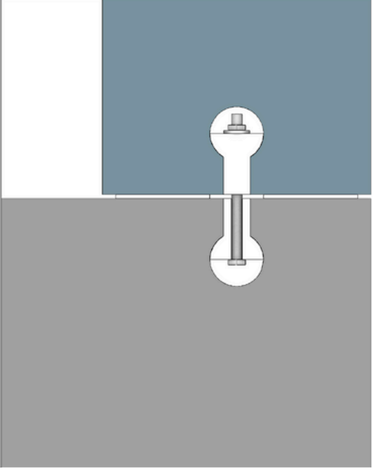
TU Delft



Modular Float Glass Systems Designed for Reuse

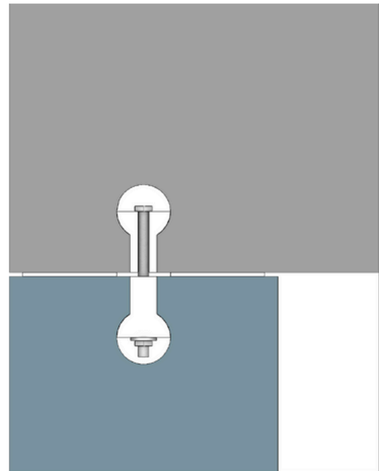
Novel connections designed for reusability and sustainability of laminated glass

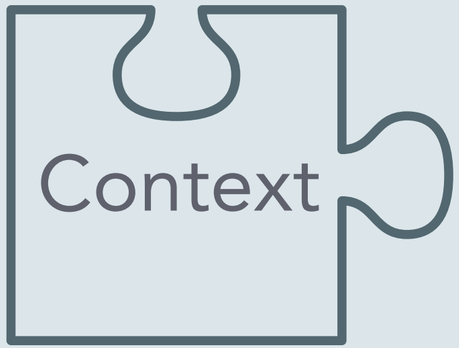
P4 Presentation

by
Minoo Motedayen

Mentors:

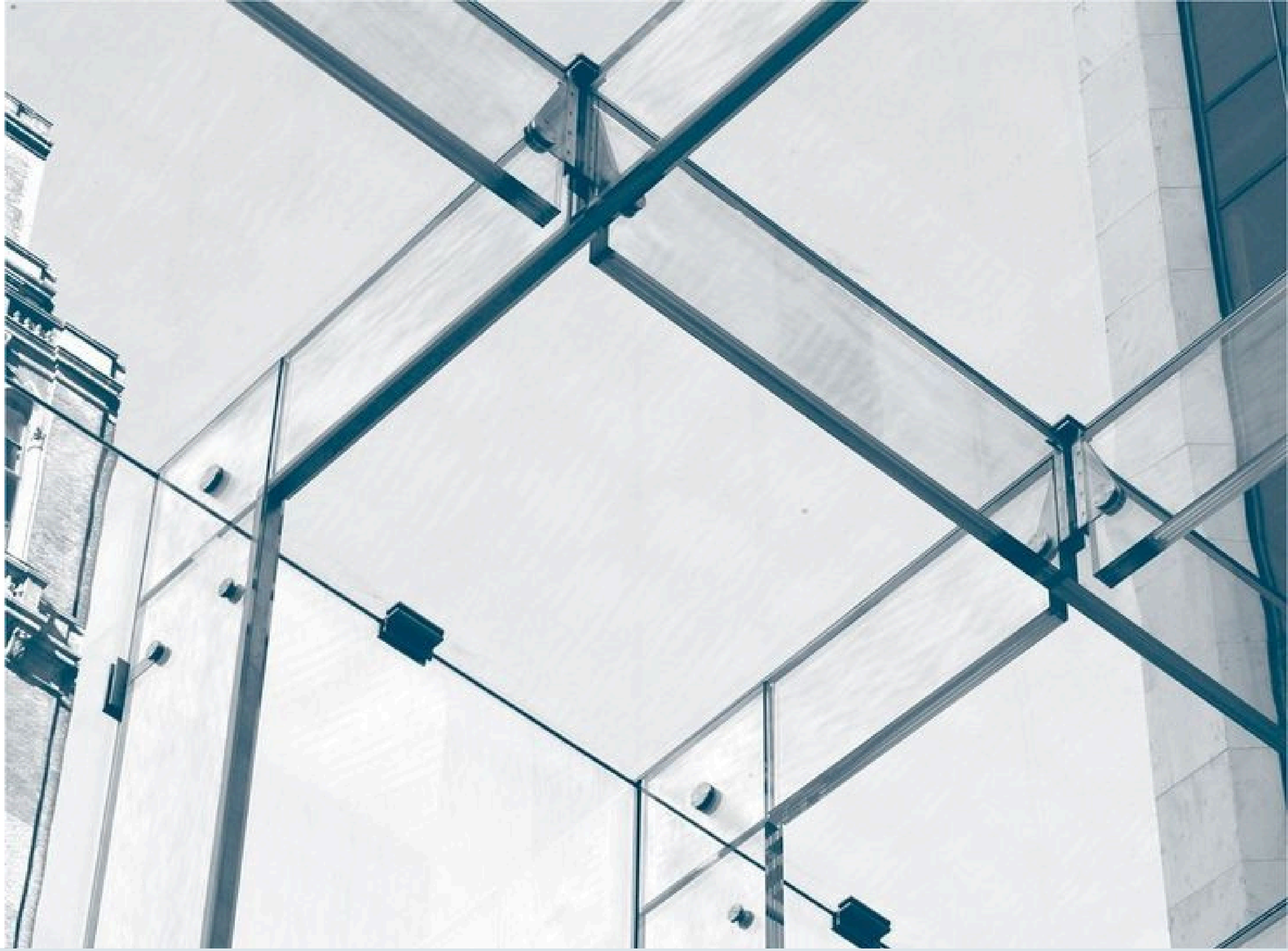
Prof. James O'Callaghan
Dr. Ing Marcel Bilow




Context

Glass Structures

- Strength
- Transparency
- Elegance



Glass Structures

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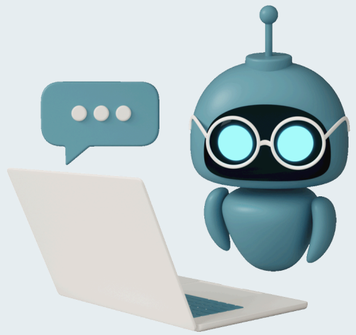
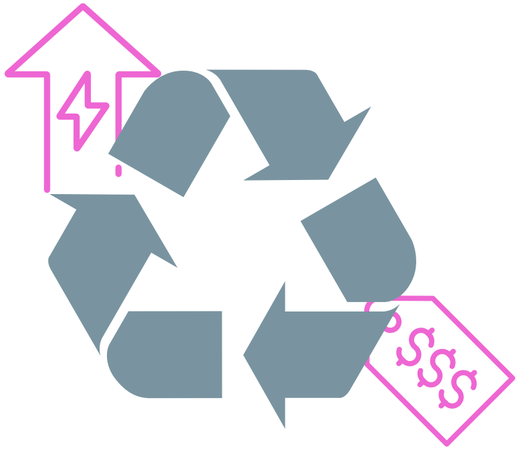


BUT?!

- Lifecycle & Recyclability

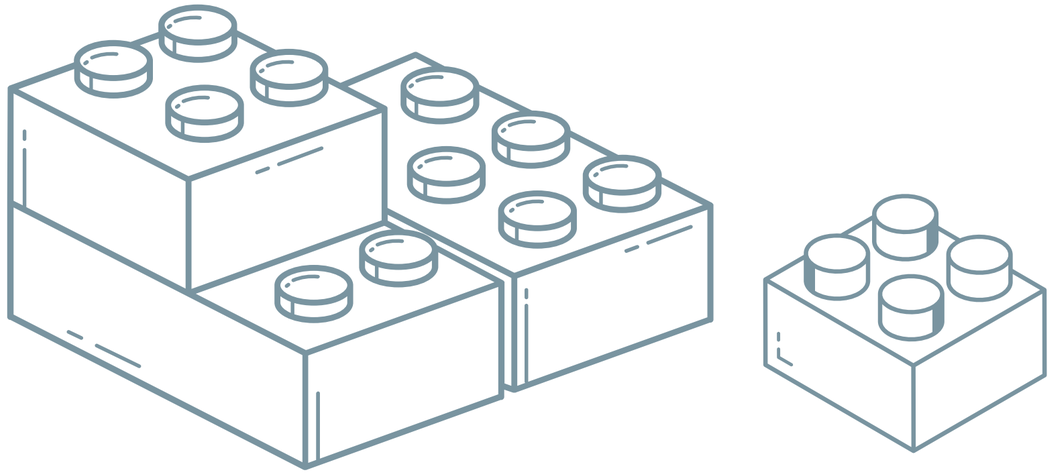


Costly and Environmentally taxing

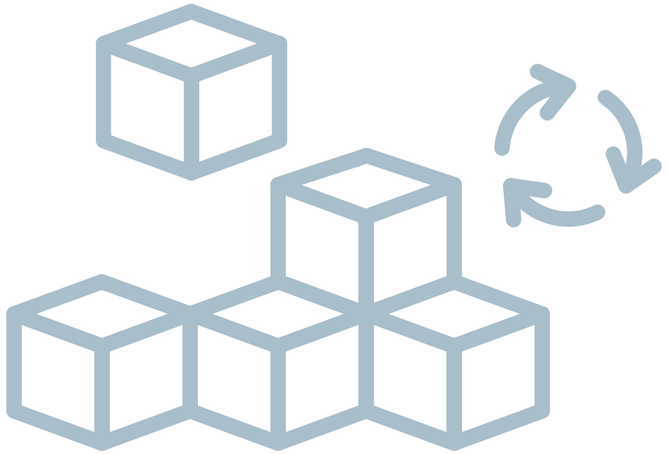
Single use

Multiple use

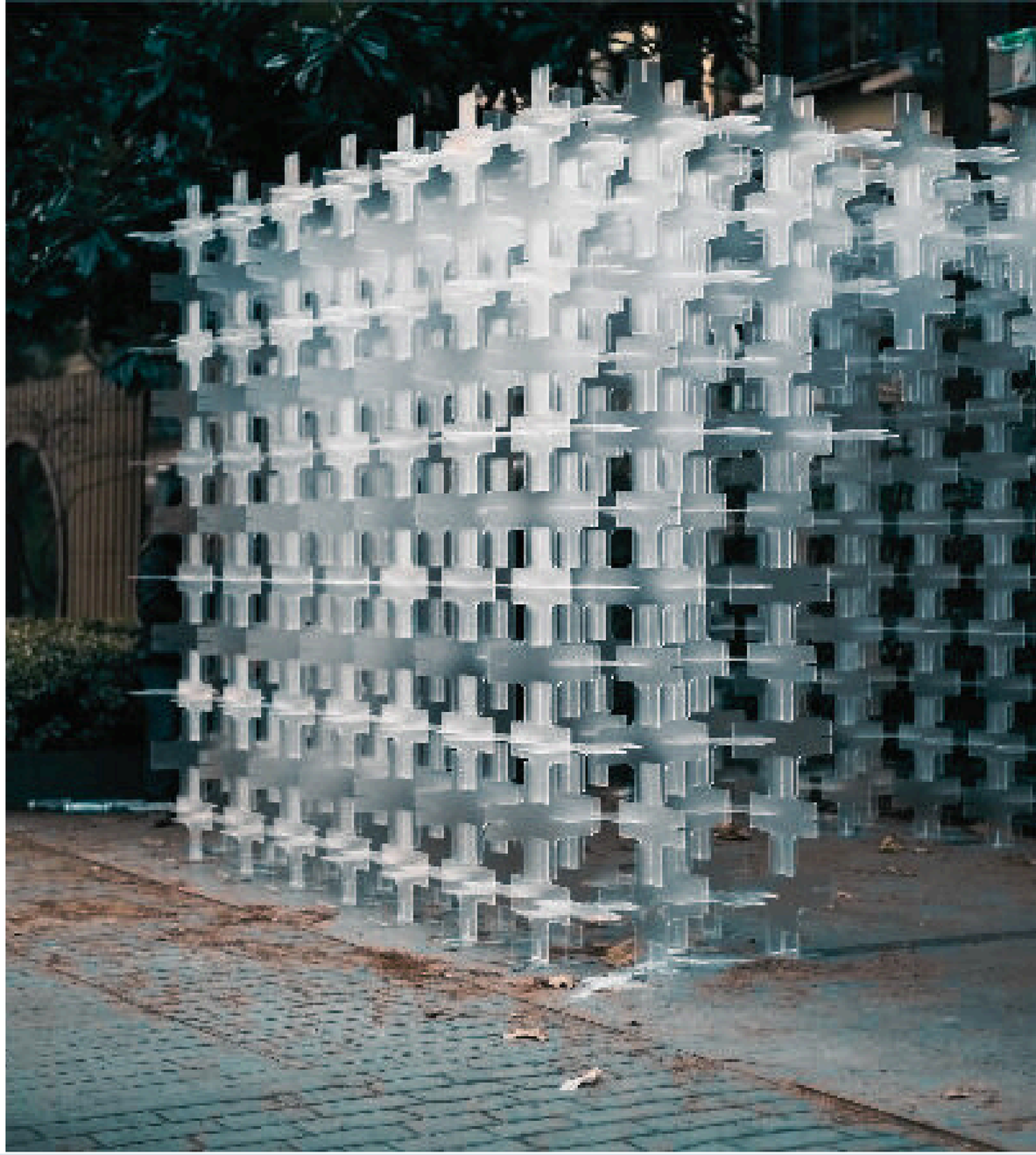
- Modularity



- Research Question

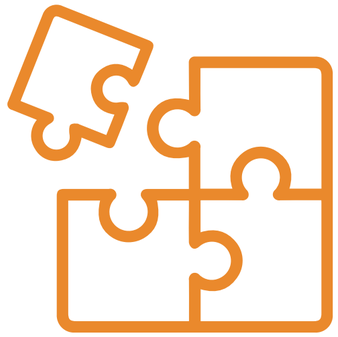


''How might we achieve a modular glass structure that allows for easy disassembly and reuse of its components with minimum use of other materials? "



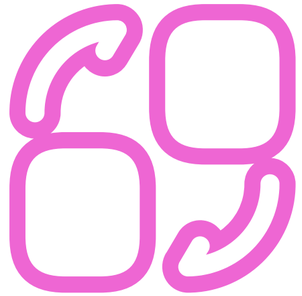

Scope

- Objectives
  - Modular float glass system



  - Assembly / Disassembly

  - Adaptability

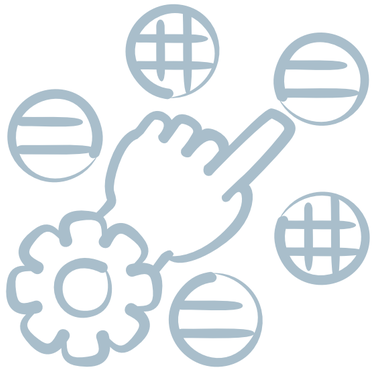


- Aim

  - Novel connection

- Boundary Conditions

- Versatility

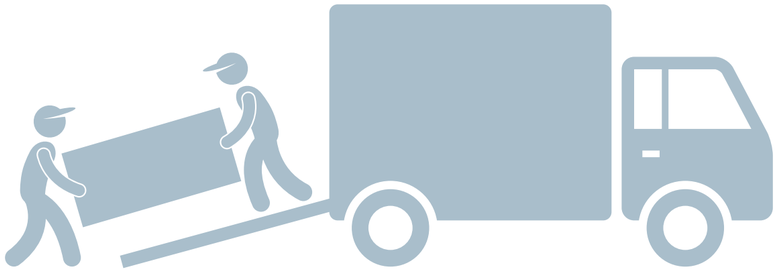


Two configurations
of Pavilion Design

- Structural performance

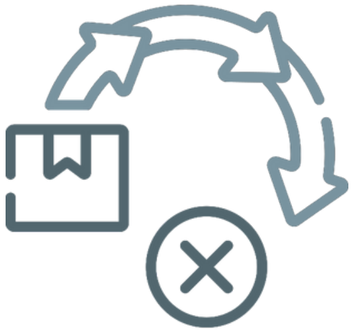
Stability
Safety

- Portability and Easy assembly

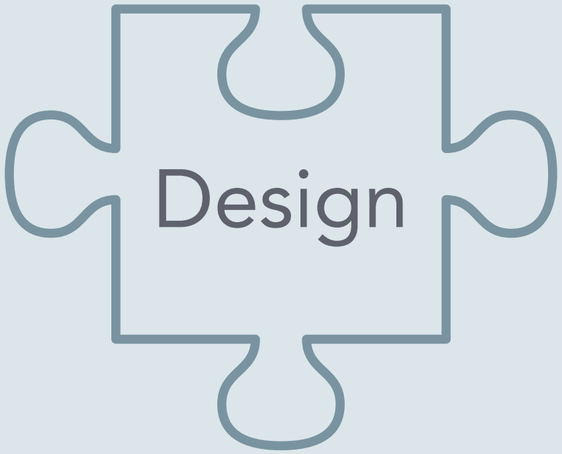


Modul's Size
Simple Joints

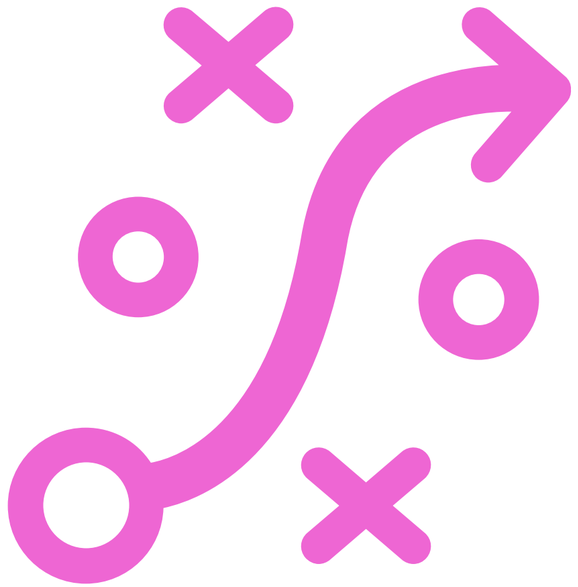
- End-of-life



Modul's Size
Simple Joints

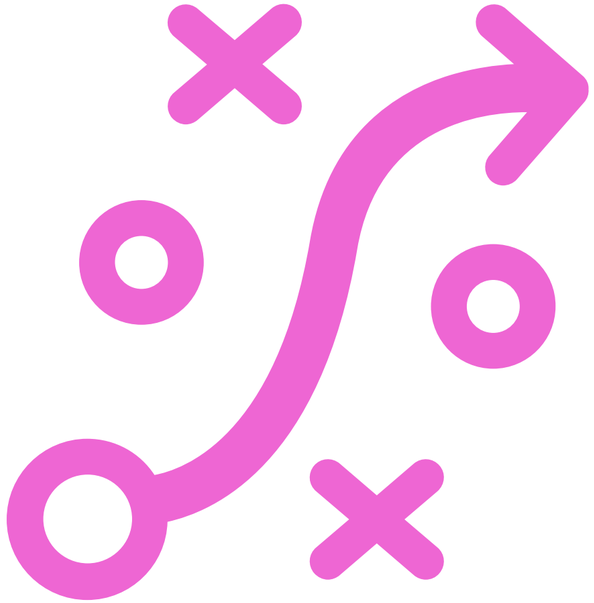

Design

- Approach



1. Connection-to-system approach
2. System-to-connection approach

- Approach



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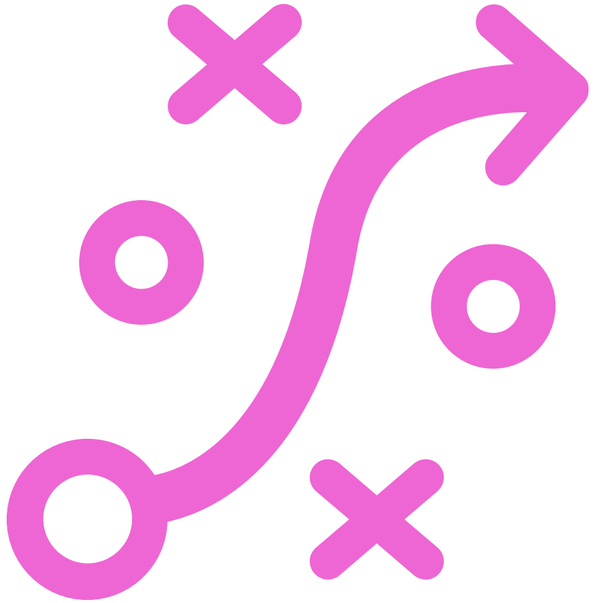

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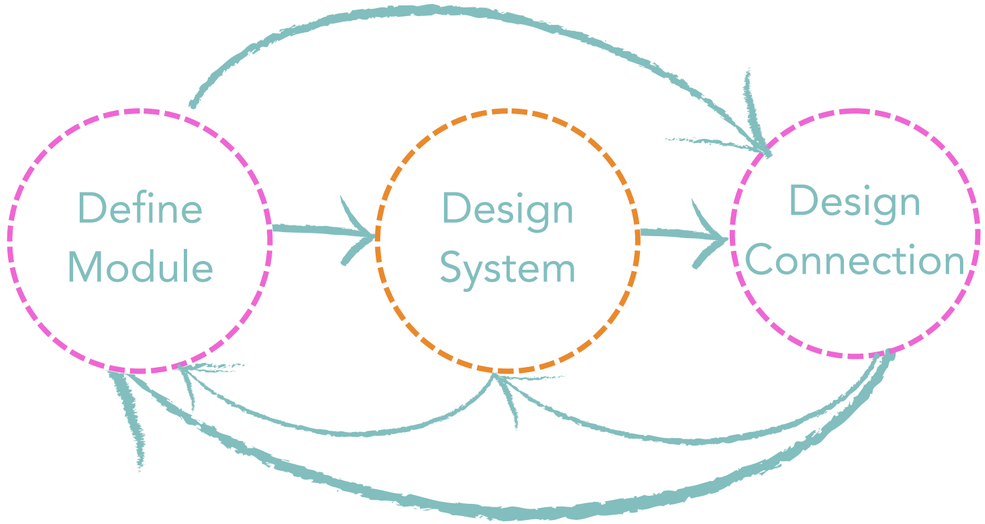
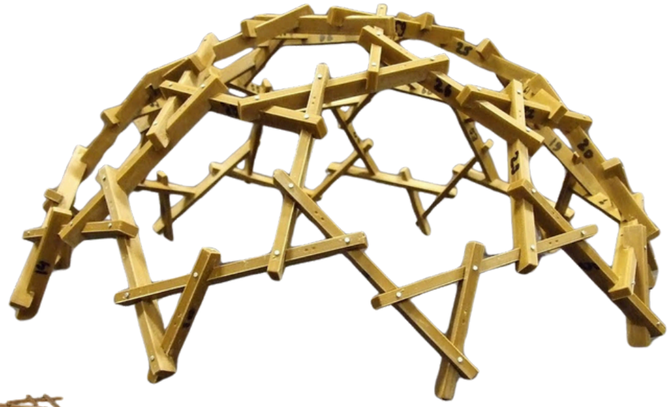


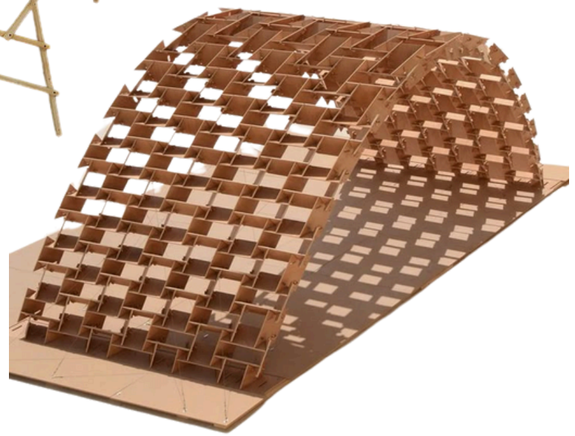
- Inspiration

Reciprocal Structures

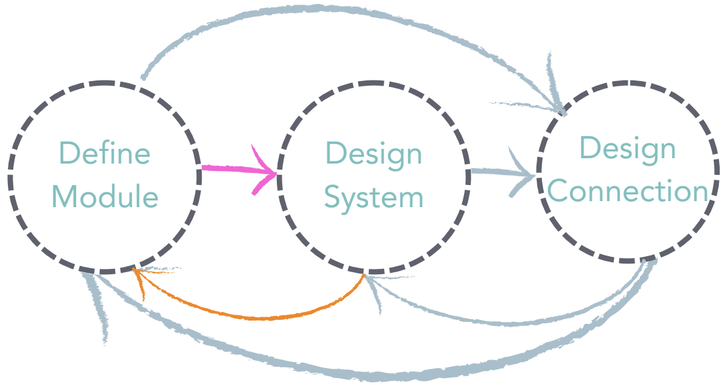
Mutually supporting elements arranged in a **closed circuit**, where each component both supports and is supported by its neighbors.

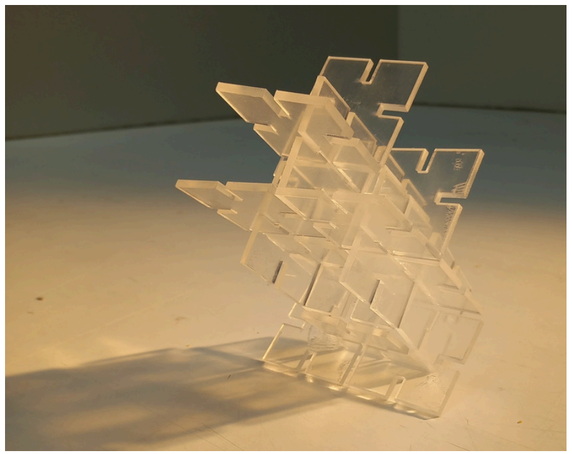
- Wide Spans
- Complex Geometries
- Relatively Simple Elements

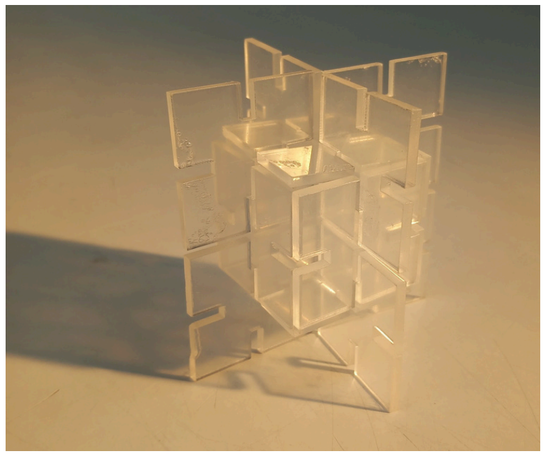


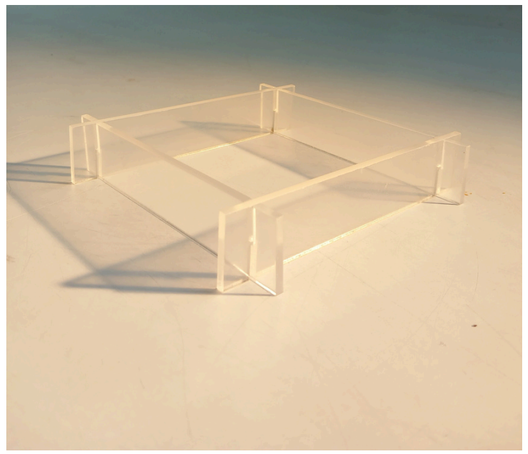


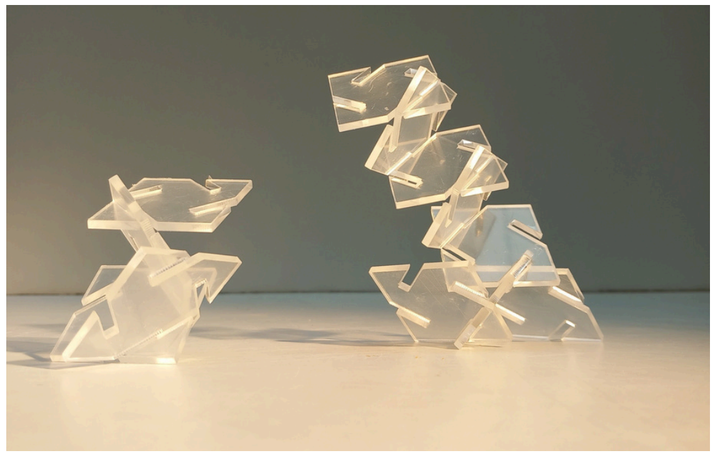
- Defining Module Process











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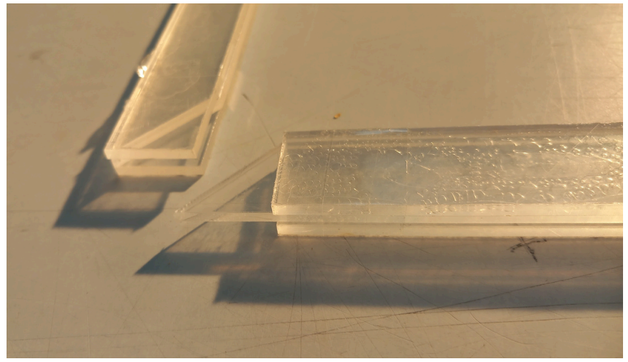
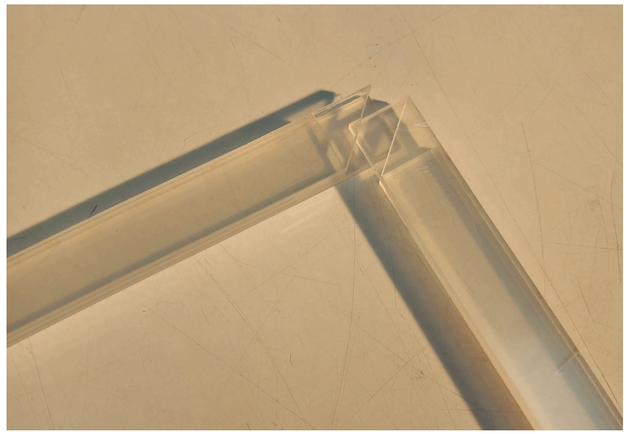
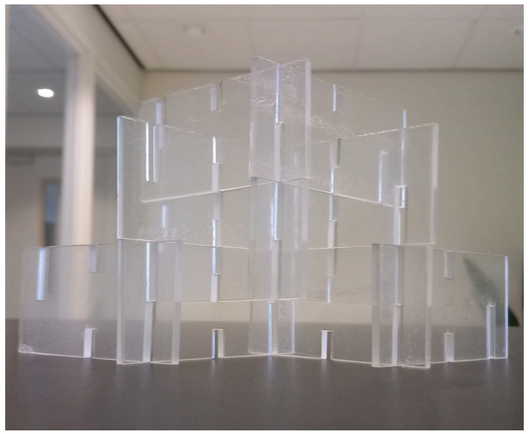
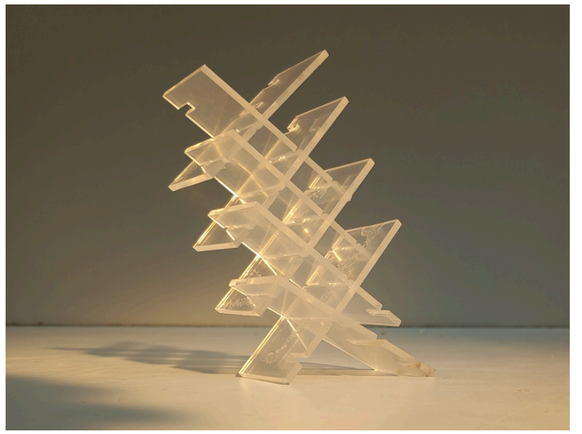
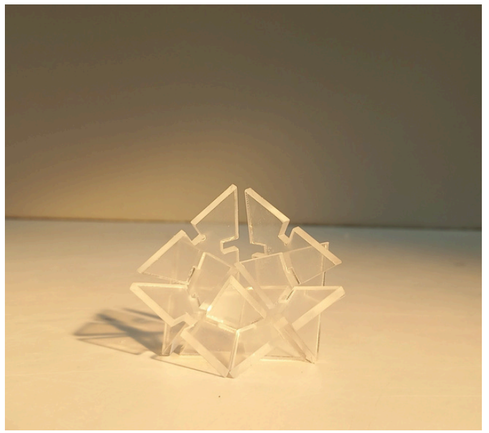
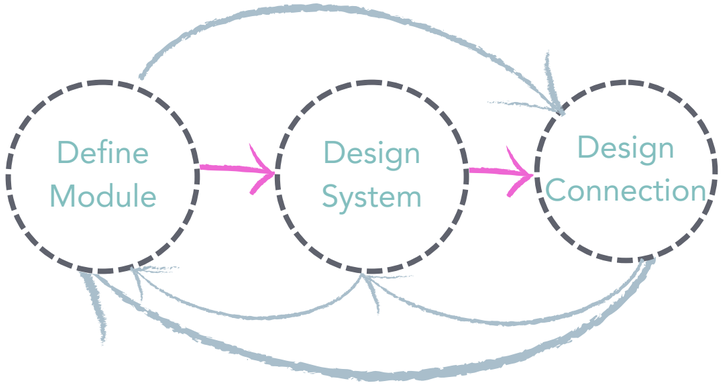
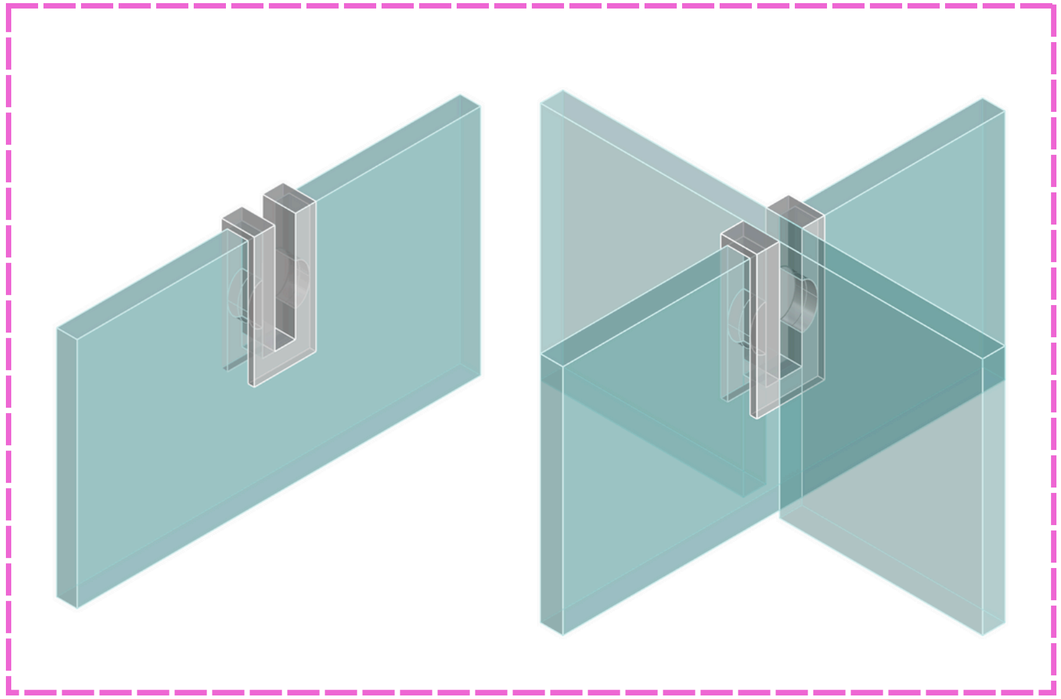




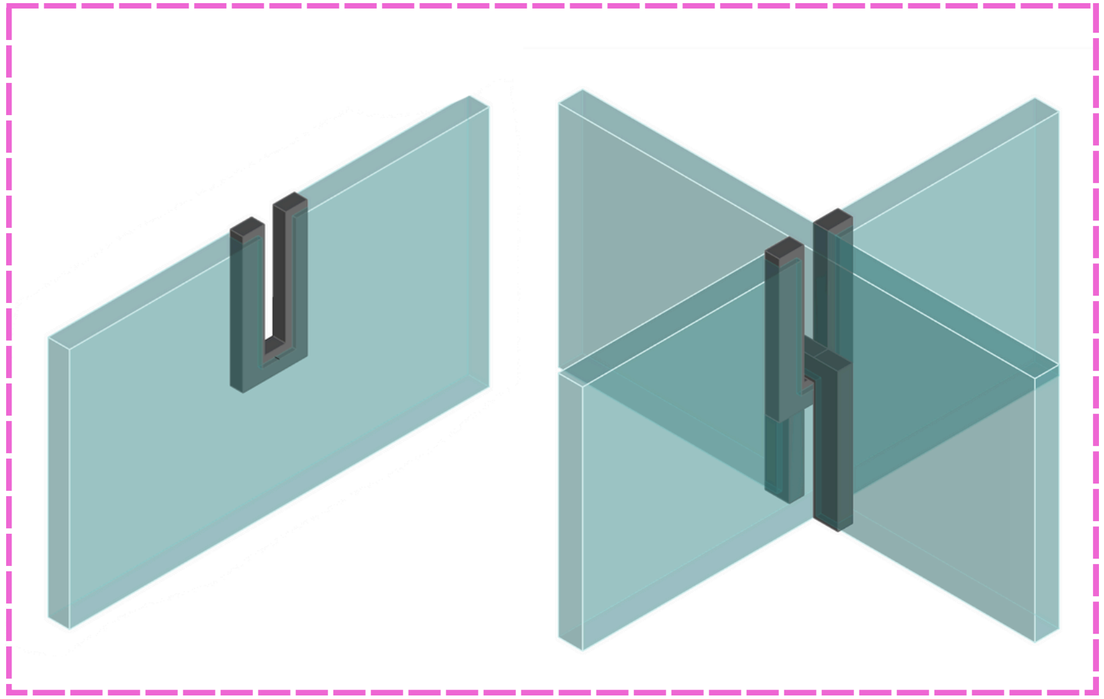





- Exploitative Connection Design : Slot joint



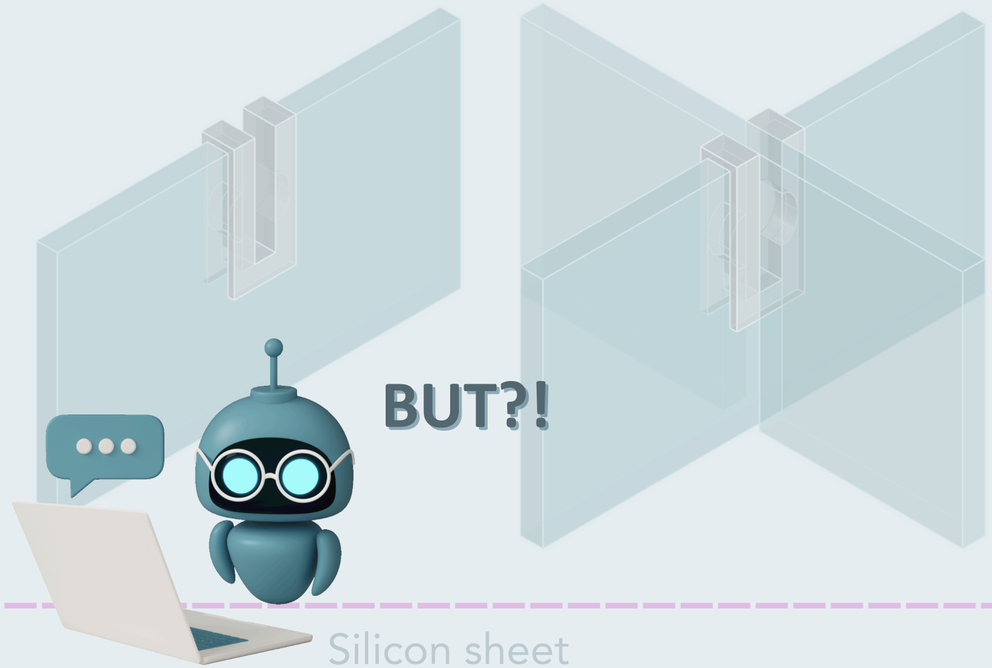


Silicon sheet

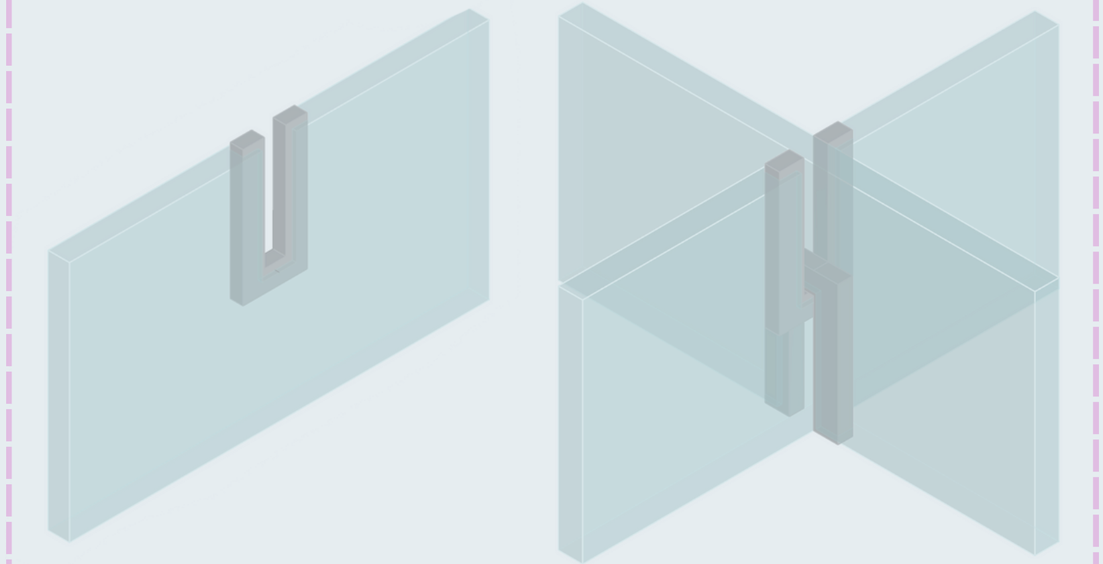


Embedded Steel plate

- Exploitative Connection Design : Slot joint



Silicon sheet



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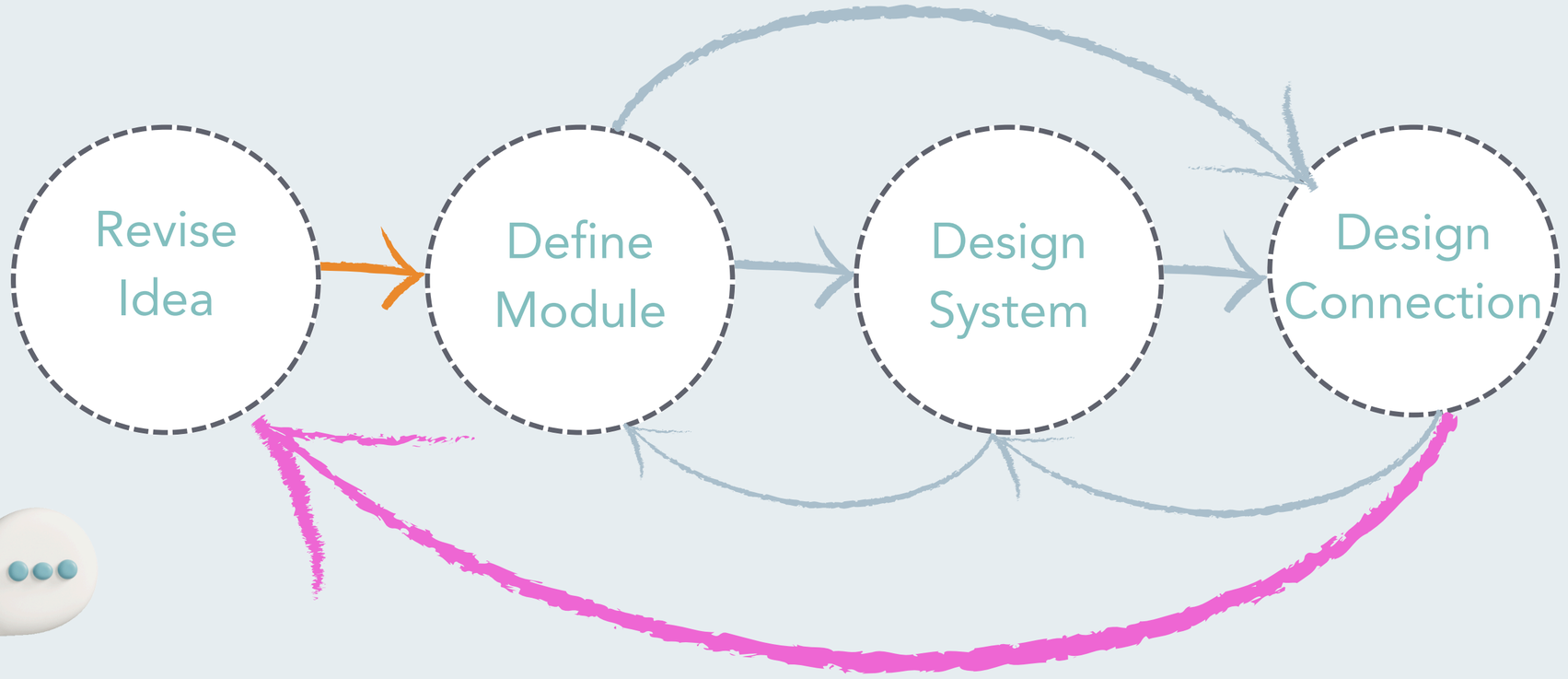
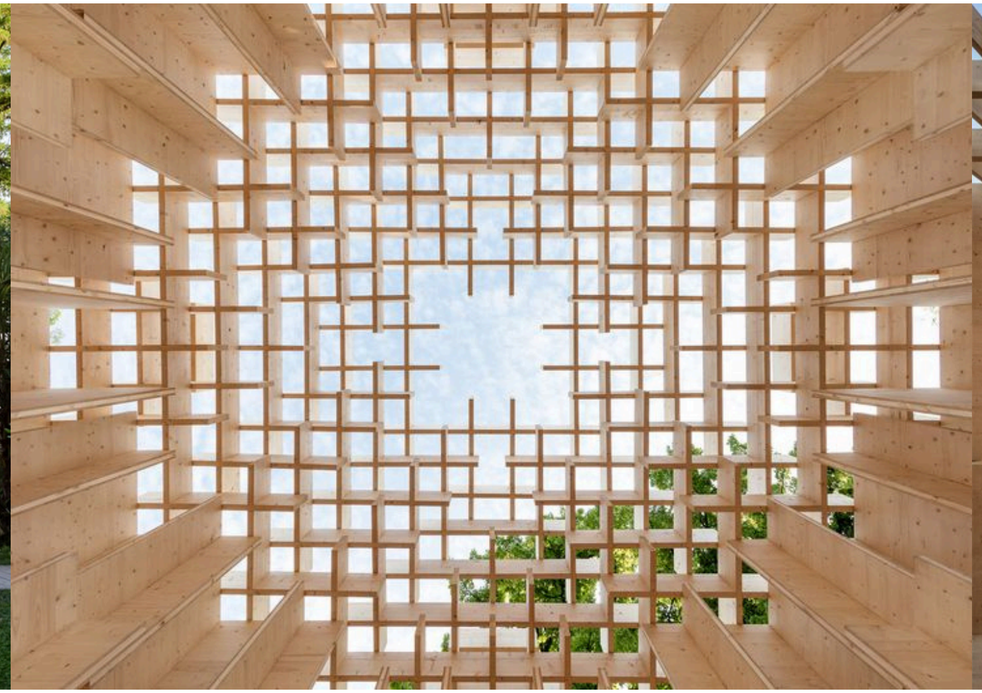
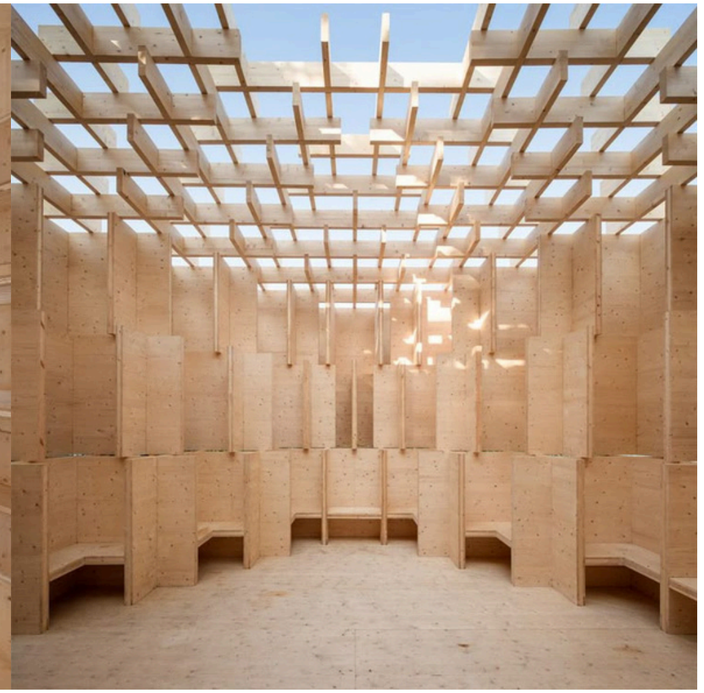

Revise Idea
Define Module
Design System
Design Connection

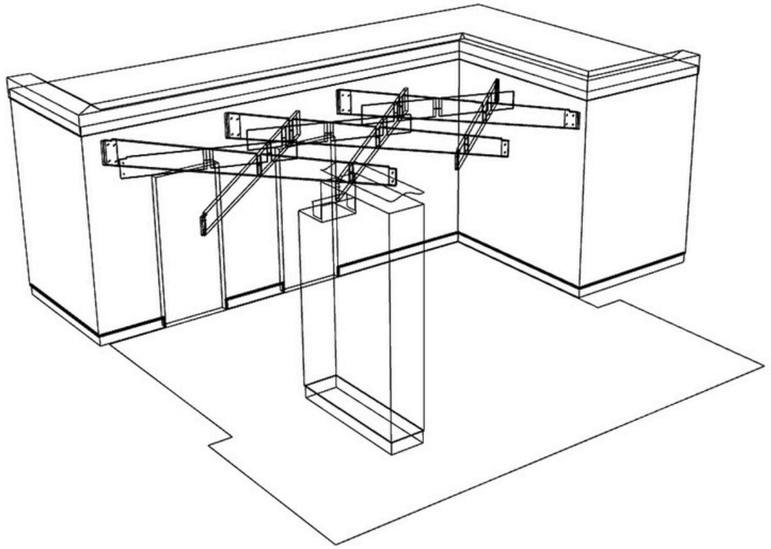
- Reciprocal Roof Structure as the Basis for Design





Forests of Venice Pavilion, Venice Architecture Biennale 2016. Source: Kjellander Sjöberg, Arvet

- Reciprocal Roof Structure as the Basis for Design

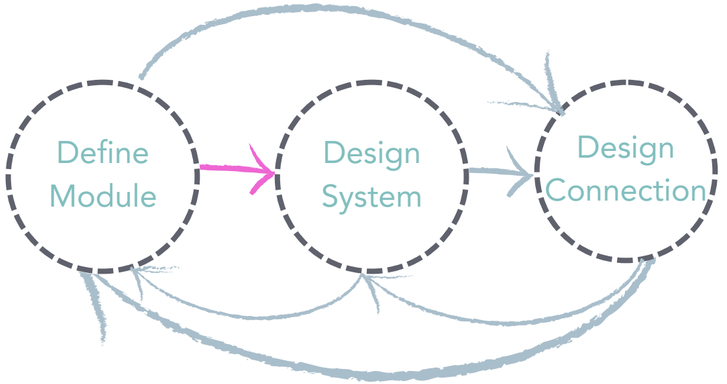


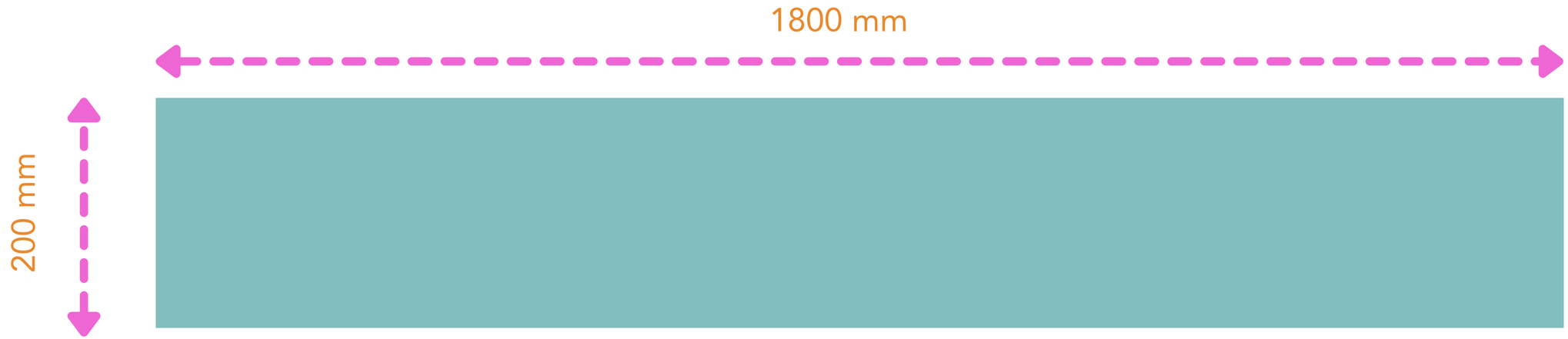
Reciprocal Roof, 2014, Outdoor Covering | Reutlingen | Germany, Source: Aalto University Design of Structures. https://www.ads-aalto.fi/reciprocal-roof

- Reciprocal Roof Structure as the Basis for Design

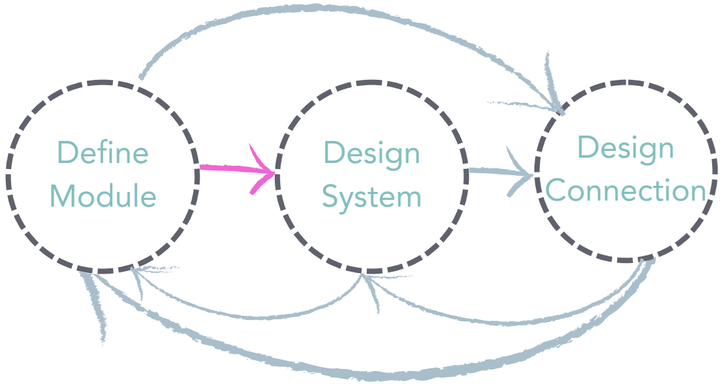
left, Glass house, Milan, Italy, By Carlo Santambrogio and Ennio Arosio. right, Apple store, new york, by Eckersley O'Callaghan

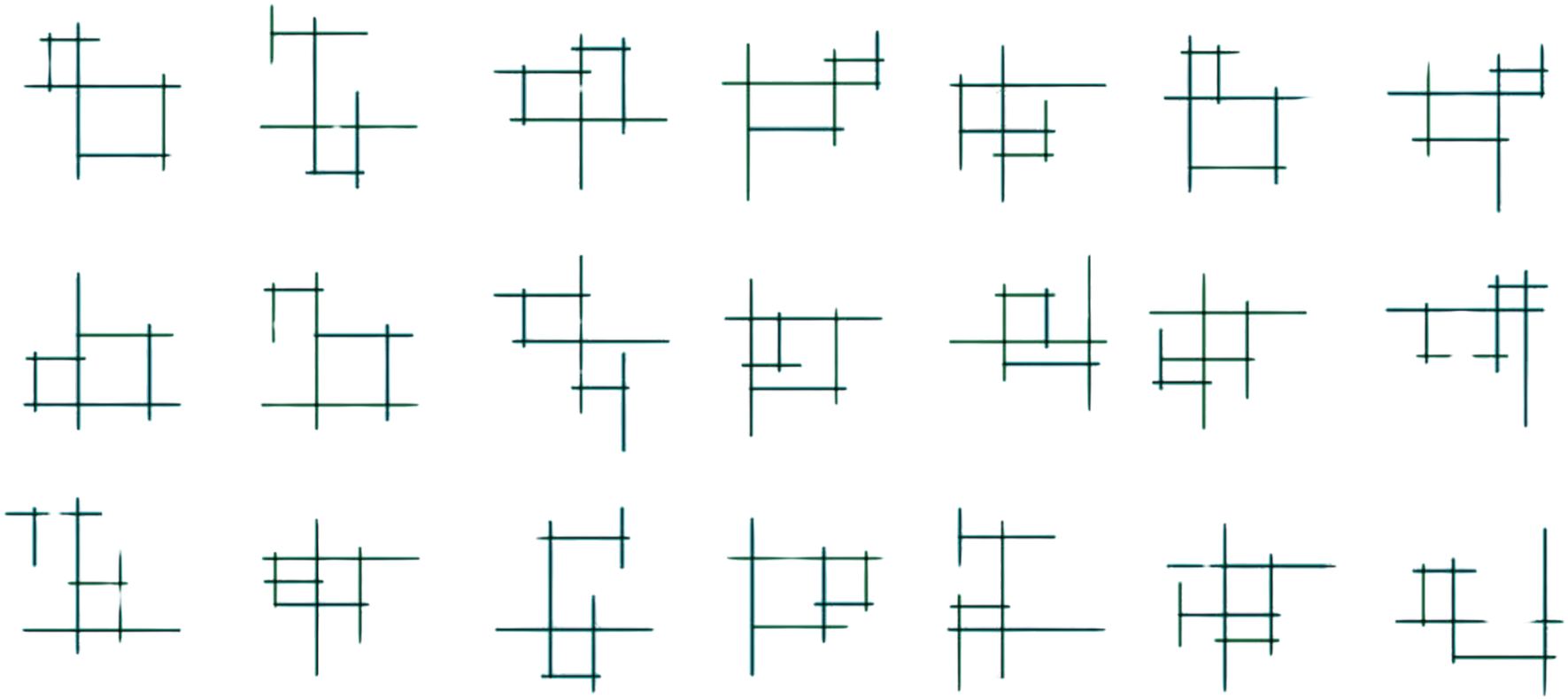
- Define Module



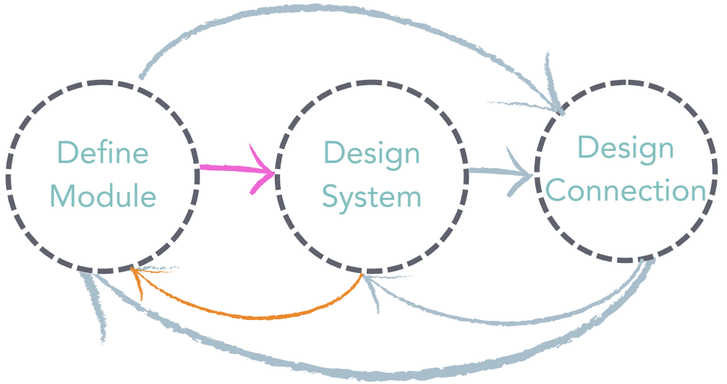


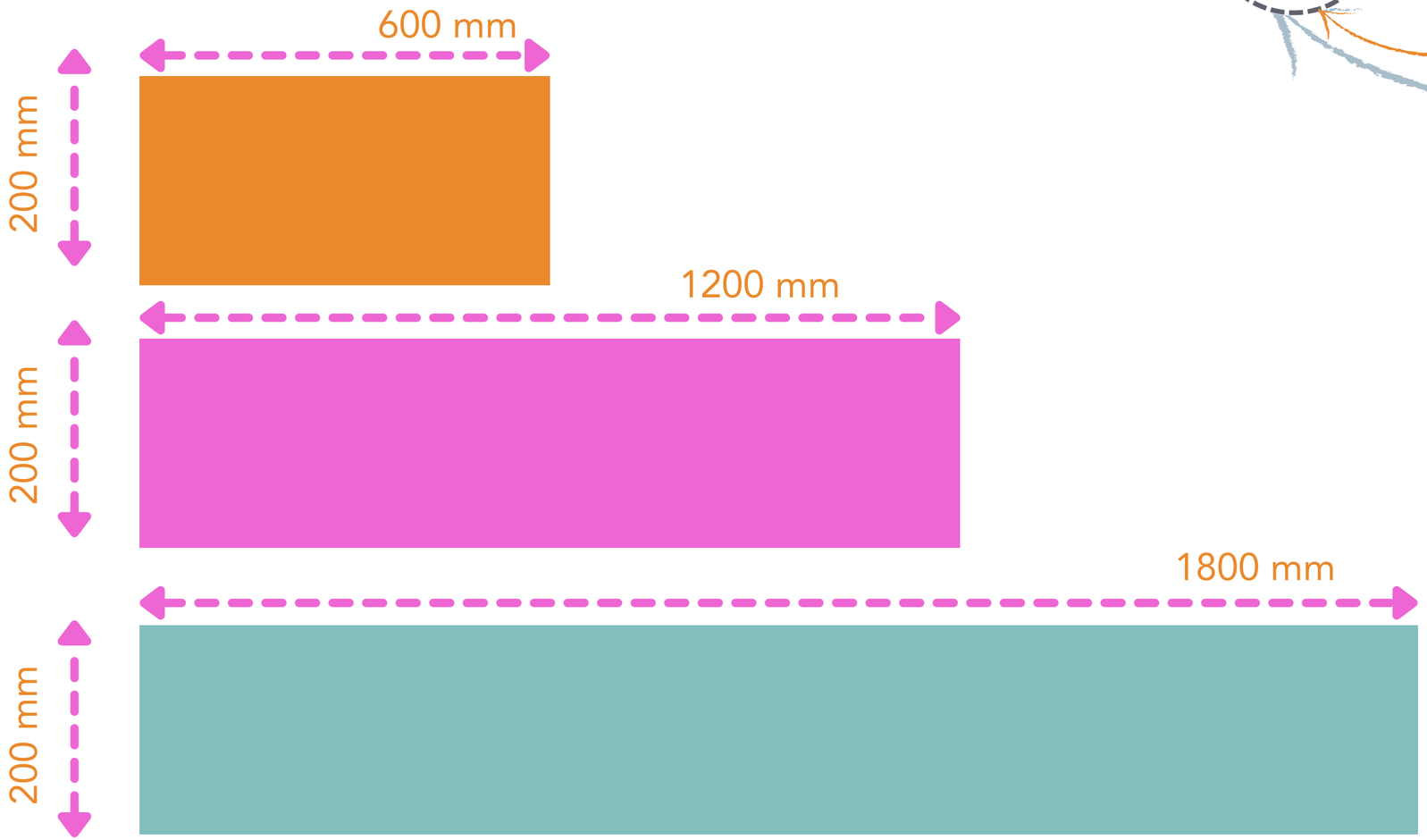
- Design System



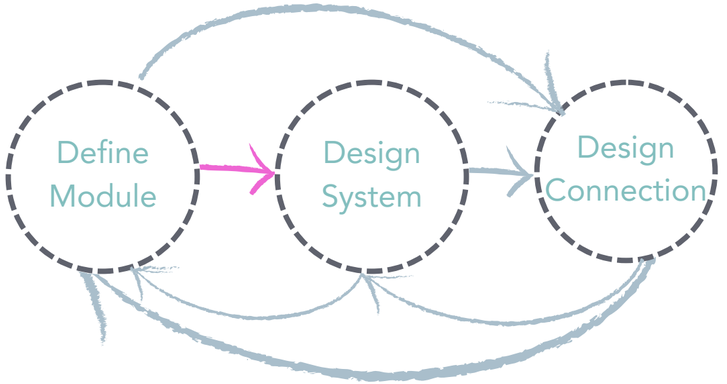


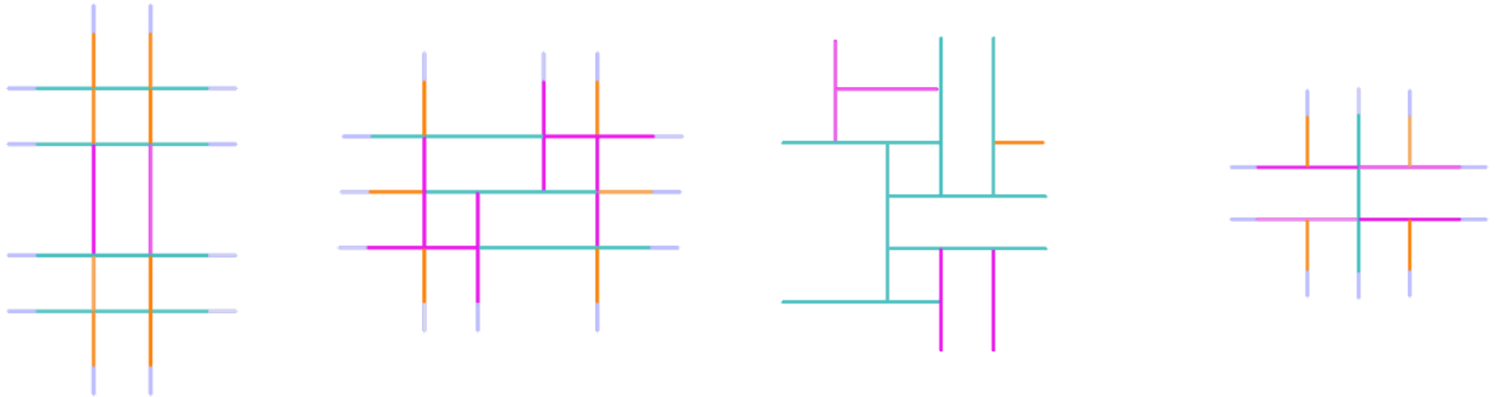
- Redefine Module

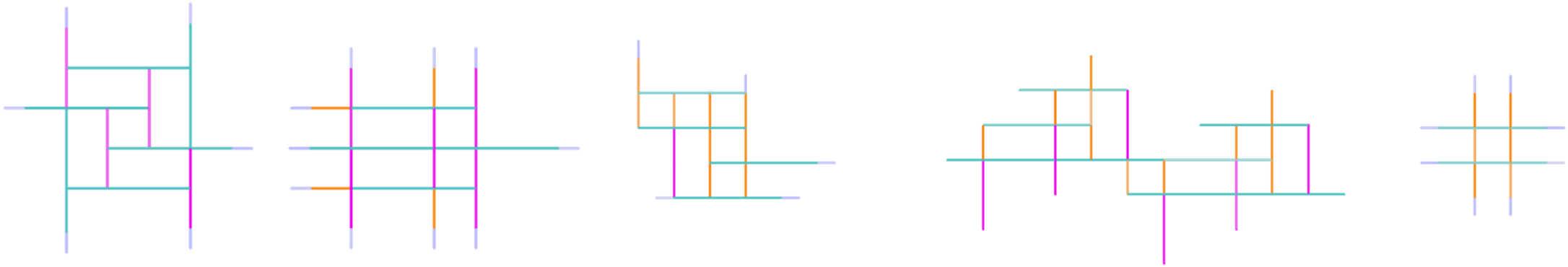




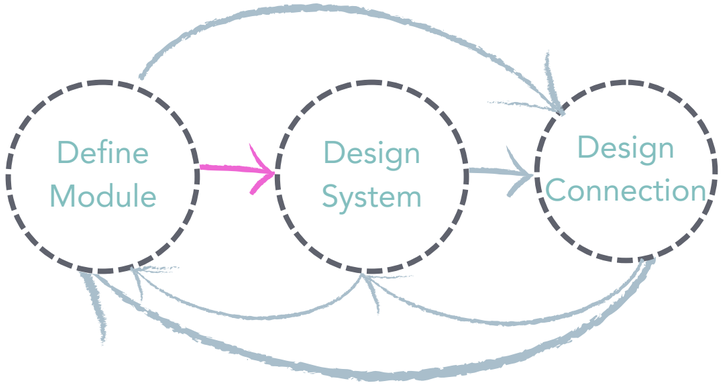
- Design System

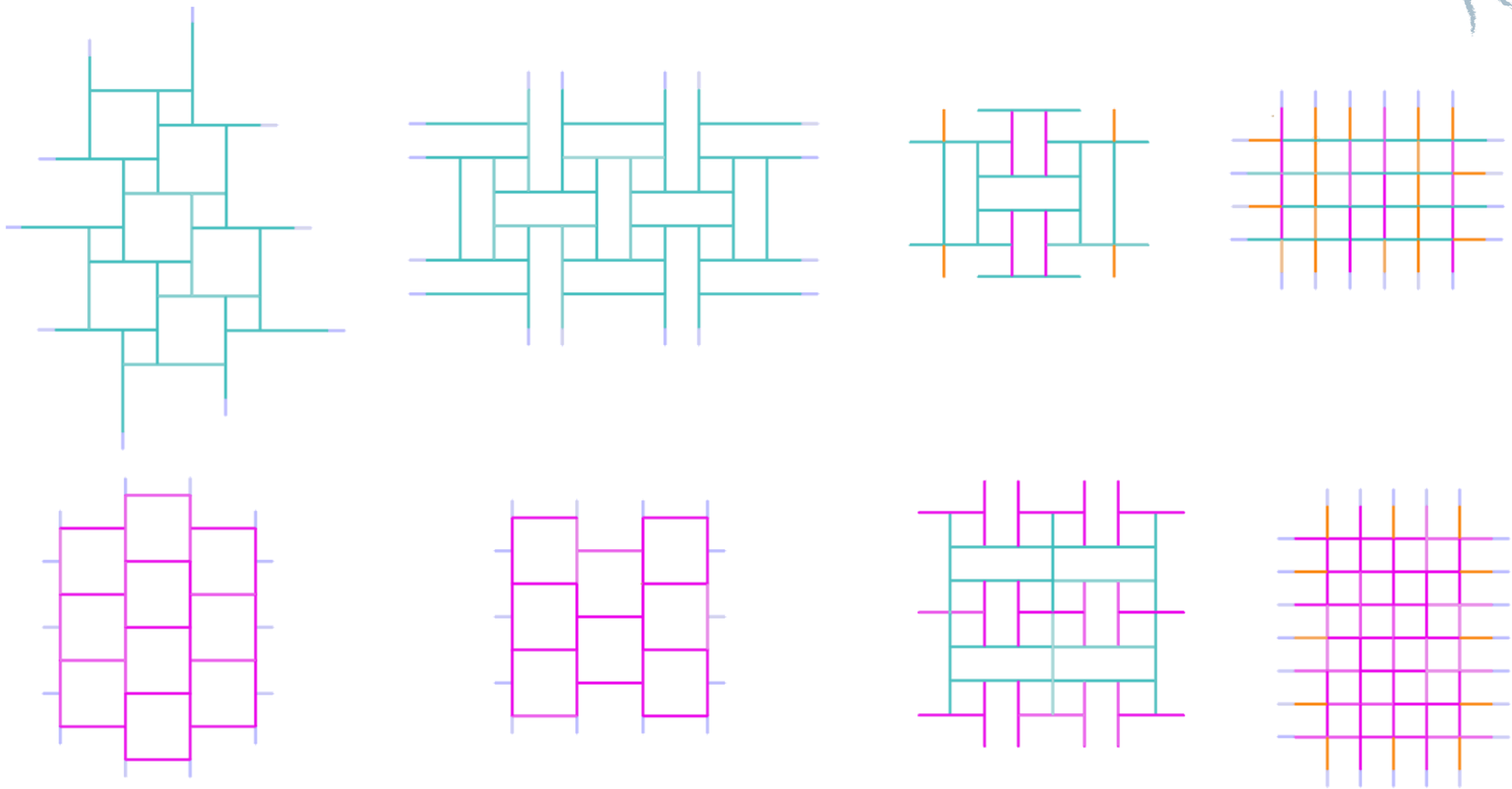




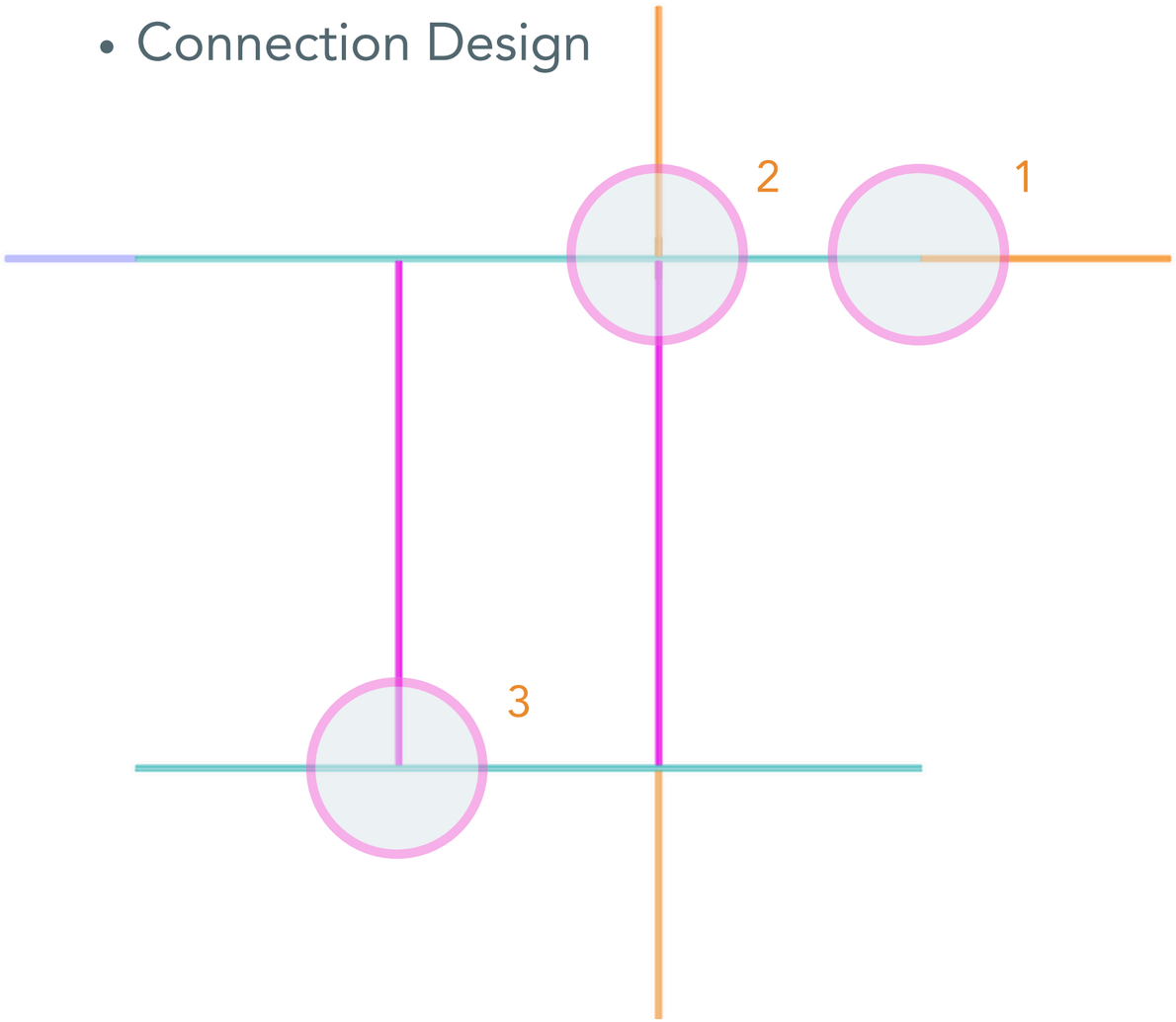


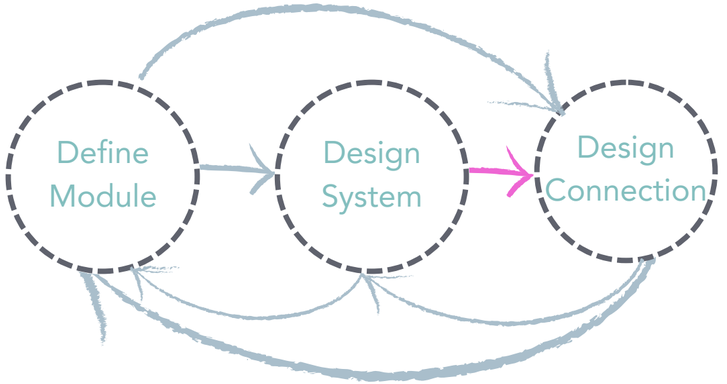
- Design System

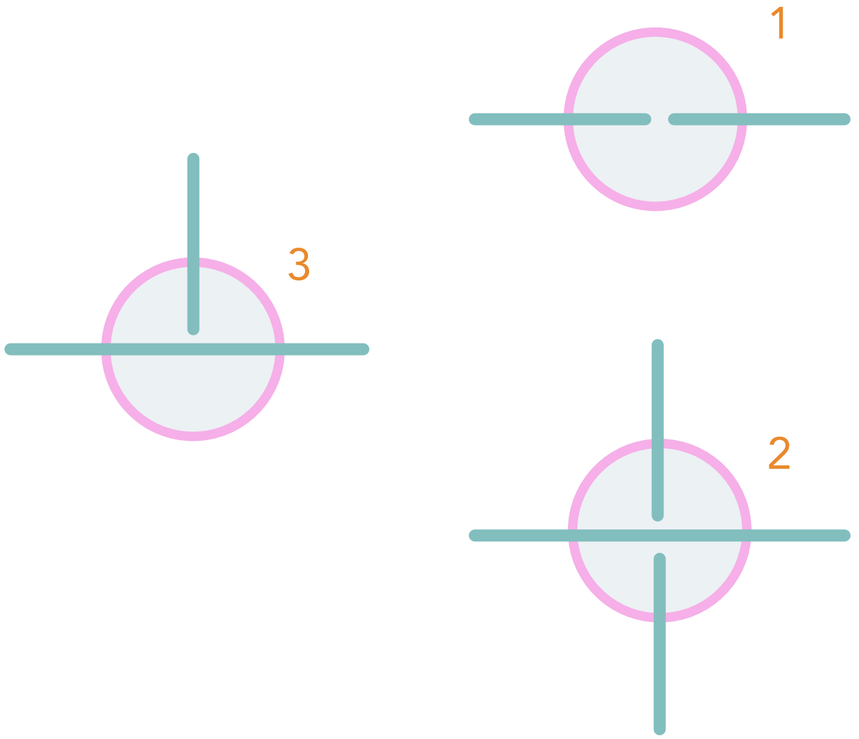




- Connection Design

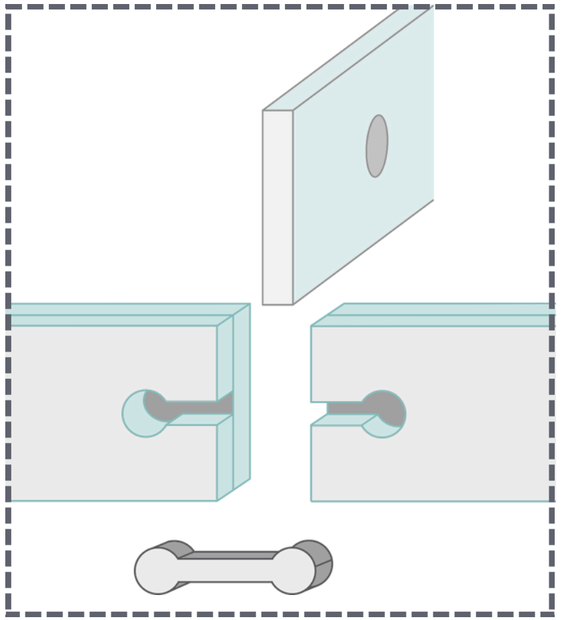


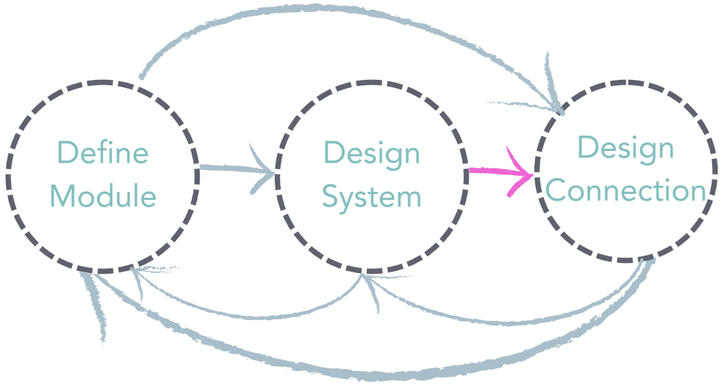


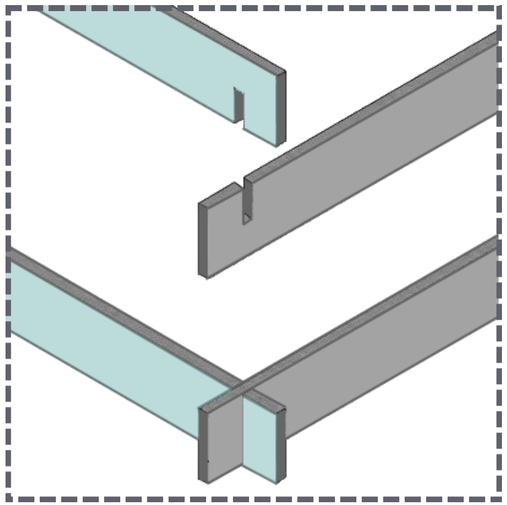


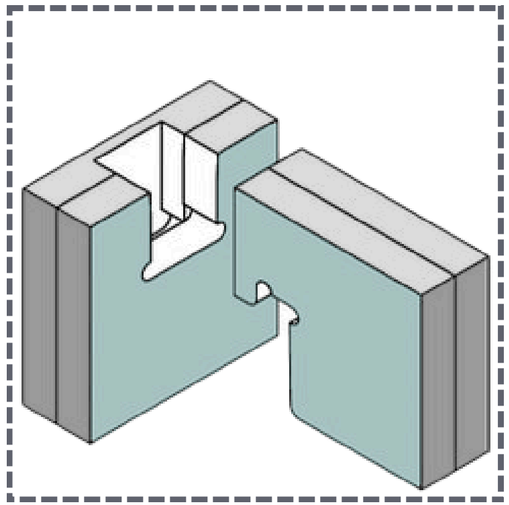
- Connection Design

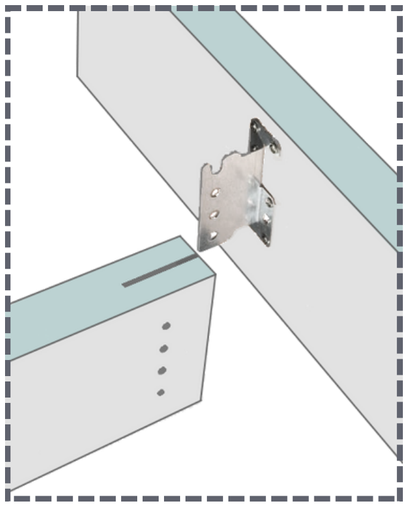
Alternatives

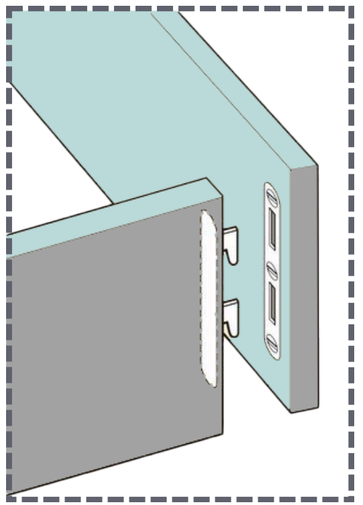


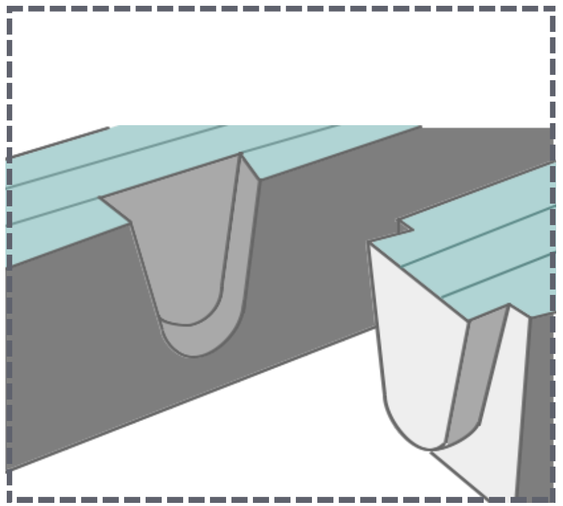






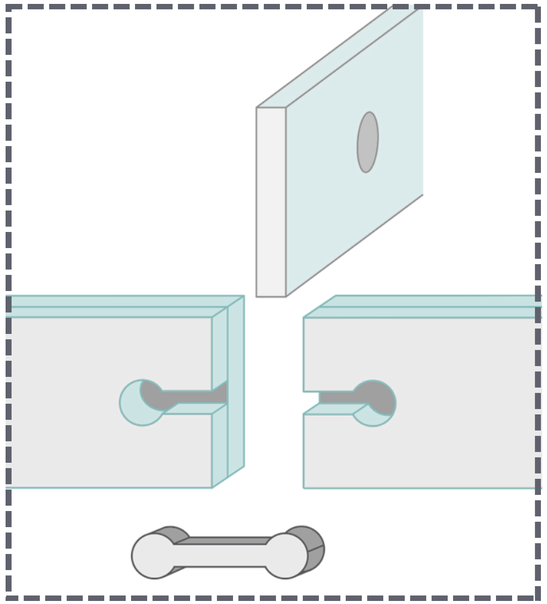


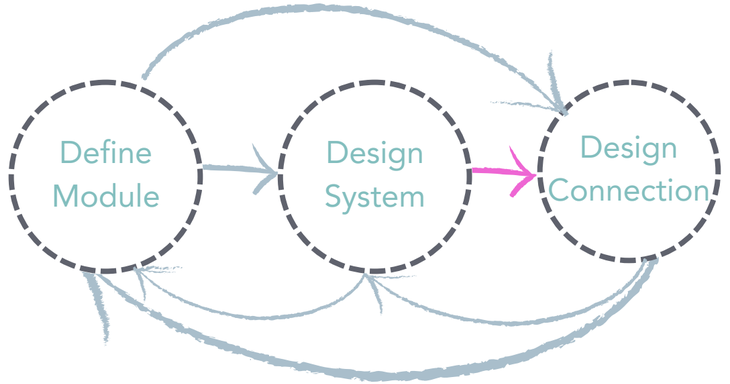




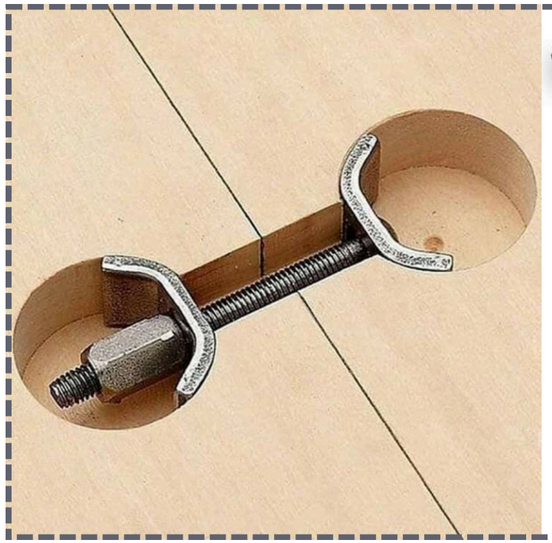
- Connection Design

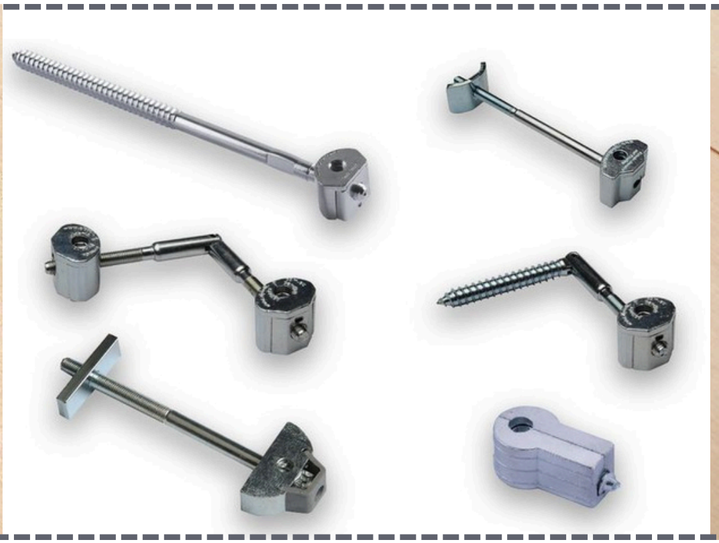
Inspiration

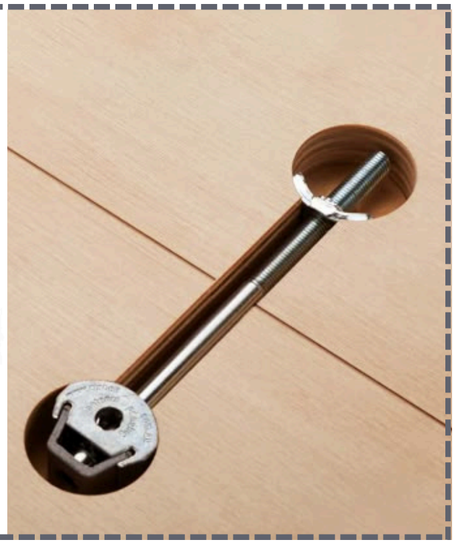




Strong connection,
not easy to loose track,
to ensure the toy train
running smoothly.



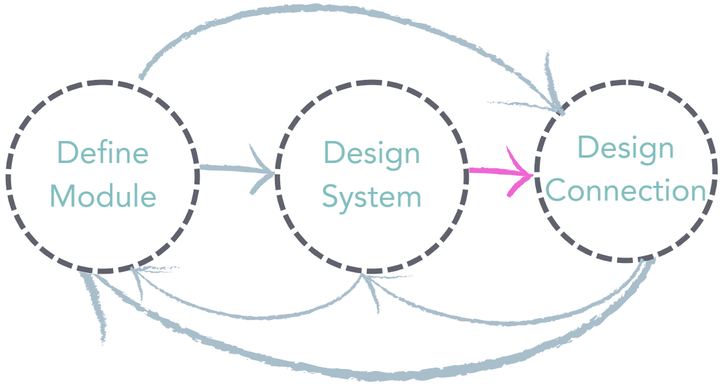


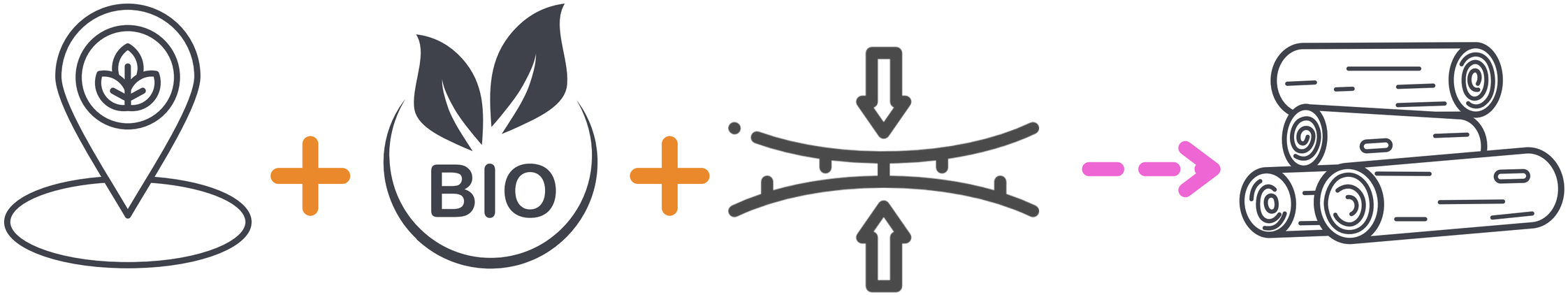


TU Delft

- Connection Design

Material Choice





Locally sourced

Bio Based & Sustainable

Young's modulus

Hard wood

- Connection Design

Material Choice

Primary criteria – must have

Young's Modulus ≤ 70 GPa

Compressive strength ≥ 5 MPa

Thermal expansion ≈ 3–10 × 10^{-6} K^{-1}

Manufactured to r ≥ 1.5 t fillets

- Young's modulus ≤ 70 GPa (slightly less than glass)
- Tensile/compressive strength ≥ design load × safety factor
- Thermal expansion close to glass (≈ 3–10 × 10^{-6} K^{-1})
- Can be machined or molded into smooth dog-bone geometry with r ≥ 1.5 t fillets

Secondary criteria – nice to have

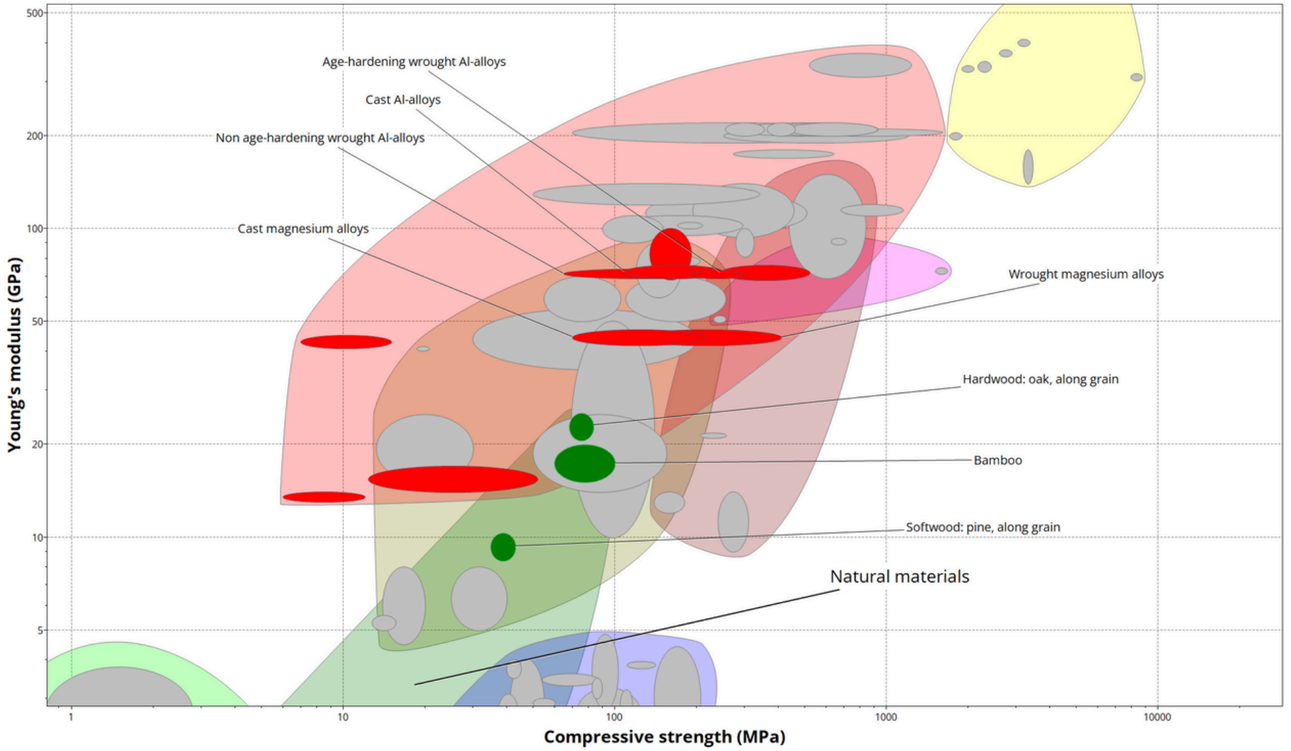
Low Carbon

Low Cost

High Recycling rate

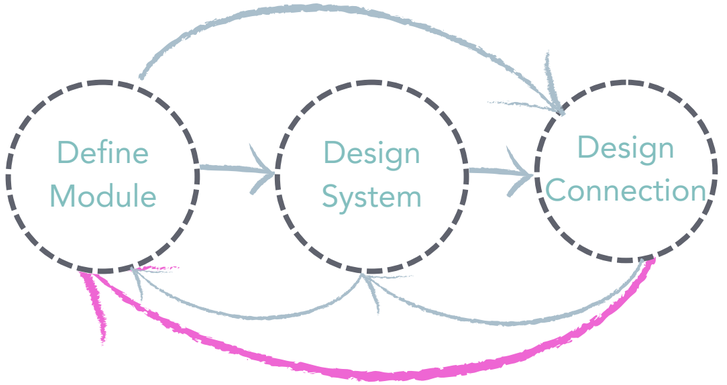
Durability

- Low embodied CO_2 per kg
- Competitive material and processing cost
- High recycled content / easy to recycle
- Durability against water, UV and fire

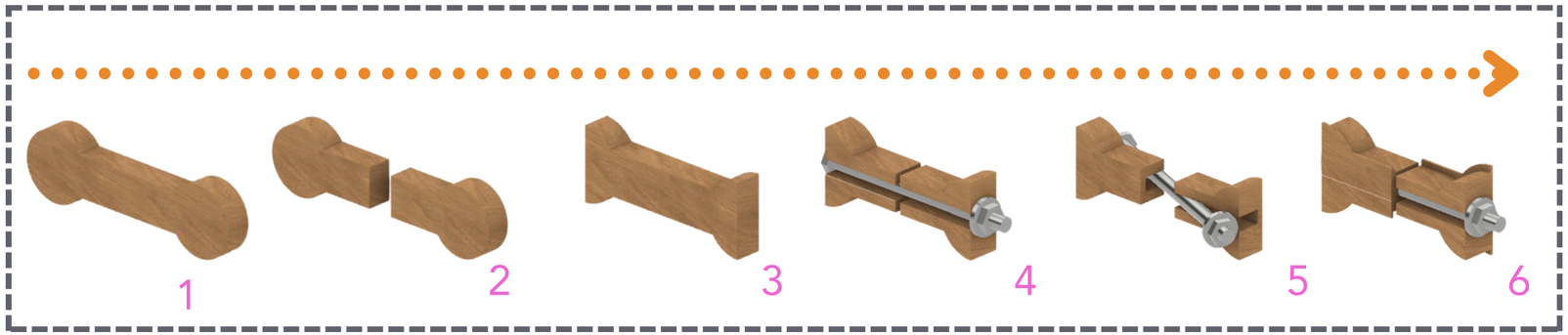


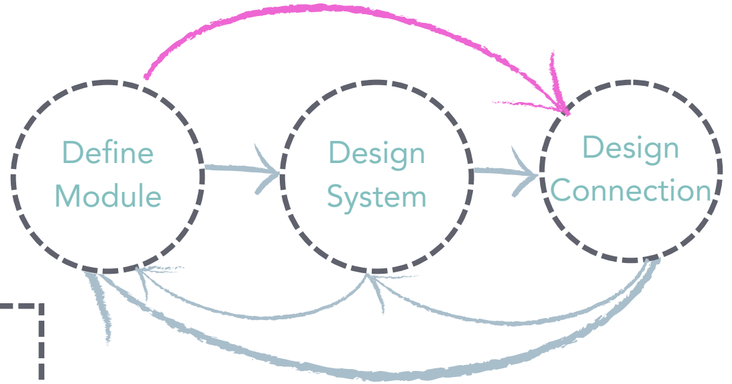
Material	Typical E (GPa)	Strength (MPa)	Pros	Watch-outs
6061/6082 aluminium	69 – 70	150 – 290	Near-perfect modulus match; easy CNC; mature fatigue data	CTE 22 × 10^{-6} K^{-1}—add 0.5–1 mm PU/PTFE washer
Magnesium alloys	≈ 45	160 – 240	Very light; E safely below glass; CNC + anodise	Needs coating against corrosion; limited façade record
Short-carbon-fibre PEEK	18 – 25	160 – 200	High temp, chemical and creep resistance; matte black finish	Expensive; mould-only, anisotropic if fibres mis-aligned
Hardwood oak (quartered, kiln-dried)	20 – 25	70 – 100 (parallel grain)	Renewable, very low CO_2; easy to machine; warm look	Anisotropic; moisture-sensitive—seal well; fire rating needs treatment

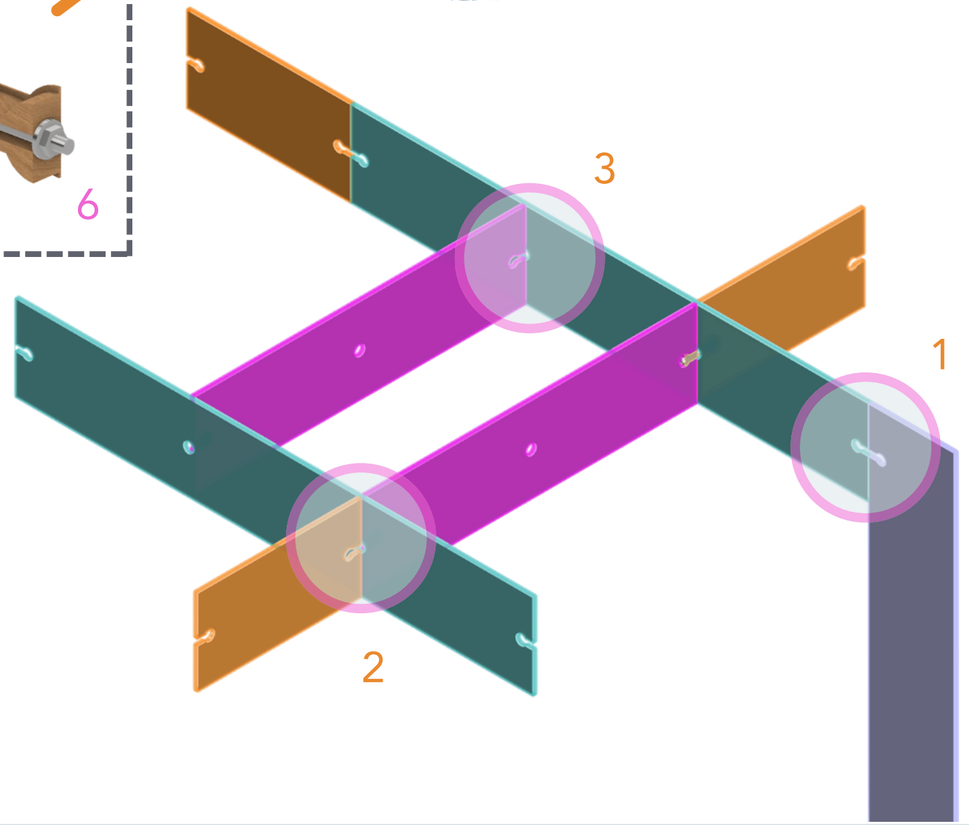
- Revise Modules

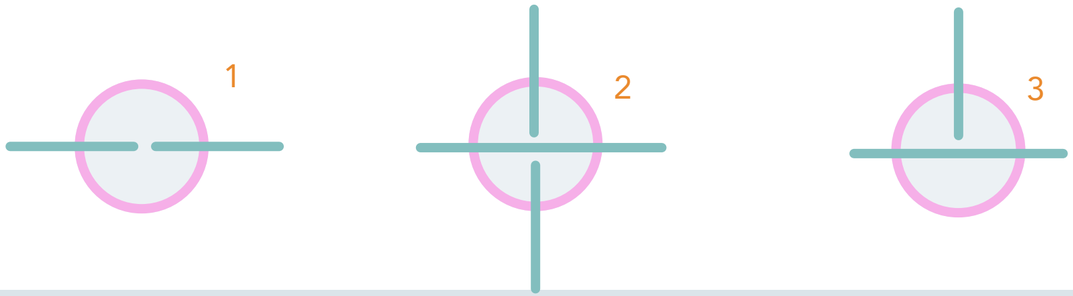


- Connection Design

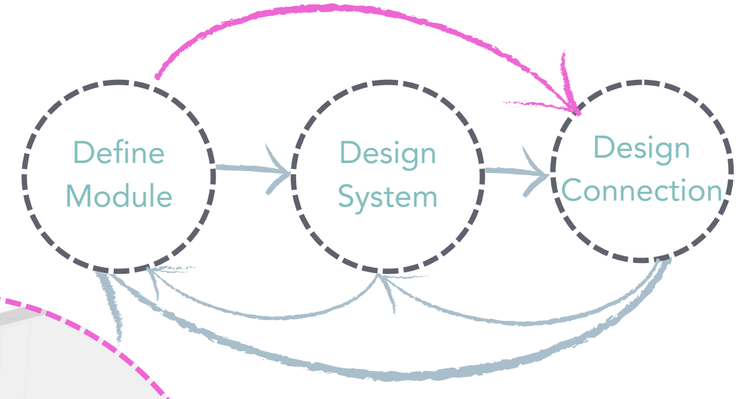


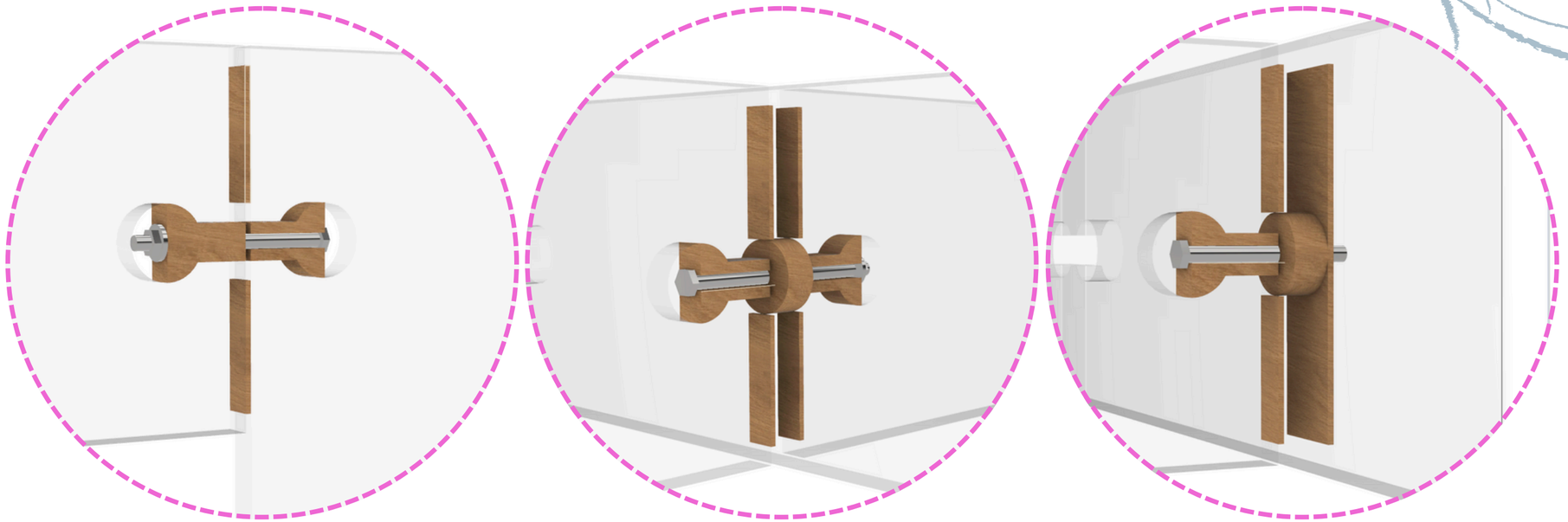


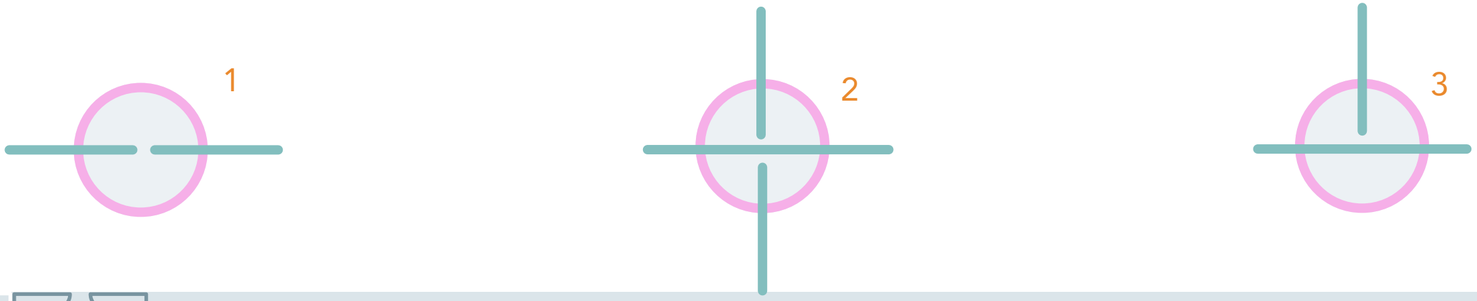




- Connection Design

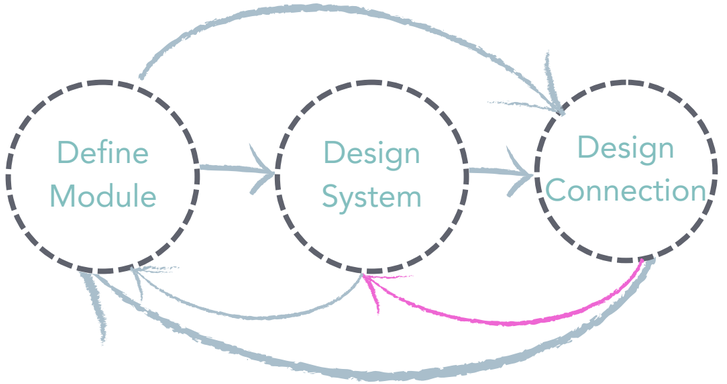


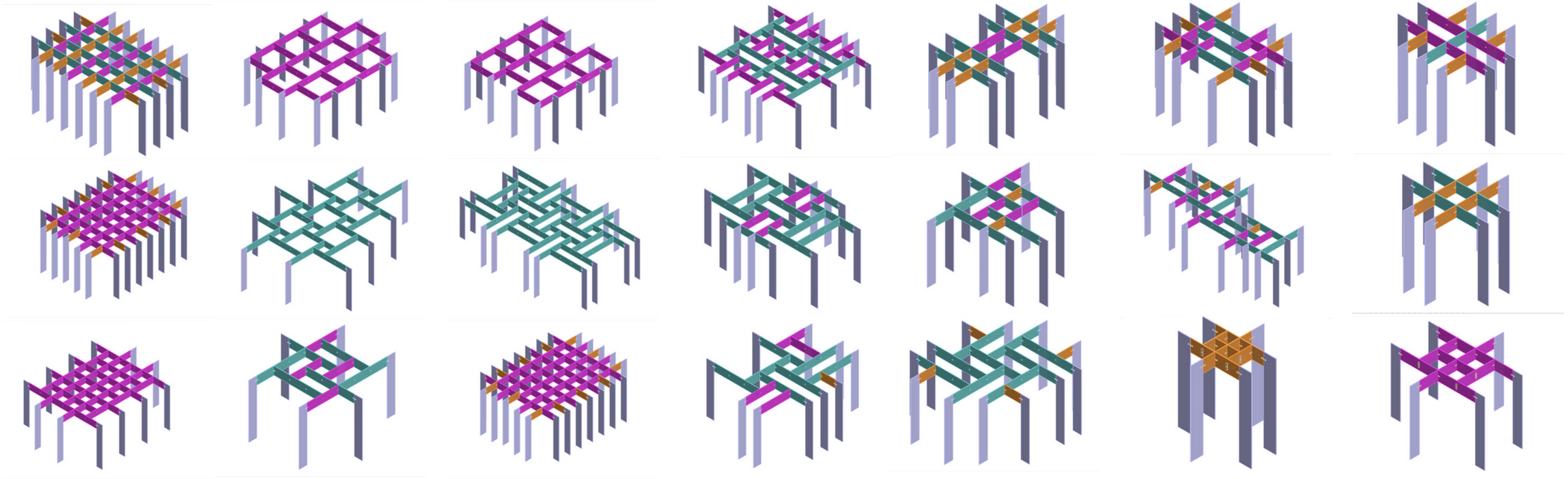


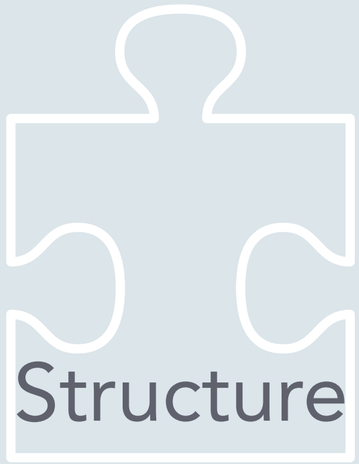


TU Delft

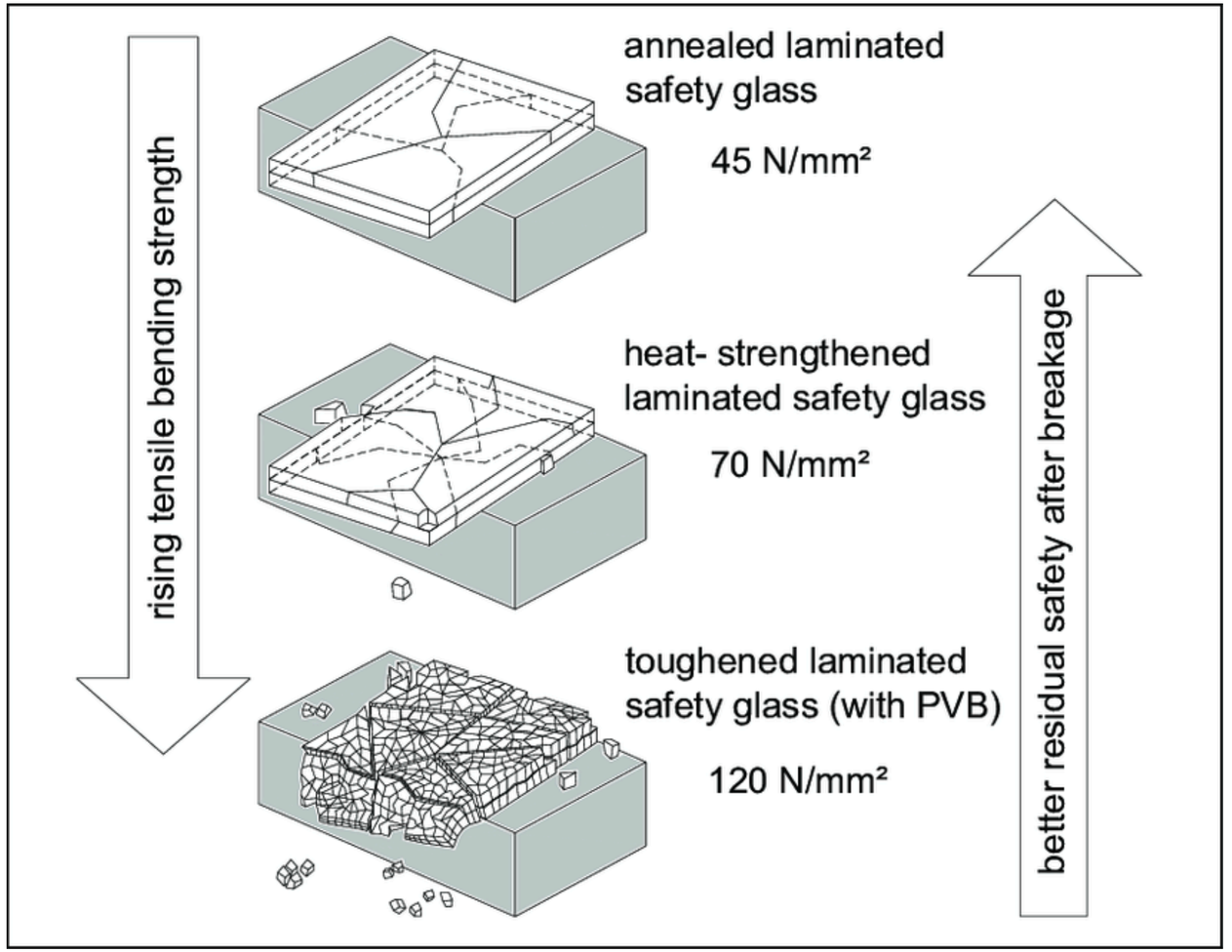
- Design System






Structure

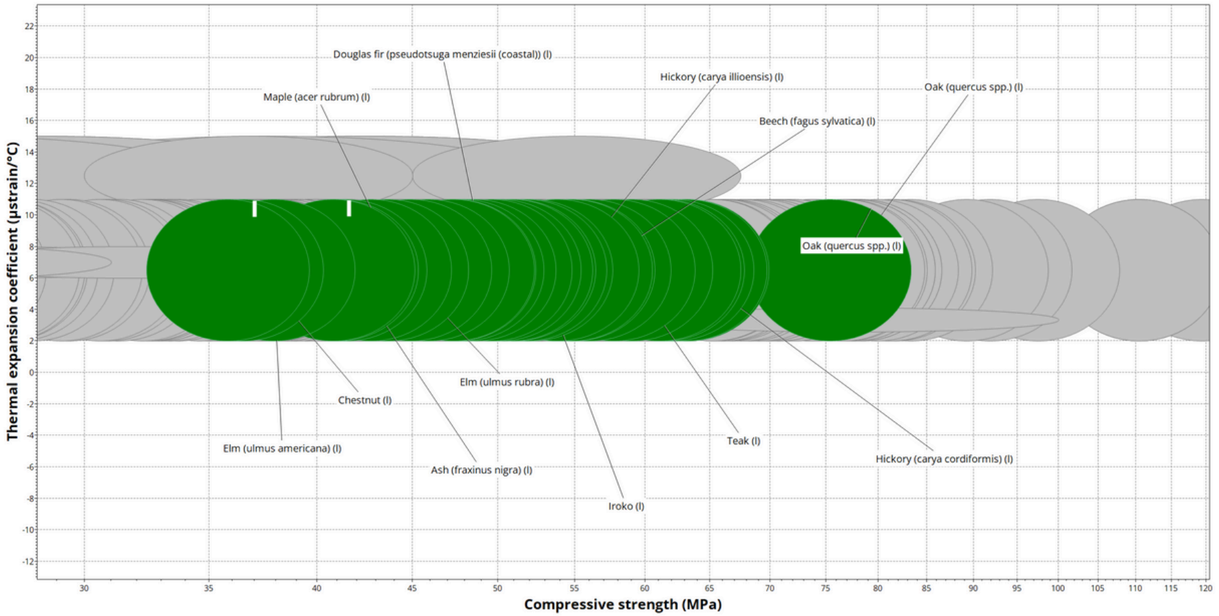
- Structural Analysis



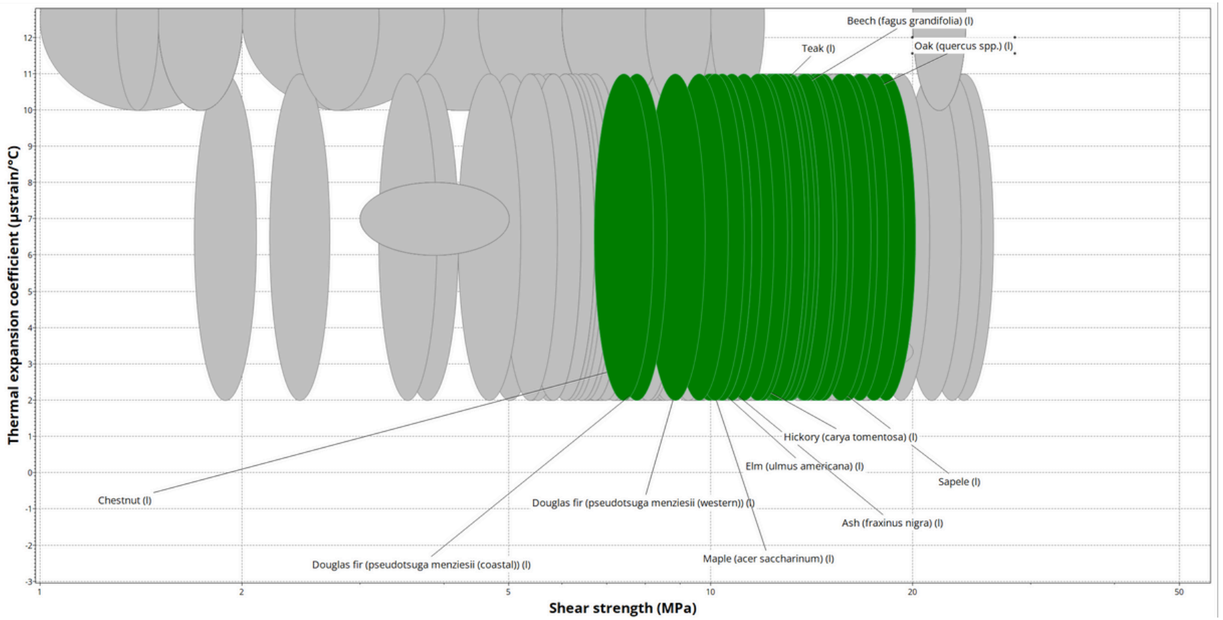
- Structural Analysis

Longitudinal Direction

Compressive Strength Oak:80 MPa



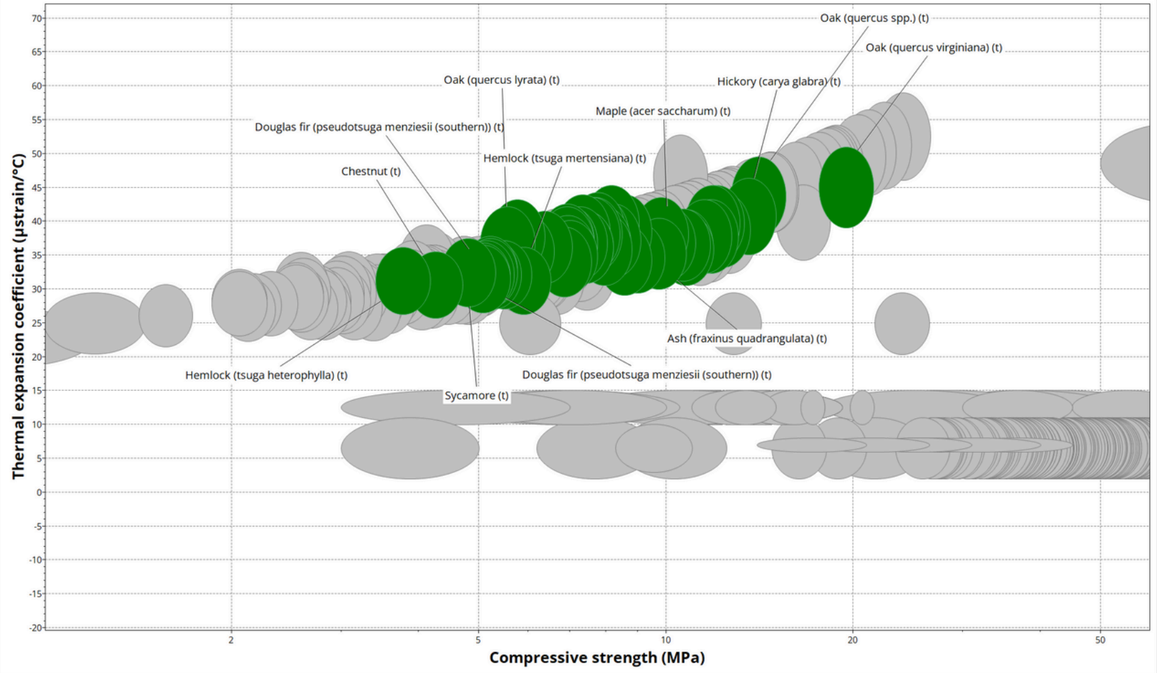
Shear Strength Oak:18 MPa



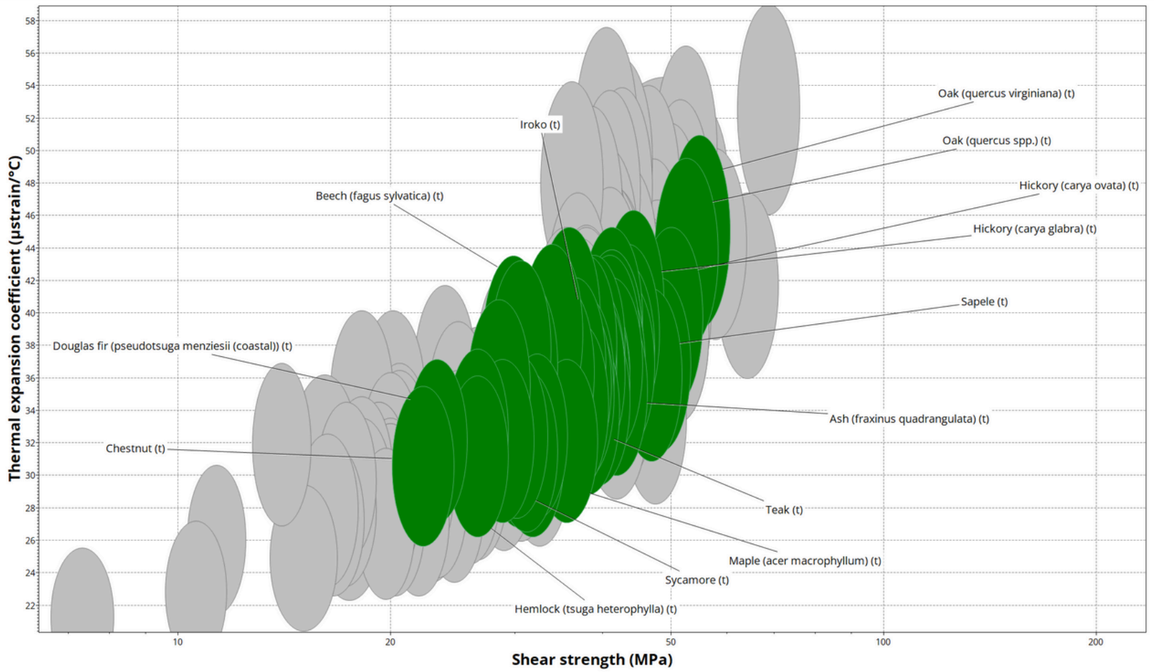
- Structural Analysis

Transversal Direction

Compressive Strength Oak:20 MPa

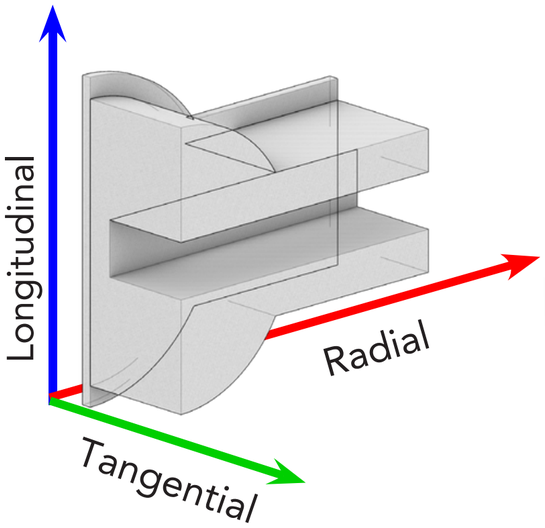


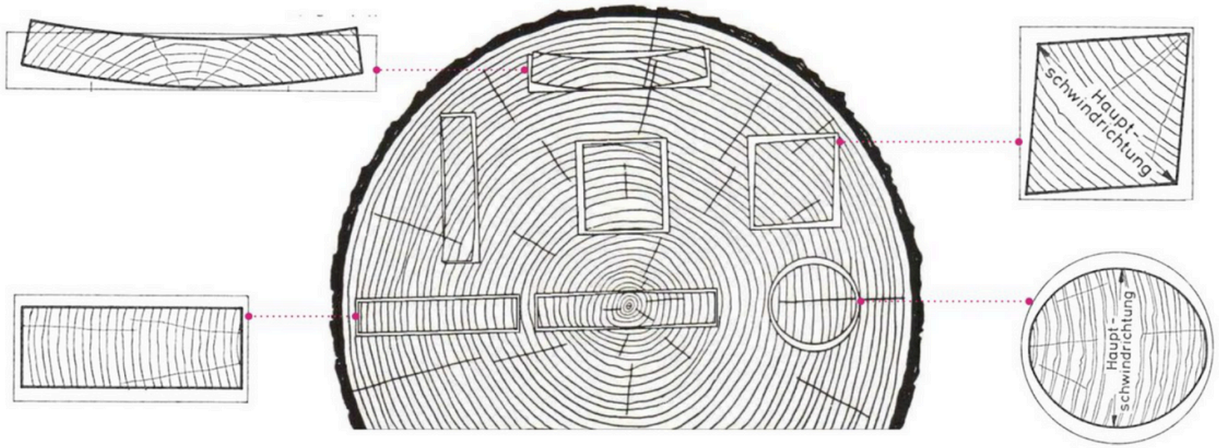
Shear Strength Oak:55 MPa

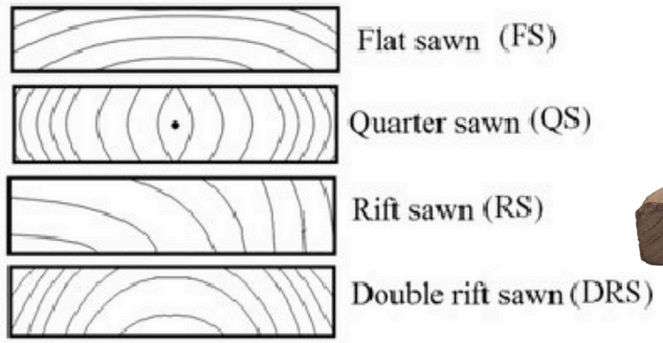


- Structural Analysis

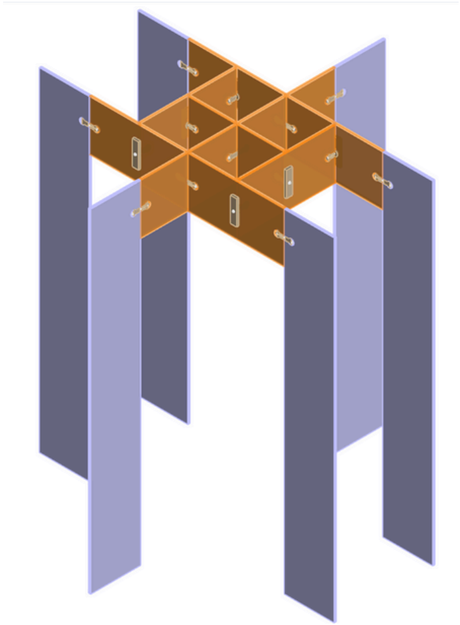
Choosing Direction of wood



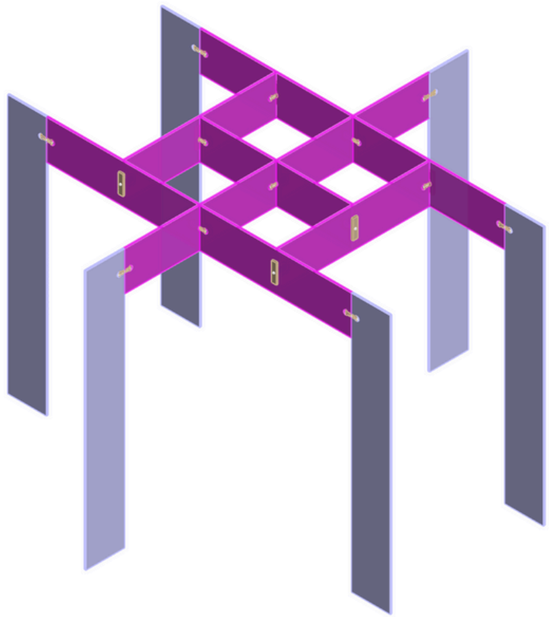




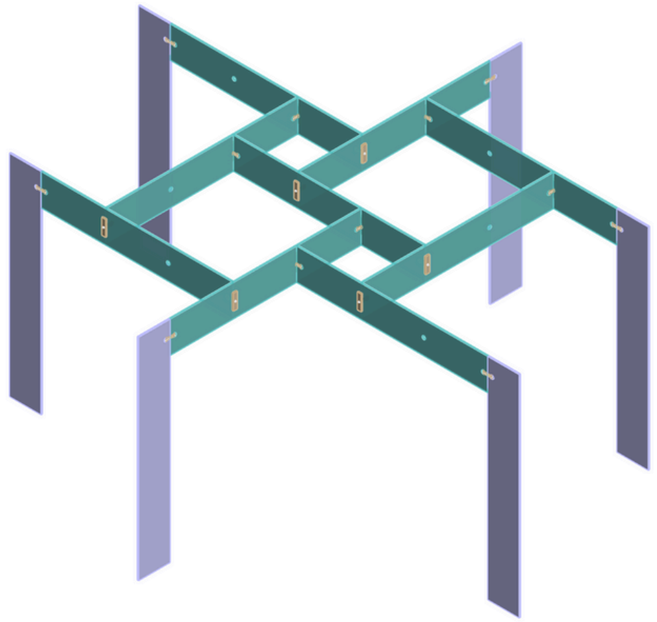
- Structural Analysis



Module Size S: 600mm

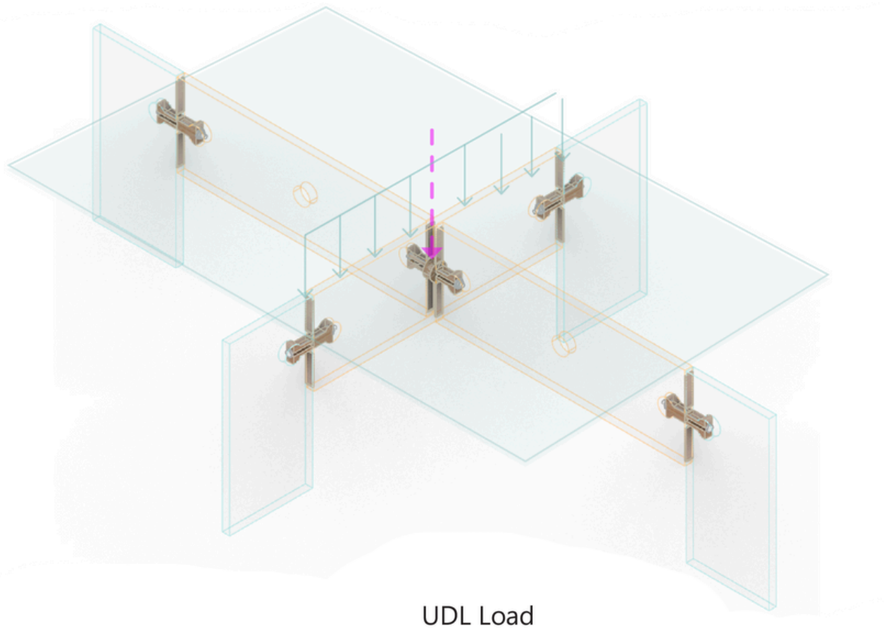


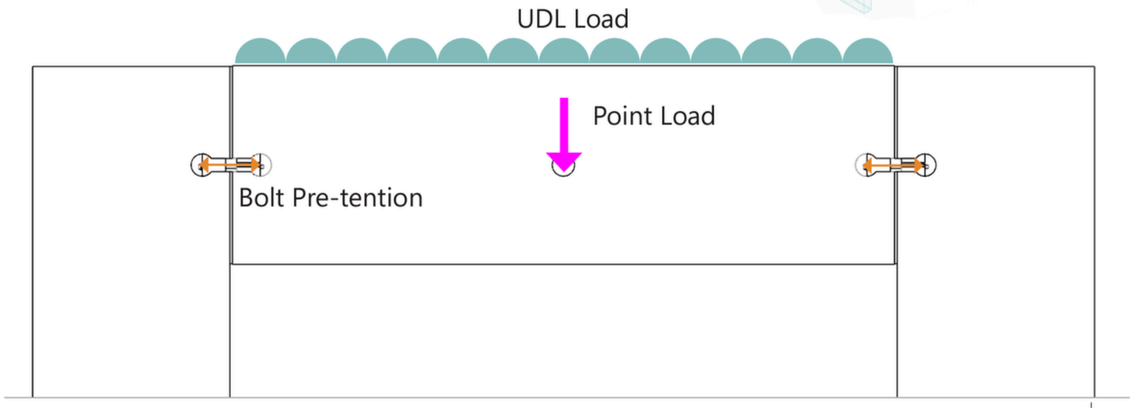
Module Size M: 1200mm



Module Size L: 1800mm

- Structural Analysis





$$F = \mu \cdot N$$

Frictional Force

friction coefficient

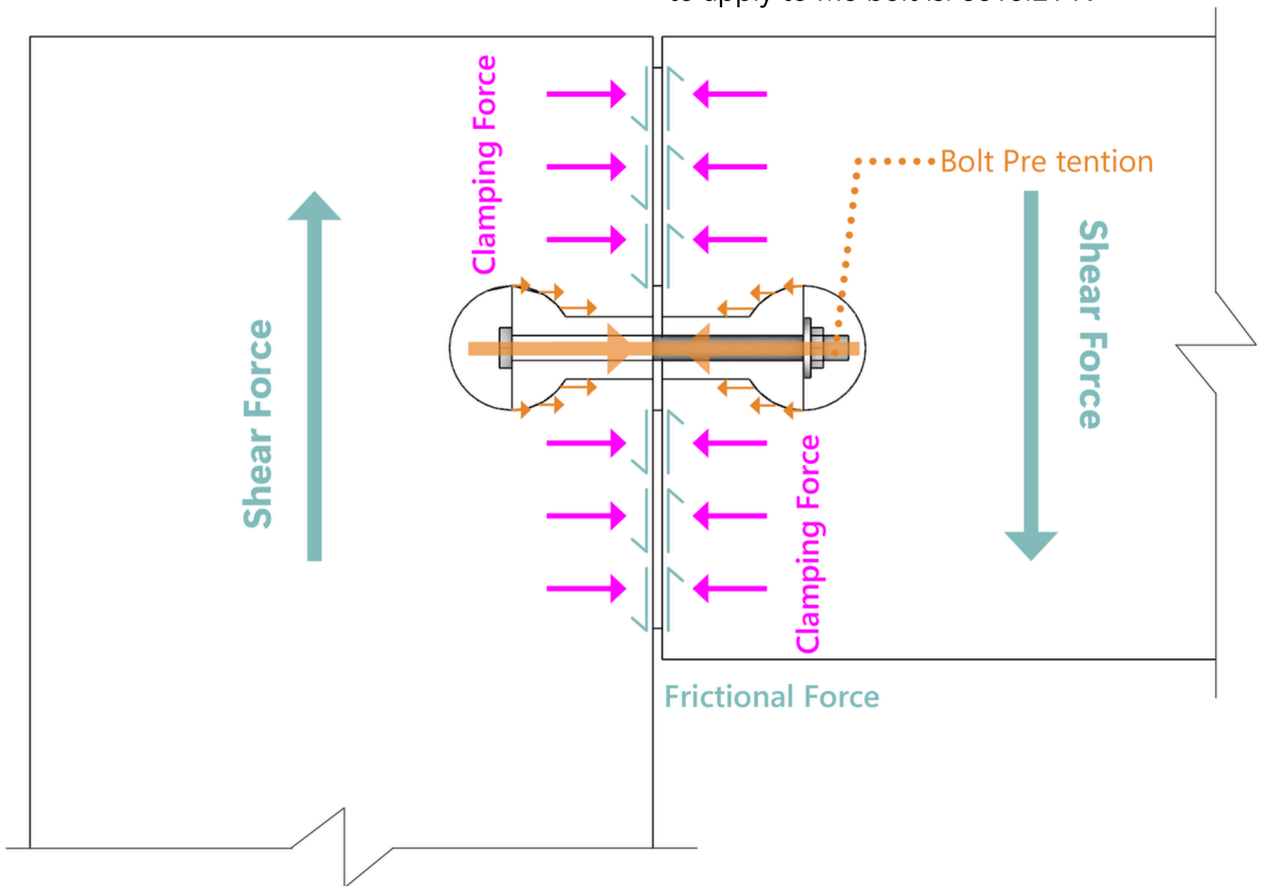
Normal Force

UDL Loads converted to point load=0.117KN

Point loads= 0.170 KN

Total loads= 0.285KN

Then the maximum preload allowed to apply to M8 bolt is: 8818.21 N



- Structural Analysis

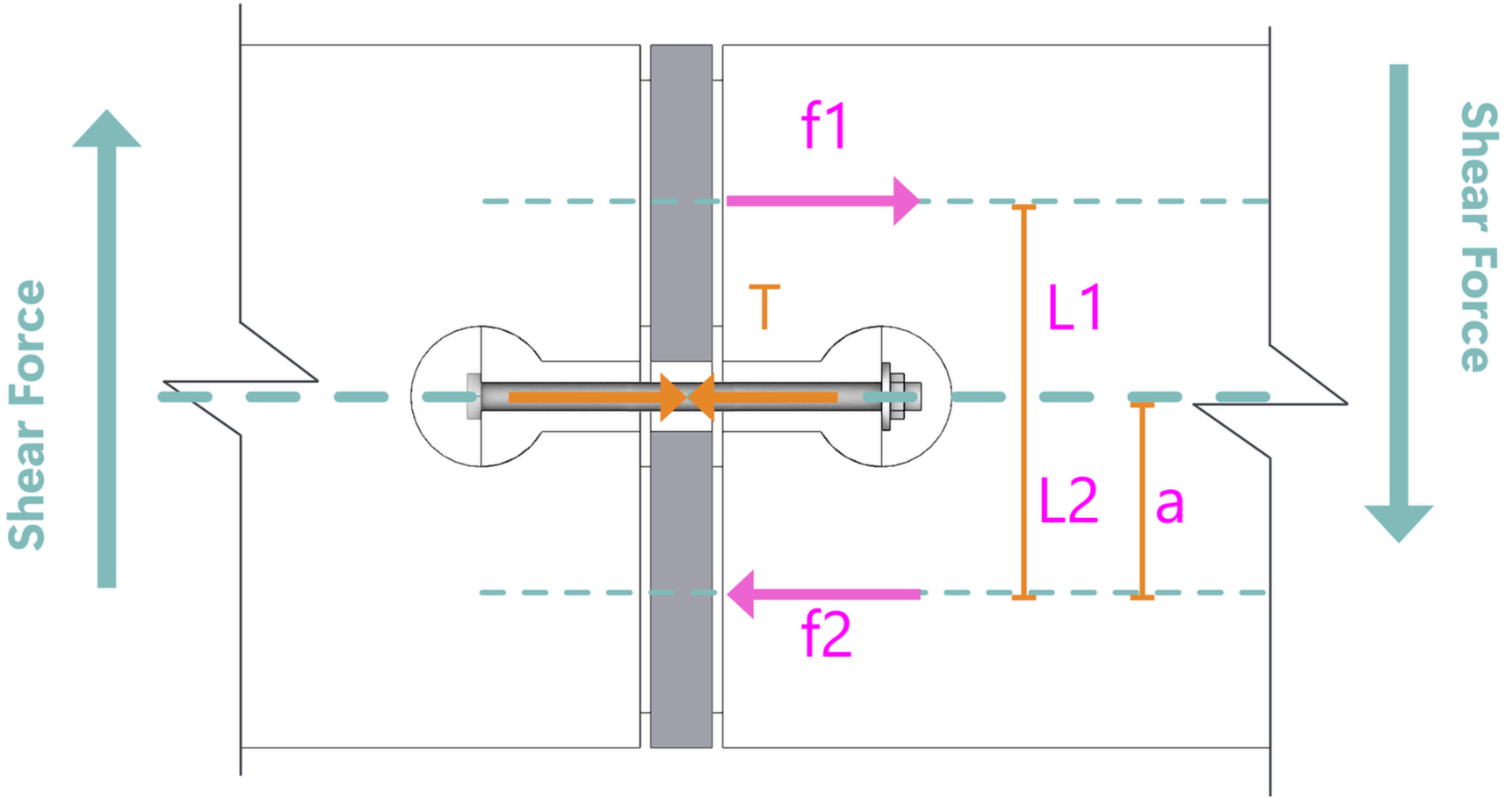
Ms = F * Length of beam /4
0.285 KN * 0.6 M /4 = 0.042 KNm

f1 = f2 = Ms / L1 or L2

0.042 KNm / 0.1m = 0.42 KN

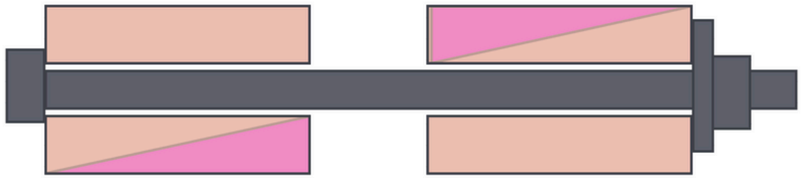
Preload = f1/0.4

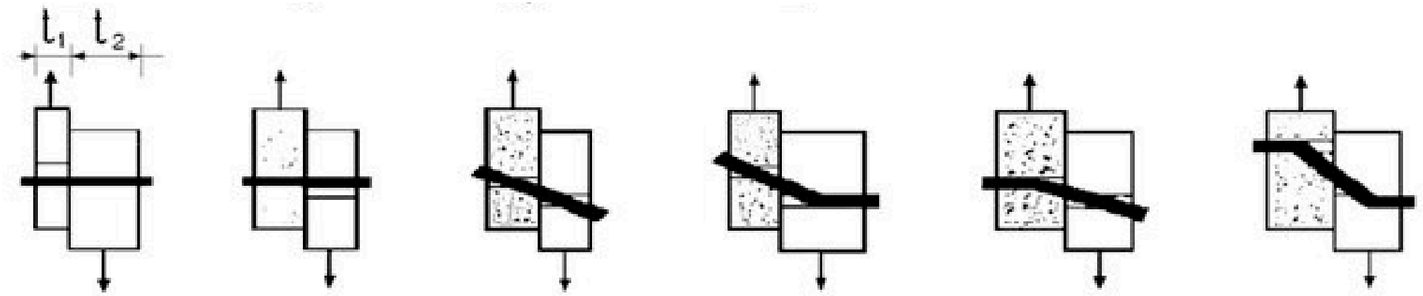
0.42 KN / 0.4 = 1.068 KN

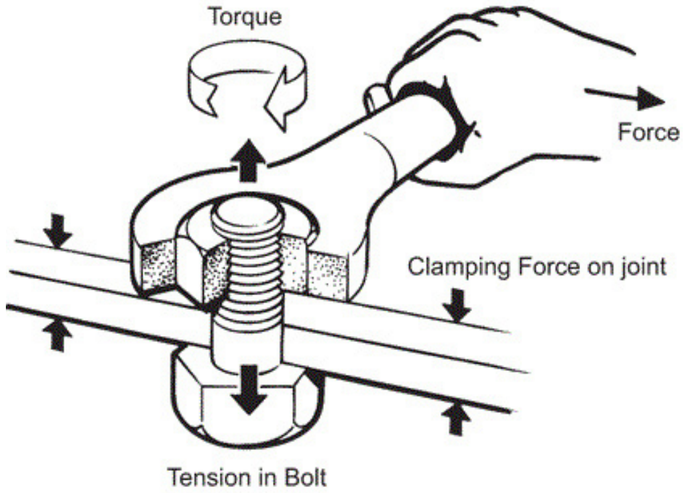


- Structural Analysis

The parts of wooden connectors resisting maximum loads







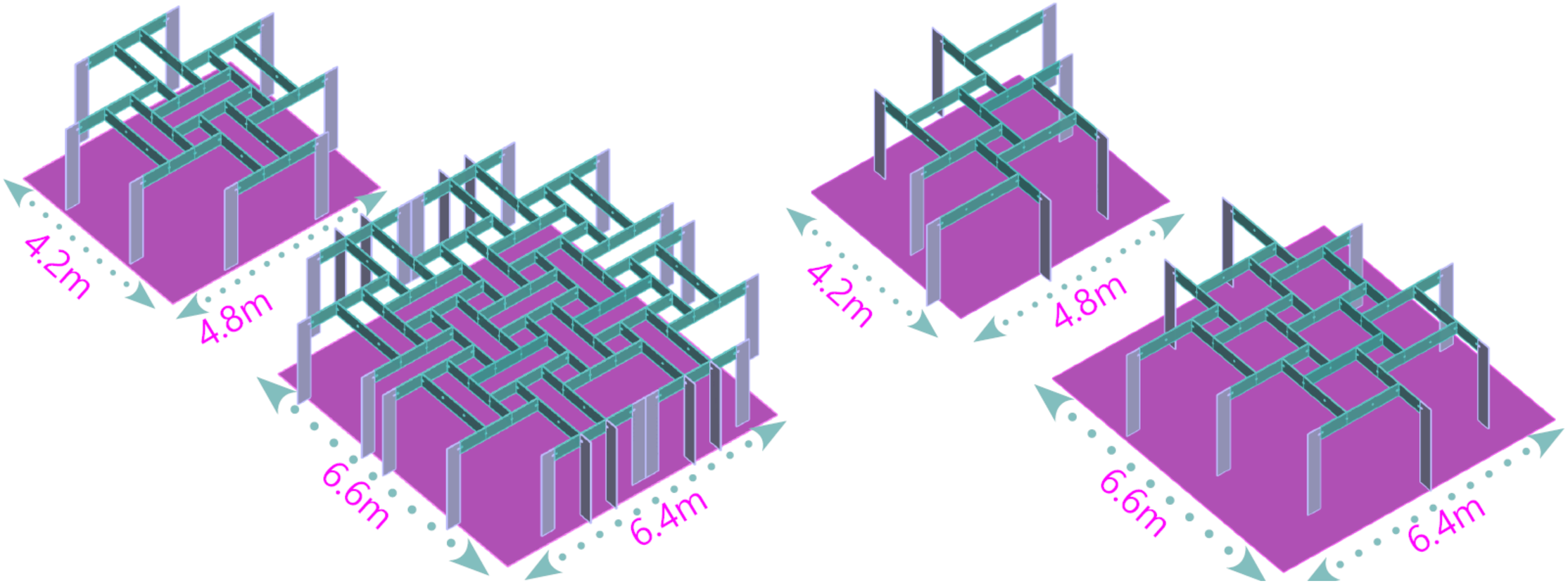
$$T = K \times F \times d$$

- F = normal force
- T = torque
- K = torque coefficient
- d = bolt diameter

T = 0.2 * 1068 *8 = 1.708Nmm

- Structural Analysis

  Macro Analysis



- In reality, safety factor by doubling the nominal glass thickness to 16 mm—to account for accidental breakage and unforeseen loads

Governing formulae

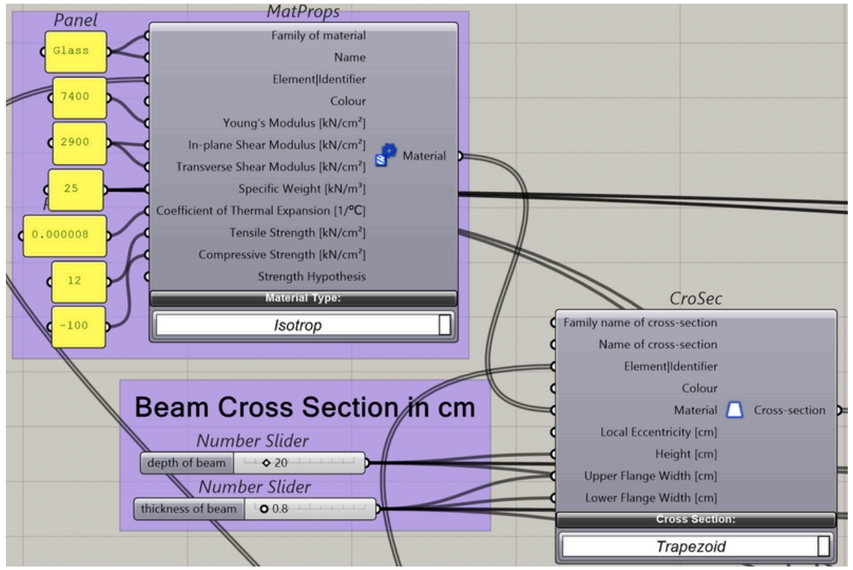
$$C_t = \frac{F}{\Delta}, \qquad C_r = \frac{2\,\mu N r}{\theta}, \qquad \theta = \frac{\Delta}{2r}$$

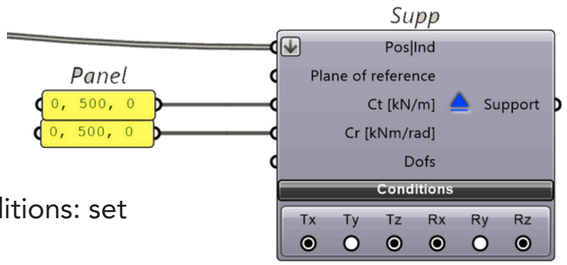
where

μ = 0.40 (static friction glass–oak)

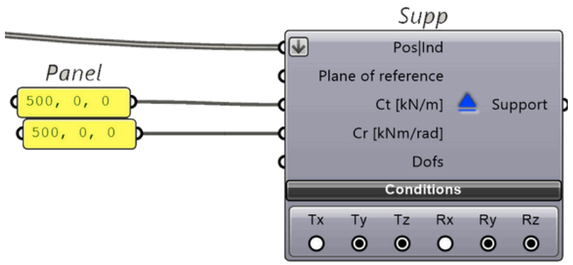
N = 3.5 kN (bolt preload from 5.5 N·m tightening torque)

r = 57.5 mm (half the 115 mm pad spacing)

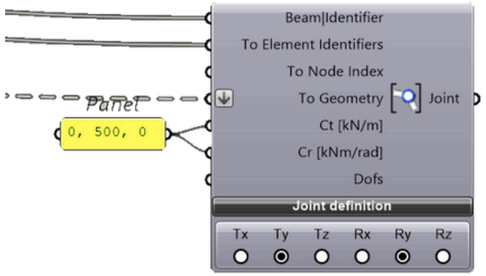


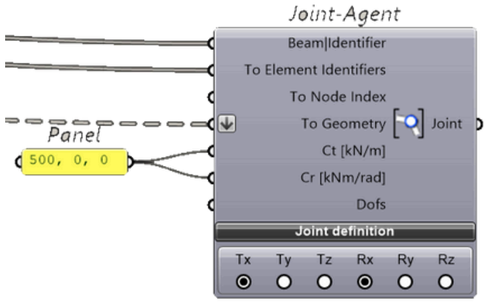


Support conditions: set to be fixed



joint conditions: set to be released





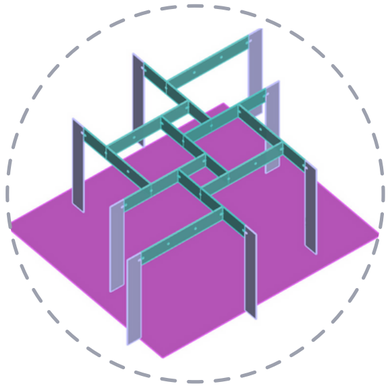
- Structural Analysis

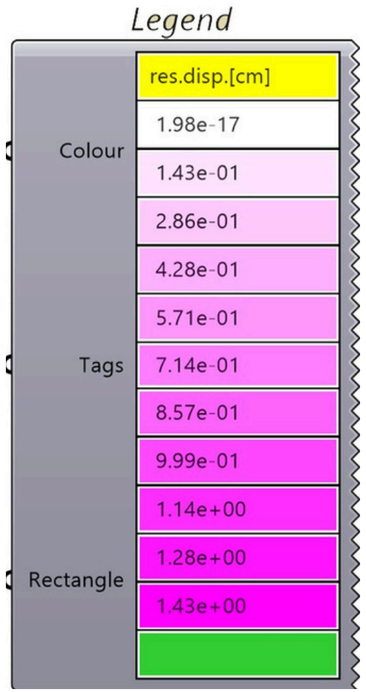
Macro Analysis

Alternative Three:

Pergola Design Span

4.2 * 4.8m



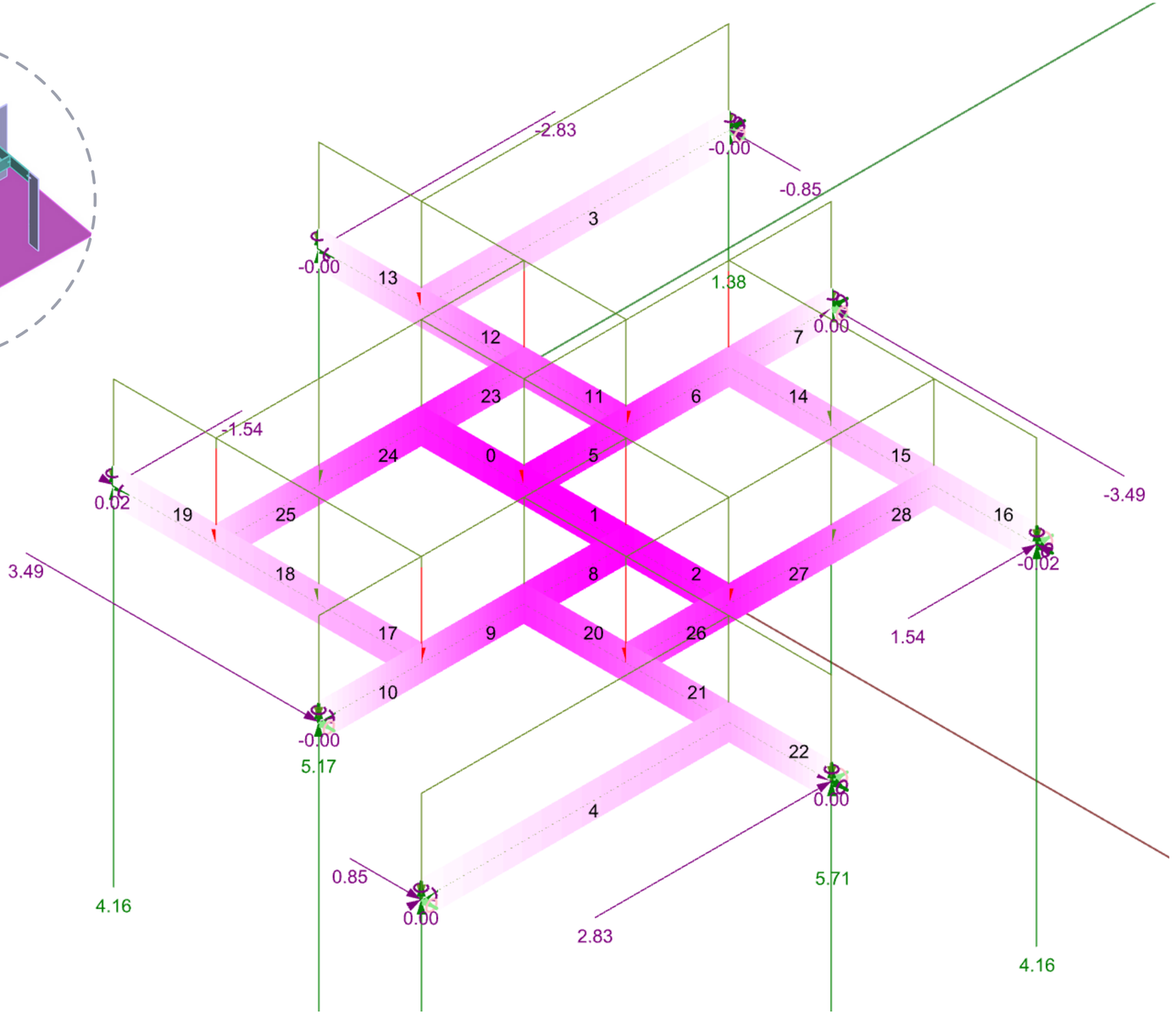


Allowable deflection Span/300:

480 / 300 = 1.6 cm

Actual deflection: 1.43 cm

1.6 > 1.4 Safe ✓



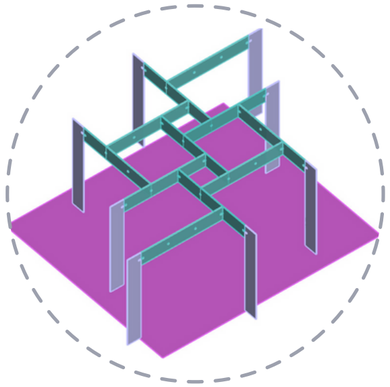
- Structural Analysis

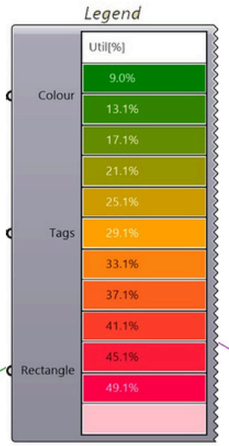
Macro Analysis

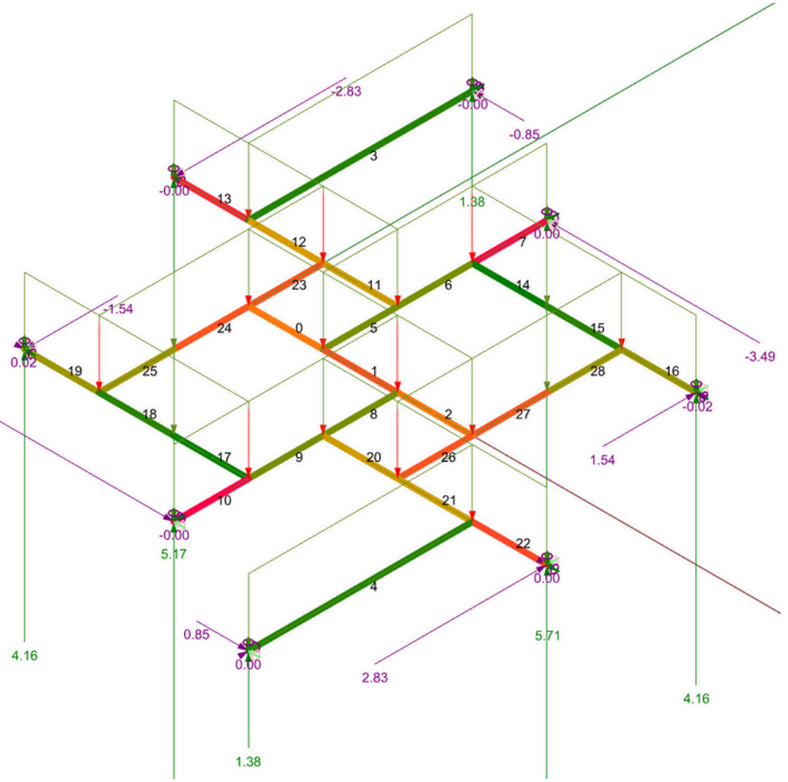
Alternative Three:

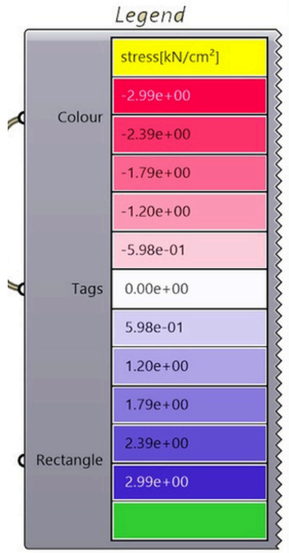
Pergola Design Span

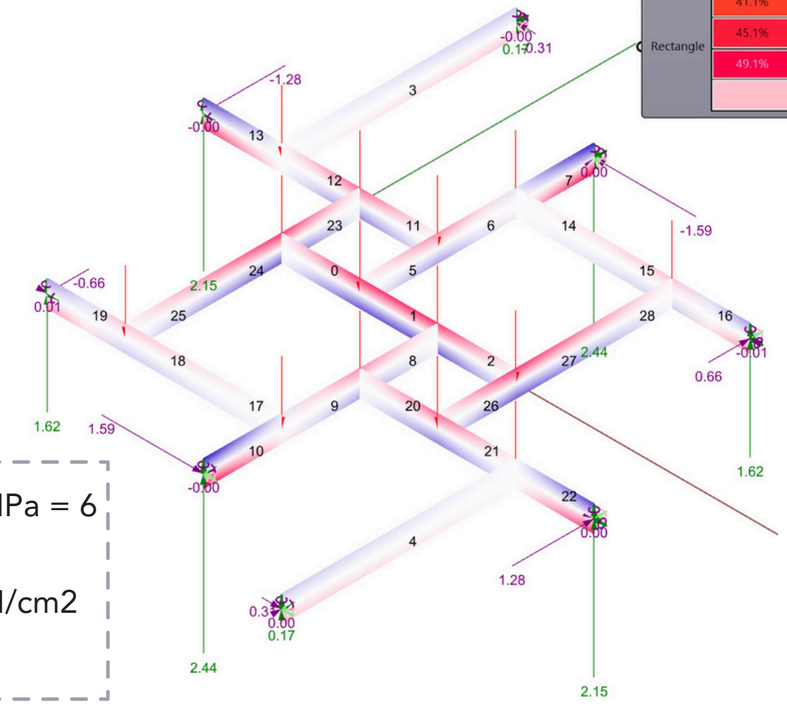
4.2 * 4.8m











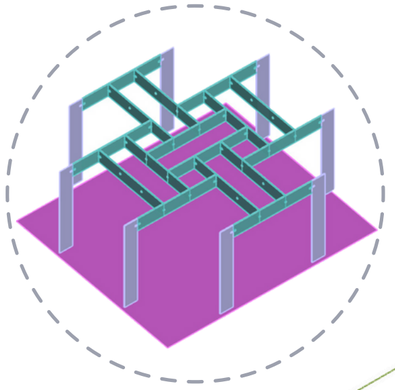
Allowable Stress: 60MPa = 6 KN/cm2

Actual Stress: 2.99 KN/cm2

6 > 3 Safe ☑

- Structural Analysis

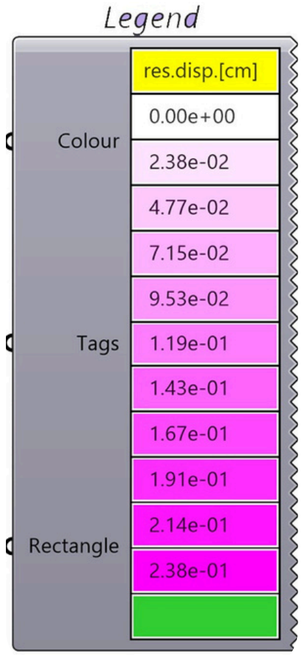
Macro Analysis

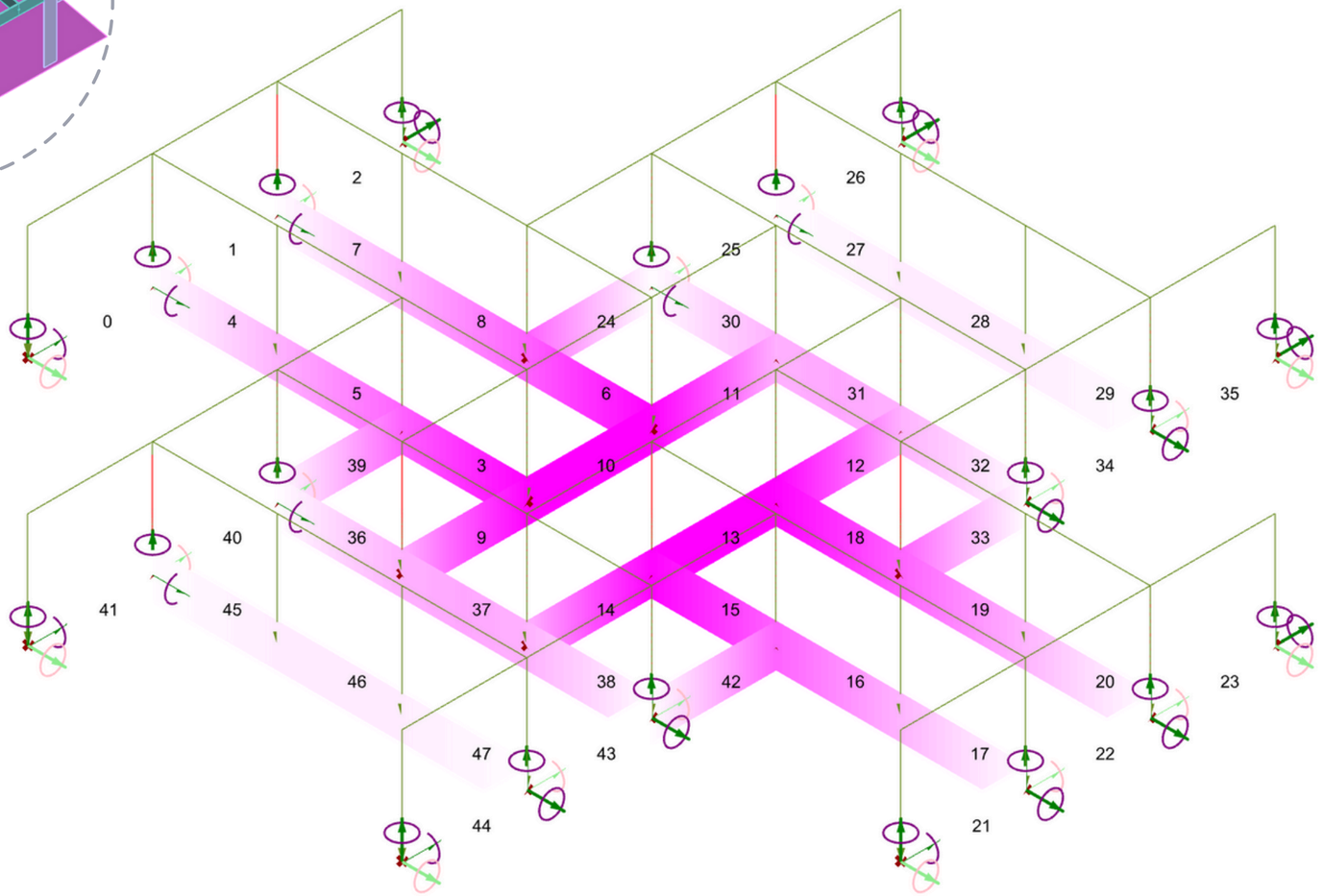


Alternative Three:

Pergola Design Span

4.2 * 4.8m





Allowable deflection

Span/300: 480 / 300 = 1.6 cm

Actual deflection: 0.238 cm

1.6 > 0.238 Safe ☑

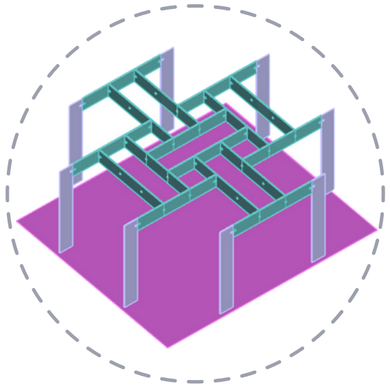
- Structural Analysis

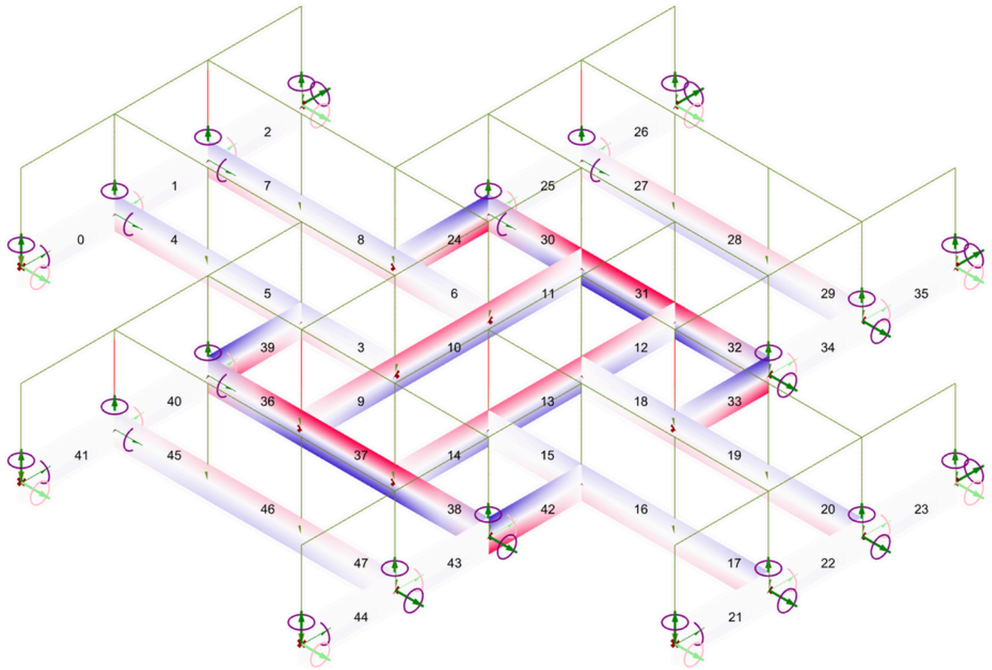
Macro Analysis

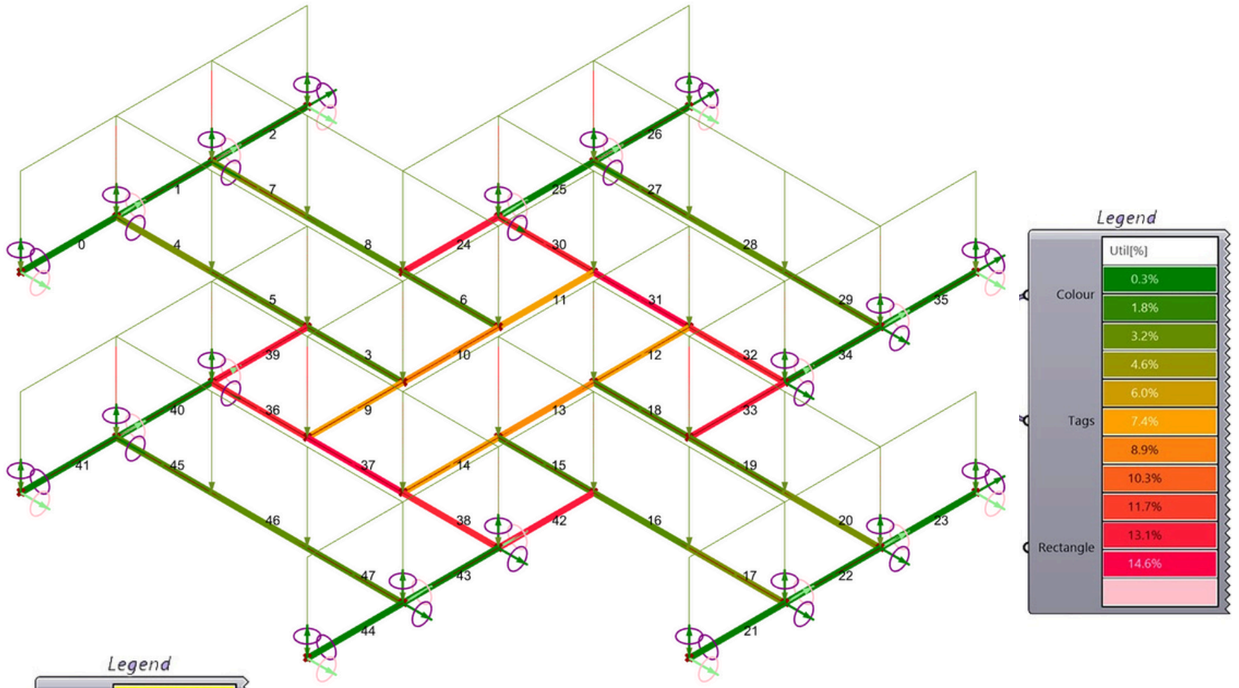
Alternative Three:

Pergola Design Span

4.2 * 4.8m







Allowable Stress: 60MPa = 6 KN/cm2

Actual Stress: 1.78 KN/cm2

6 > 1.78 Safe ☑

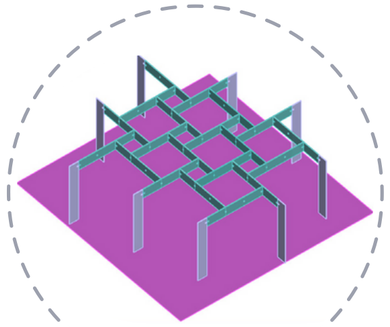
- Structural Analysis

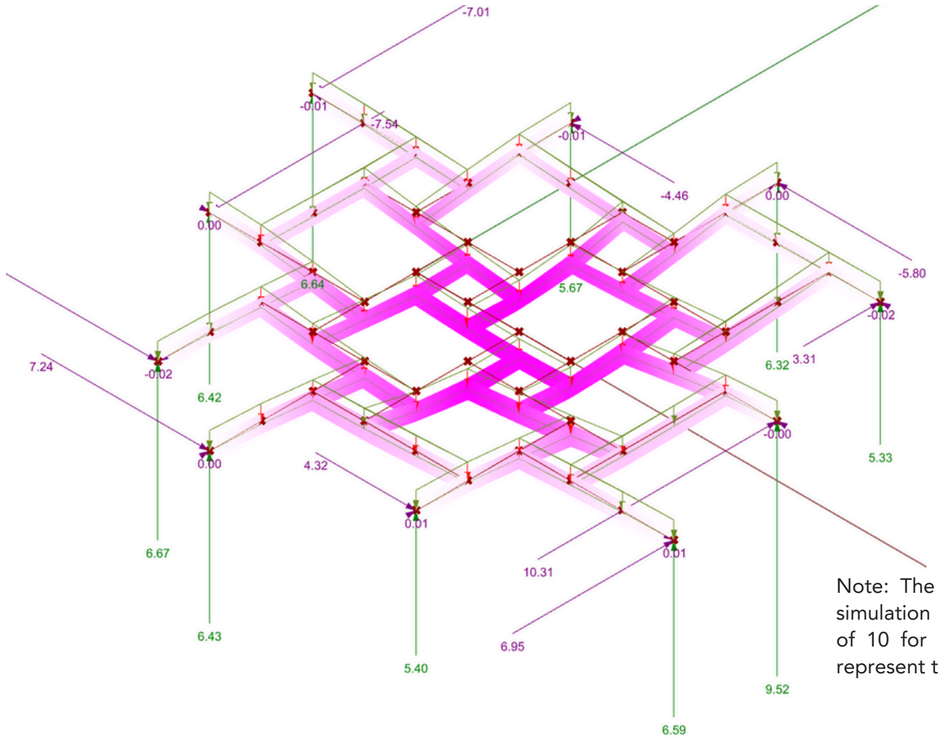
Macro Analysis

Alternative Four:

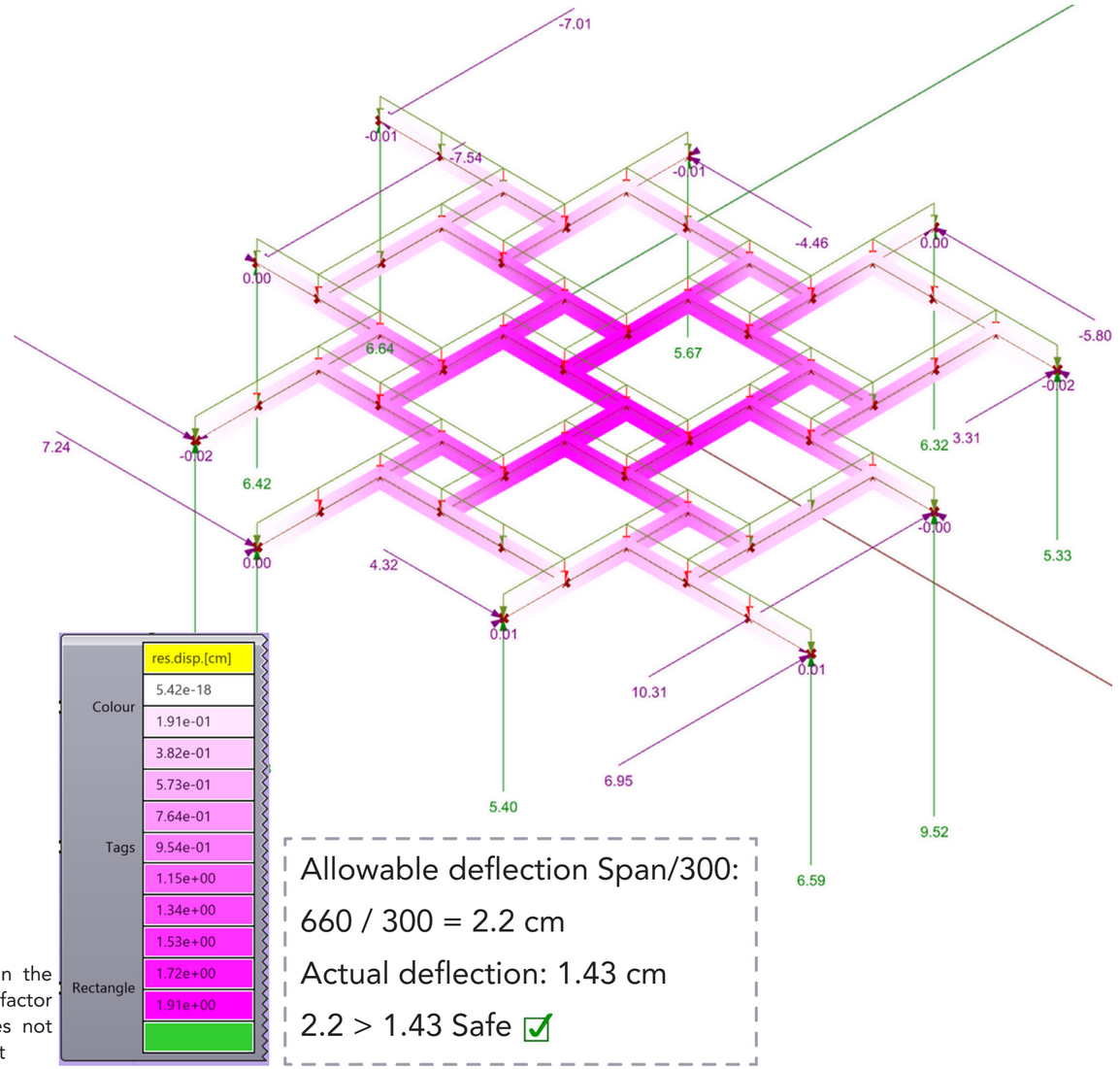
Pergola Design Span

6.6 * 6.4m





Note: The deformation shown in the simulation is exaggerated by a factor of 10 for visual clarity and does not represent the actual displacement



Allowable deflection Span/300:

660 / 300 = 2.2 cm

Actual deflection: 1.43 cm

2.2 > 1.43 Safe ☑

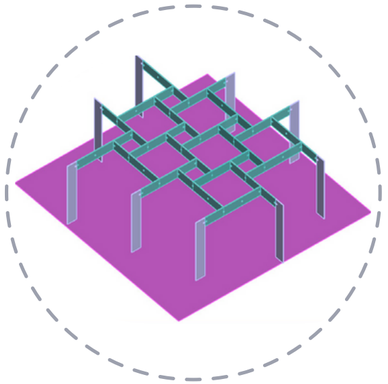
- Structural Analysis

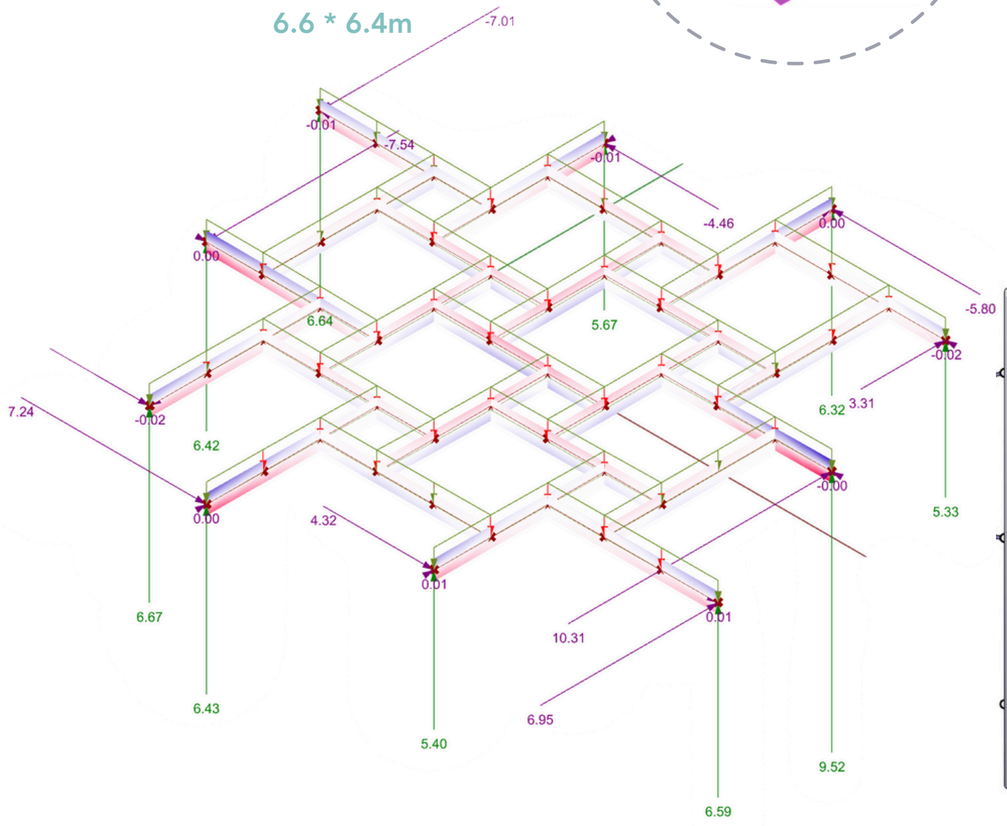
Macro Analysis

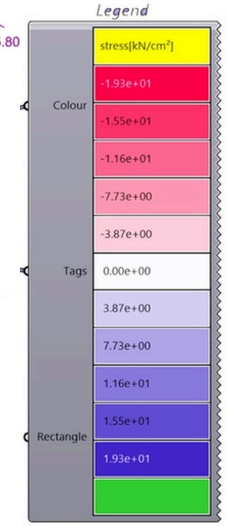
Alternative Four:

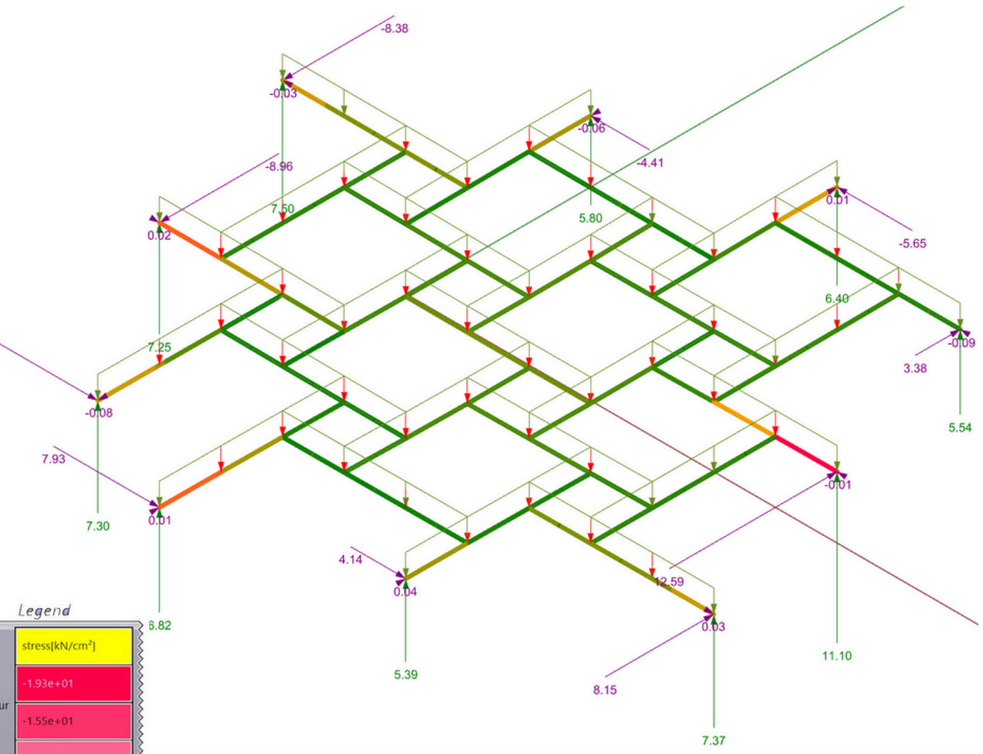
Pergola Design Span

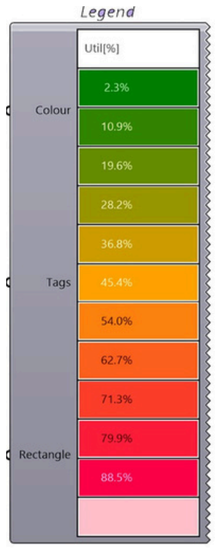
6.6 * 6.4m











Allowable Stress: 60MPa = 6 KN/cm2

Actual Stress: 1.93 KN/cm2

6 > 1.93 Safe ☑

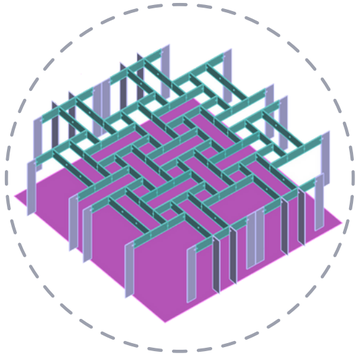
- Structural Analysis

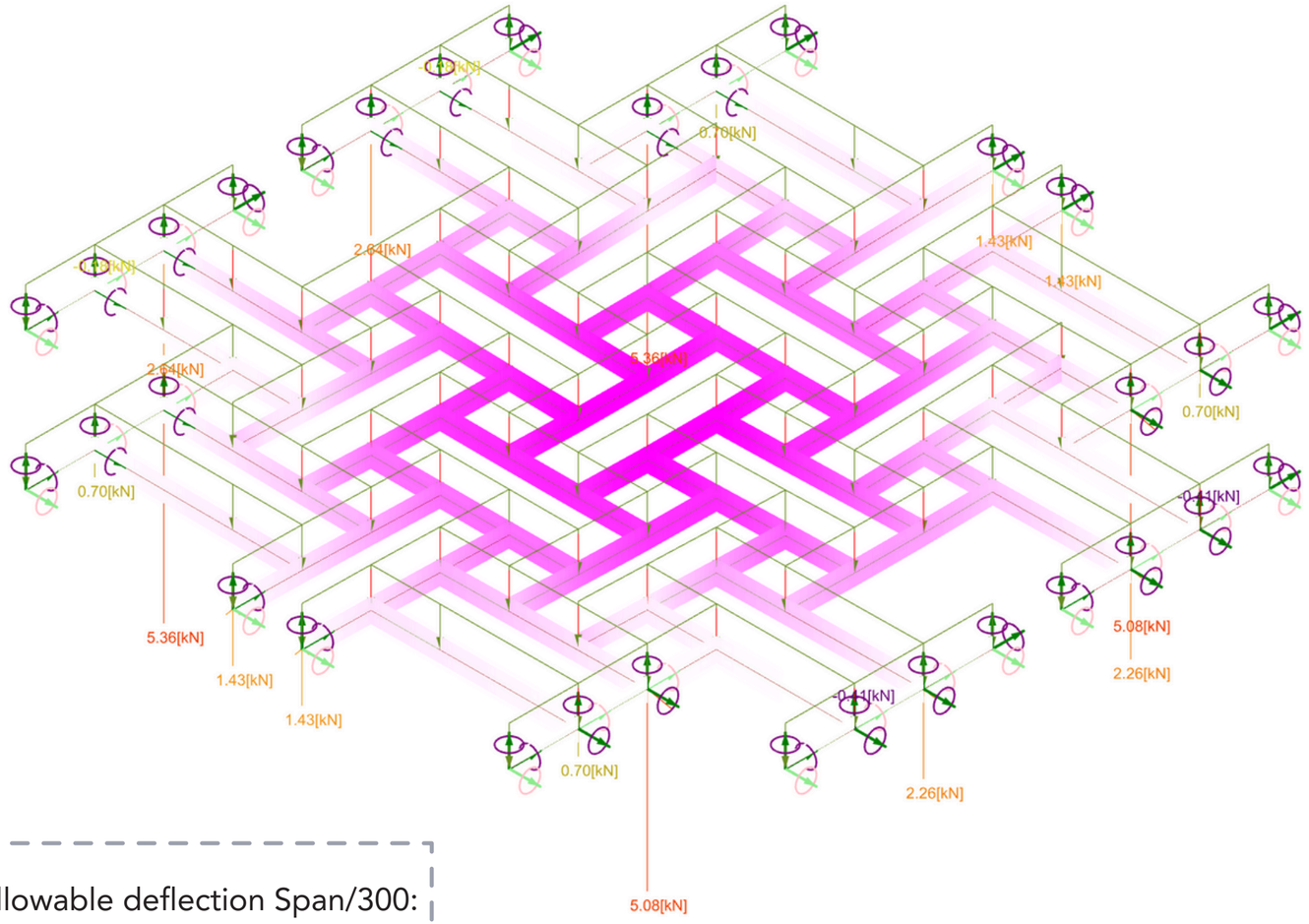
Macro Analysis

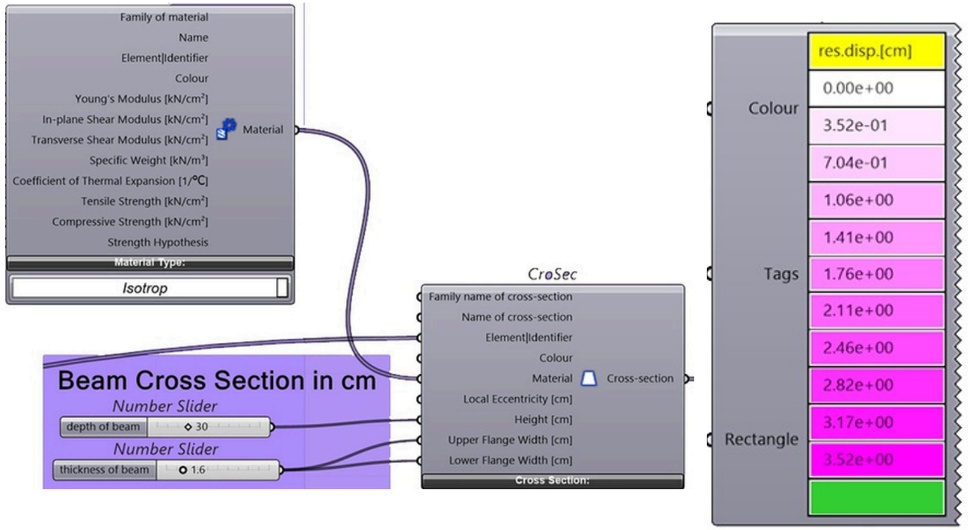
Alternative Four:

Pergola Design Span

6.6 * 6.4m







Allowable deflection Span/300:

660 / 300 = 2.2 cm

Actual deflection: 1.43 cm

2.2 < 3.5 Not Safe ×

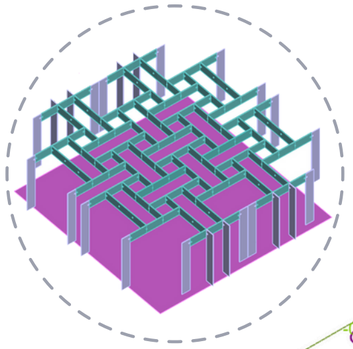
- Structural Analysis

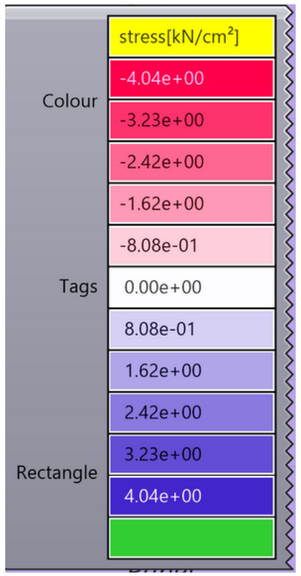
Macro Analysis

Alternative Four:

Pergola Design Span

6.6 * 6.4m

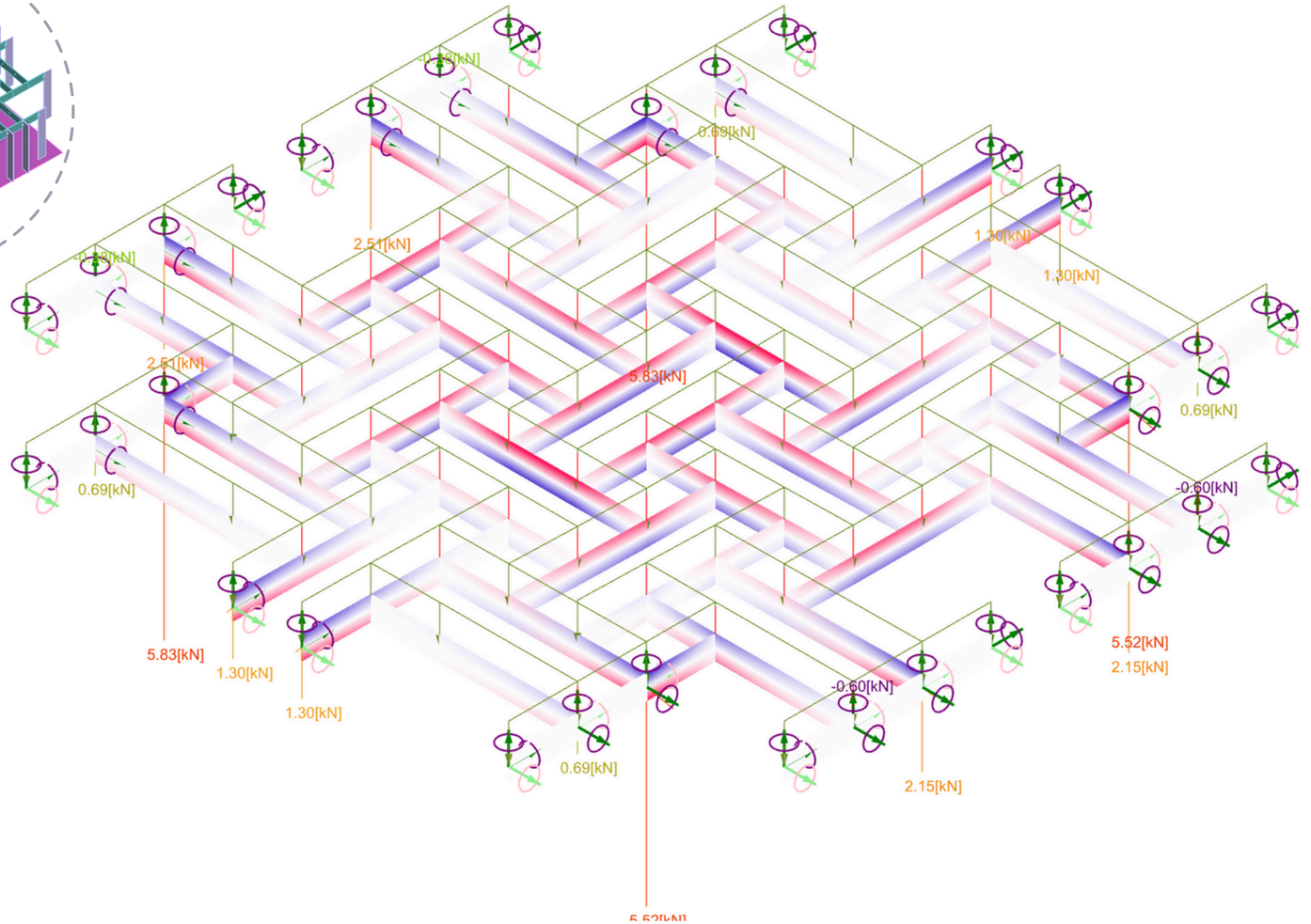




Allowable Stress: 60MPa = 6 KN/cm2

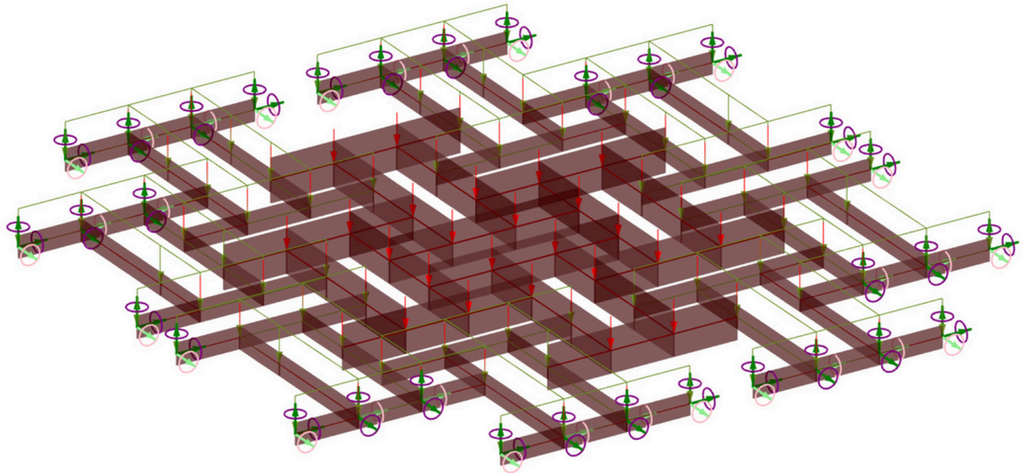
Actual Stress: 1.93 KN/cm2

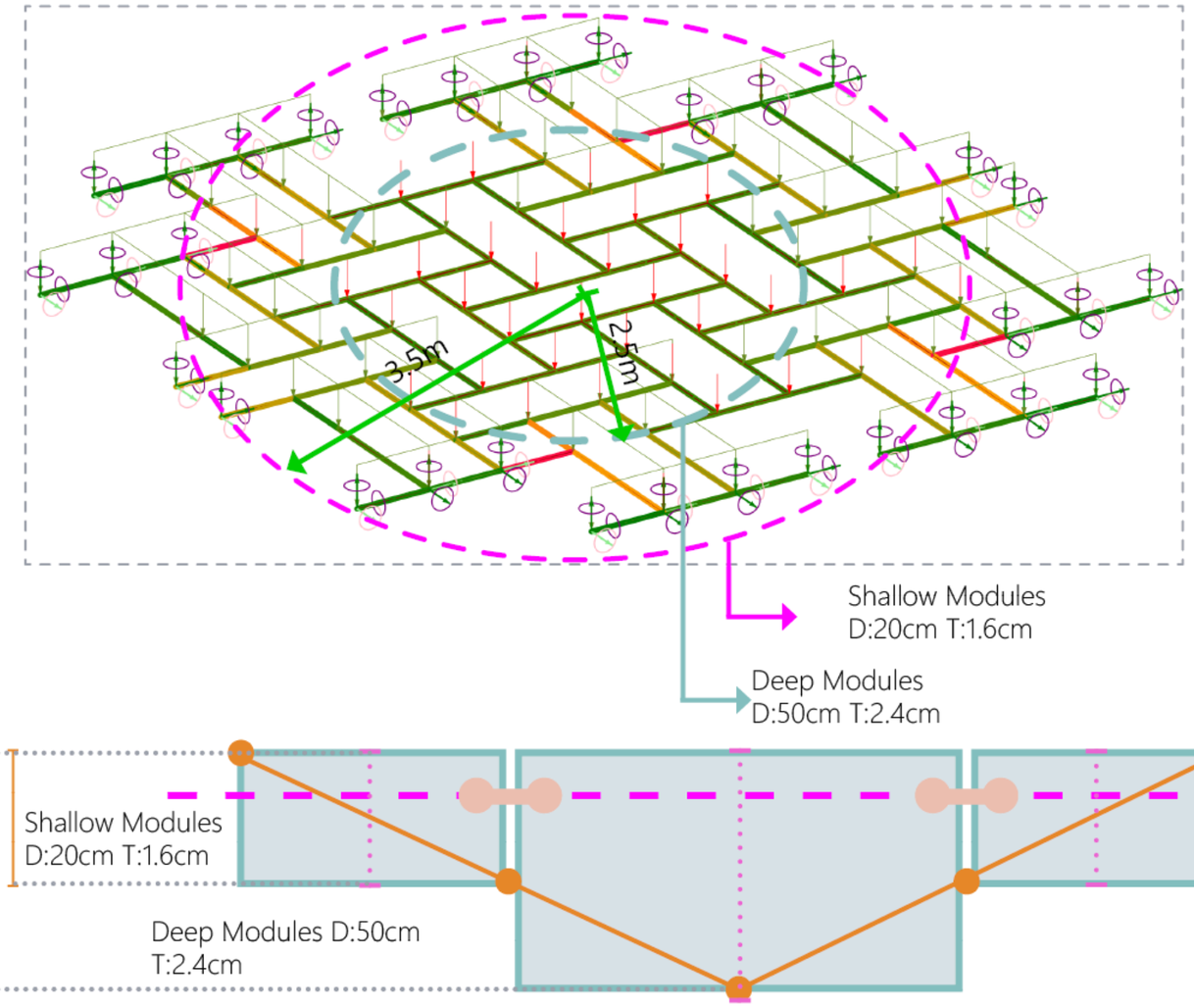
6 > 4 Safe ☑



- Structural Analysis

Macro Analysis





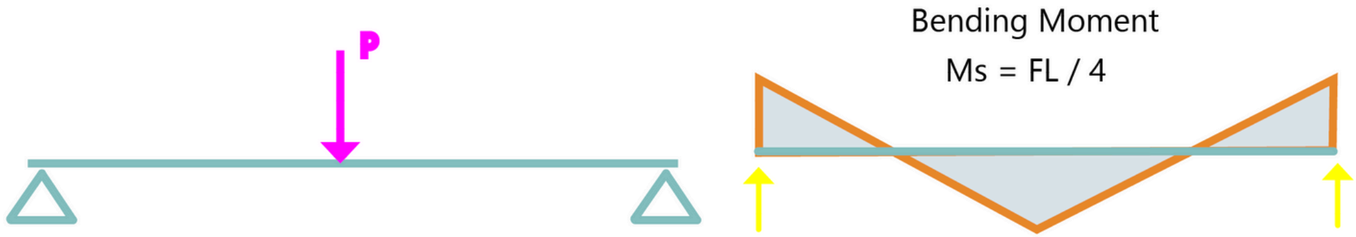
- Increasing glass thickness to 24 mm with 50 cm depth, or 32 mm with 30 cm depth, to meet allowable deflection

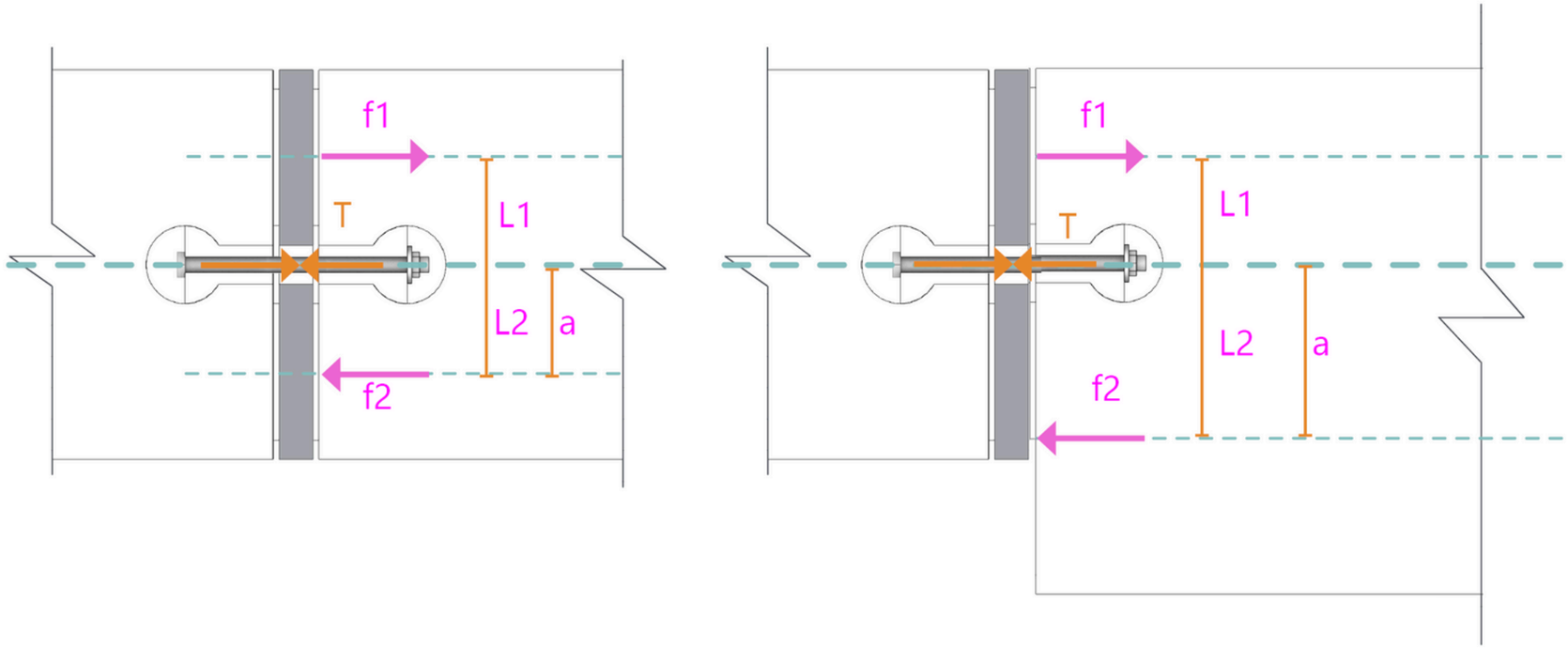
Better Strategy:

- Deeper modules placed at mid-span to resist higher bending moments
  - Centre: 50 cm depth + 24 mm glass
  - Edges: 20 cm depth + 16 mm glass

- Structural Analysis

  Macro Analysis





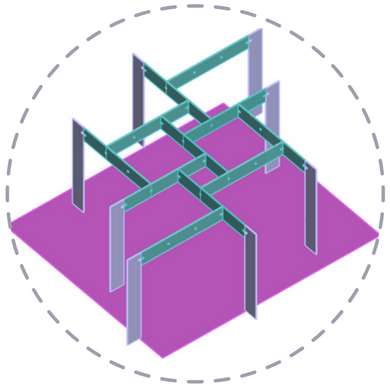
- Structural Analysis

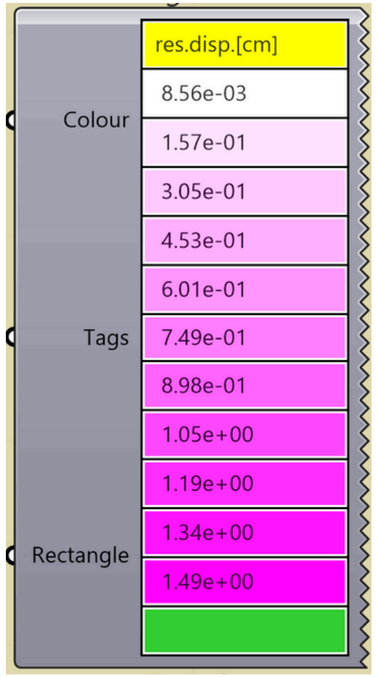
Macro Analysis

Alternative Three:

Pergola Design Span

4.2 * 4.8m



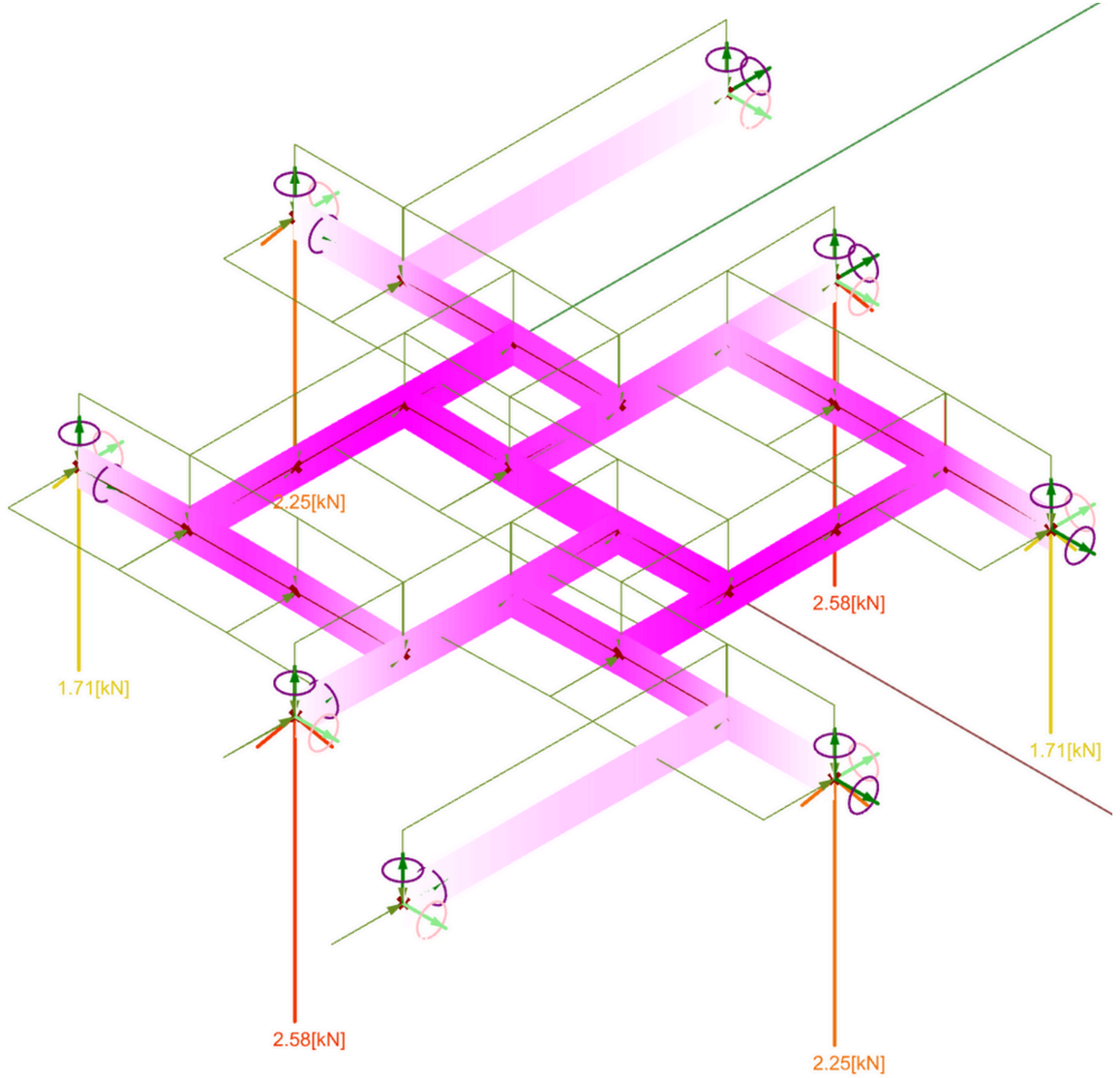


Allowable deflection Span/300:

660 / 300 = 2.2 cm

Actual deflection: 1.43 cm

2.2 > 1.49 Safe ☑



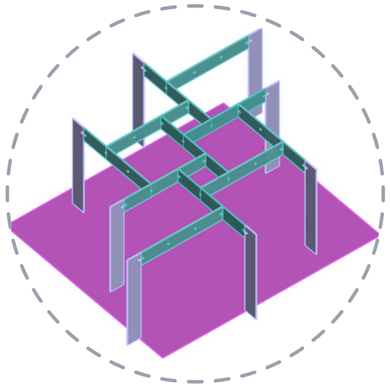
- Structural Analysis

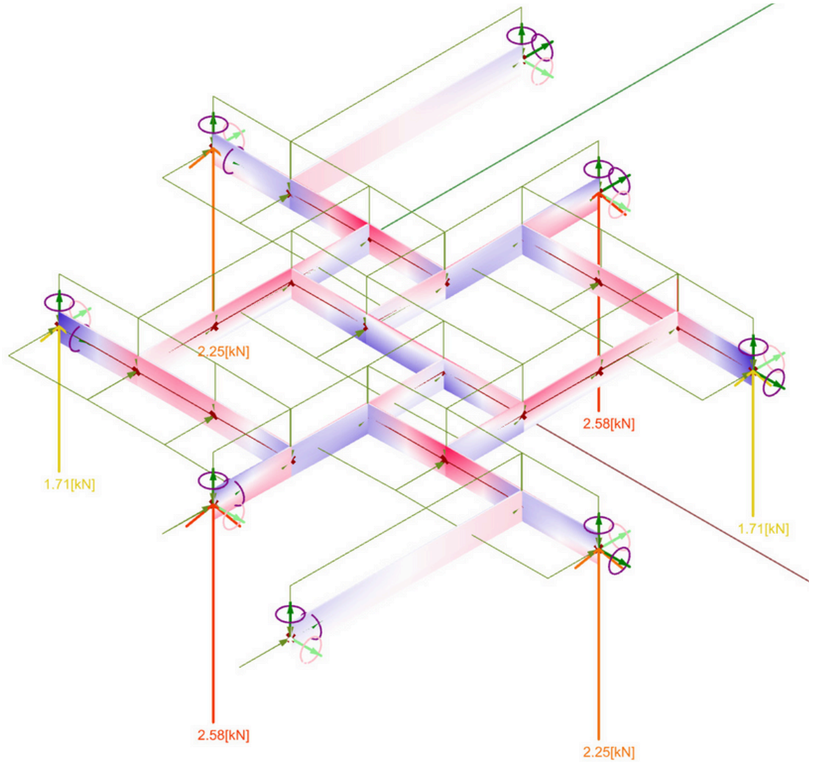
Macro Analysis

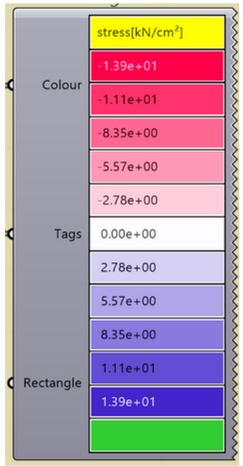
Alternative Three:

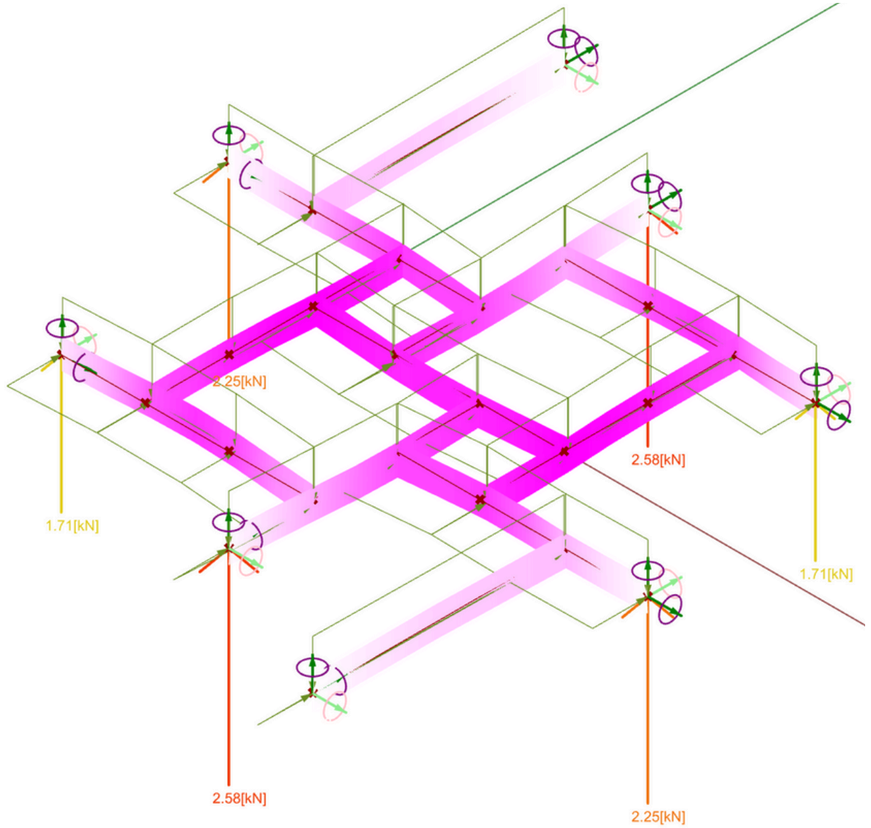
Pergola Design Span

4.2 * 4.8m









Allowable Stress: 60MPa = 6 KN/cm2

Actual Stress: 1.93 KN/cm2

6 > 1.39 Safe ☑

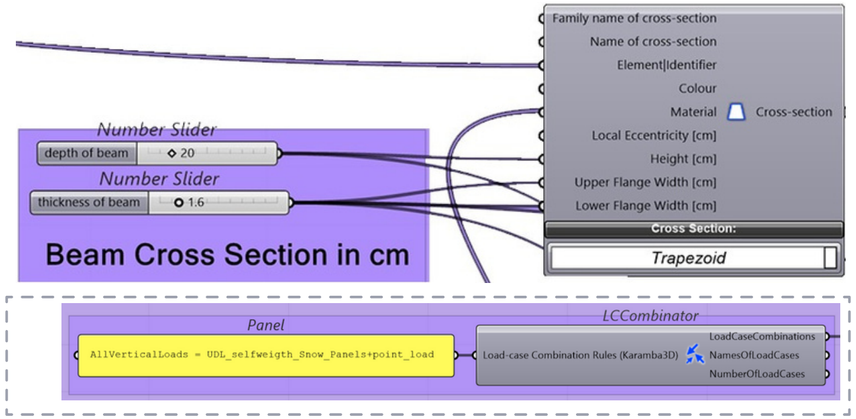
- Structural Analysis

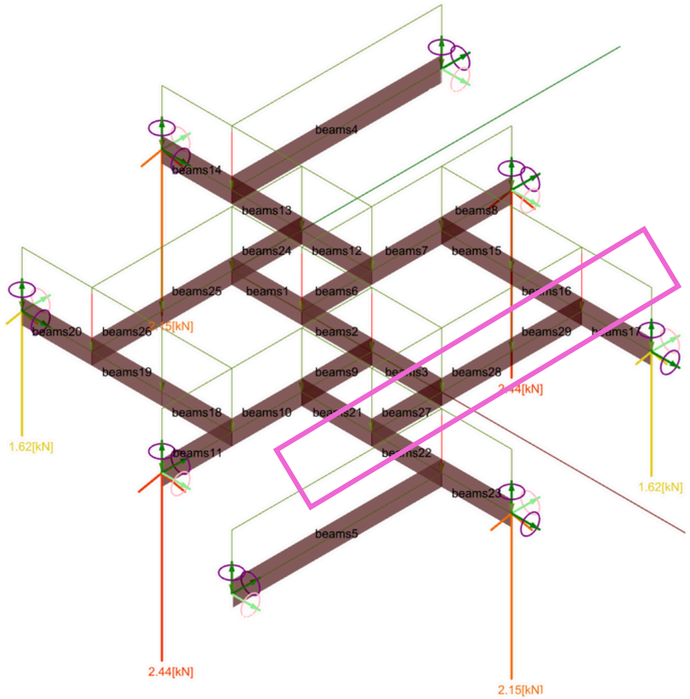
Macro Analysis

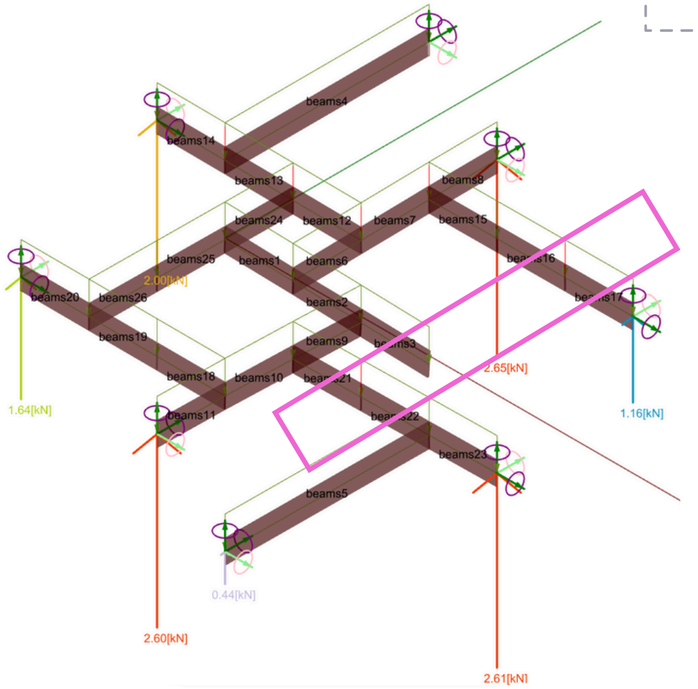
Alternative Three:

Pergola Design Span

4.2 * 4.8m







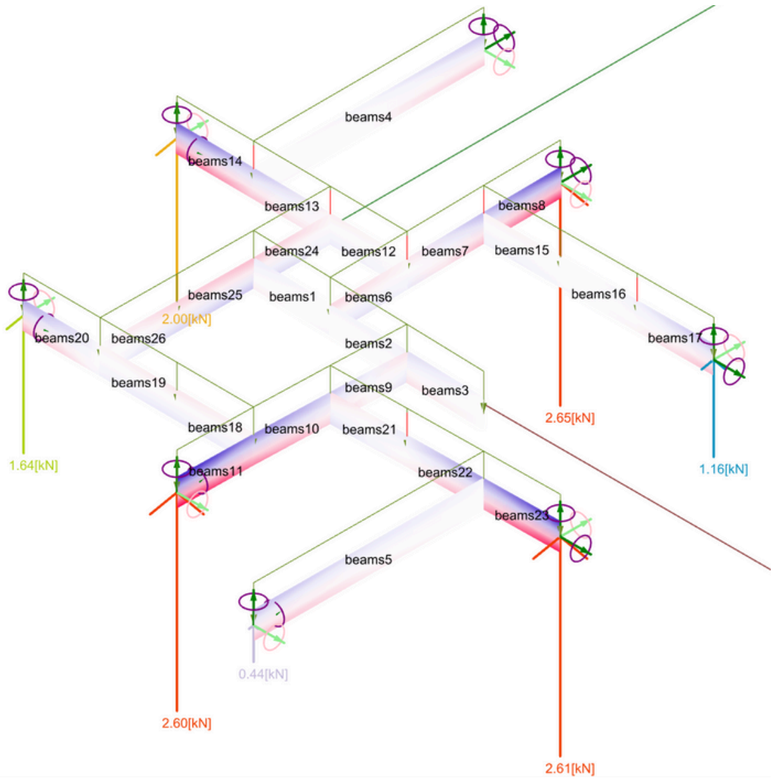
- Structural Analysis

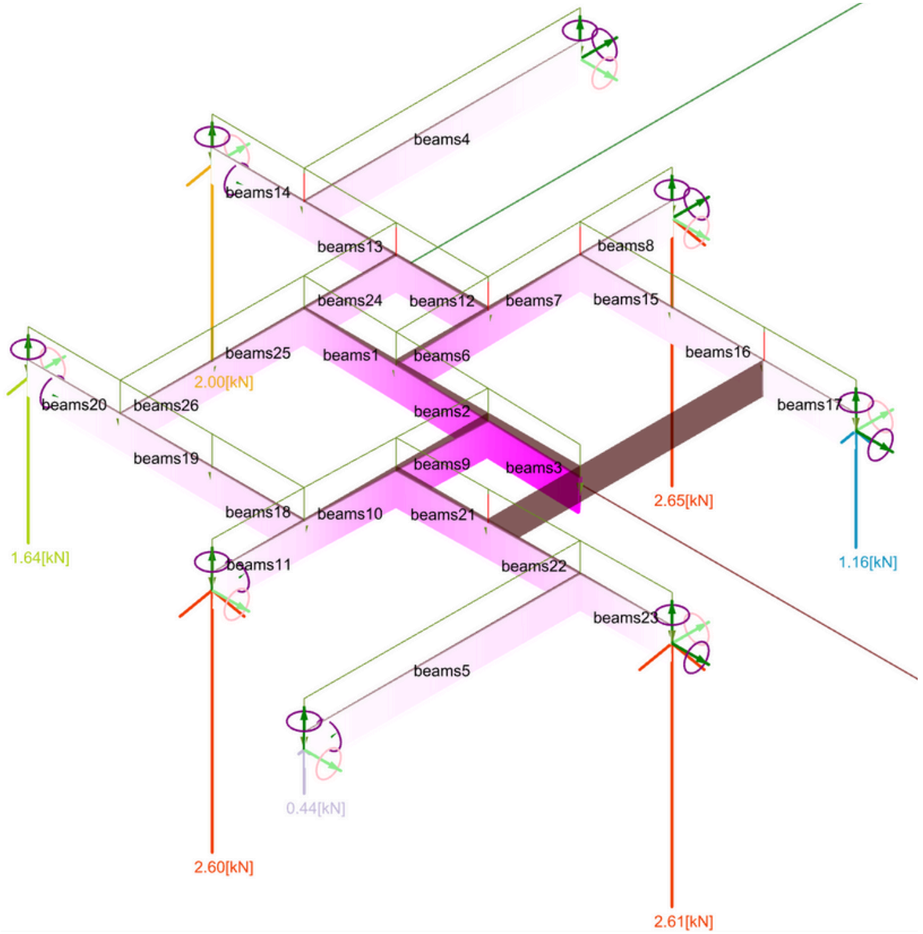
Macro Analysis

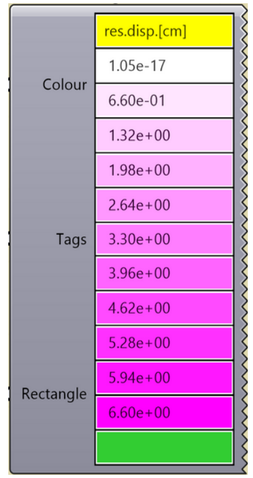
Alternative Three:

Pergola Design Span

4.2 * 4.8m





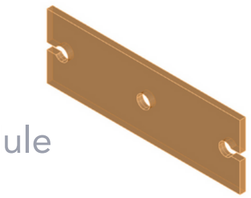


- Structural Analysis

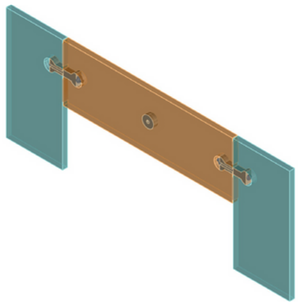
Micro Analysis

Assembly variation

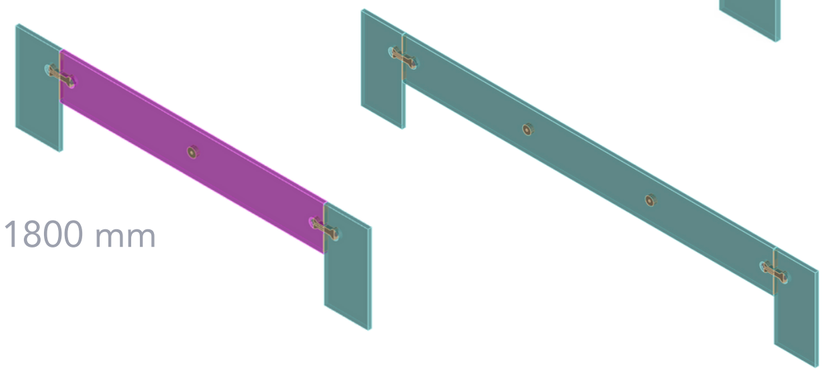
L = 600 mm Module

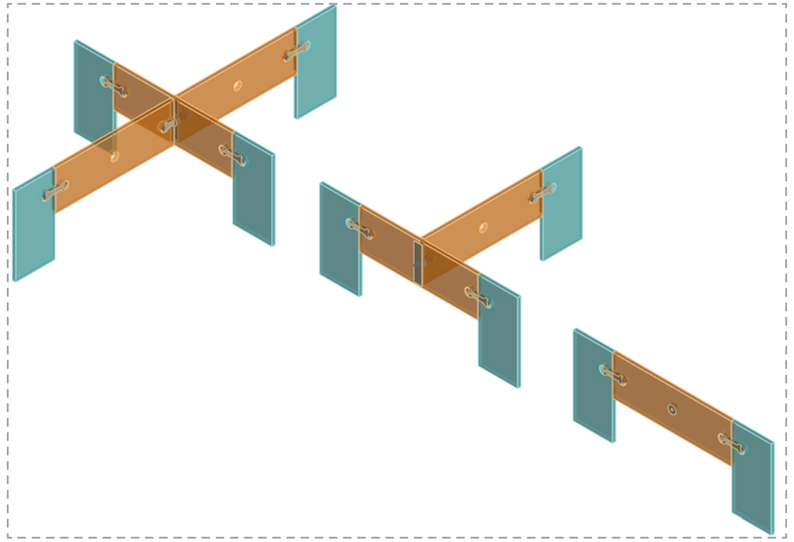


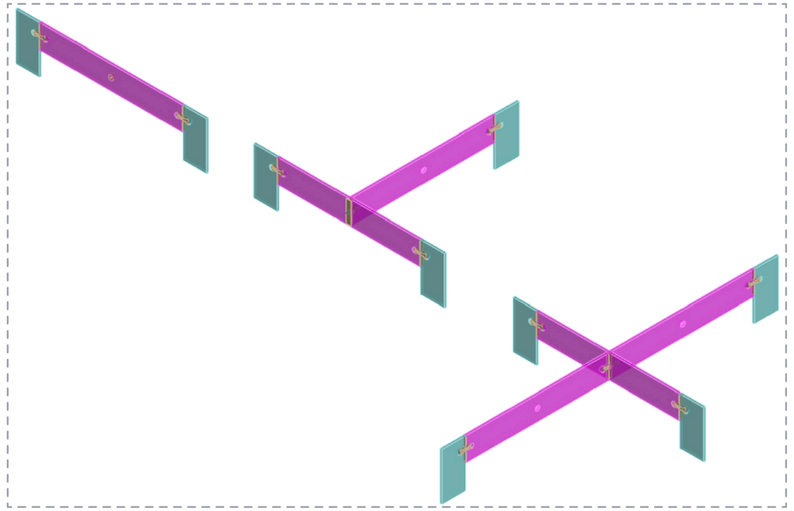
Line joint L=600 mm Module



Line joint L=1200 and L=1800 mm Module



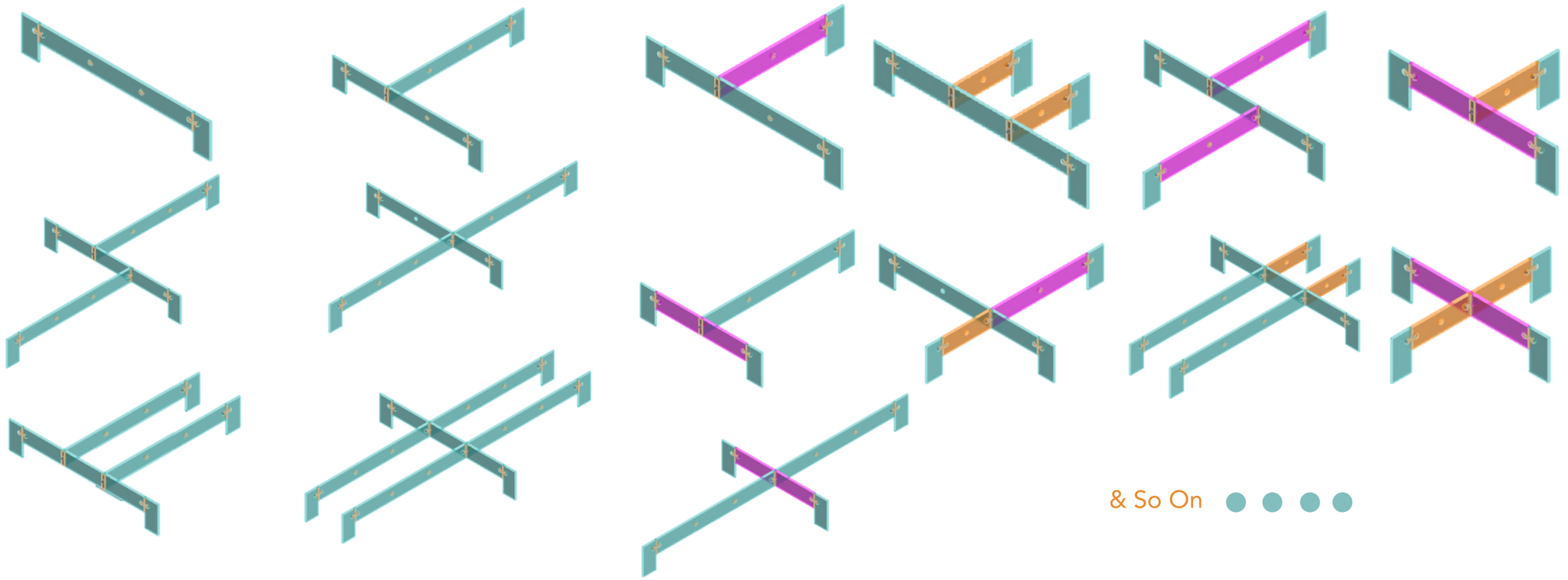




- Structural Analysis

  Micro Analysis

Assembly variation

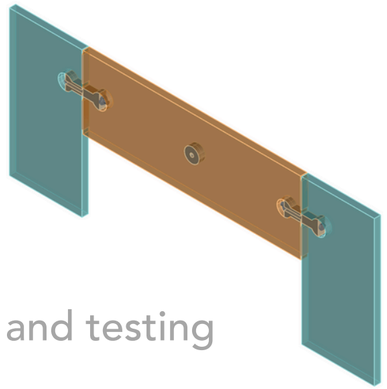


- Structural Analysis

Micro Analysis

Linear Joint Simulation

L600mm module

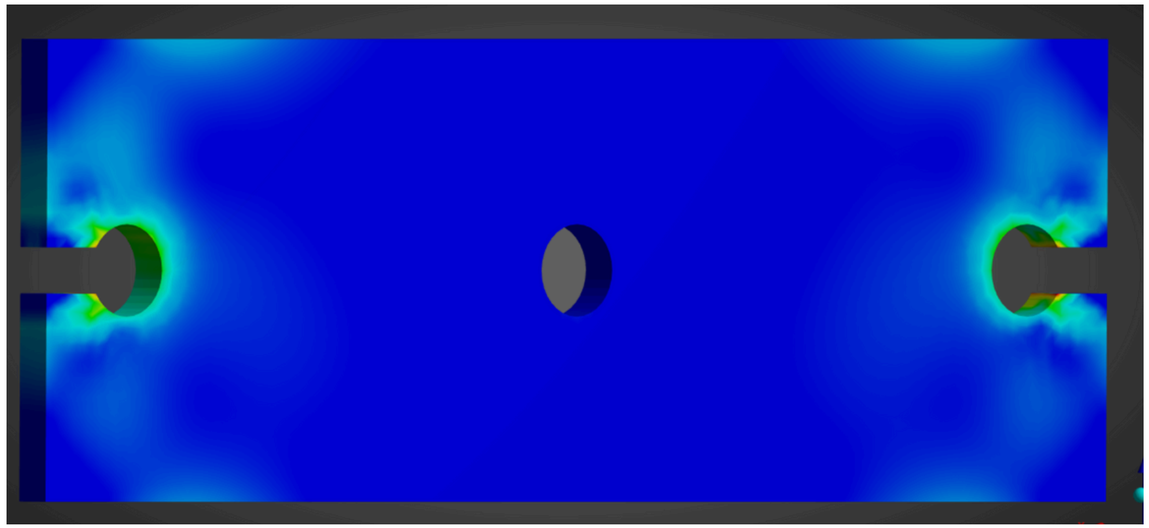


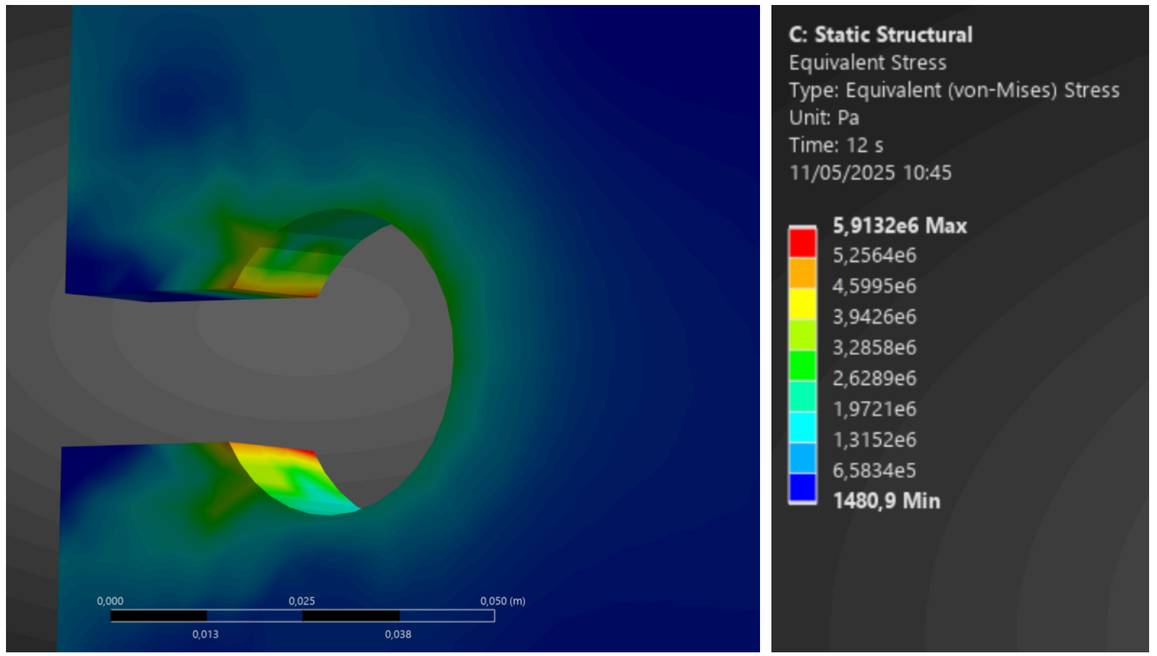
Model for Analysis and testing

Equivalent stress

Allowable max Stress: 60MPa

Model Max Stress: 5.9 MPa





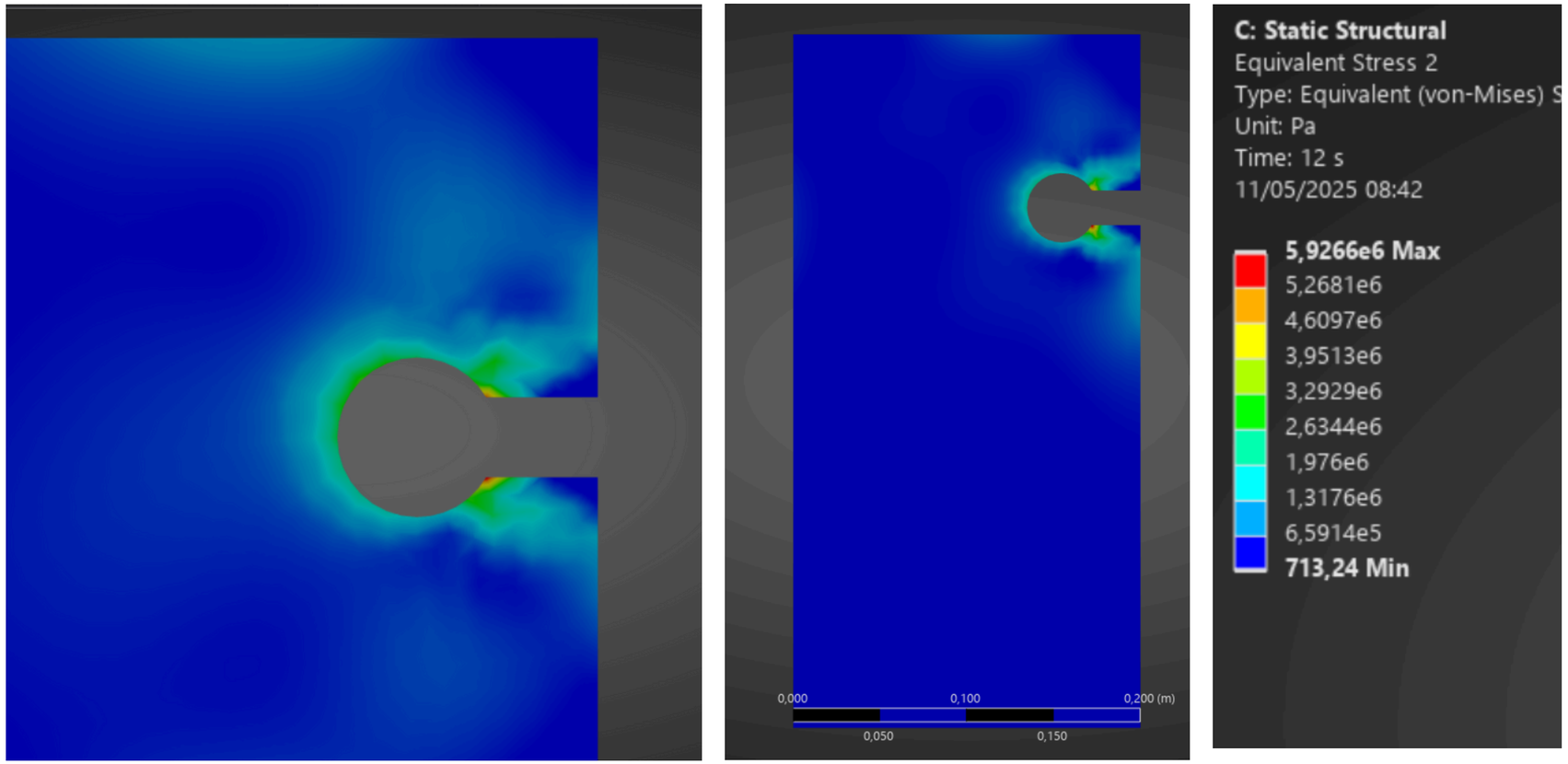
- Structural Analysis

Micro Analysis

Equivalent stress

Allowable max Stress: 60MPa

Model Max Stress: 5.92 MPa



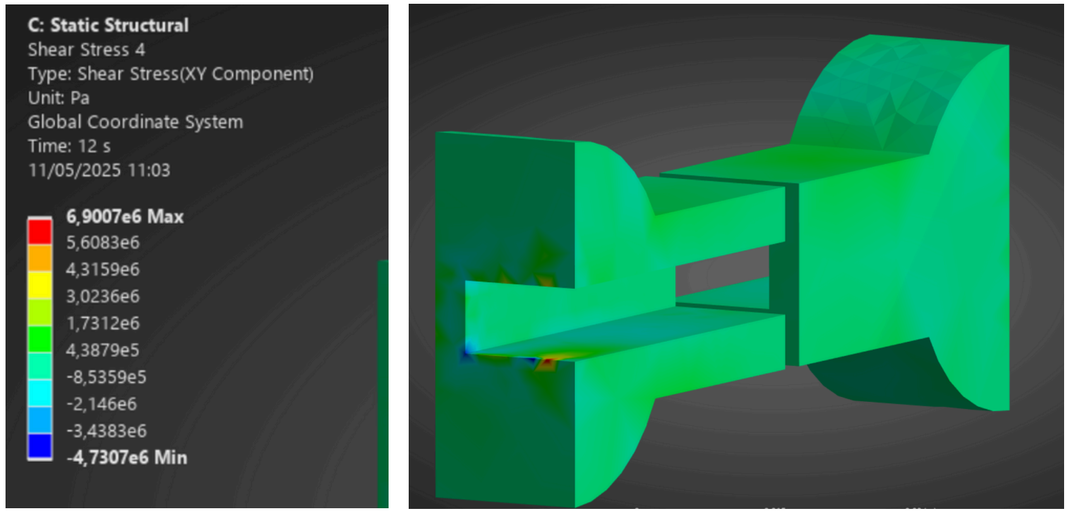
- Structural Analysis

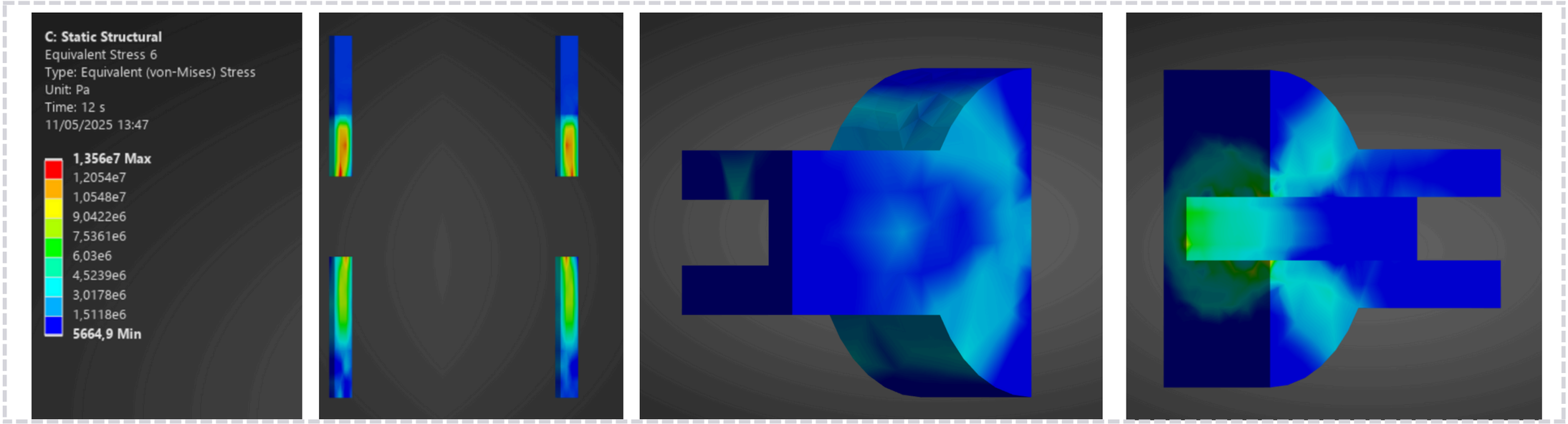
Micro Analysis

Equivalent stress and shear

Allowable max Stress: 20MPa

Model Max Stress: 13.5 MPa





- Structural Analysis

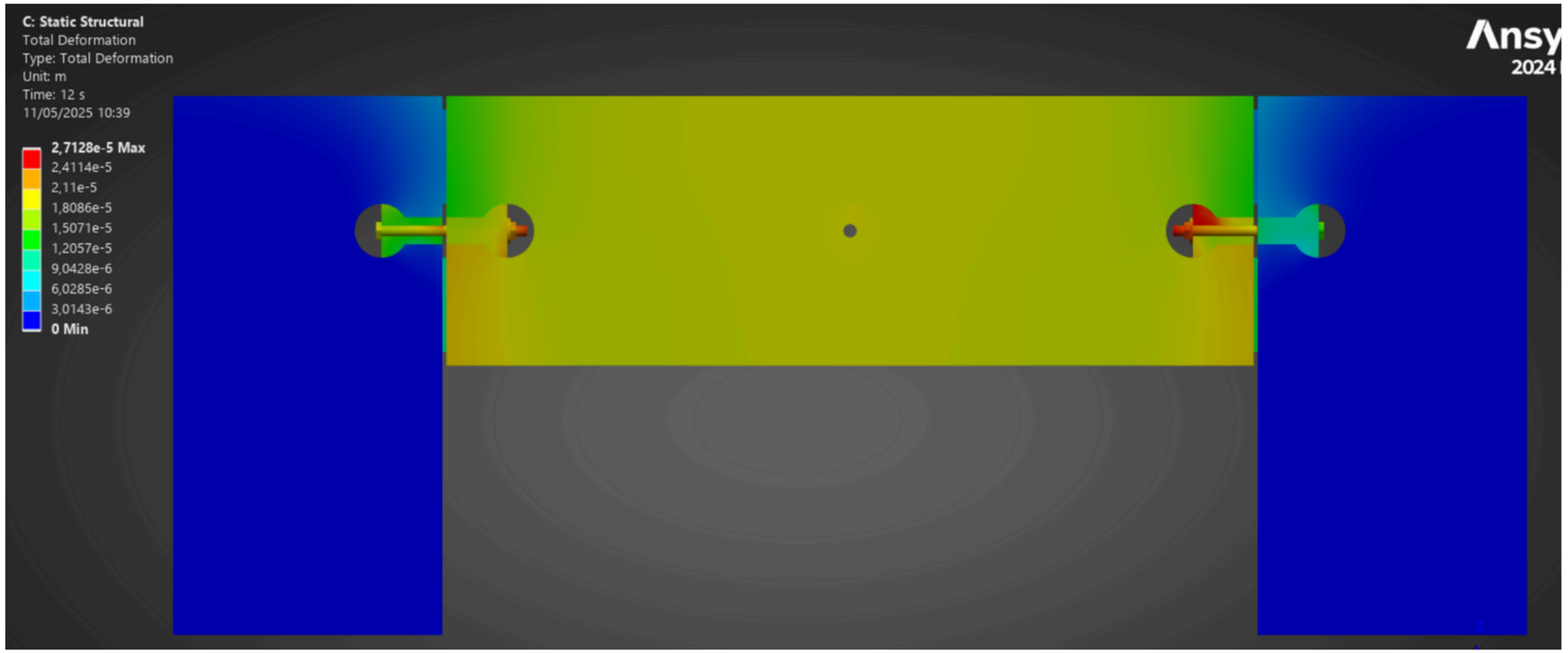
  Micro Analysis

Total deformation

Allowable max Displacement: 600/300= 2mm

Simulation Max Displacement: 0.27 mm

Experiment Max Displacement: 0.24 mm (driven from excel data sheet as out put rom lab facilities



- Structural Analysis

Micro Analysis

Total deformation

Allowable max Displacement: 600/300= 2mm

Simulation Max Displacement: 0.0213 mm

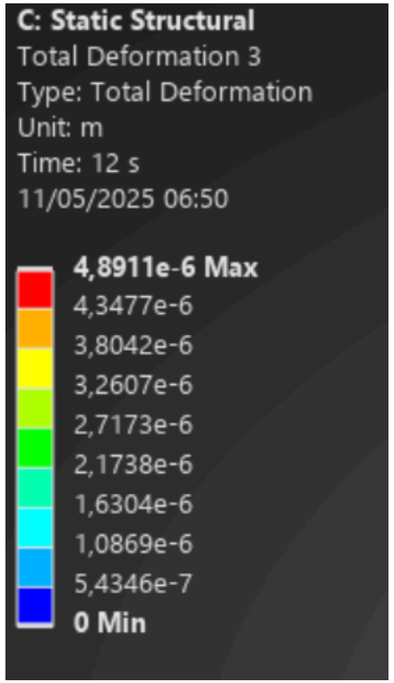
- Structural Analysis

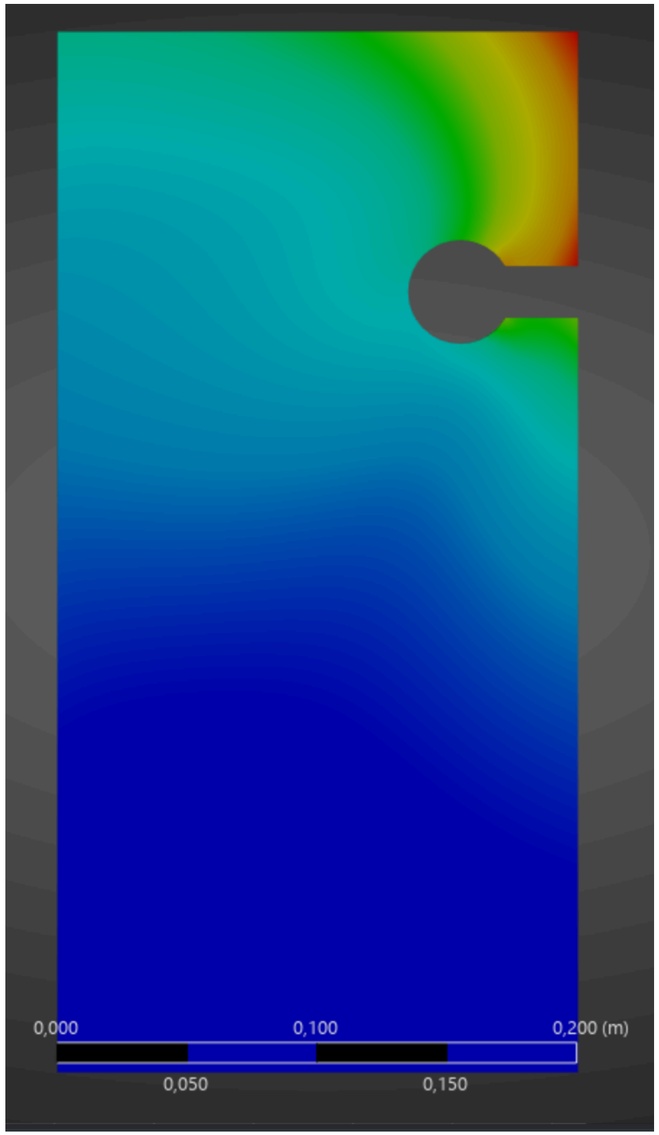
  Micro Analysis

Total deformation

Allowable max Displacement:
600/300= 2mm

Simulation Max Displacement:
0.00489 mm

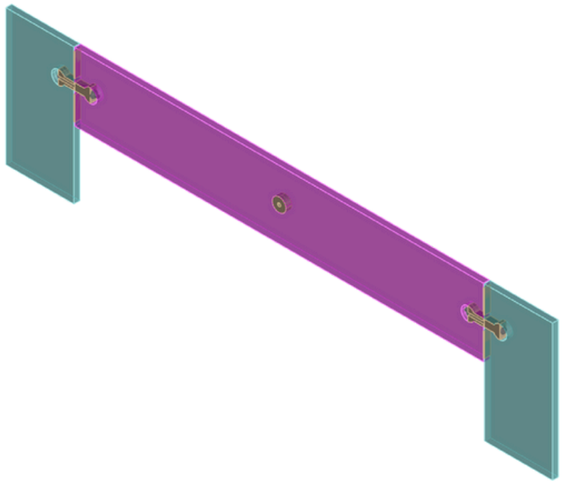




- Structural Analysis

Micro Analysis

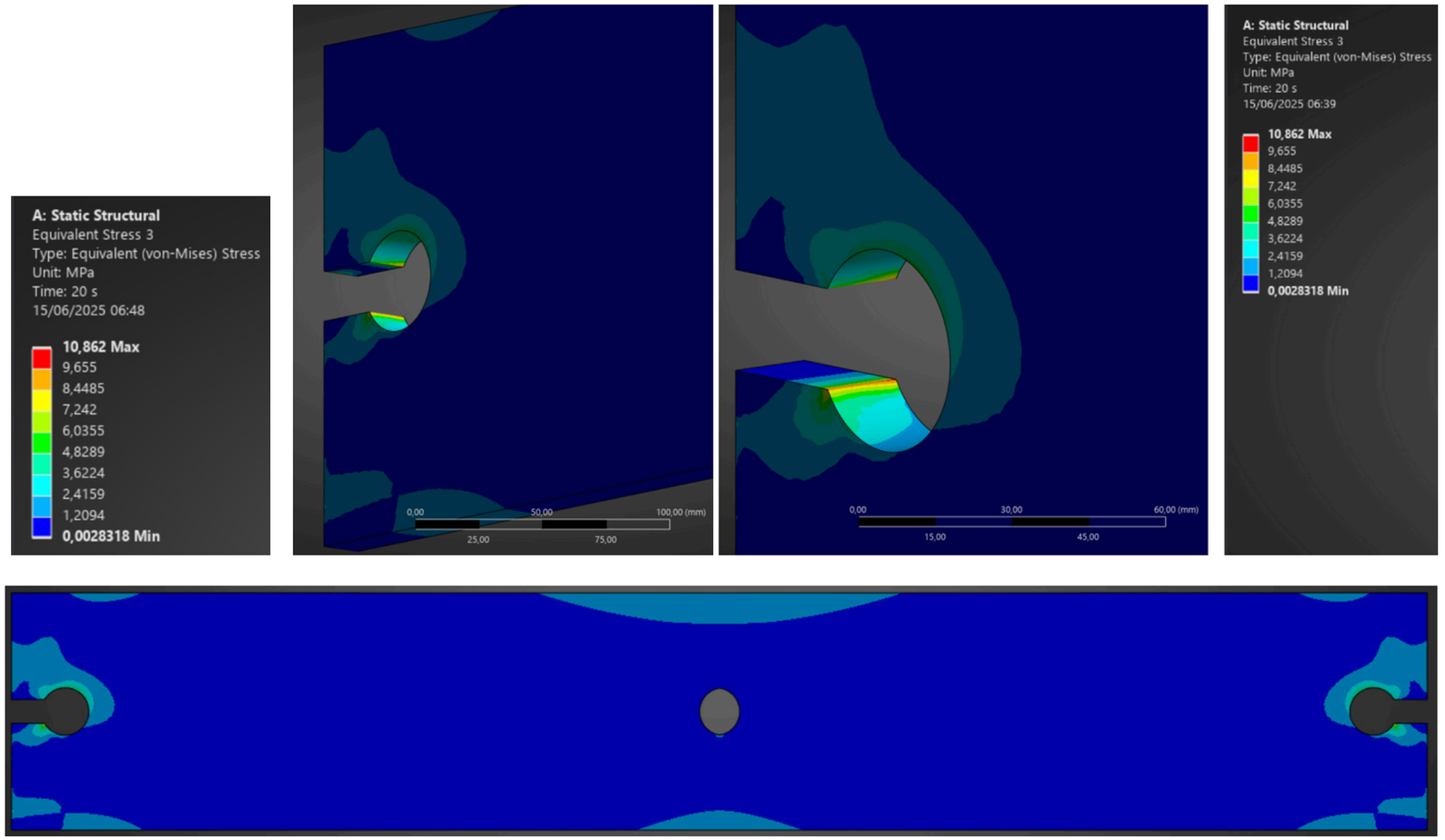
Linear Joint Simulation
L1200mm module



Equivalent stress

Allowable max Stress: 60MPa

Model Max Stress: 10.8 MPa



- Structural Analysis

Micro Analysis

Linear Joint Simulation
L1200mm module

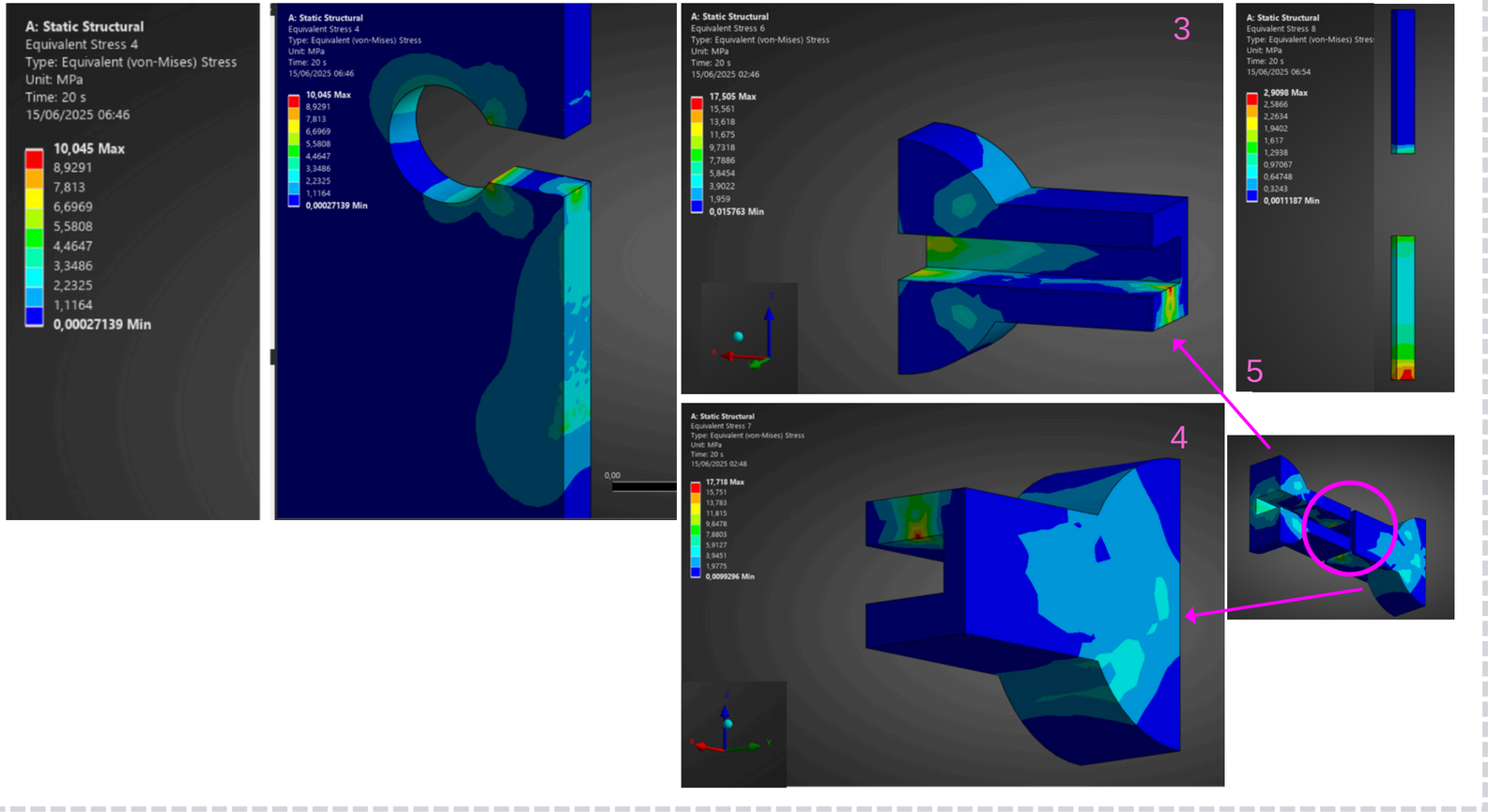
Equivalent stress in glass

Allowable max Stress: 60MPa
Model Max Stress: 10 MPa

Equivalent stress in wood

Allowable max Stress: 20MPa

Model Max Stress: 17 MPa



- Structural Analysis

Micro Analysis

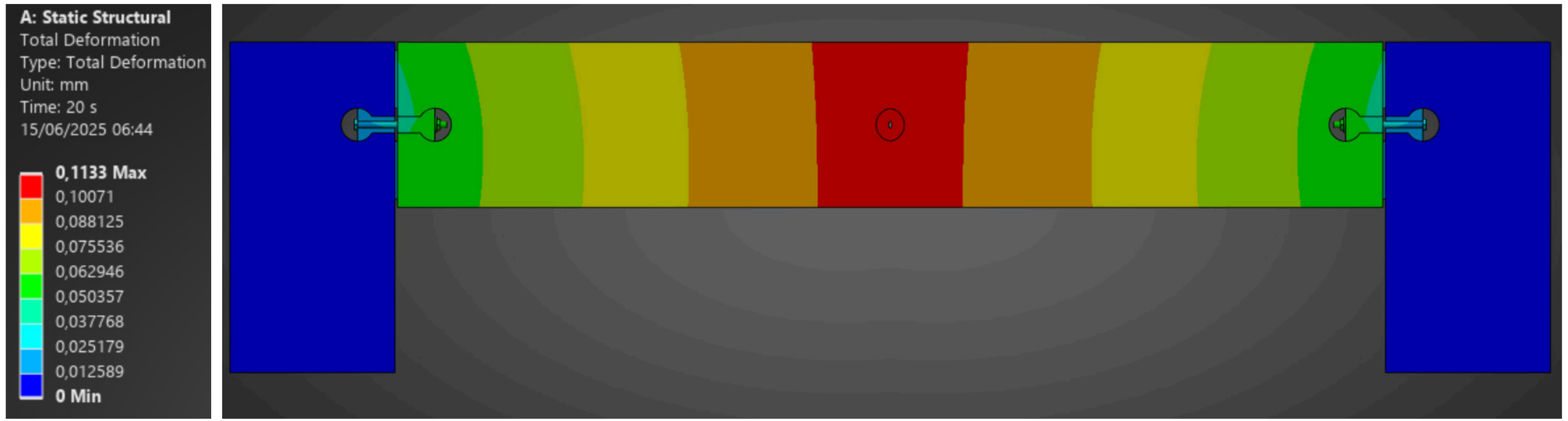
Linear Joint Simulation

L1200mm module

Total deformation

Allowable max Displacement:
1800/300= 4mm

Simulation Max
Displacement: 0.1133 mm

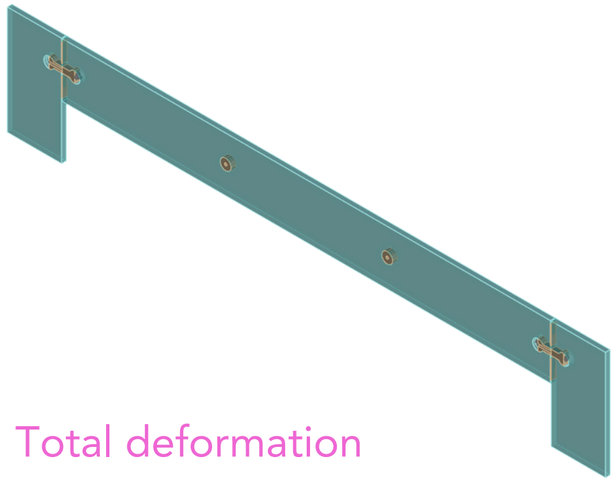


- Structural Analysis

Micro Analysis

Linear Joint Simulation

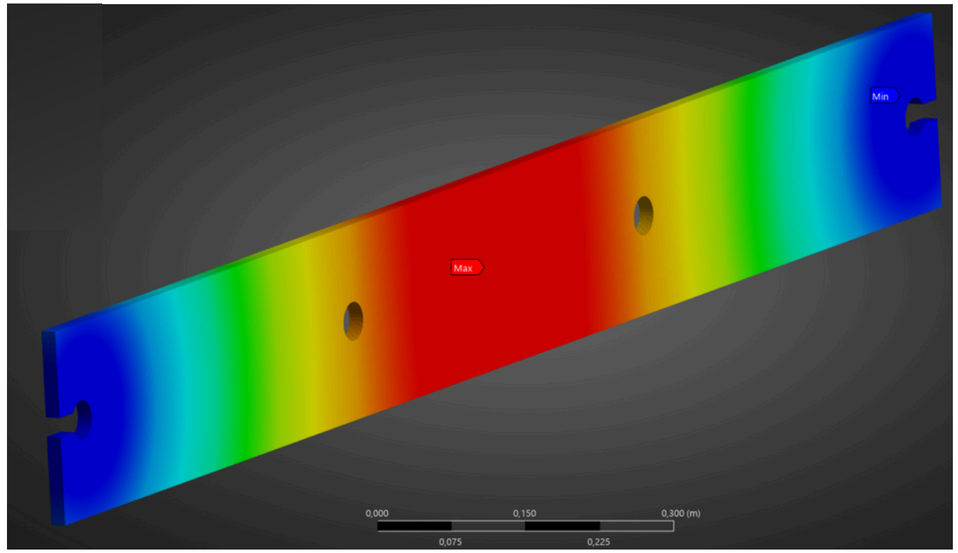
L1800mm module

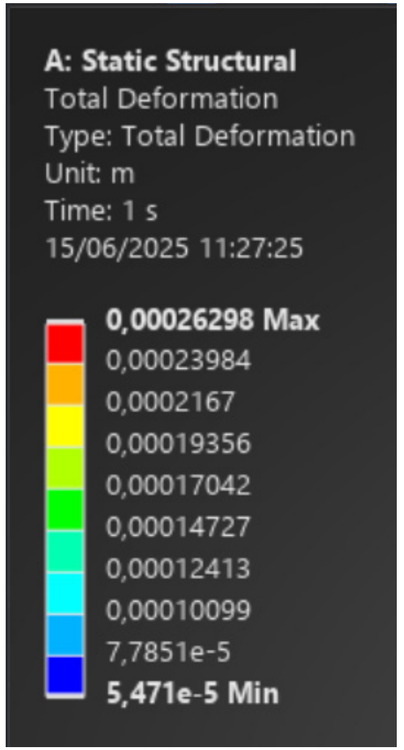


Total deformation

Allowable max Displacement:
1800/300= 6mm

Simulation Max
Displacement: 0.2 mm





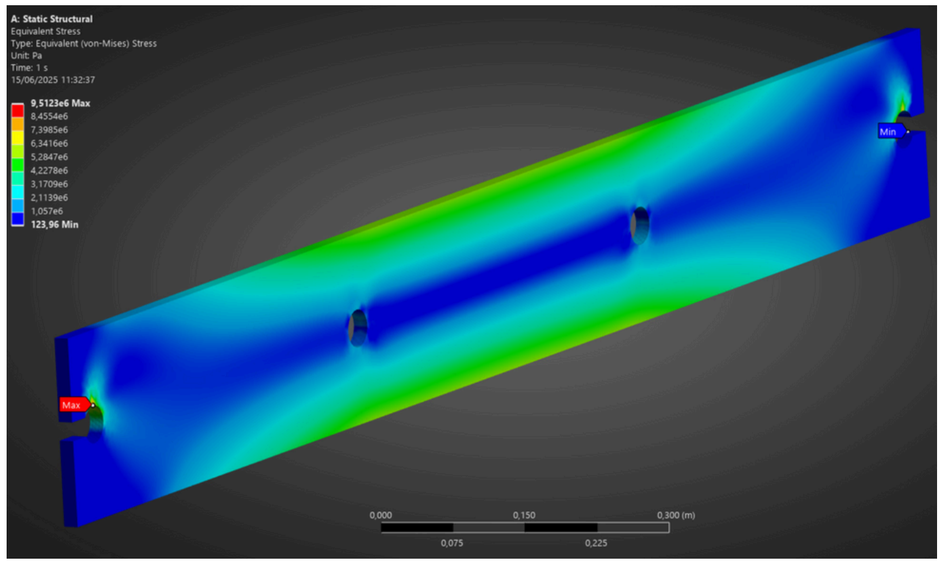
- Structural Analysis

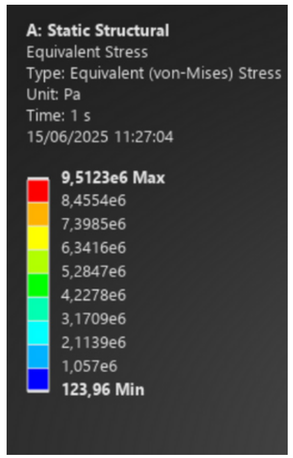
Micro Analysis

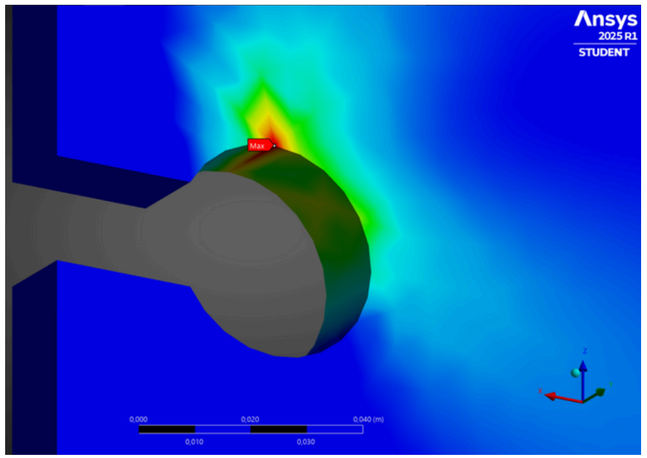
Linear Joint Simulation
L1800mm module

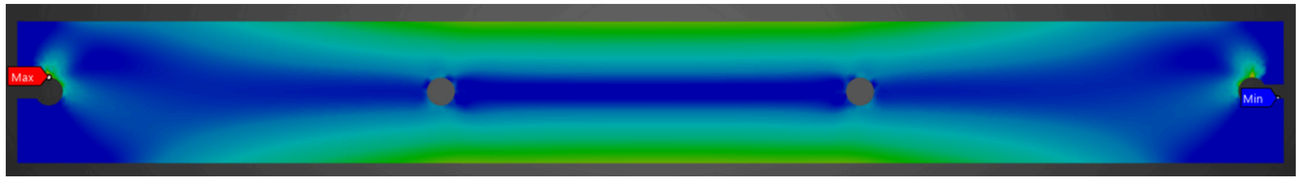
Equivalent stress in glass

Allowable max Stress: 60MPa
Model Max Stress: 9.5 MPa



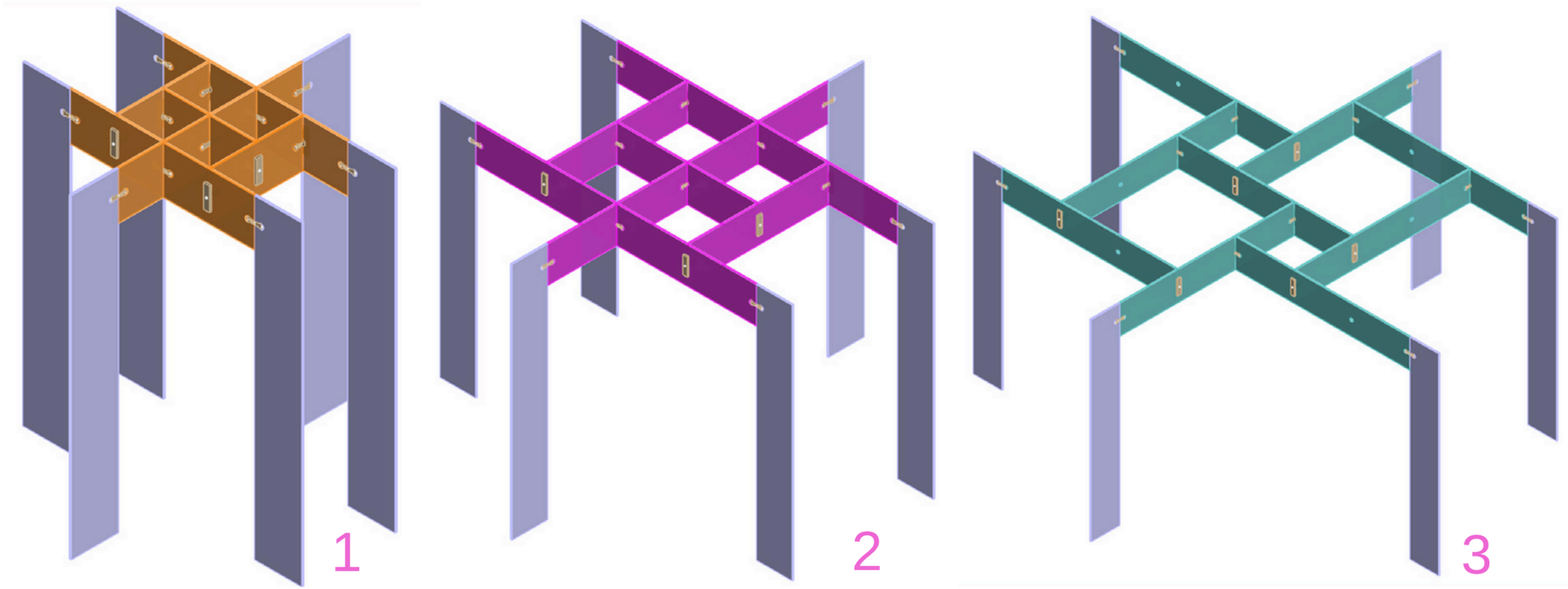






- Structural Analysis

  Micro Analysis

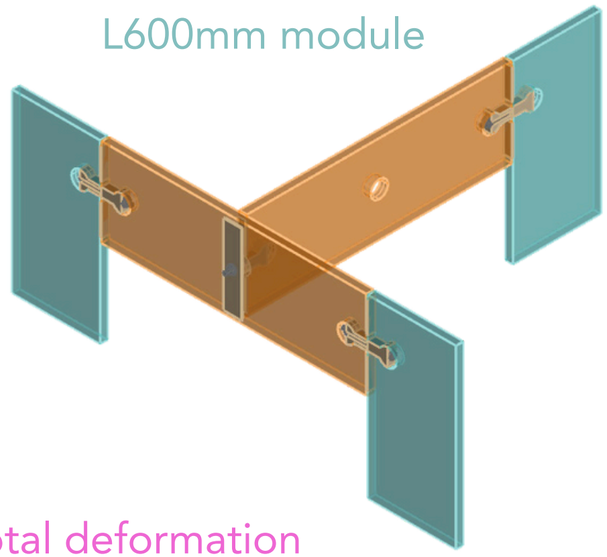


- Structural Analysis

Micro Analysis

T shape Joint Simulation

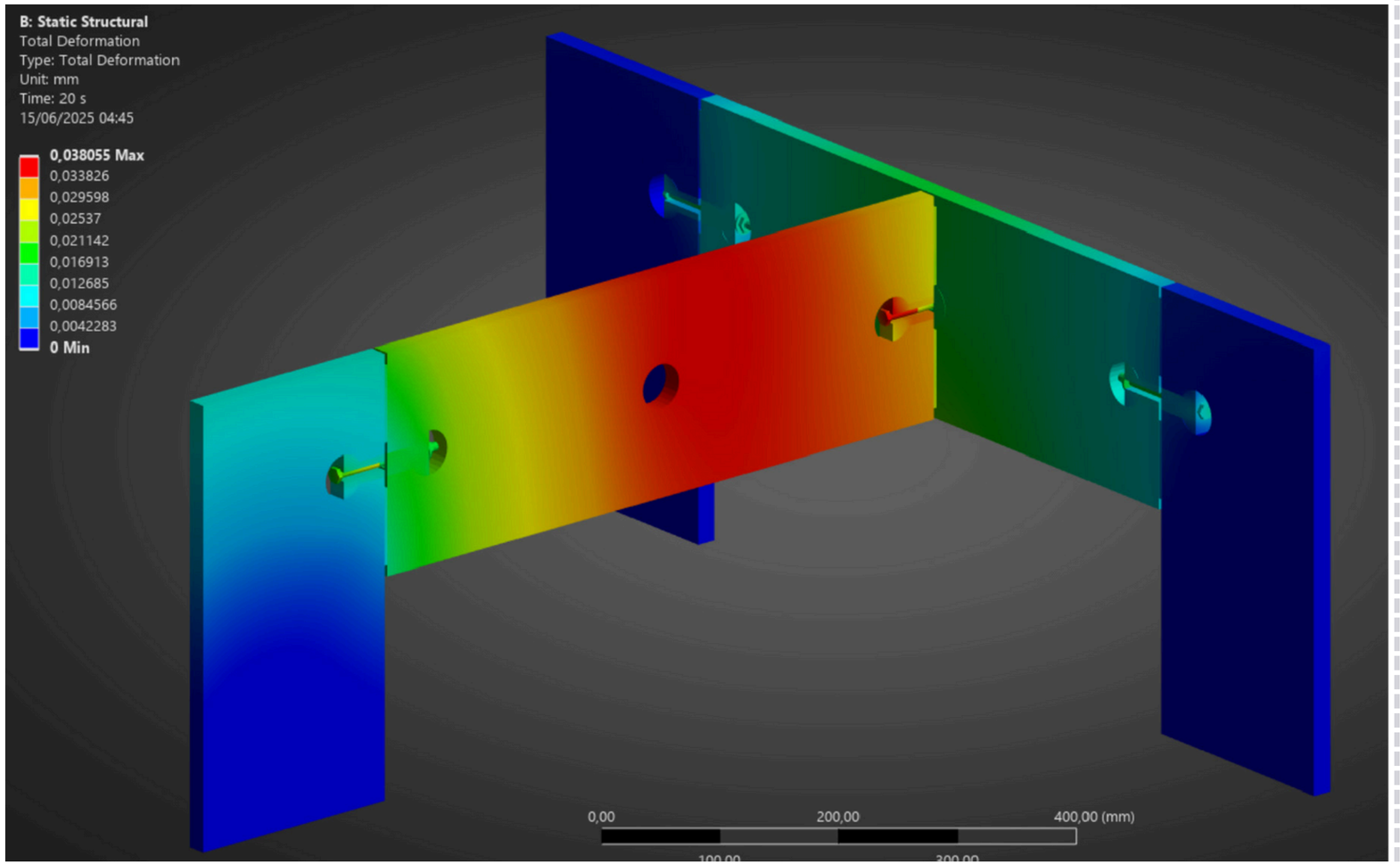
L600mm module



Total deformation

Allowable max Displacement:
600/300= 2mm

Simulation Max
Displacement: 0.3 mm



- Structural Analysis

Micro Analysis

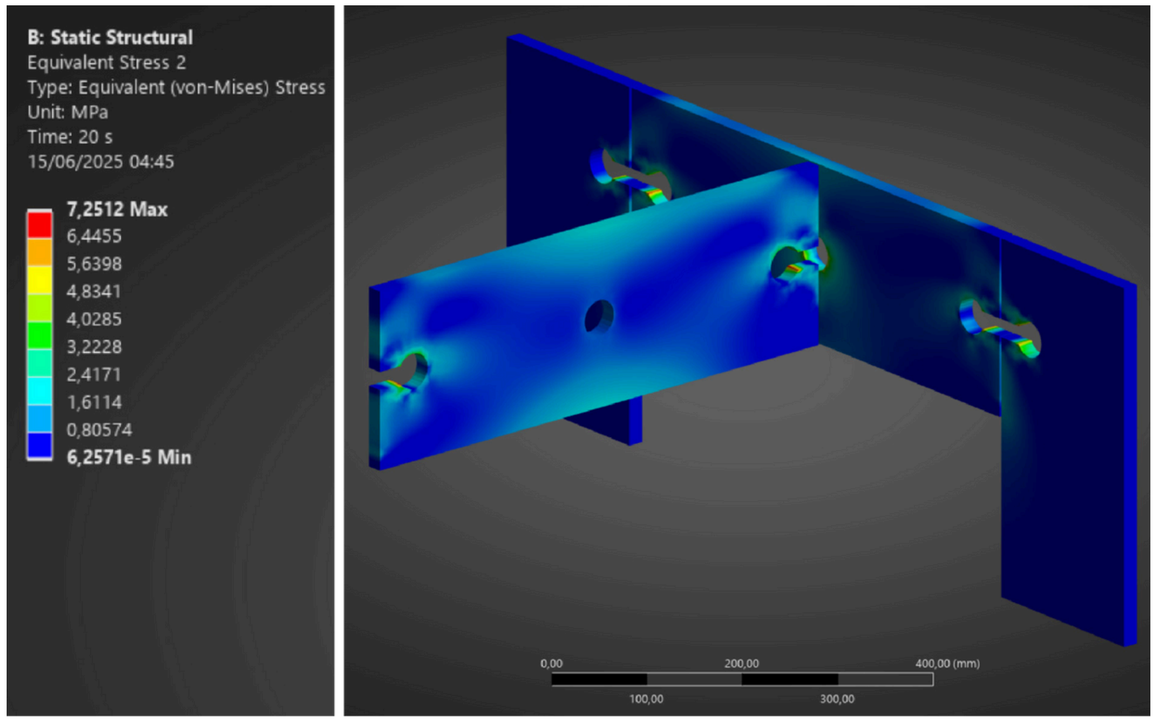
Equivalent stress in glass

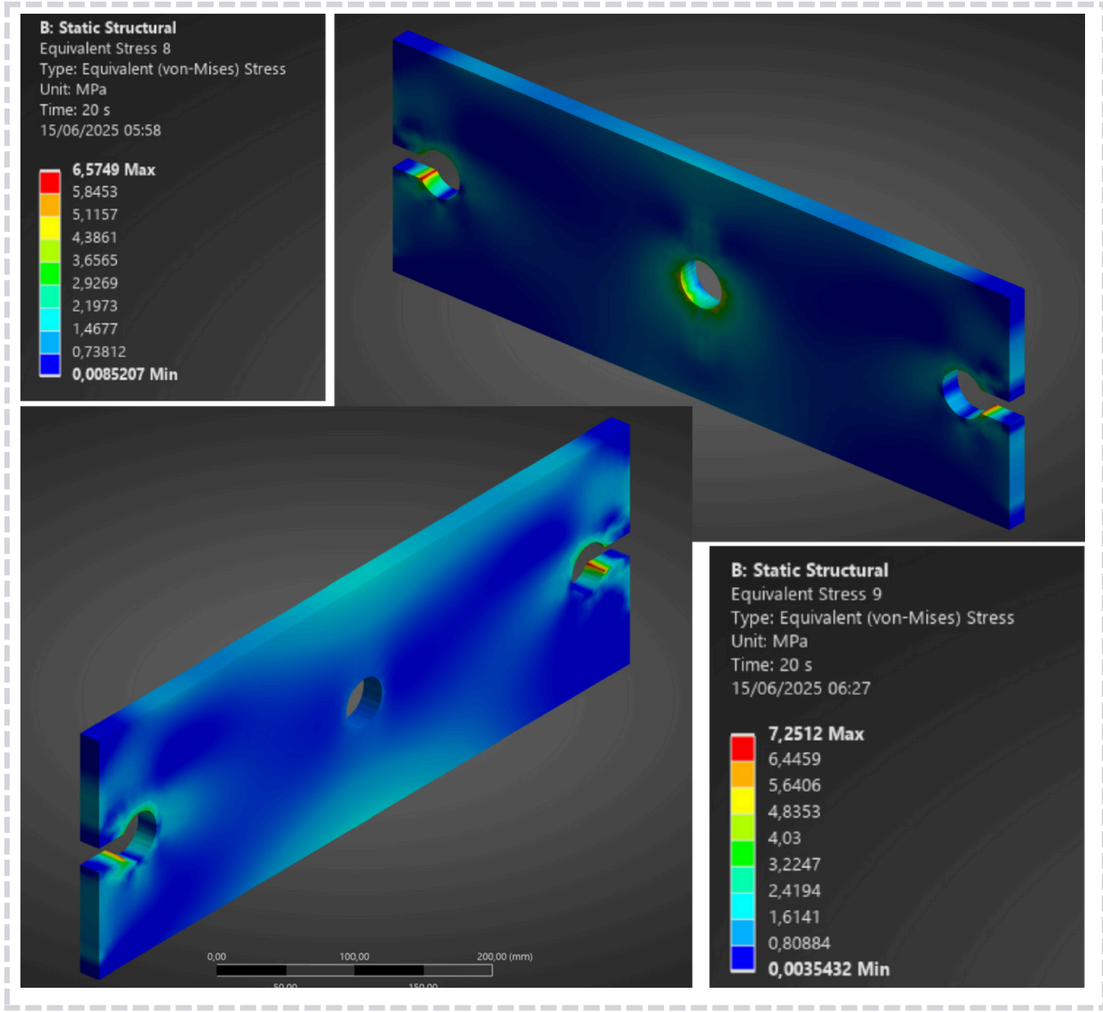
T shape Joint Simulation

L600mm module

Allowable max Stress: 60MPa

Model Max Stress: 7.2 MPa





- Structural Analysis

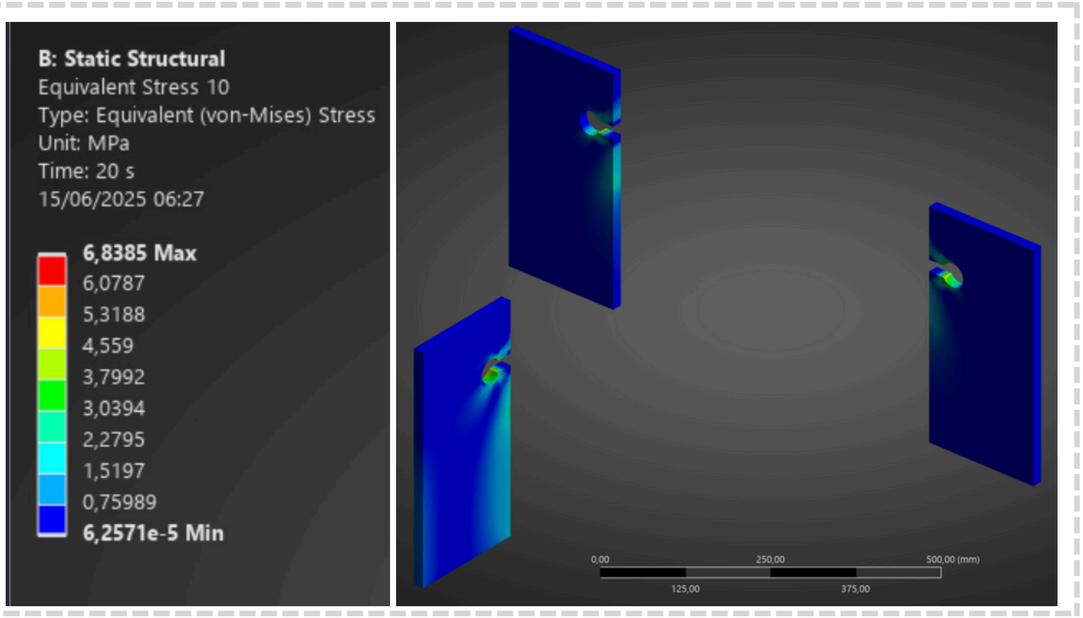
Micro Analysis

T shape Joint Simulation
L600mm module

Equivalent stress in glass

Allowable max Stress: 60MPa

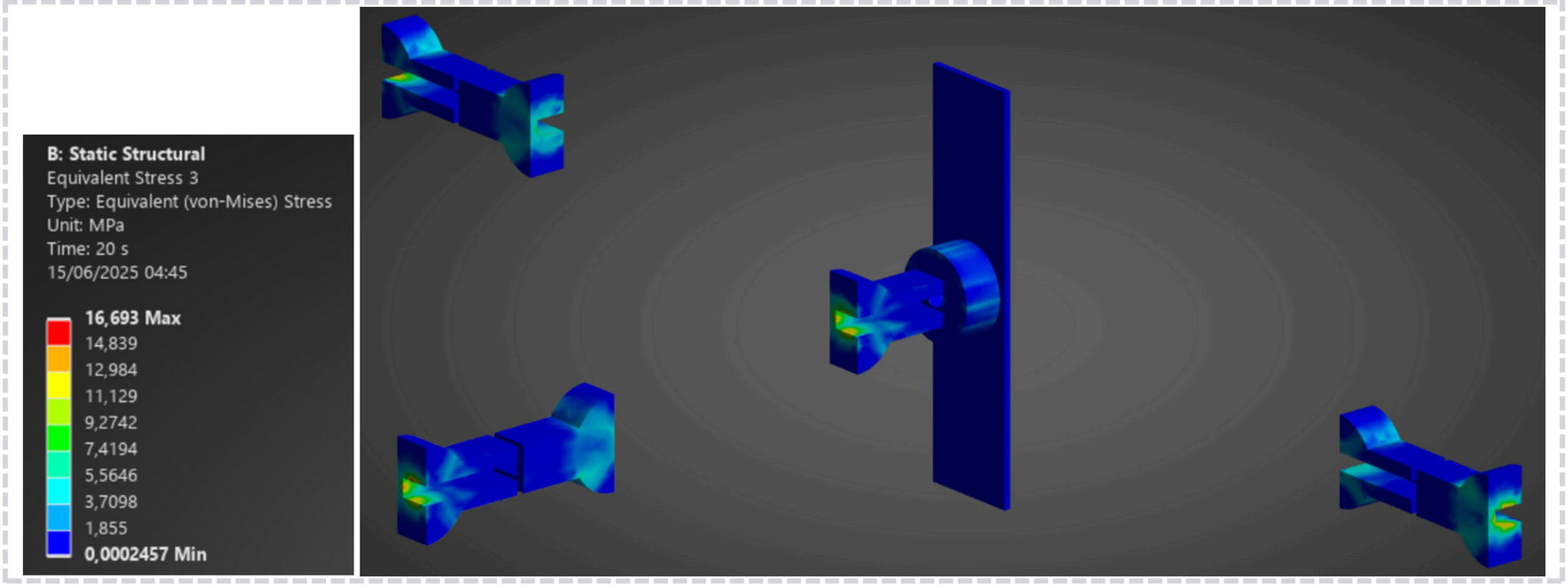
Model Max Stress: 7.2 MPa



Equivalent stress in wood

Allowable max Stress: 20MPa

Model Max Stress: 16.6 MPa



- Structural Analysis

Micro Analysis

T shape Joint Simulation

L600mm module

Equivalent stress in wood

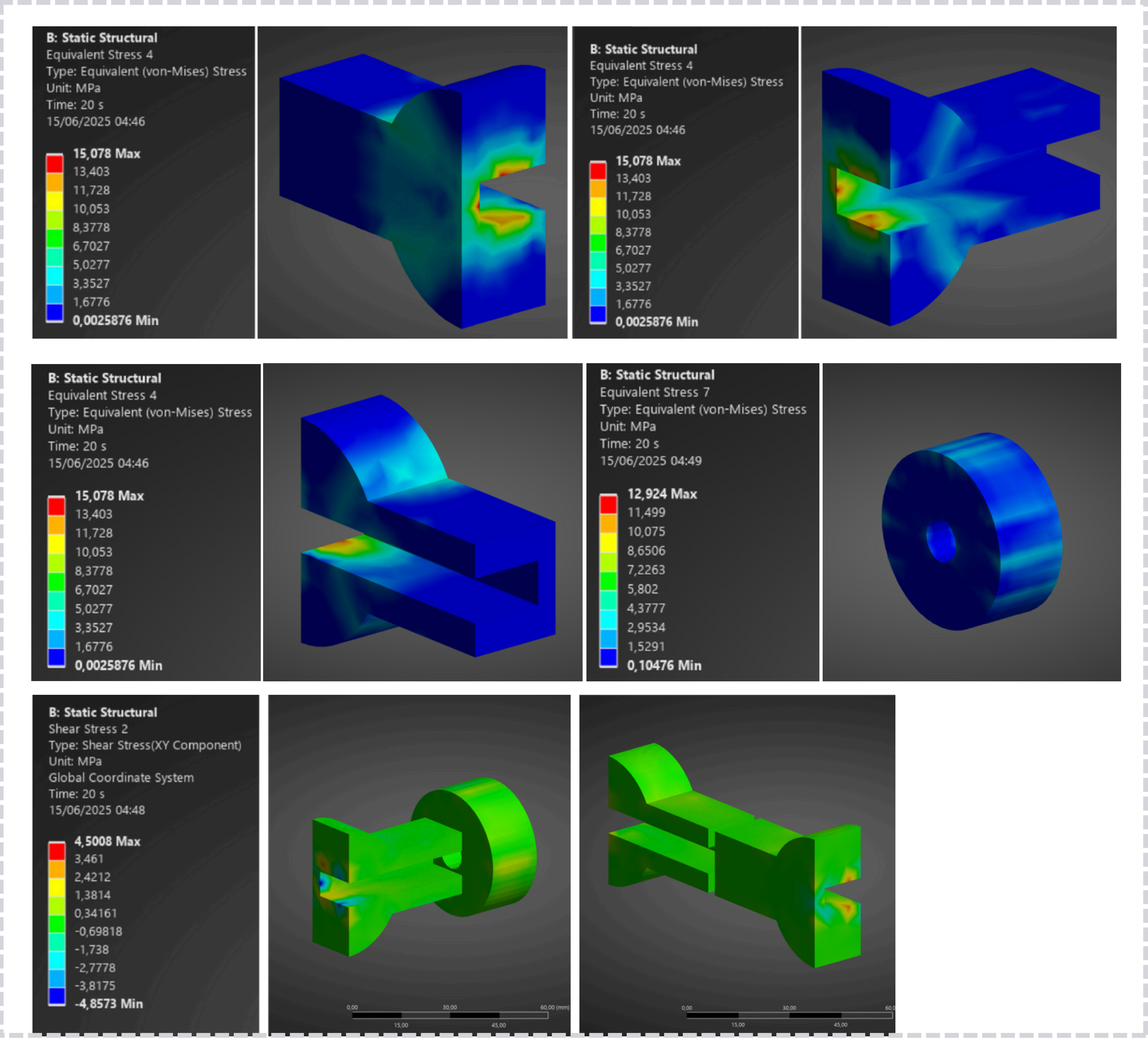
Allowable max Stress: 20MPa

Model Max Stress: 16.6 MPa

Shear stress in wood

Allowable max Stress: 18 MPa (parallel) and 50–55 MPa (perpendicular

Model Max Stress: 4 MPa

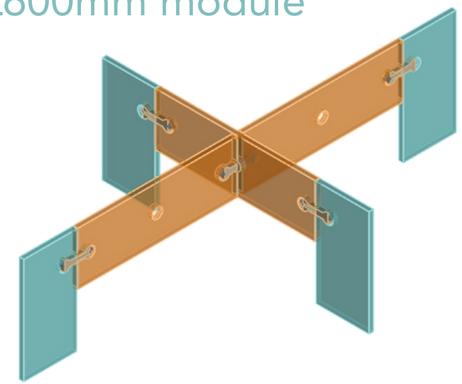


- Structural Analysis

Micro Analysis

Cross shape Joint Simulation

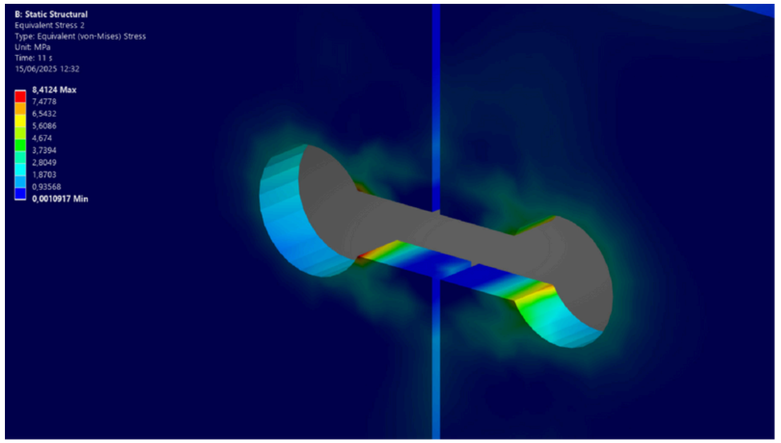
L600mm module

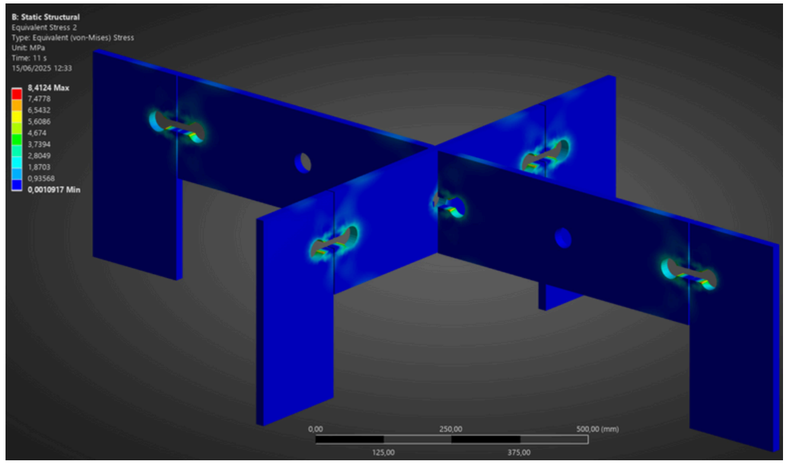


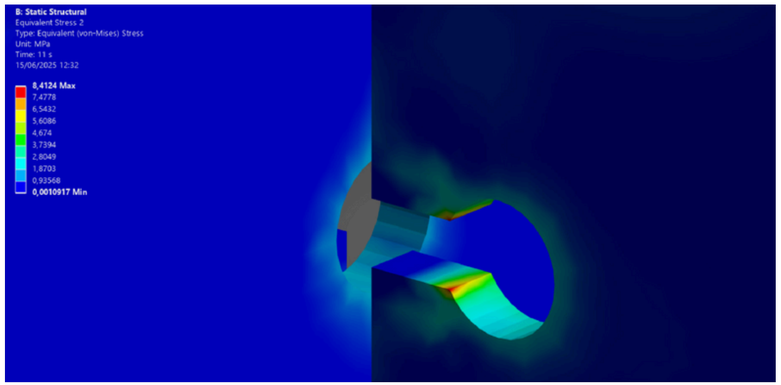
Equivalent stress in glass

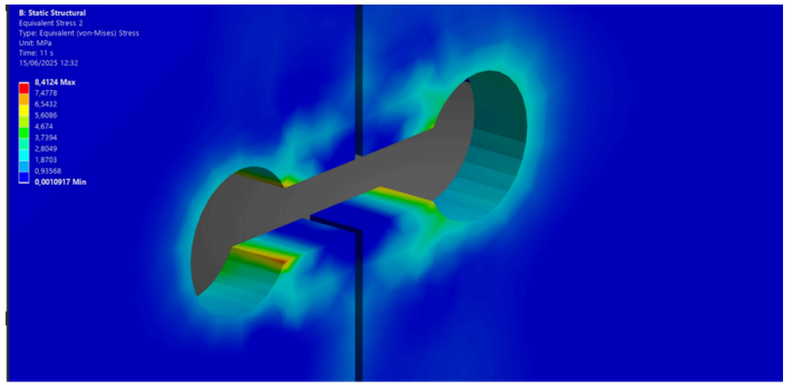
Allowable max Stress: 60MPa

Model Max Stress: 8.4 MPa









- Structural Analysis

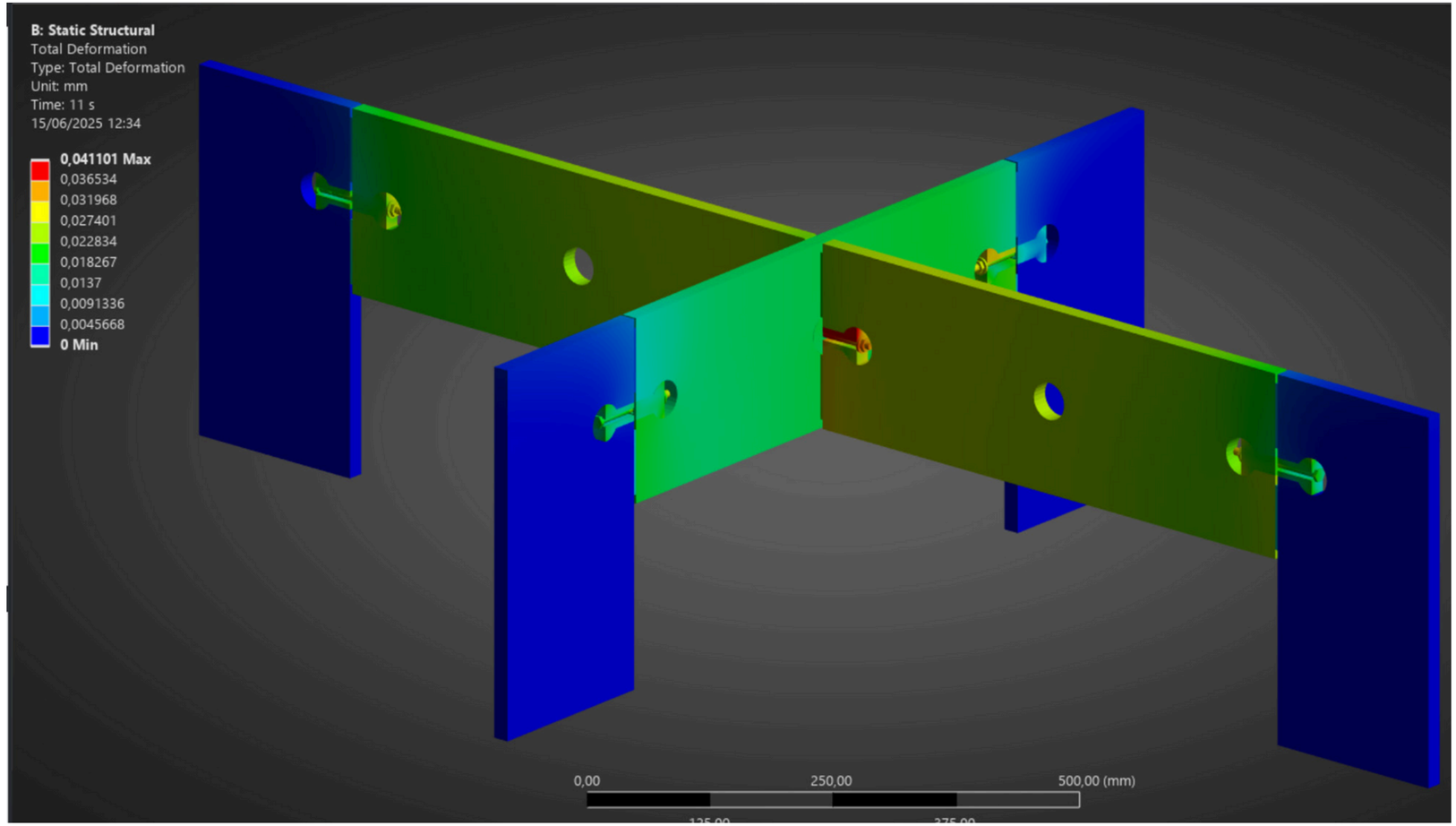
Micro Analysis

Cross shape Joint Simulation
L600mm module

Total deformation

Allowable max Displacement:
600/300= 2mm

Simulation Max
Displacement: 0.3 mm



- Structural Analysis

Micro Analysis

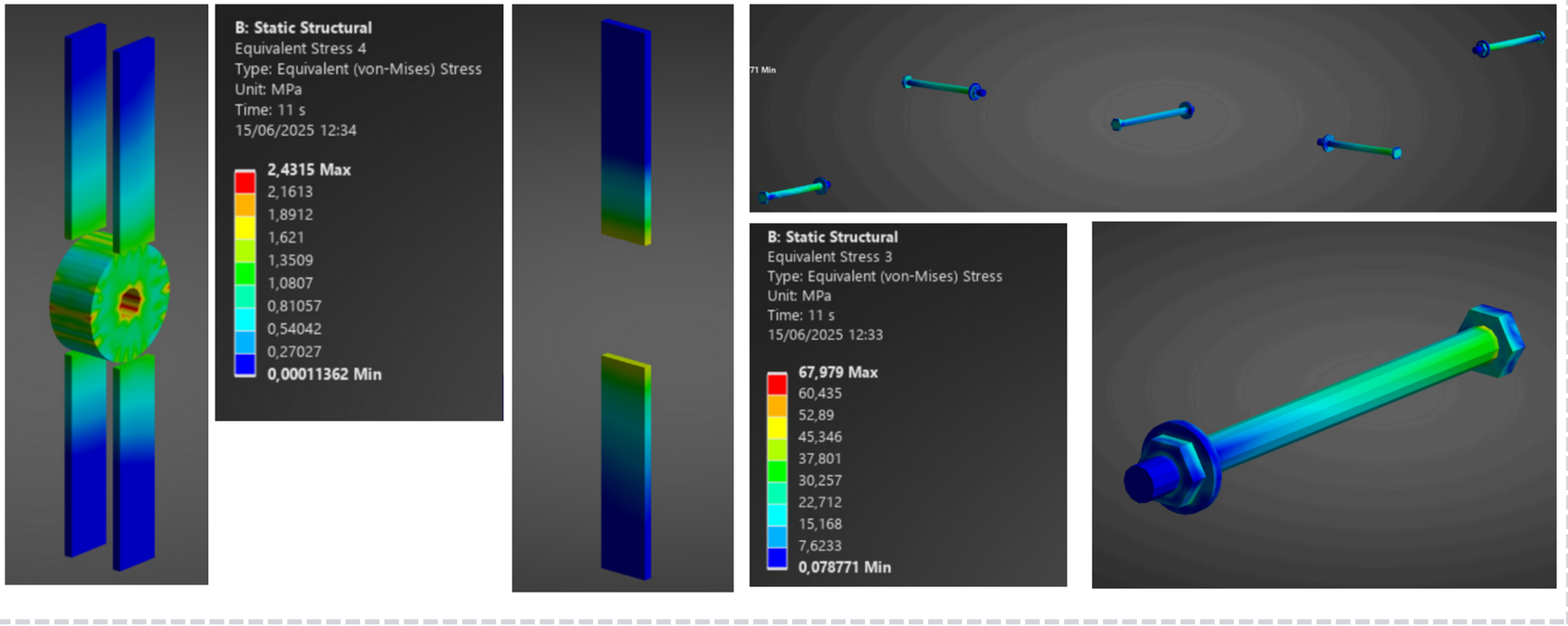
Cross shape Joint Simulation

L600mm module

Equivalent stress in wood

Allowable max Stress: 20MPa

Model Max Stress: 2.4 MPa



- Structural Analysis

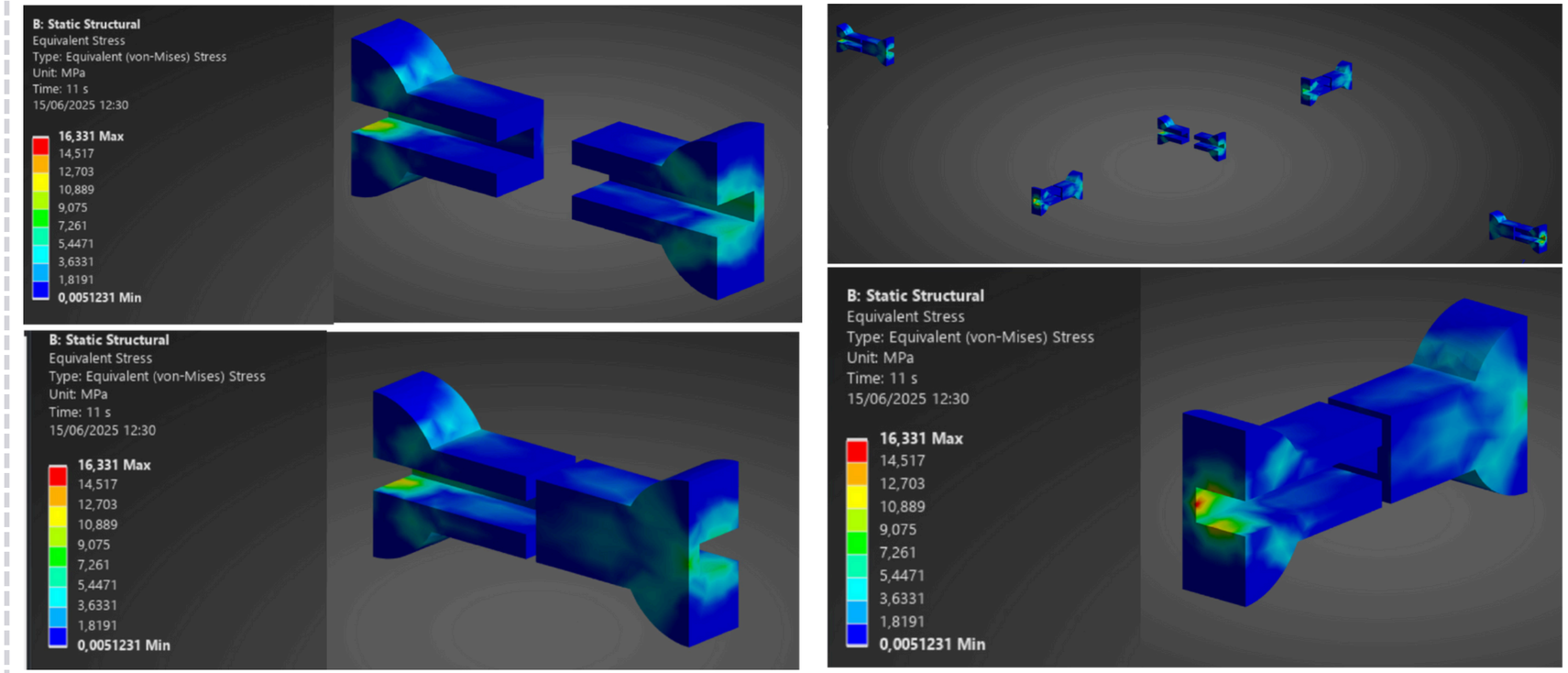
Micro Analysis

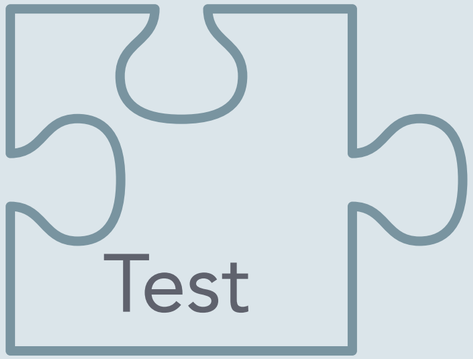
Cross shape Joint Simulation
L600mm module

Equivalent stress in wood

Allowable max Stress: 20MPa

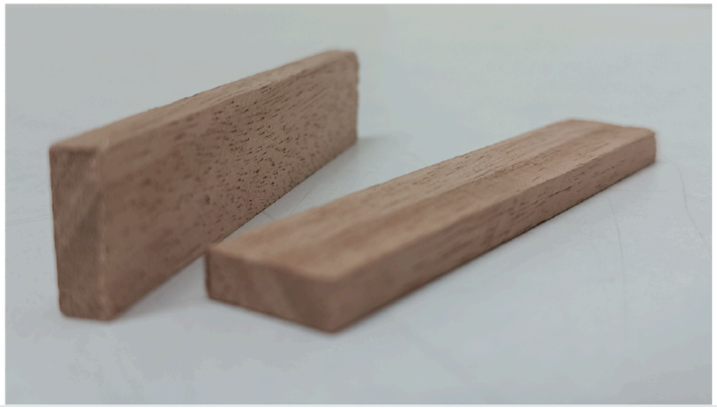
Model Max Stress: 16 MPa




Test

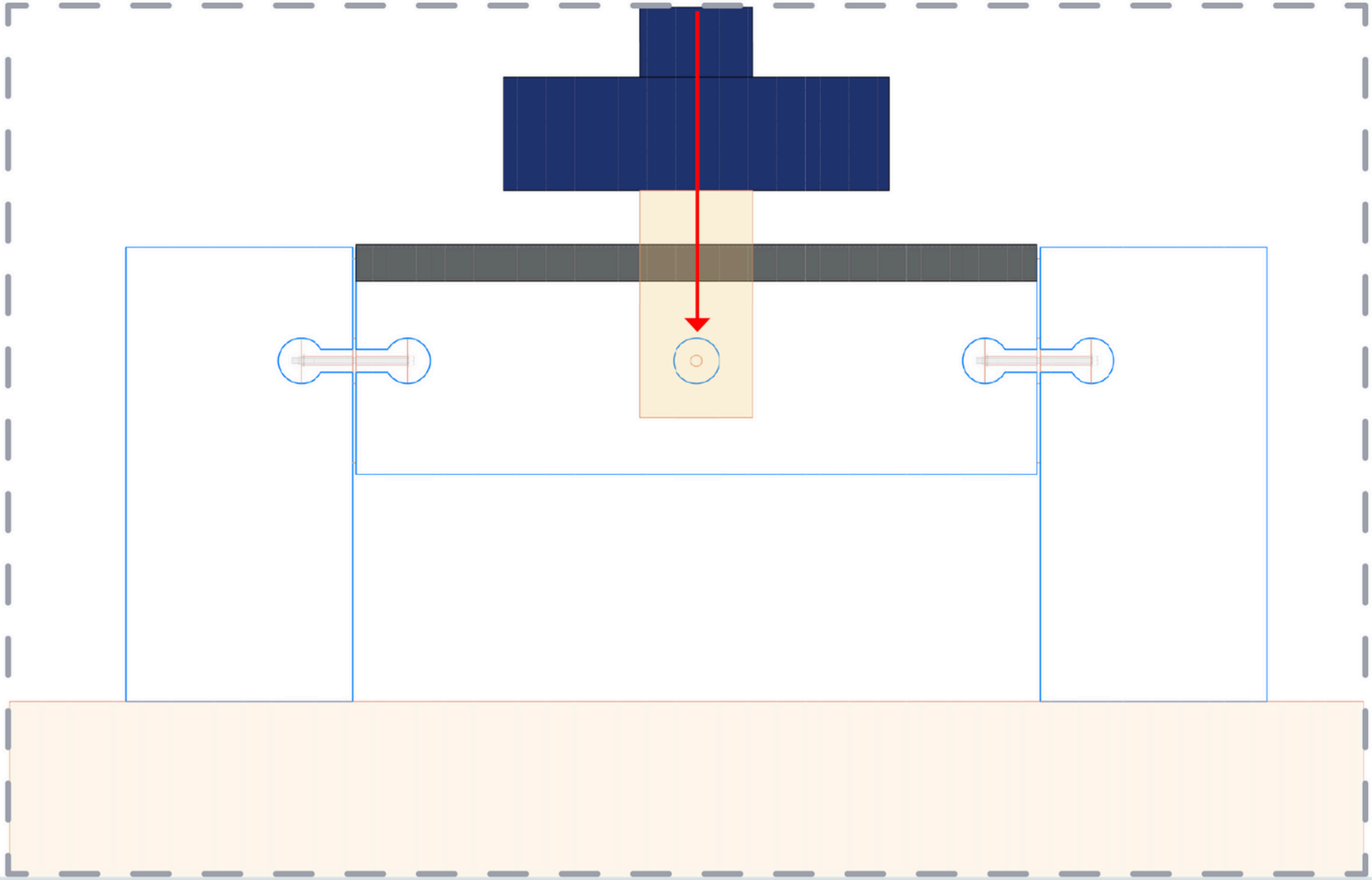
- Experiment

Plexiglass & Meranti



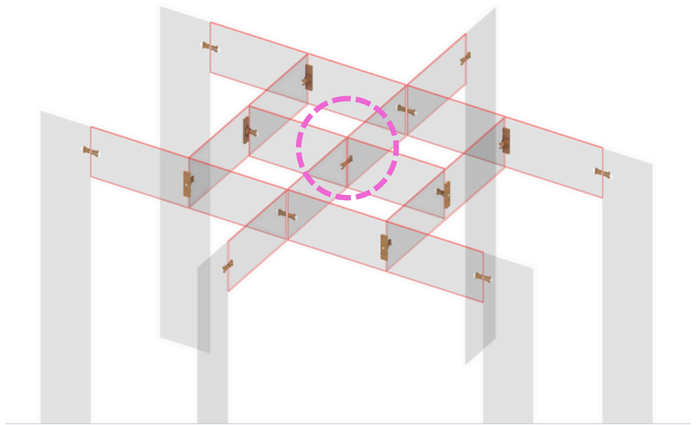
- Experiment

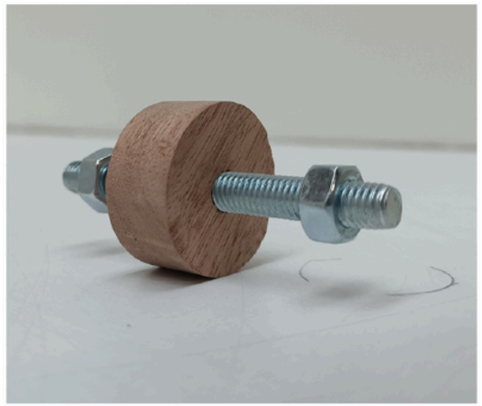
Test set up

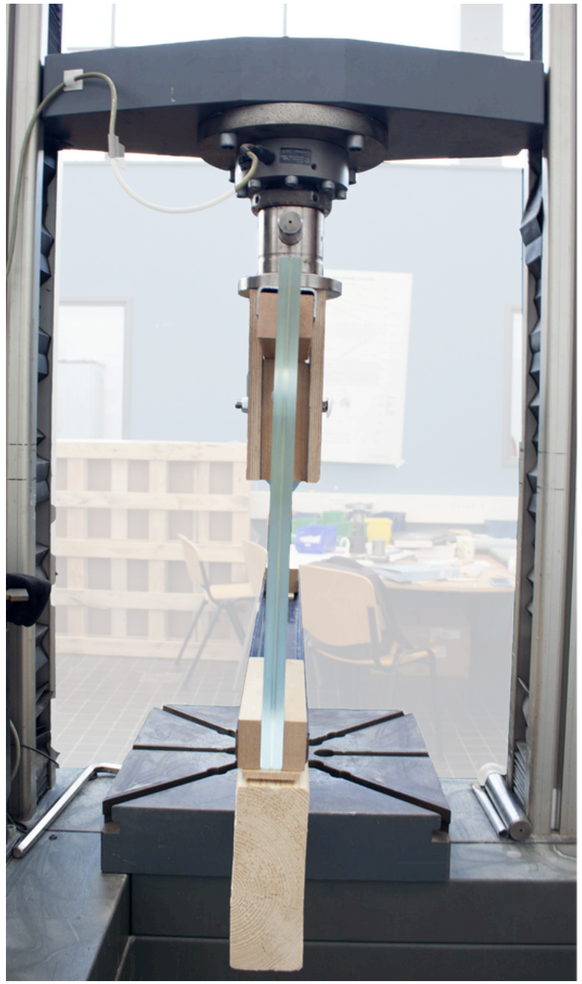


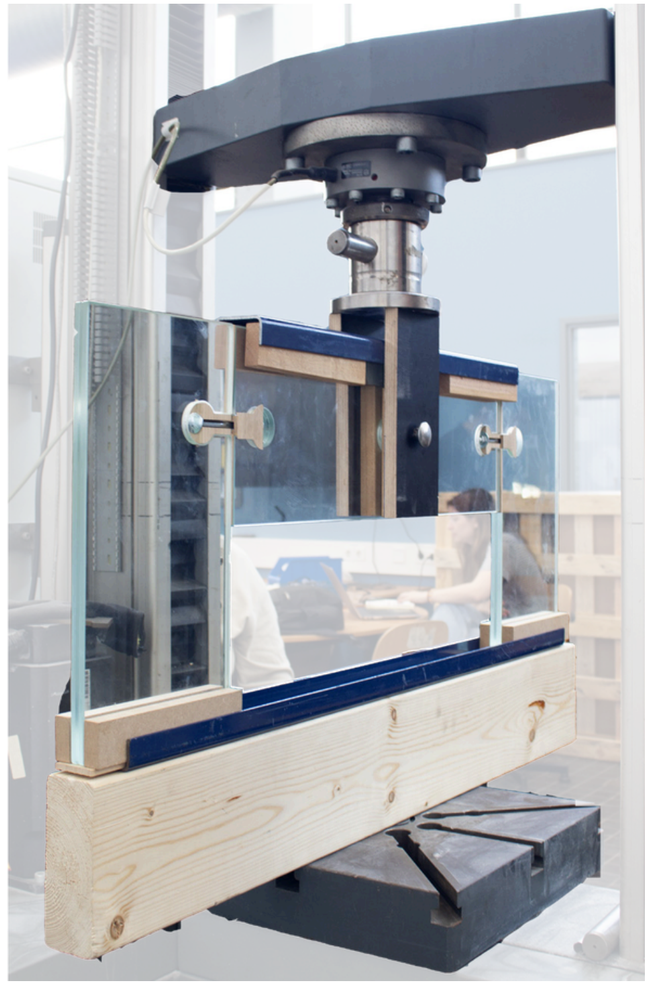
- Experiment

Test set up



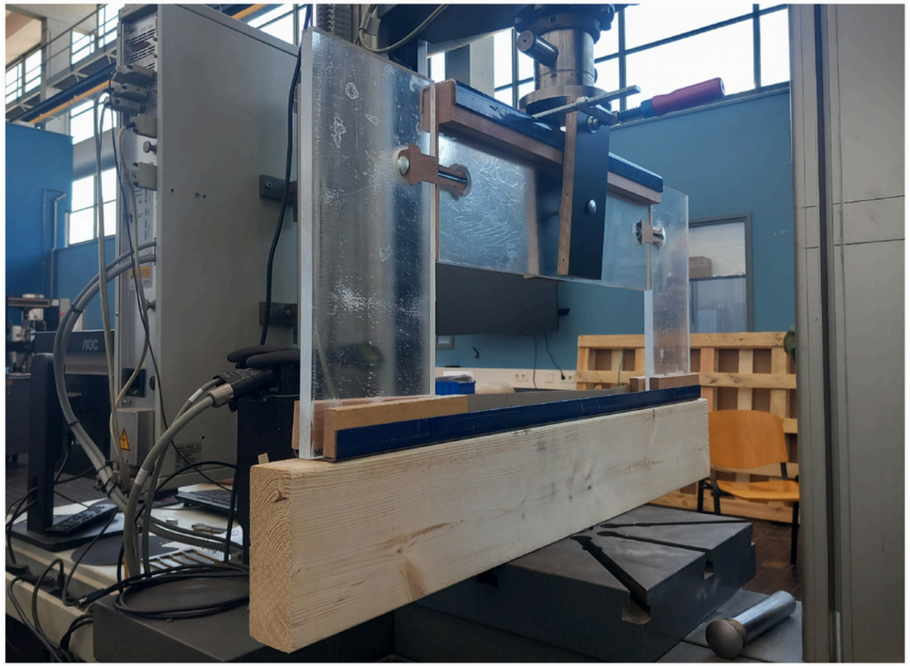


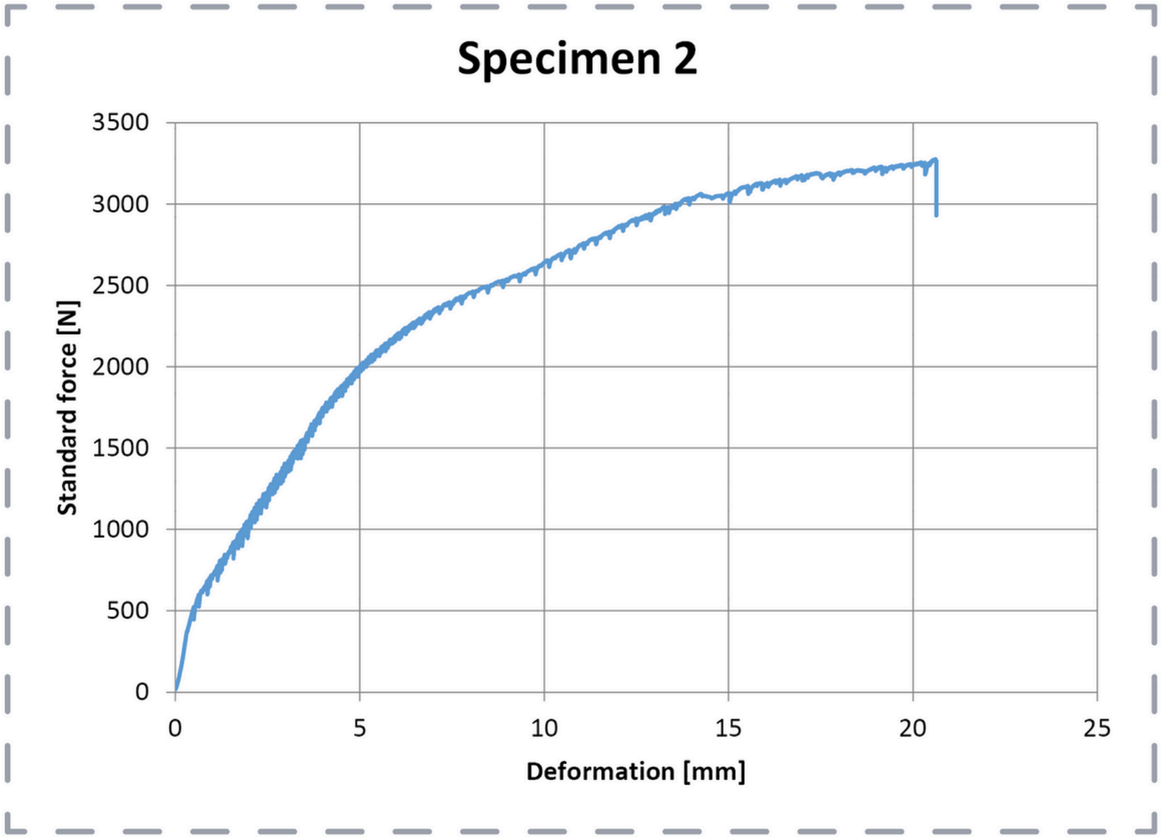




- Experiment

  Key Observations





Stage 1:
Fmax:
285 N
dL at Fmax:
0.3 mm

Stage 2:
Fmax:
1032 N
dL at Fmax:
2.6 mm

Stage 3: Fmax:
2484N dL at
Fmax:
8.3 mm

Stage 4: Ultimate
Fmax: 3050N dL
at Fmax:
20 mm

- Experiment

Key Observations

Point Load Behaviour

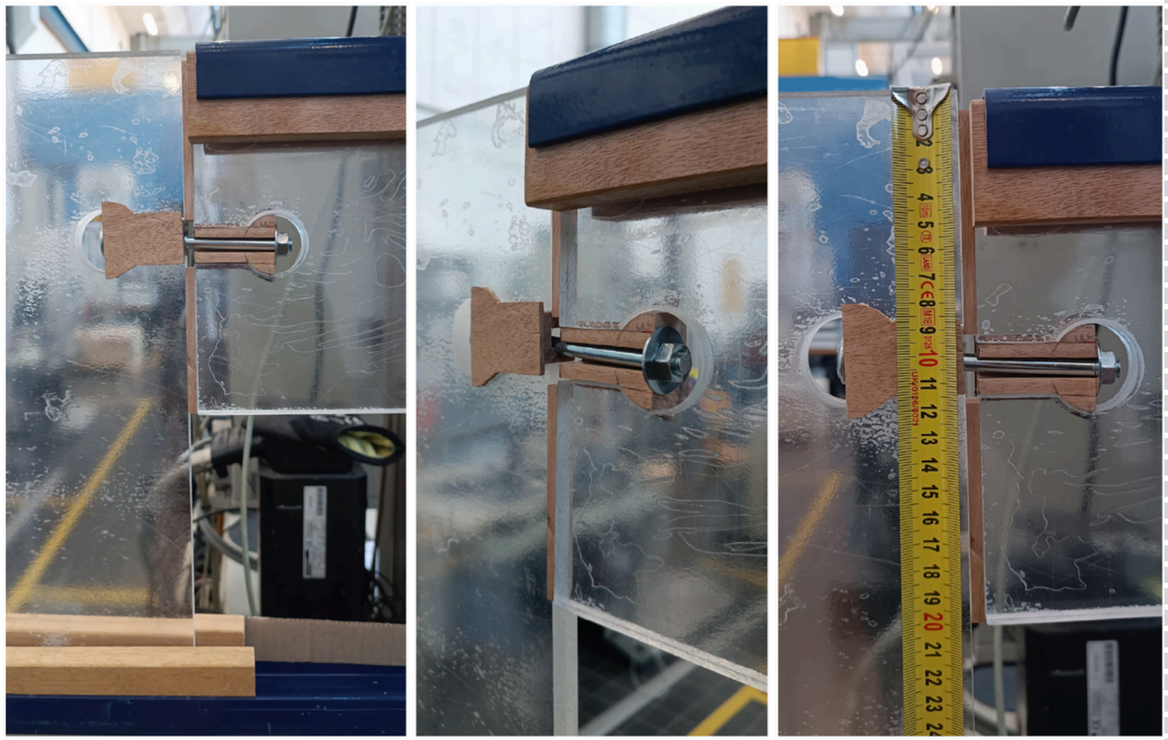
Revised configuration for applying the point load to prevent failure of the steel pin and to obtain more accurate results in identifying failure points and potential maximum local stress concentrations.

- Experiment

Key Observations

Load Response: 2.5 mm, manually measured

Left side:



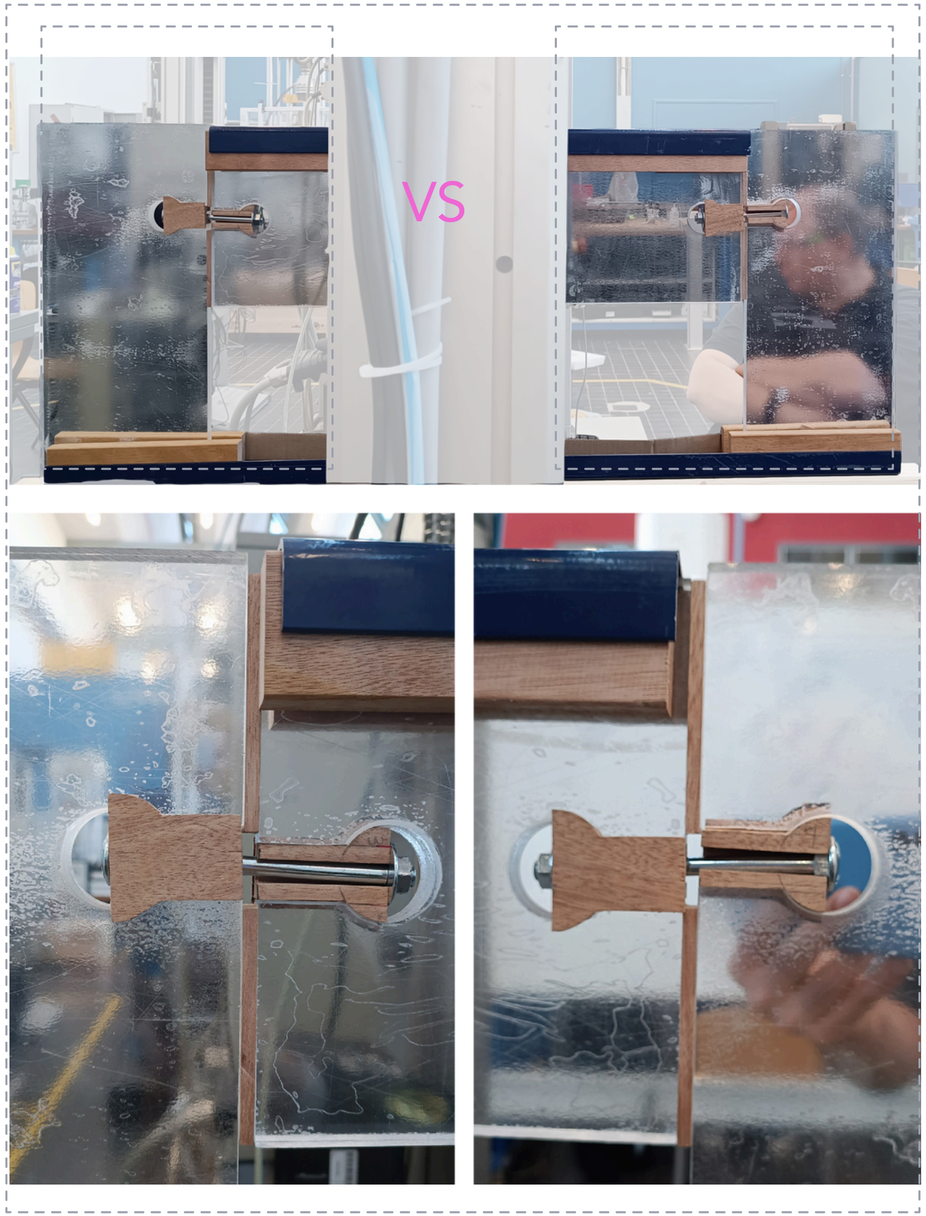
Right side:

- Experiment

Key Observations

Asymmetric Deformation

Torque-controlled bolt tightening to ensure uniform pretension and prevent asymmetric deformation.



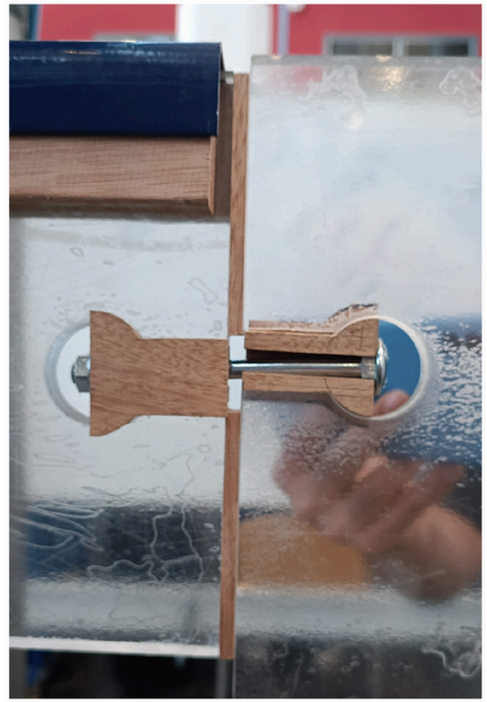
- Experiment

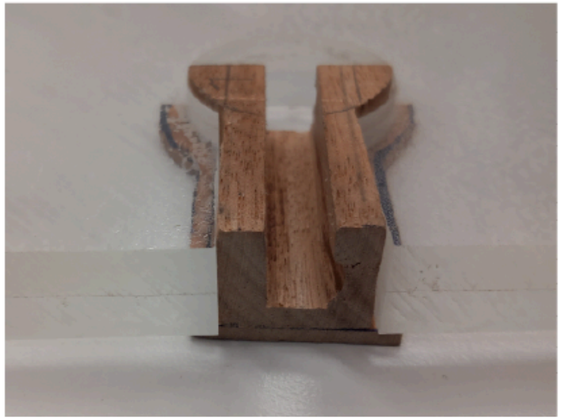
Key Observations

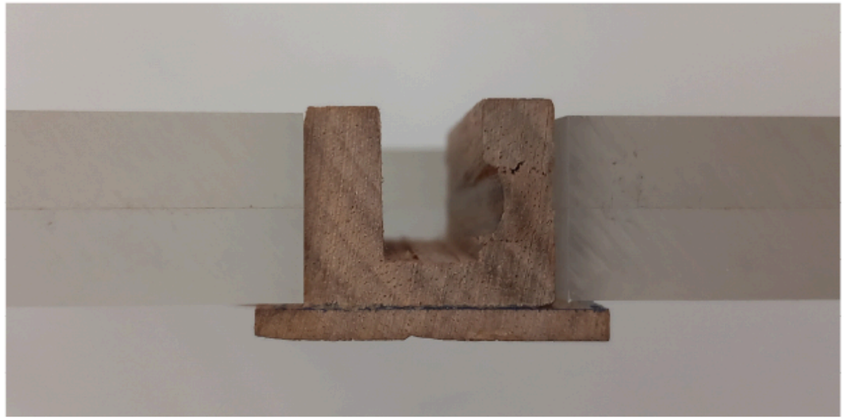
Hole Precision & Fit

Bolt Deviation Under Point Load

Tolerances , space needed for bolt fastening and reduce stress concentrations.



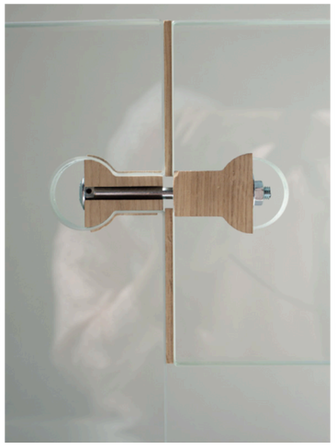


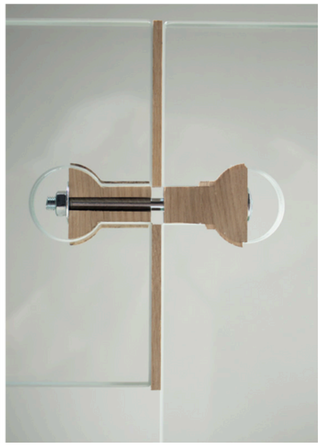


- Experiment

Glass & Oak

Fabrication and Prototyping





- Experiment

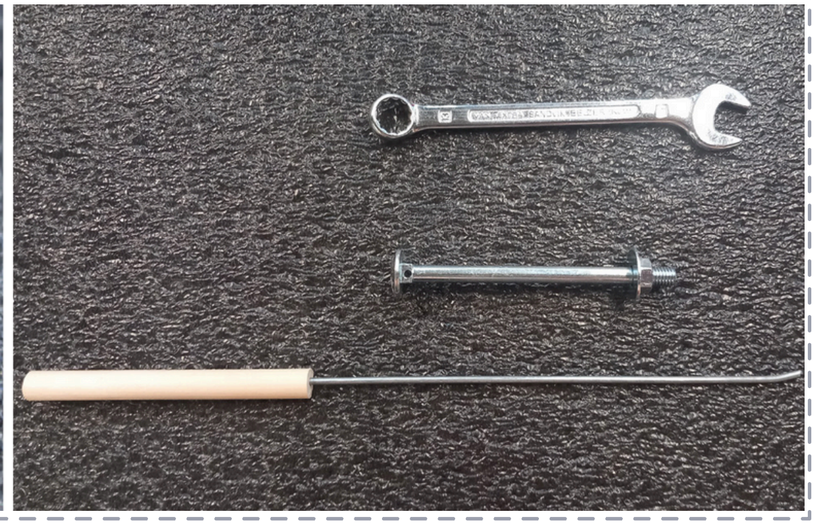
Change in set ups

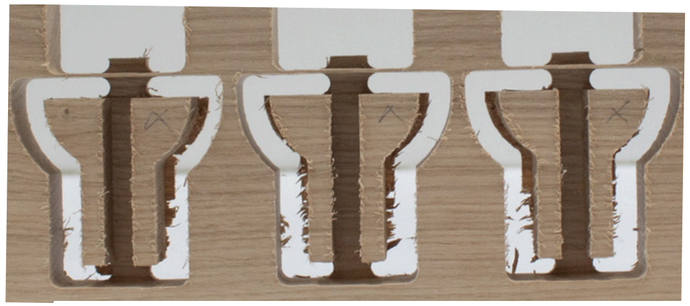
- **Larger bolt holes in the glass panels**
- **Revised configuration for applying the point load**

- Experiment

Change in set ups

Fabrication and Prototyping



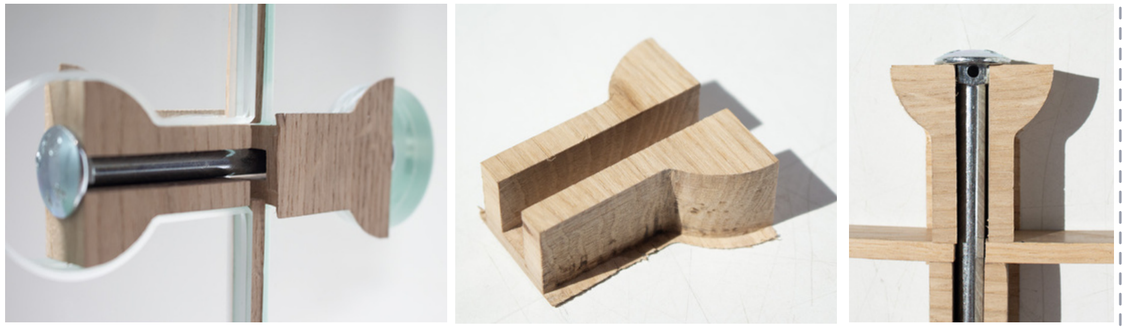


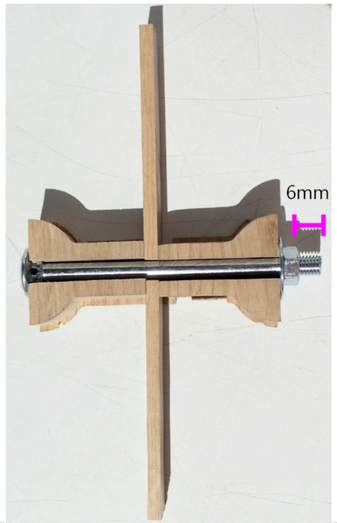
- Experiment

  Change in set ups

Test Setup and Procedure Revised from pretest:

1. Larger bolt holes in the glass panels
2. Revised configuration for applying the point load
3. Torque-controlled bolt

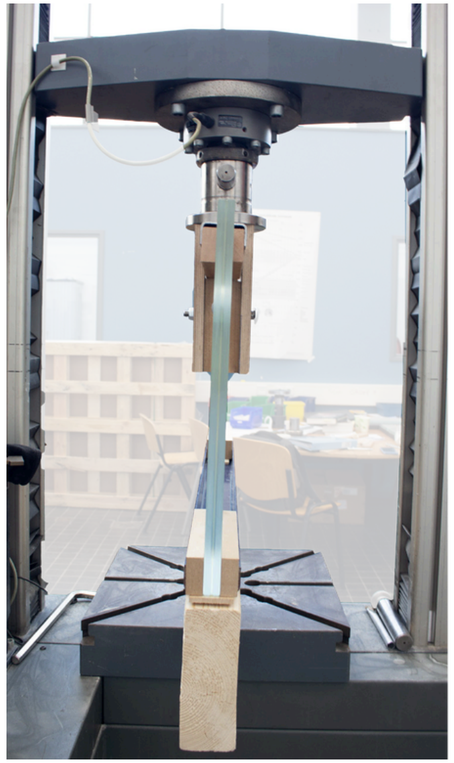


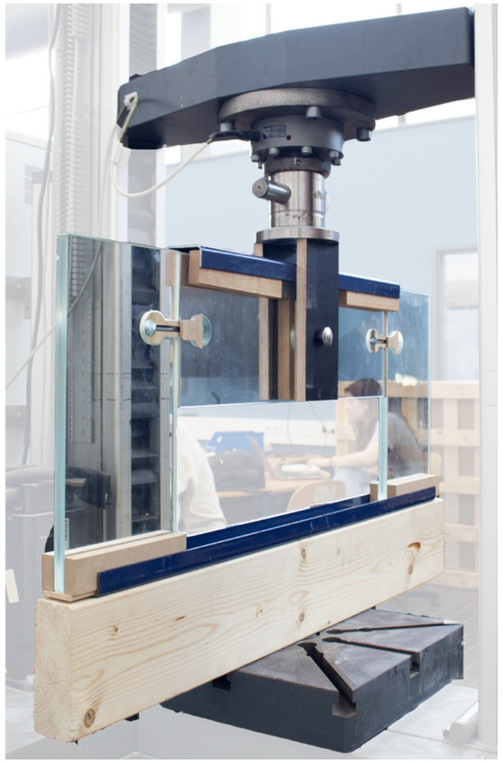


- Experiment

Final set ups

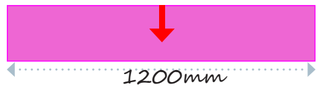
Loading condition





UDL converted to mid point load:
117N Point Load: 165N

UDL converted to mid point load:
468N Point Load: 657N



UDL converted to mid point load:
1170N Point Loads: 2* 657 = 1314N

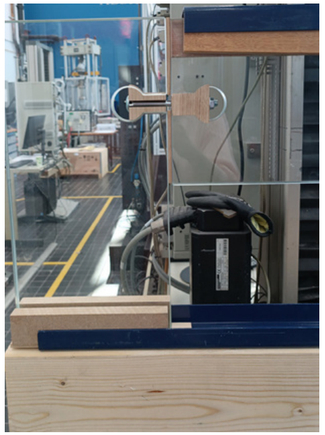
Step 1: 0.285KN

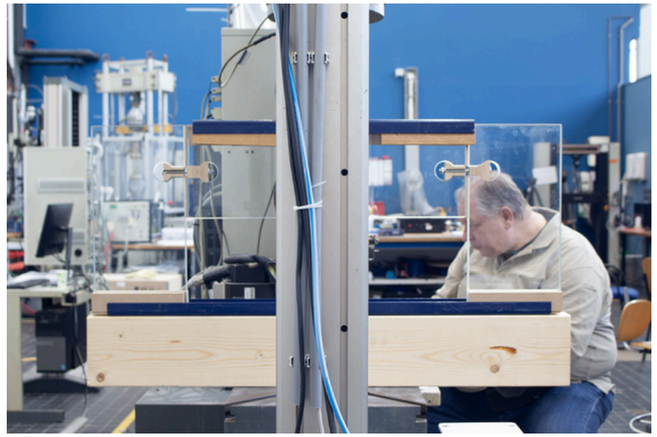
Step 2:1.032KN

Step 3: 2,484KN

Step 4: 2,688KN

Step 5: 5,800 KN





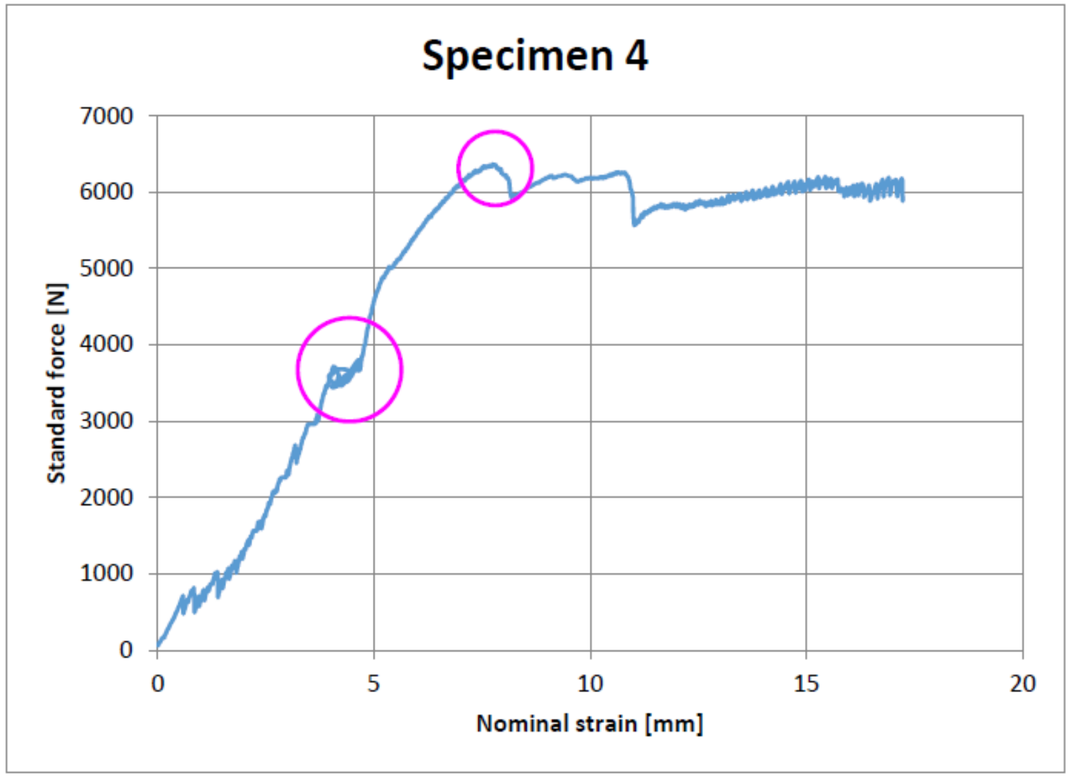
- Experiment

  Key Observations

- Left Side
- Right Side

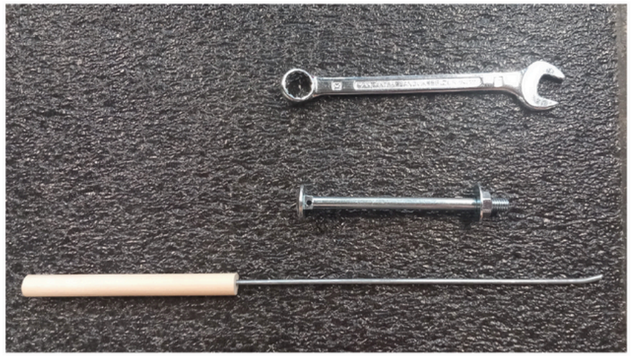
- Experiment

Key Observations



Stage 1: Fmax: 285 N **dL at Fmax:** 0.2 mm	**Stage 2:** Fmax: 1032 N **dL at Fmax:** 1.7 mm	**Stage 3:** Fmax: 2484N **dL at Fmax:** 2.9 = 3 mm
Stage 4: Fmax: 2688N **dL at Fmax:** 3.3 mm	**Stage 5:** Fmax: 584N **dL at Fmax:** 6.6 mm	**Stage 6: Ultimate** Fmax: 5900N **dL at Fmax:** 17.2 mm

- Experiment
  - Test Results & Improvements



The design performed well under the tested loads, showing **promising mechanical behavior**.

- Accuracy limitation: **smaller modules** were tested under loads **meant for longer modules.**

Bolt & Fastening Insights:

1. Current method required **tools to pass through glass holes**—not ideal.
2. Suggestion: use bolts **accessible from the side elevation**.
3. Torque wrench head was too large → a ring/open spanner would allow better preload control.
4. Bolt rotation caused wood cracking; solved by pinning the bolt head→ slower application is safer.

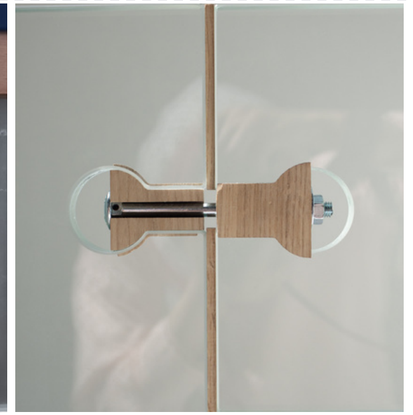
- Experiment

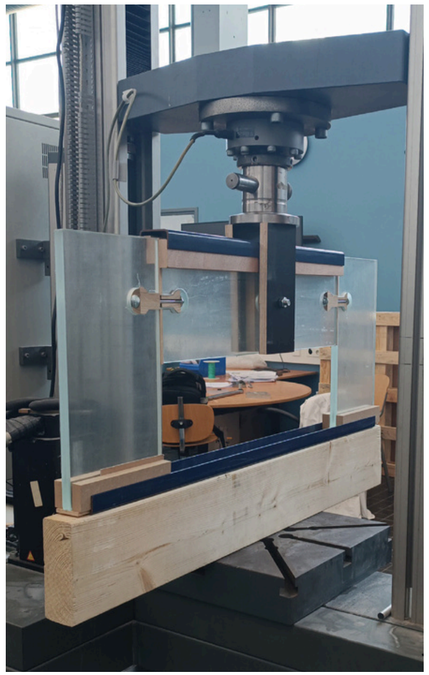
  Glass & Oak

- Experiment

Change in set ups

Fabrication and Prototyping

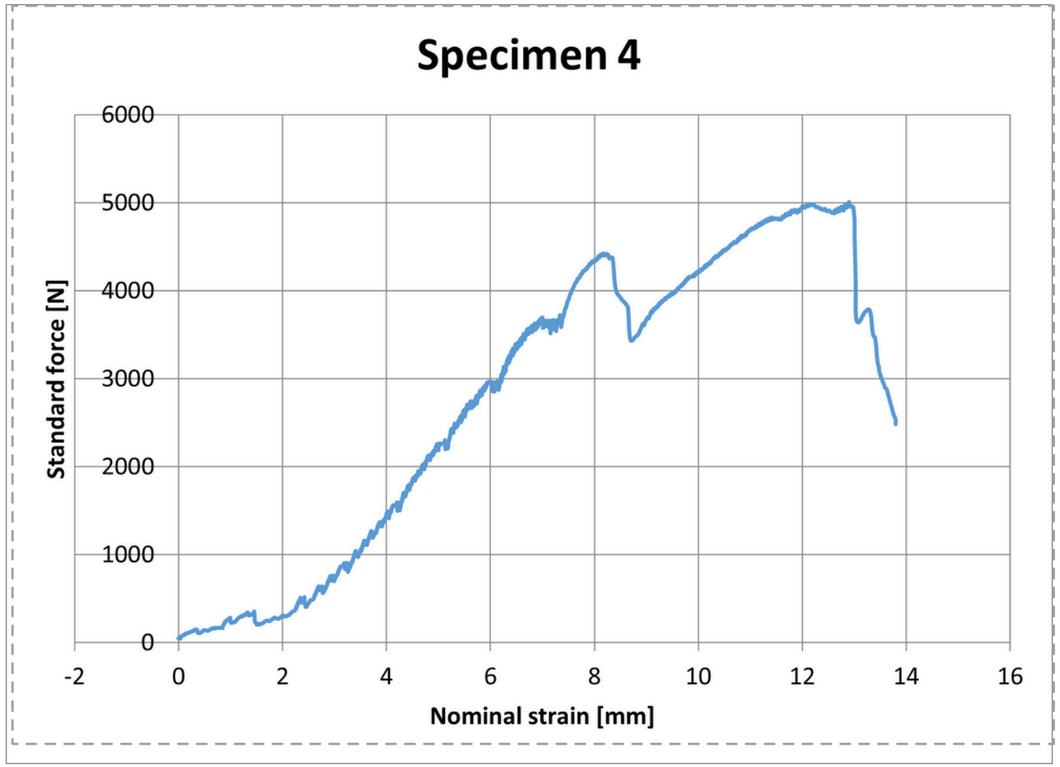




- Experiment

Glass & Oak

Stage 1: Fmax: 285 N dL at Fmax: 1.1mm	Stage 2: Fmax: 1032 N dL at Fmax: 3.4 mm		
Stage 3: Fmax: 2484N dL at Fmax: 5.3 mm	Stage 4: Fmax: 2688N dL at Fmax: 5.6 mm	Stage 5: Fmax: 5800N. dL at Fmax: -----	Stage 6: Ultimate Fmax: 5009N dL at Fmax: 13 mm

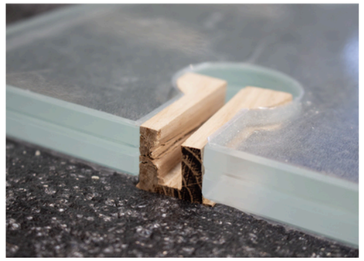


- Experiment

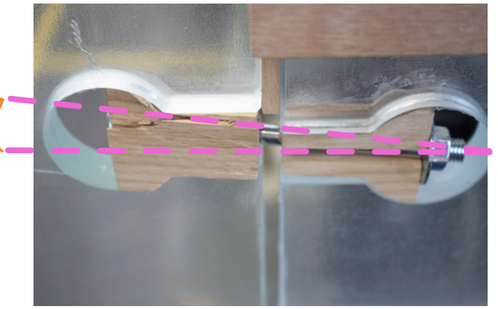
  Key Observations





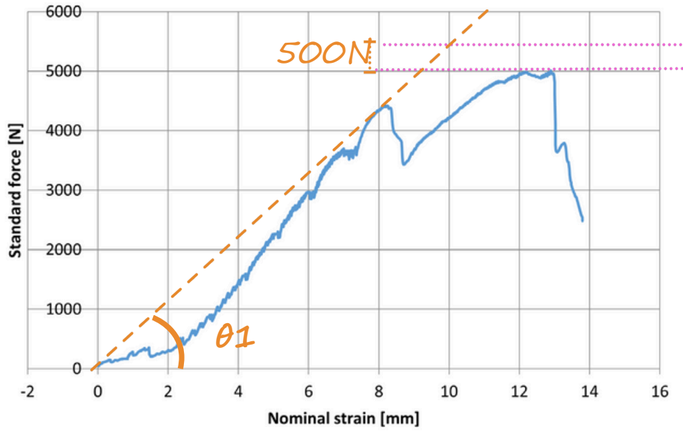
Stage 6: Ultimate
Fmax: 5009N dL
at Fmax:
13 mm

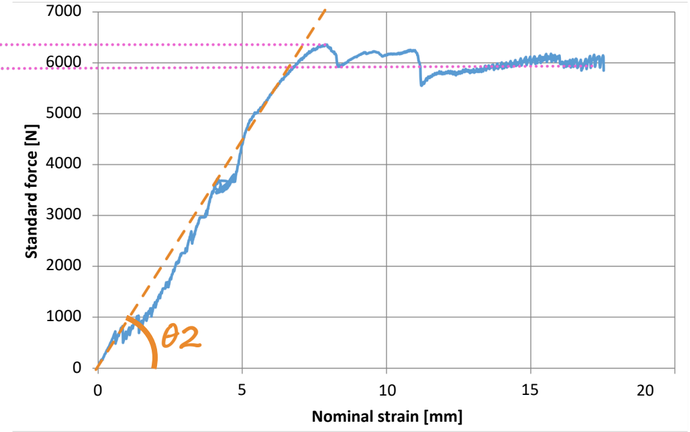
- Experiment

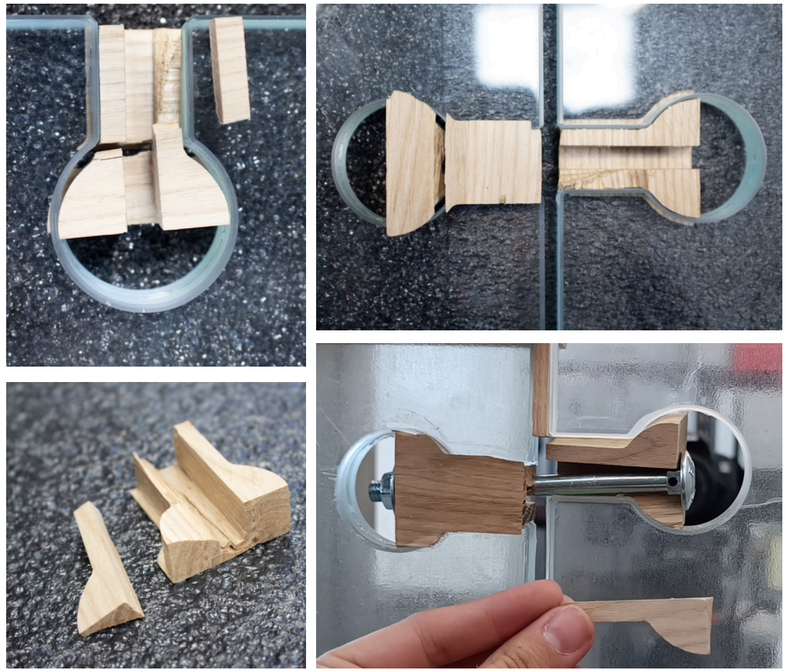
  Comparisom

Perpendicular to grain



Parallel to grain





- Test 3

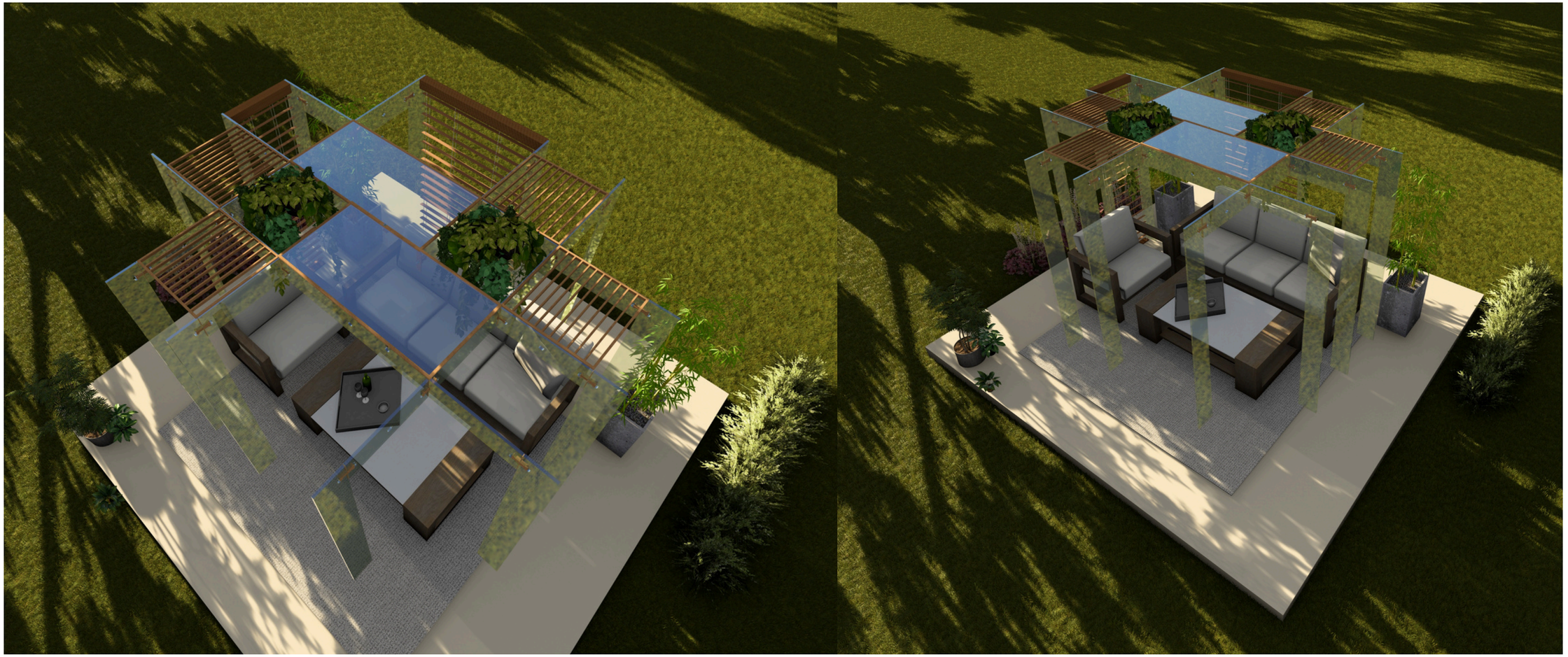

Final
Design

- Final design : Use cases

  Pergola

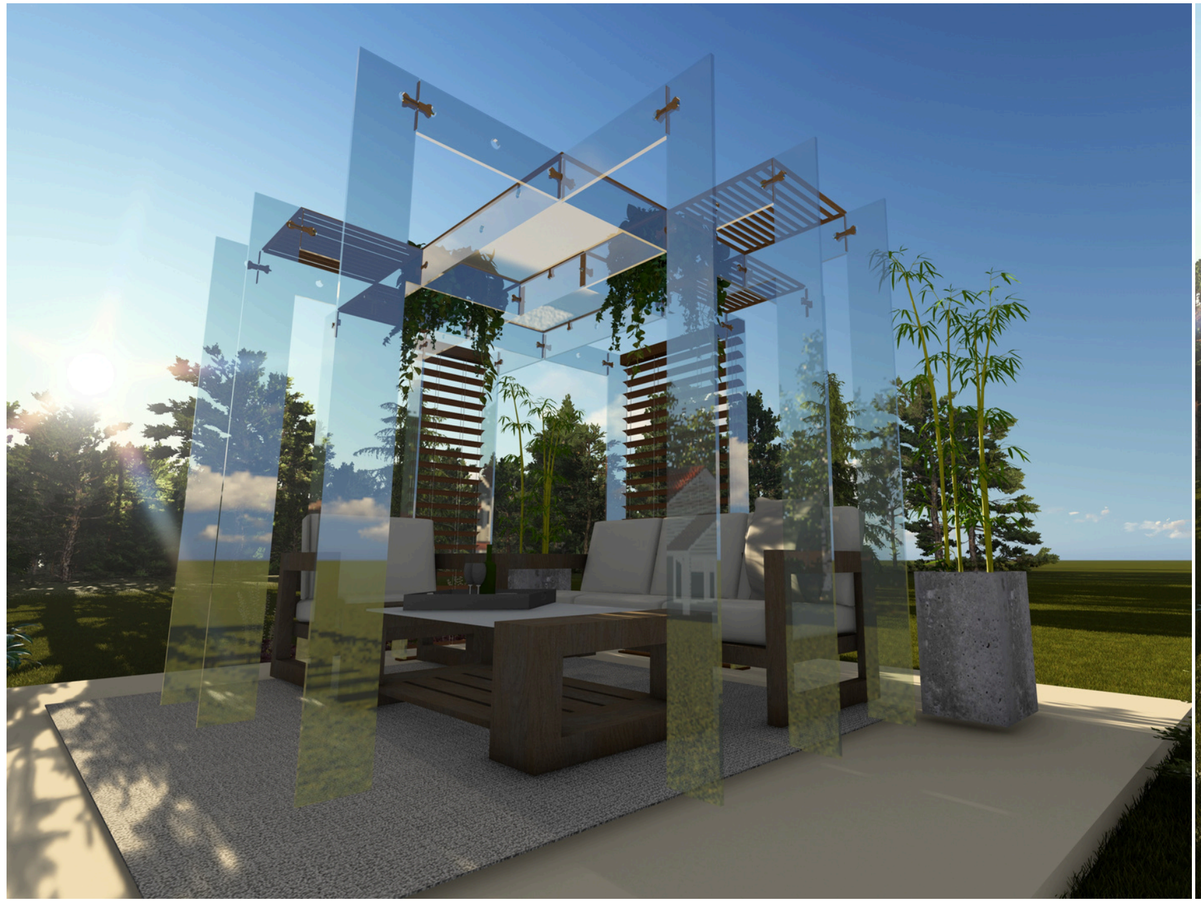
- Final design : Use cases

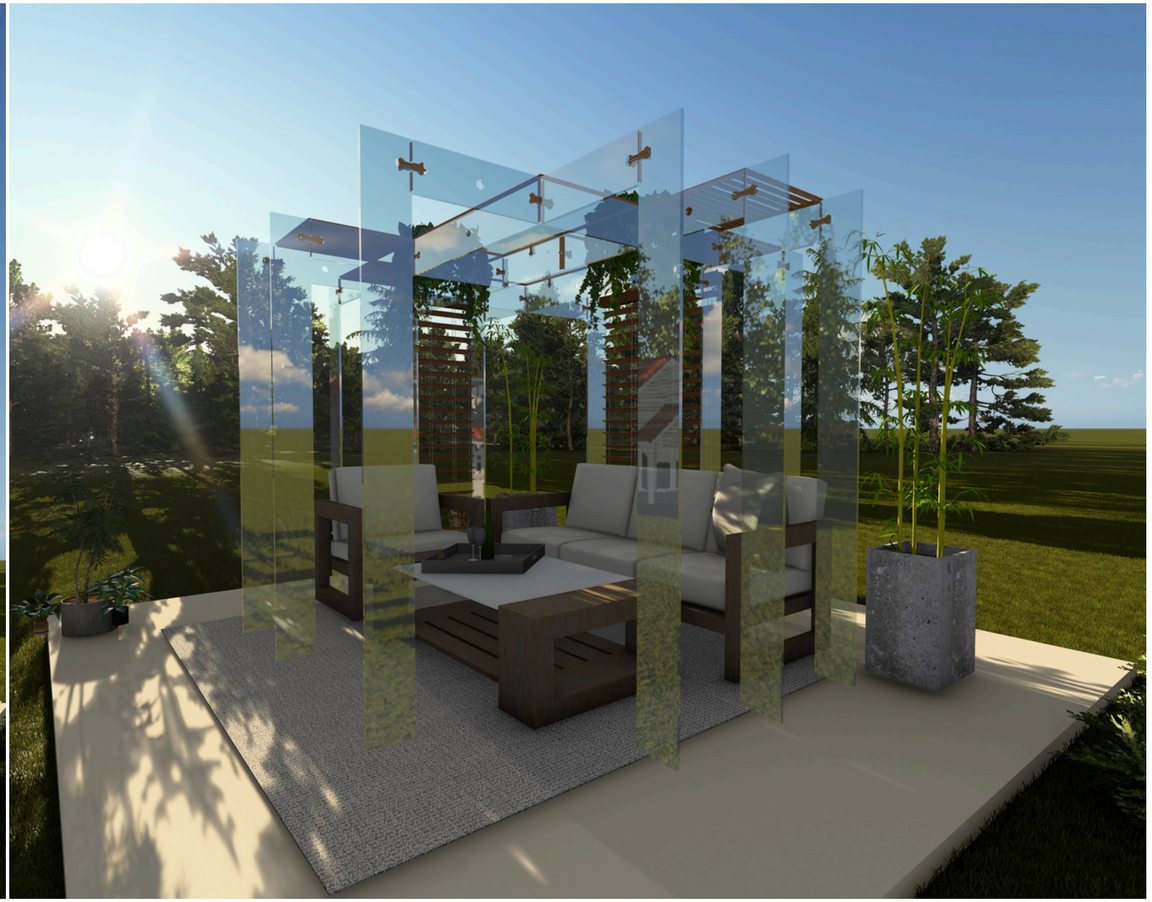
Pergola



- Final design : Use cases

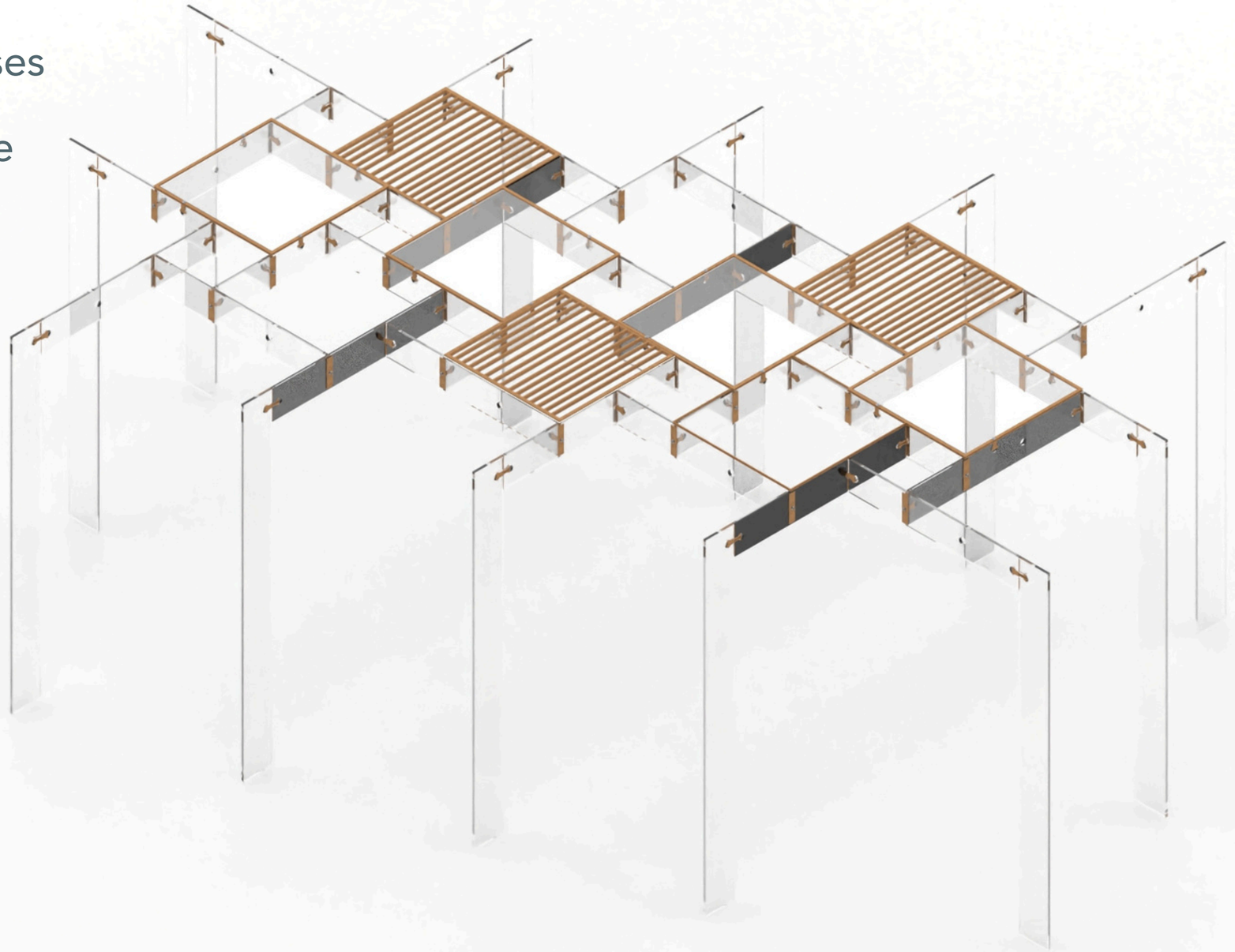
Pergola





- Final design : Use cases

  Walk way shade
  or Pergola

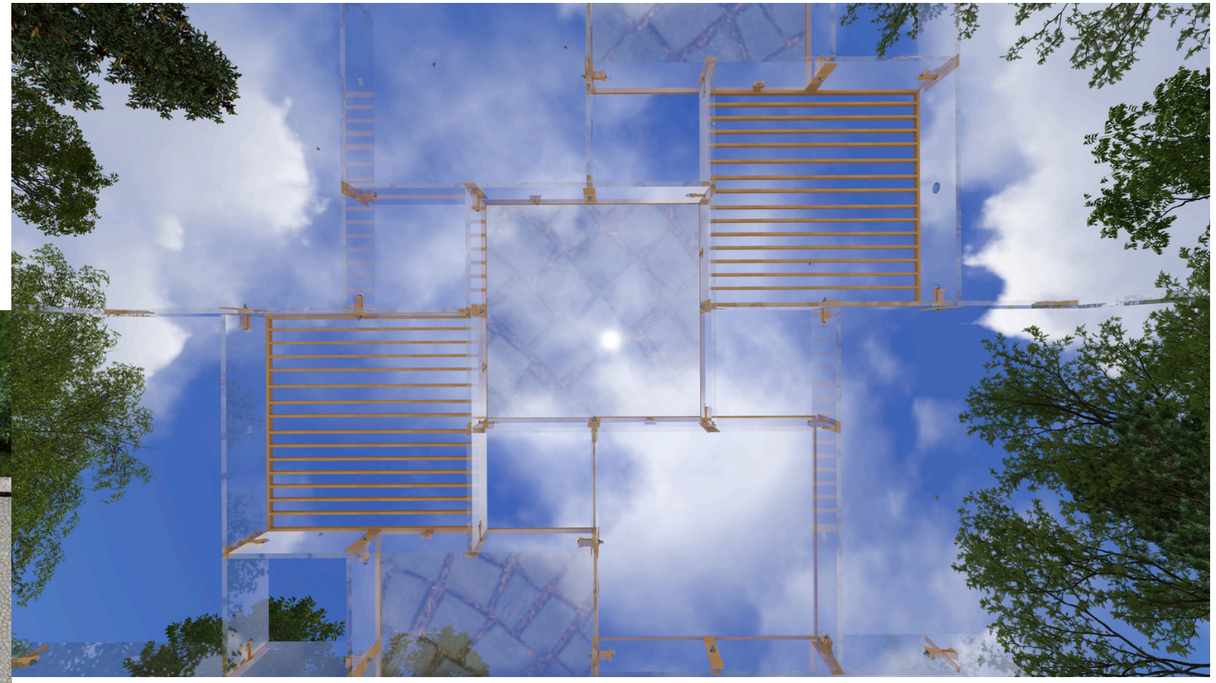


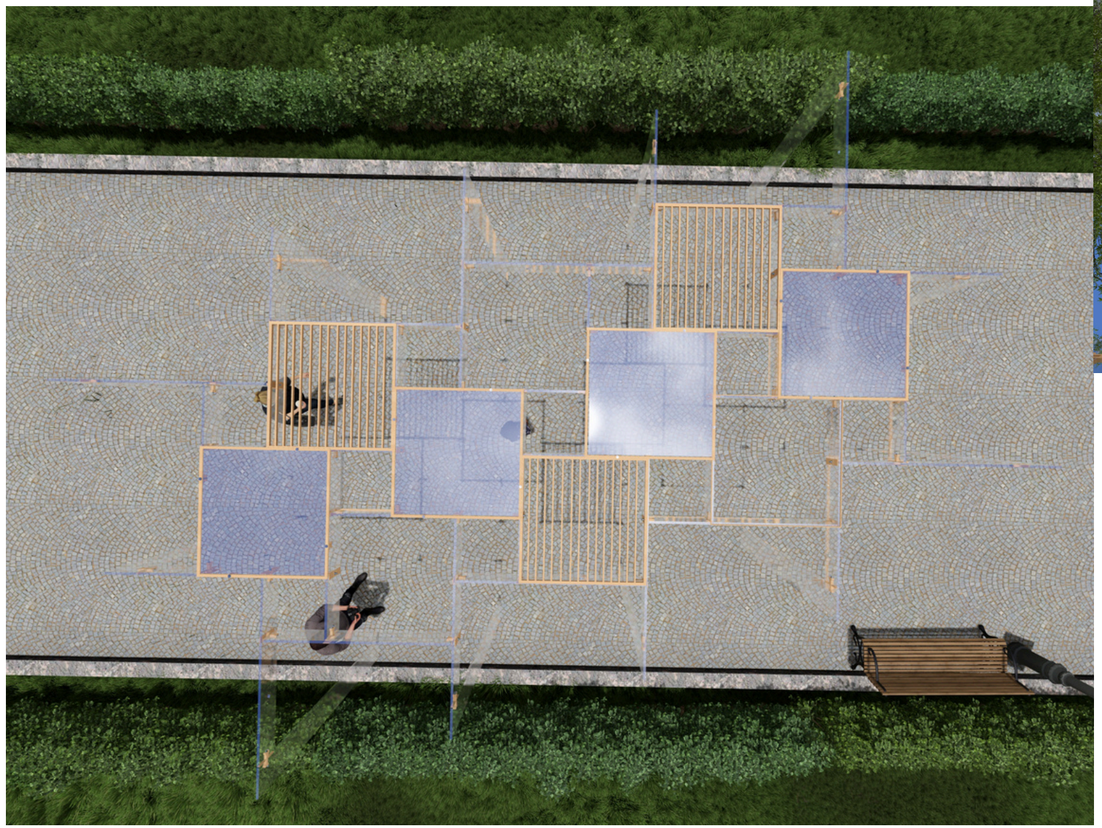
- Final design : Use cases

Walk way shade or Pergola

- Final design : Use cases

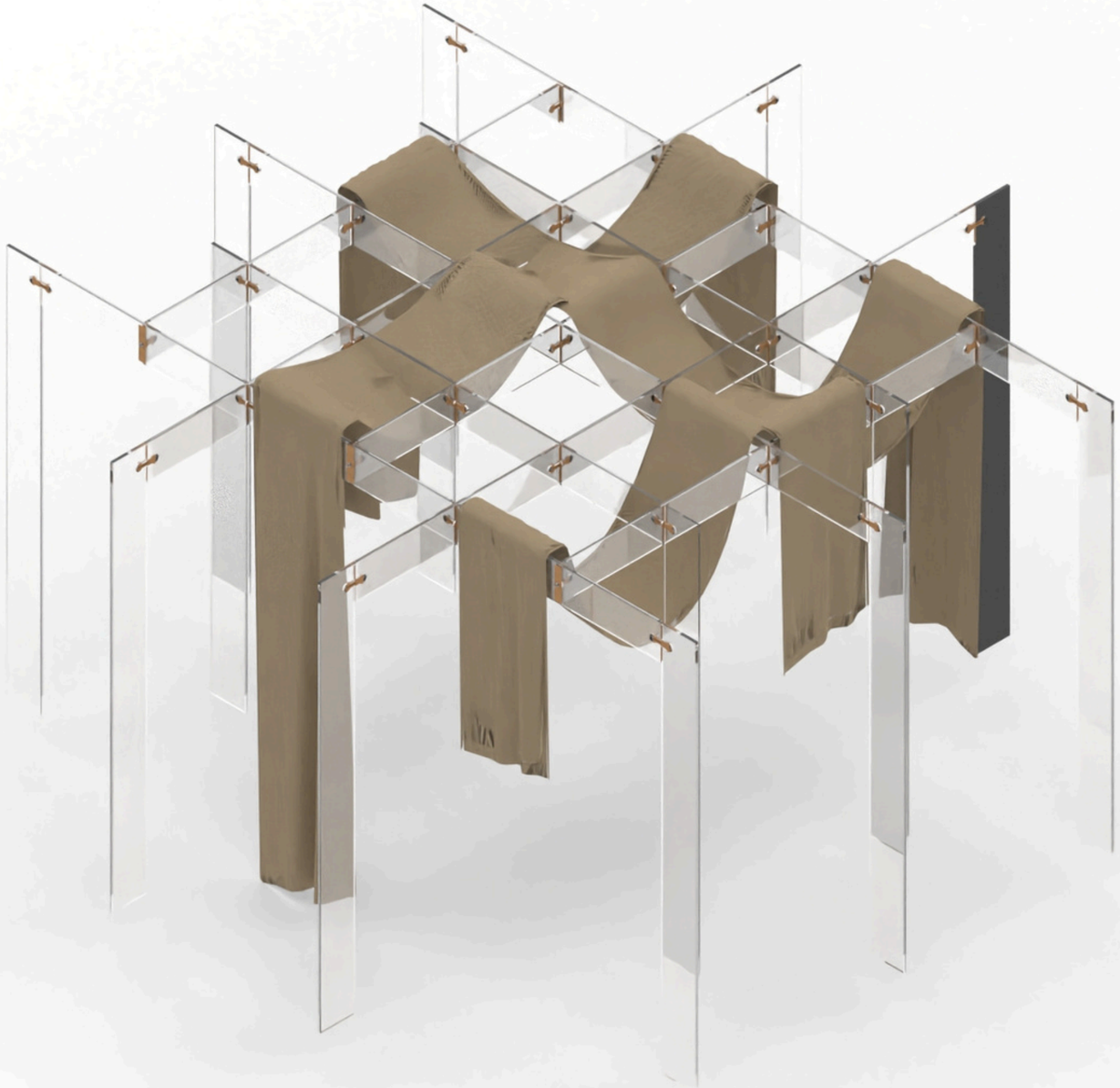
  Walk way shade
  or Pergola





- Final design : Use cases

  Exhibition pavilion

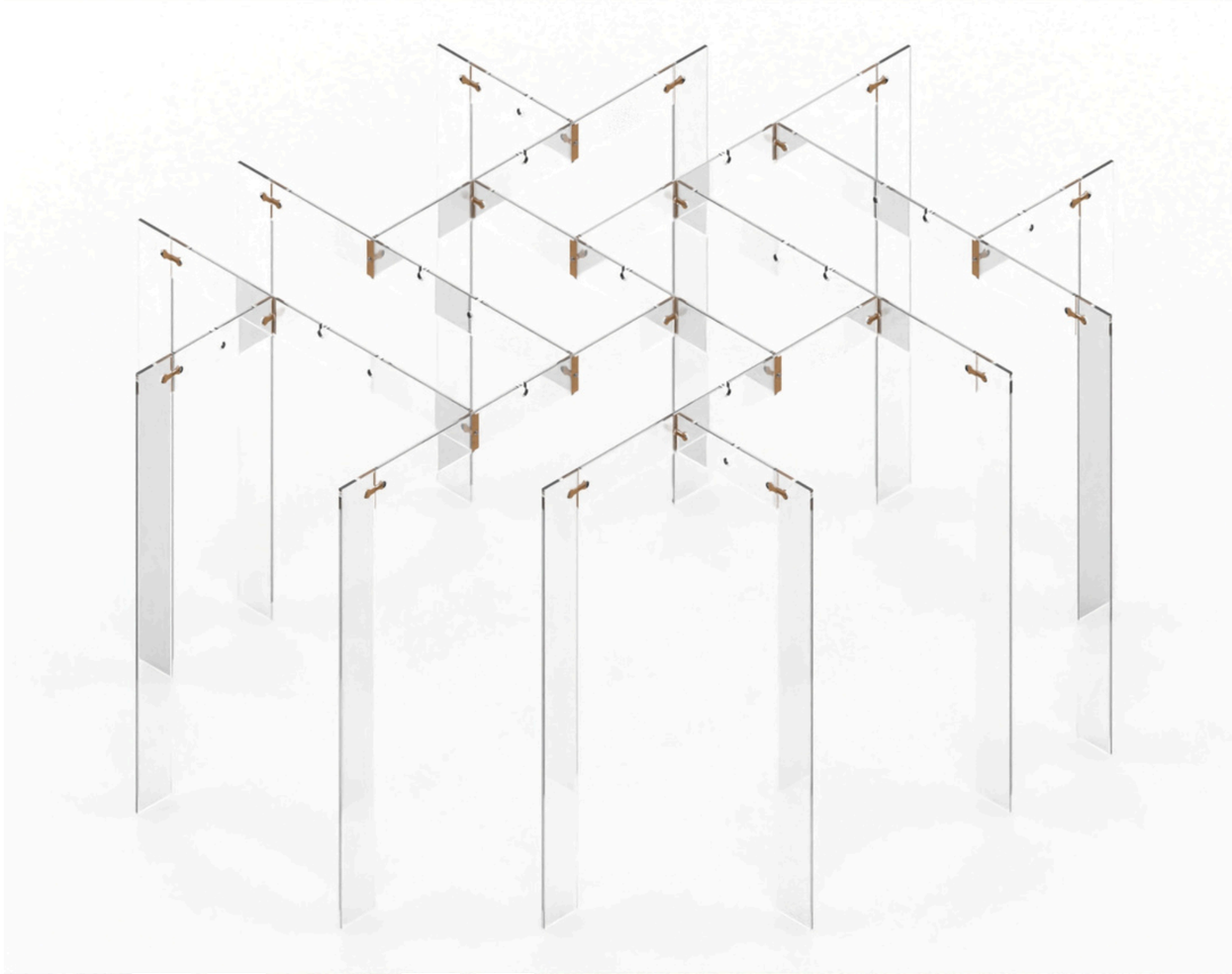


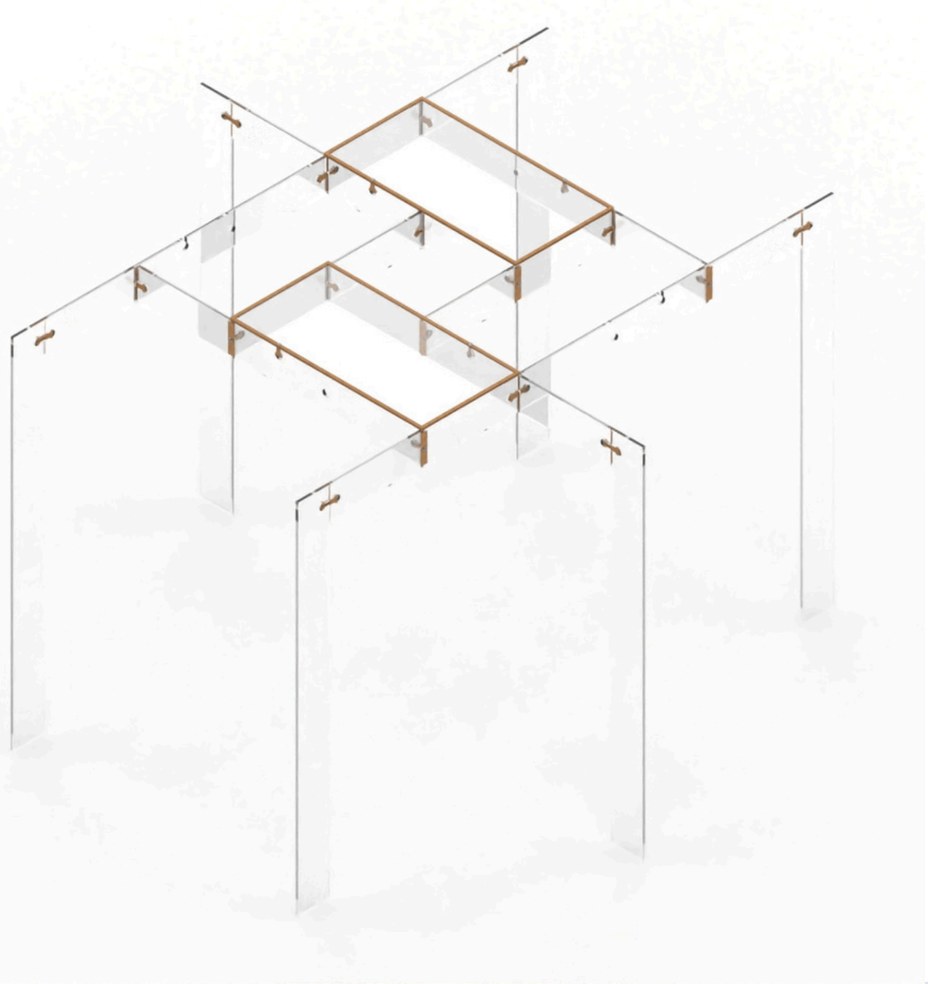
- Final design : Use cases

  Exhibition pavilion

- Final design : Use cases

  Exhibition pavilion





- Final design : Use cases

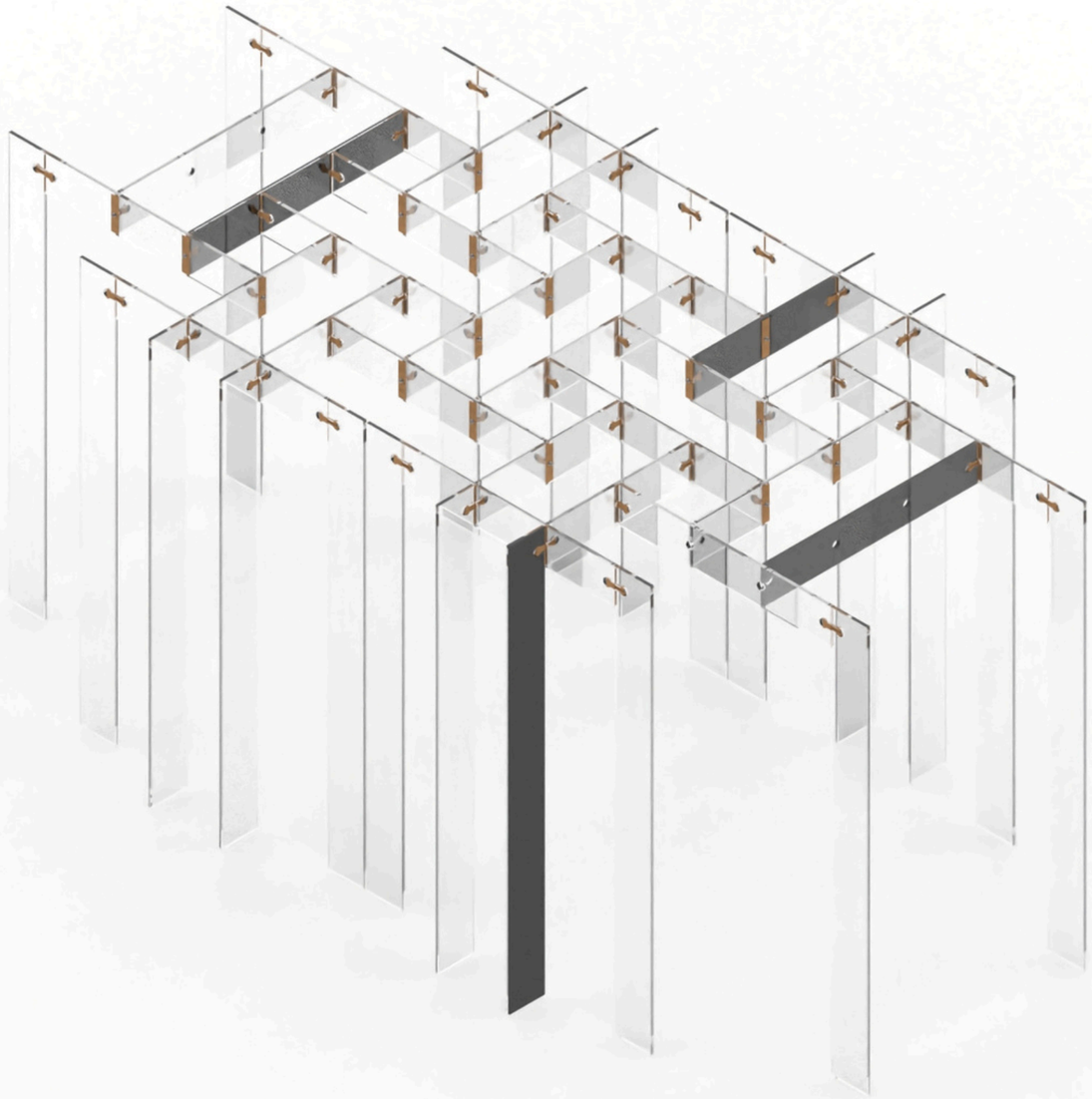
  Exhibition pavilion

- Final design : Use cases

Exhibition pavilion

- Final design : Use cases

  Walk way shade
  or Pergola



- Final design : Use cases

Walk way shade
or Pergola

- Final design : Use cases

Walk way shade
or Pergola

- Final design : Use cases

  Patio glass reciprocal roof structure

- Final design : Use cases

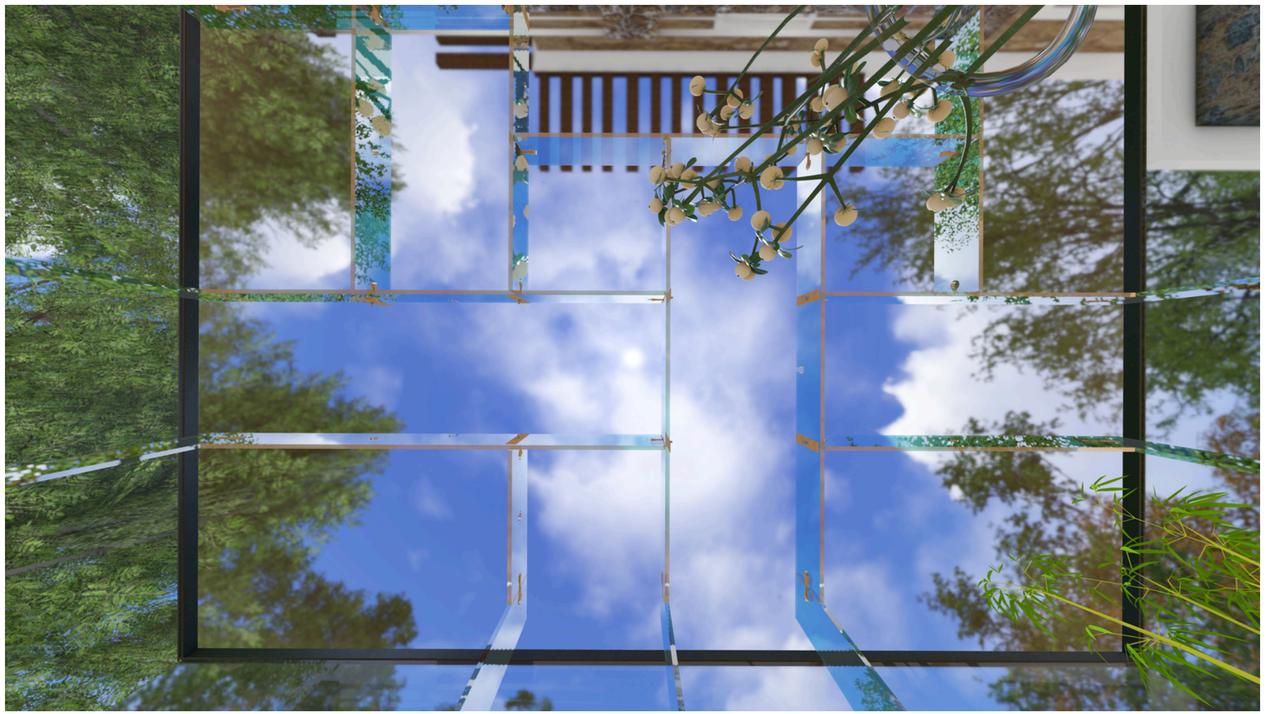
  Patio glass reciprocal roof structure

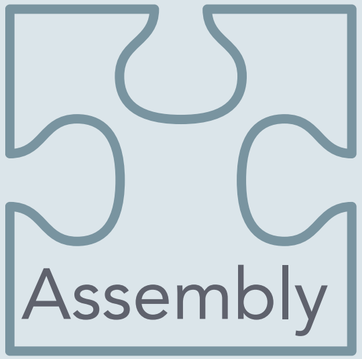
- Final design : Use cases

  Patio glass reciprocal roof structure

- Final design : Use cases

  Patio glass reciprocal roof structure




Assembly

- Assembly order

Assembly and Transport

- Assembly order

Assembly and Transport

- Assembly order

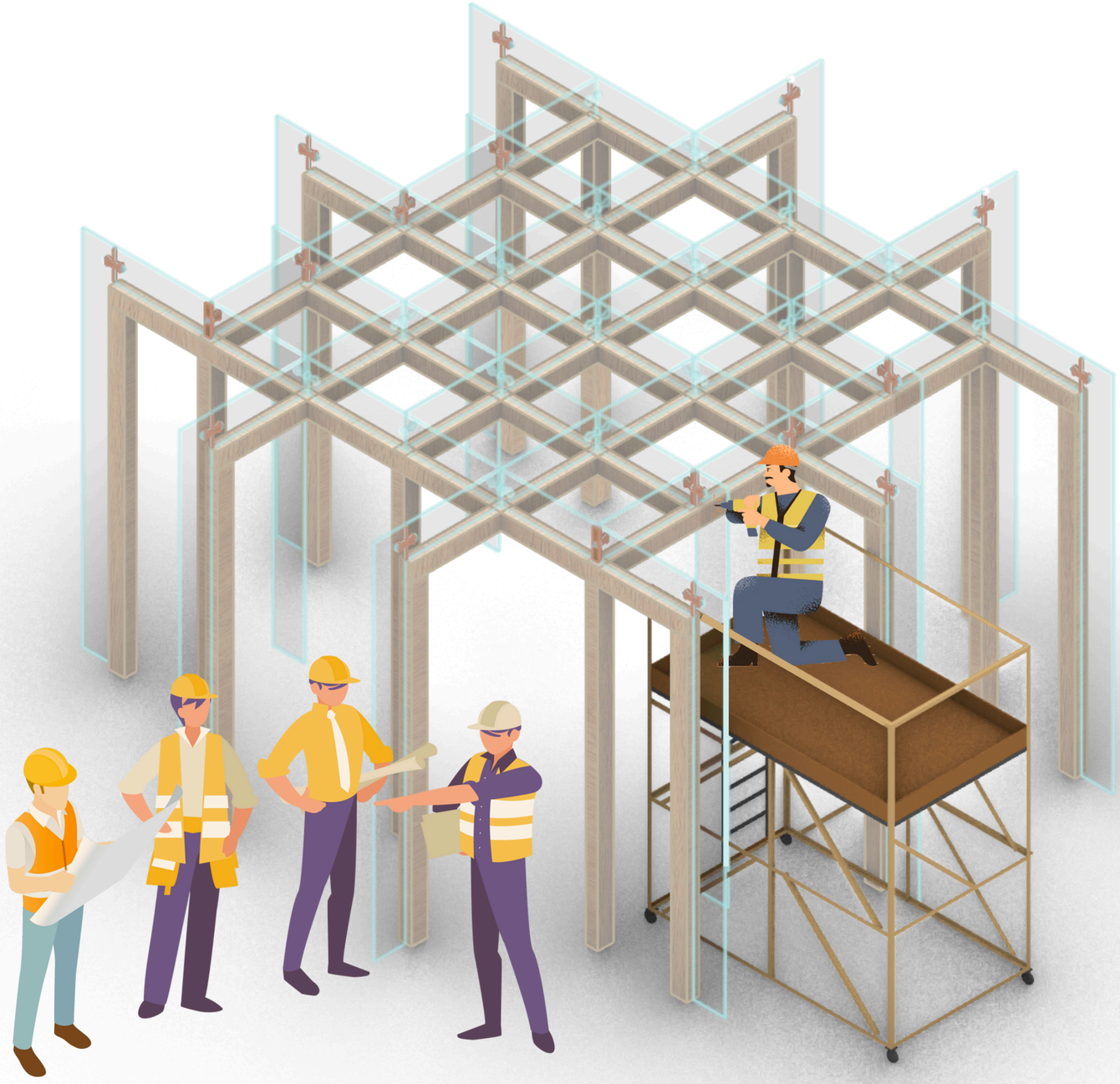
Assembly and Transport

- Assembly order

Assembly and Transport

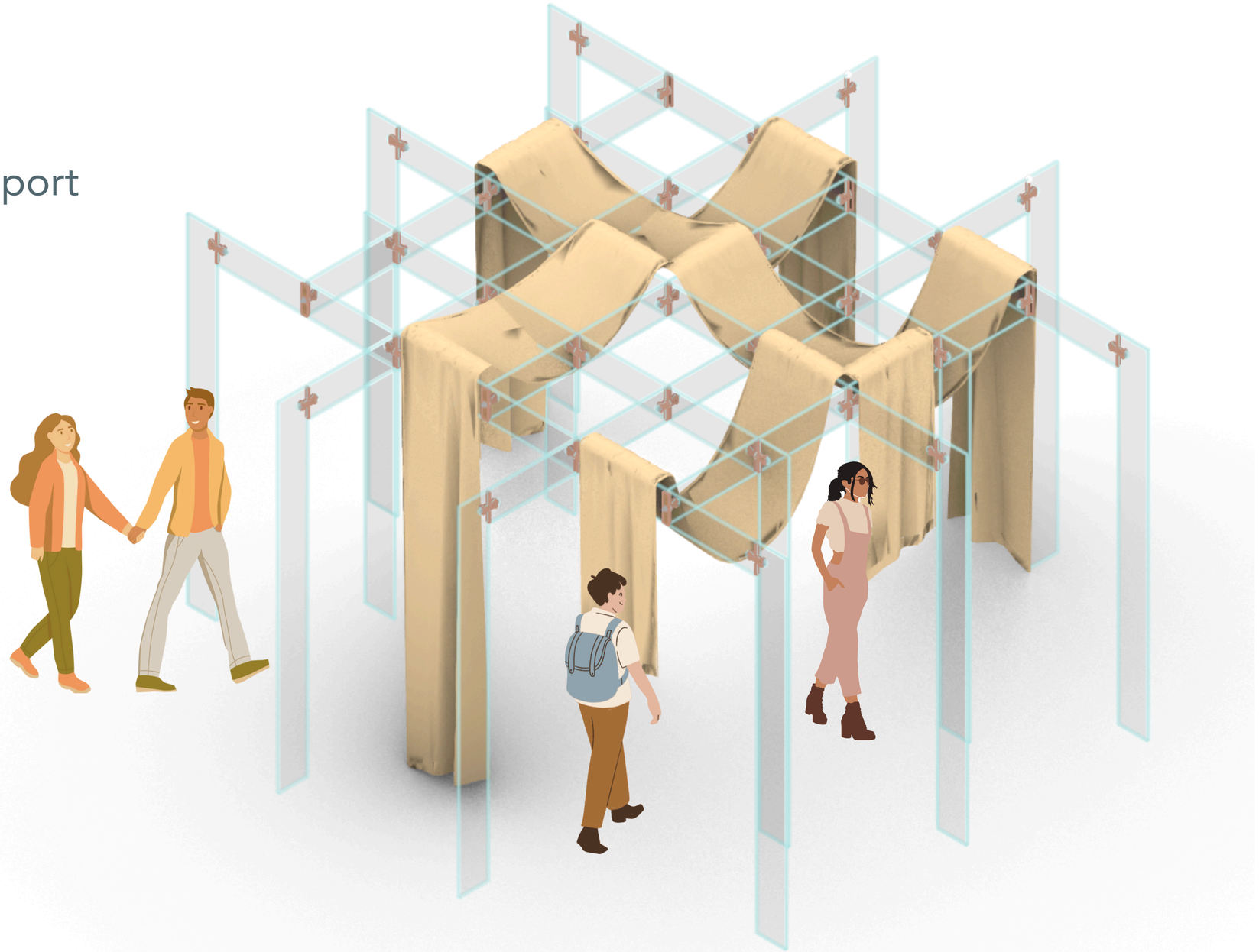
- Assembly order

Assembly and Transport



- Assembly order

Assembly and Transport

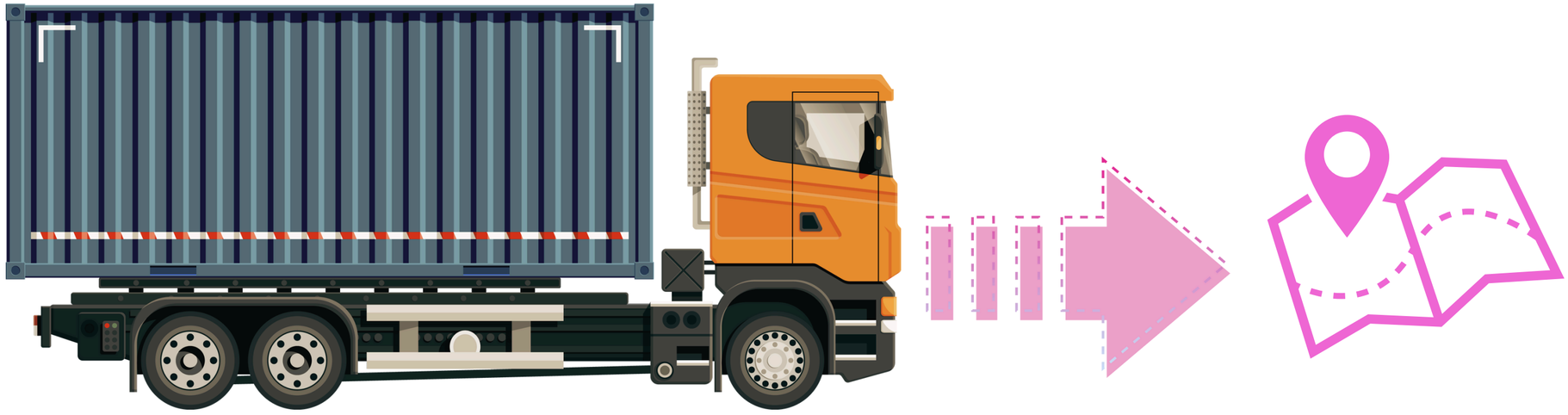


- Assembly order

Assembly and Transport

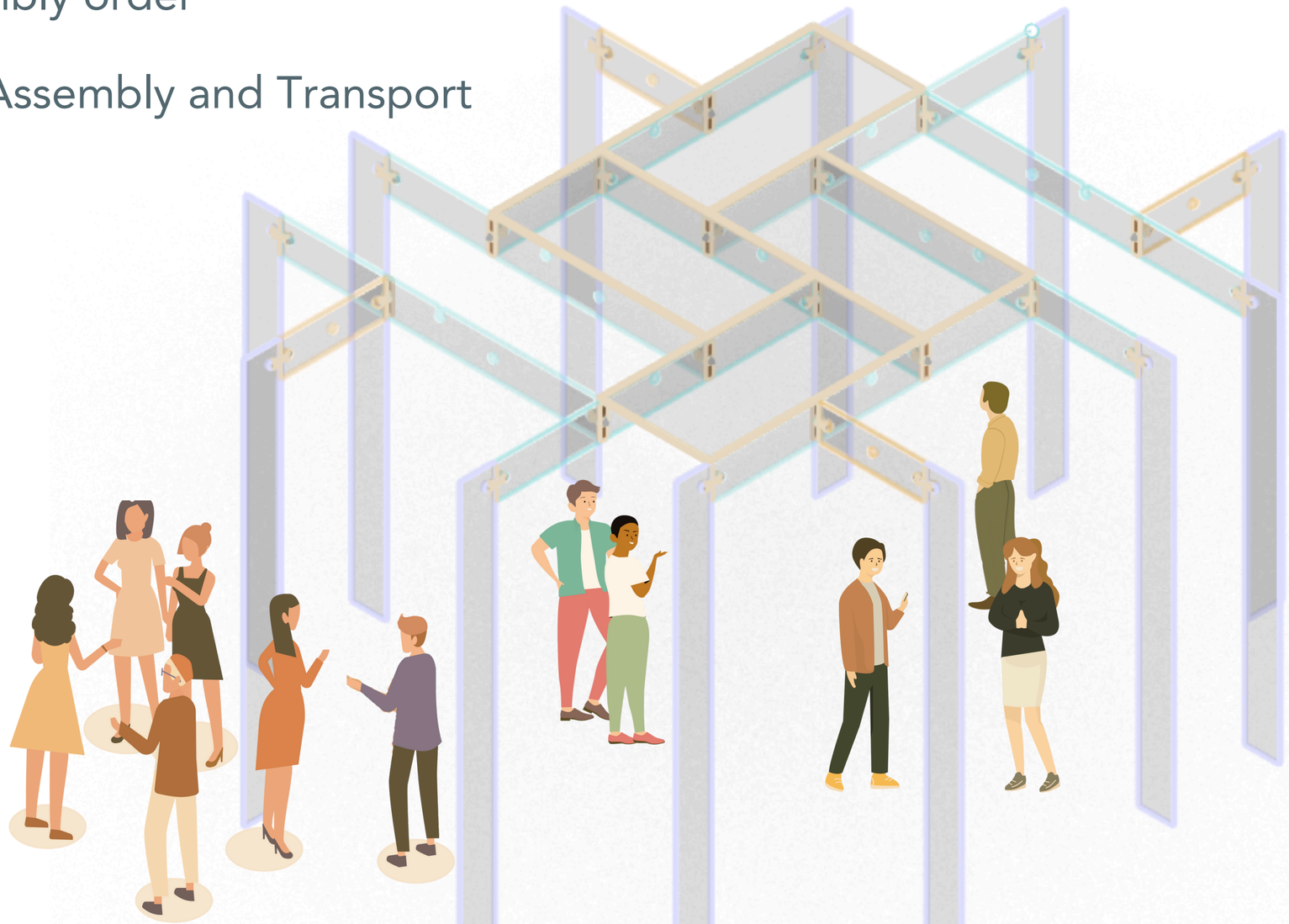
- Assembly order

Assembly and Transport

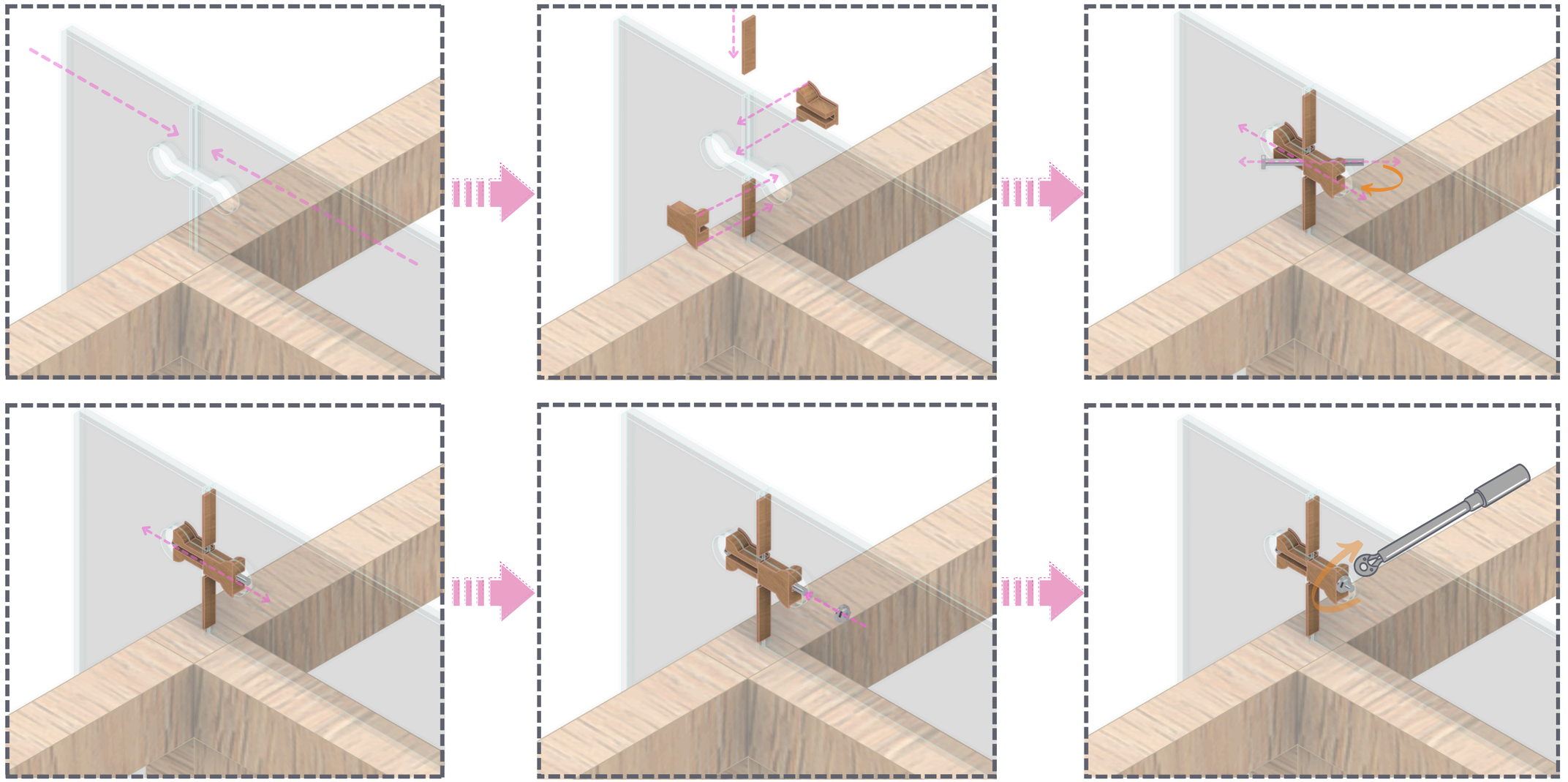


- Assembly order

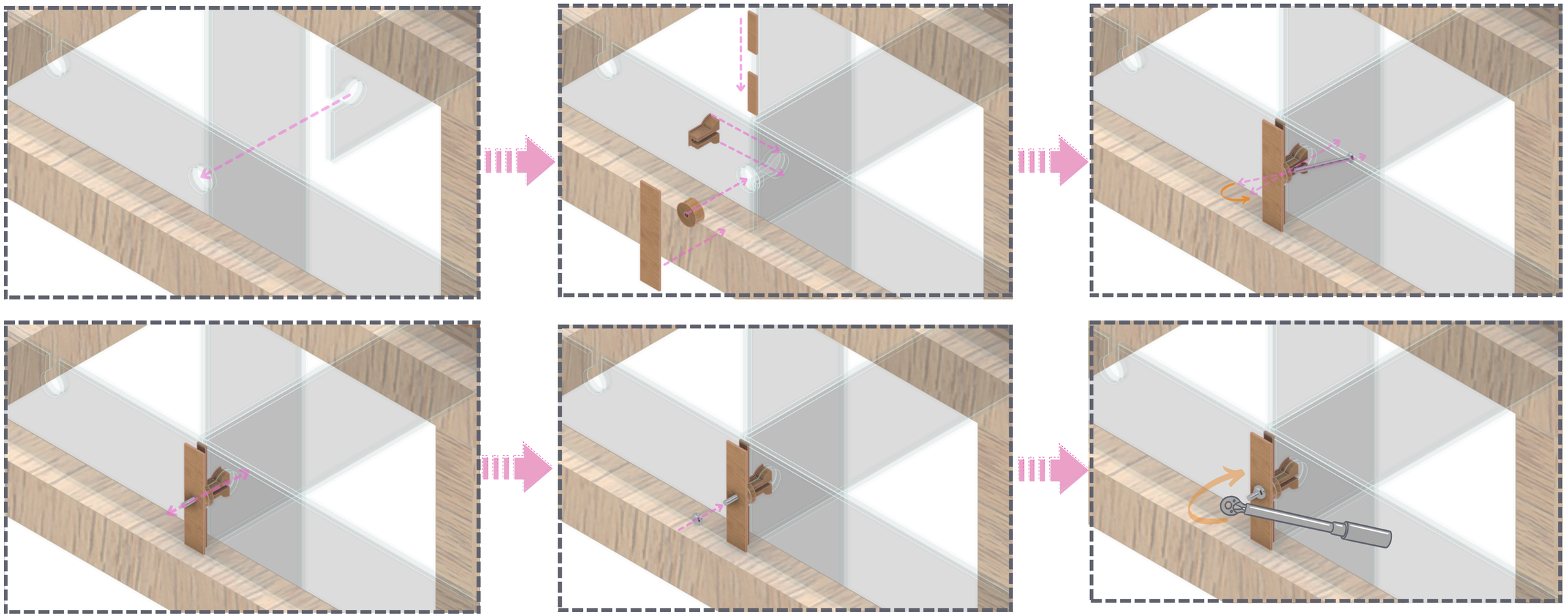
Assembly and Transport



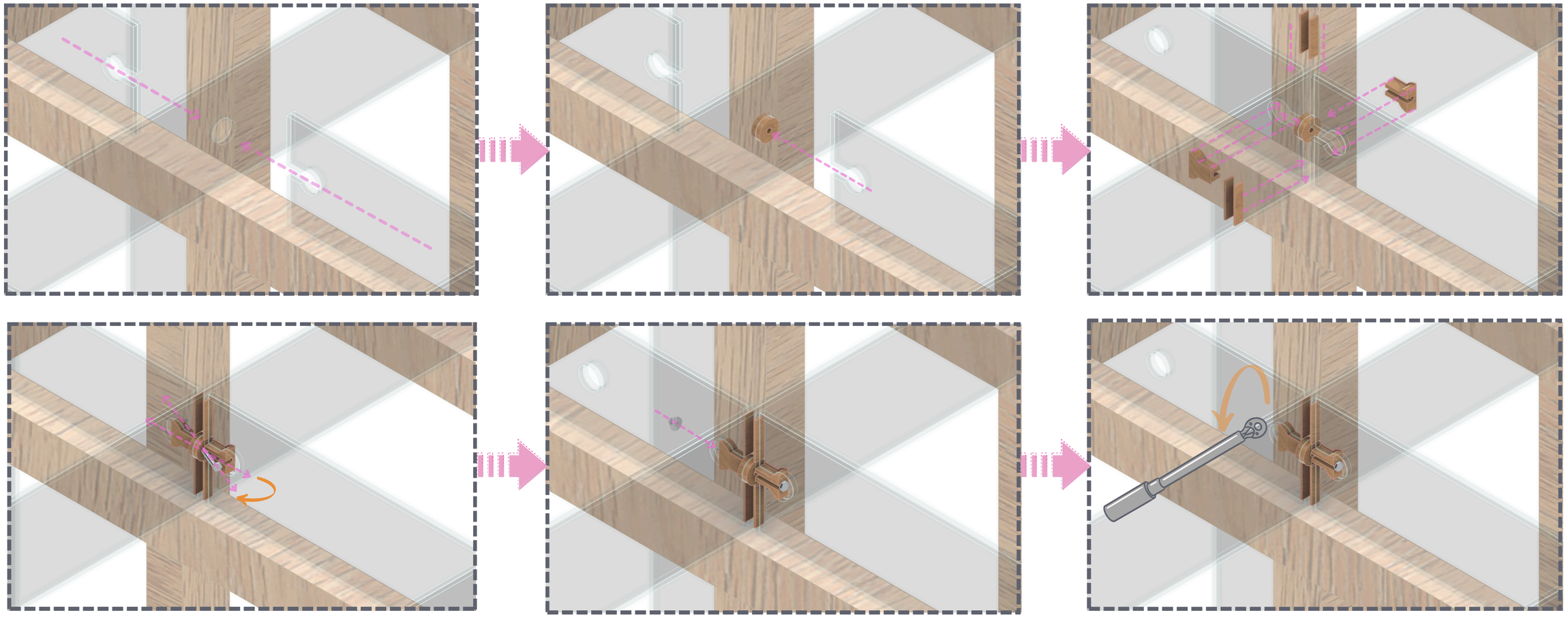
- Assembly sequence of line connection

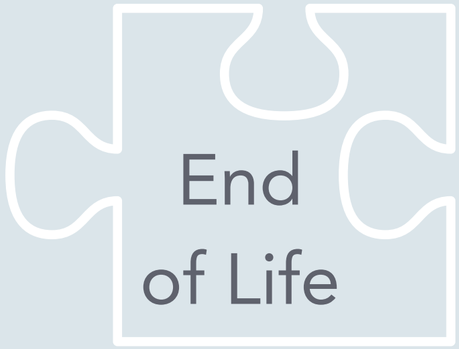


- Assembly sequence of T shape connection

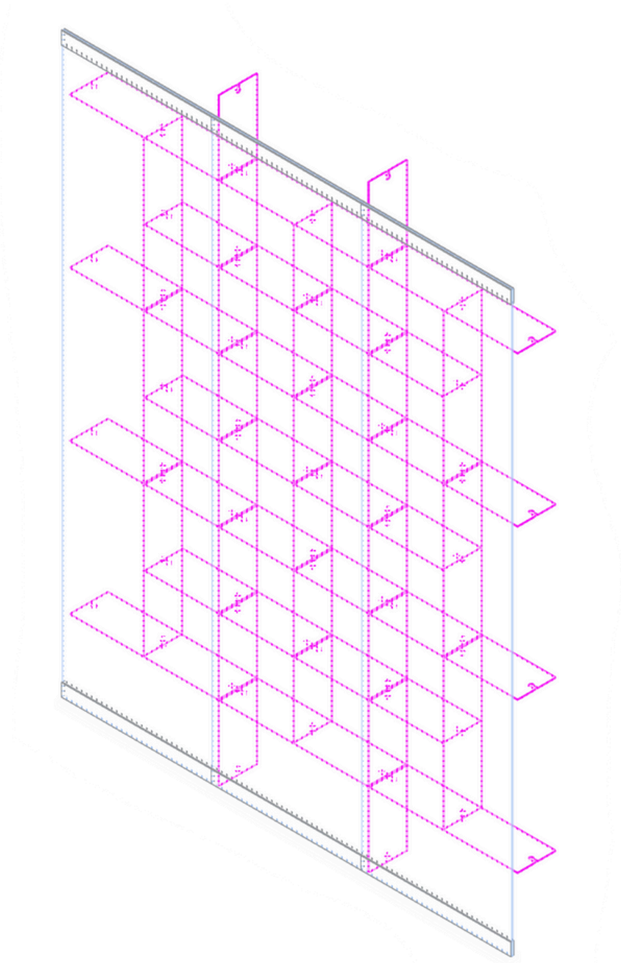


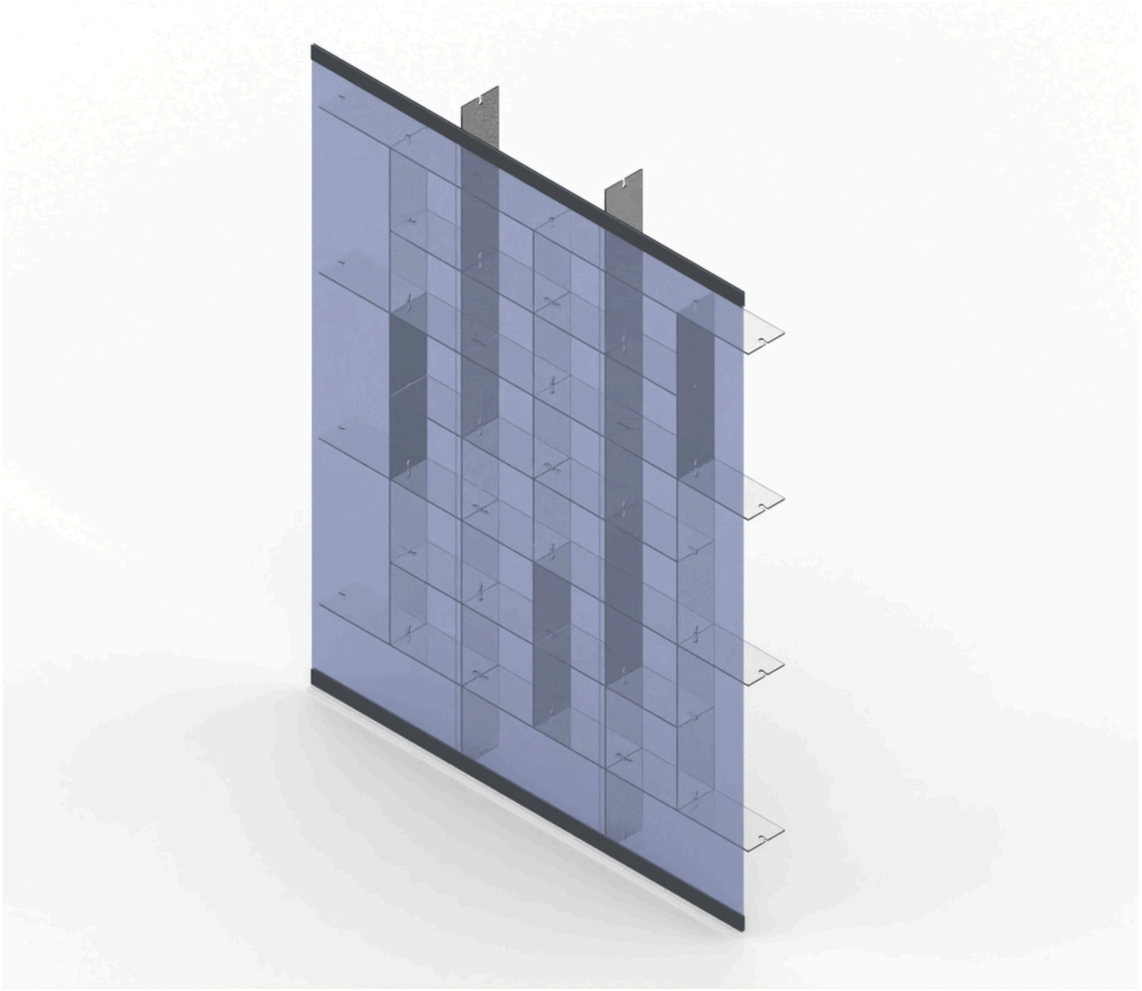
- Assembly sequence of T shape connection

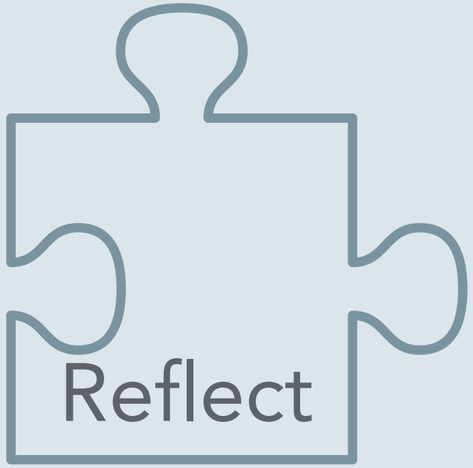



End
of Life

- End of life scenario sketch






Reflect

- Final Reflection

  - **Reimagines** glass as a **reusable, modular element**
  - Used a **research-through-design** method with **iterative loops** between **design and testing**.
  - **Integrated tools**: Rhino, Grasshopper, Karamba, ANSYS for design + simulation.
  - **Designed interlocking systems** inspired by wood joinery and cabinetry techniques.
  - **Prototyped** with Plexiglass & Meranti, finalized with heat-strengthened glass & oak.
  - ANSYS results **aligned** with real-world tests → **validated simulation reliability**.
  - System showed **redundancy and resilience** even after **partial connector failure**.
  - Ethical choice: used **locally sourced**, **sustainable hardwood** to reduce embodied carbon.

- Societal Impact & Relevance

  - Enables disassembly, reconfiguration, and reuse of glass units.
  - Reduces material waste, energy use, and supports circular building strategies.
  - Demonstrates synergy between glass, wood, and steel in sustainable design.
  - Proposes a new architectural language of reversibility and modularity.

• Limitations

- The project successfully achieved its initial goals and validated the proposed modular system.
- Only four module variations were tested; many other combinations exist and must be checked by future users.
- Physical testing was limited to the smallest module size due to lab constraints.
- Structural simulations using ANSYS covered additional module sizes and connection types to compensate.
- Lateral loading was only tested once; future outdoor applications require more in-depth analysis.
- Although designed as a pure shear joint, the system behaved more like a moment connection under load.
- Oak connectors performed well for moderate spans; longer spans may require stiffer materials like aluminium or titanium.
- Wood was chosen for being cost-effective, predictable in failure, and 50× cheaper than aluminium for CNC fabrication.
- Bolt access and preload application posed practical challenges; specialised tools could improve this.
- Manufacturing was sensitive to moisture and precision tolerances but manageable with proper storage.
- Even after partial connector failure, the system stayed stable—demonstrated through Karamba simulation.


Next

• Nexr steps

- Further testing of new connection types and module sizes, potentially in collaboration with civil engineering.
- Testing of alternative materials like aluminium or titanium for higher structural capacity.
- Exploration of new module shapes, such as curved or connector-specific geometries.
- Design refinements:
- More connection points to increase system capacity.
- Larger bolt holes (aesthetically balanced) to reduce local stress.
- Bigger bolts and added wooden caps to improve preloading and reduce slippage.
- Stronger spacer materials between glass panels to increase load transfer.
- Adapting the design for broader applications like facades, furniture, or shading systems.
- Using this project as a foundation for future research in modular and reversible glass systems.
- Advancing parametric tools in Grasshopper and Karamba to automate design and structural evaluation based on constraints and goals.

THANK YOU!