Stock discretised structural timber elements

A structural evaluation on a computational optimised timber structural system, discretised by available stockpile

P5 | Final presentation
25-06-2024

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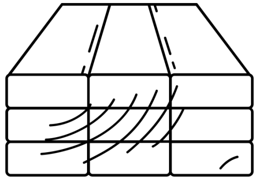
Overview

1. Problem introduction & Research outline
2. Structural design & Algorithmic development
3. Algorithmic performance
4. Design implementation
5. Conclusion & recommendations

Problem introduction & Research outline

Current practice in construction



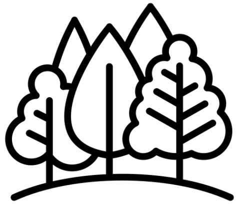
Timber is becoming a more popular material

- Positive ecological footprint

(EOC City of freemen's school swimming pool, 2018)

Problems

Large material extraction

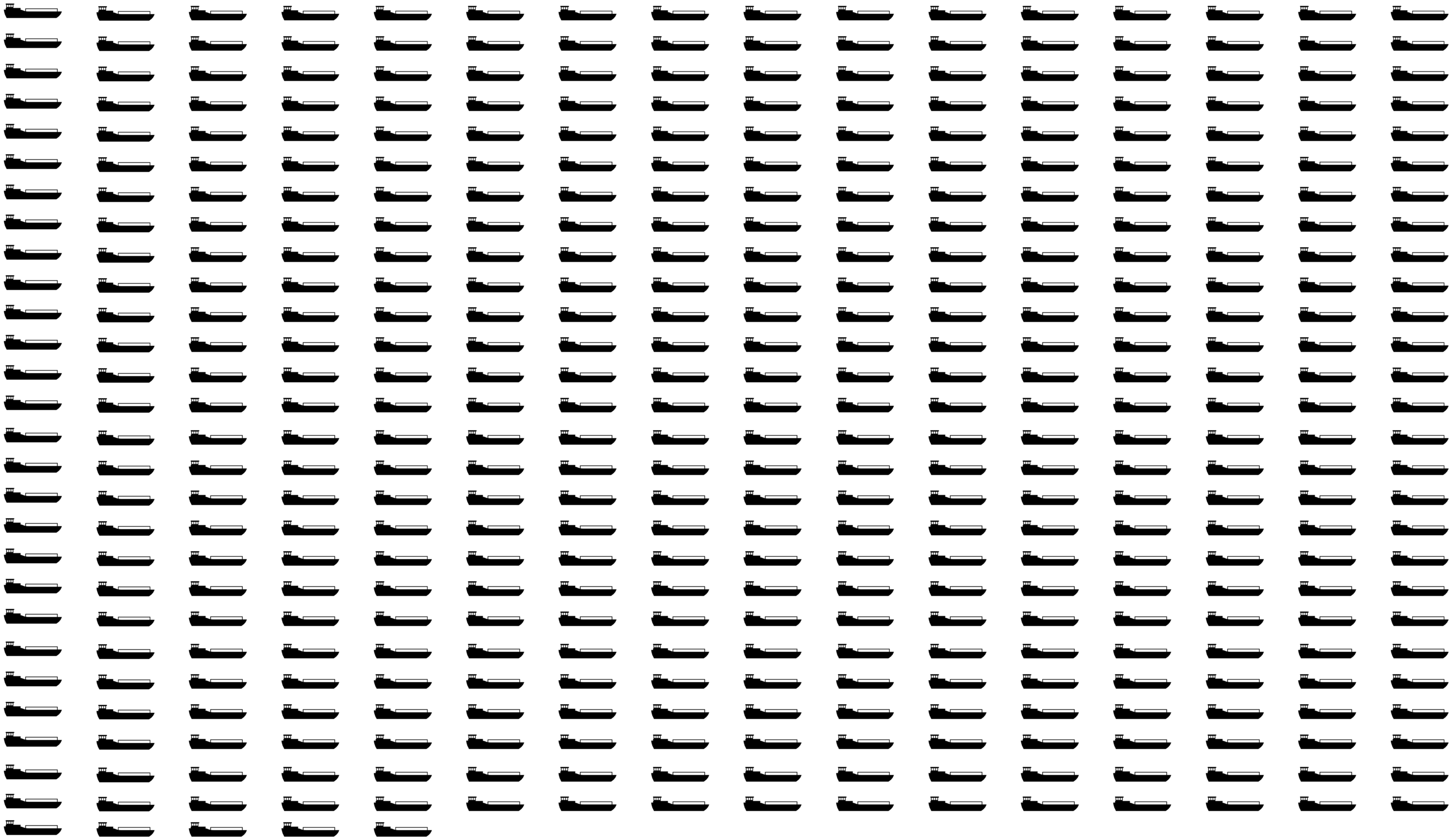


Forest are not infinite

Waste problem

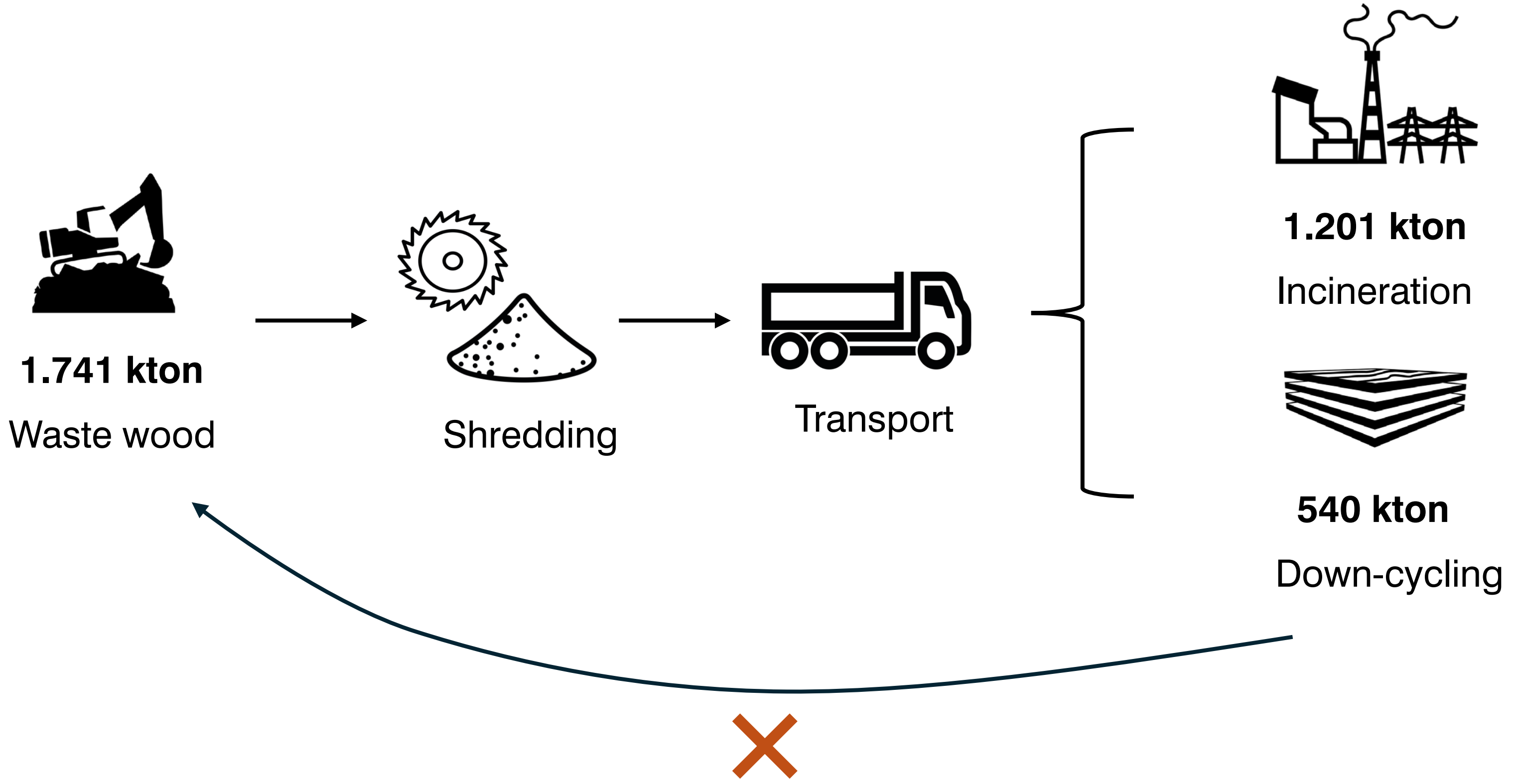
Annually 1.740.000.000 kg waste

(Bruggen & Zwaag, 2017)



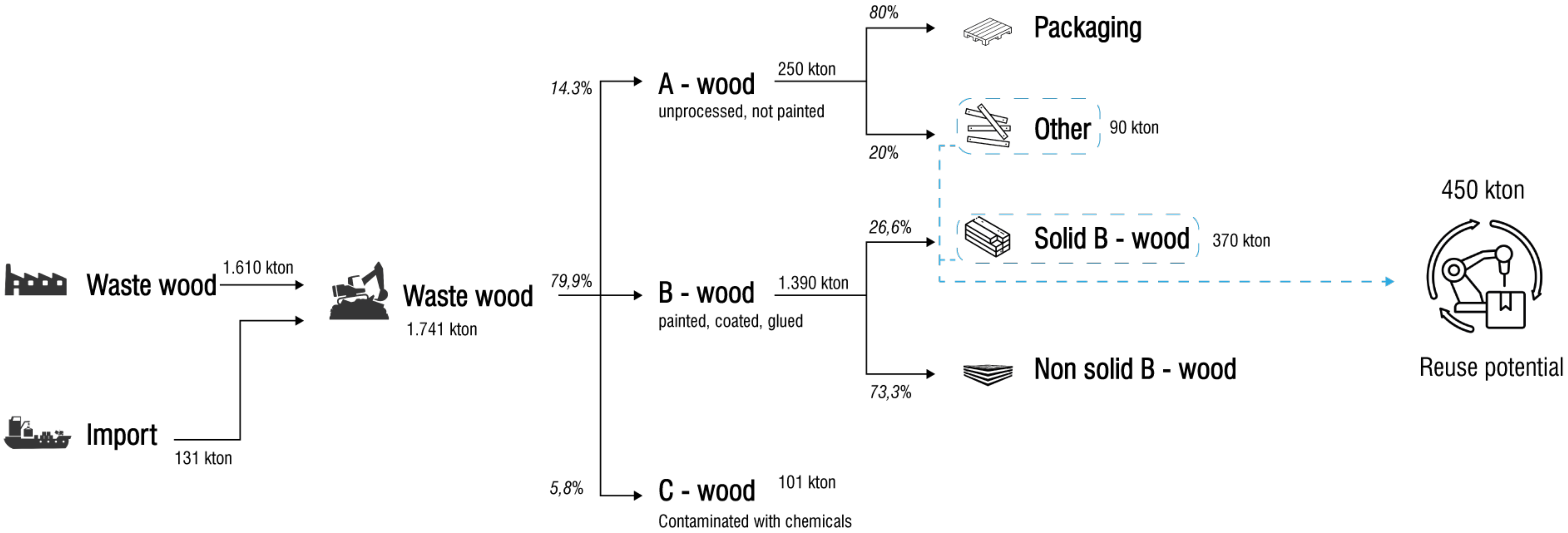
Equivalent of 500 fully loaded barges

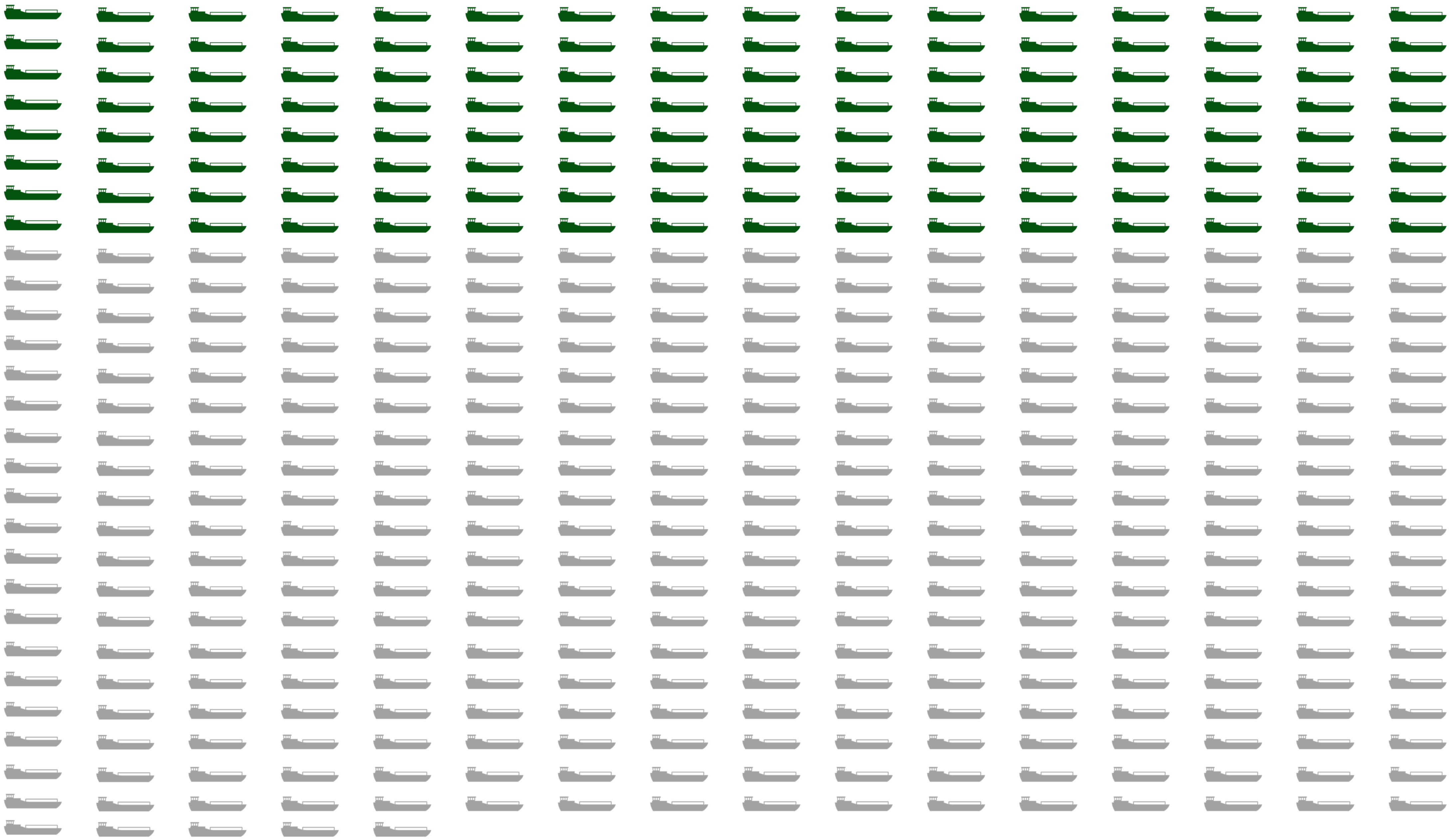
Recycling process



Recycling = down-cycling = refusing

Waste stream





Equivalent of 128 fully loaded barges

Bottlenecks for reuse

Size

Database

Sorting

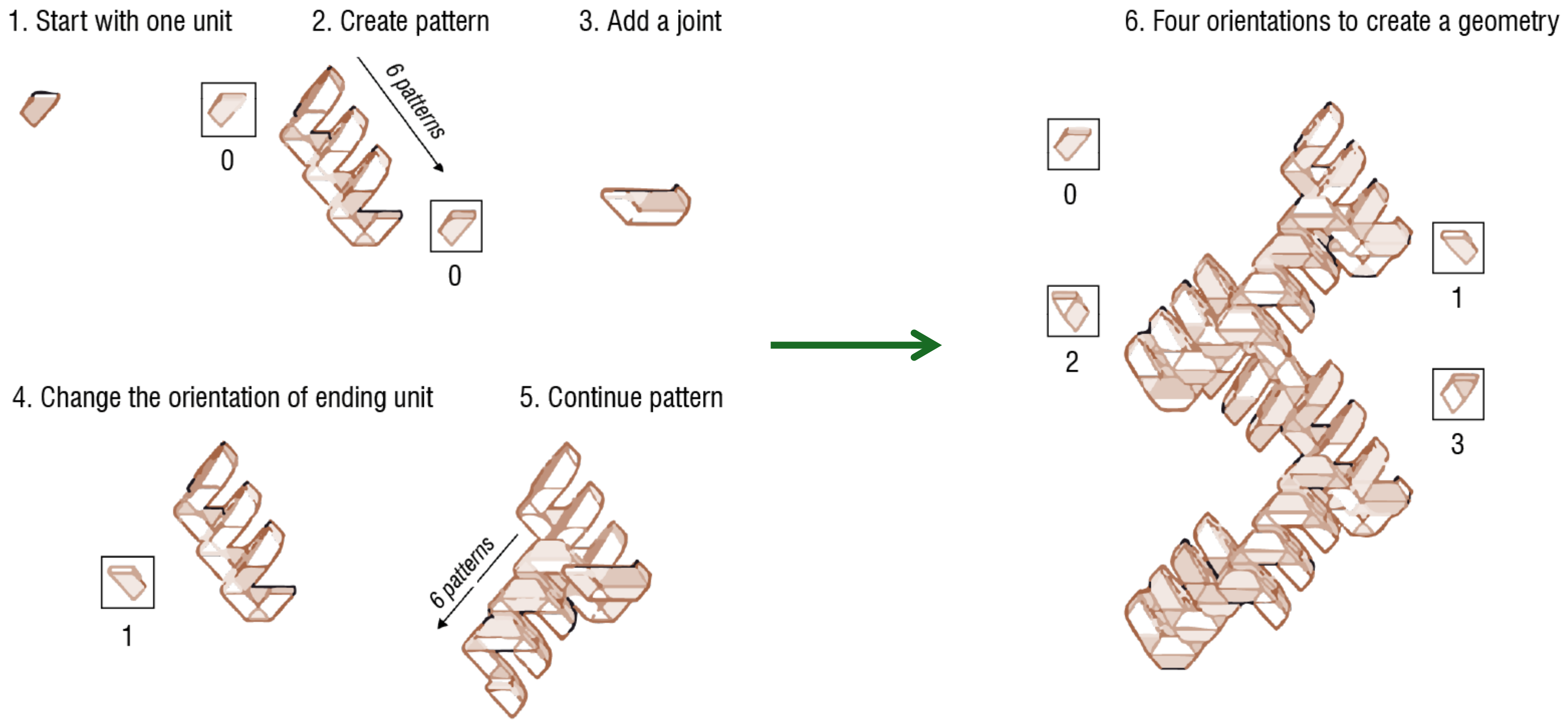
Competition

Shift in design thinking,
Discrete design

Shift in processing
waste wood

Discrete design

"By combining a set of parts, a bigger building block can be created which can evolve into any type of structure."



(Adapted from, Sánchez, 2017)

Flexibility* | *Geometric freedom* | *Great complexity

Pizza Robot
Gilles Retsin, 2018

The Tallinn pavilion
Gilles Retsin, London, 2017

The Sequential Roof
Gramazio Kohler Research, Switzerland, 2016

Reversible timber beam
SDU Create group, Denmark, 2021

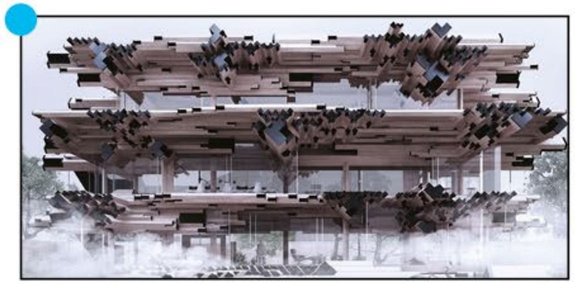
Plexus
Studio Symbiosis, India, 2021

Styx
AA Visiting School, Switzerland, 2018

Skilled-in Office
Studio RAP, Netherlands, 2017

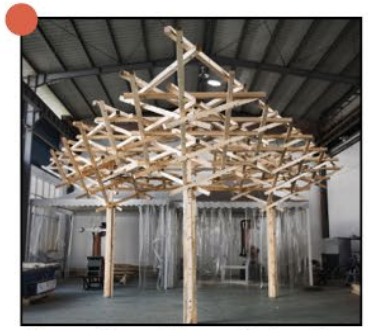
Coeda House
Kengo Kuma, Japan, 2017

Recon timber slab
SDU Create group, Denmark, 2023

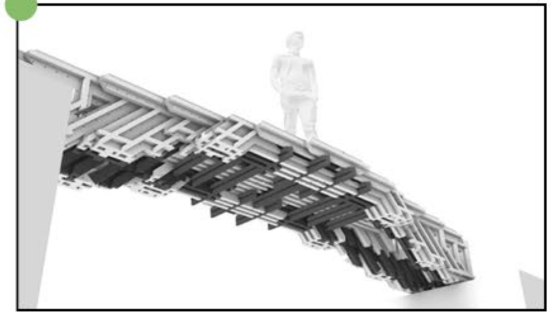


Diamonds House
Gilles Retsin, 2015

Circular Experience
Studio Rap, The Netherlands, 2019



Reconfigurable modular timber grid (RMTG)
Hao Hua et al, China, 2022



Topology optimized bridge
SDU Create group, Denmark, 2019

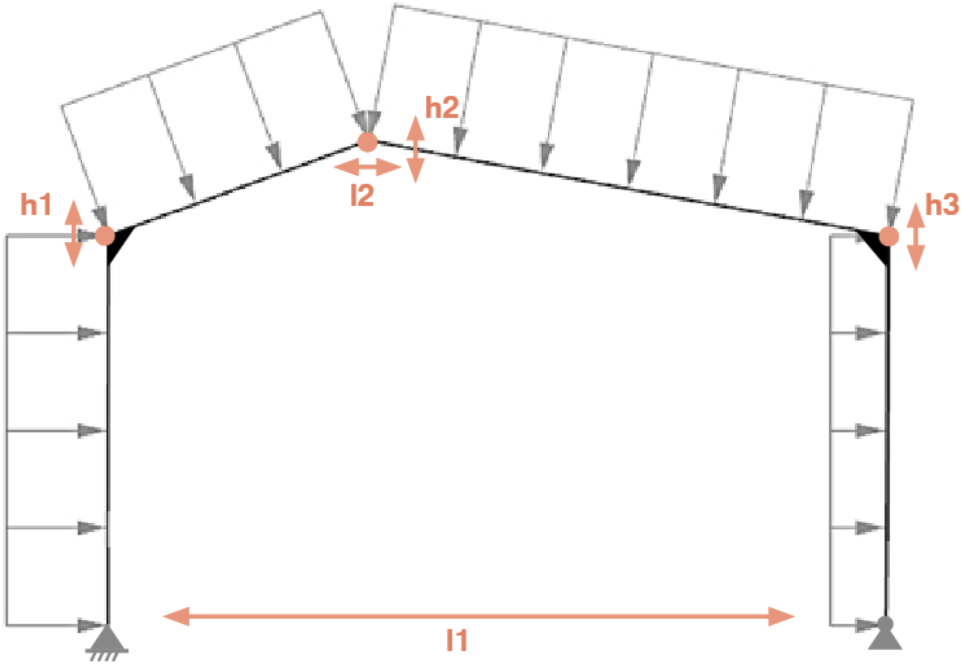
Highly architectural ← → Highly Structural

Conceptual systems · Self-supporting systems · Load-bearing element

Design assignment

Design and build a portal frame generator

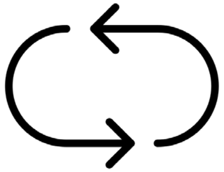
Analyzation of both horizontal and vertical elements subjected to bending moments in joints



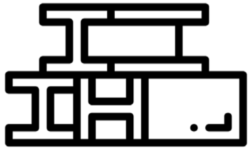
Research aim

*“Creating a tool that is able to generate a structural system using reclaimed timber that can support a more **efficient, circular and transformable** form of architecture.”*

Proof of concept for construction industry:

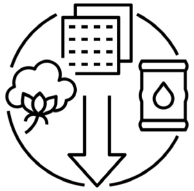


Circular life-cycle



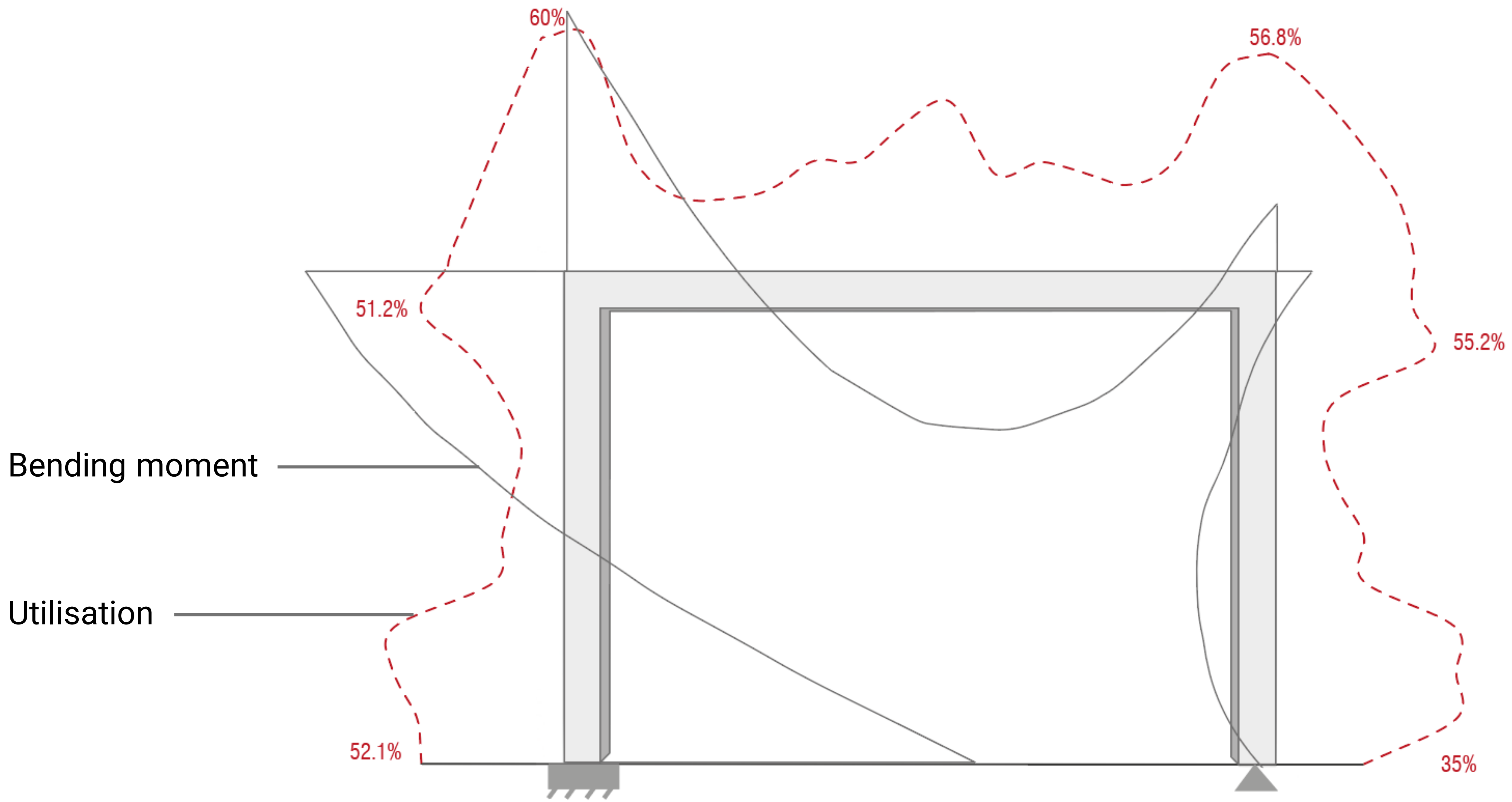
Better structural understanding

Spark new ideas

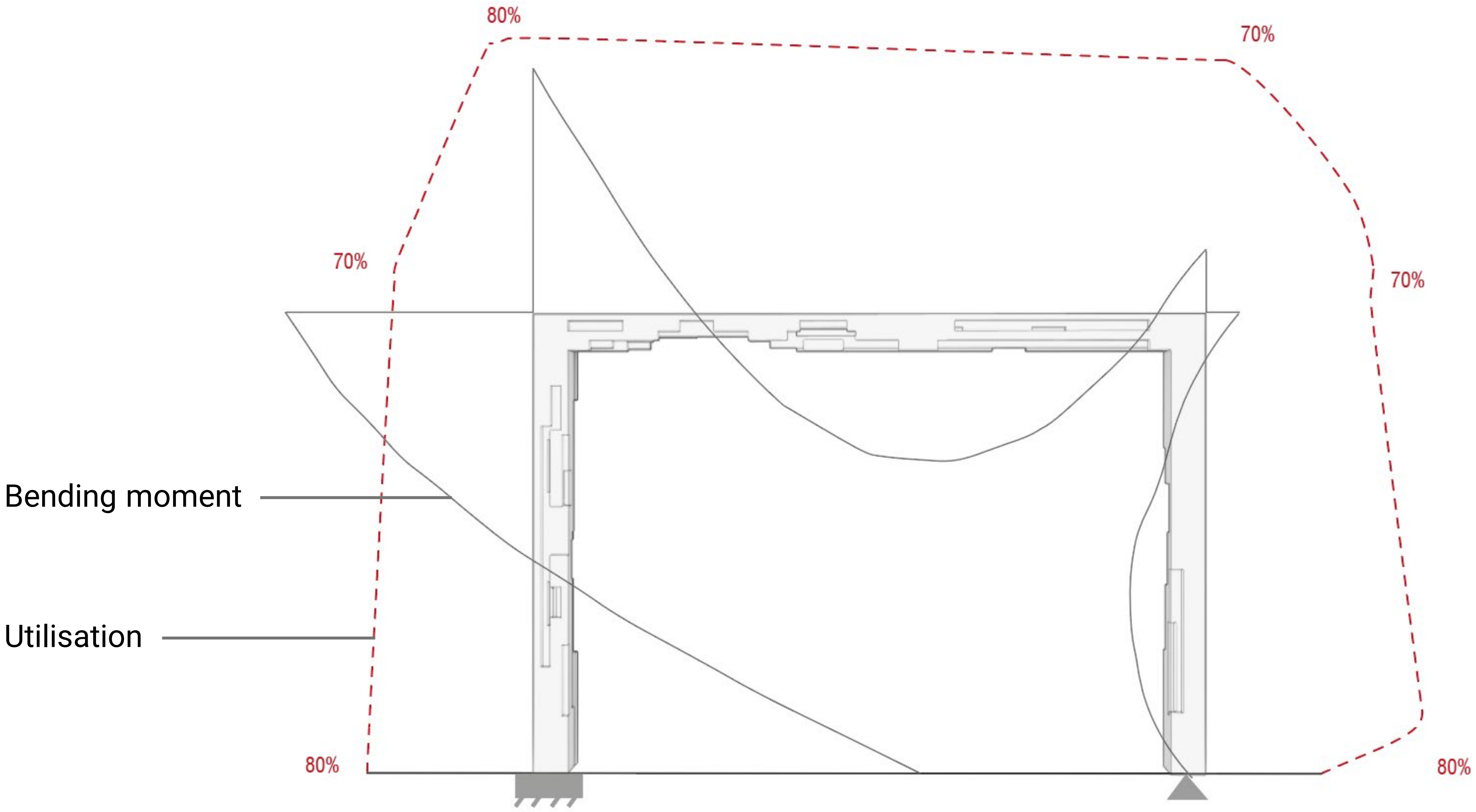


Reduce virgin material consumption

What is a structural efficient structure?

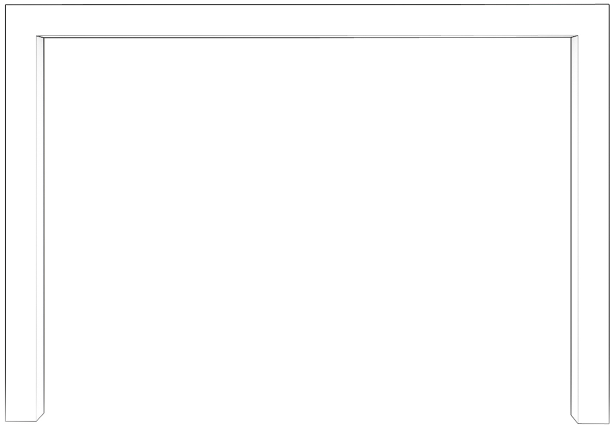


Structural efficiency

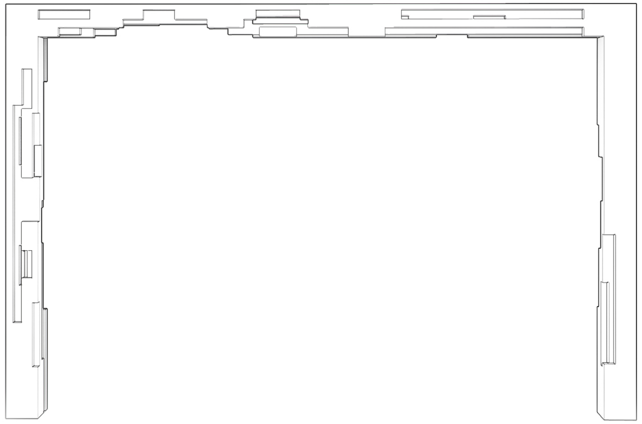


Identified problems

1. Efficient matching



2. Efficient structure

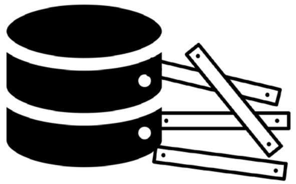


Efficient = minimizing cutting losses and material consumption

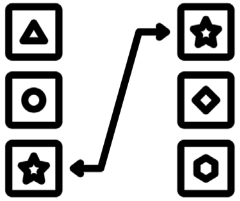
“Efficiently matching parts manually is a nearly impossible task that can take days or even weeks and requires an algorithmic design approach”

Research question

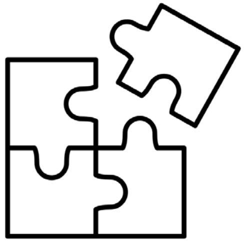
How can programming be utilised to create a discrete structural system using reclaimed timber parts that **maximizes efficiency and adaptability** but **minimizes the need for virgin materials** in construction?



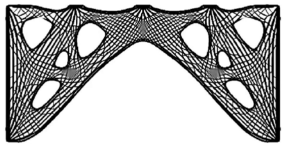
Variable stock of reclaimed timber



Matching of pieces

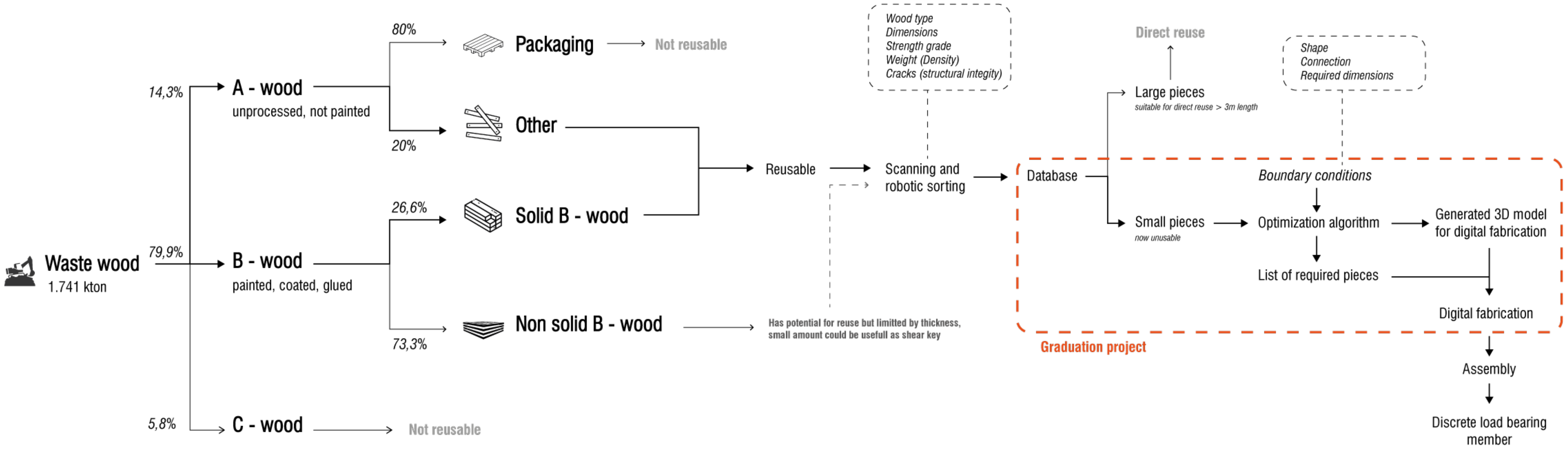


Discrete structural design



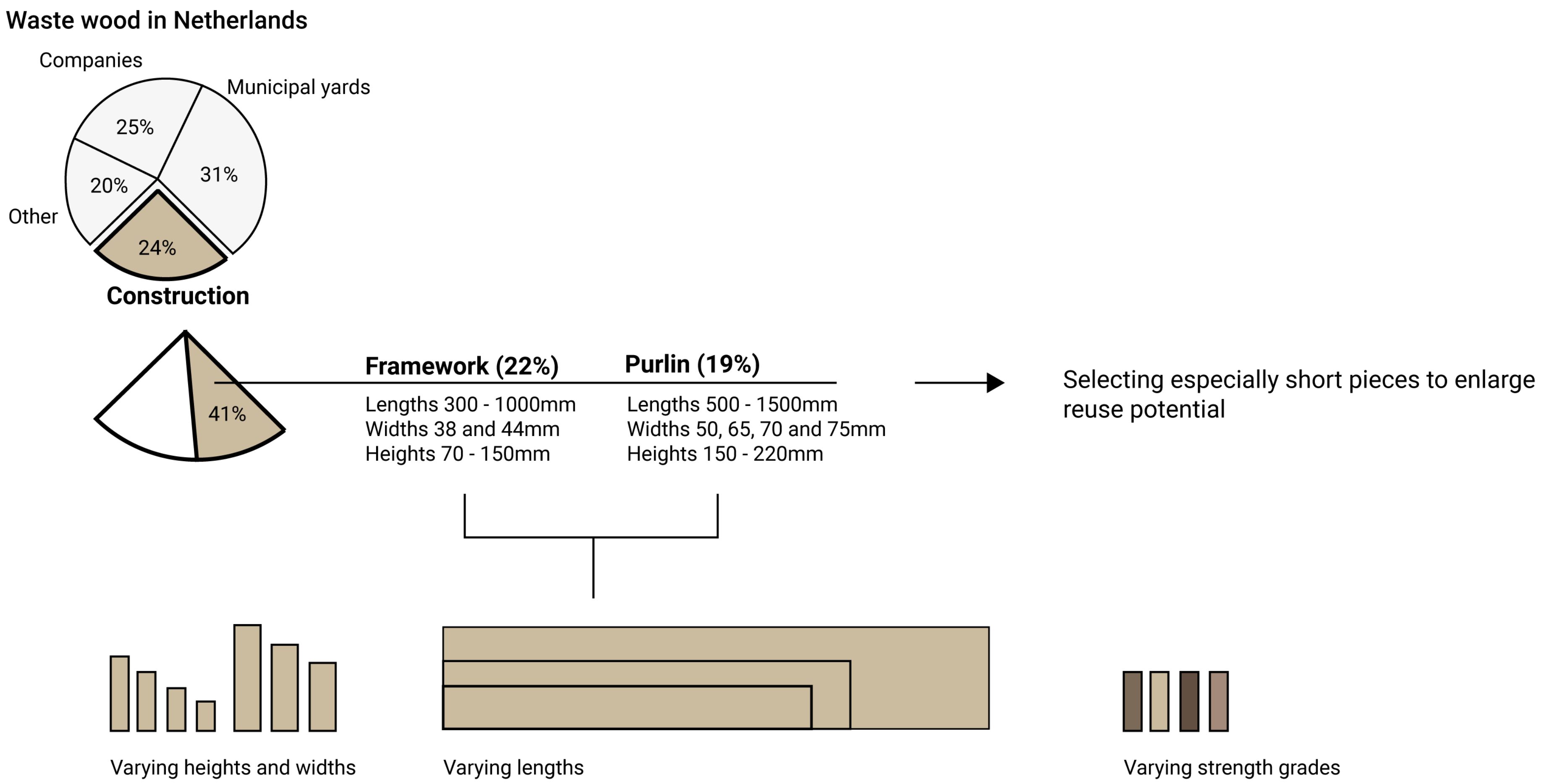
Structural optimisation

Research scope



"The graduation project will start with the assumption that timber is collected, scanned sorted and inputted in a database. The database can be linked to a computational tool which generates a structure from waste wood."

Reclaimed timber database



Structural design

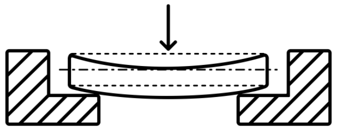
Design Criteria

Reversible joints

Minimize modifications

→ **Circular and adaptable**

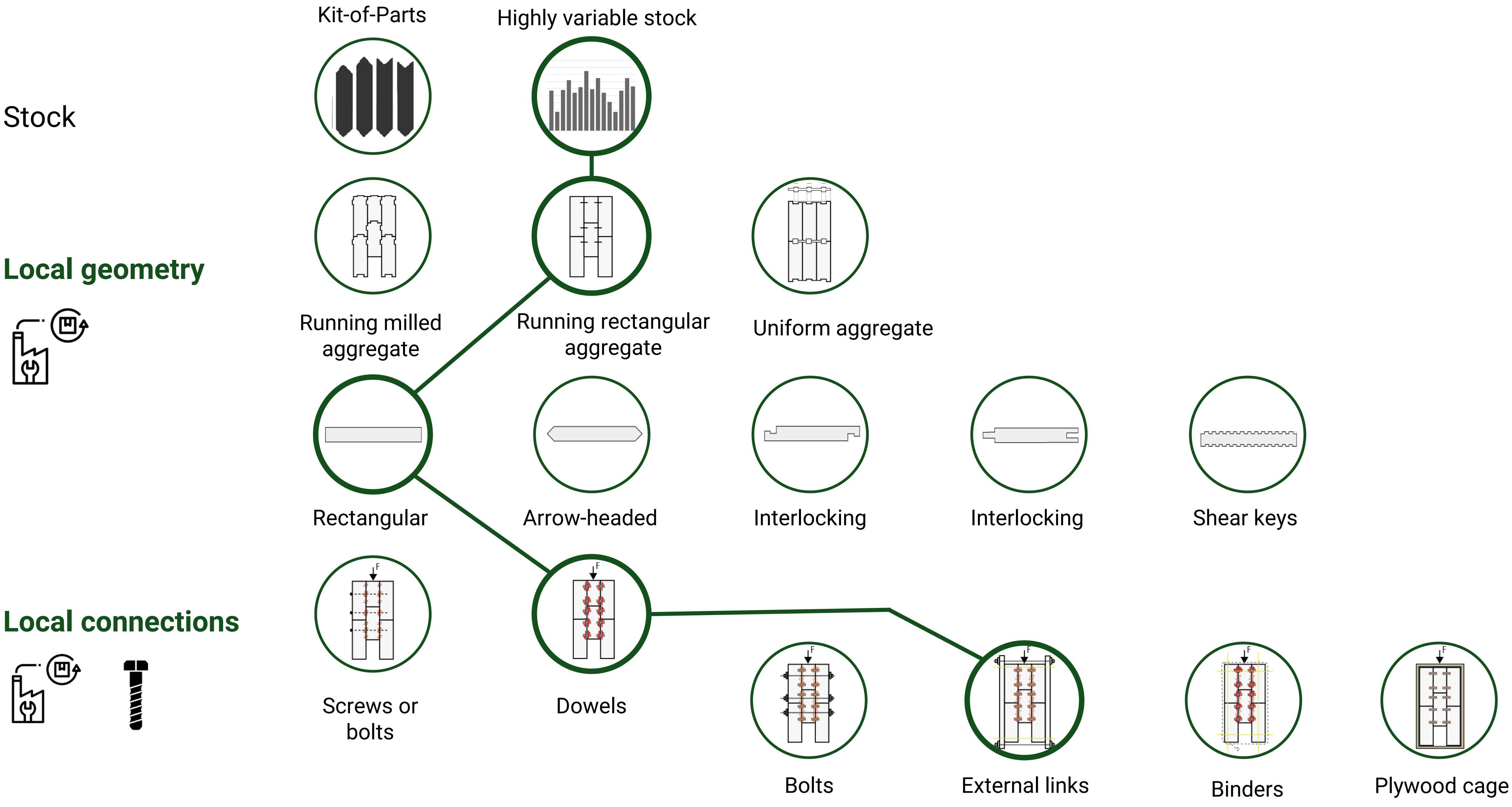
Strength grade matching



Ductile system

→ **Efficient, safe, stiff and strong**

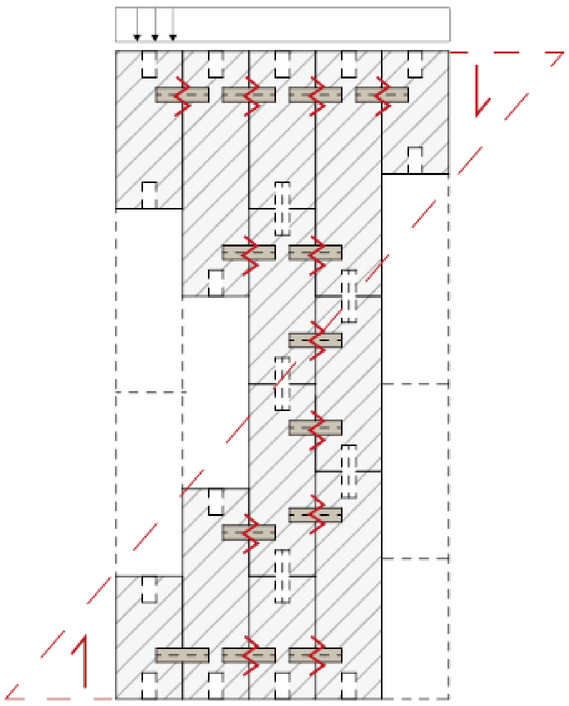
Design alternatives



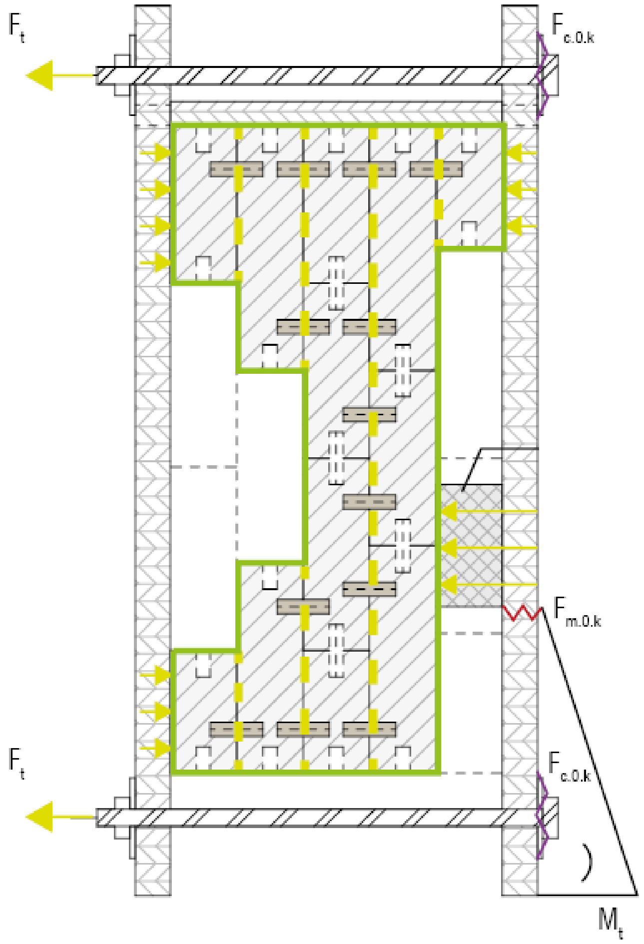
Local connection

Cross-sectional view

Optimised section without composite behavior

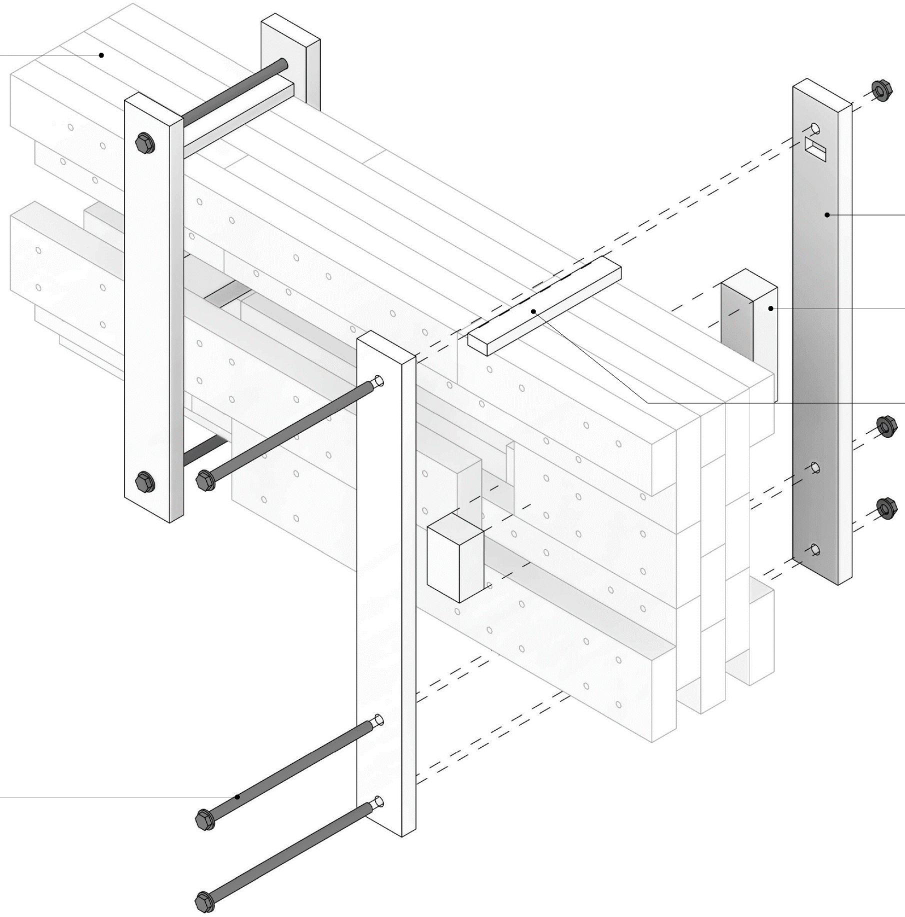


Optimised section with composite behavior

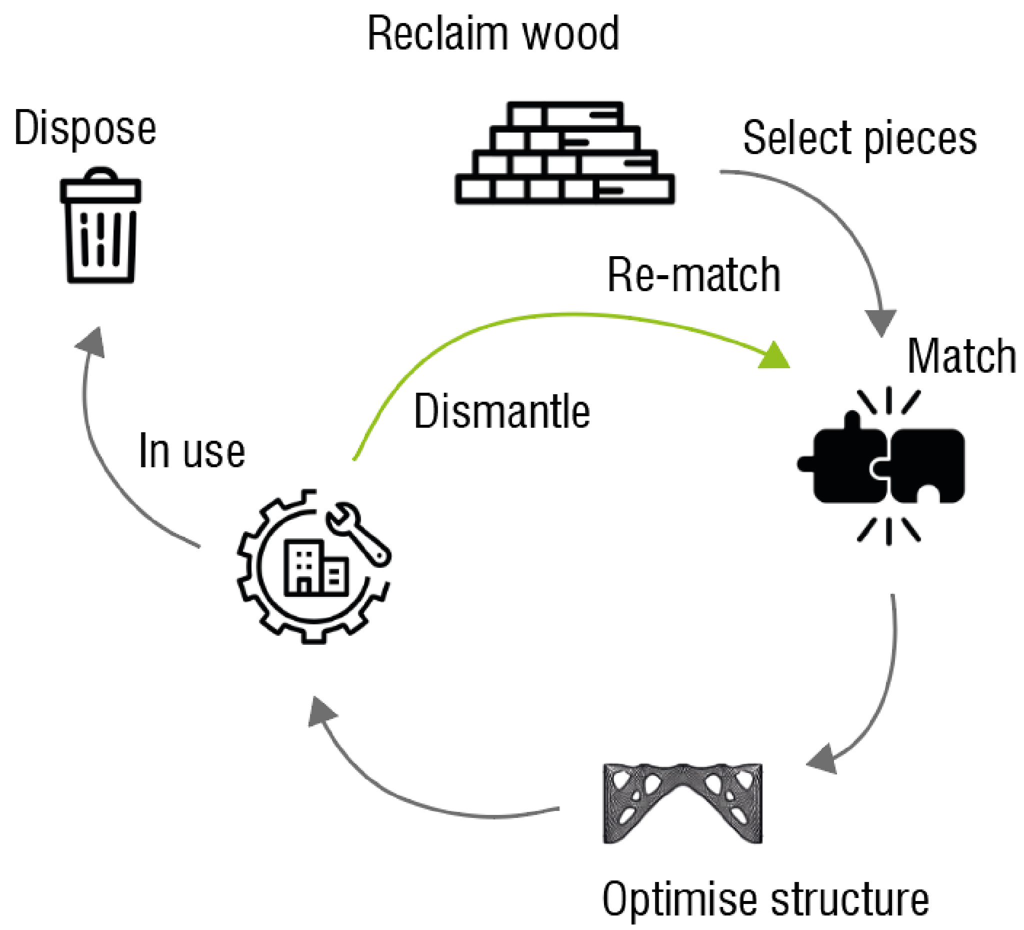


Local connection

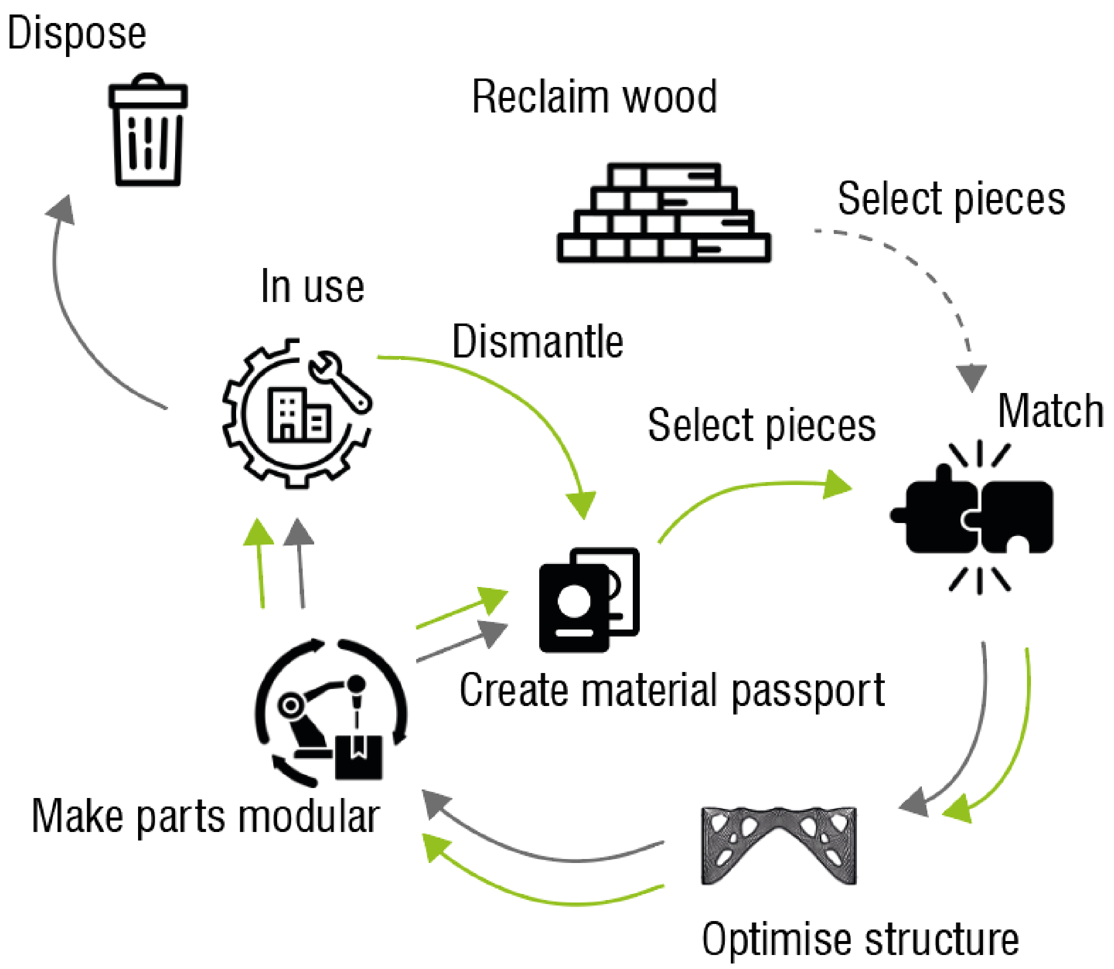
3D exploded view



Circular vision

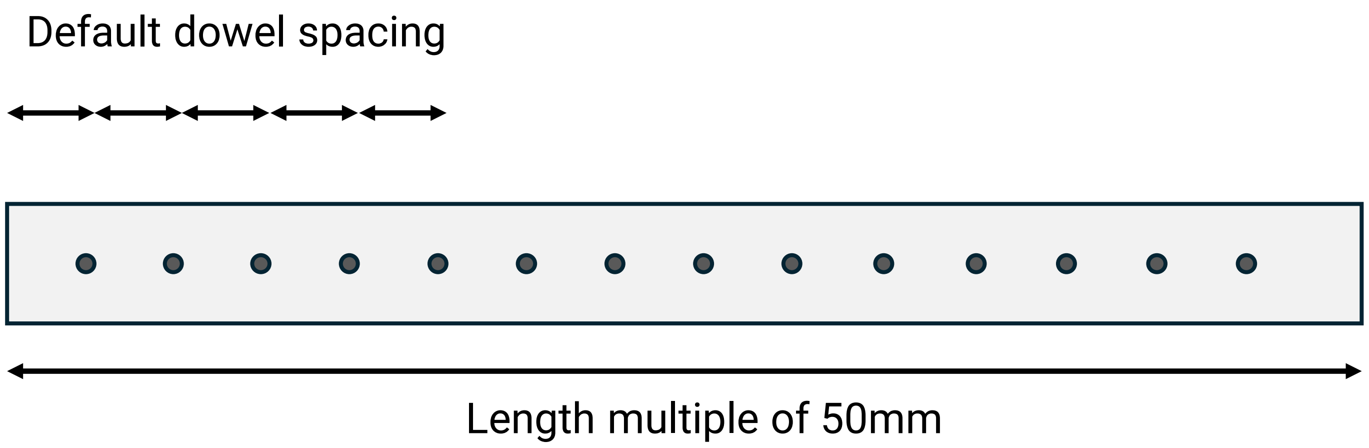


Circular vision



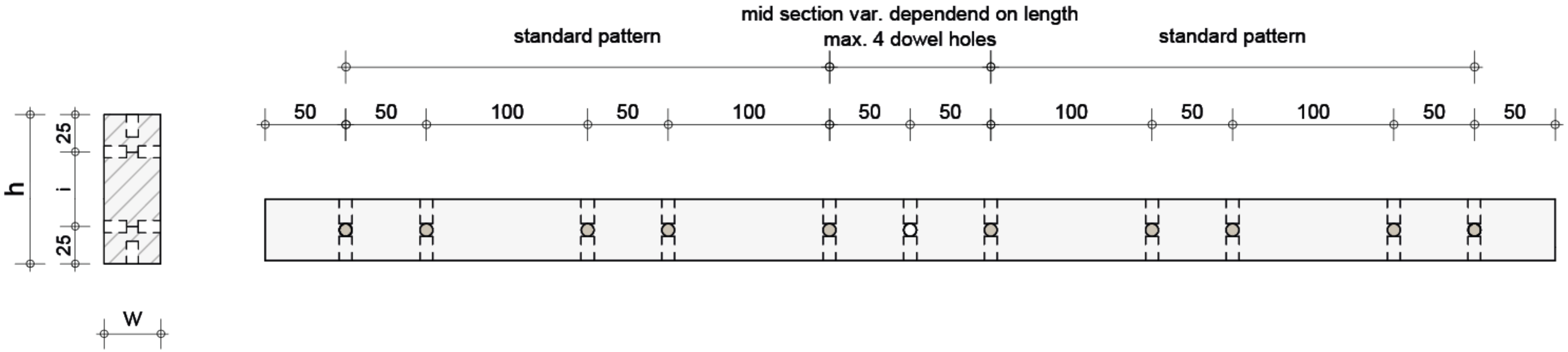
Modular system

Side view of part



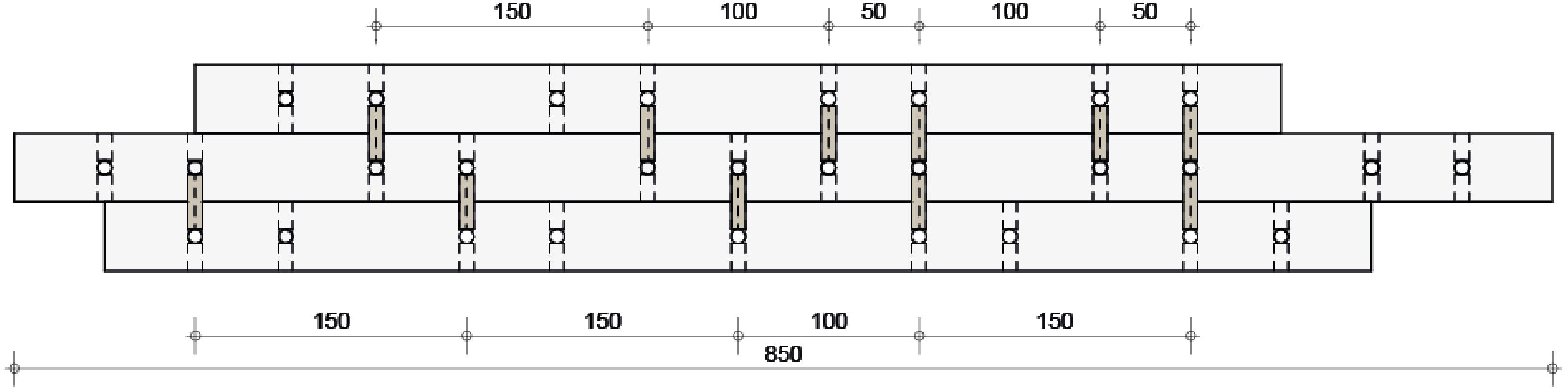
The modular part

Top view



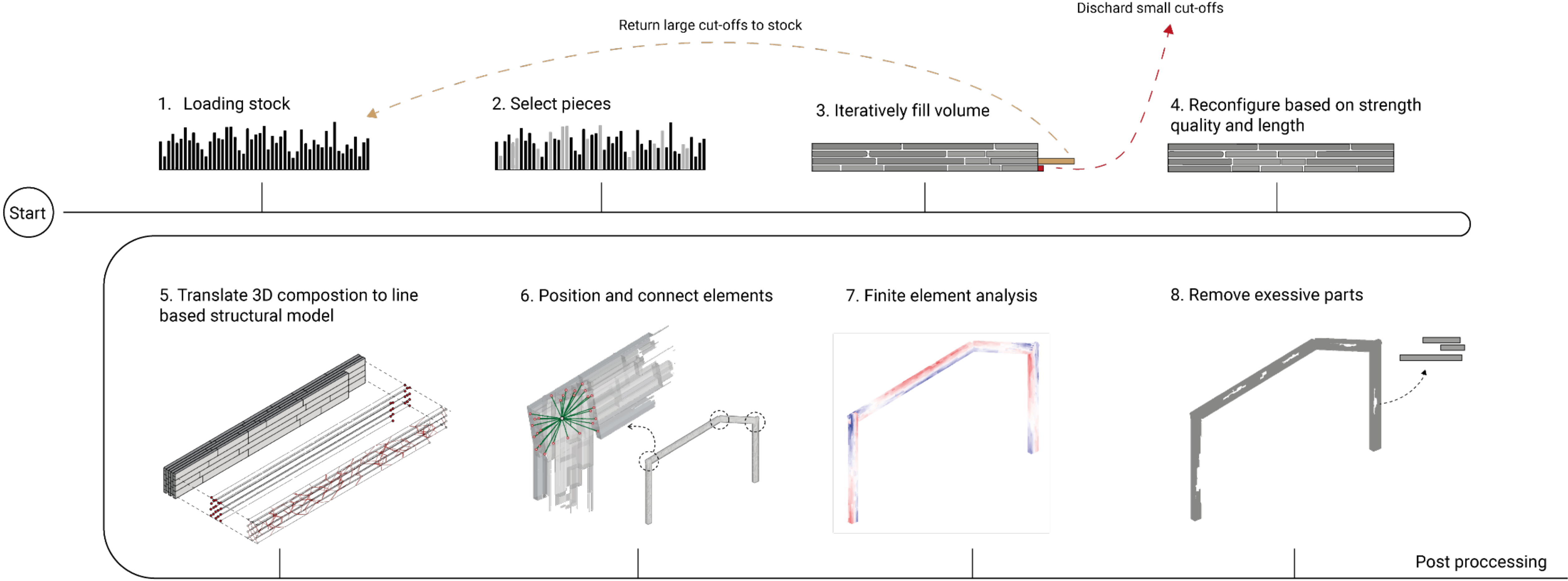
Dowel pattern

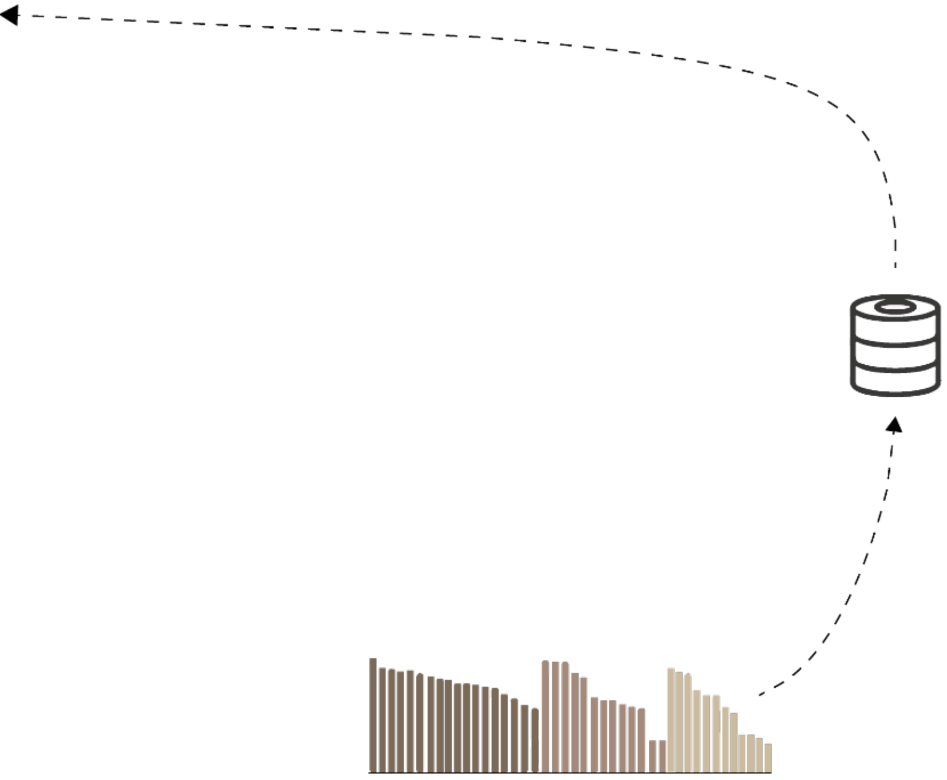
Top view of layers



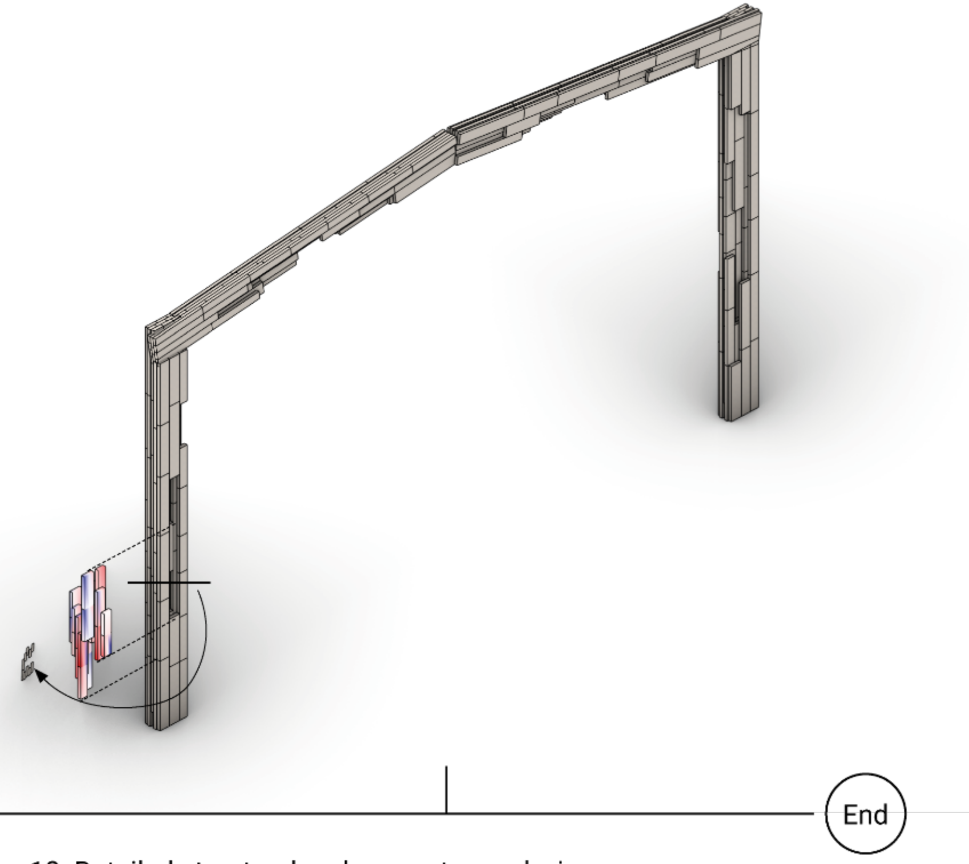
Algorithmic development

Overview of the workflow



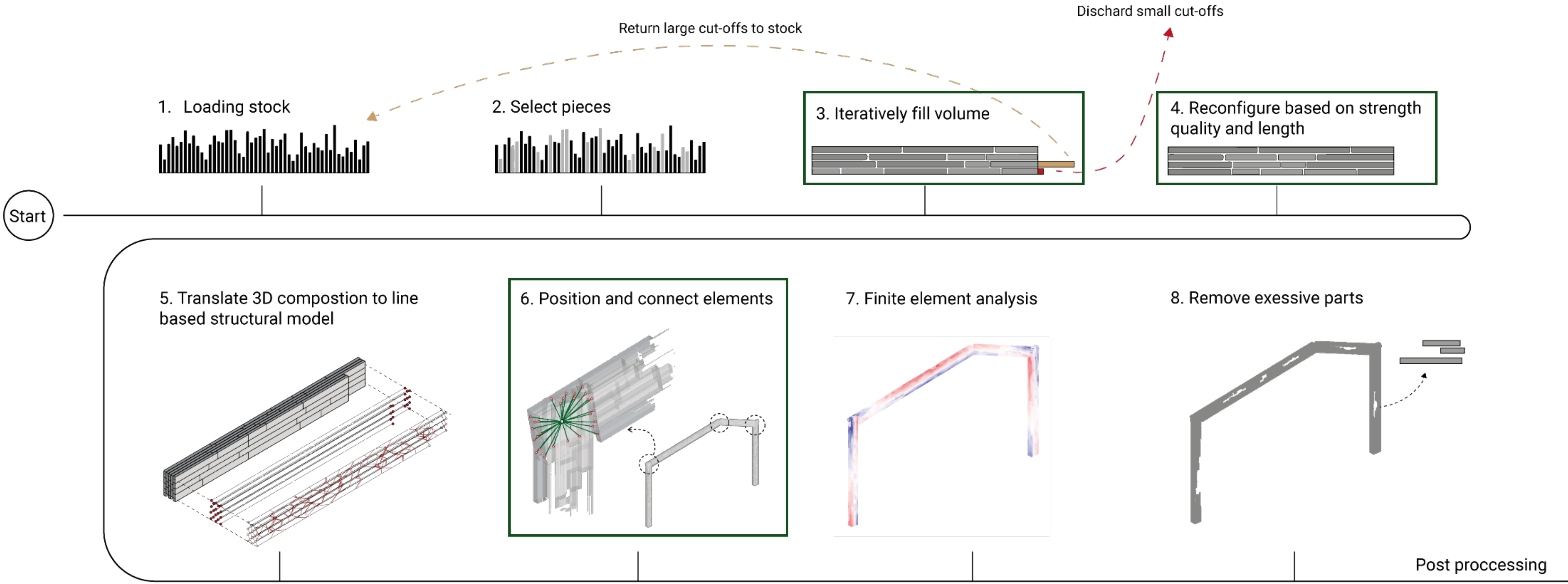


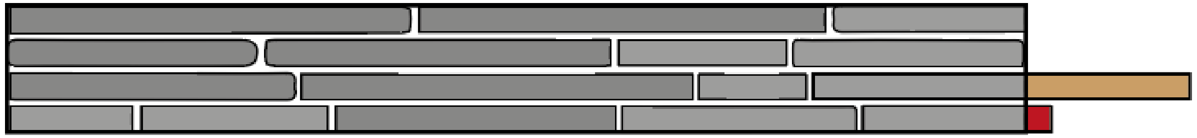
9. Send used pieces to new database for future rematching



10. Detailed structural and geometry analysis

Overview of the workflow

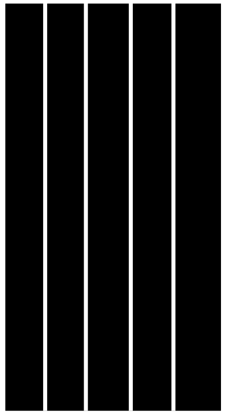


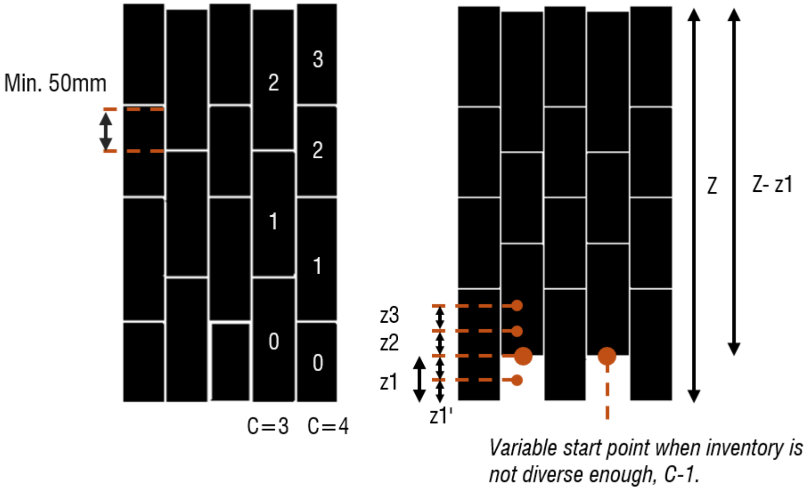


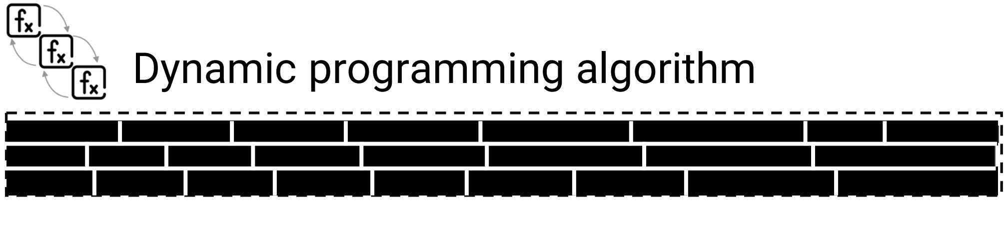
Iterative matching of pieces in design domain

One dimensional combinatorial problem solving

Cross-sections (1 and 2) and side view (3)







Blocks used = 24
Filling rate avg. 95 - 99%

1. Y-direction

2. Z-direction

3. X-direction

Dynamic matching performance

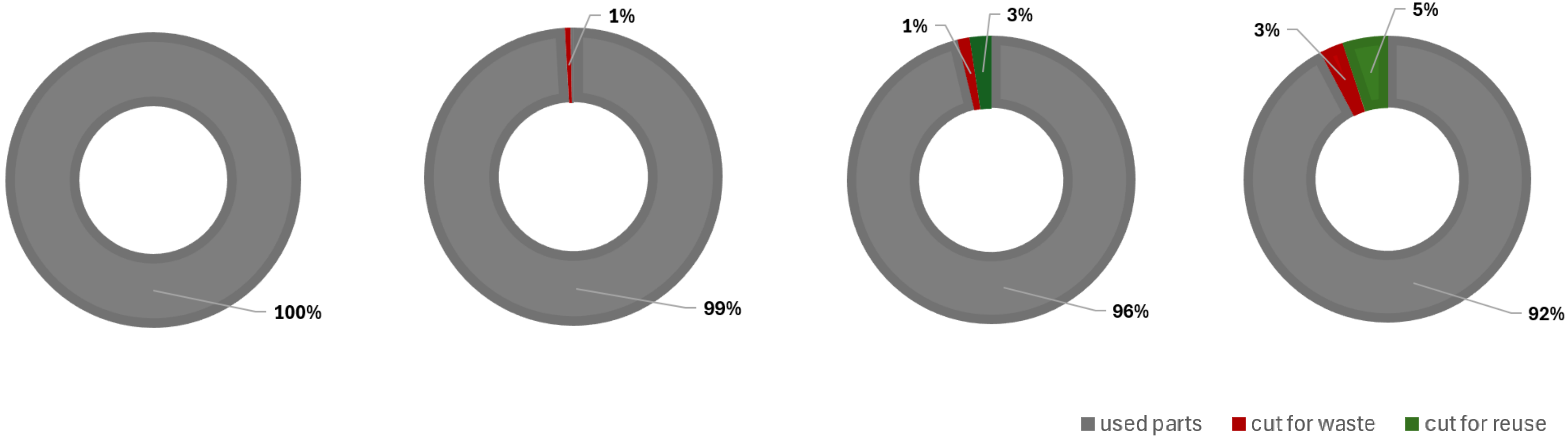
Effect of stock sizes

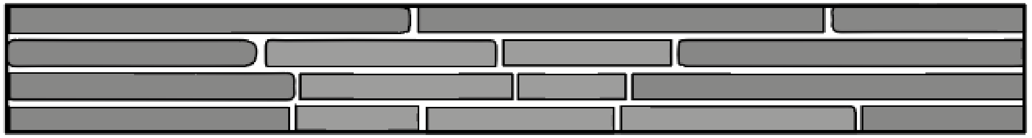
- **Abundant stock**
- **Lengths 300 – 1000mm**

- **Limited stock**
- **Lengths 500 – 1000mm**

- **Limited stock**
- **Lengths 800 – 1000mm**

- **Limited stock**
- **Lengths 900 – 1000mm**



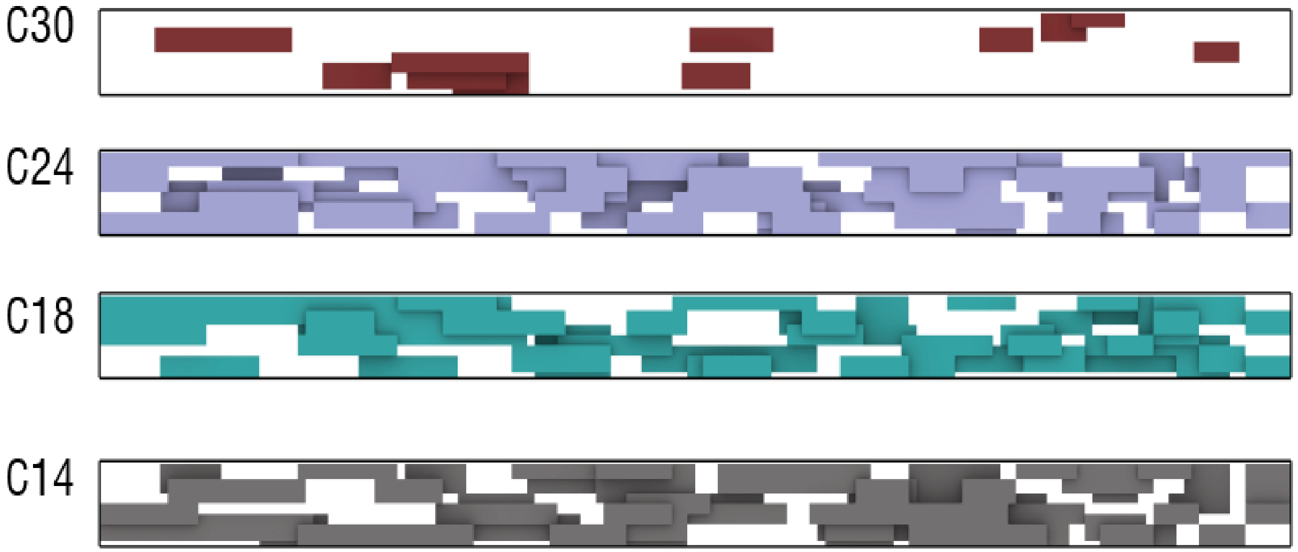


Strength optimisation by reconfiguration of pieces

Placement of pieces without optimisation

Front view of horizontal member

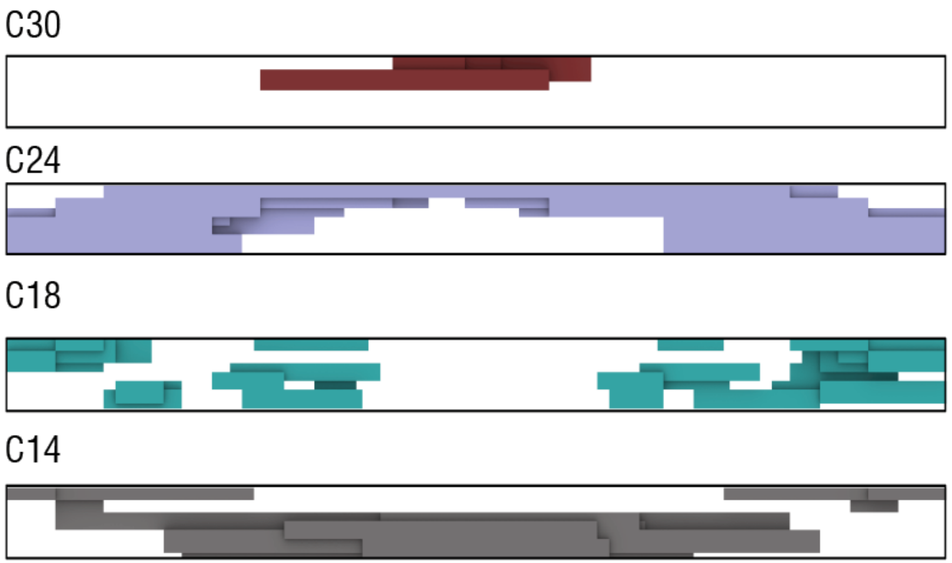
Strength classes of timber



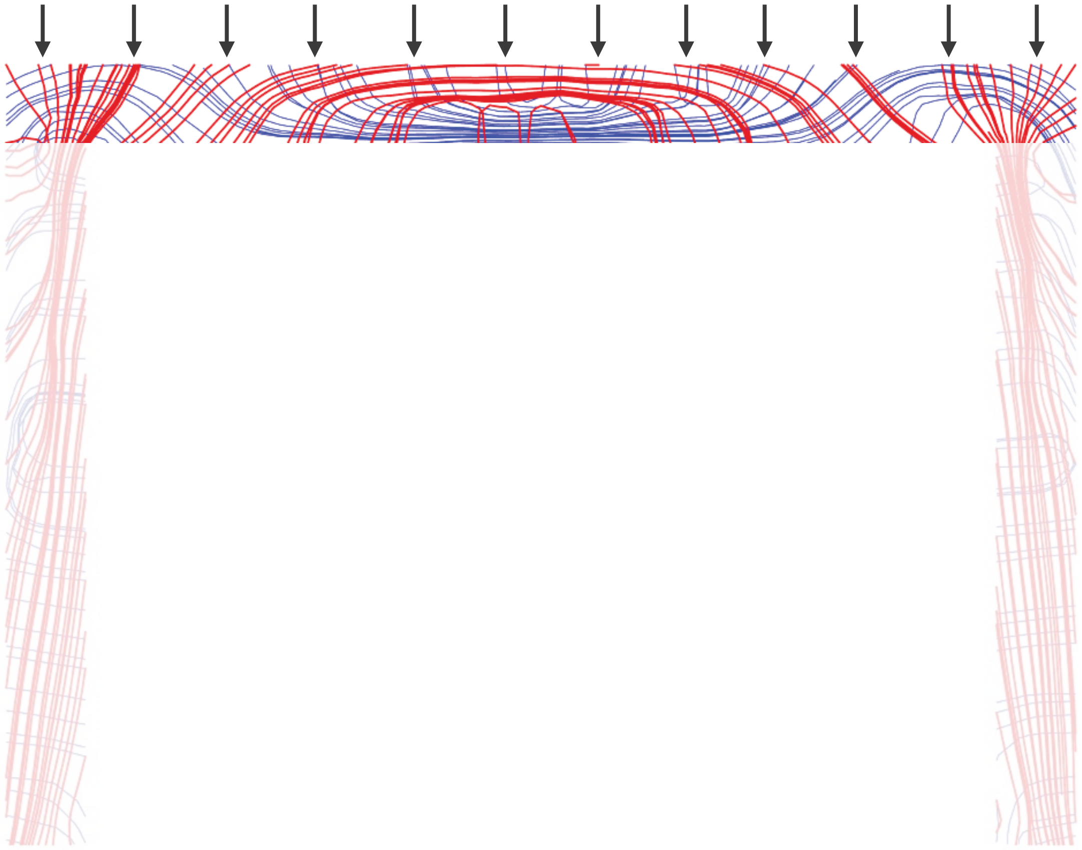
Placement of pieces with optimisation

Front view of horizontal member

Strength classes of timber



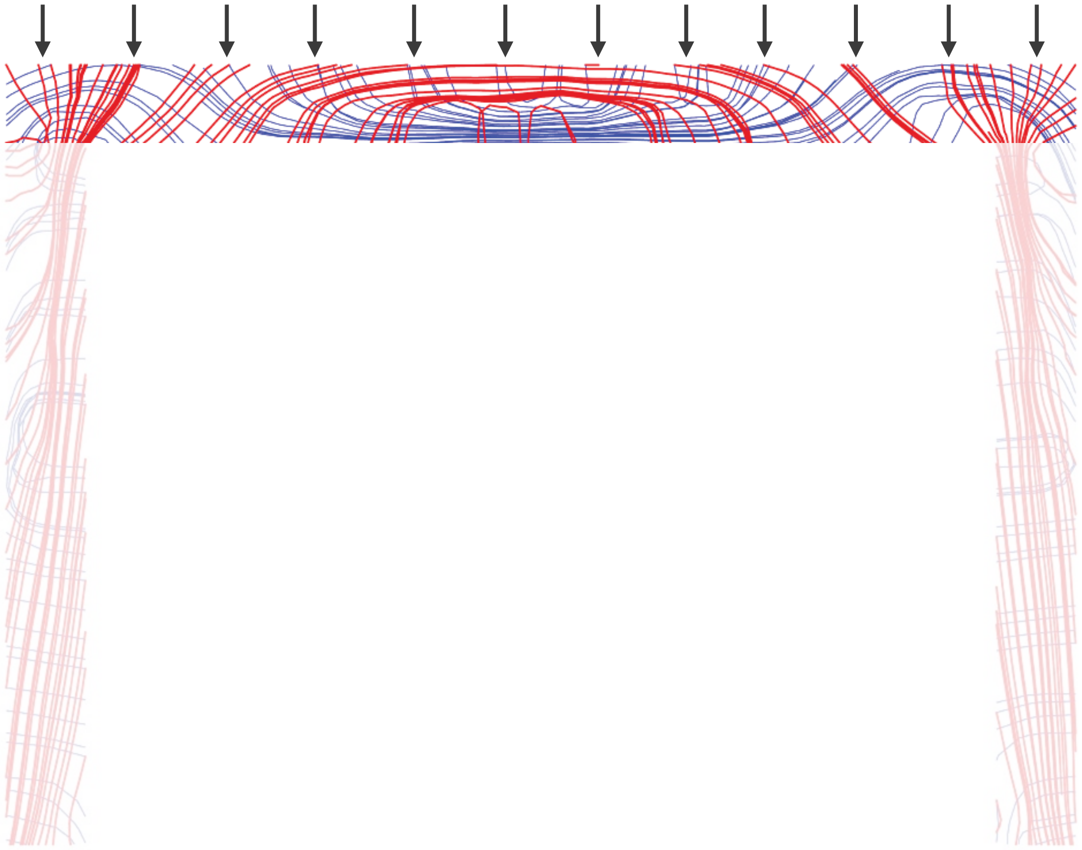
Principal stress-lines



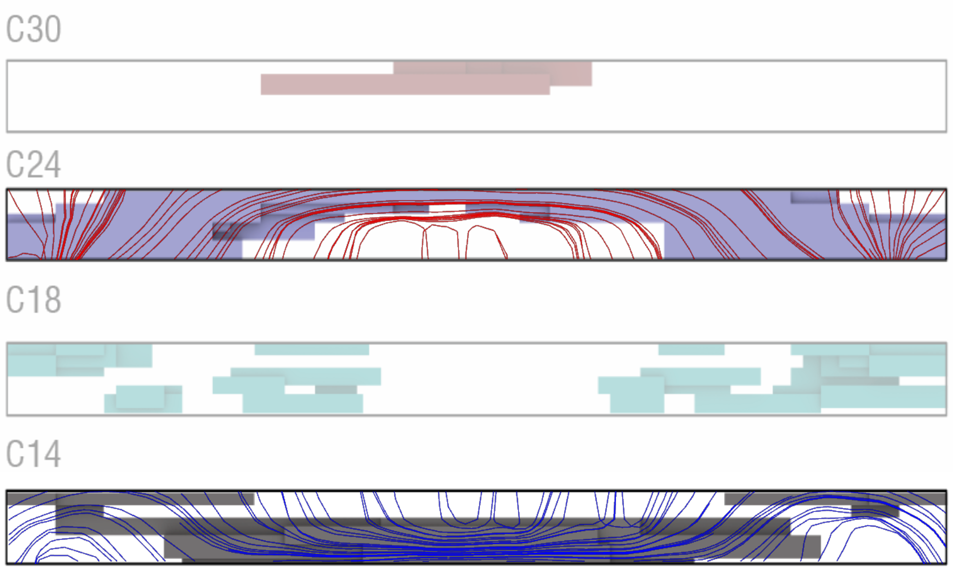
Placement of pieces with optimisation

Front view of horizontal member

Principal stress-lines

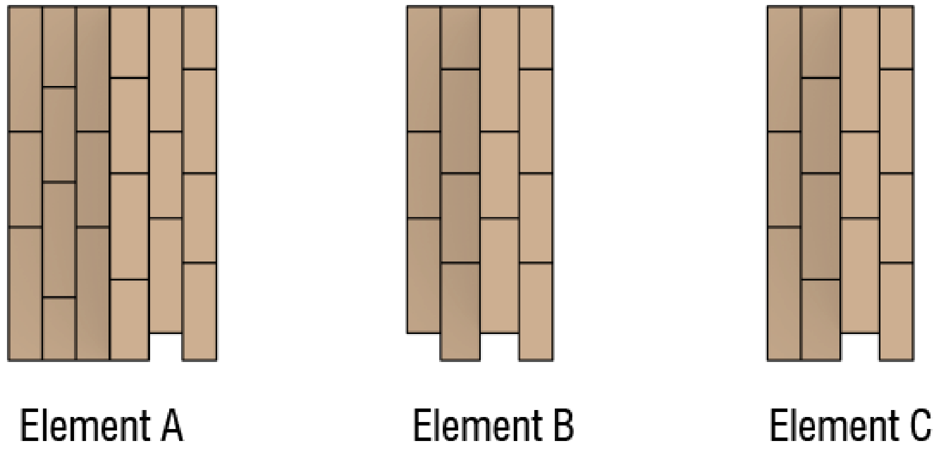


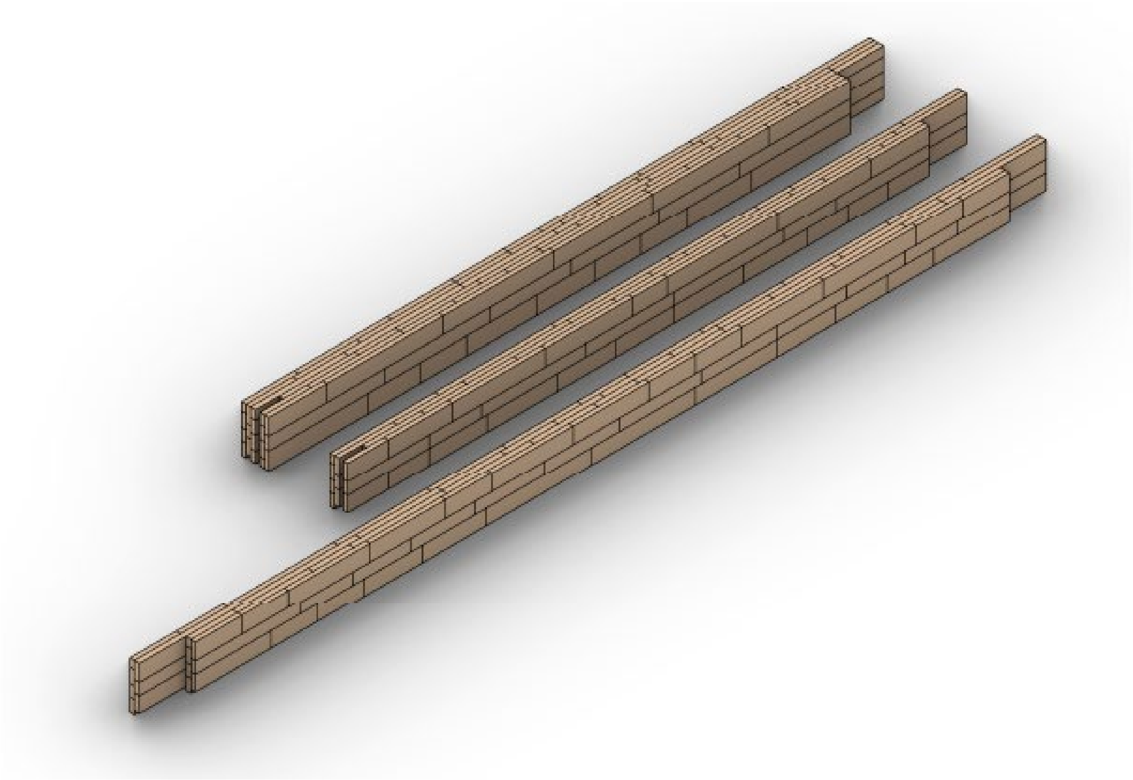
Strength classes of timber

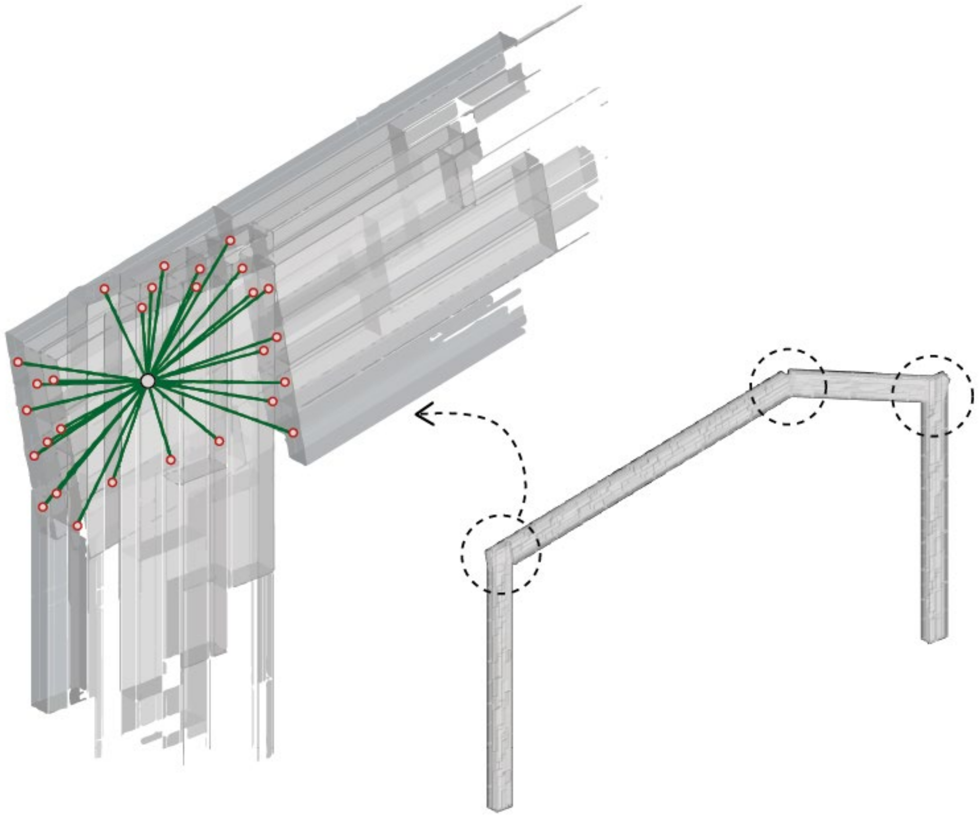


21% gain in strength
34% gain in stiffness

Aggregated elements



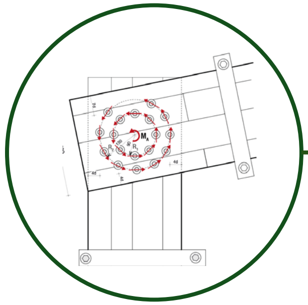




Moment connection in structural model

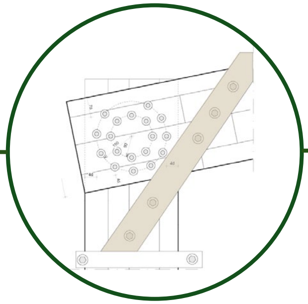
Connection alternatives

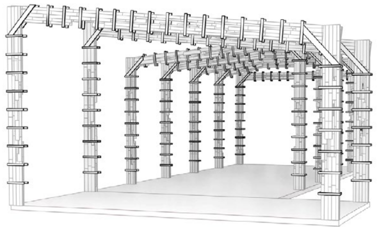
Bolted connection



Insufficient rotational stiffness

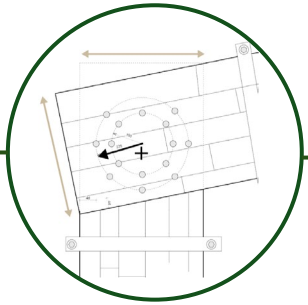
Diagonal plywood stiffeners





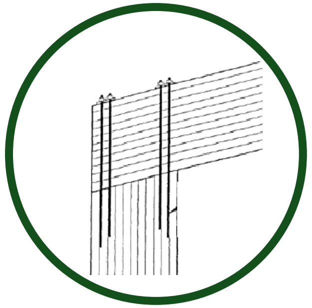
Architecturally invasive

Enlarging section

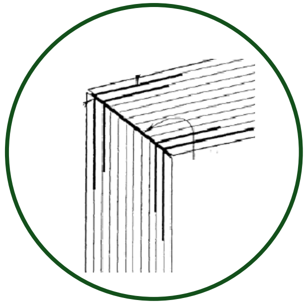


High material consumption

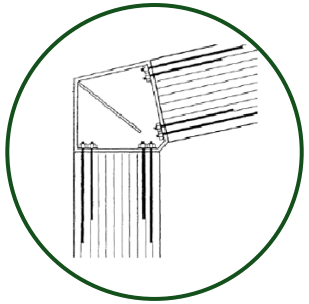
Steel connections



Treaded steel rods, vertically inserted



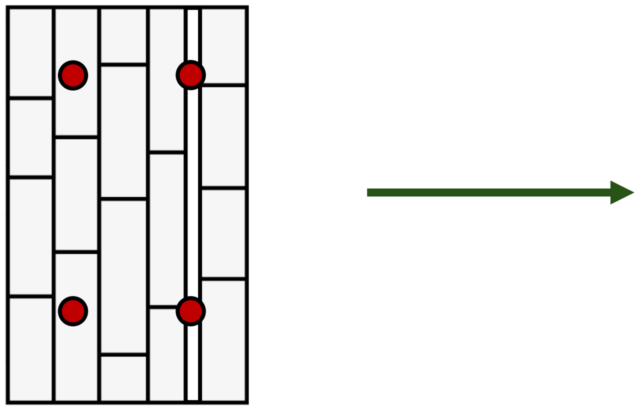
Treaded steel rods, inserted in two directions

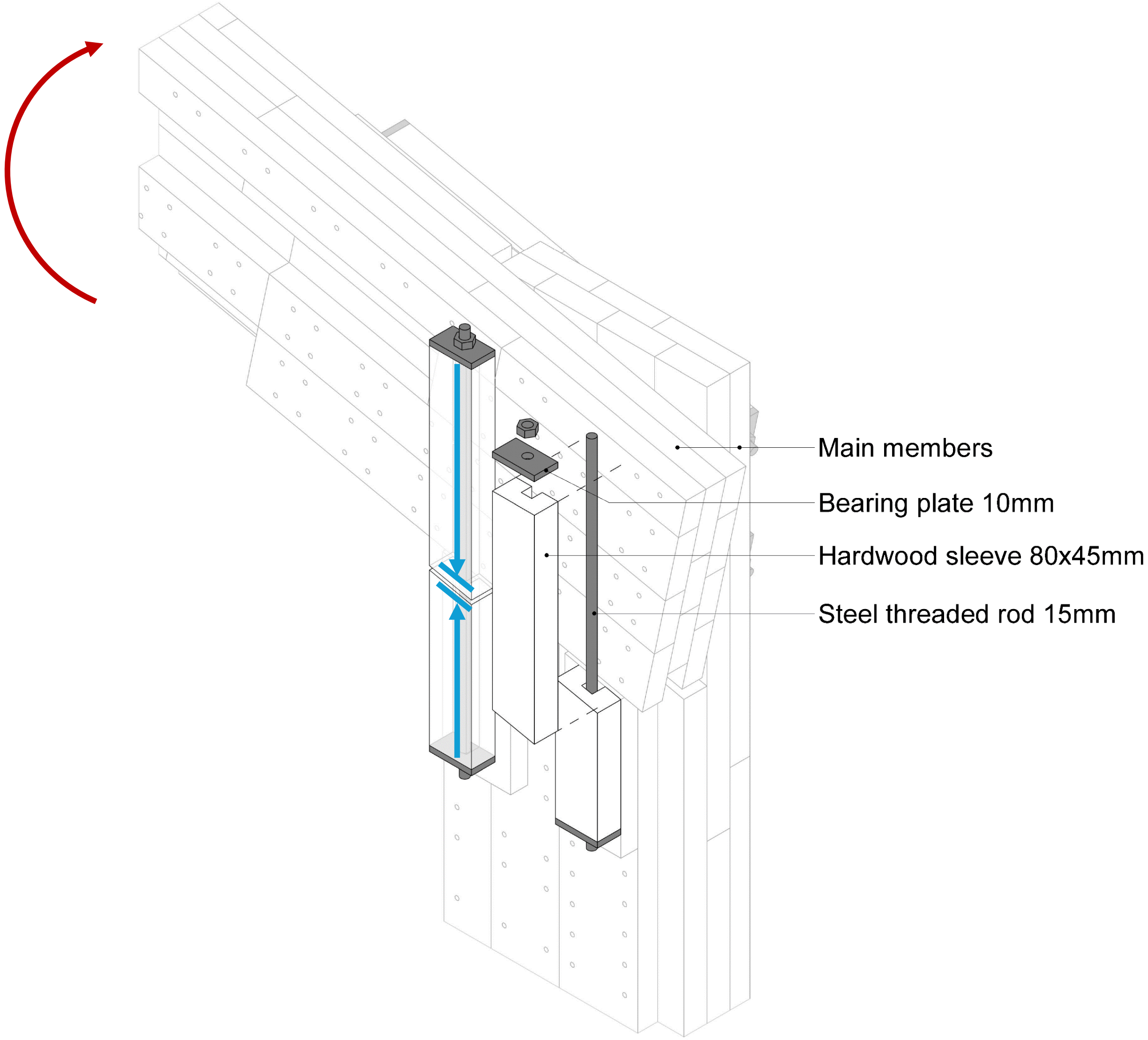


Steel bracket

Chosen connection

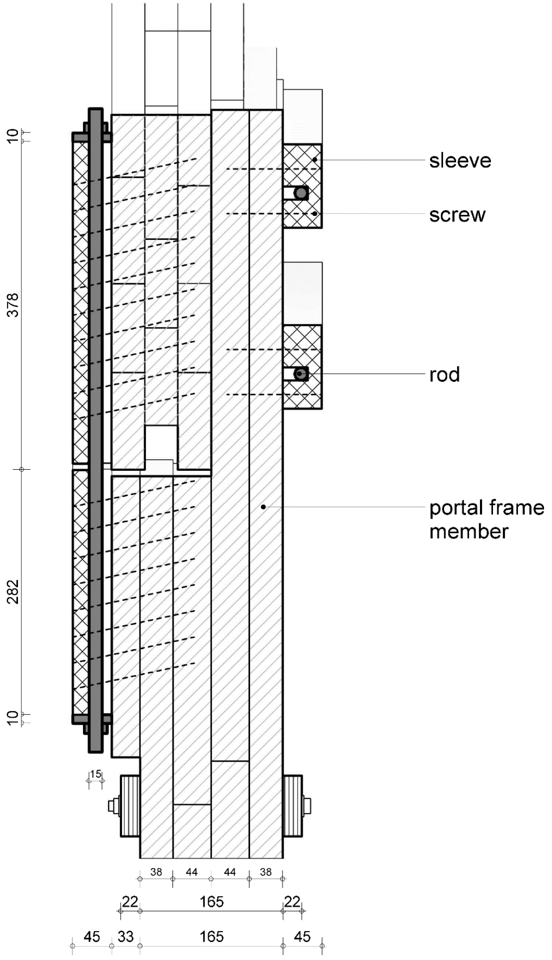
Splicing of parts

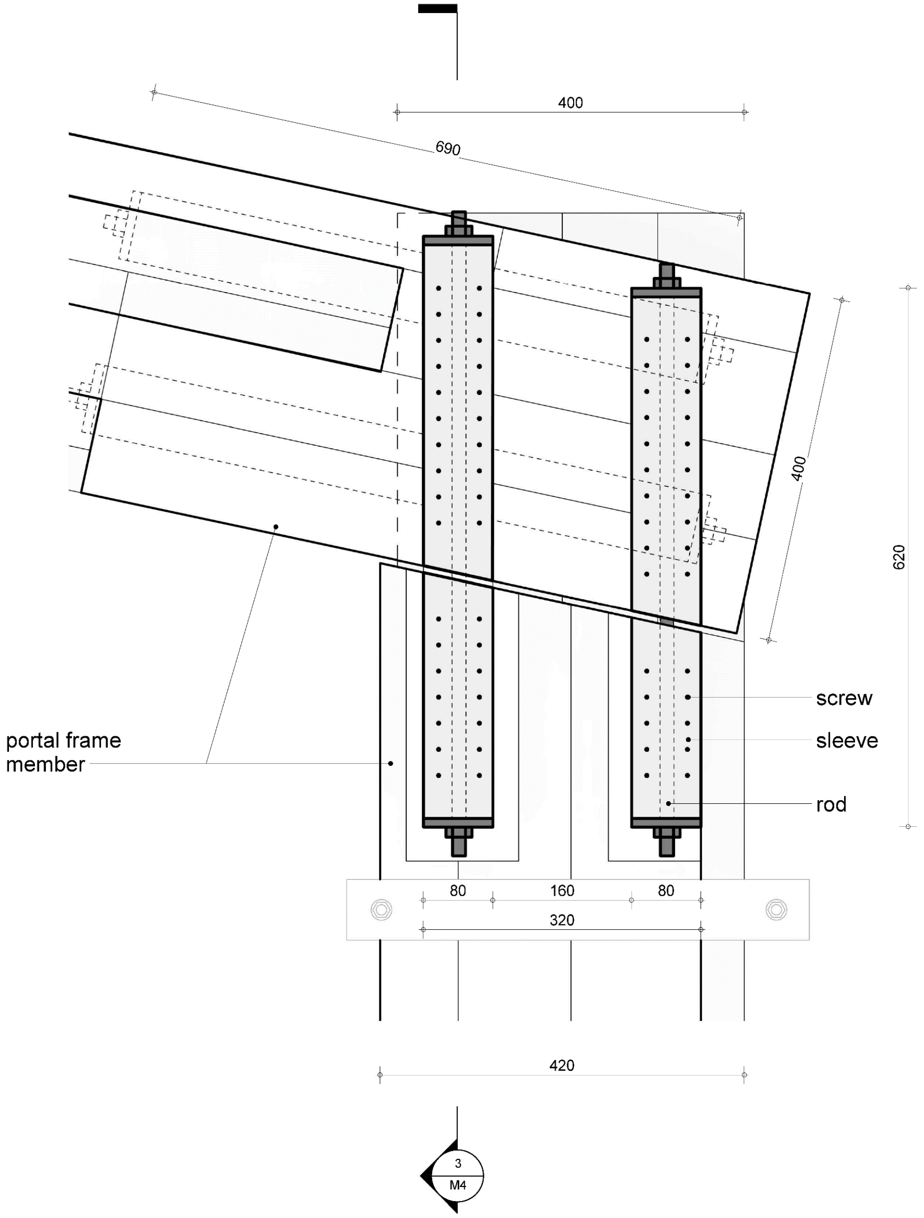




Final moment connection

Section and front view

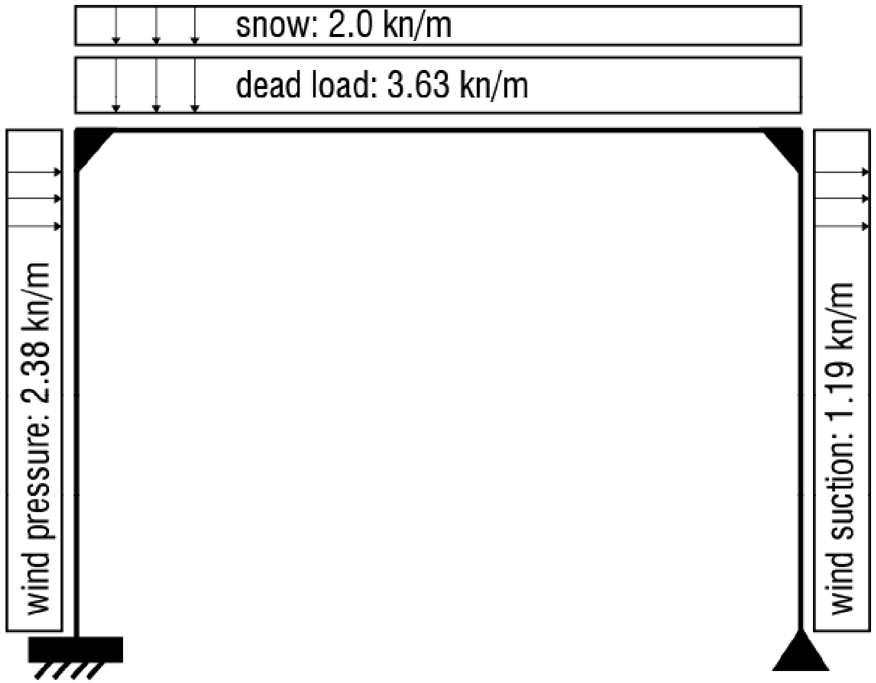


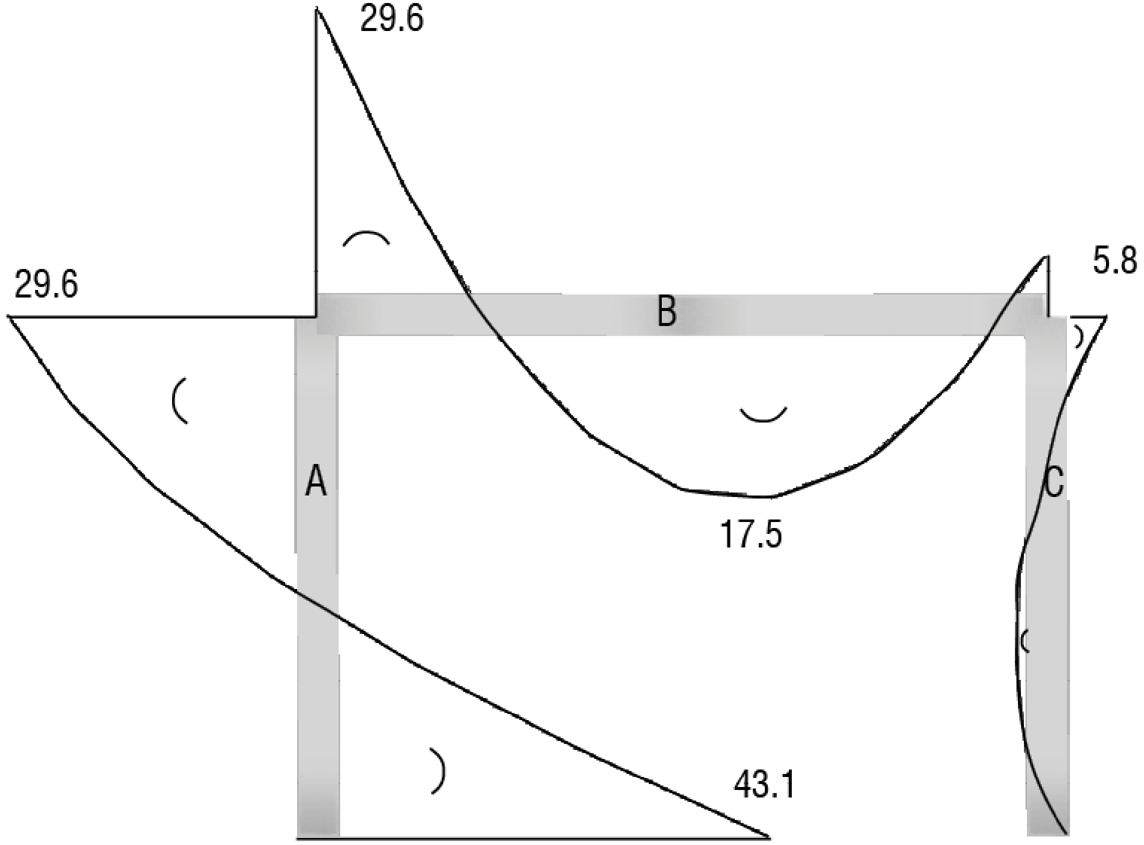


Algorithmic performance

Test set-up

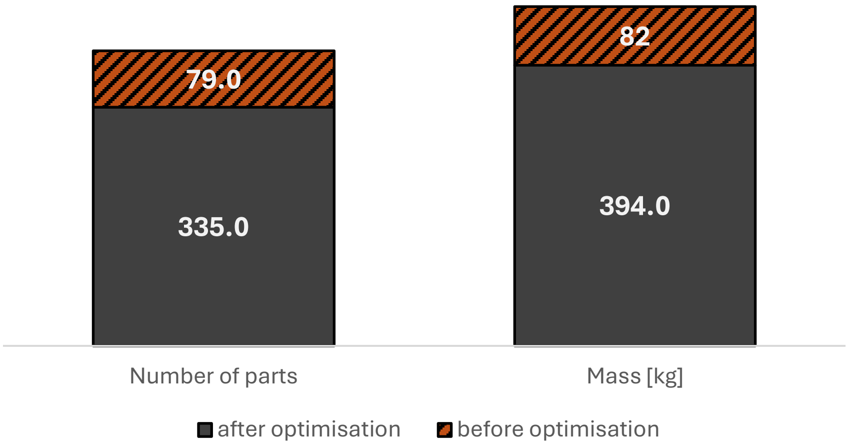
Front view



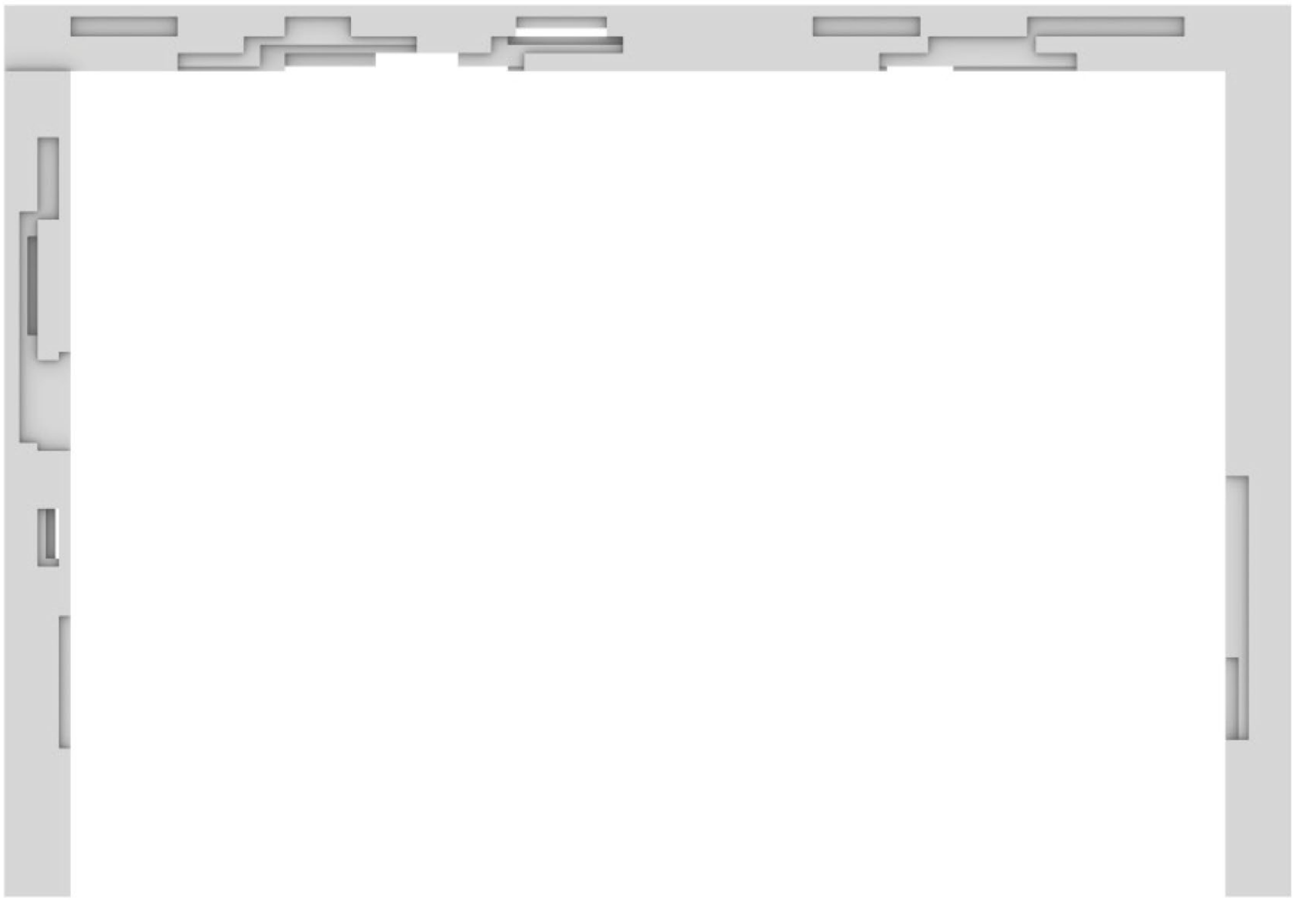


Varying composition

Front view



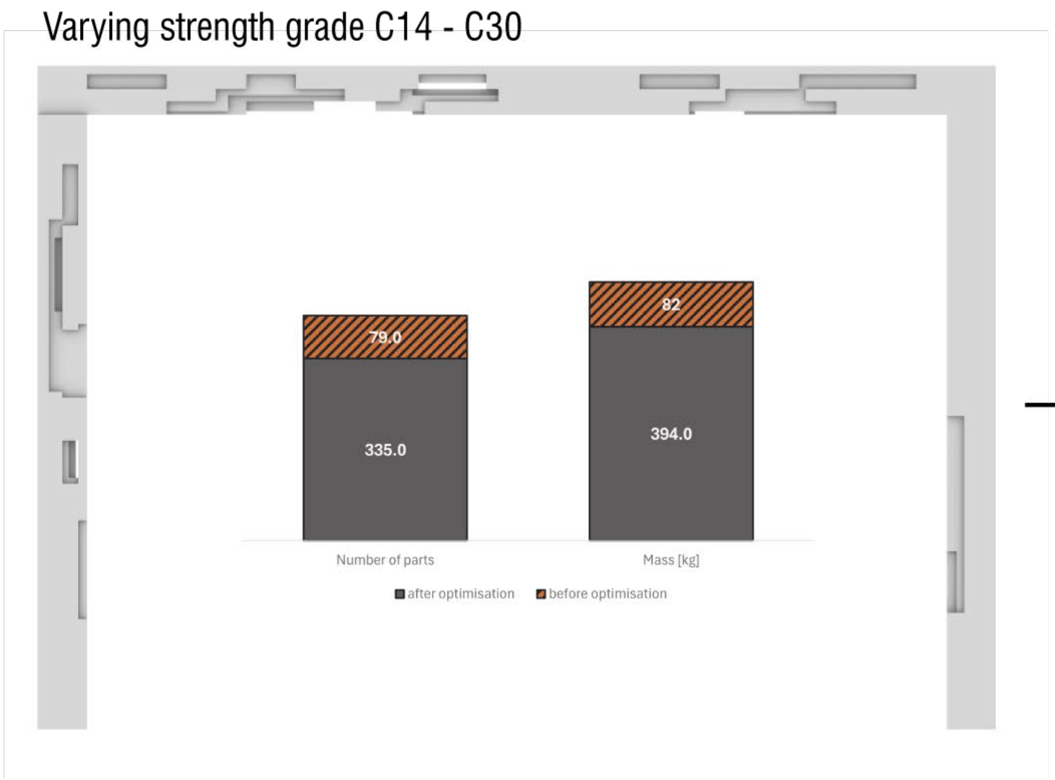
Strength grade	Used parts				
	Element A	Element B	Element C	total	percentage
C14	41	59	27	**127**	*31%*
C18	36	36	26	**98**	*24%*
C24	54	61	43	**158**	*38%*
C30	17	9	5	**31**	*7%*
total	**148**	**165**	**101**	**414**	*100%*

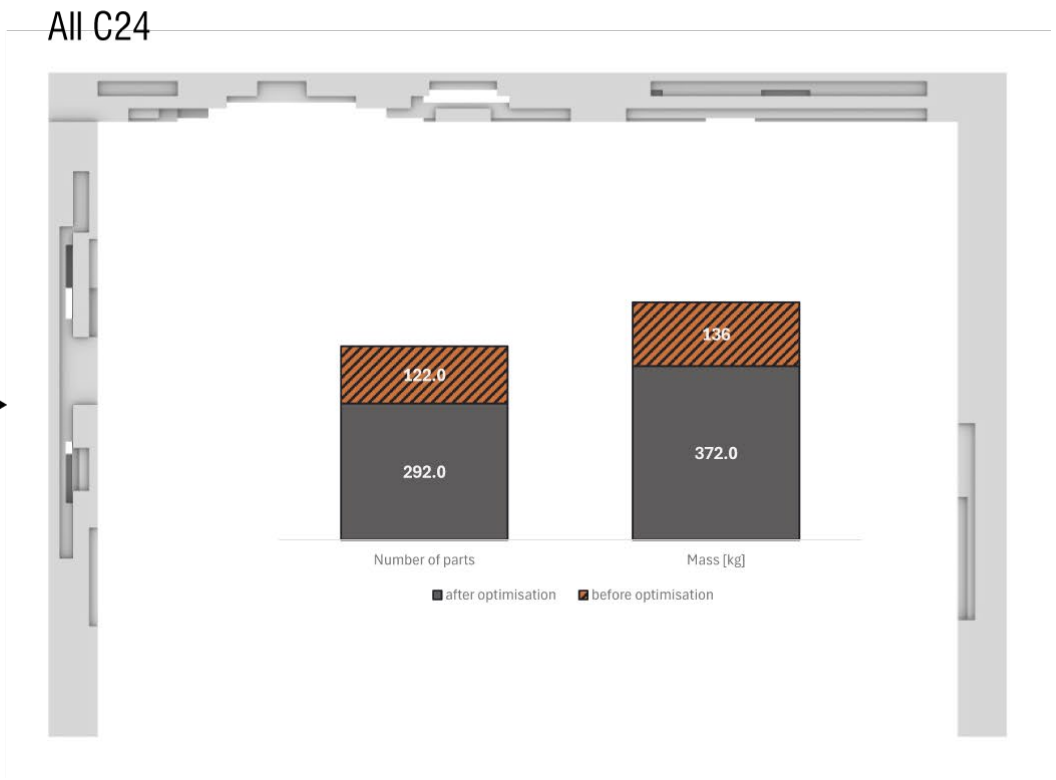


Global optimum: mass reduction of +/- 20%

Strength grade influence

Front view

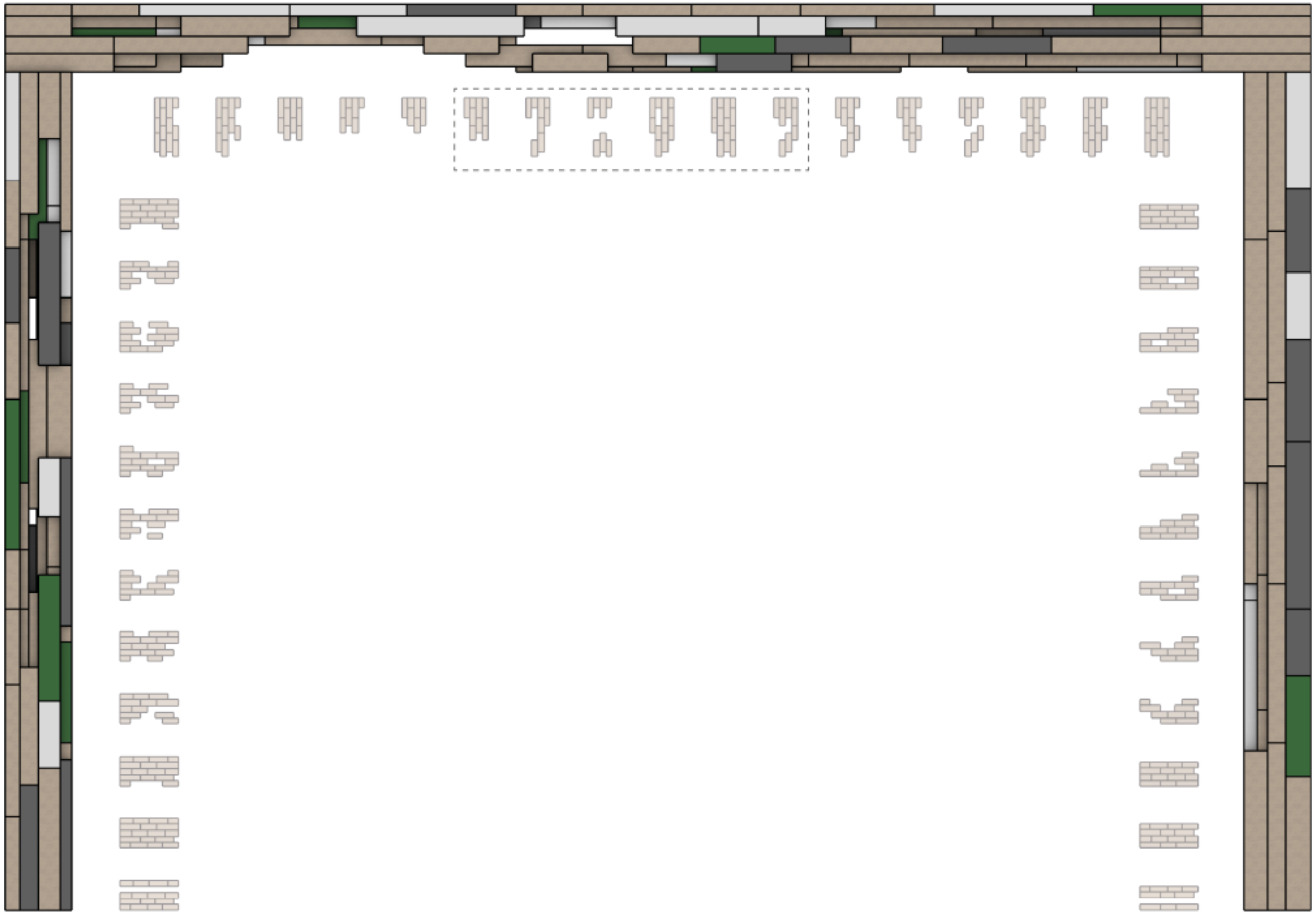




Global optimum: mass reduction of +/- 30%

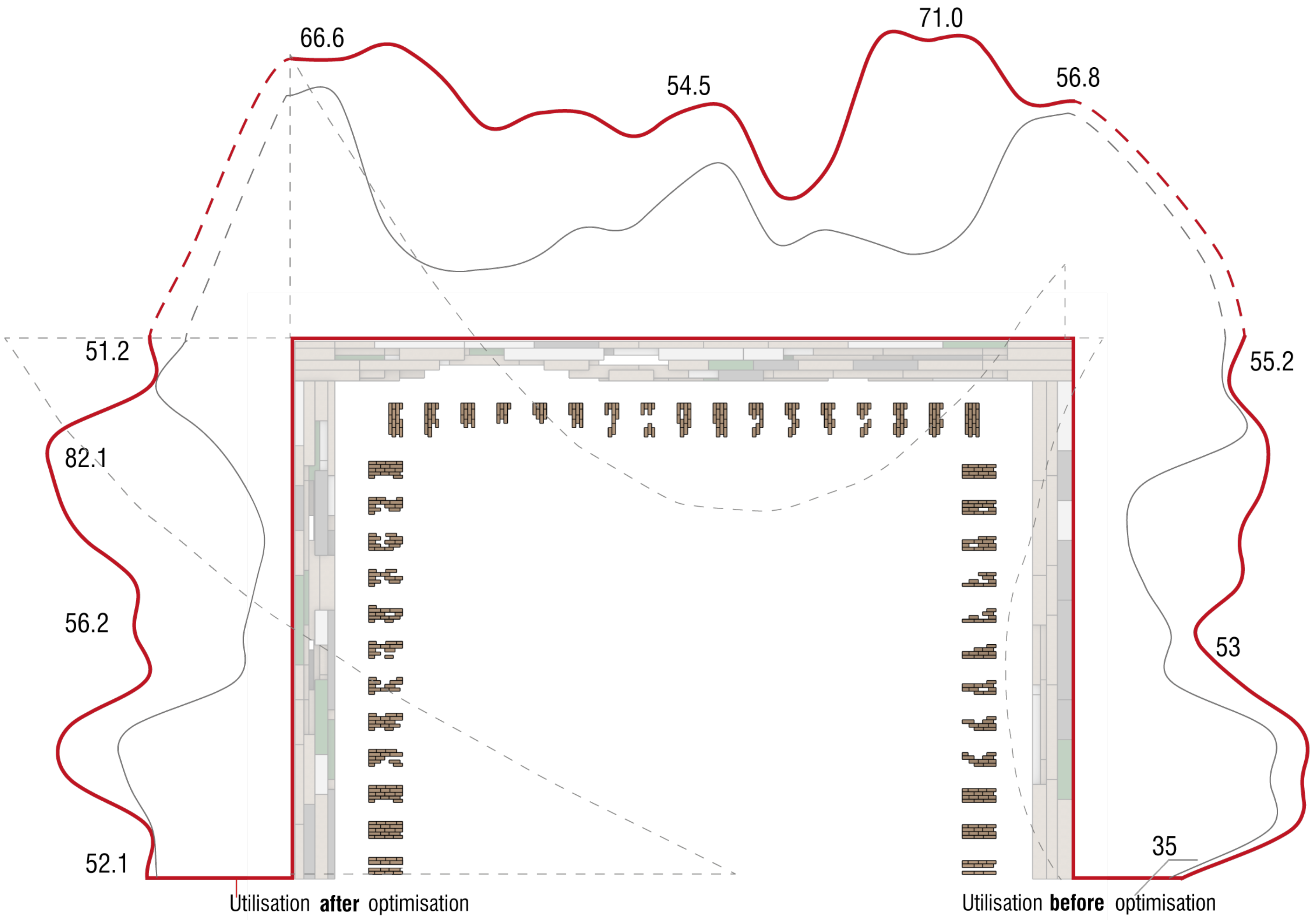
Final aggregated portal frame

Front view



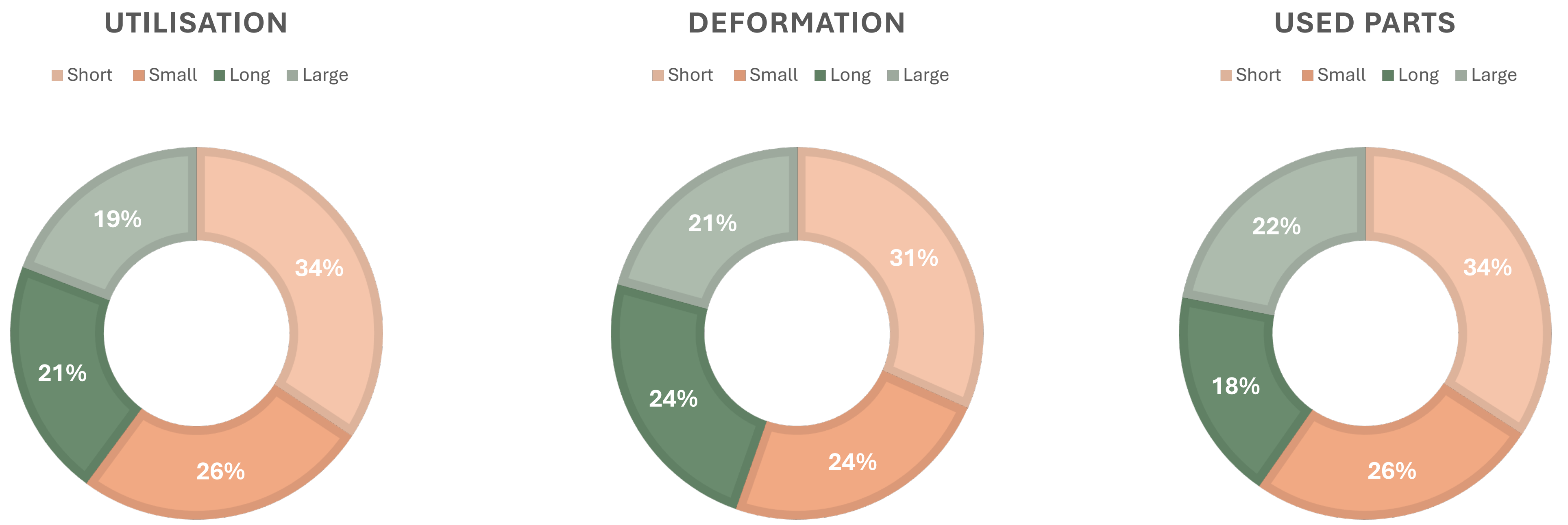
Utilisation improvement

Front view



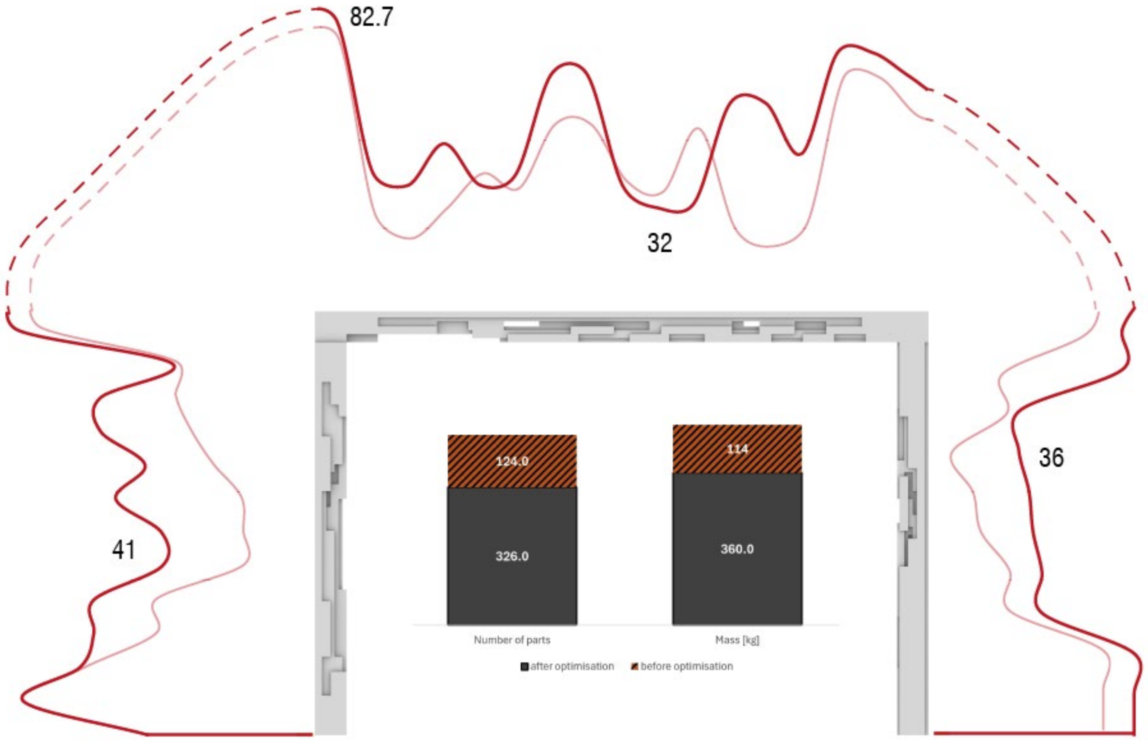
Stock dimensions initial influence

Effect of short, small, long and large pieces

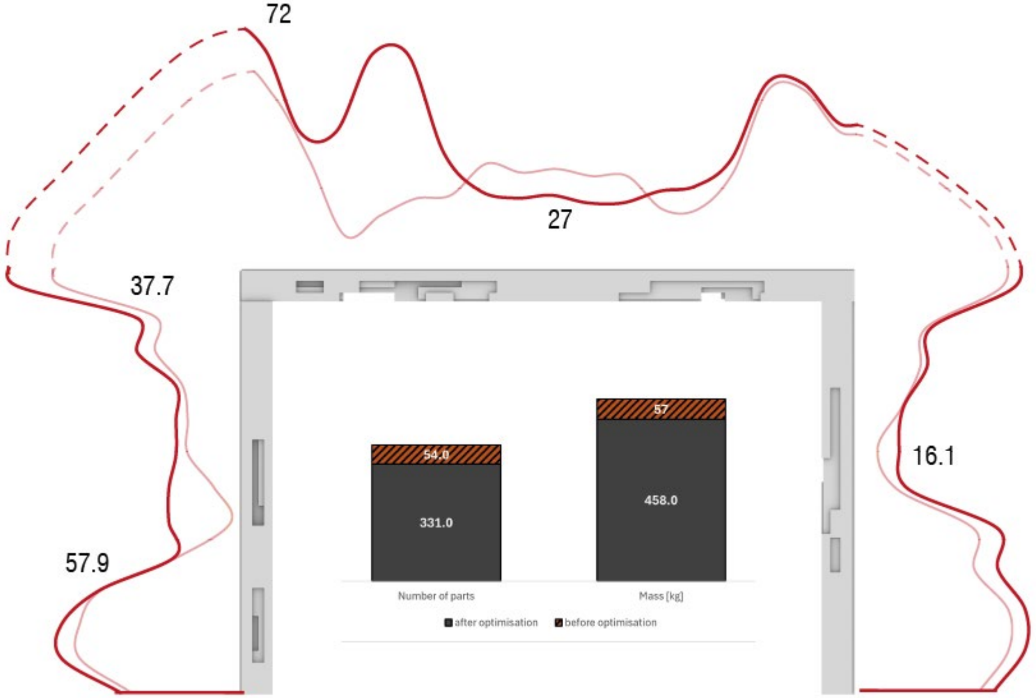


Stock dimensions influence on optimisation

Front view



Only short and small parts

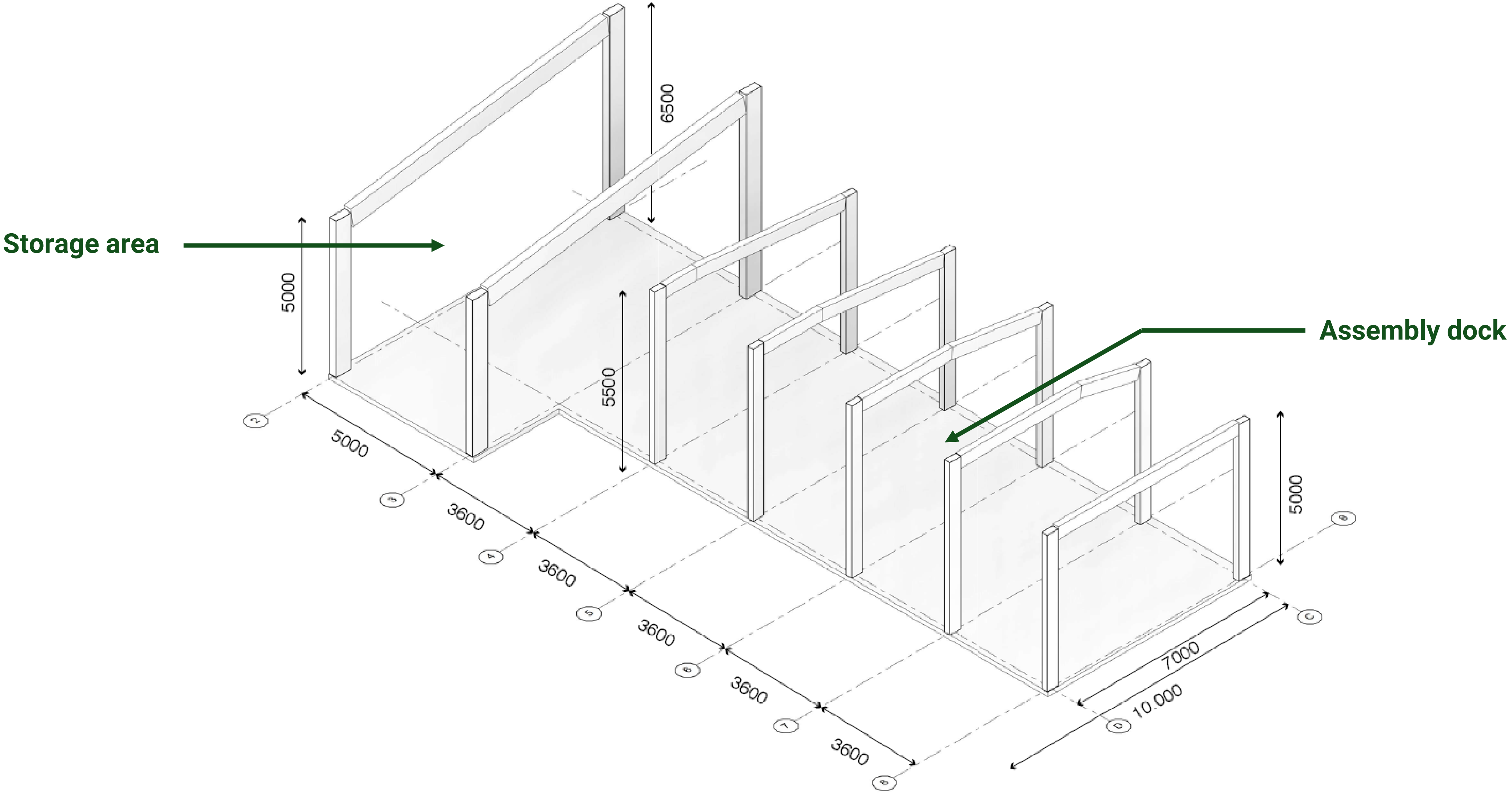


Only long and large parts

Design implementation

Design implementation

Remanufacturing facility

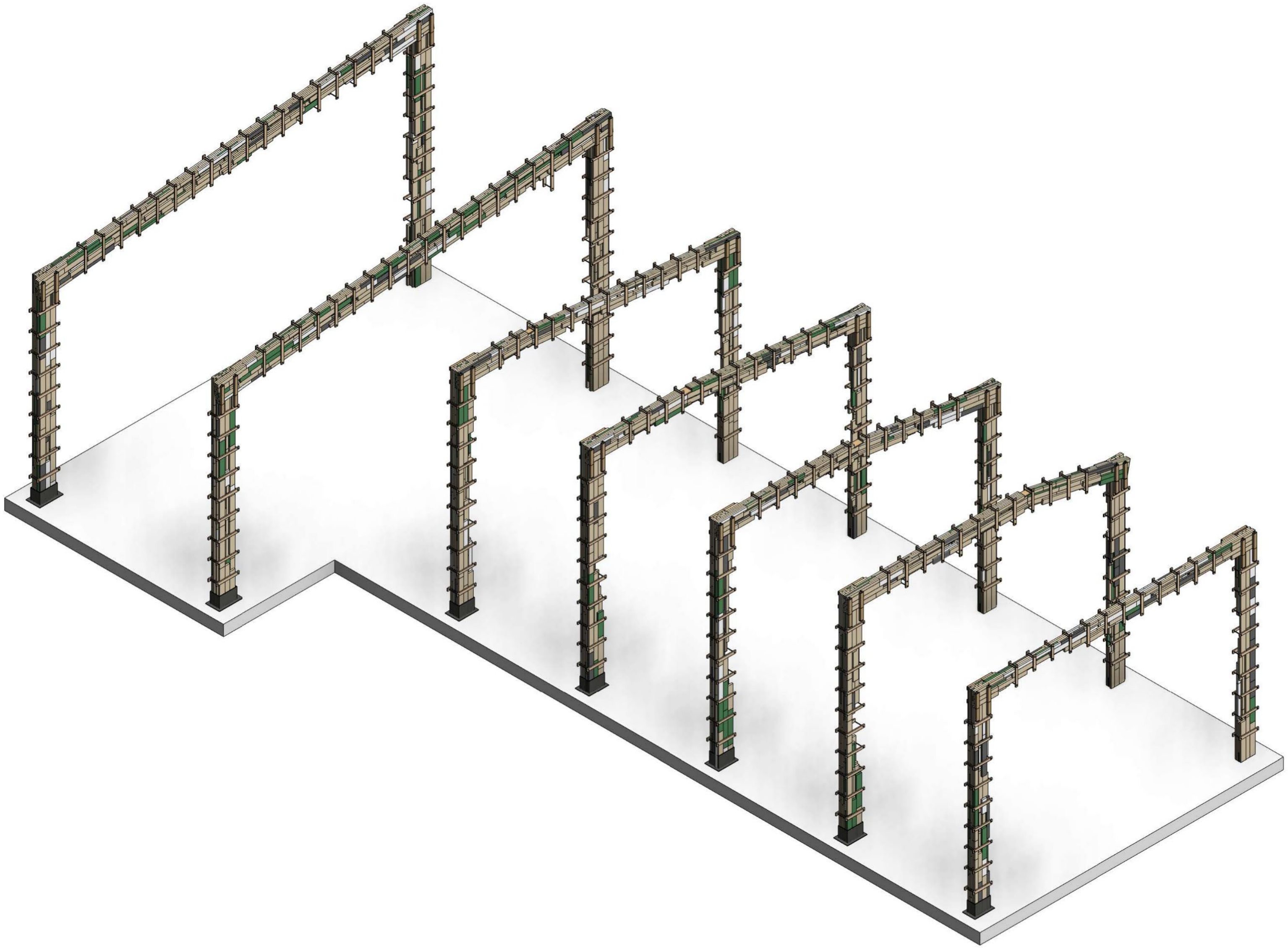


Generated portals

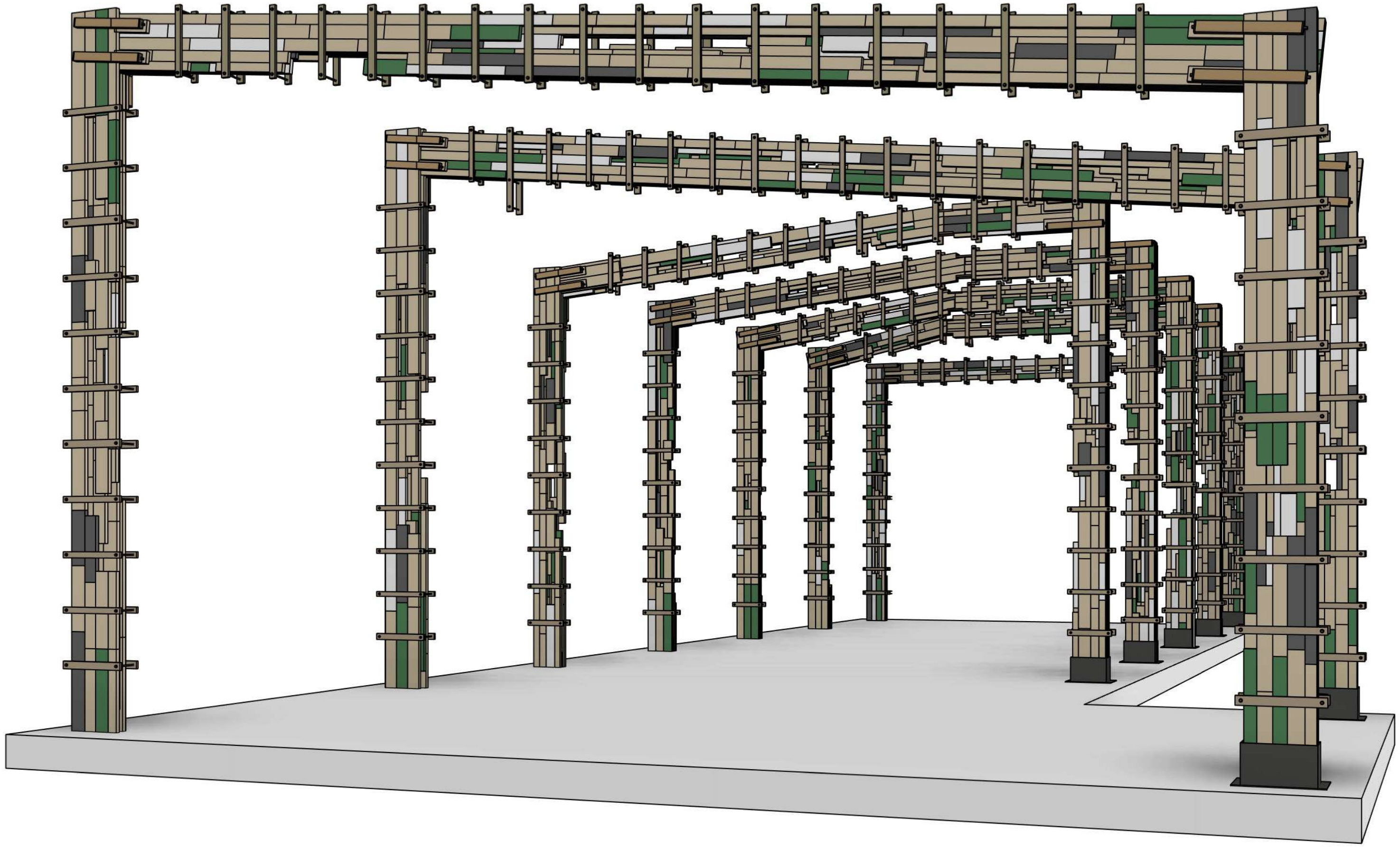
Used parts: 2.891
Reused wood: 3.220 kg = 

Optimisation results

Integration structural design and algorithmic results



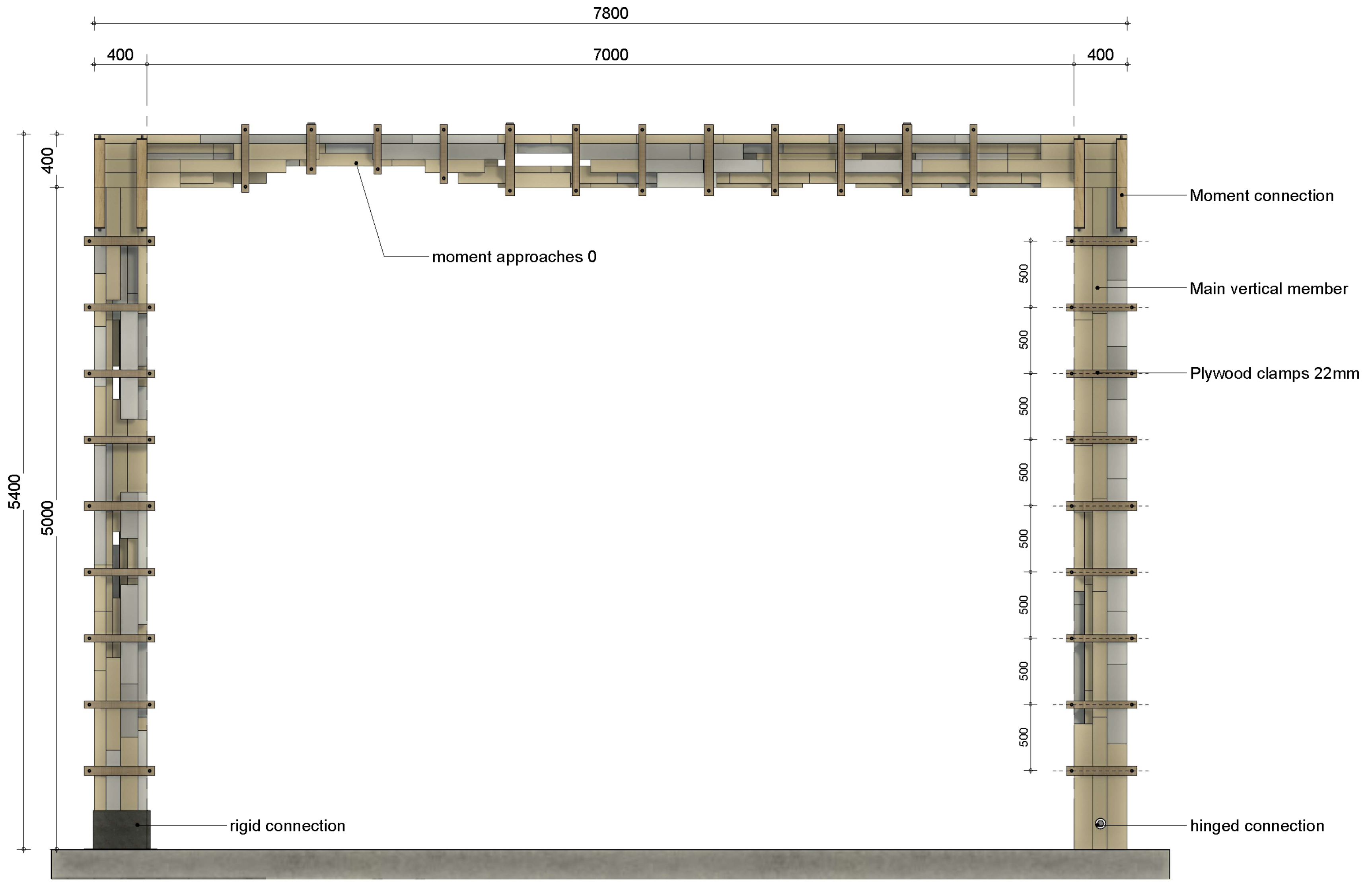
Detailed views



2D front view of portal frame (tested composition)

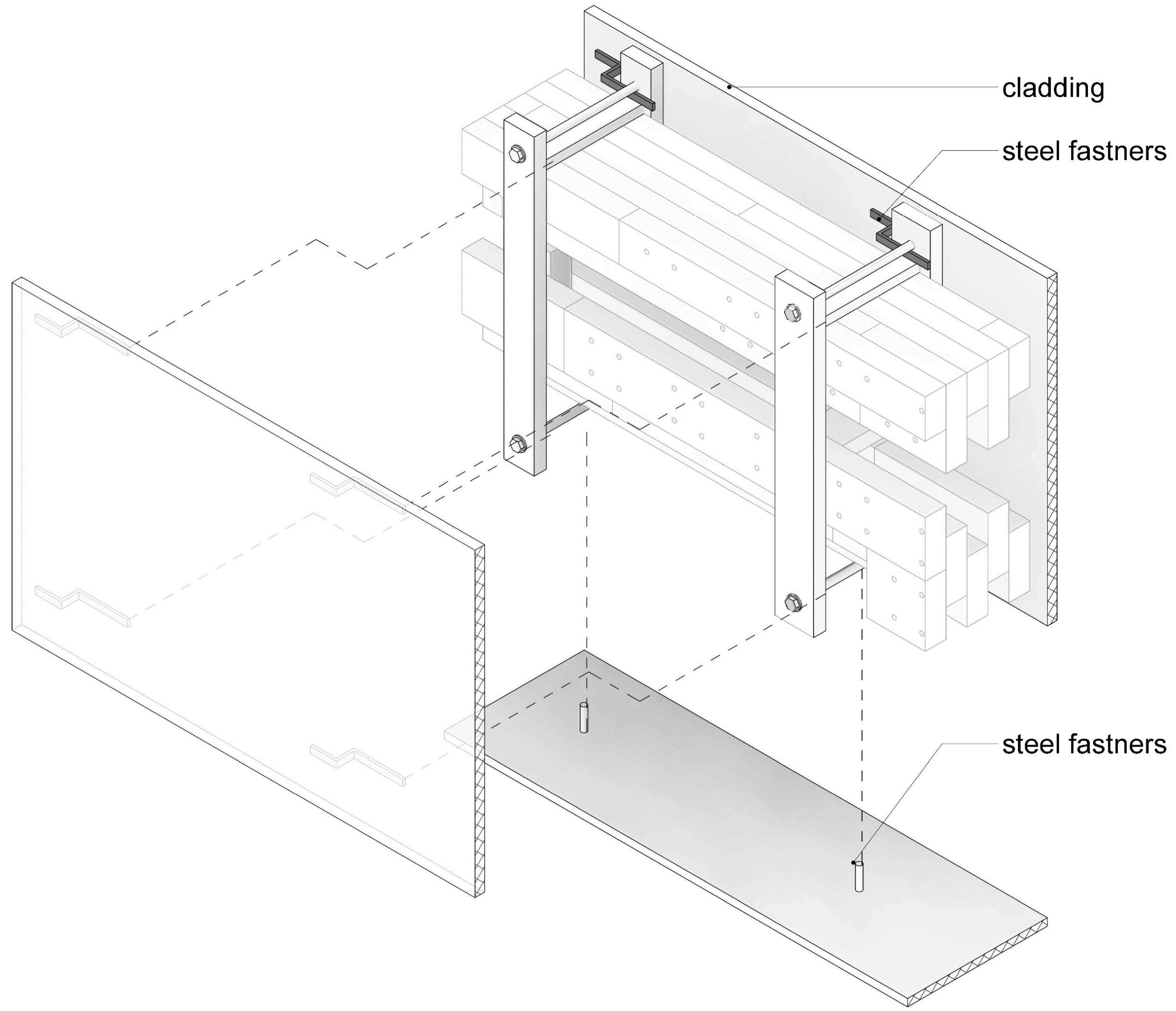
Dimensions: 160x400mm
Total links: 30
Distance: 500mm

Final mass: 410kg

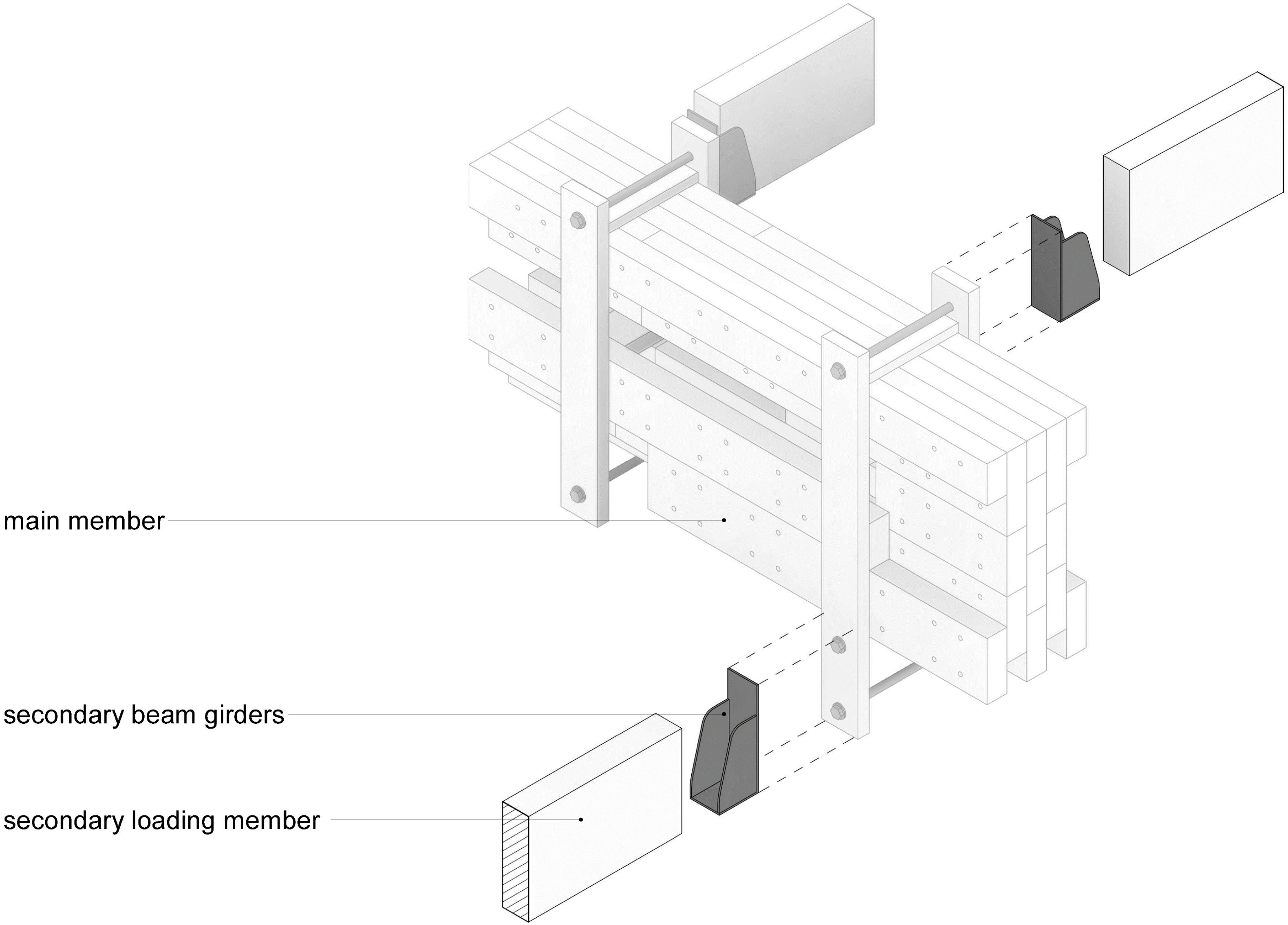


Mass of a glulam structure with similar utilisation: 437kg

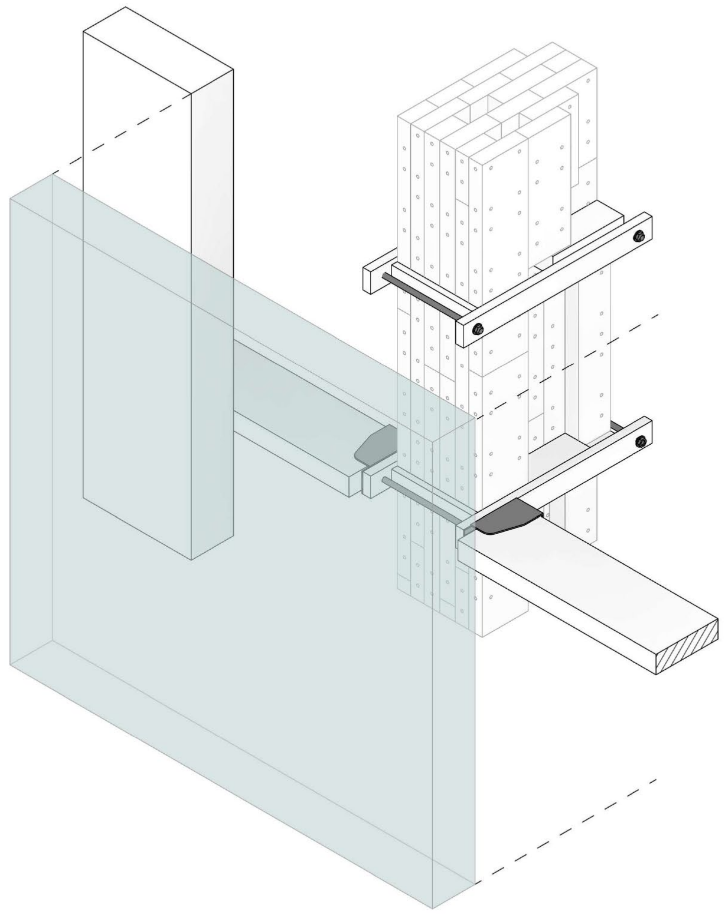
Potential extension of usage for the links



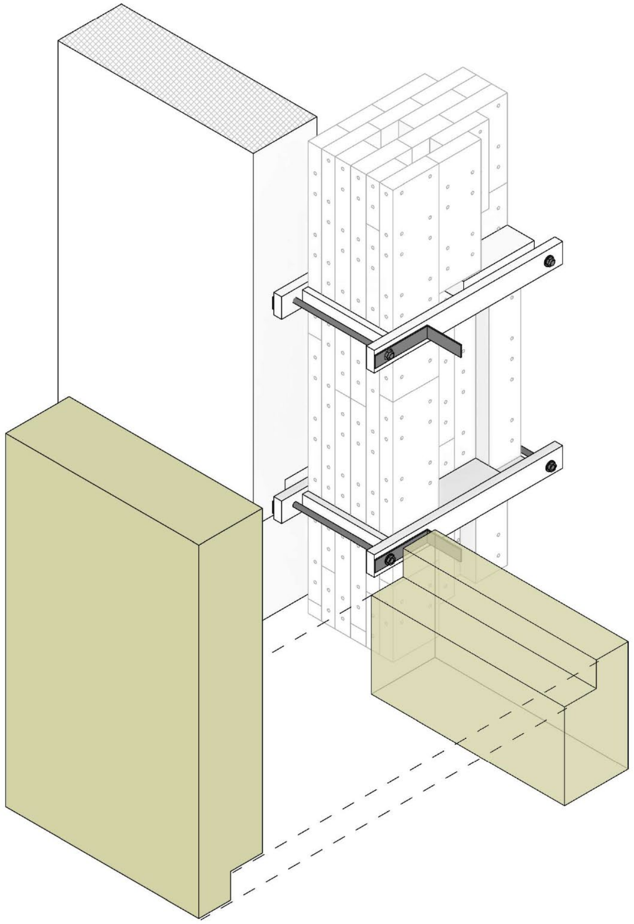
Potential extension of usage for the links



Vertical local connection

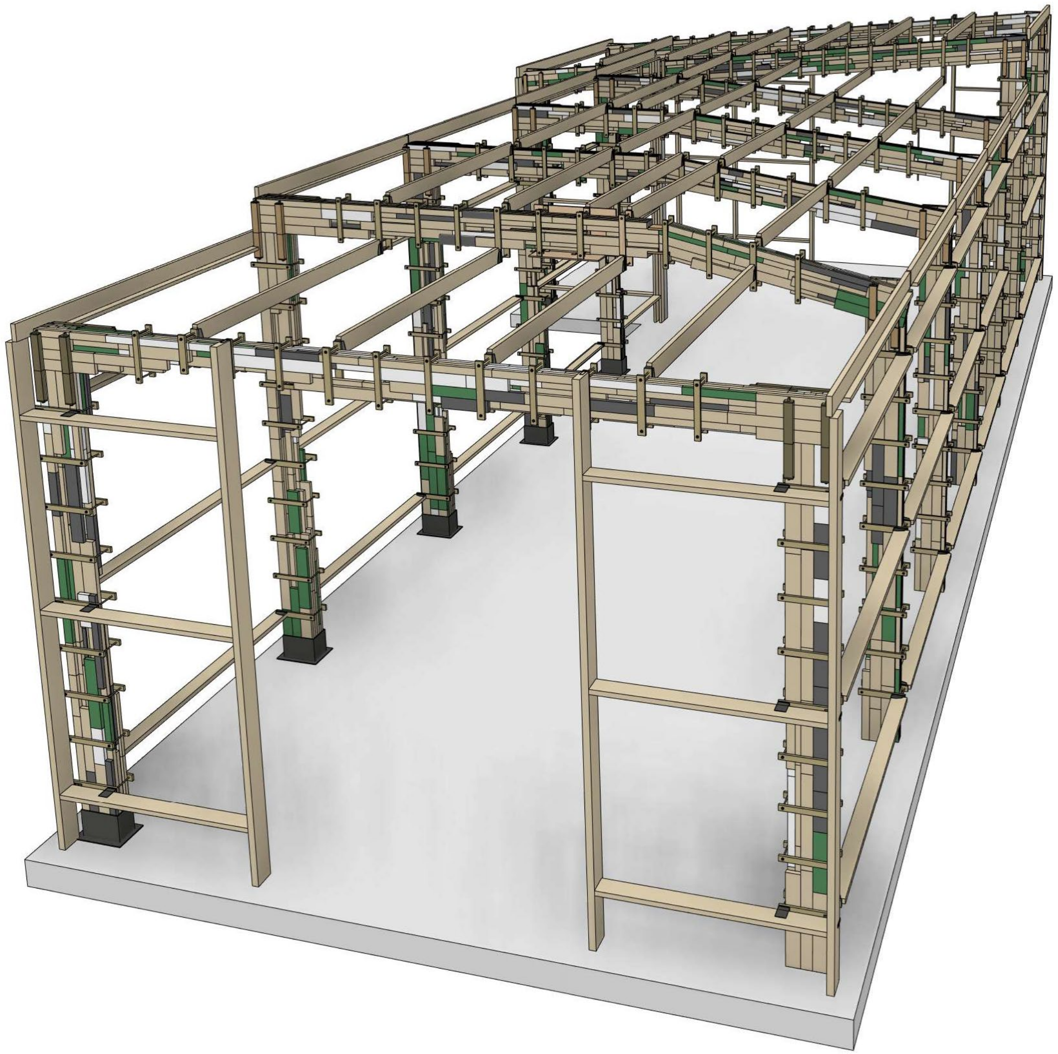


Secondary structure



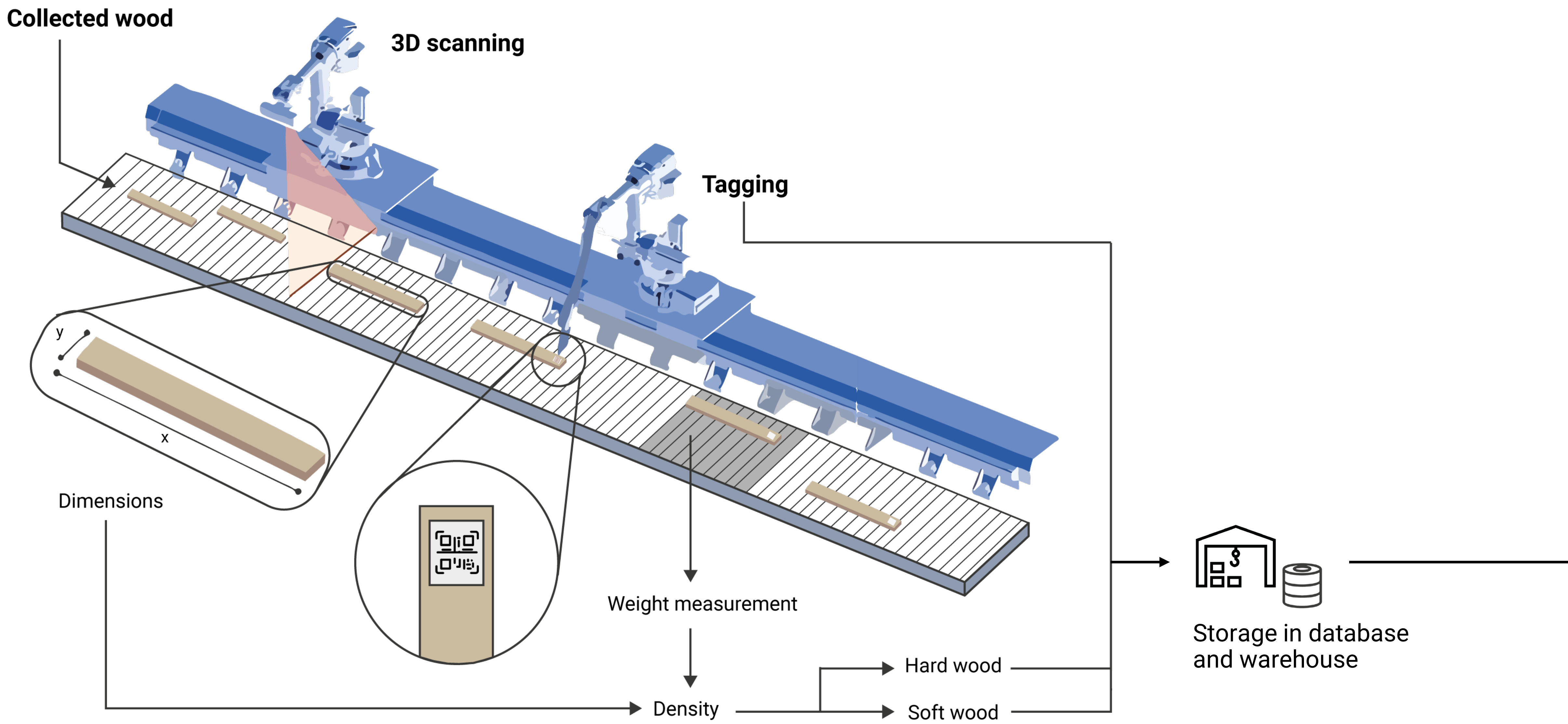
Self-supporting elements

3D view of secondary structure



Potential building process

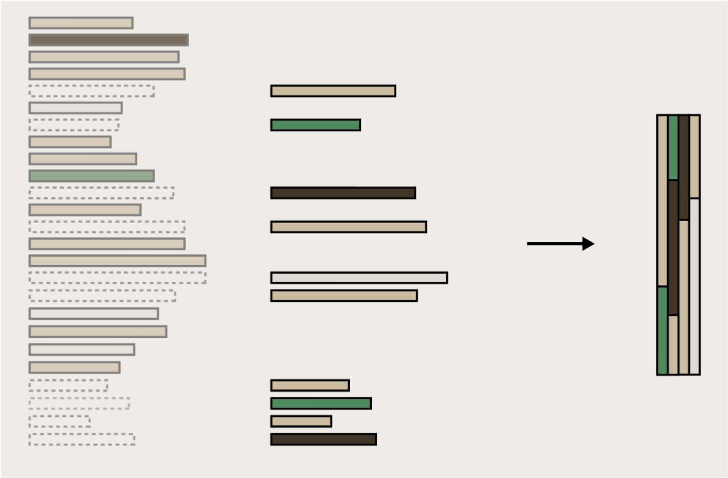
Processing facility



(Adapted from, HvA Urban Technology, 2024)

Potential building process

Design and order pieces

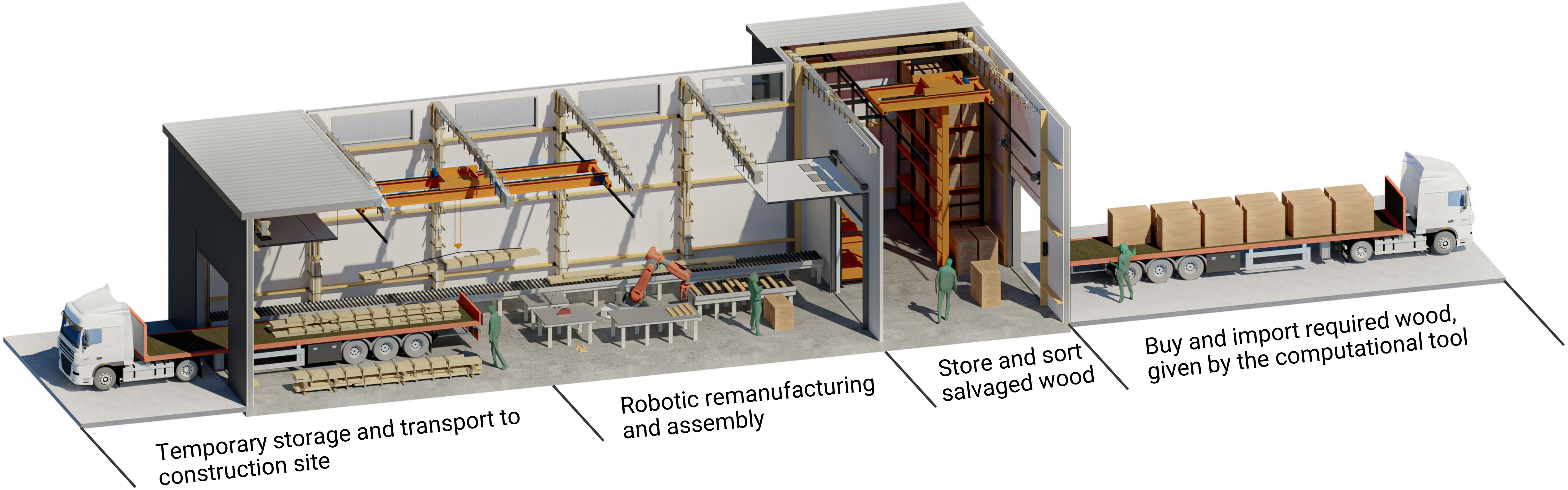


Connect database to computational tool and match pieces in a design domain

Buy selected pieces and transport to remanufacturing facility

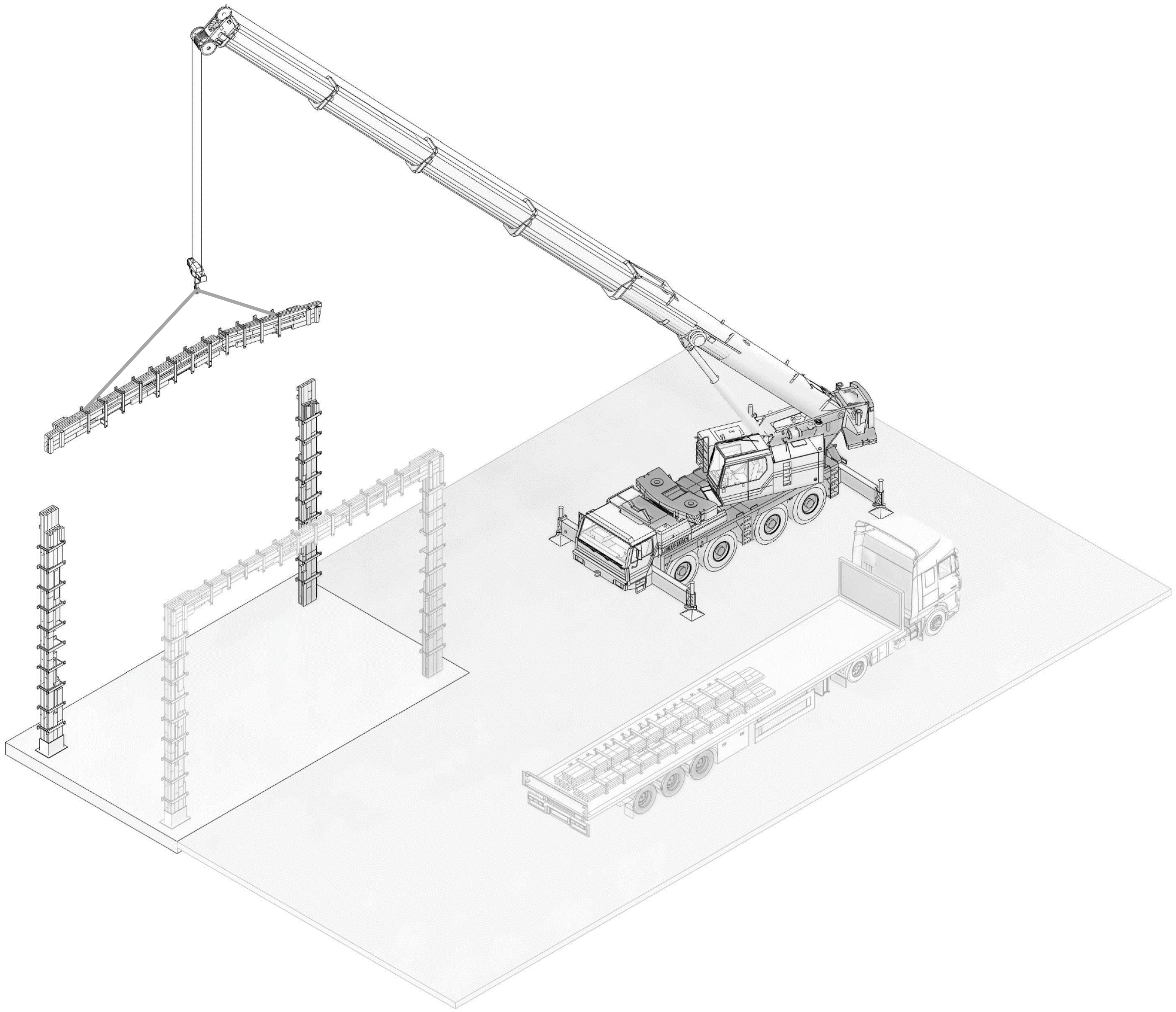
Potential building process

Remanufacturing facility



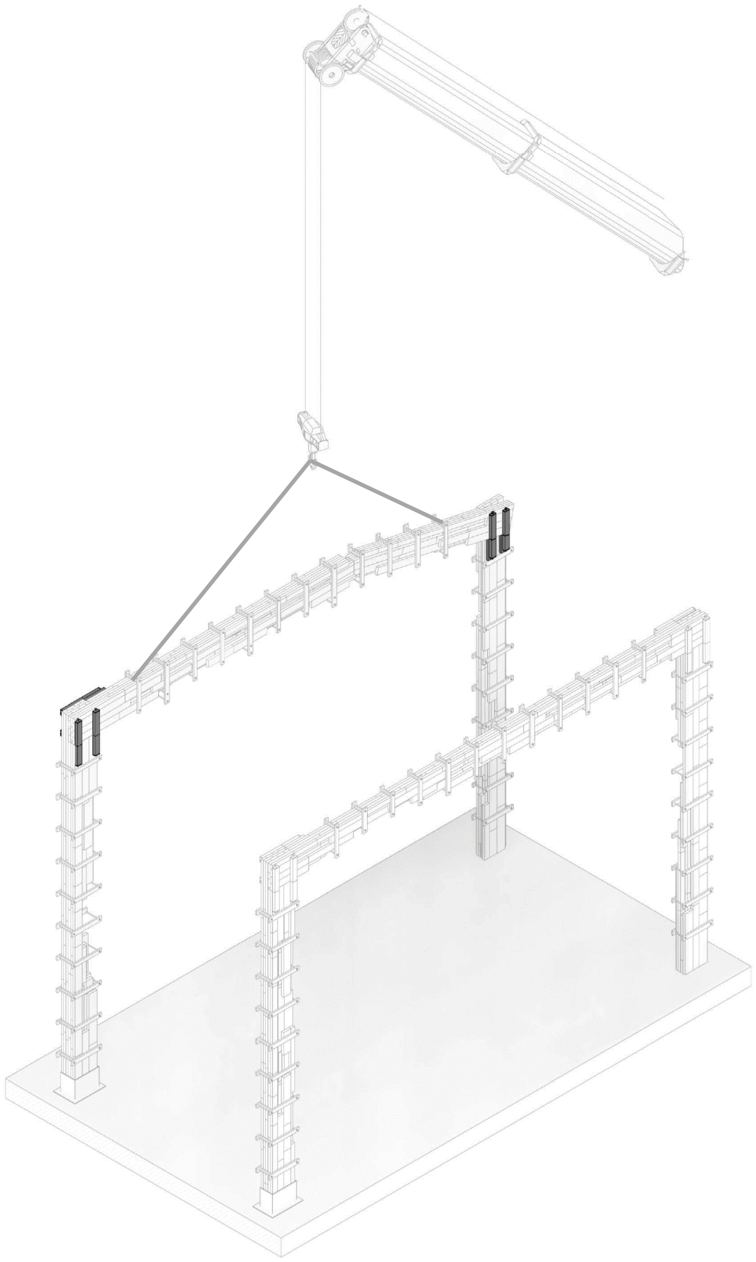
Potential building process

Lift parts in place



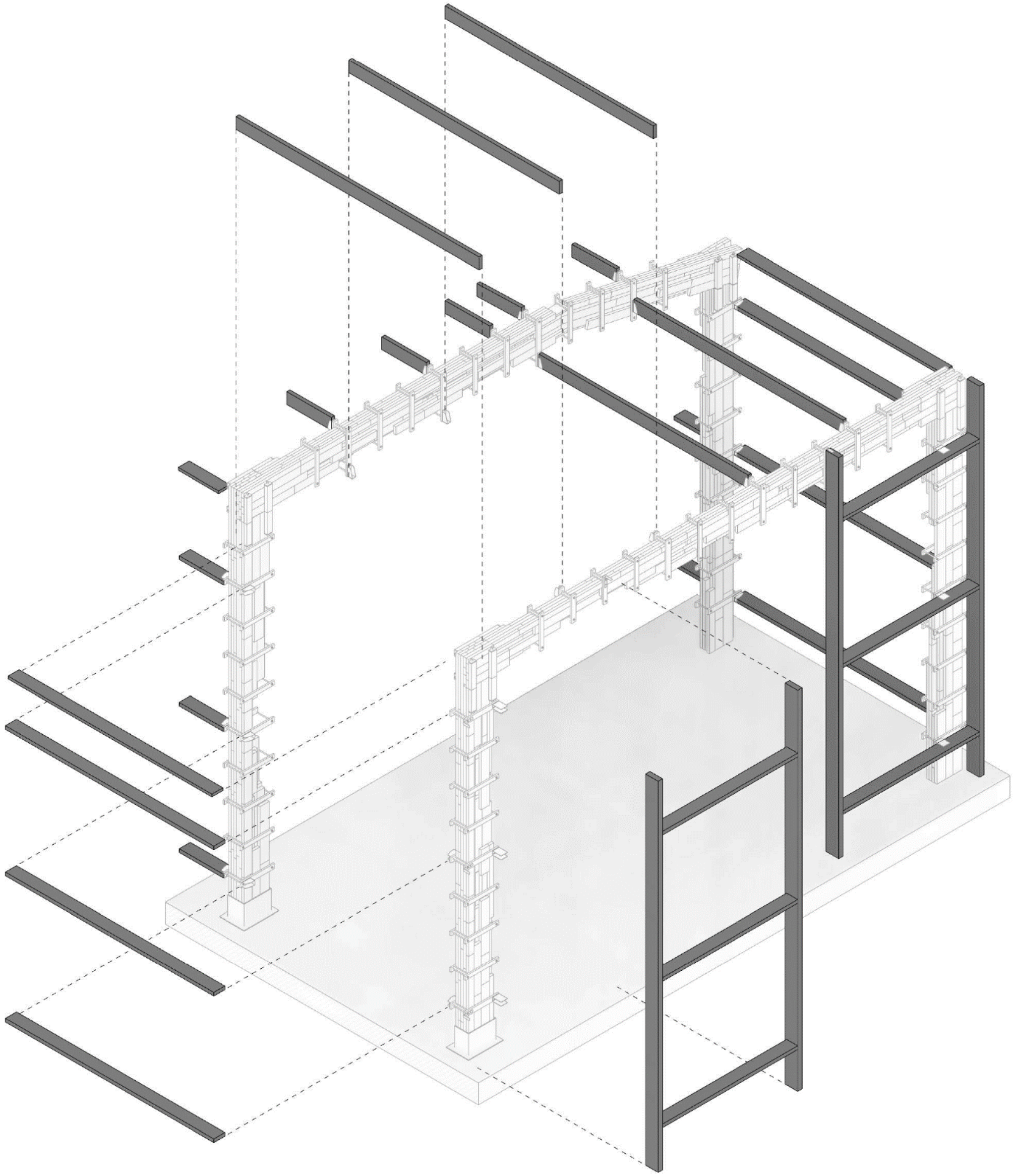
Potential building process

Tighten moment connection



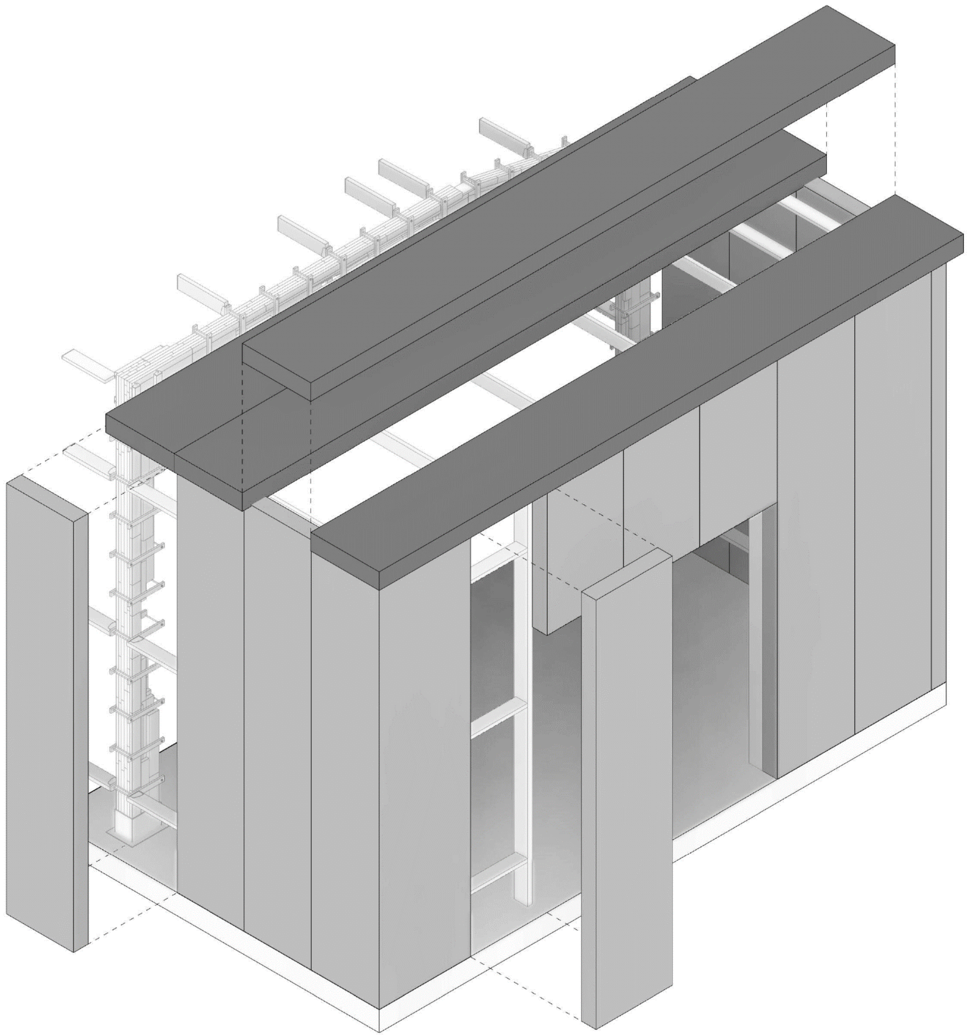
Potential building process

Add secondary structure



Potential building process

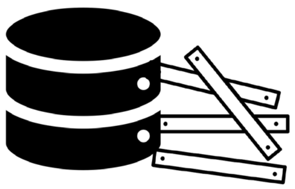
Add cladding and roofing



Conclusion

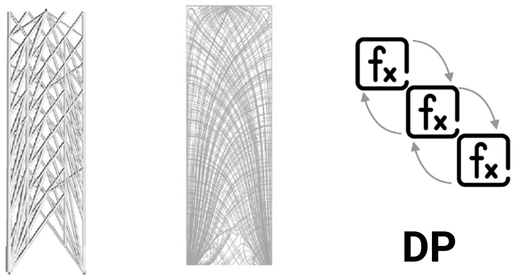
How can programming be utilised to create a discrete structural system using ***reclaimed timber*** *parts that* ***maximizes efficiency and adaptability*** *but* ***minimizes*** *the need for* ***virgin materials*** *in construction?*

Reclaimed timber



Database

Efficient

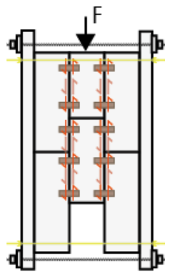


Dynamic programming

Strength grade matching

Mix between small and large pieces

Circularity



Modular parts

Reversible joints

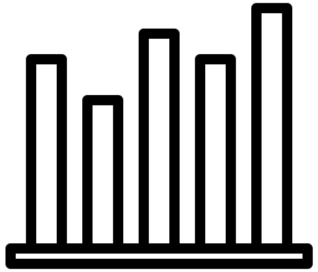
Minimal modifications

Limitations

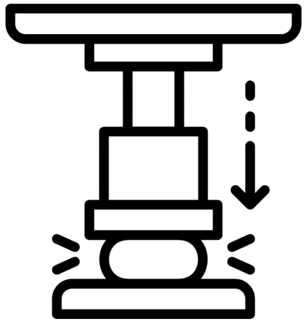
1. Fire resistance

2. Buckling

Recommendation



1. Stability of the programs output

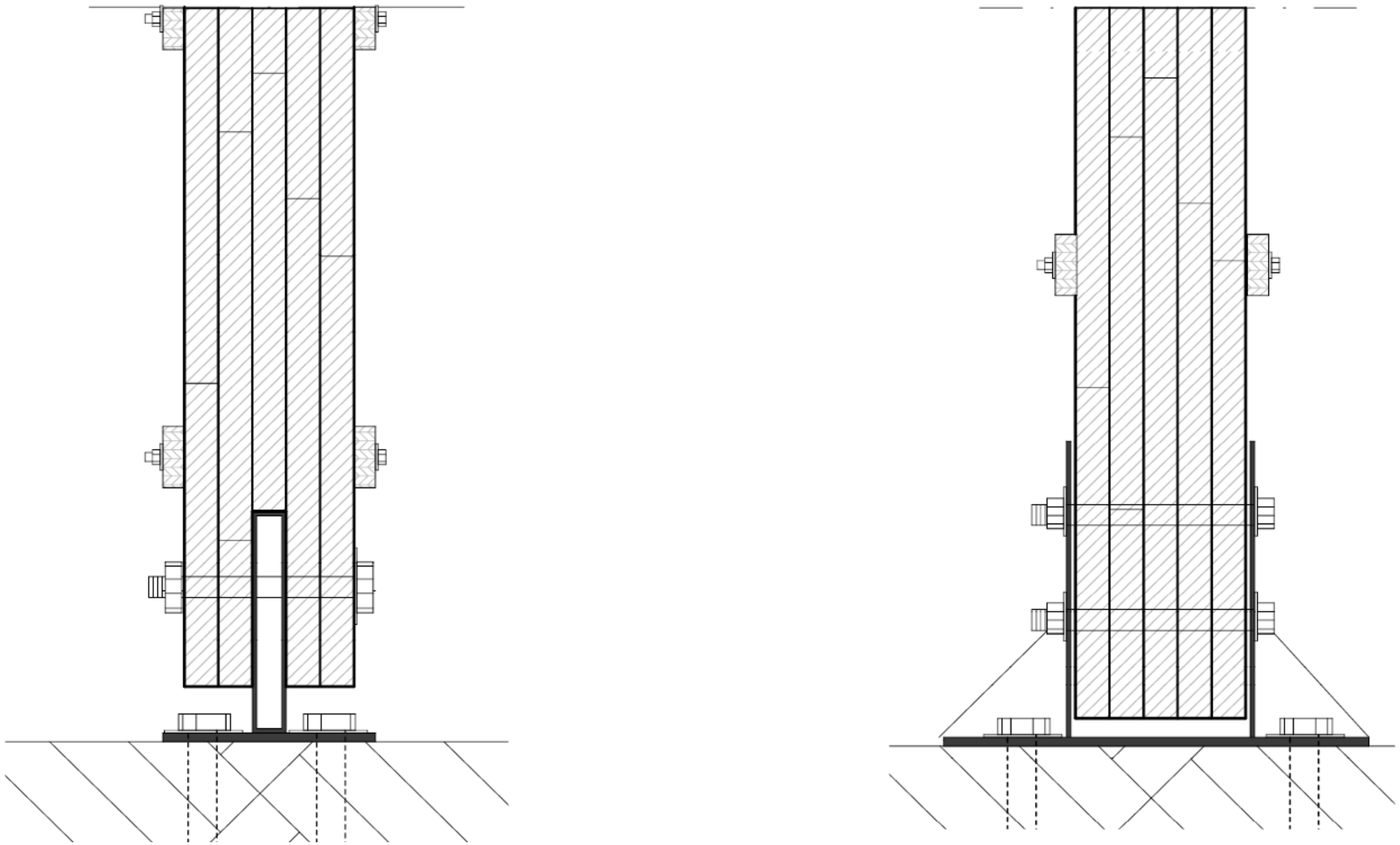


2. Mechanical testing

Thank you

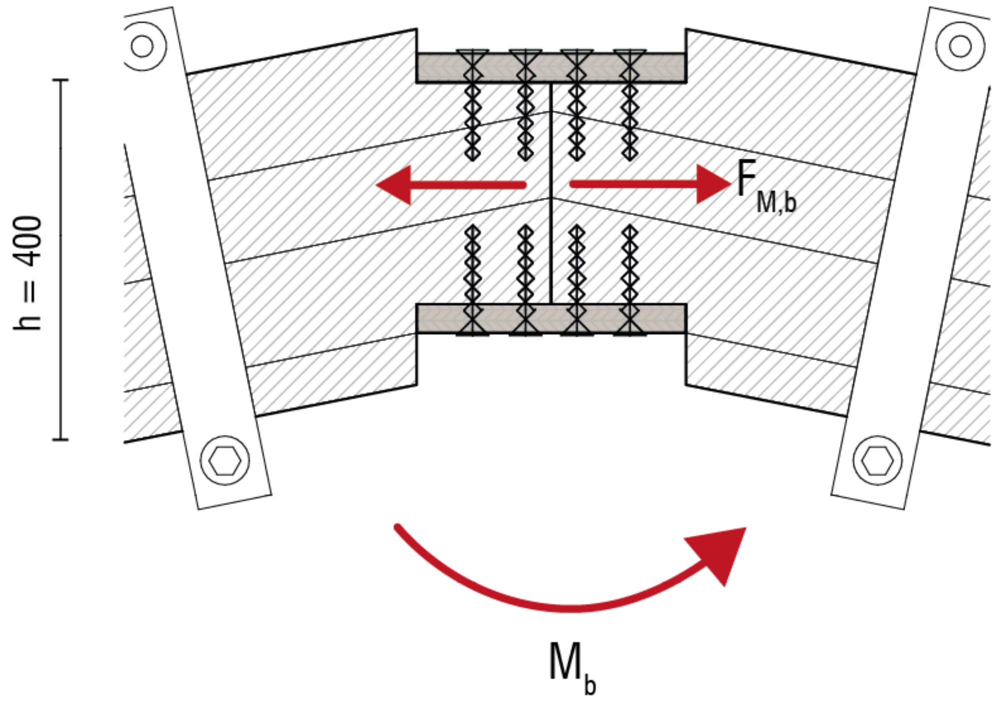
Appendix 1: Support connections

Cross-section



Appendix 2: Crown connection

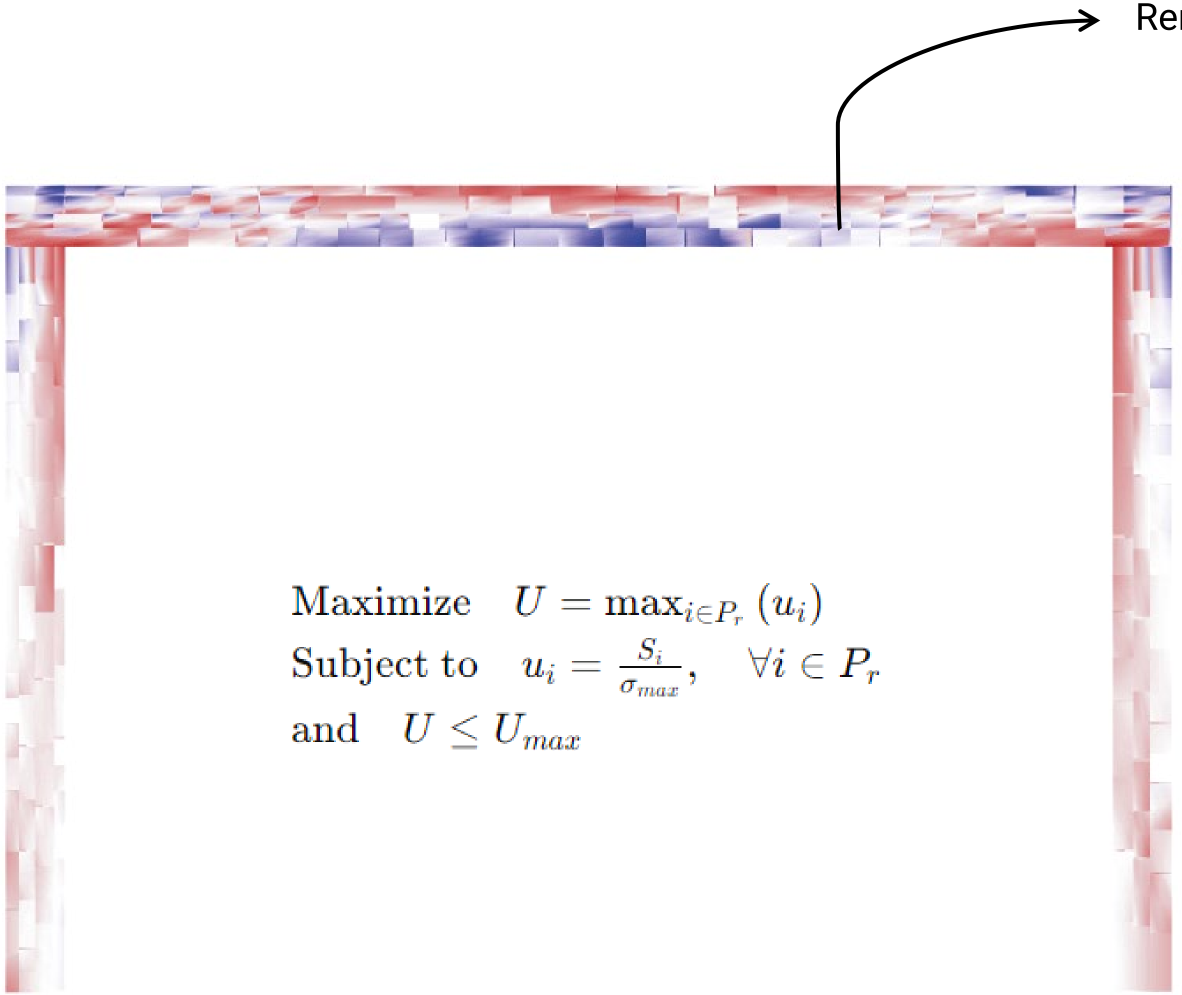
Front view



Appendix 3: Optimisation approach

Front view

Removal of pieces with low stress



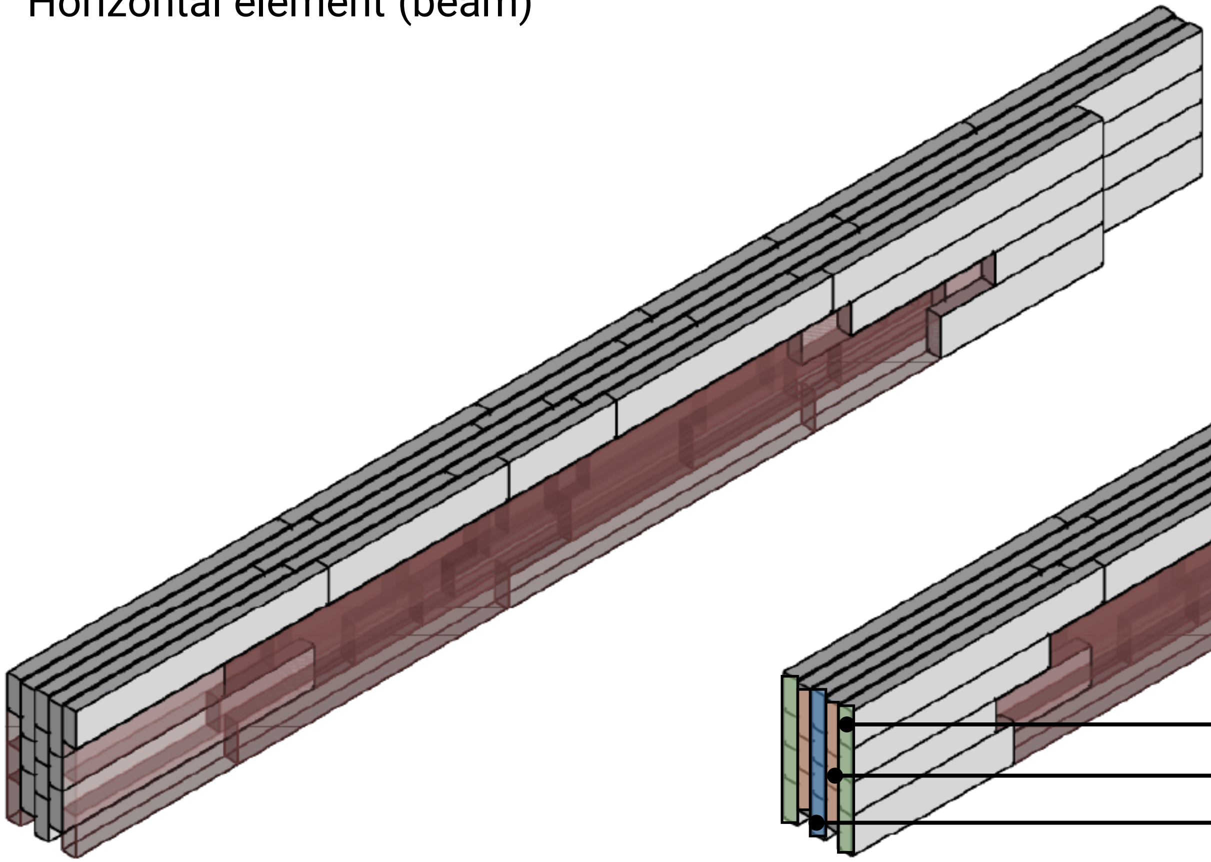
$$\text{Maximize} \quad U = \max_{i \in P_r} (u_i)$$

$$\text{Subject to} \quad u_i = \frac{S_i}{\sigma_{max}}, \quad \forall i \in P_r$$

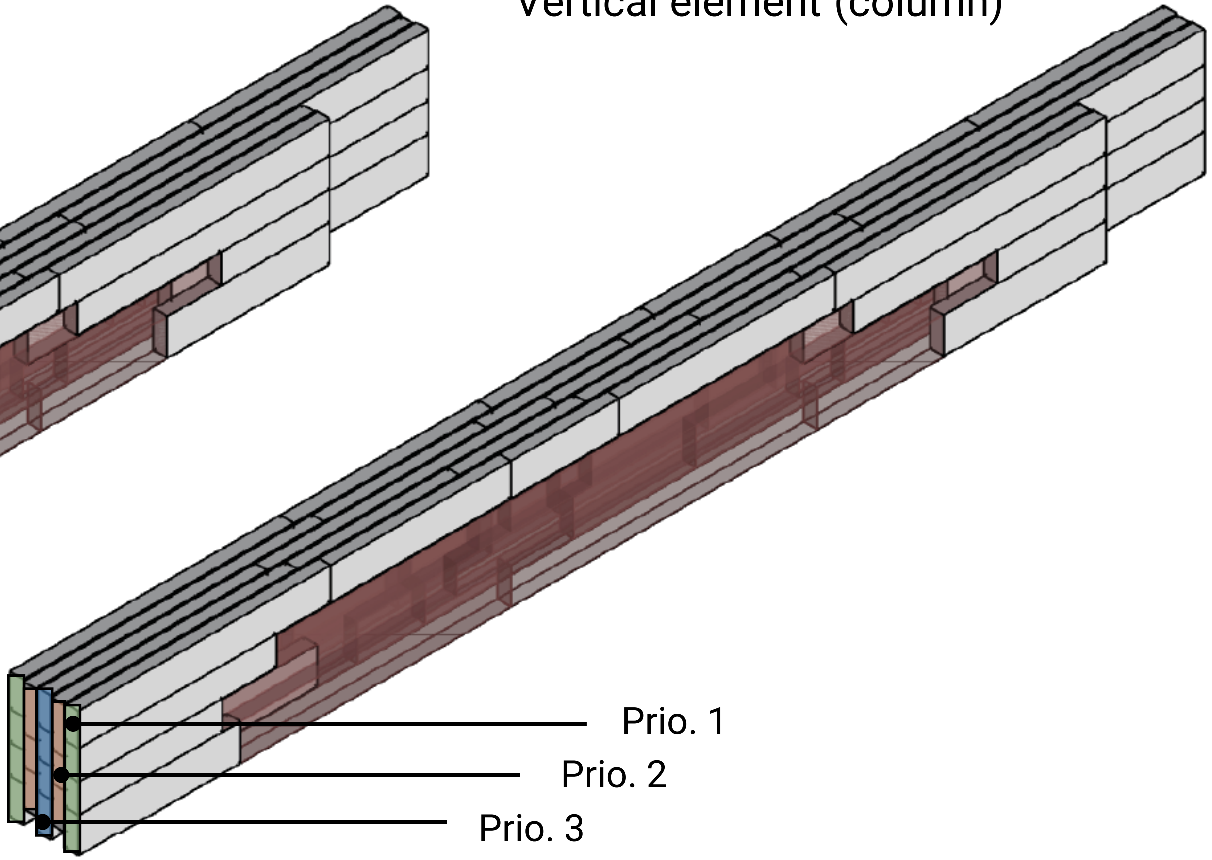
$$\text{and} \quad U \leq U_{max}$$

Appendix 4: Optimisation constraints

Horizontal element (beam)



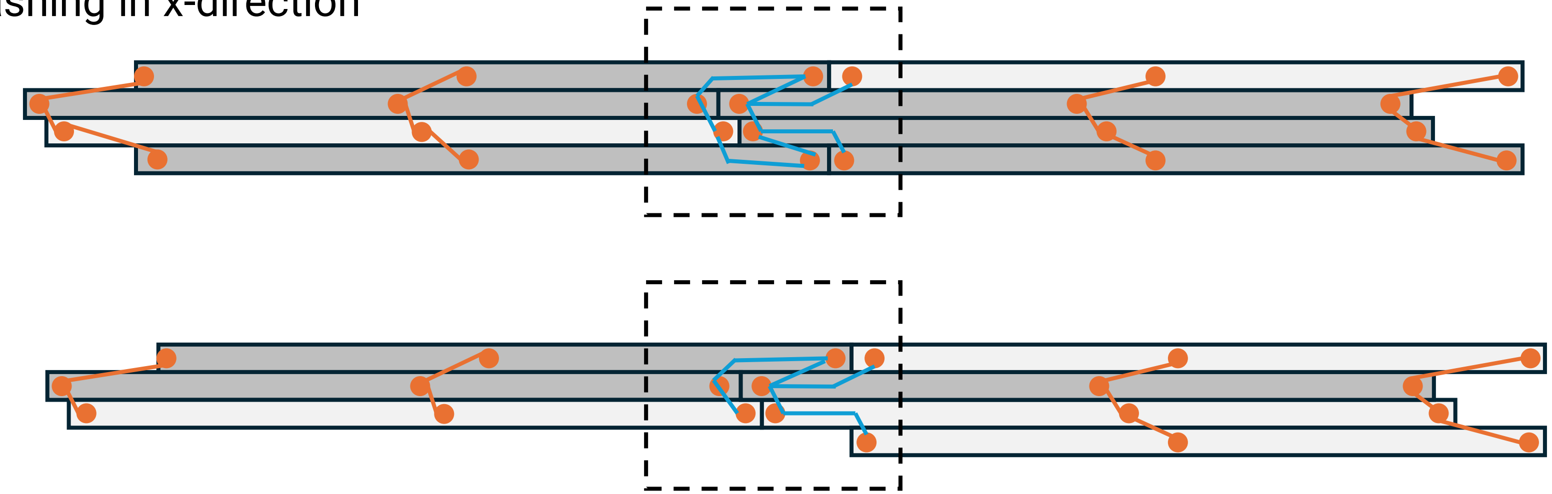
Vertical element (column)

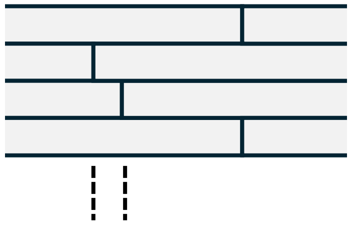


Appendix 5: Connectivity issues due to little overlap

Top views

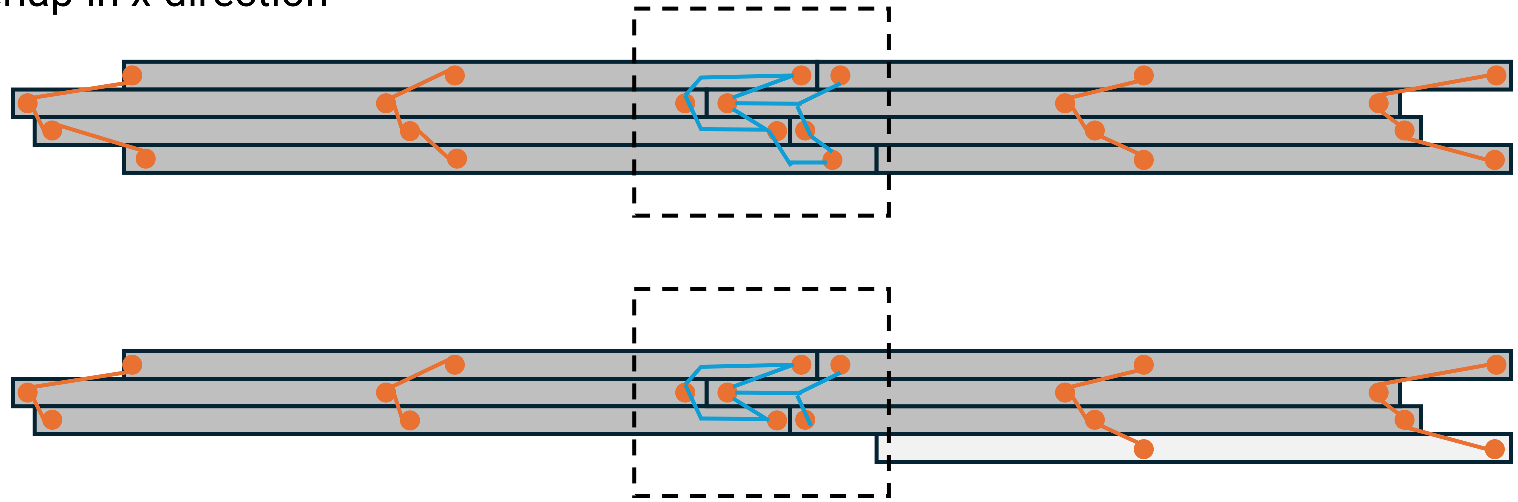
Composition 1: Clashing in x-direction

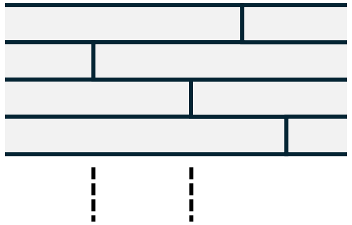




Not enough overlap to connect

Composition 2: Overlap in x-direction





Enough overlap to connect

Appendix 6: Vertical attachments of links