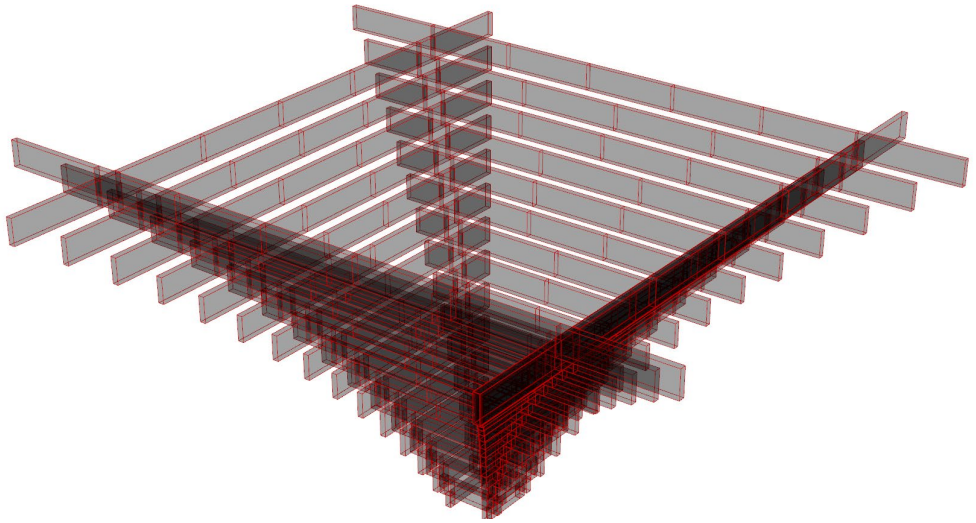
Material and/or strength grade of material

**Results are compared to the wide column*

Aggregating discrete timber elements

Additional simulations – variable cross section

Variable cross section

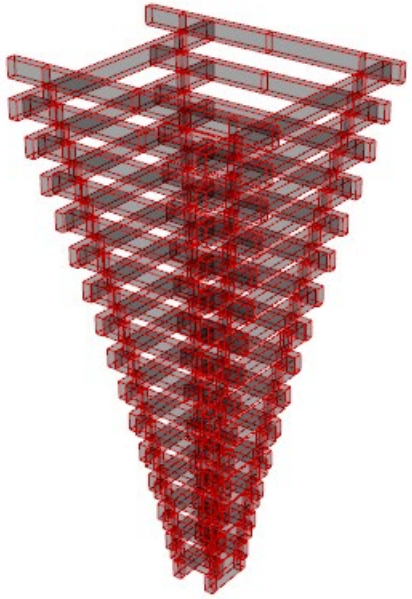


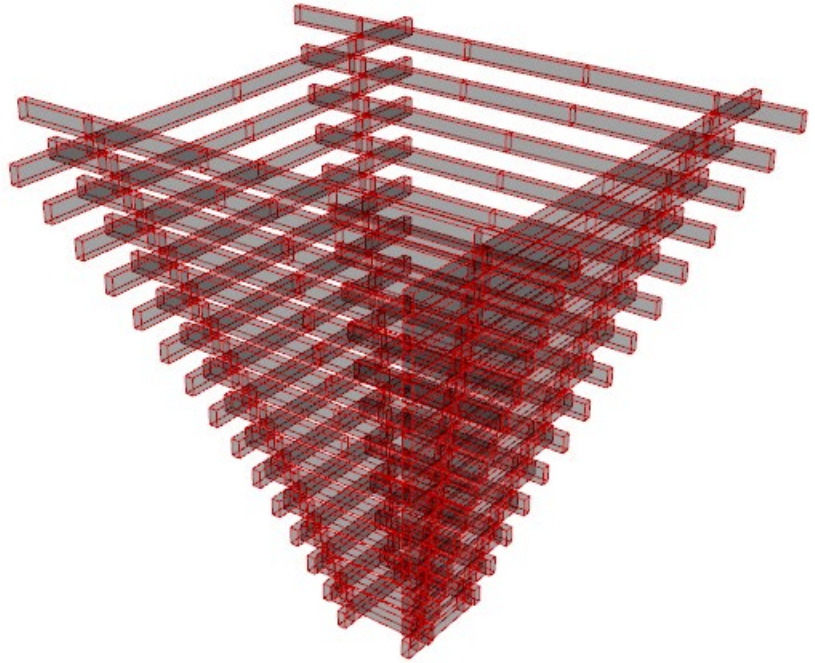
**Results are compared to the wide column*

Aggregating discrete timber elements

Additional simulations – column base size

Column base size





**Results are compared to the wide column*

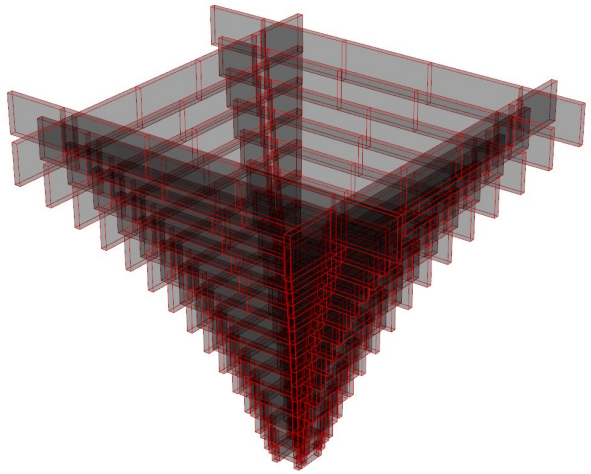
Aggregating discrete timber elements

Additional simulations

Material

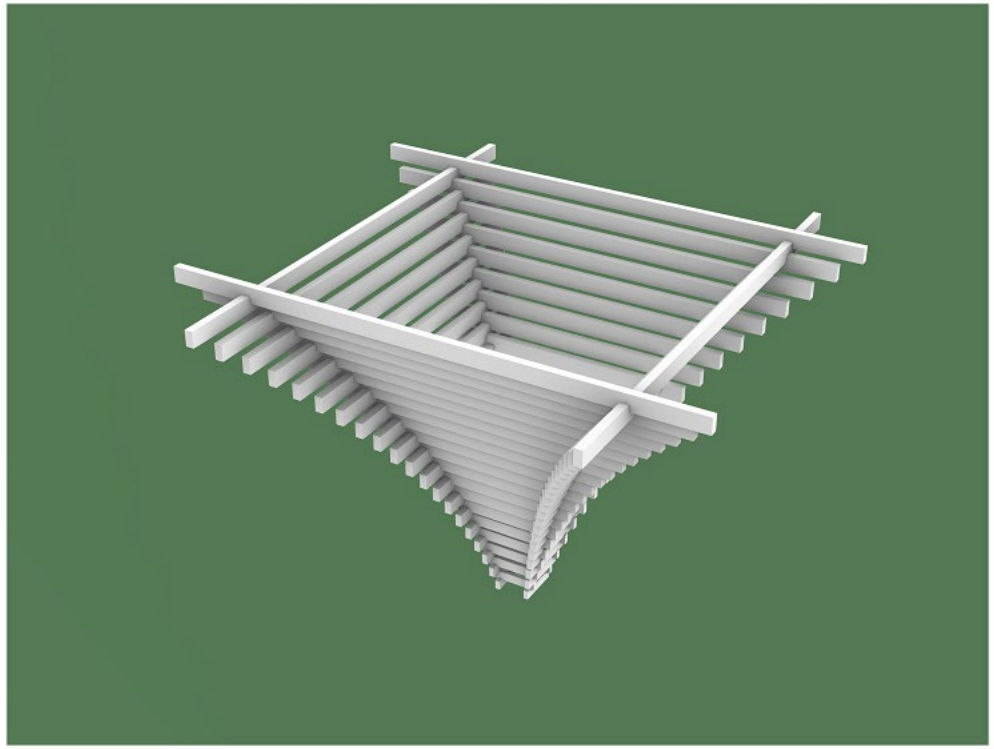
Variable cross section

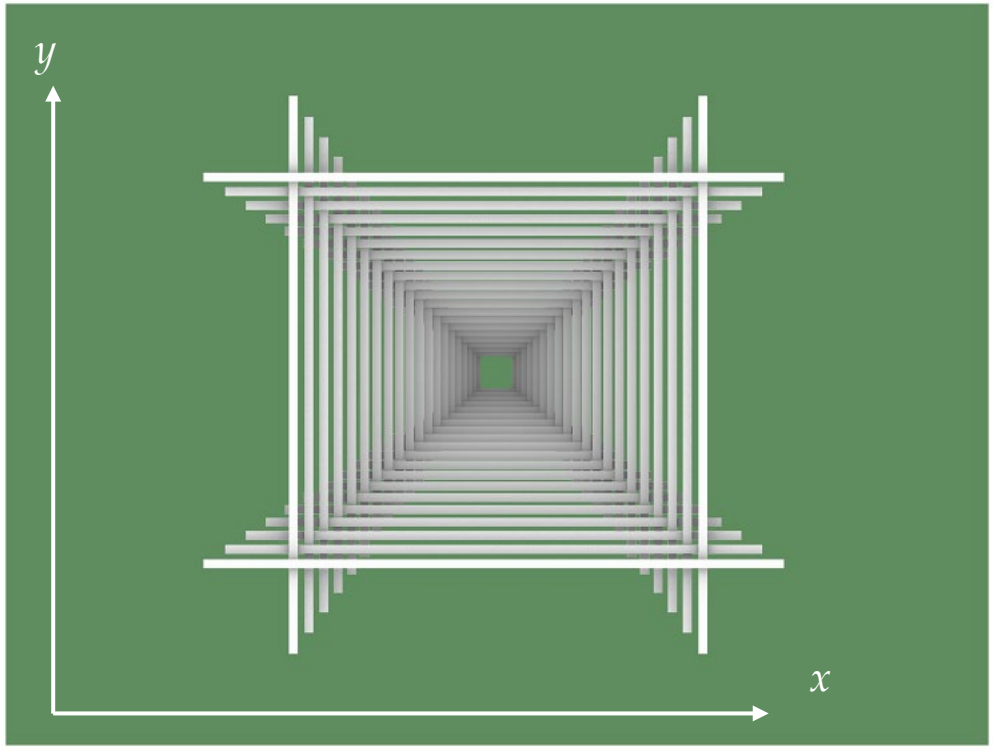
Column base size



Aggregating discrete timber elements

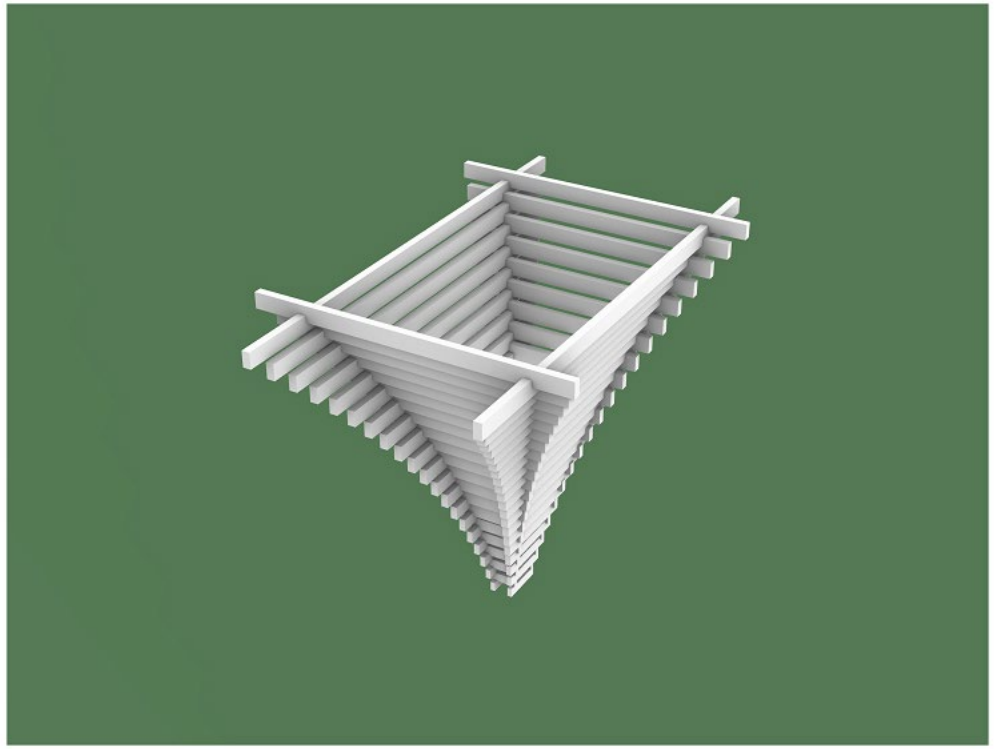
Variations of the system's aggregation

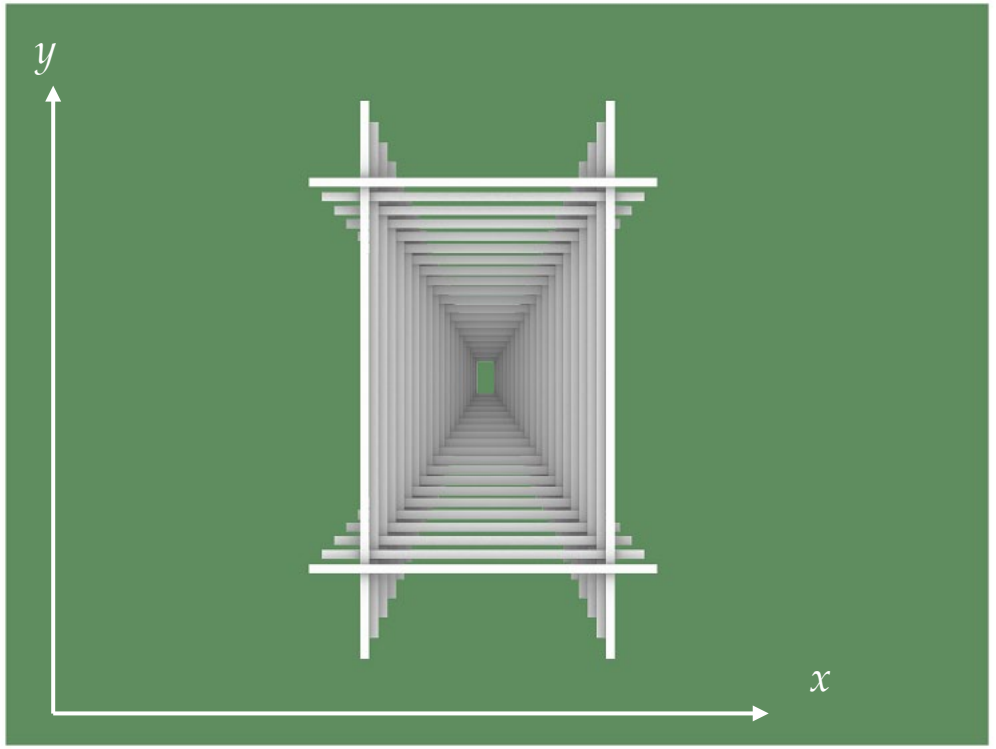




Aggregating discrete timber elements

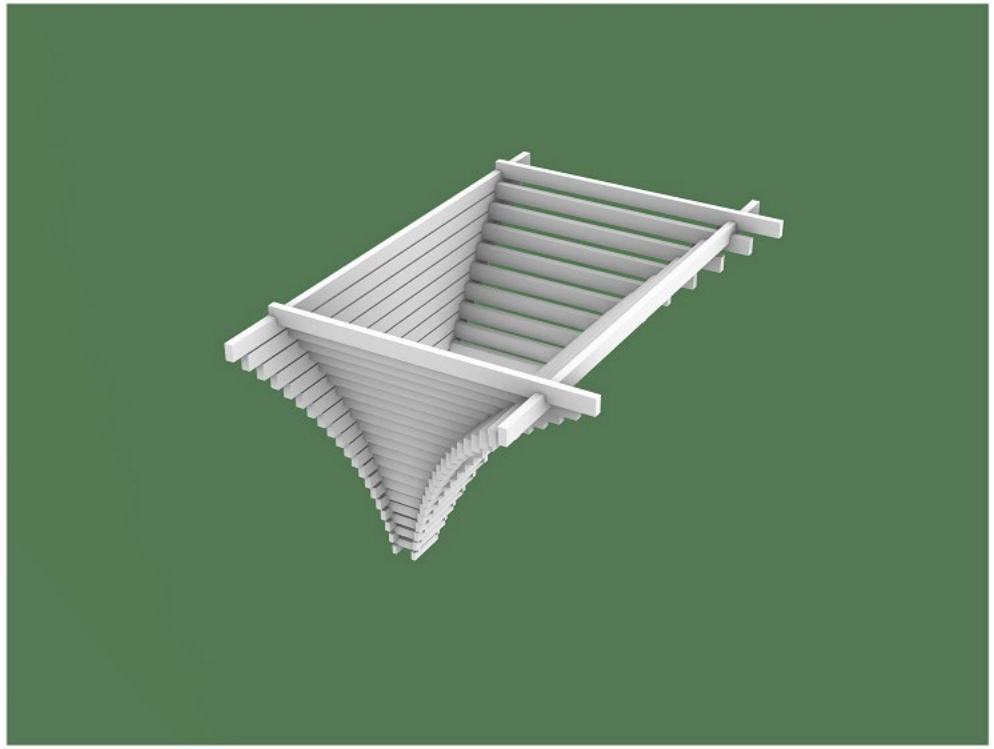
Variations of the system's aggregation

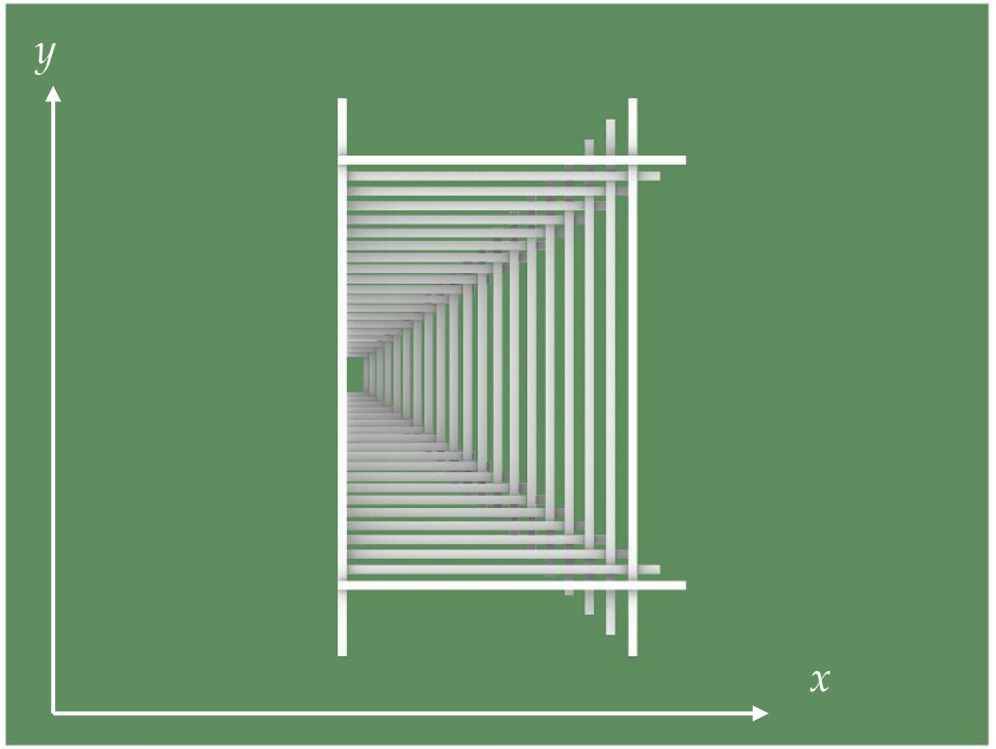




Aggregating discrete timber elements

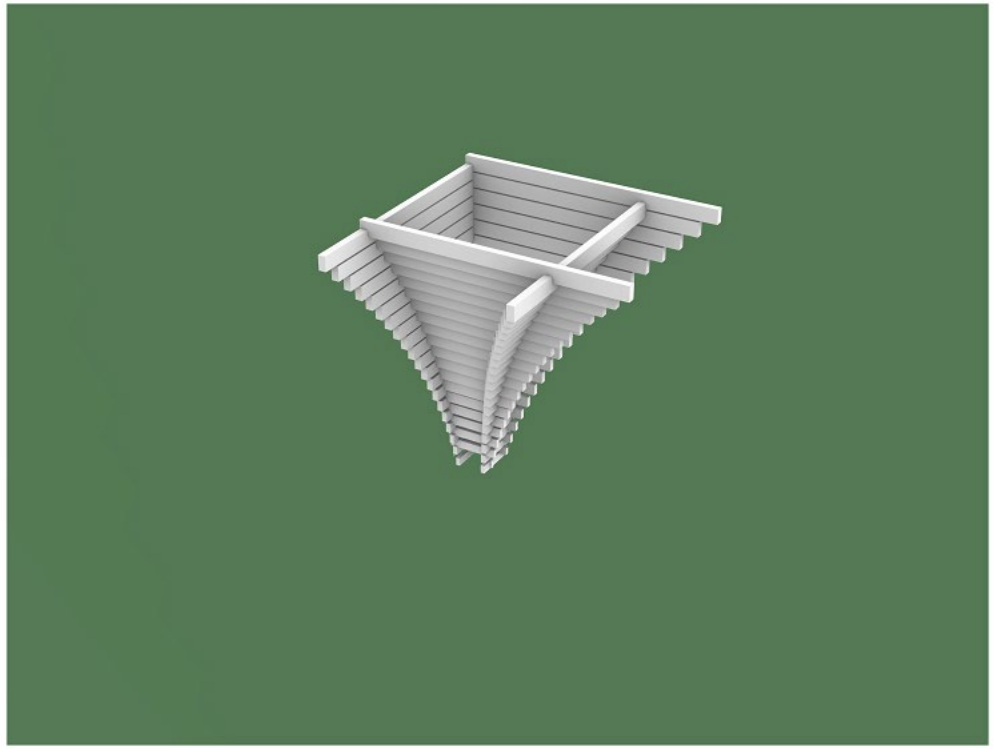
Variations of the system's aggregation

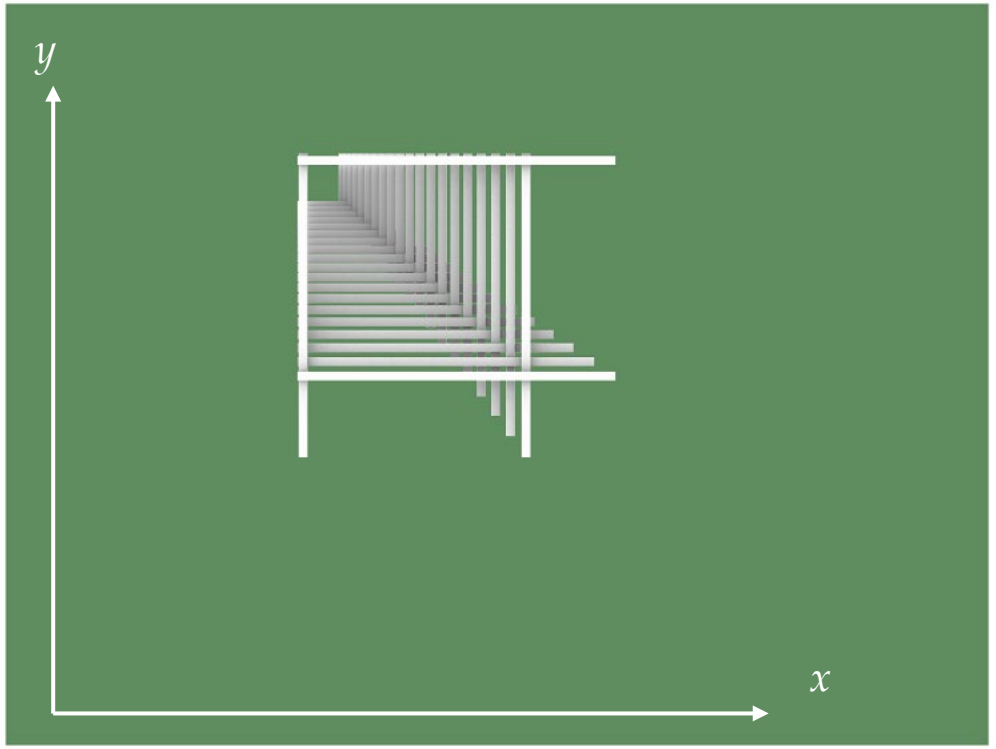




Aggregating discrete timber elements

Variations of the system's aggregation



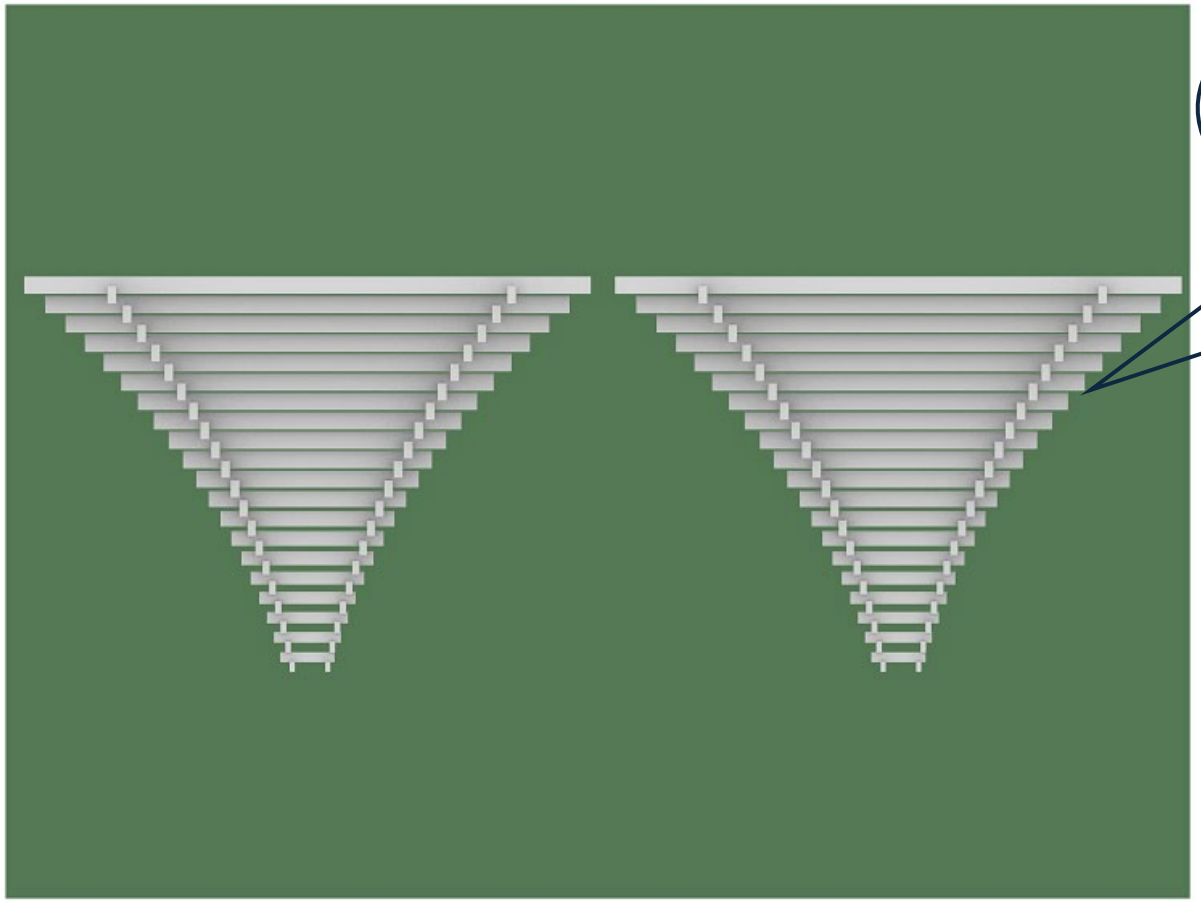


Aggregating discrete timber elements

Branching out above the existing building

Aggregating discrete timber elements

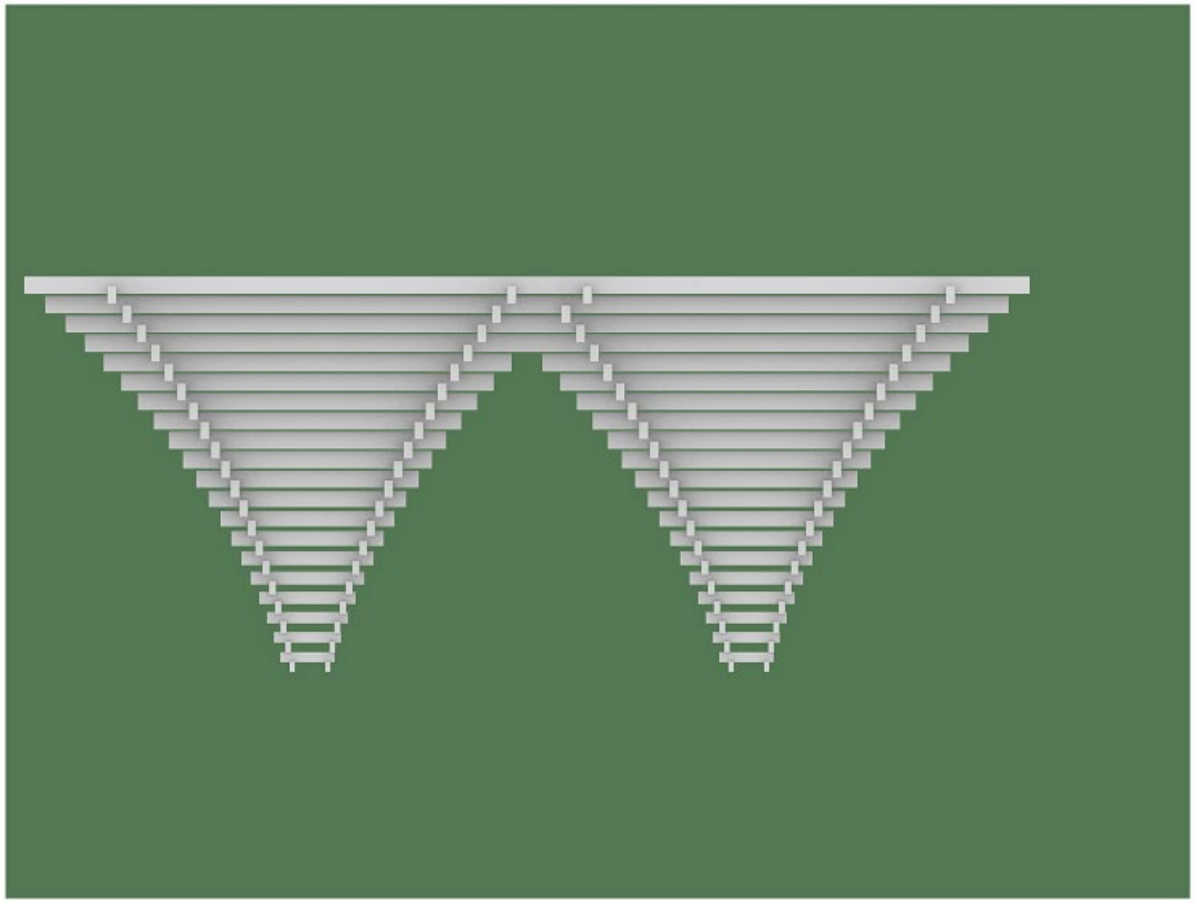
Combining columns



**You see those steel structures?
They are calling us weak**

Aggregating discrete timber elements

Combining columns

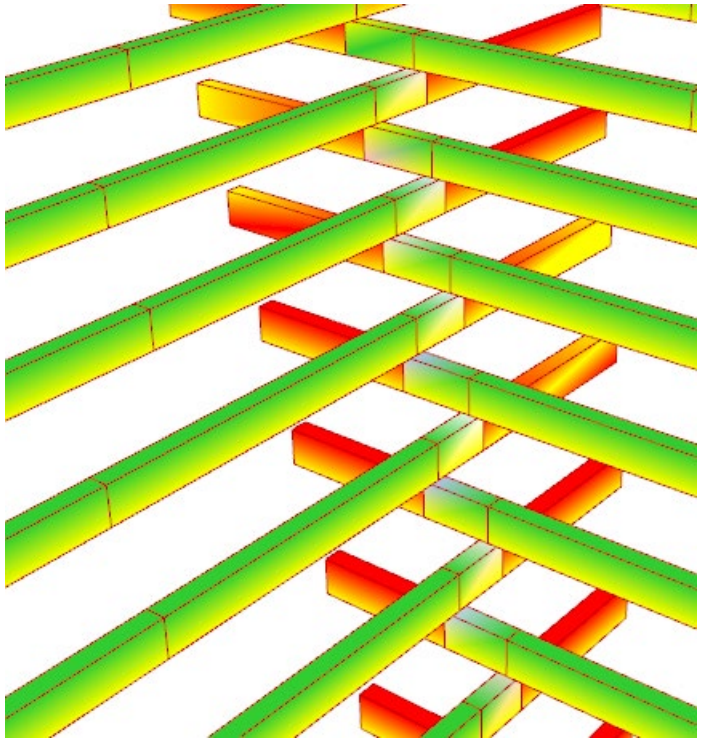


Aggregating discrete timber elements

Findings

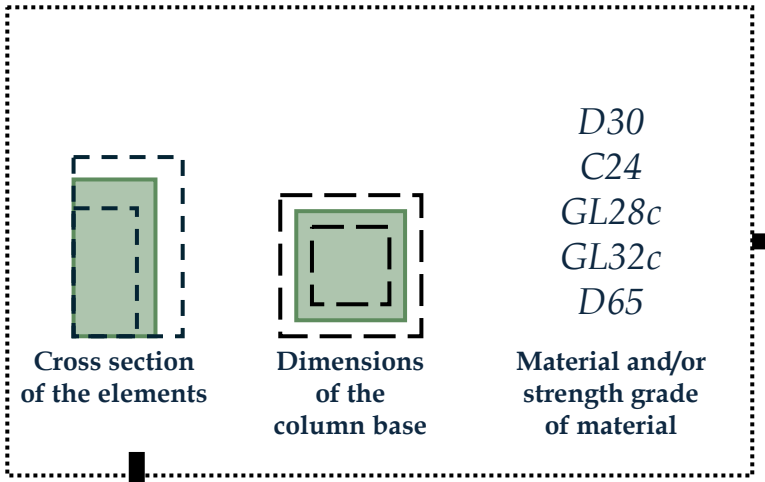
Aggregating discrete timber elements

(under)utilization



Aggregating discrete timber elements

Conclusions



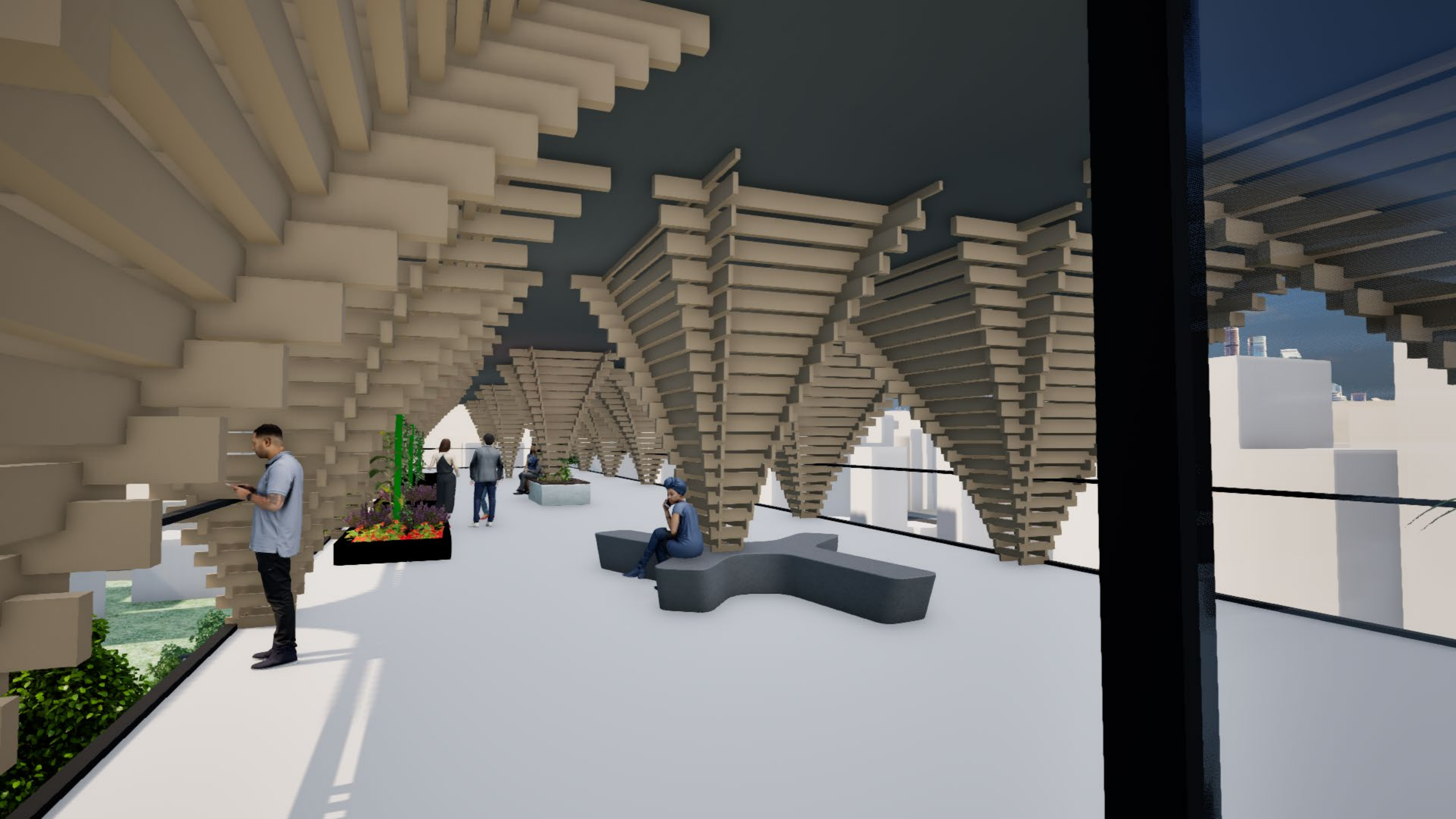
Displacement down
Weight up

Largest displacement reduction with variable cross-section

Displacement is still **too high**

How would this look applied to the case study?

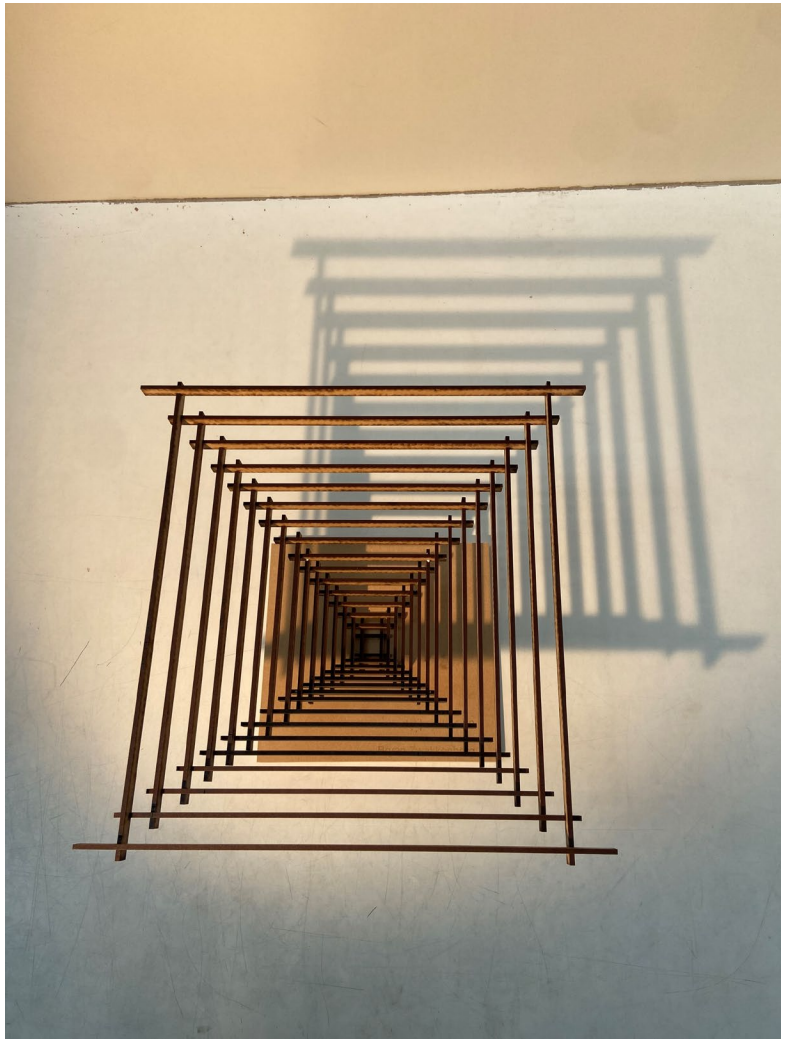
New houses
Communal space
Communal space
Existing block
Existing block



Implementation

Conclusion

Research question

How can a reversible discrete timber system be a feasible alternative to conventional structural timber?

Thank you.