Wood-LOM

Using laminated object manufacturing to reimagine the use of wood

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Overview

> Introduction

> Research framework

> Laminated Object Manufacturing

> Veneer and laminated wood

> Wood-LOM

> Design process

> Final design

> Conclusions

Introduction

Global CO_2 emission increased ≈50% since 1990

Goal: net zero at 2050

Construction industry responsible for ≈15% of greenhouse gas emissions

7.2% of CO_2 emissions from iron and steel production

Introduction

Wood: old but sustainable building material

Engineered wood products provide substitutions for concrete and steel

Ongoing development in wood as a building material

Research aims to contribute to the development of wood as a reliable alternative

Research framework

Problem statement

> Production of steel is one of the biggest CO_2 emitters

> Steel often used for connective parts when building

> Desirable to replace with a more sustainable material

Research framework

Problem statement

> Production of steel is one of the biggest CO_2 emitters

> Steel often used for connective parts when building

> Desirable to replace with a more sustainable material

> Wood is a sustainable alternative

> New manufacturing methods to be explored

> Laminated object manufacturing has potential with wood

Research framework

Goal of the research

> Create a wooden connection element

> Use a wood-on-wood connection

> Make a 1:1 physical model of an example connection node

Research framework

Research questions

Main research question
How can Layer Object Manufacturing (LOM) technology be used to create wooden nodes for timber structures?

Sub questions
What are the advantages and limitations of manufacturing wooden elements using LOM?

What are the design parameters for constructing a solid wooden connection element using LOM?

What methods can be used to create reliable connections between a wood-LOM produced node and a timber structure?

Research framework

Research methodology

Literature research

> Laminated object manufaturing (LOM)

> Wood veneer and laminated wood

> Material connections

Research by design

> Design simulations

> 1:1 physical model

Laminated object manufacturing

Developed in 1990

Various sheet materials

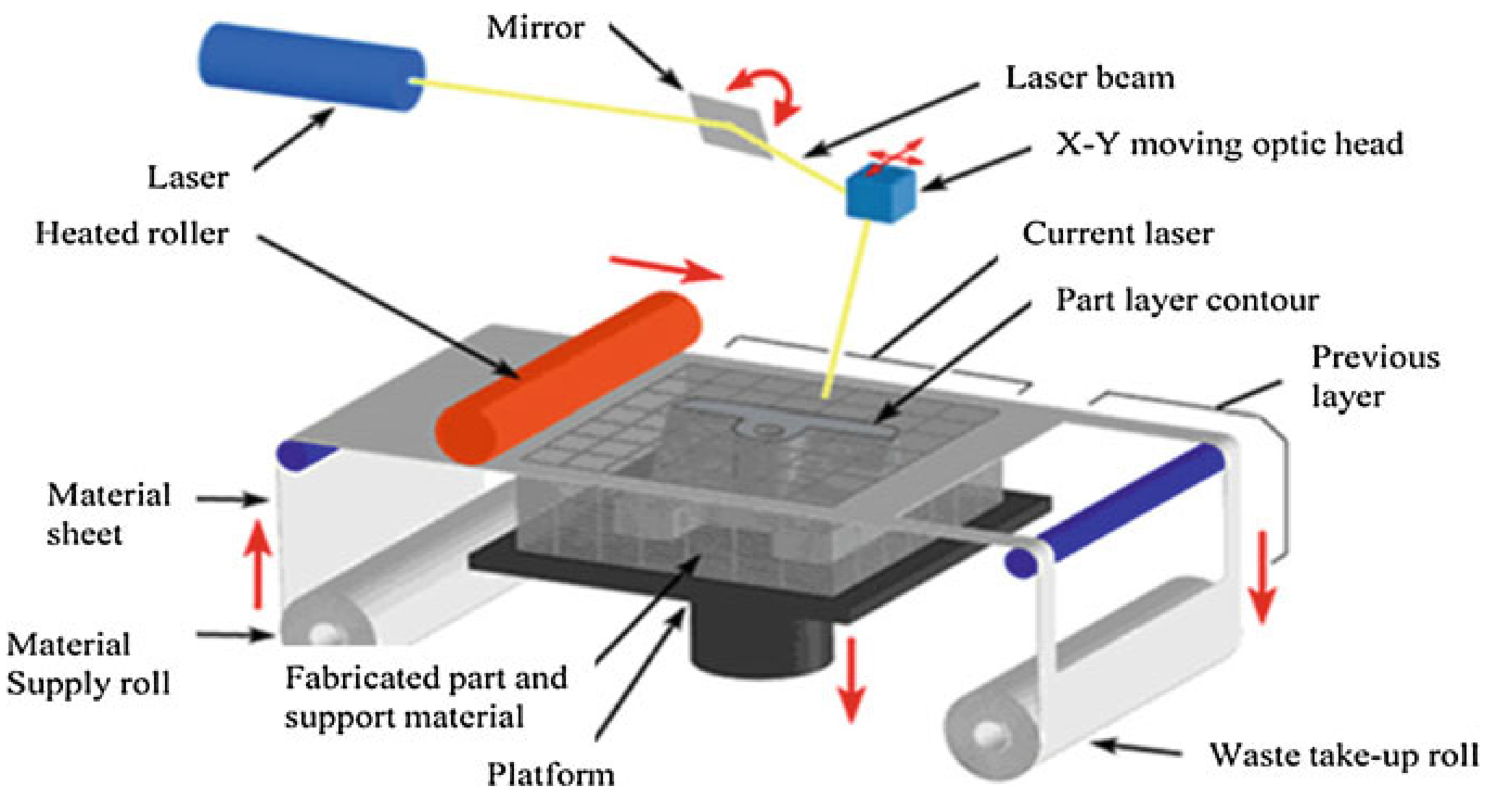
Sheet materials on a roll

Lamination process

> New material layer

> Lamination onto object

> Lasercutting contours

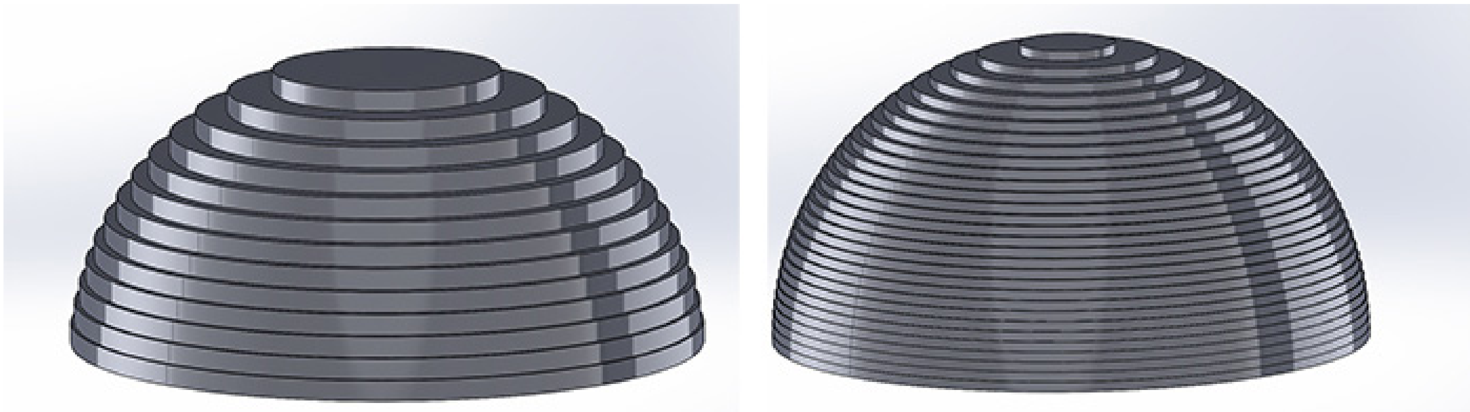


Laminated object manufacturing (LOM) (Mekonnen, 2016)

Laminated object manufacturing

High X- and Y-plane precision

Z-plane depends on layer thickness



The effect of layer thickness on the vertical resolution of an object (Verkstan, 2015)

Large amount of support material

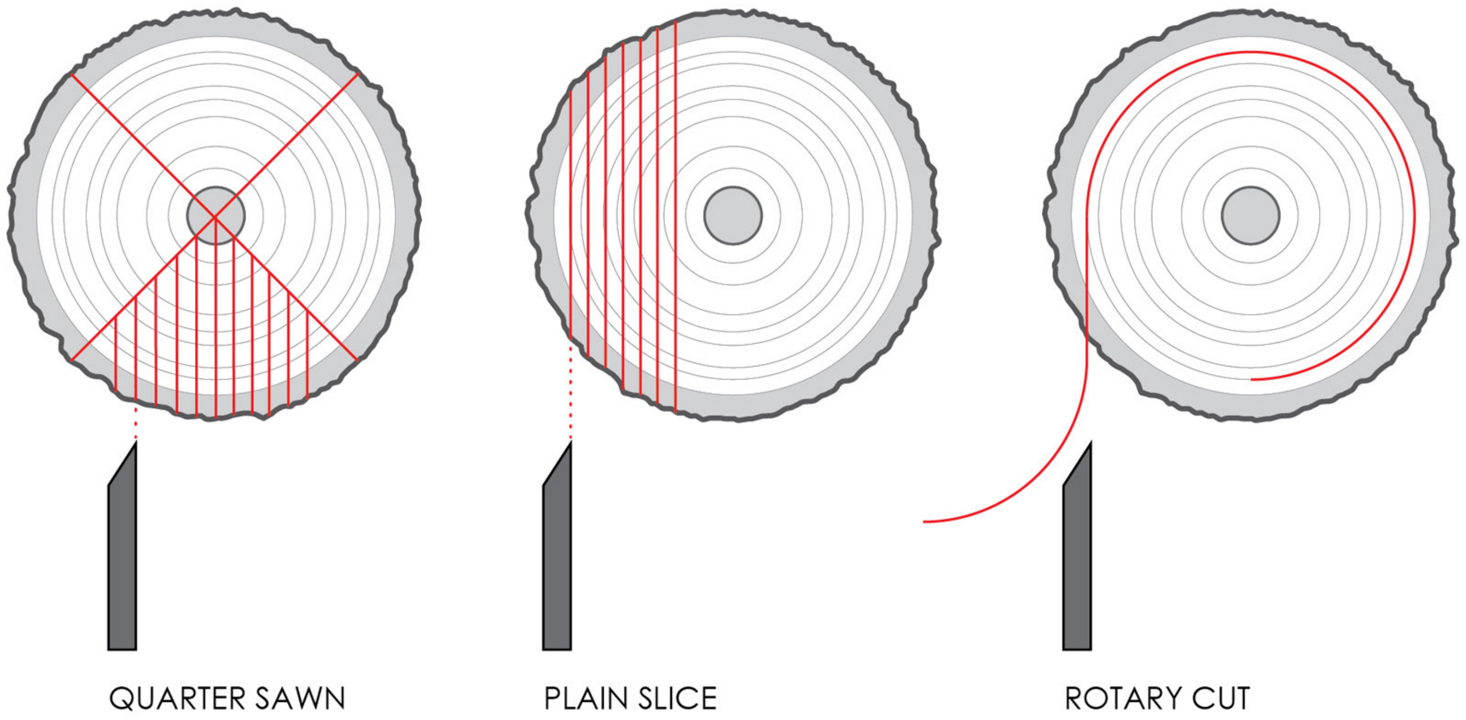
Post processing needed

Removing support material (Gibson et al., 2016)

Veneer and laminated wood

Several ways to cut logs

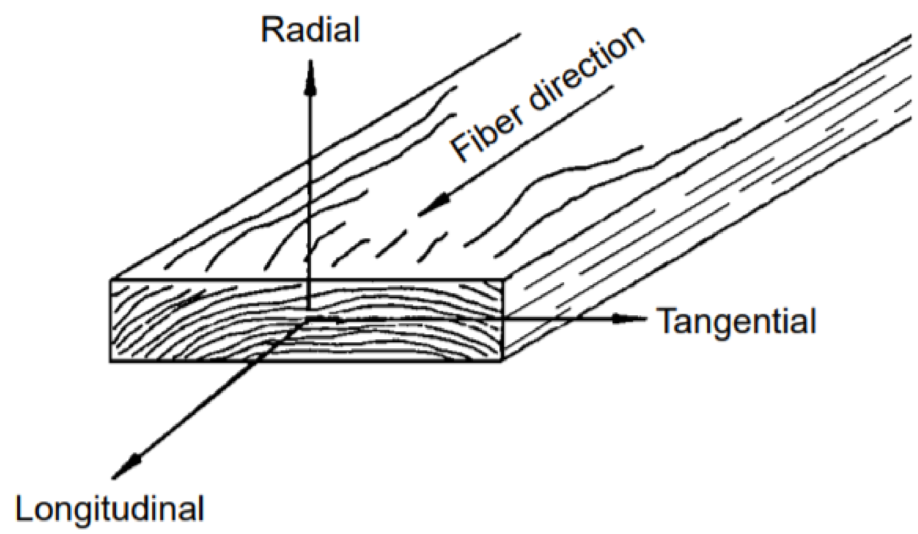
Type of cut defines characteristics



Various ways of cutting wood (LORD PARQUET, n.d.)

Wood is an anisotropic material

> Independant properties in three axes
> Strongest along fiber direction



The principle axes of wood (Borglund Aspler et al., 2019)

Veneer and laminated wood

Engineered wood products

Glue laminated beams (Glulam)

> Laminated lumber panels
> One grain direction

Glulam sample (BIMobject, n.d.)

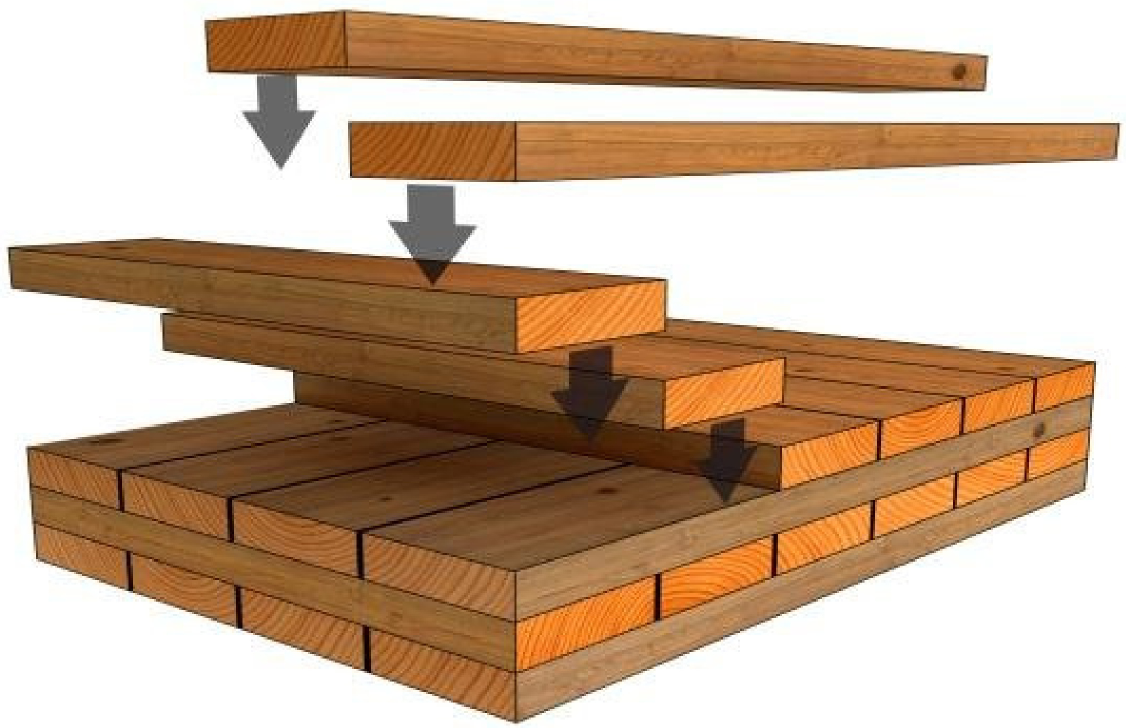
Glulam beam (Eurodita, 2022)

Veneer and laminated wood

Engineered wood products

Cross laminated timber (CLT)

> Laminated lumber panels
> Cross-laminated grain direction



CLT structure (w-a-d.in, n.d.)

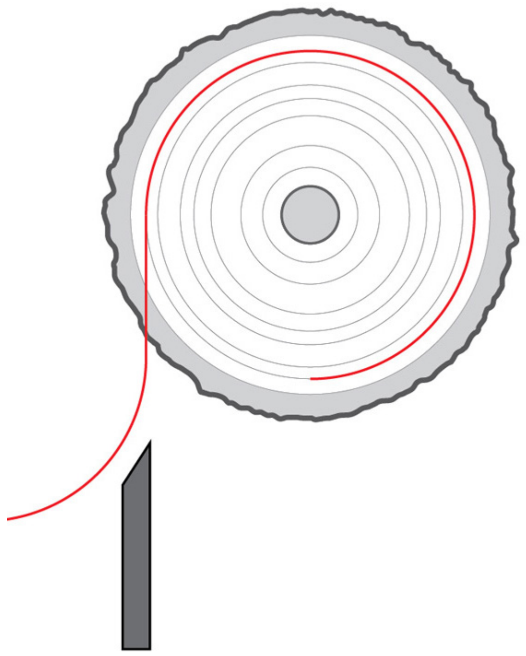
CLT in construction (WIGO, n.d.)

Veneer and laminated wood

Engineered wood products

Laminated veneer lumber (LVL)

> Laminated veneers
> One grain direction



Cutting of veneer (LORD PARQUET, n.d.)

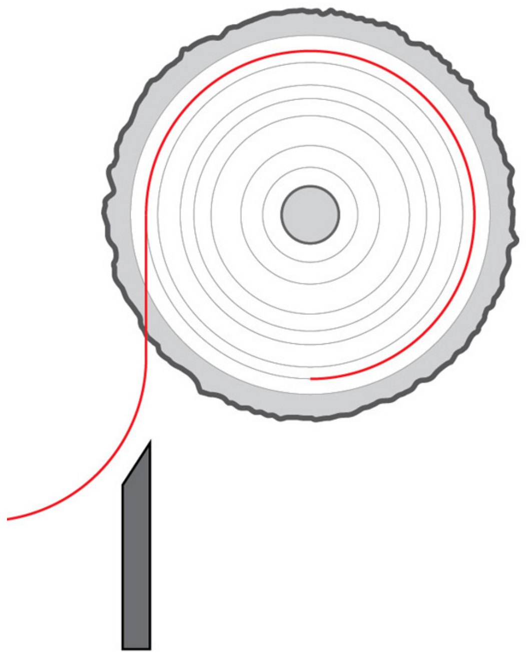
LVL samples (Metsä Group, n.d.)

Veneer and laminated wood

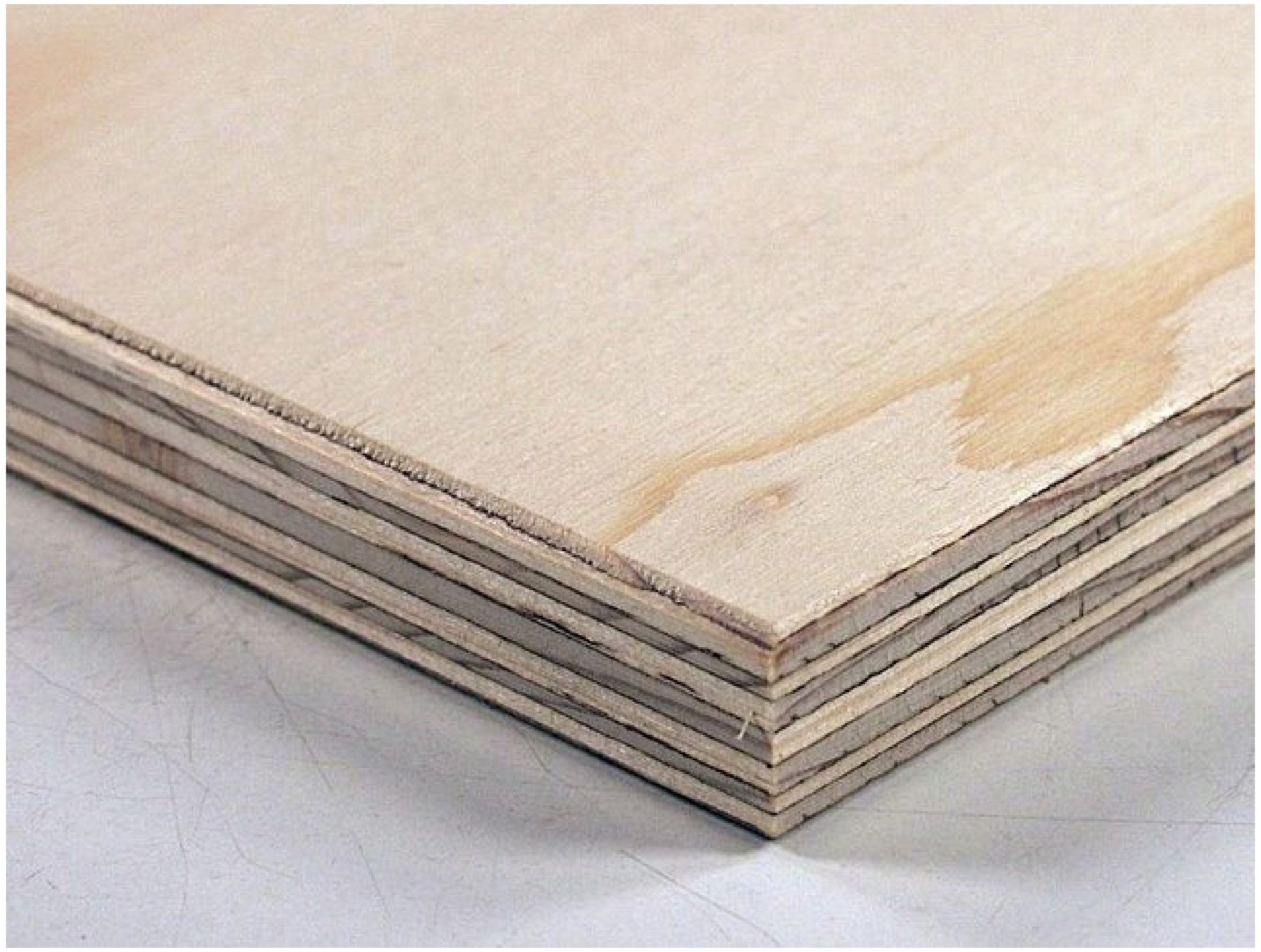
Engineered wood products

Plywood

> Laminated veneers
> Cross laminated grain direction



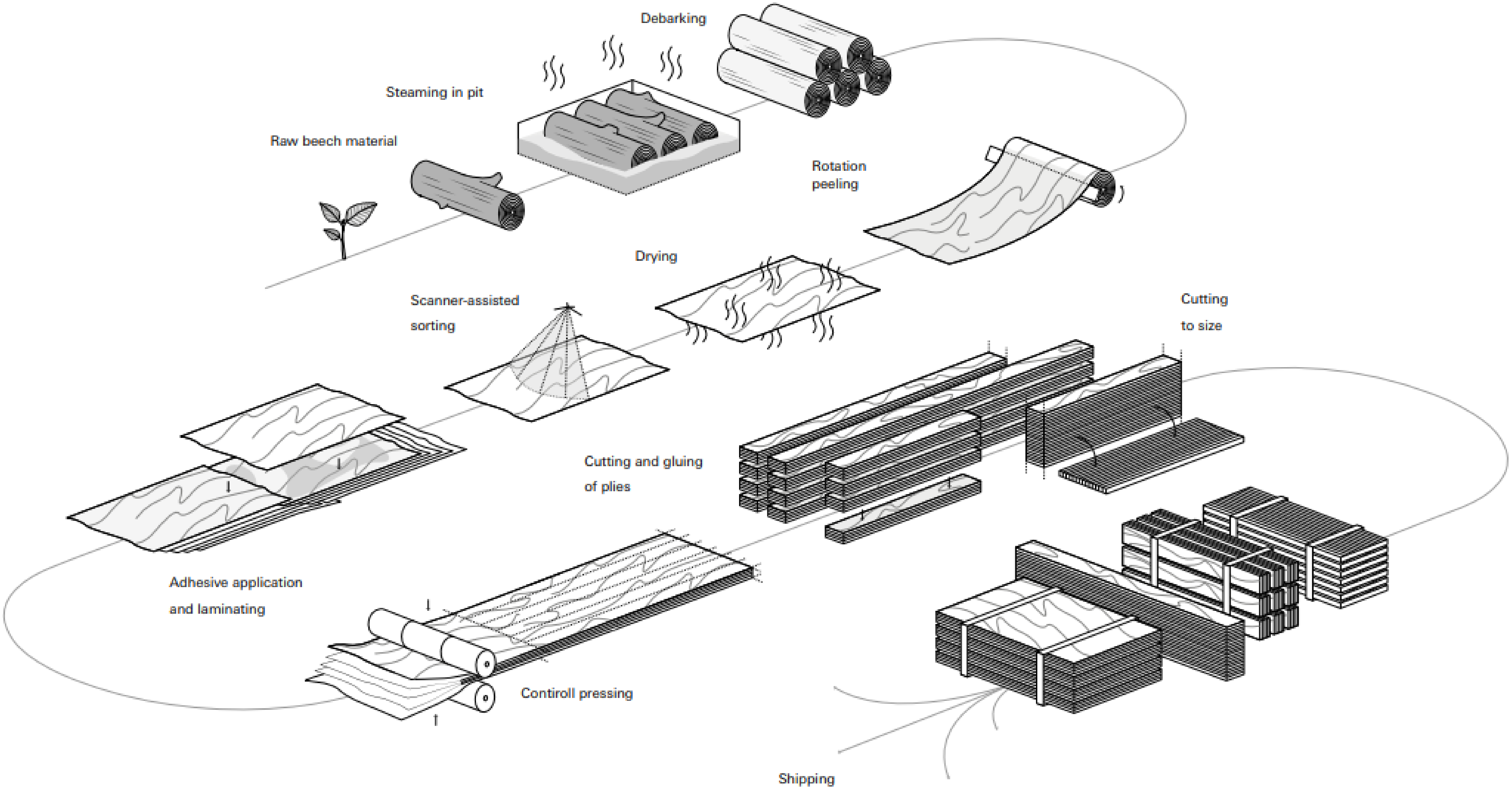
Cutting of veneer (LORD PARQUET, n.d.)



Plywood sample (Wikimedia, 2023)

Veneer and laminated wood

EWP production process



Refinement process from log to engineered wood product (Borglund Aspler et al., 2019)

Wood-LOM

In 2020 patent by Stefan Schäffer

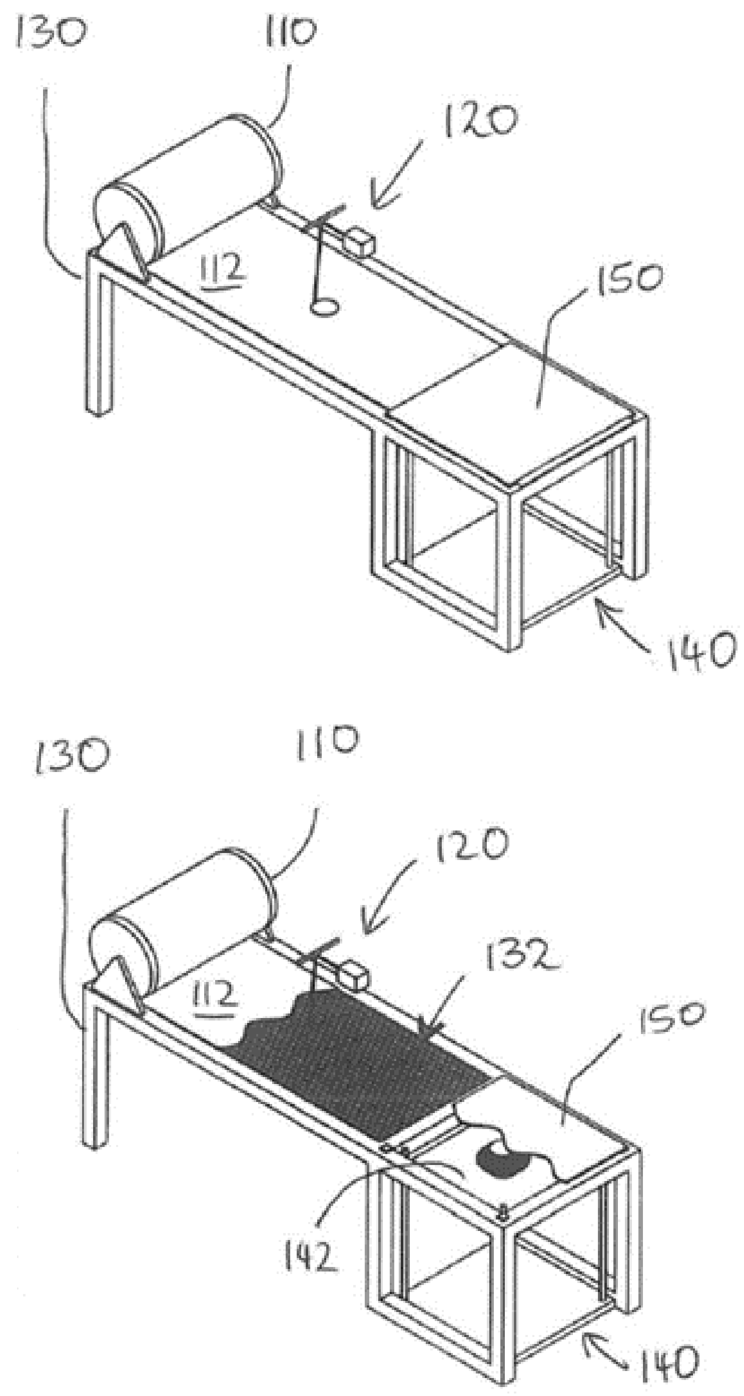
Process and device for the additive manufacturing of a layered wood structure

Improvements to make

> Cross-laminated structure

> Using sheets instead of roll

> Adhesion method



Schematic overview of a device for a LOM process with wood veneer (Schäfer, 2020)

Design process

> Choose a concept

> Substantiate material choice

> Choose a shape

> Create test case and criteria

> Test and compare test results

> Improve the design based on results

> Finalise the design

Concept development

The New Fair, Milan (Itinari, 2019)

The Yas Hotel, Abu Dhabi (Basulto, 2022)

Concept development

The New Fair, Milan (Itinari, 2019)

The Yas Hotel, Abu Dhabi (Basulto, 2022)

Bunjil Place, Melbourne (Caballero, 2022)

Swatch Office, Biel (Blumer Lehmann, n.d.)

Concept development


Swatch Office, Biel (Blumer Lehmann, n.d.)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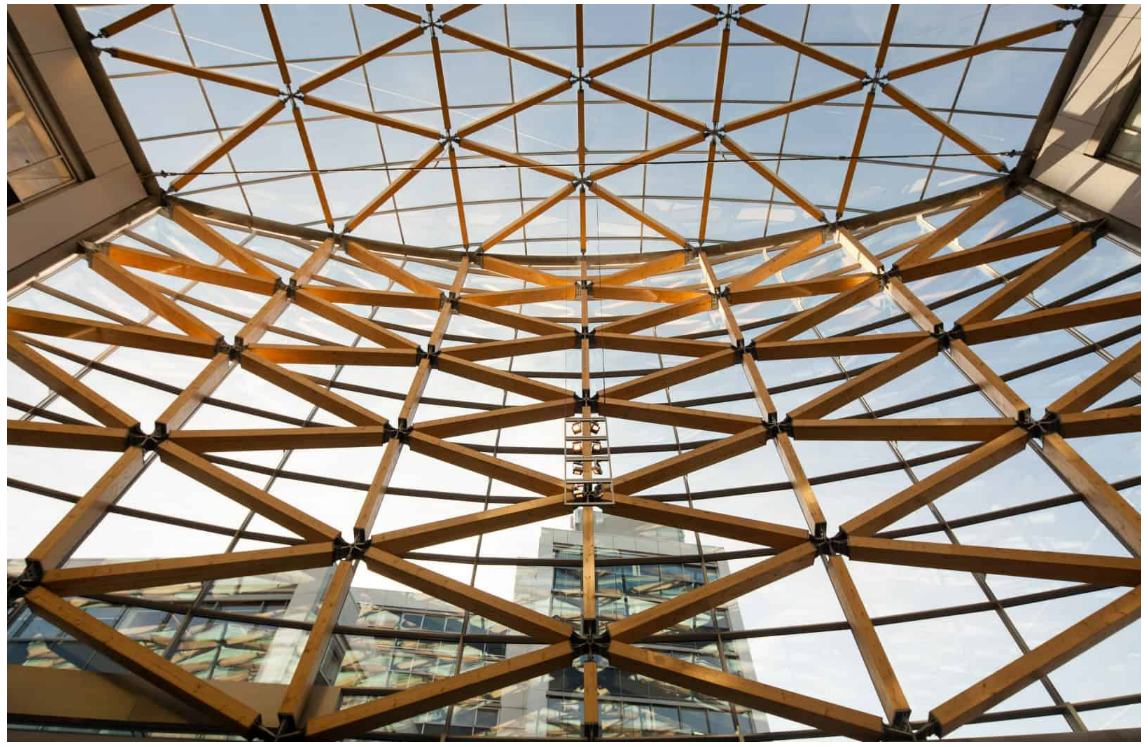
Concept development

Timber dome canopy, the Jungledome, Remouchamps (Lüning, 2006)

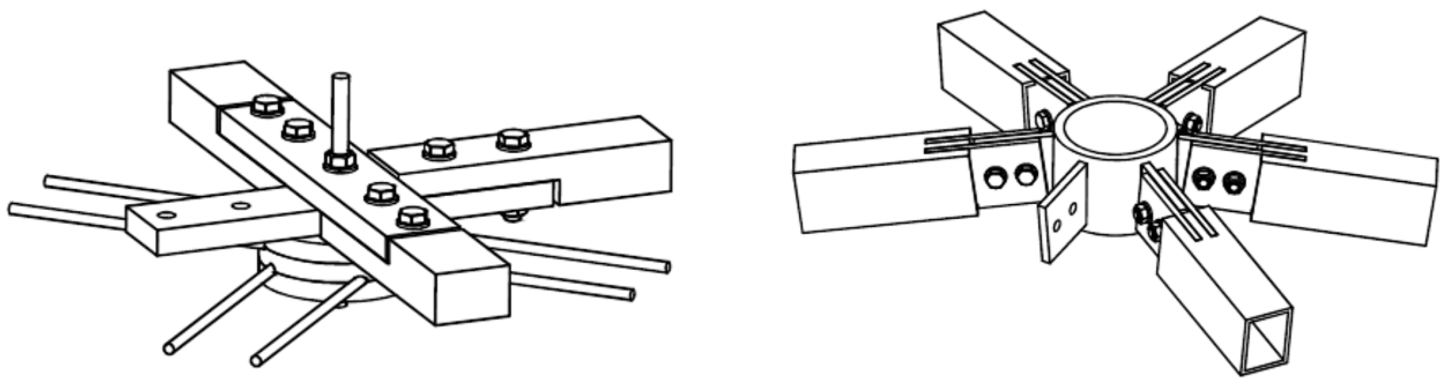
Timber dome canopy, the Jungledome, Remouchamps (Lüning, 2006)



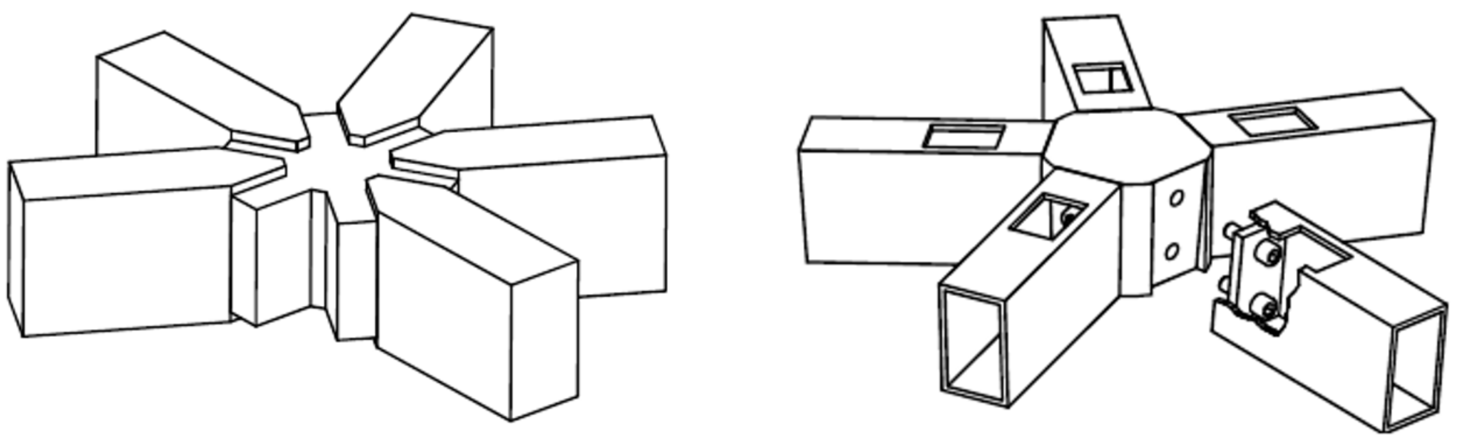
Timber facade structure, The Base, Schiphol-Centrum (De Groot Vroomshoop, 2017)

Timber facade structure, The Base, Schiphol-Centrum (De Groot Vroomshoop, 2017)

Concept development



Splice connectors



End-face connectors

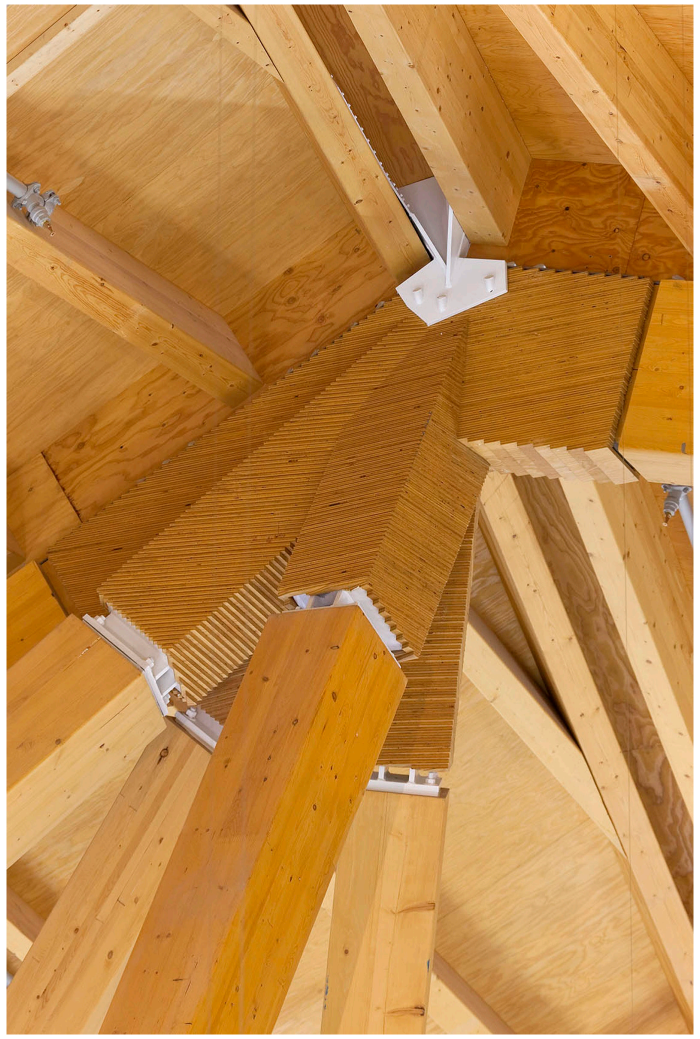
Timber dome canopy, the Jungledome, Remouchamps (Lüning, 2006)

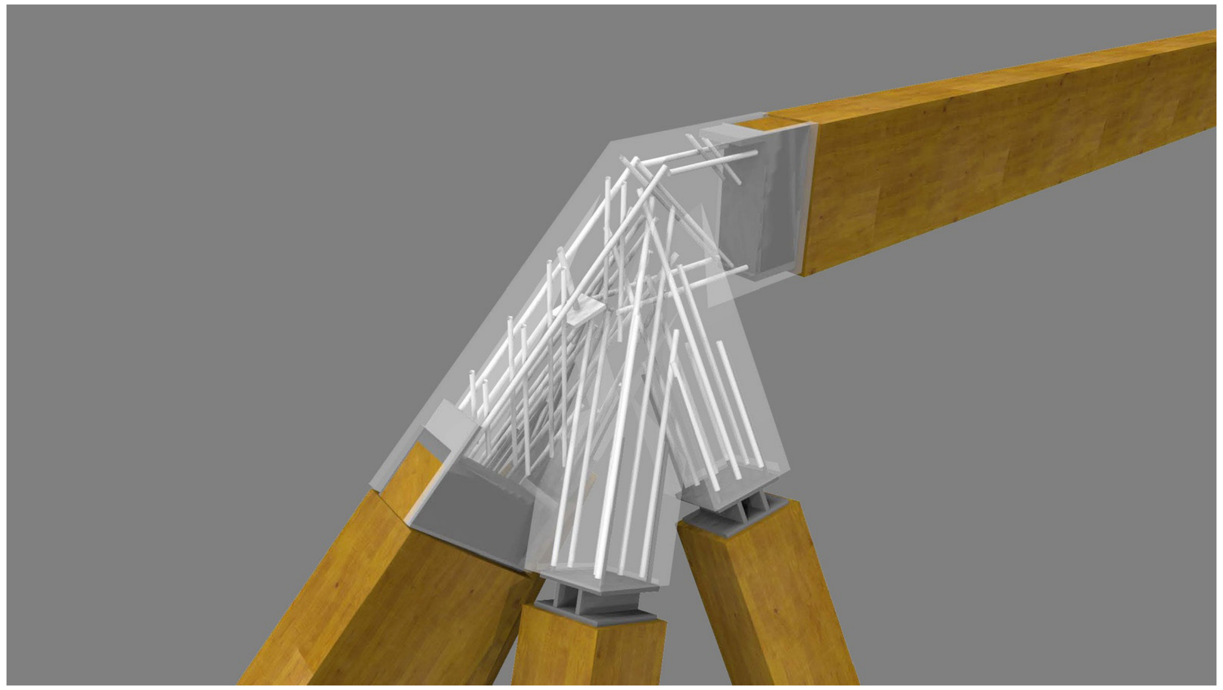
Timber facade structure, The Base, Schiphol-Centrum (De Groot Vroomshoop, 2017)

Design framework

Design principle

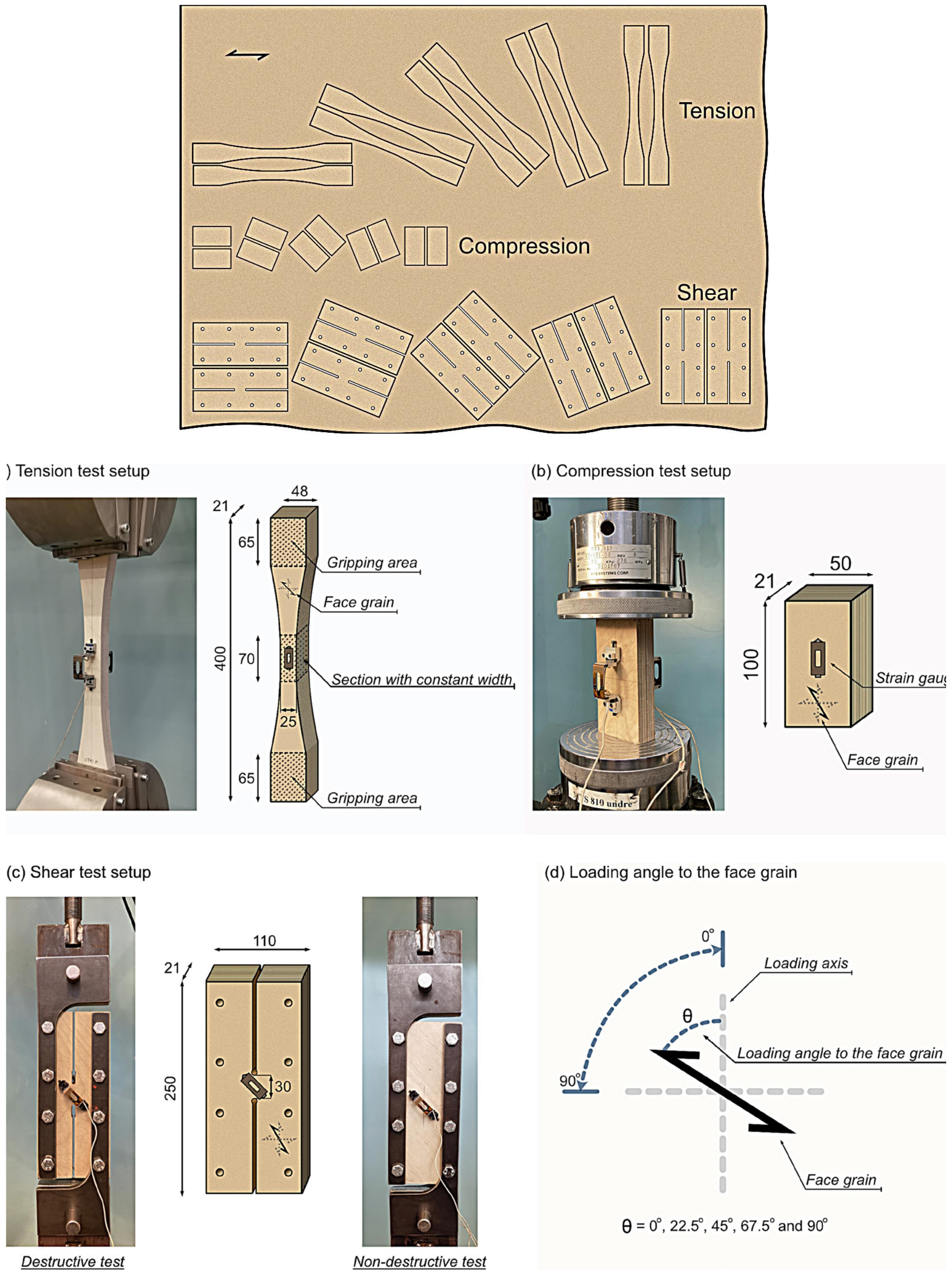
Philip J. Currie Dinosaur Museum (structurecraft.com, 2022)

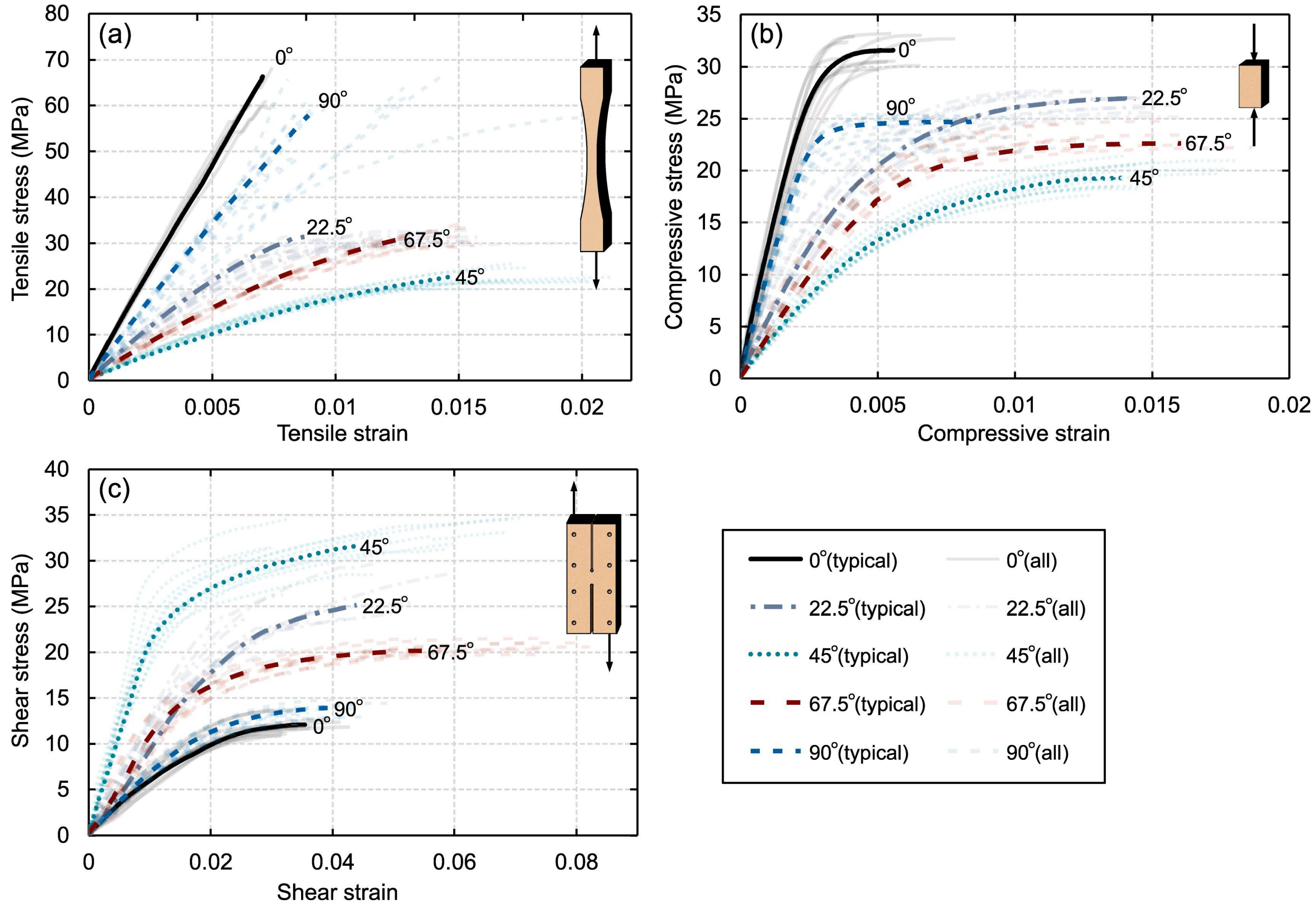




Design framework

Design principle

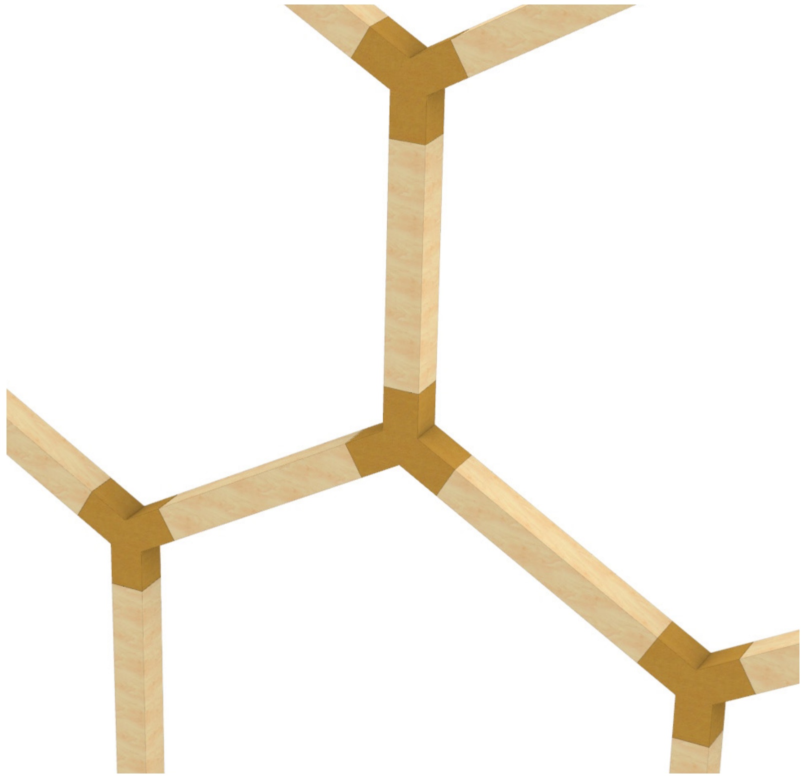


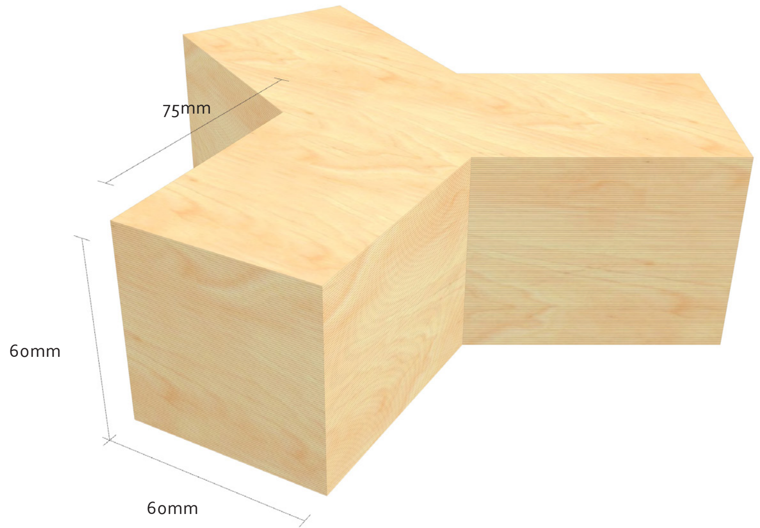


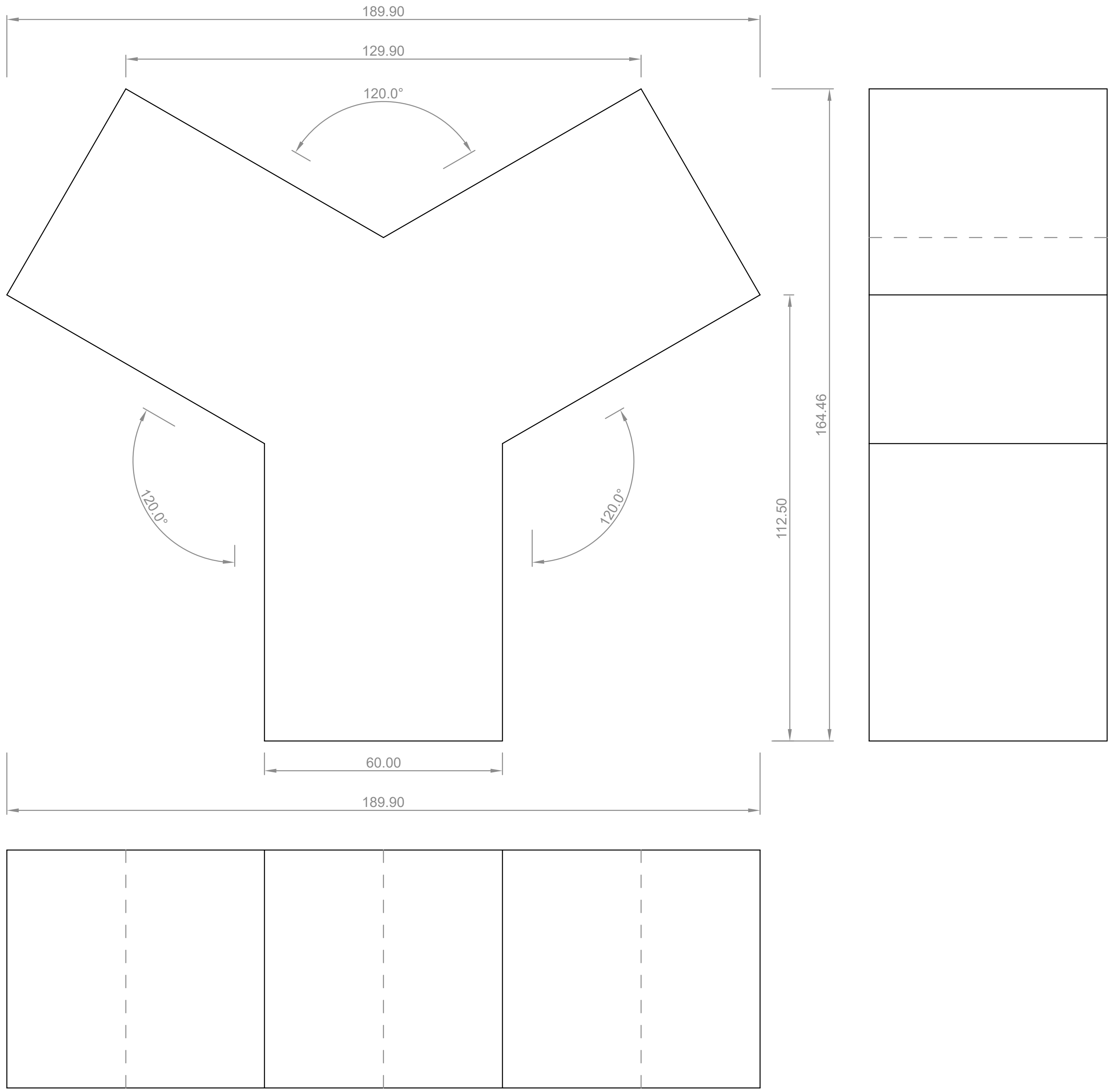
In-plane mechanical properties of plywood (Wang et al., 2022)

Design framework

Node design







Design framework

Material

Material selection criteria

> Production in Europe

> Widely available and relatively affordable

> Available as veneer

> Easy to handle

First selection

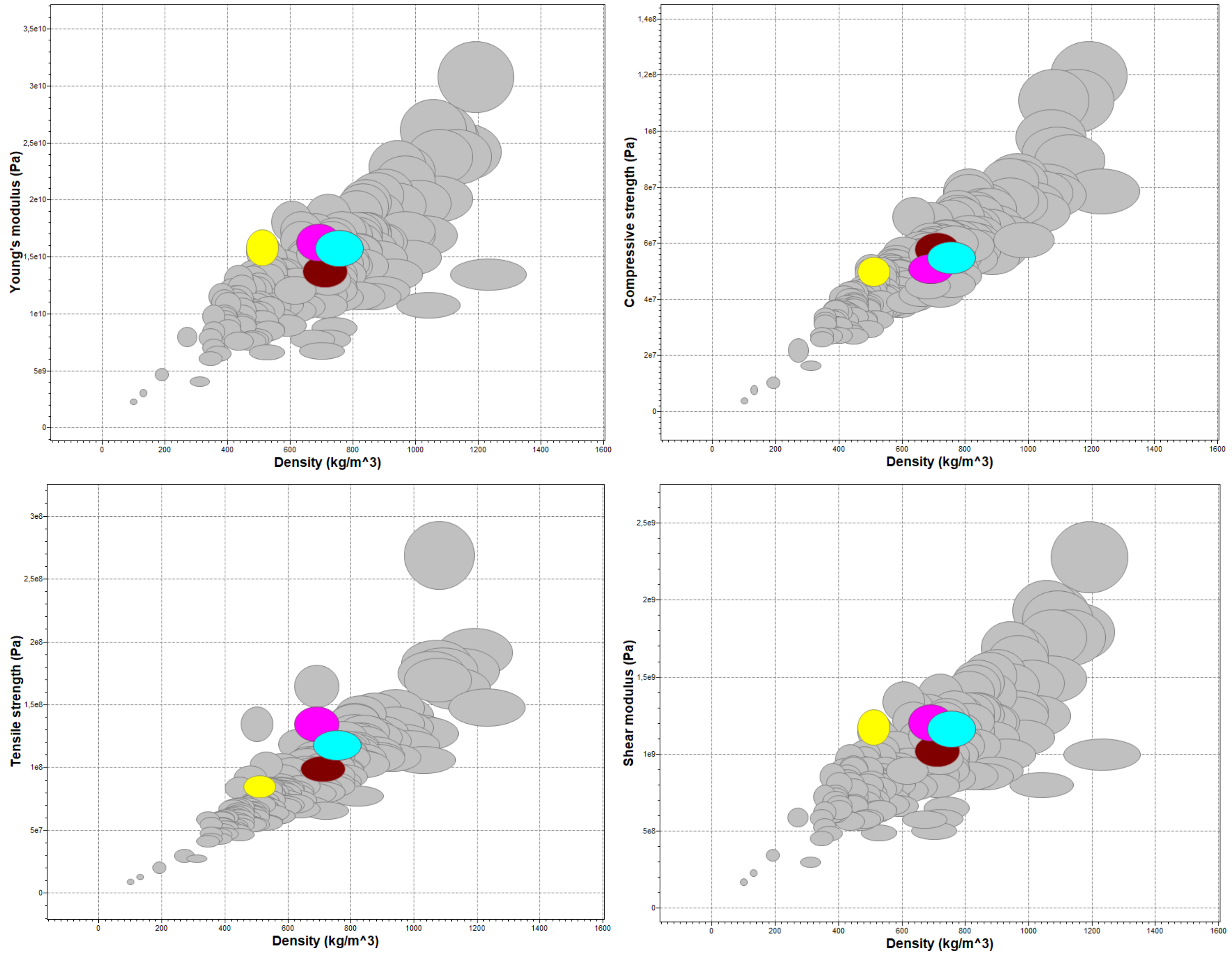
> Birch	(Betula verrucosa)
> Beech	(Fagus sylvatica)
> Spruce	(Picea abies)
> Oak	(Quercus robur)

Design framework

Material

Material properties

> Young’s modulus
> Compressive strength
> Tensile strength
> Shear strength



Legend

(cyan)	Birch	(Betula verrucosa)
(magenta)	Beech	(Fagus sylvatica)
(yellow)	Spruce	(Picea abies)
(dark red)	Oak	(Quercus robur)

A comparisson of a selection of mechenical properties of four types of wood (Ansys Granta EduPack)

Design framework

Material

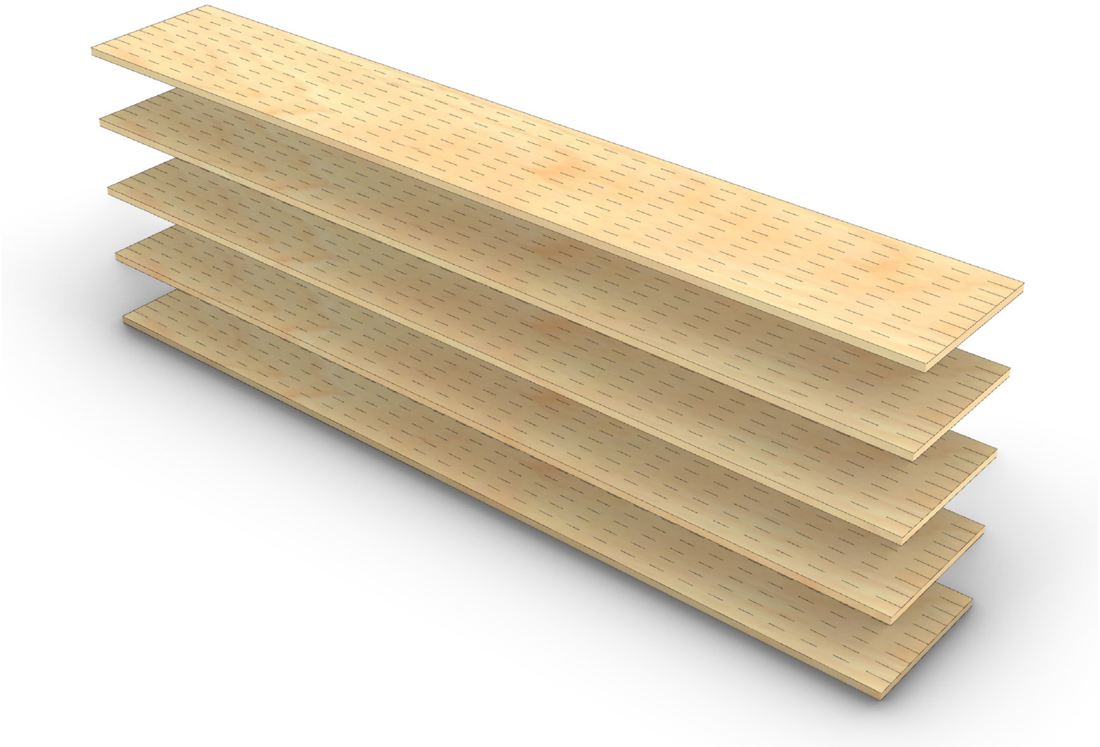
Birch veneer

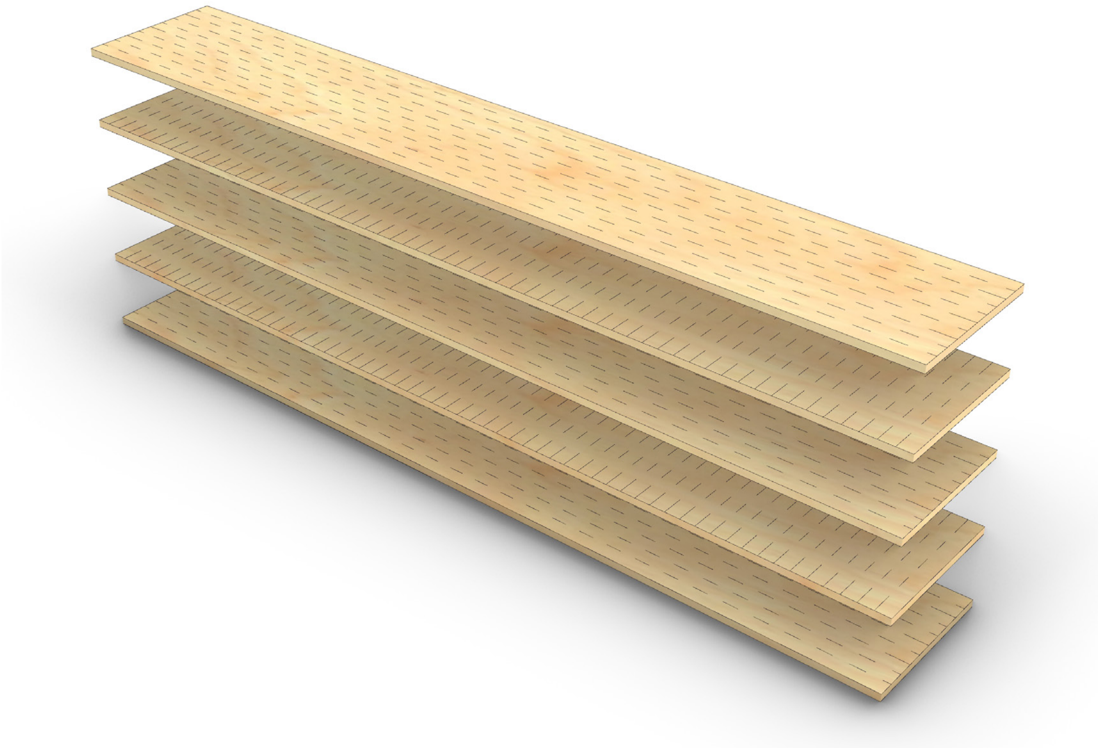
Beech veneer

Oak veneer

Design framework

Material



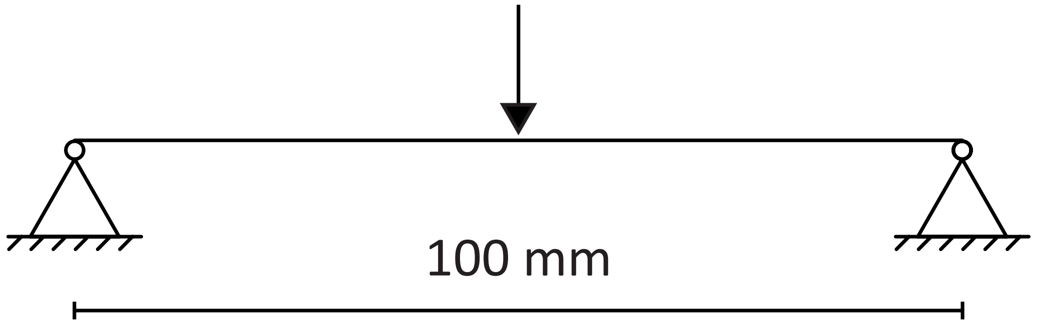


Design framework

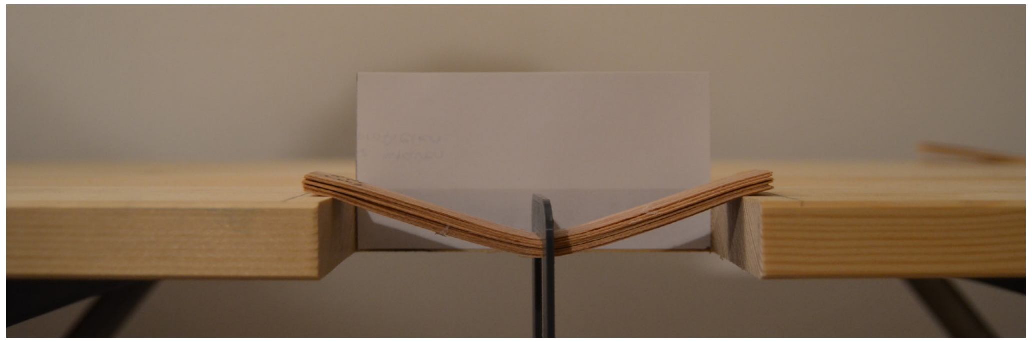
Material

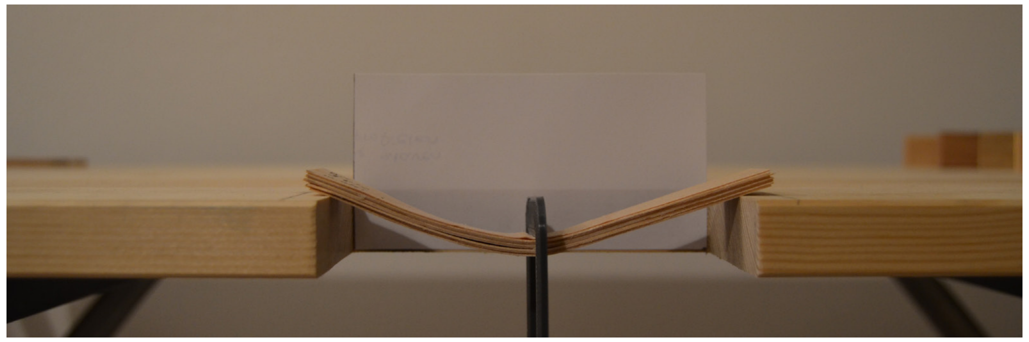
Design framework

Material




Linear birch - Max load of 103.95 N


Linear beech - Max load of 117.68 N

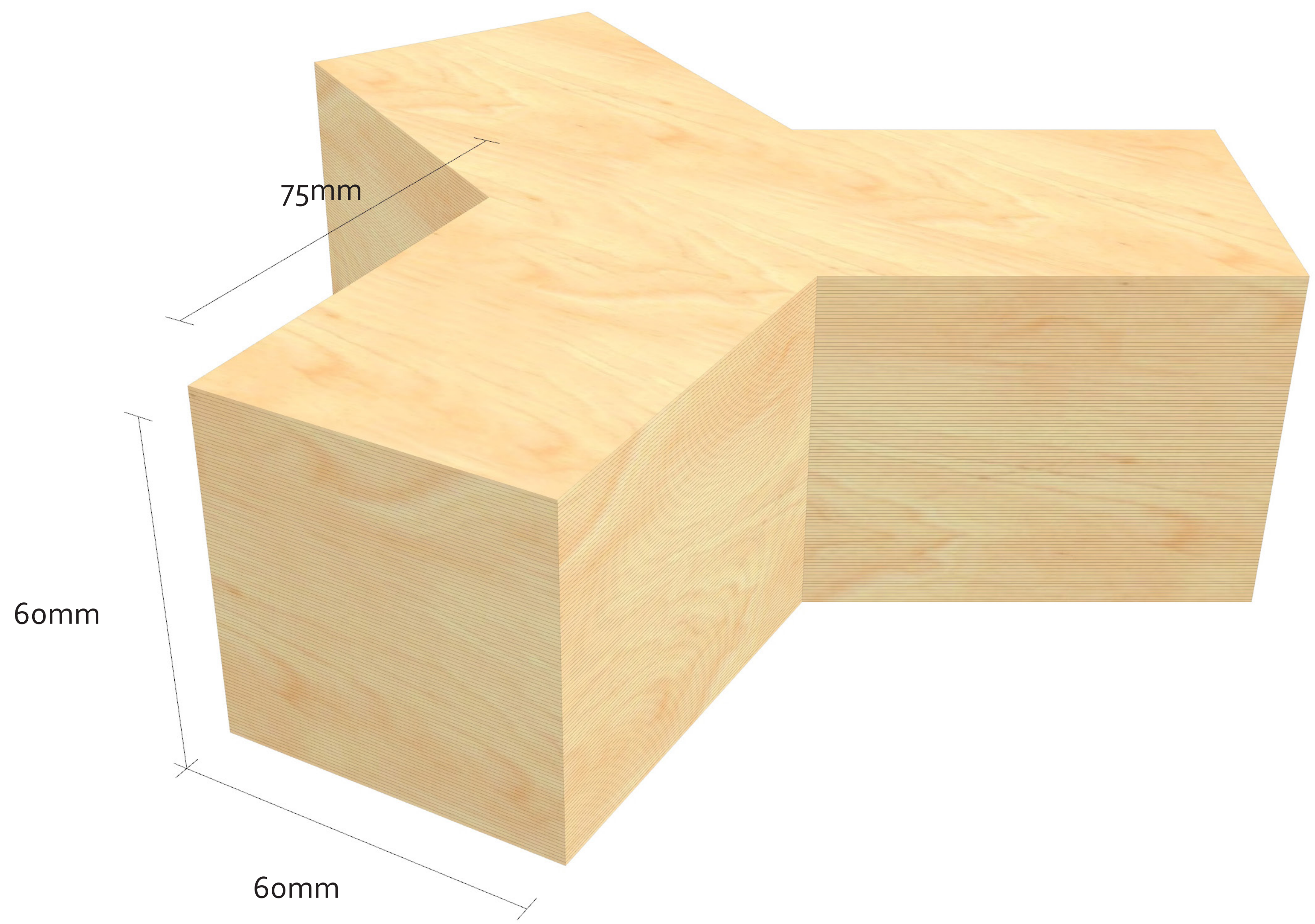

Multiple direction birch - Max load of 40.21 N


Multiple direction beech - Max load of 108.85 N

Research by design

Concept design

Concept geometry for testing



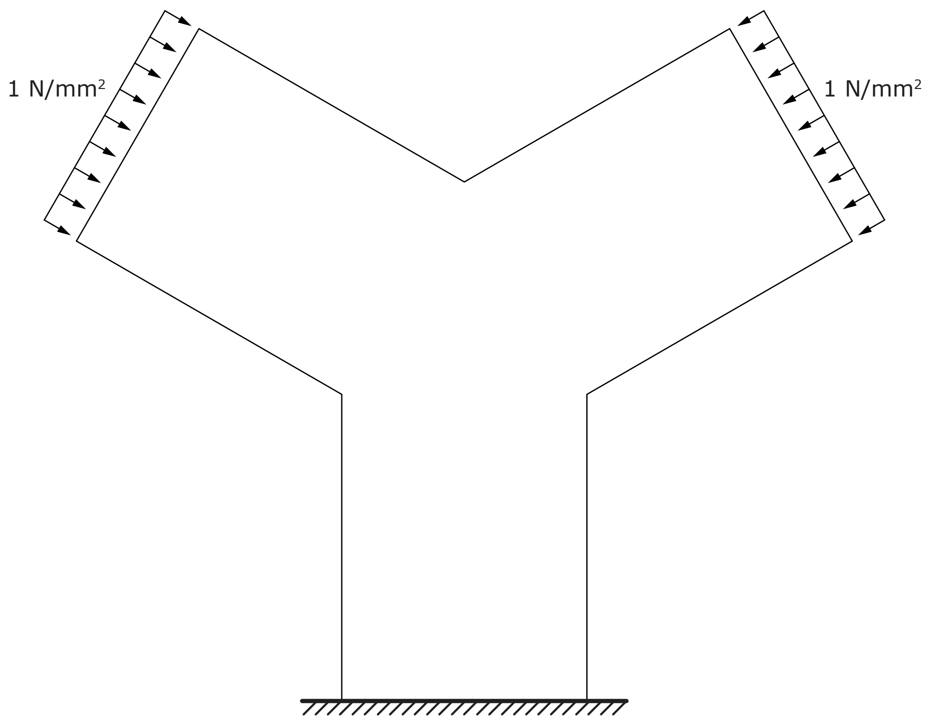
Research by design

Structural analyses and criteria

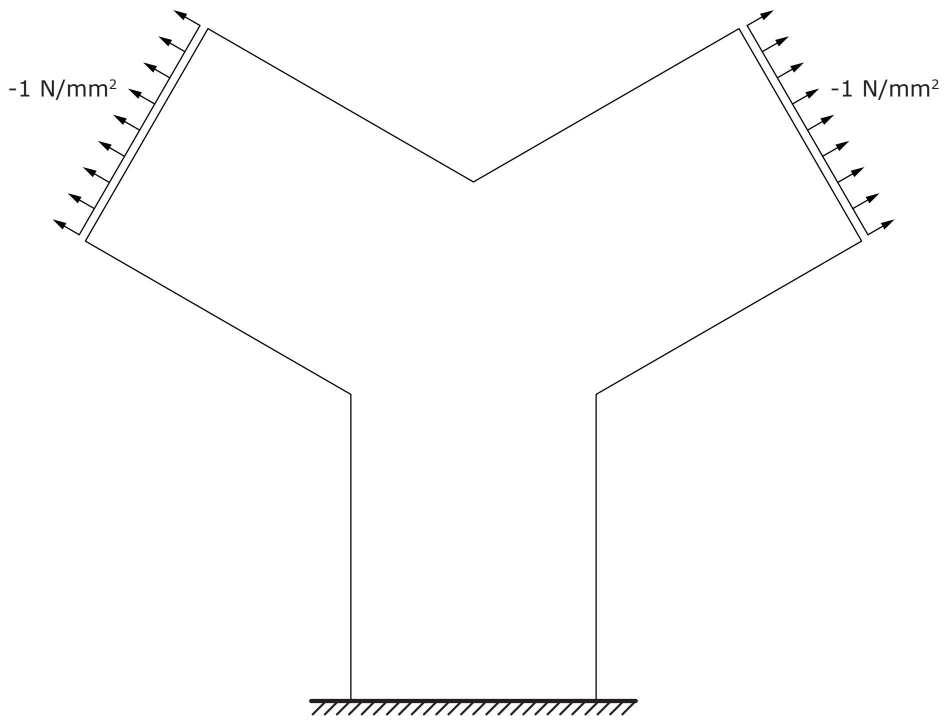
FEM analysis with Abaqus 6.13.1

Monitoring results

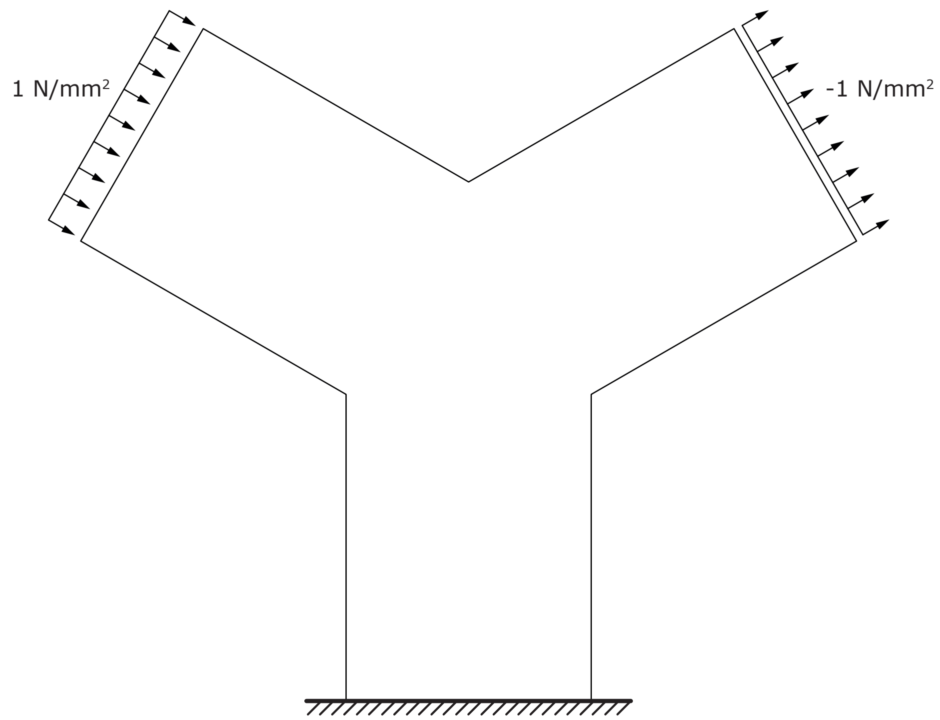
> Relative amount of stress
> Location of maximum stress



Compression



Tension

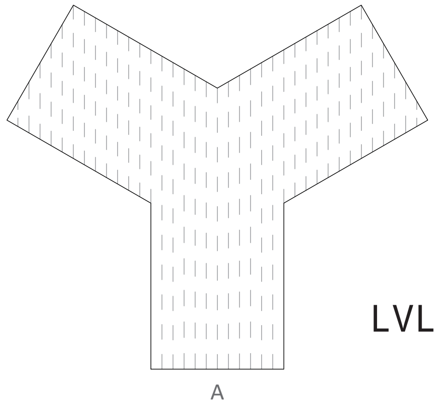


Compression + tension

Design development

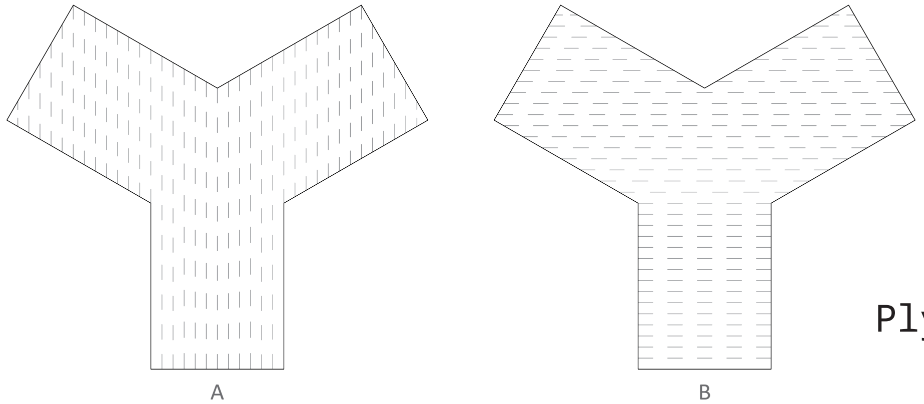
Design v0.0 and v0.1 - Compression

v0.0   A-A-A

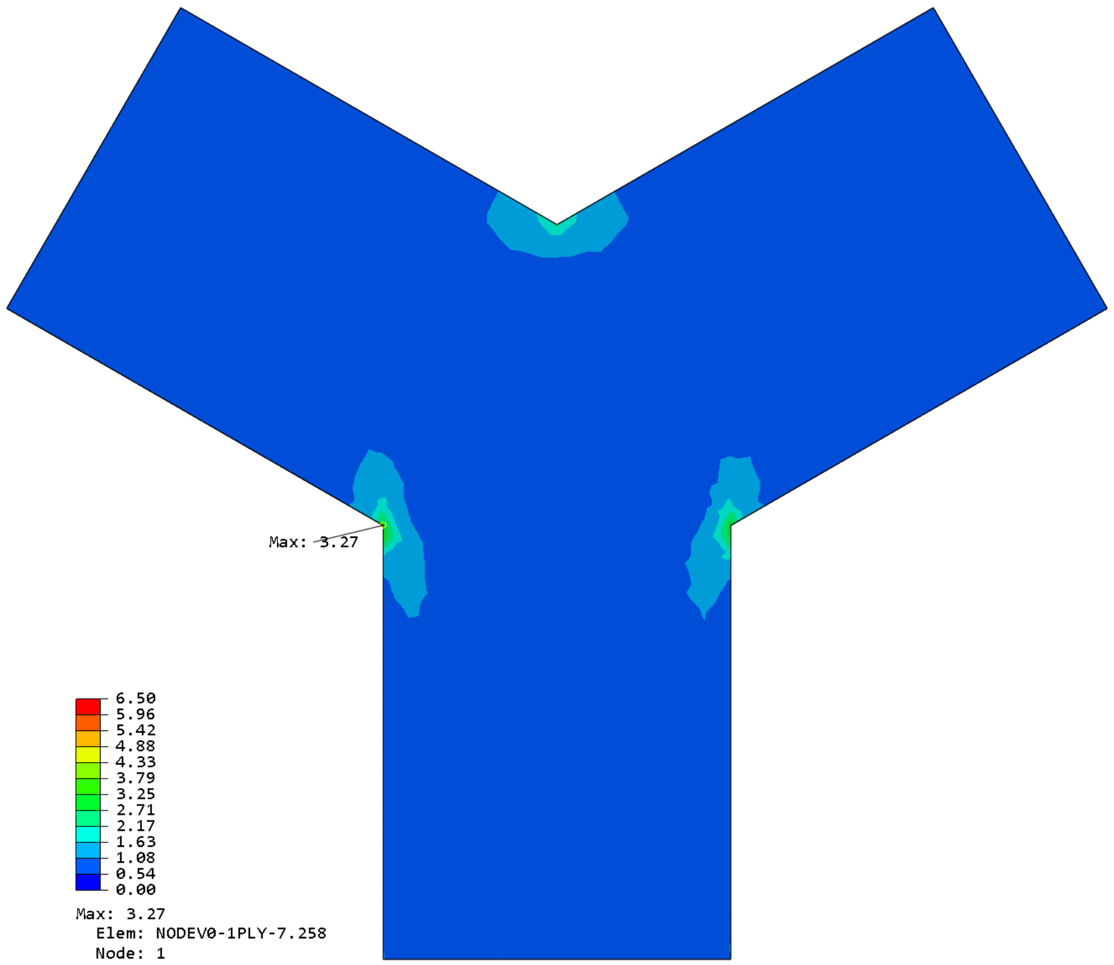


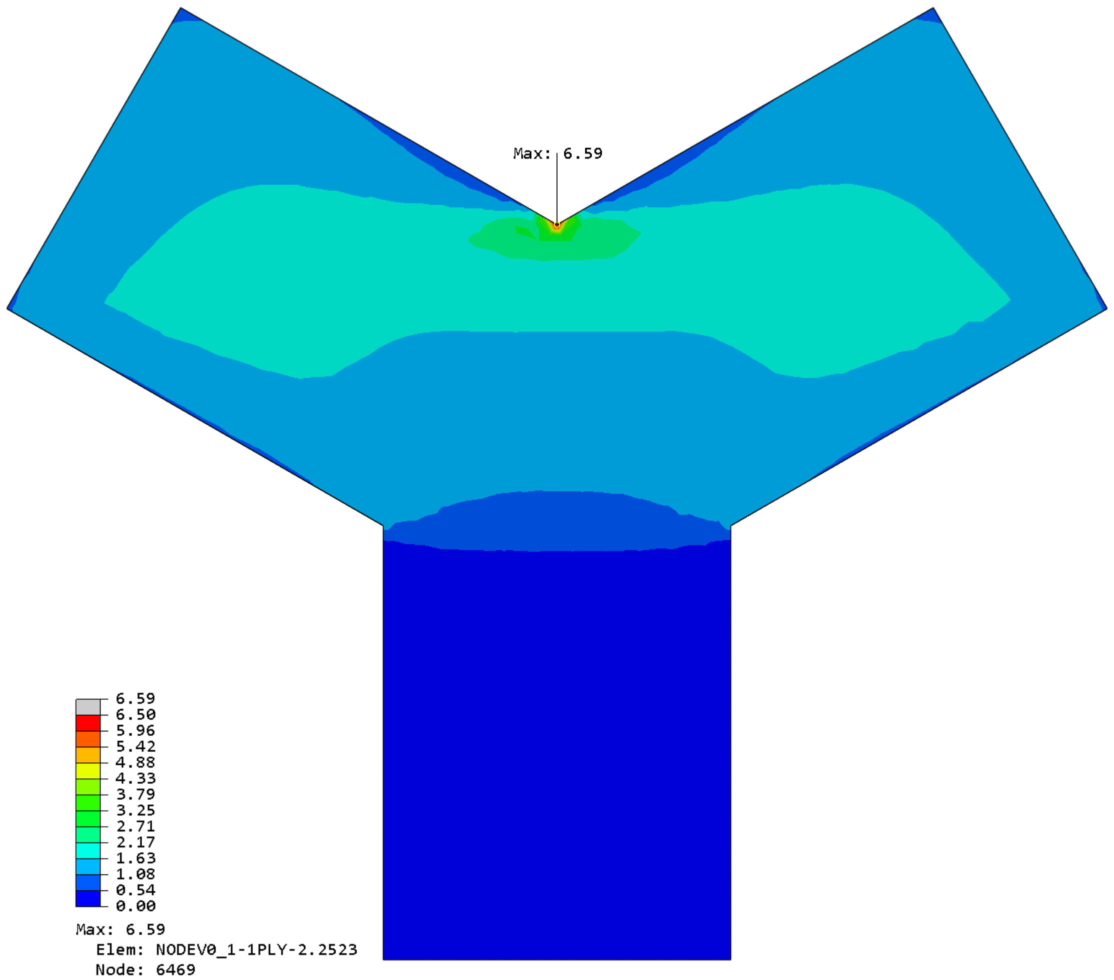
LVL configuration

v0.1   A-B-A



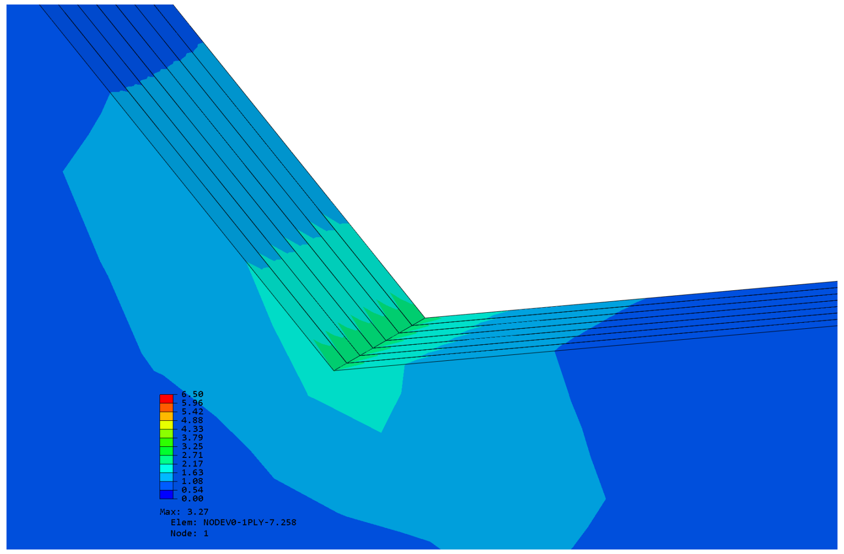
Plywood configuration

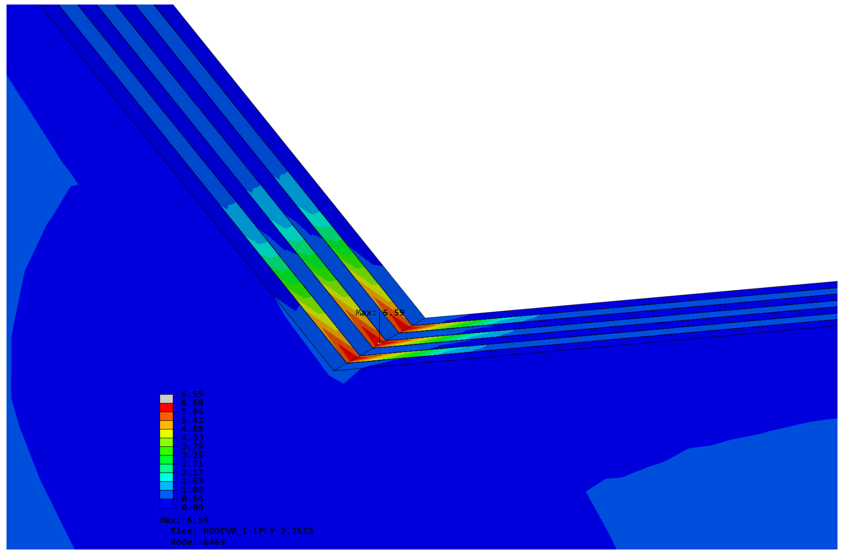


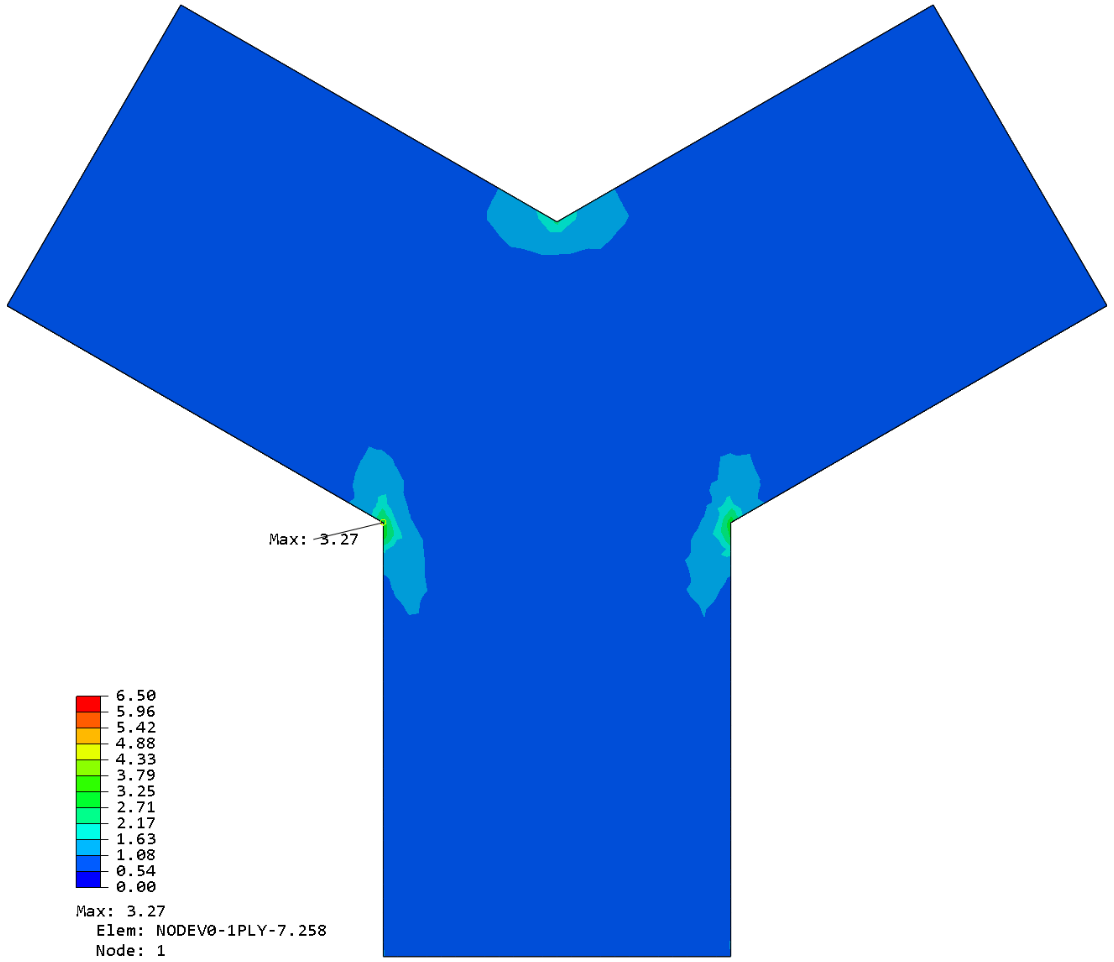


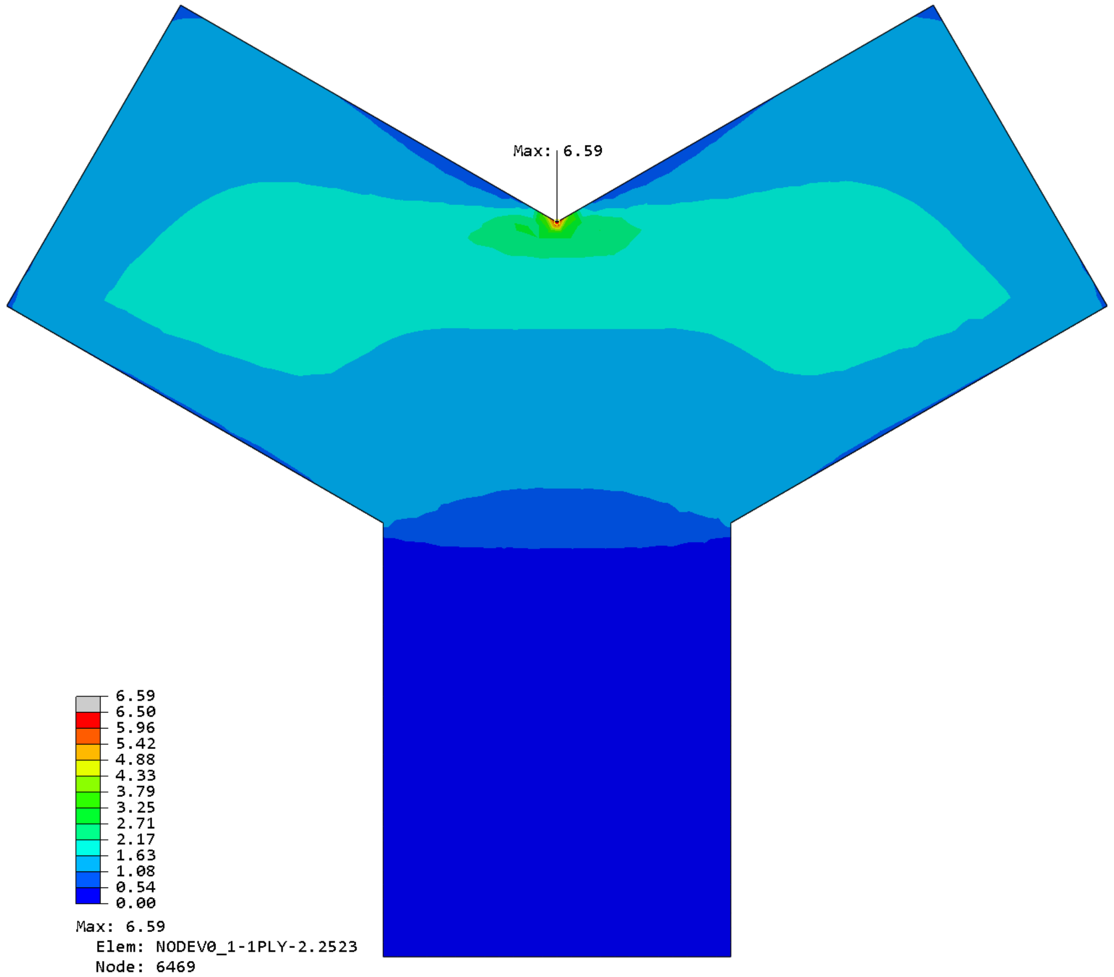
Design development

Design v0.0 and v0.1 - Compression





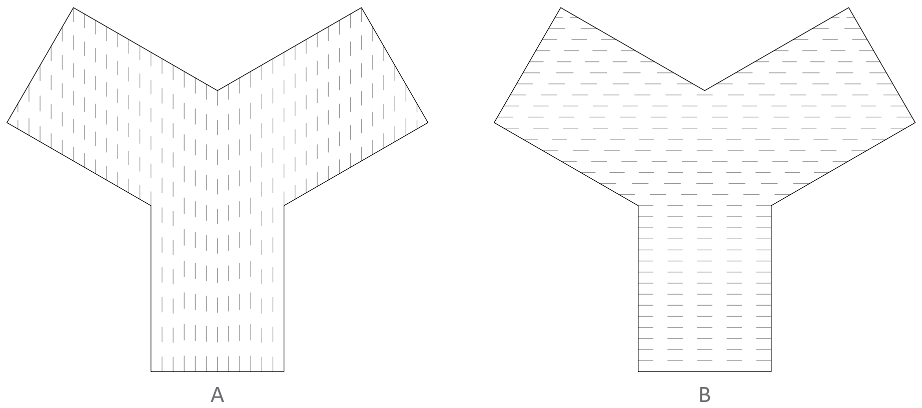




Design development

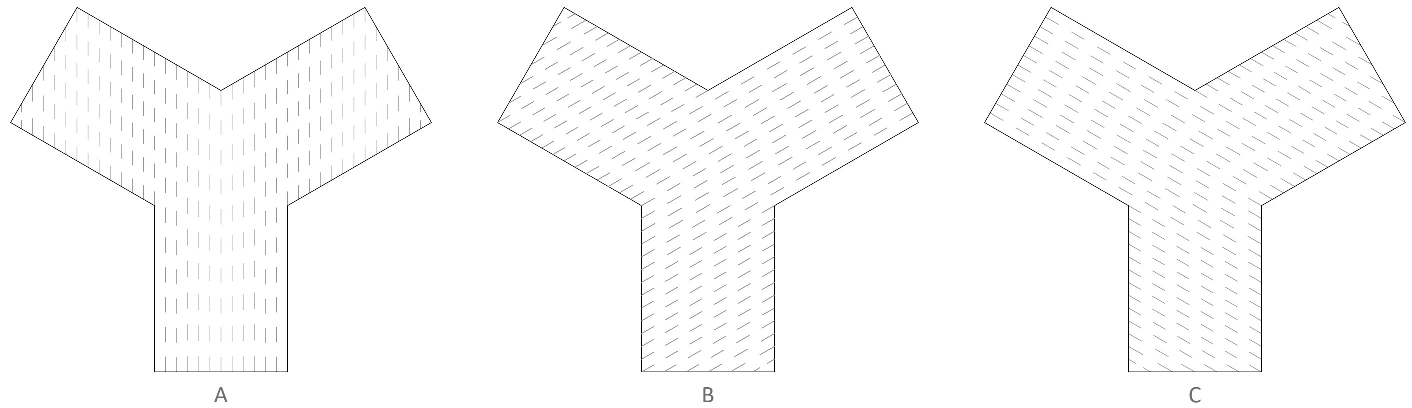
Design v0.1 and v1.1 - Compression

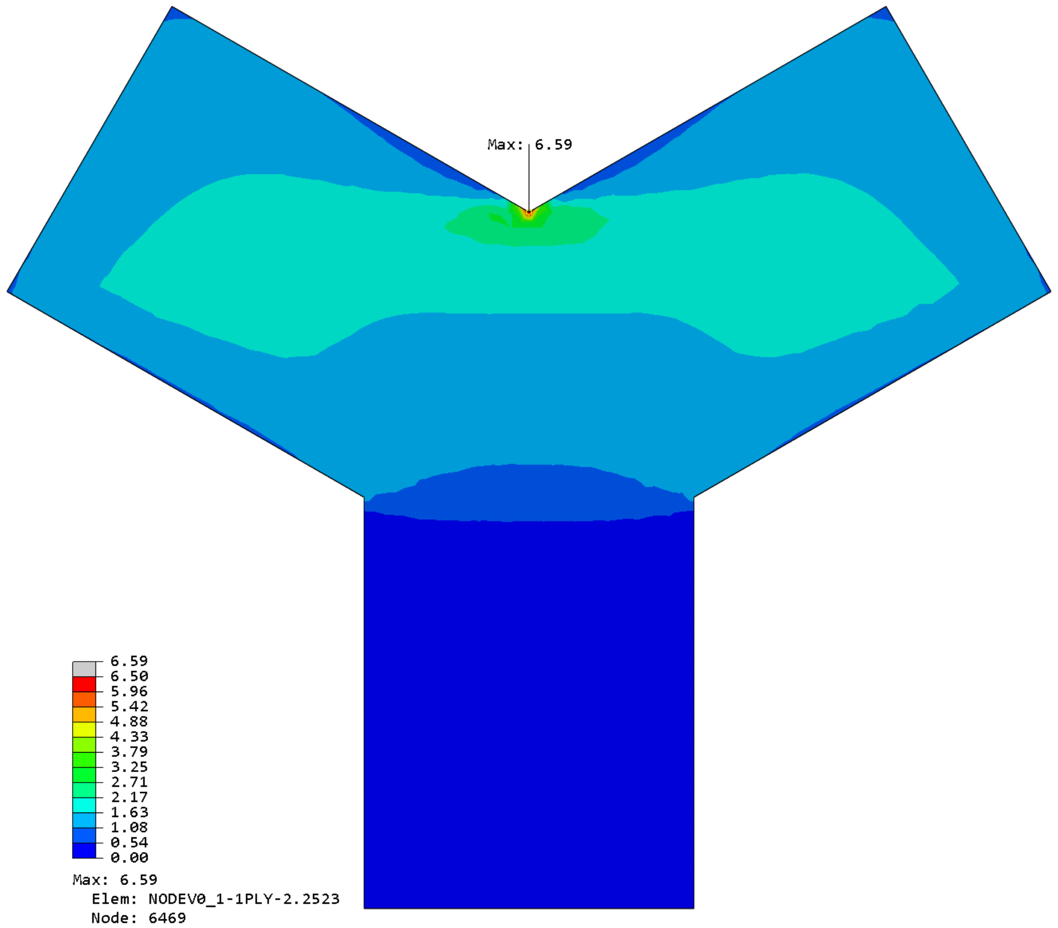
v0.1   A-B-A

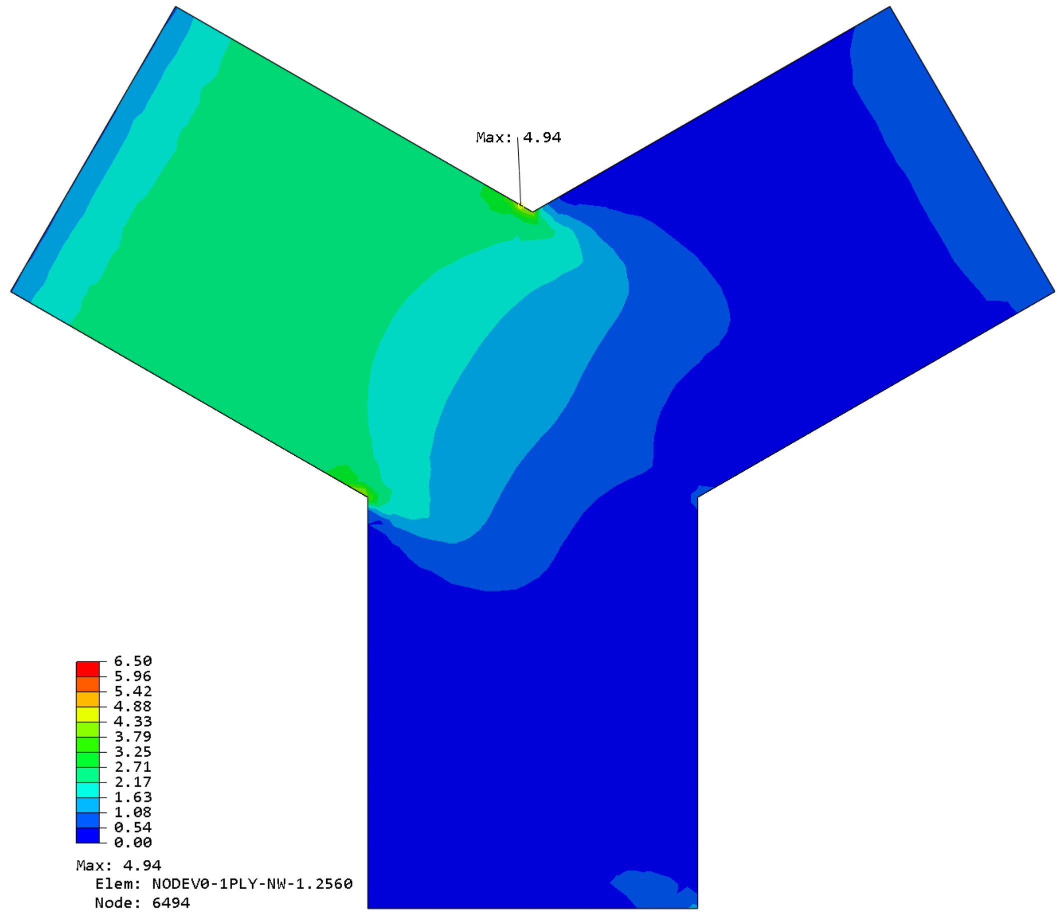


v1 layer structure

A-B-C-A-C-B-A

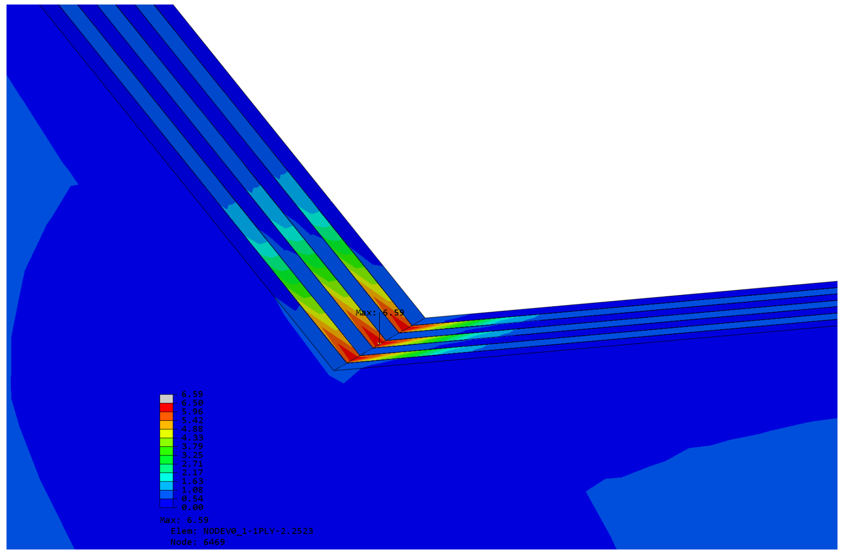


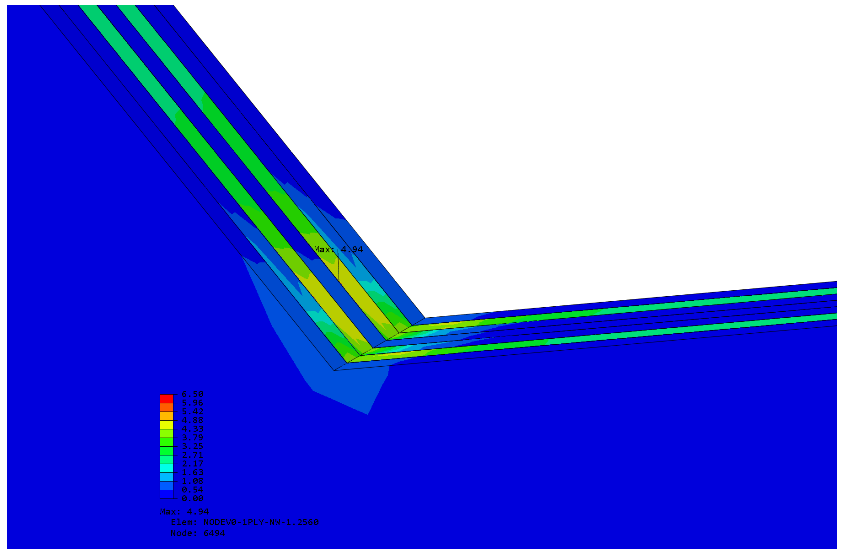


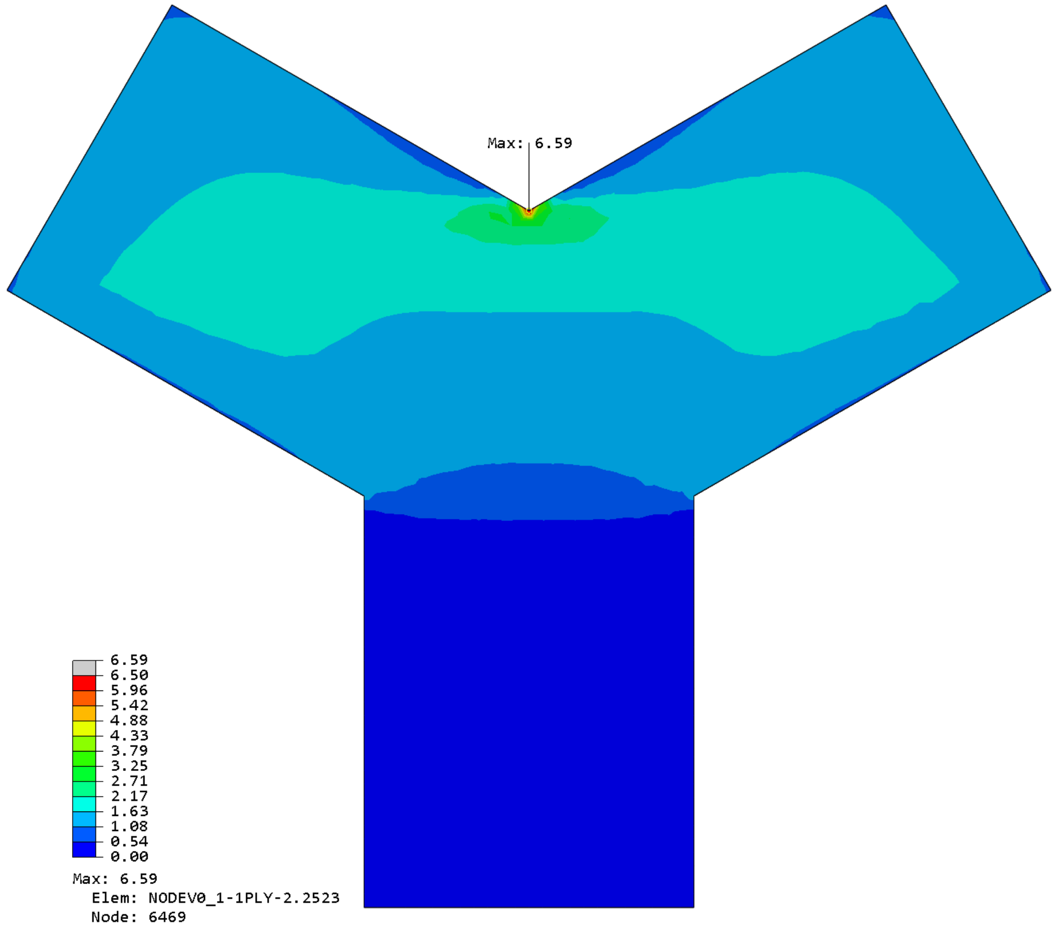


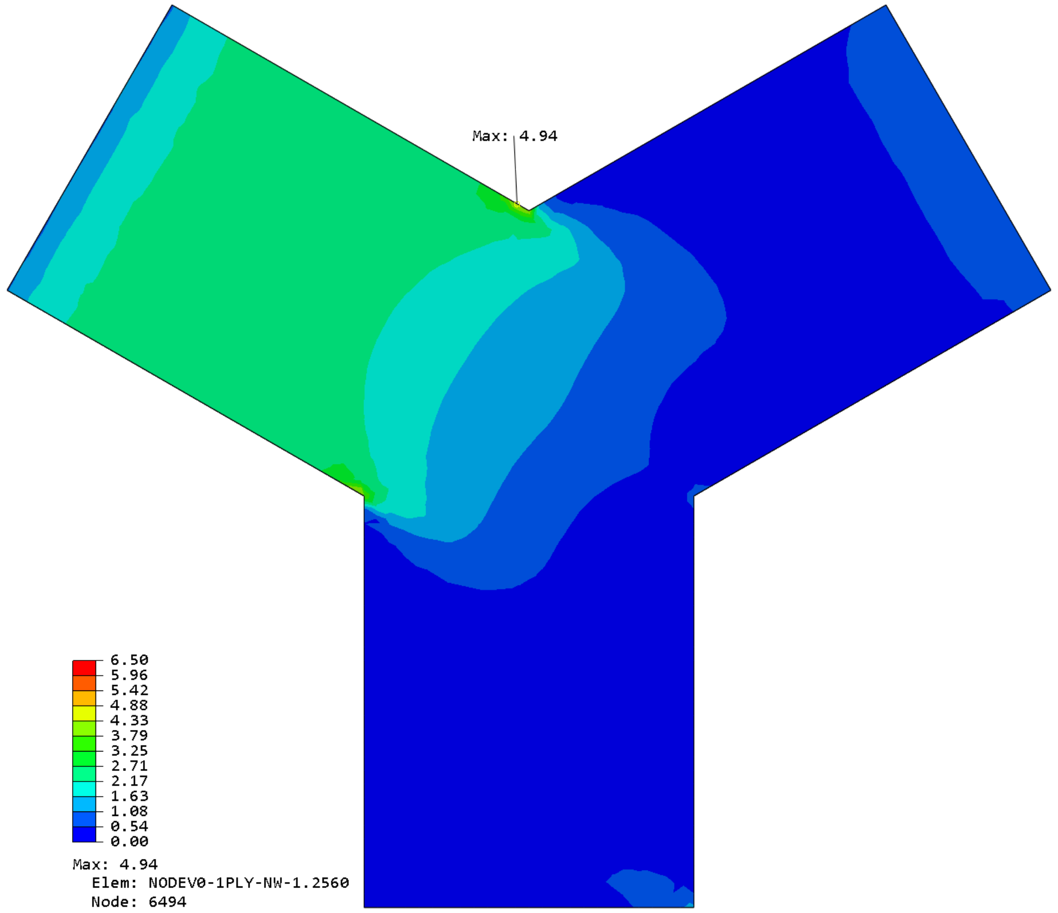
Design development

Design v0.1 and v1.1 - Compression







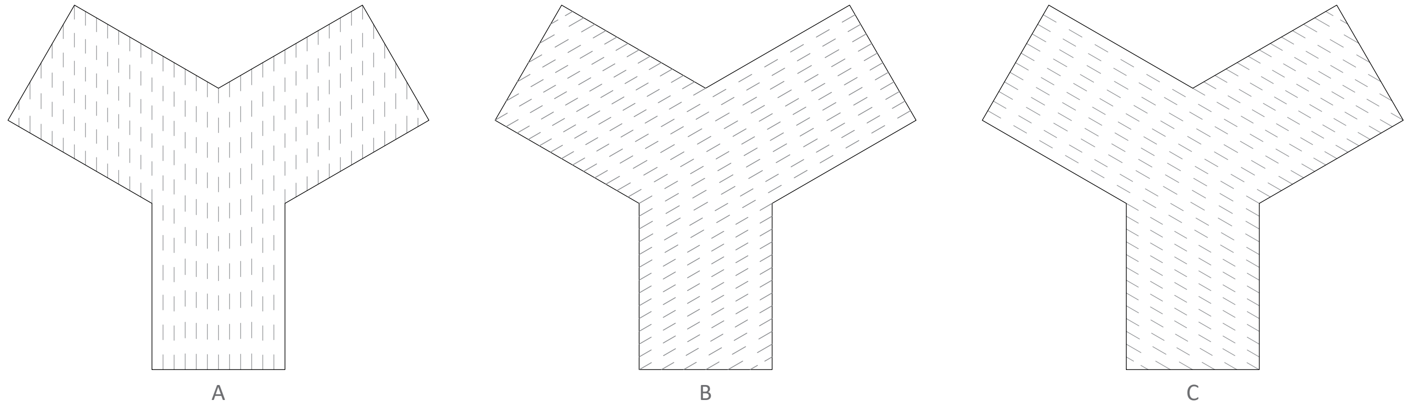


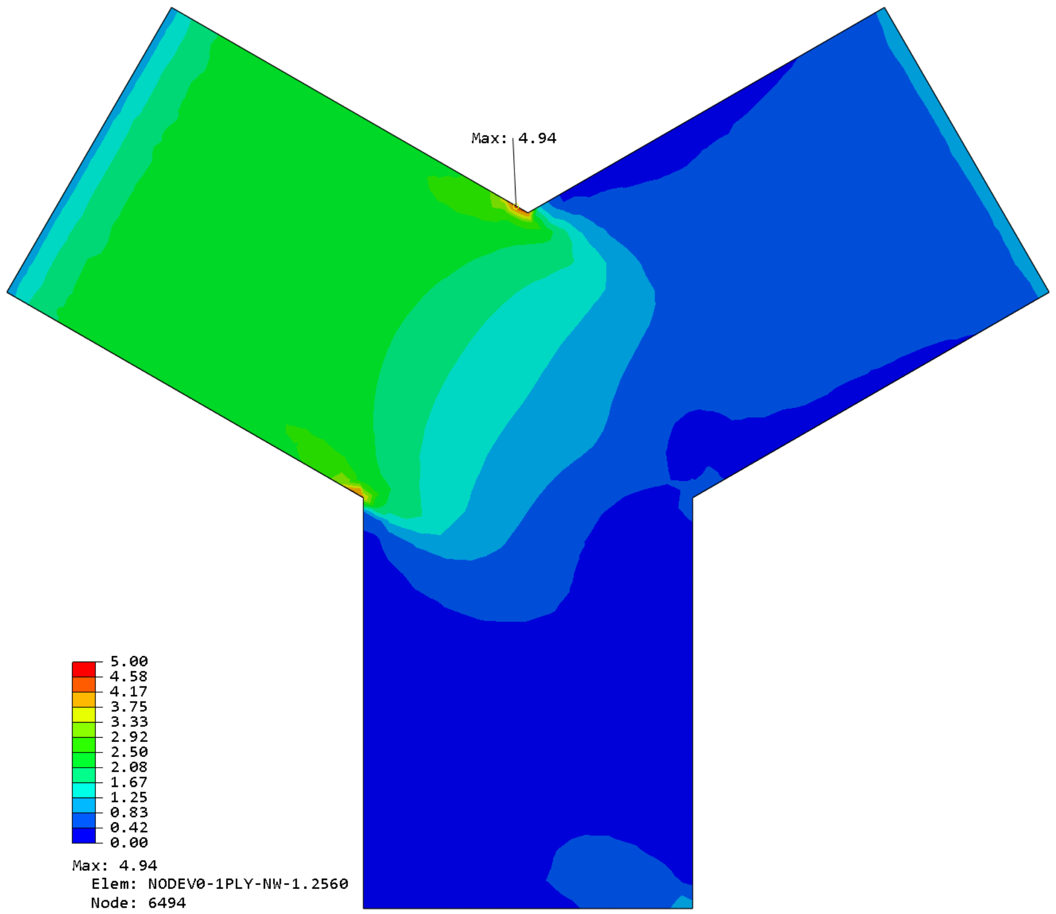
Design development

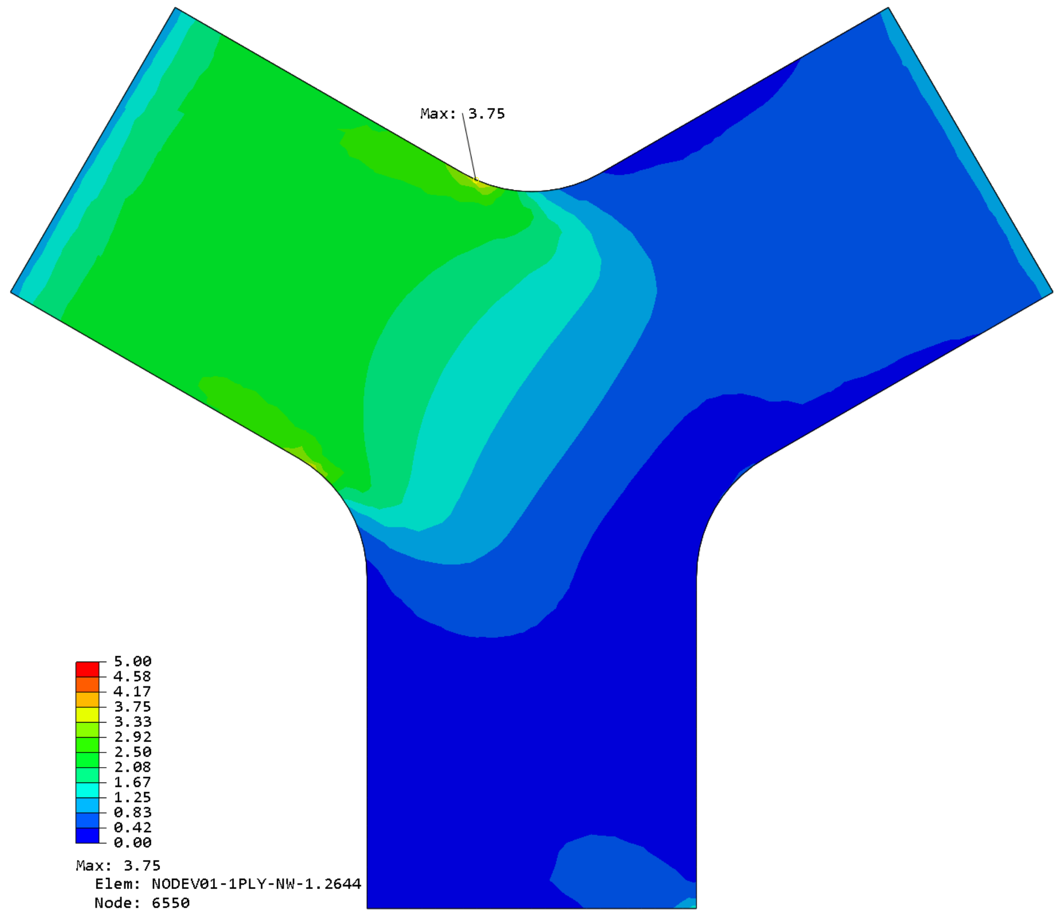
Design v1.1 and v1.2 - Compression

v1 layer structure

A-B-C-A-C-B-A

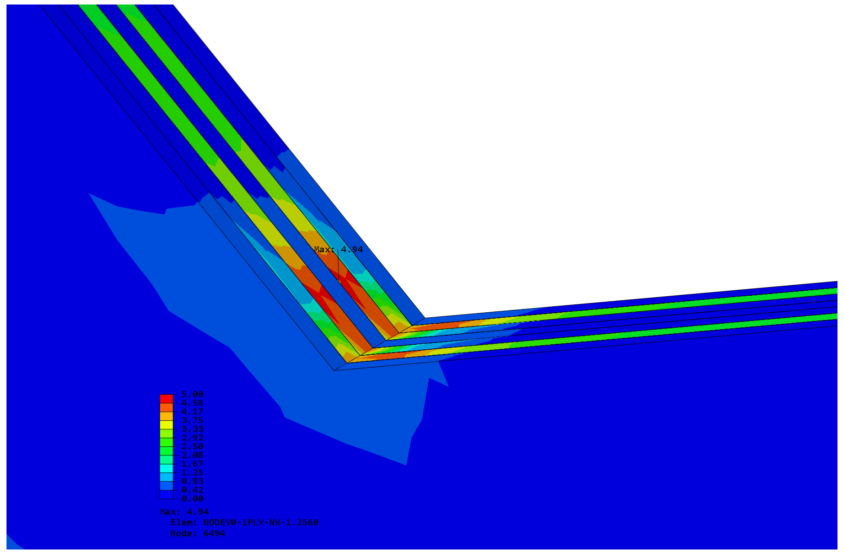


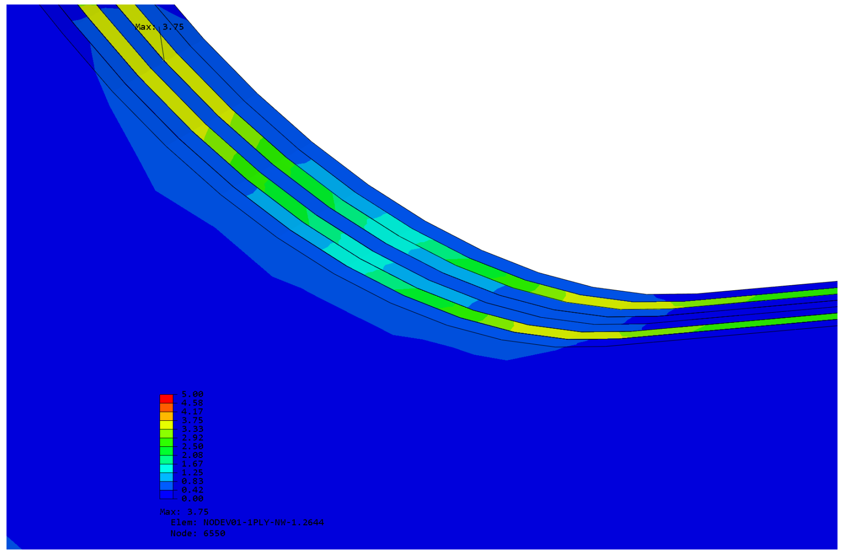


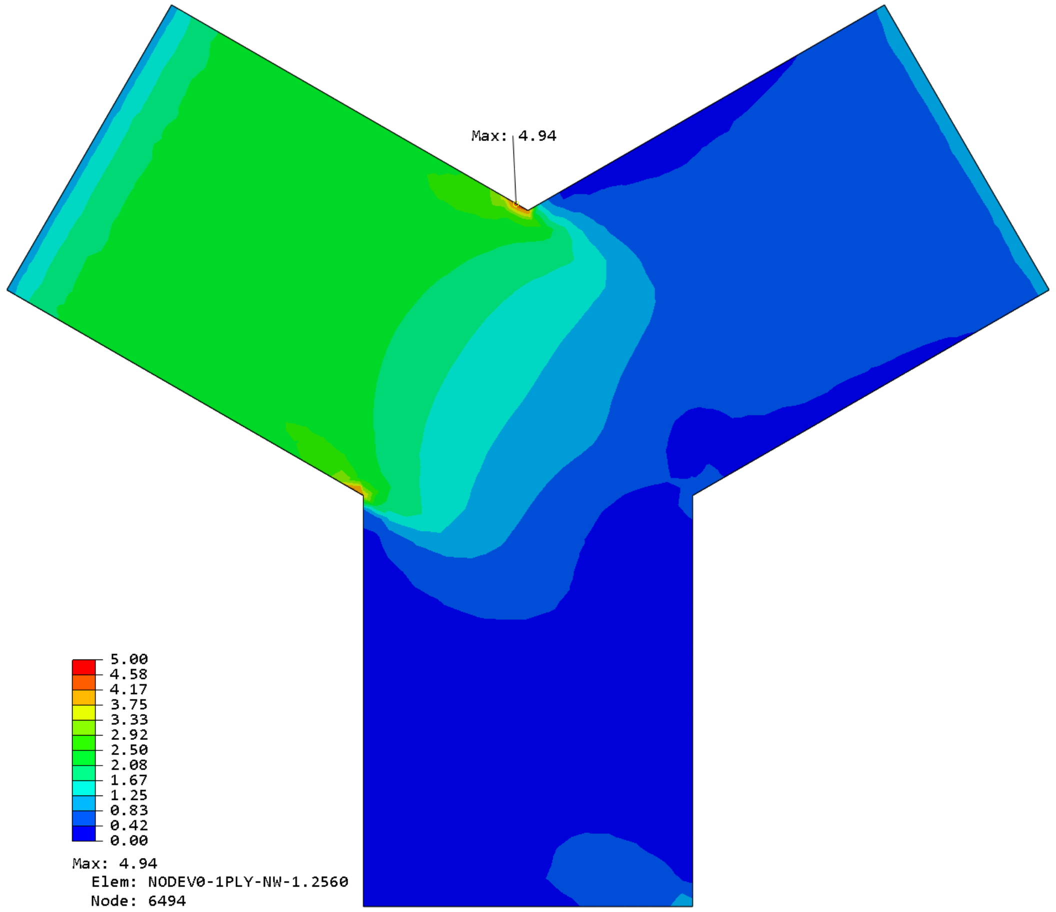


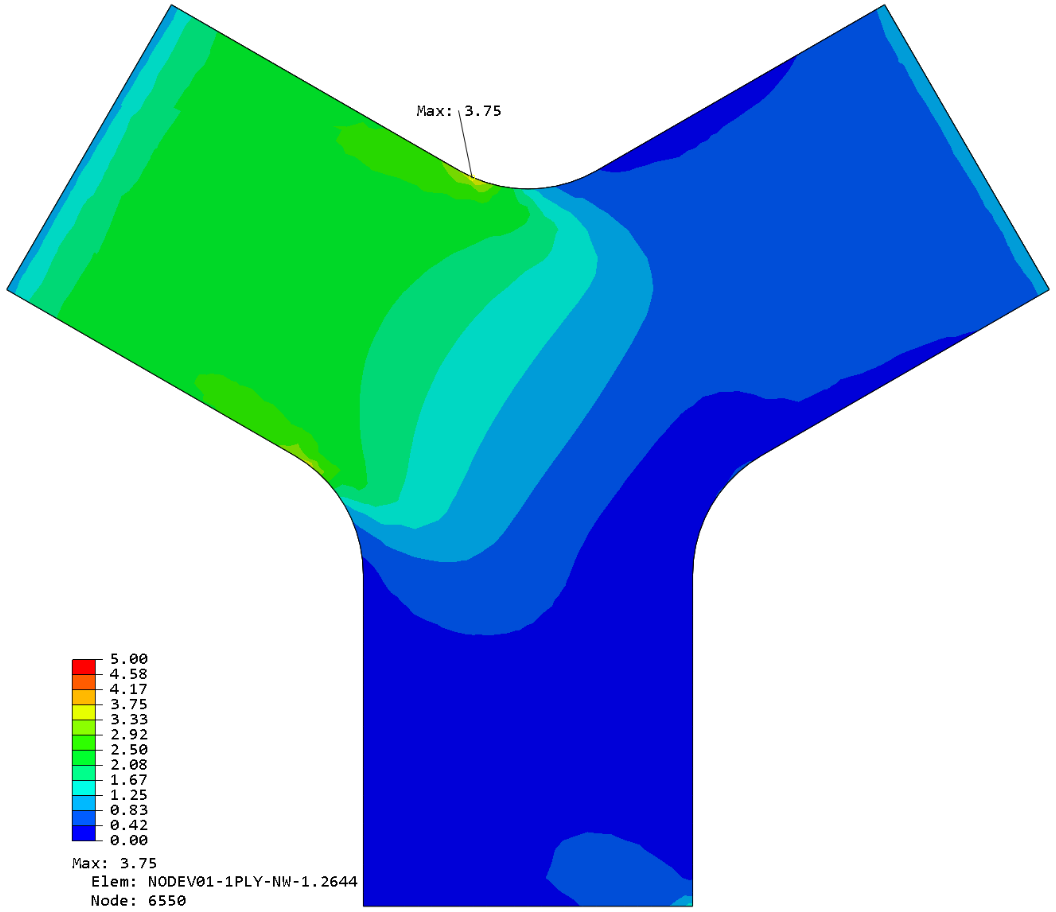
Design development

Design v1.1 and v1.2 - Compression







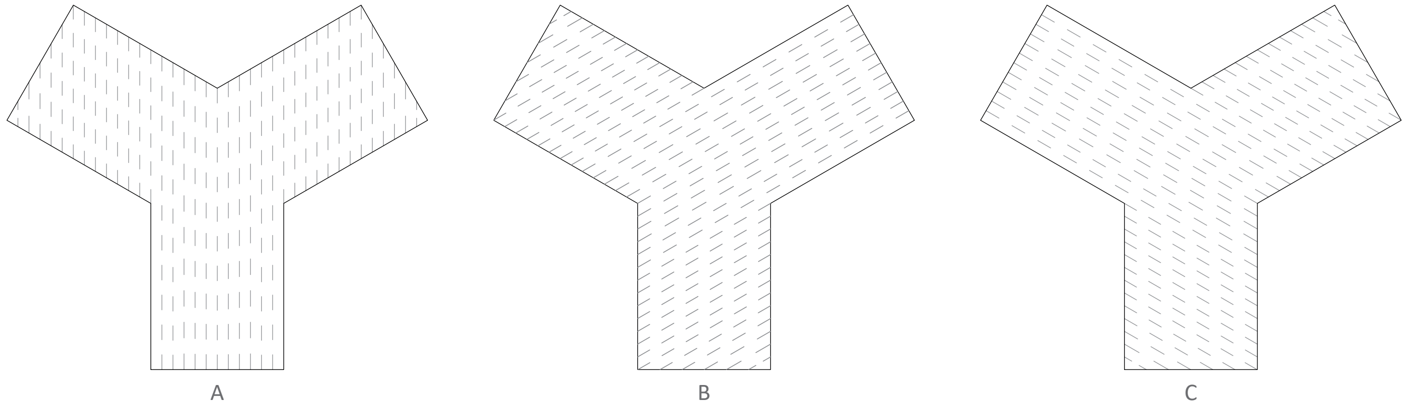


Design development

Design v1.2 and v2.2 - Compression

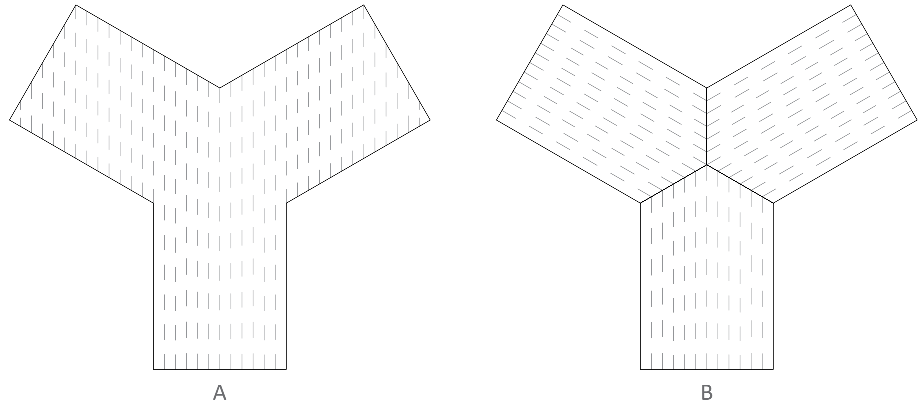
v1 layer structure

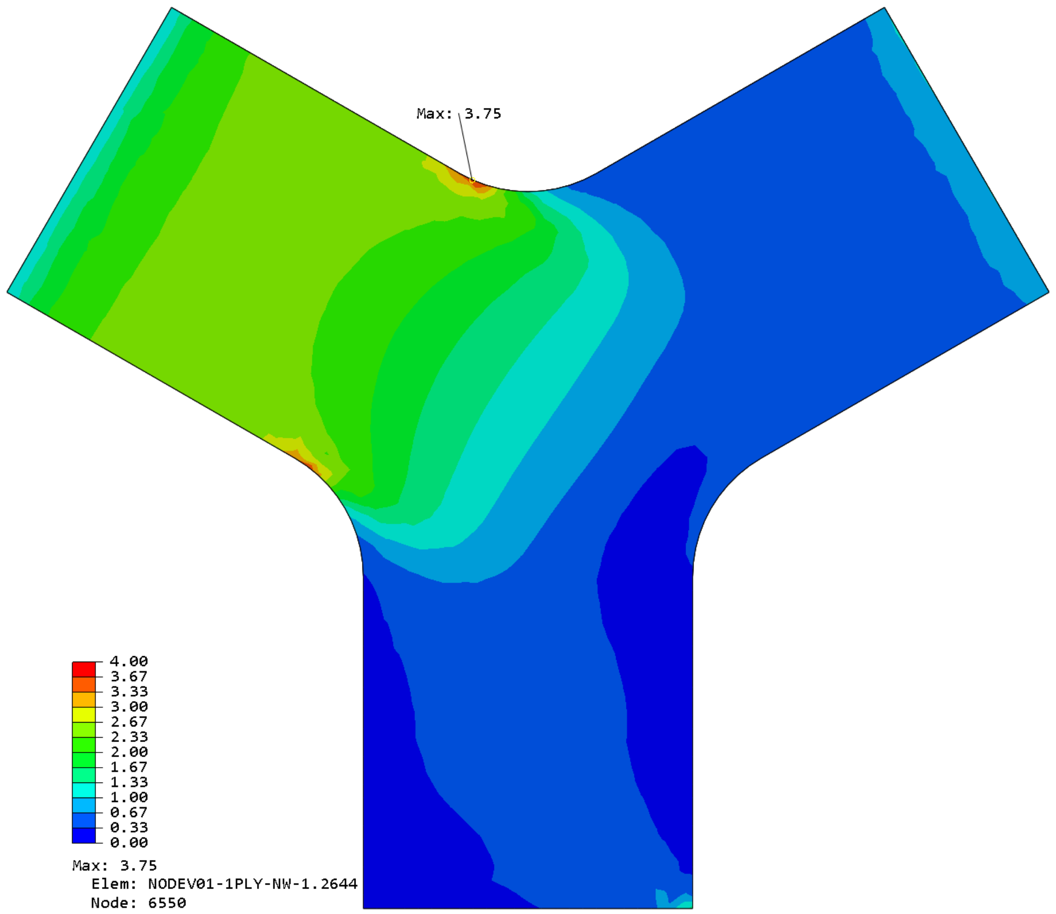
A-B-C-A-C-B-A

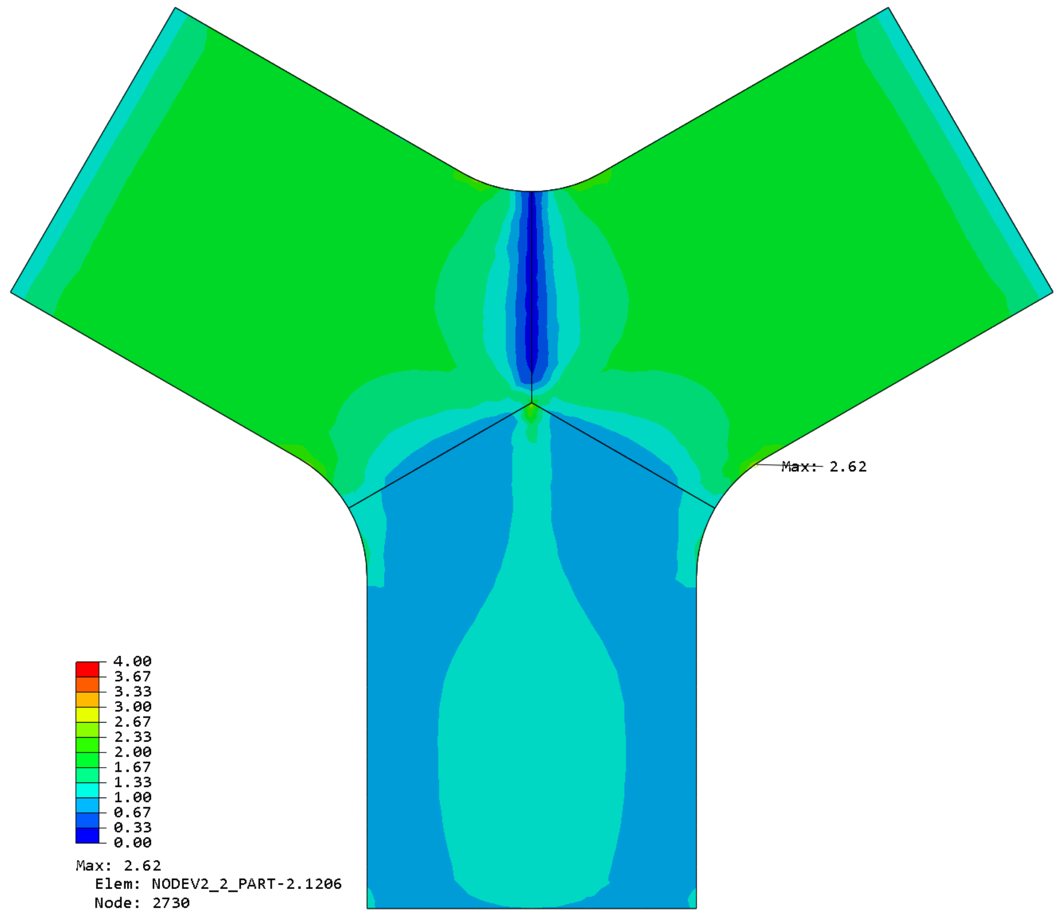


v2 layer structure

A-B-A

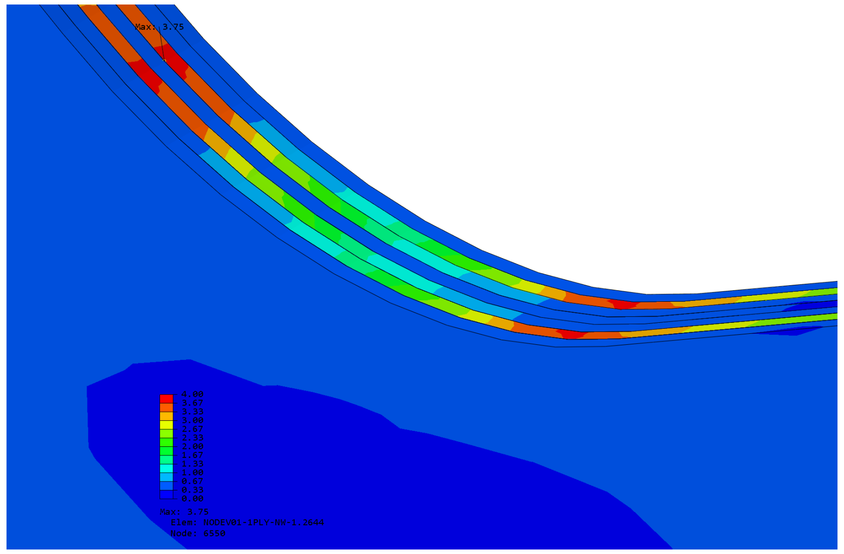


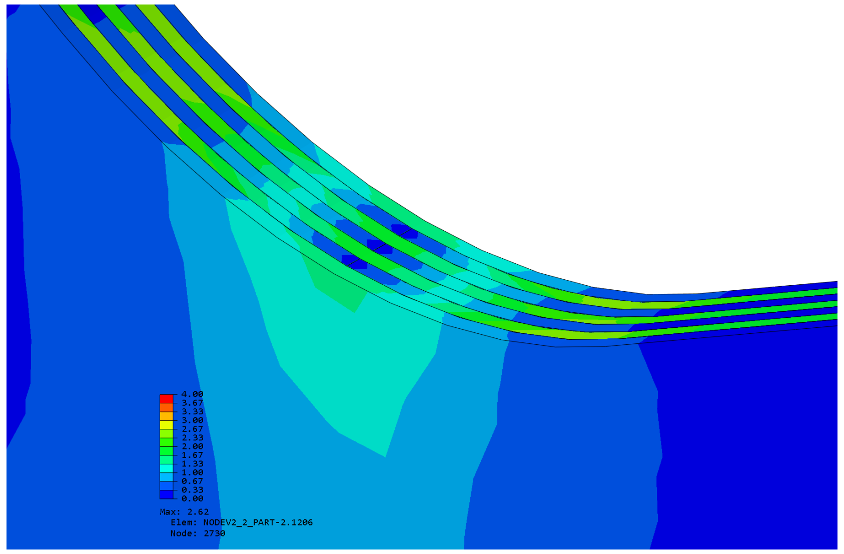


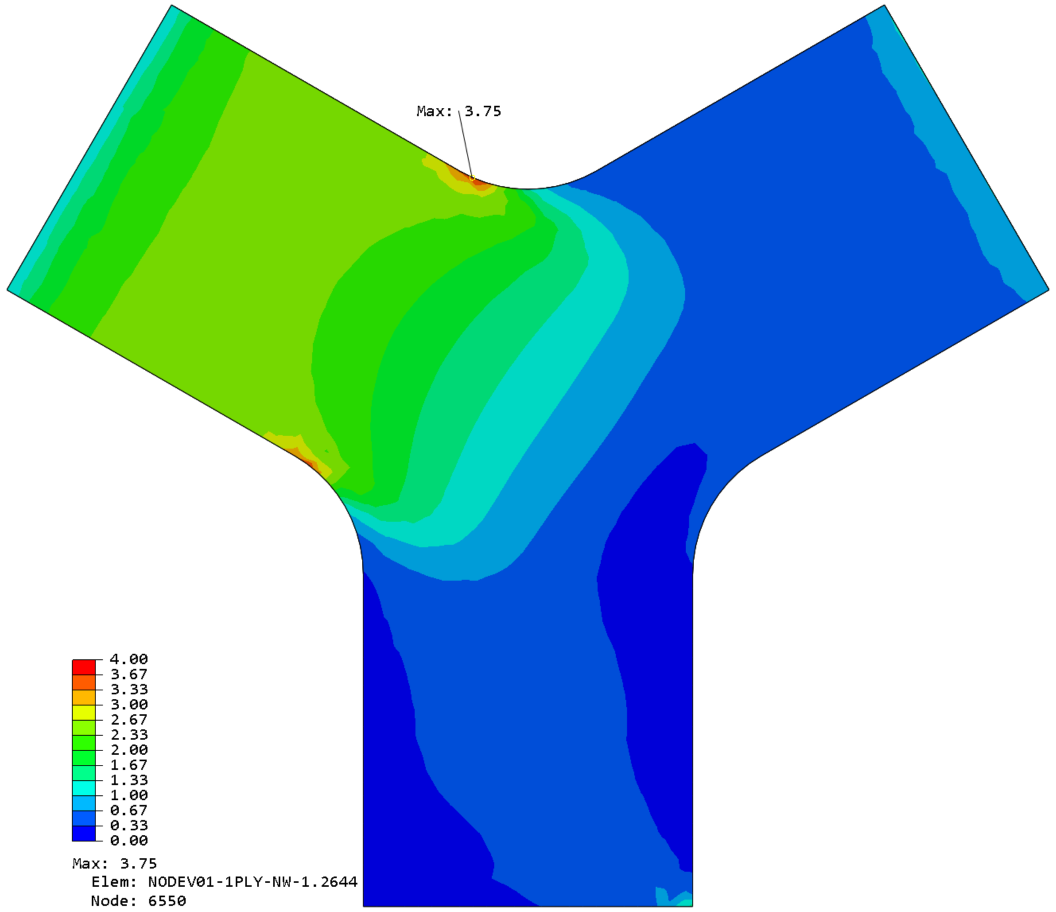


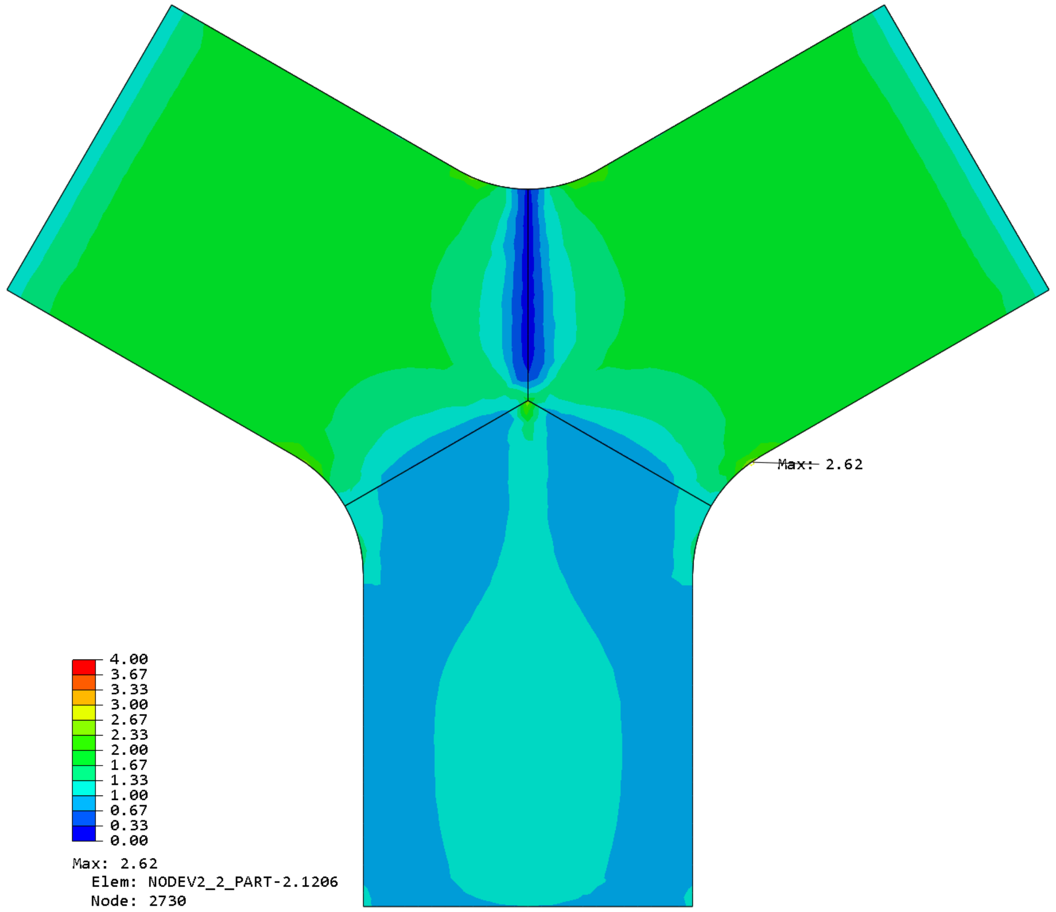
Design development

Design v1.2 and v2.2 - Compression







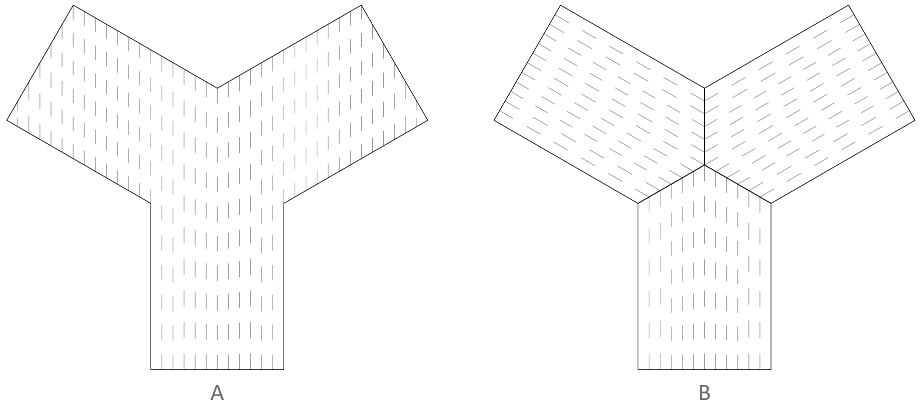


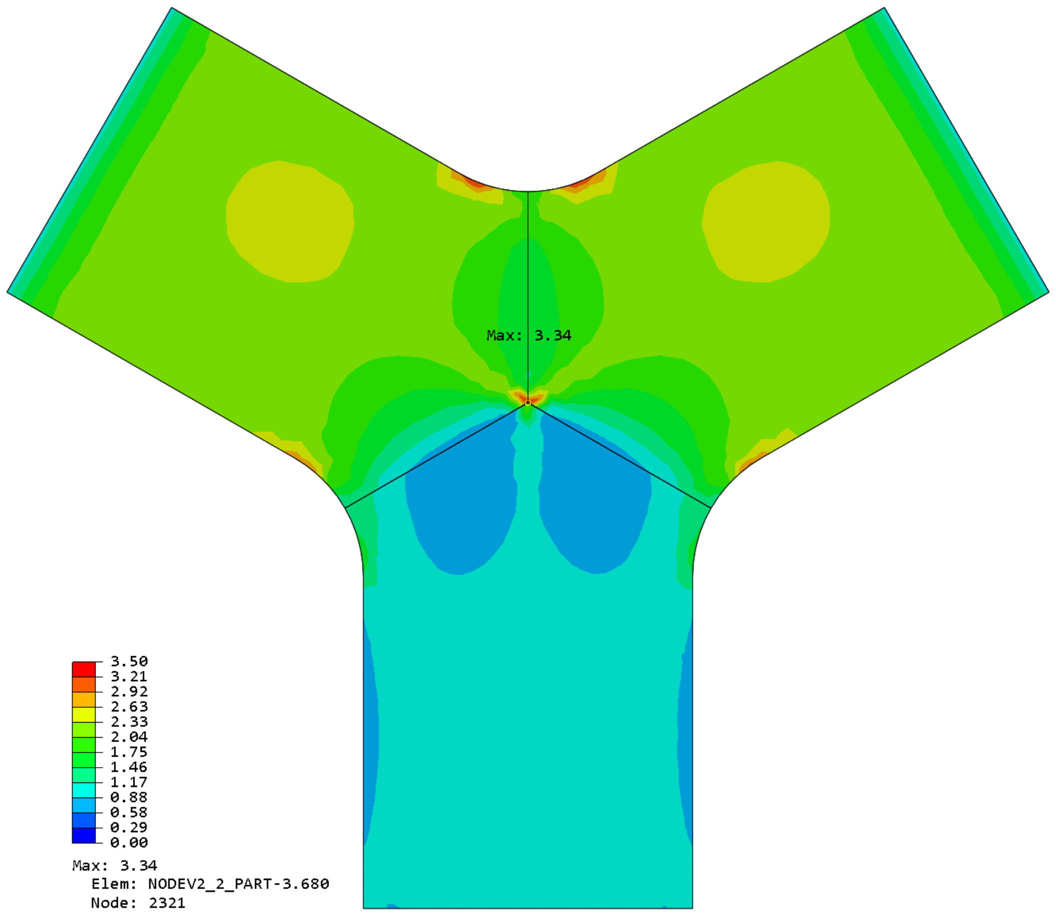
Design development

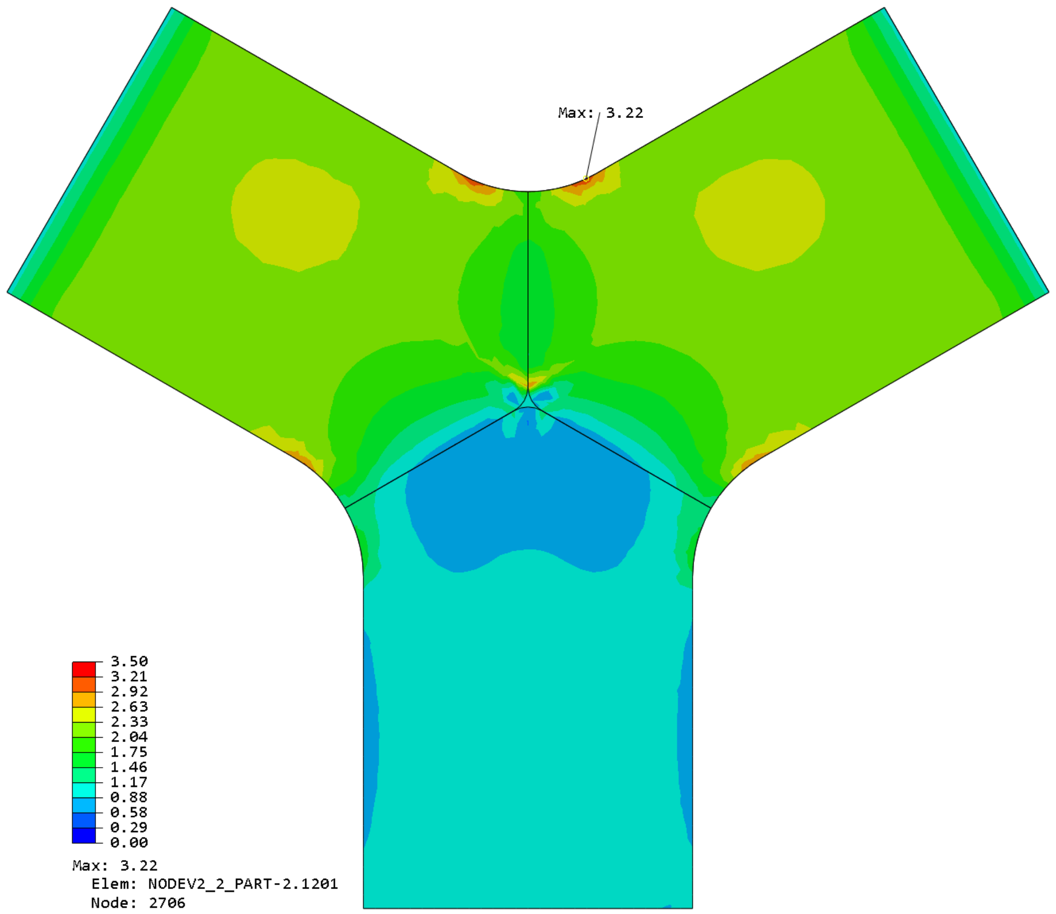
Design v2.2 and v2.3 - Compression

v2 layer structure

A-B-A





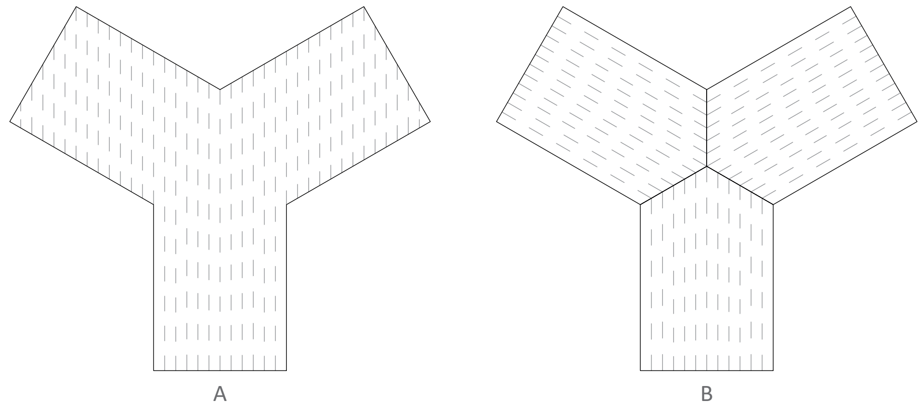


Design development

Design v2.3 and v3.3 - Compression

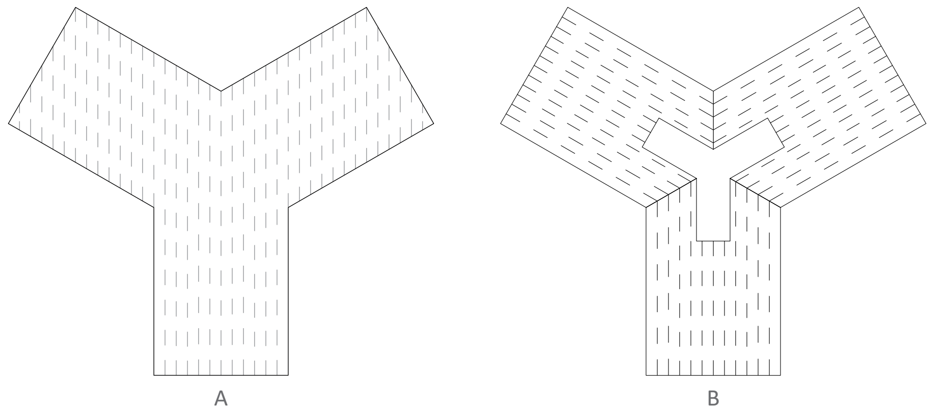
v2 layer structure

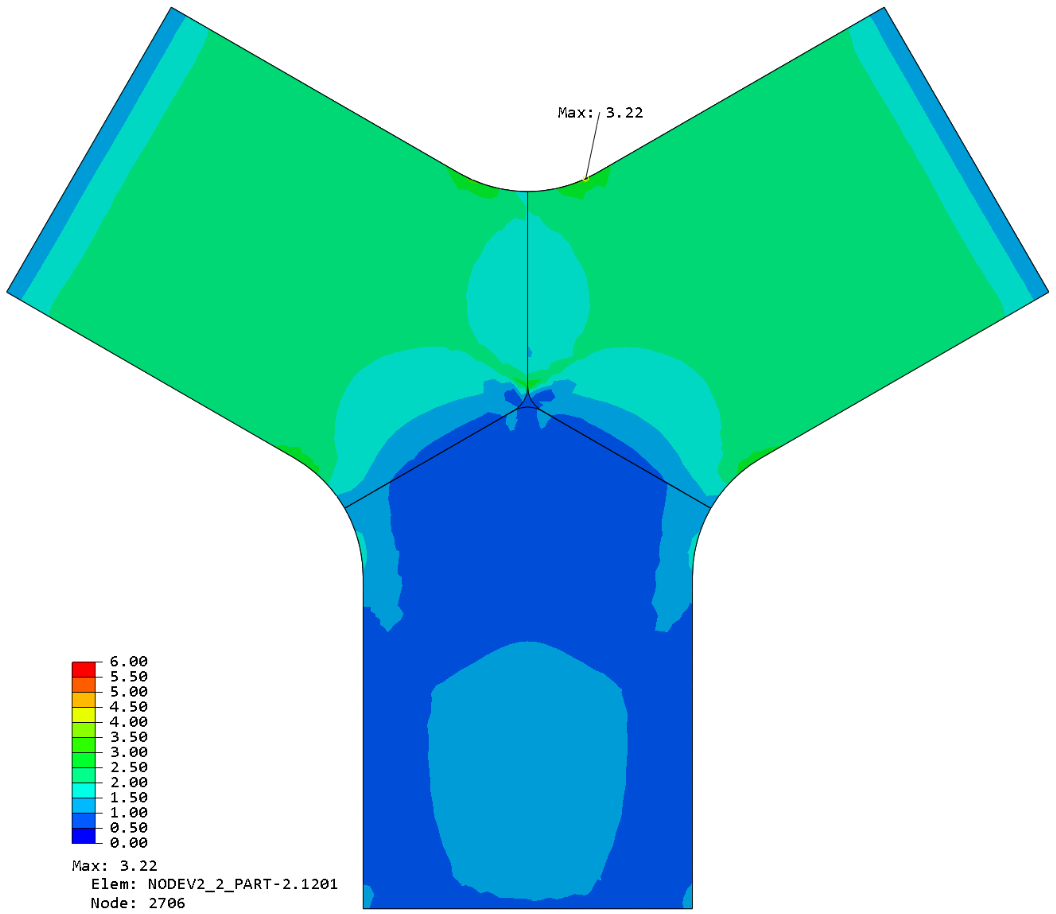
A-B-A

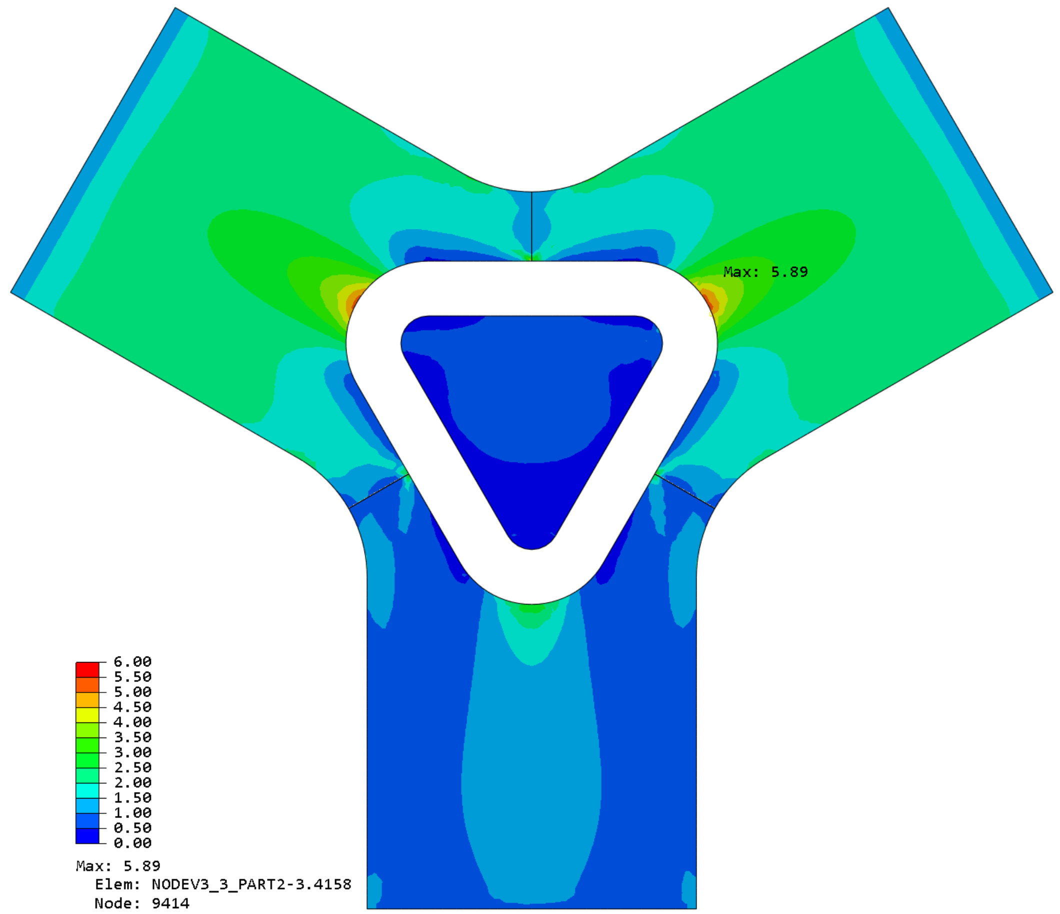


v3 layer structure

A-B-A





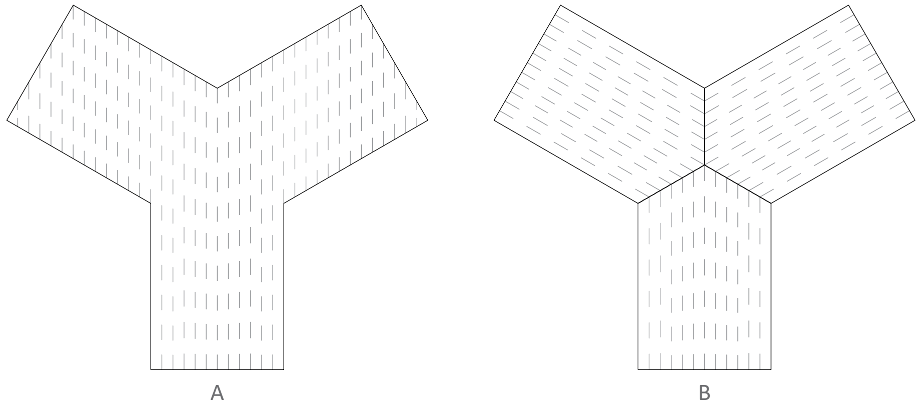


Design development

Design v2.3 and v3.3 - Tension

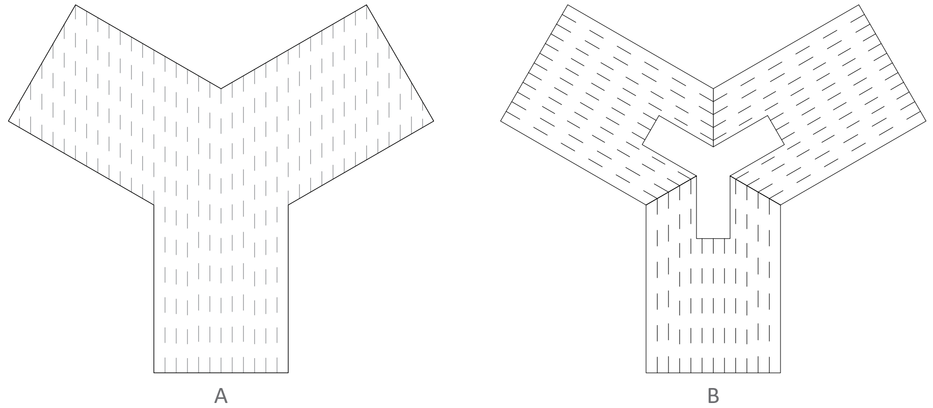
v2 layer structure

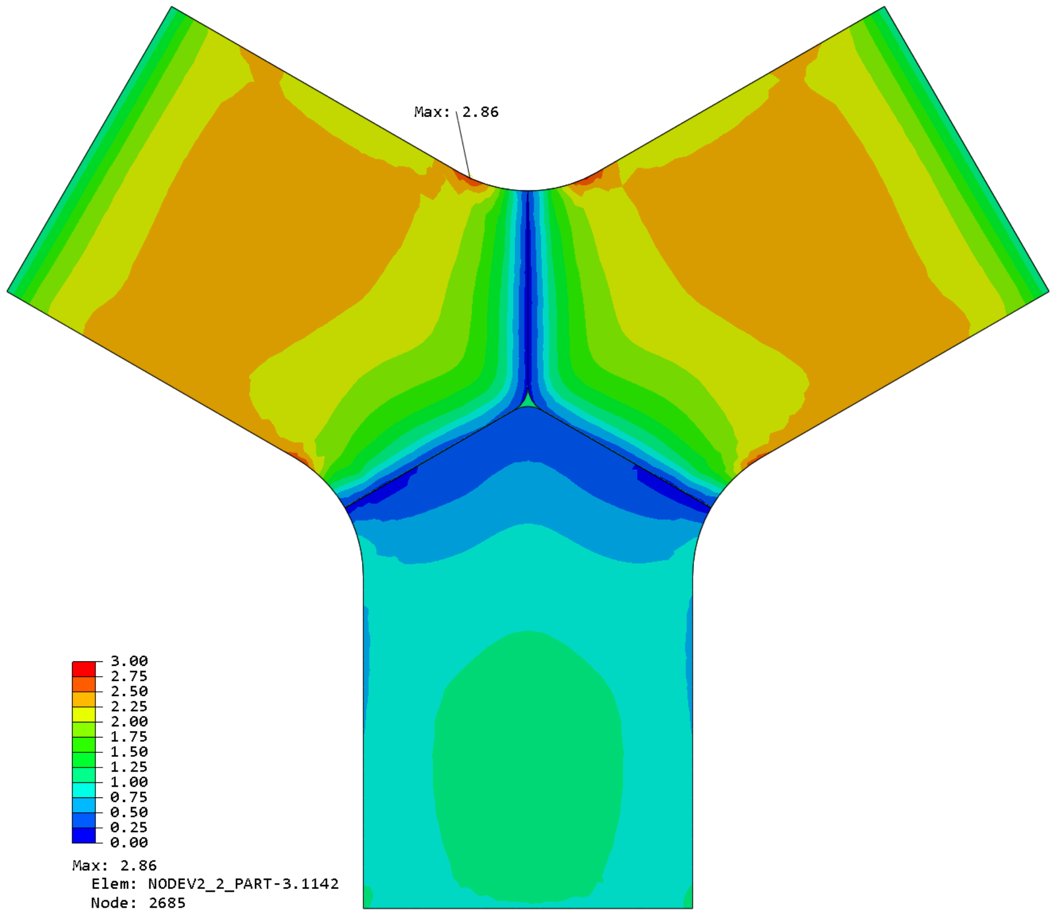
A-B-A

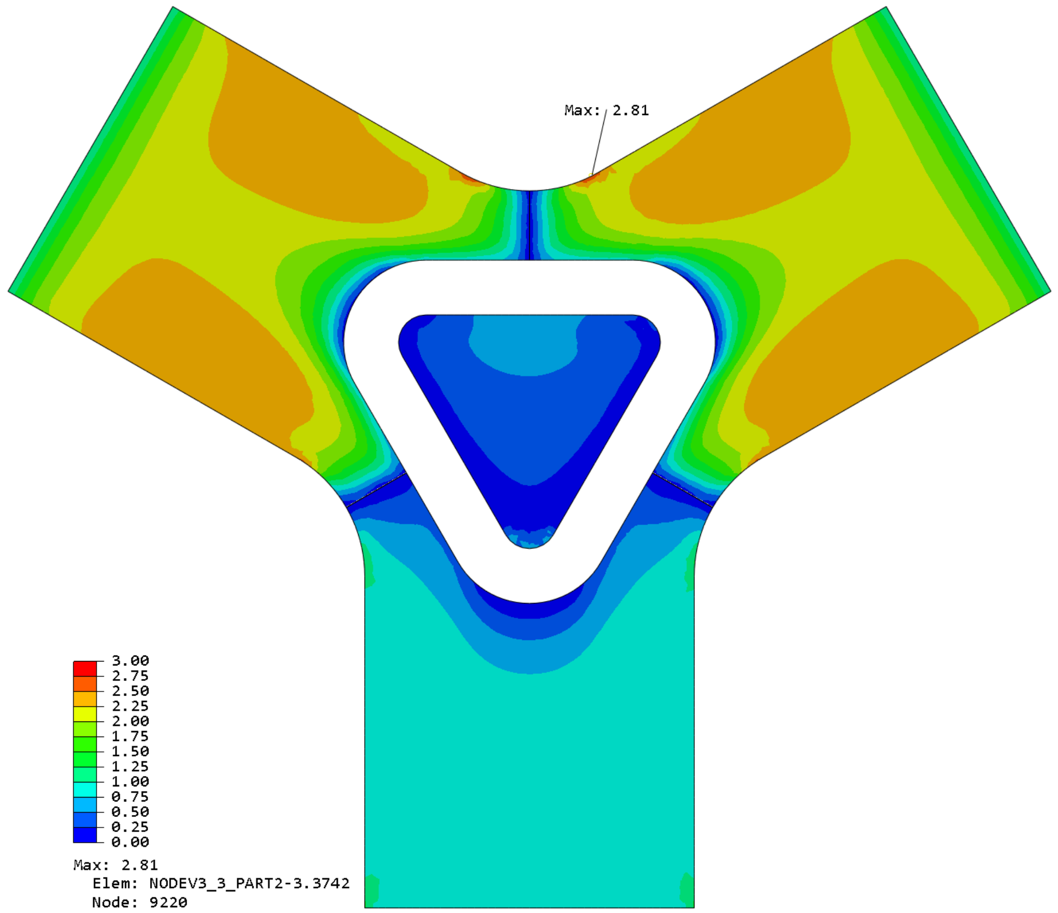


v3 layer structure

A-B-A

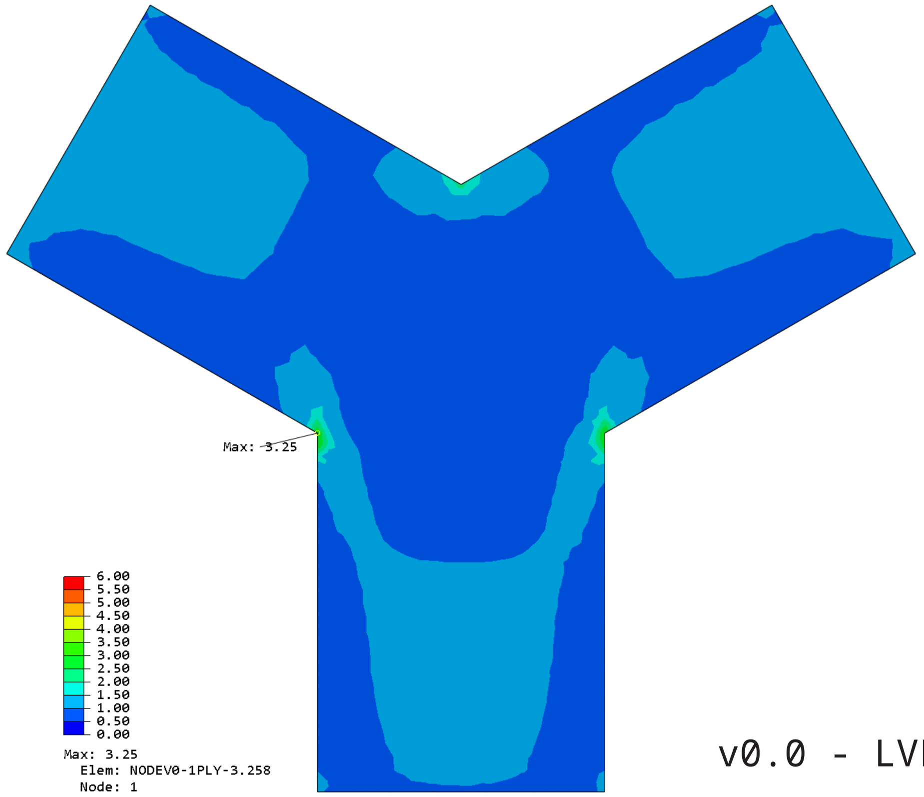




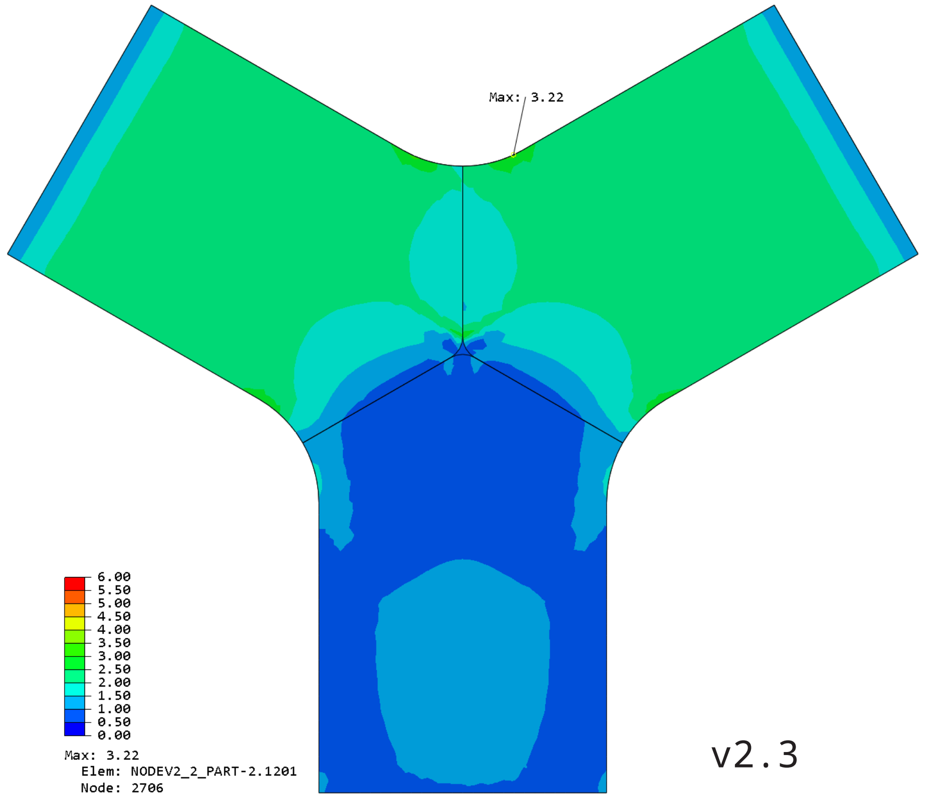


Final design

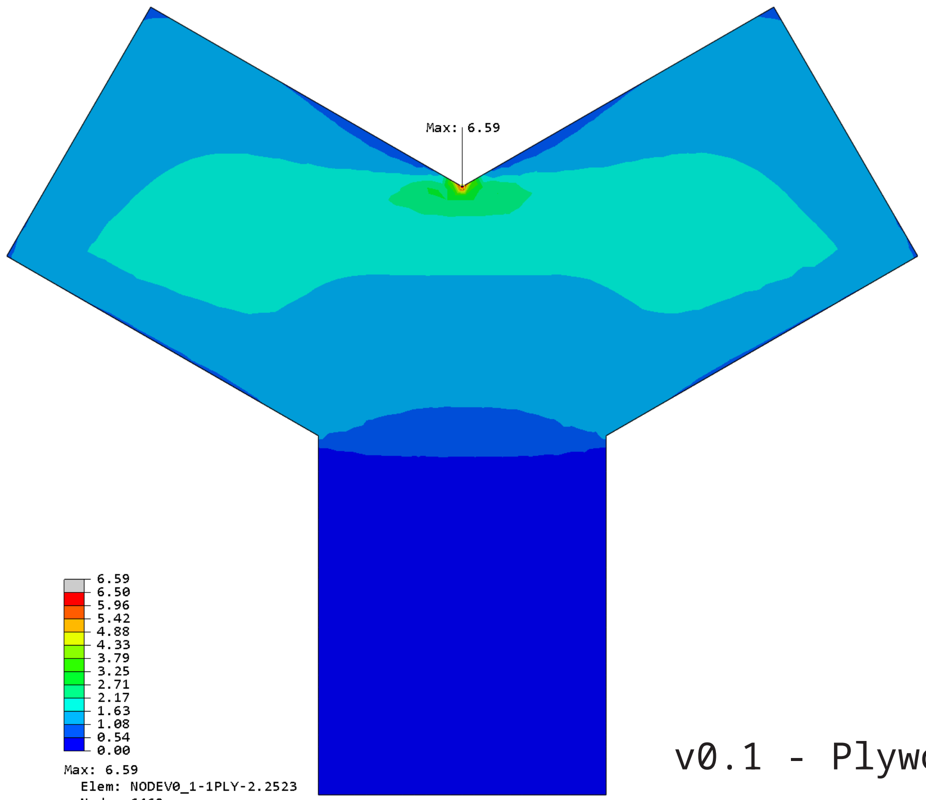
Design v2.3 and v3.3 compared to LVL and plywood



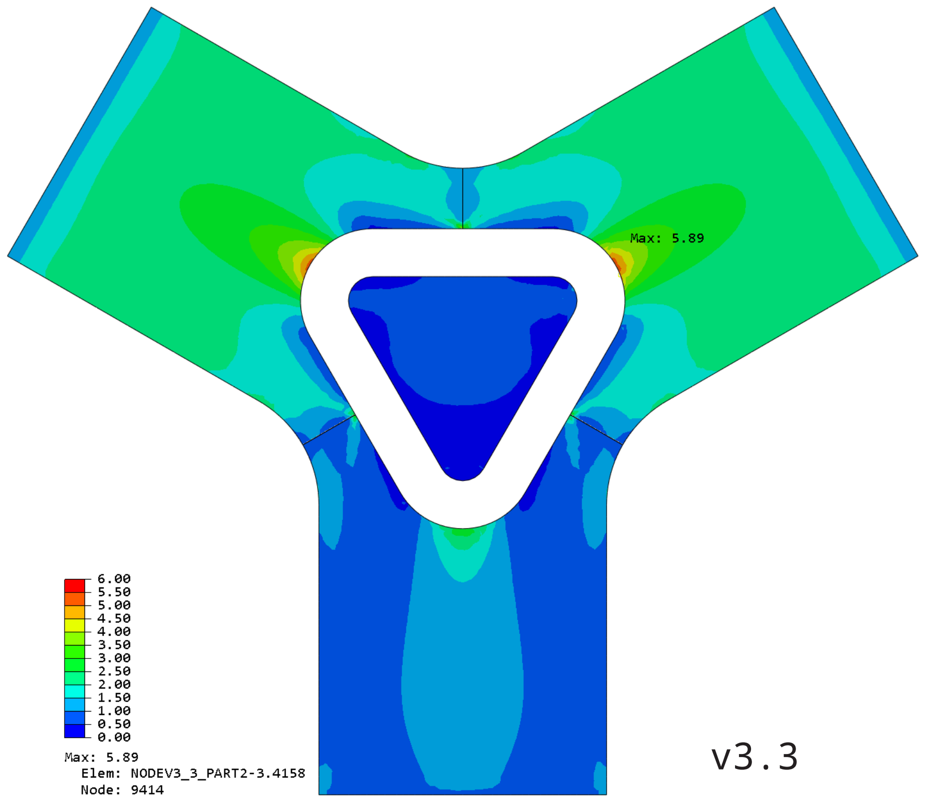
v0.0 - LVL



v2.3



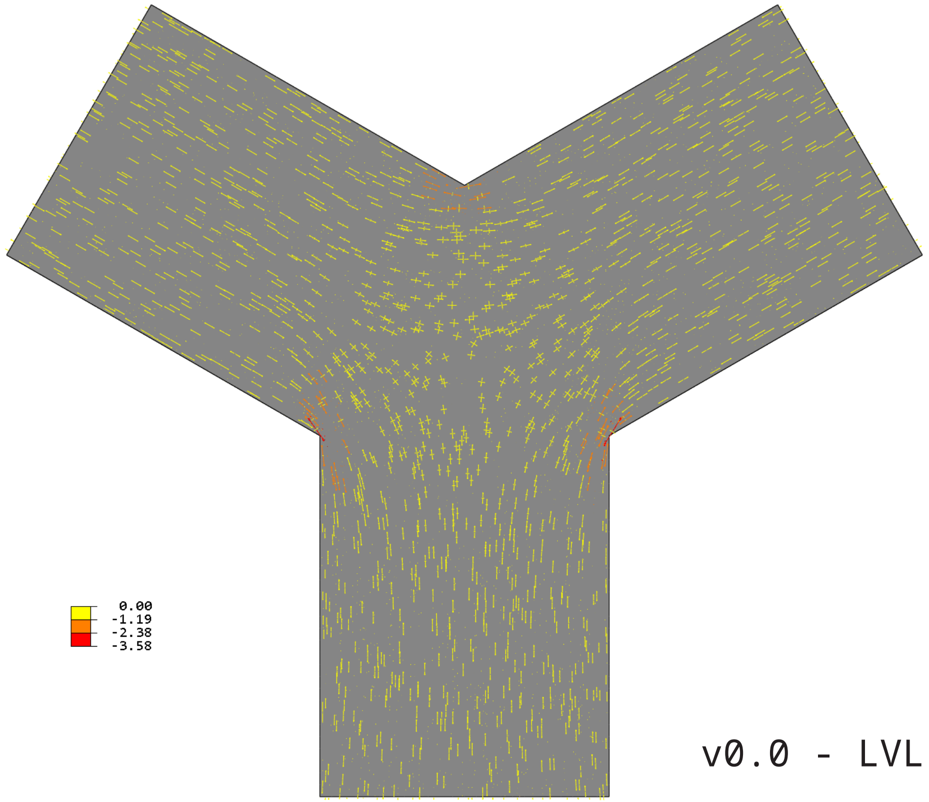
v0.1 - Plywood



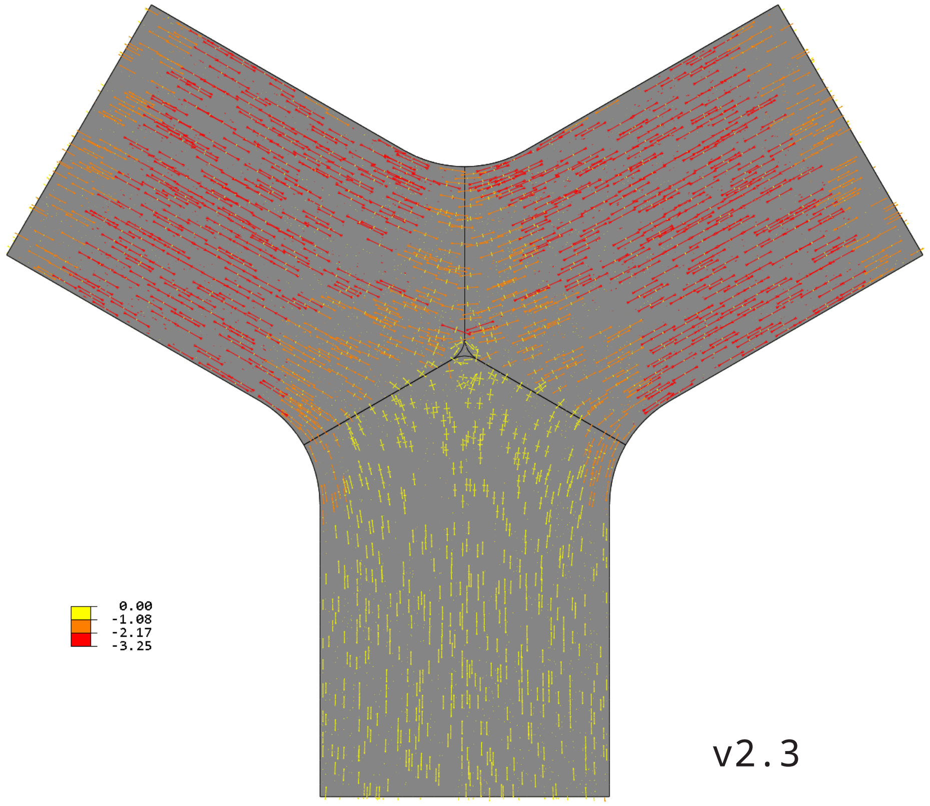
v3.3

Final design

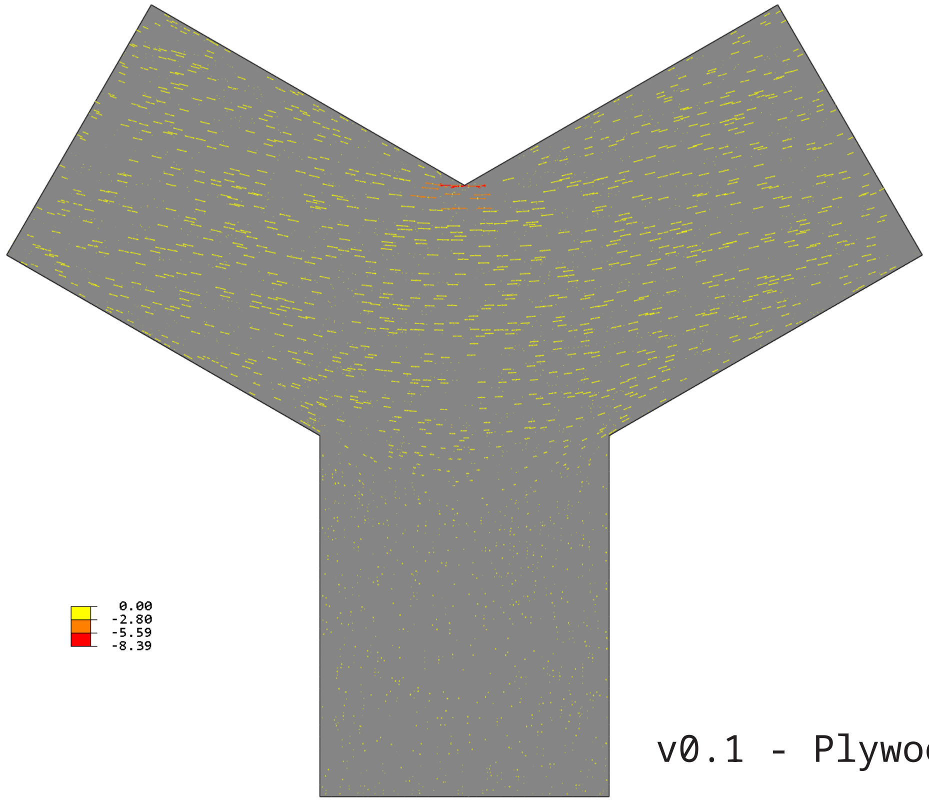
Stress directions



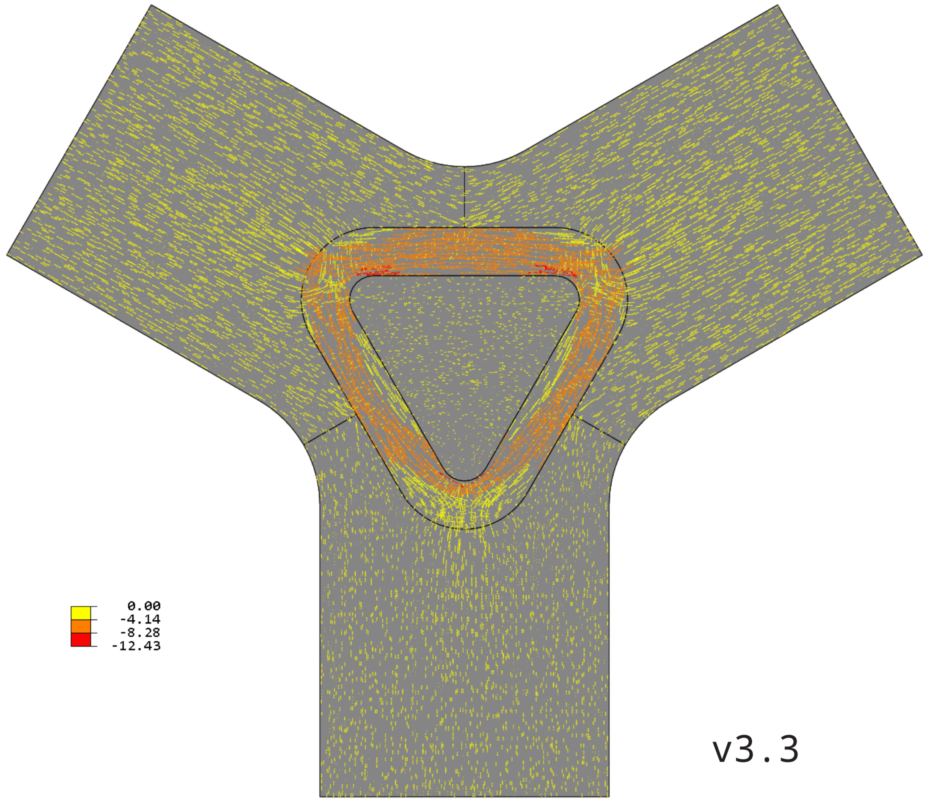
v0.0 - LVL



v2.3



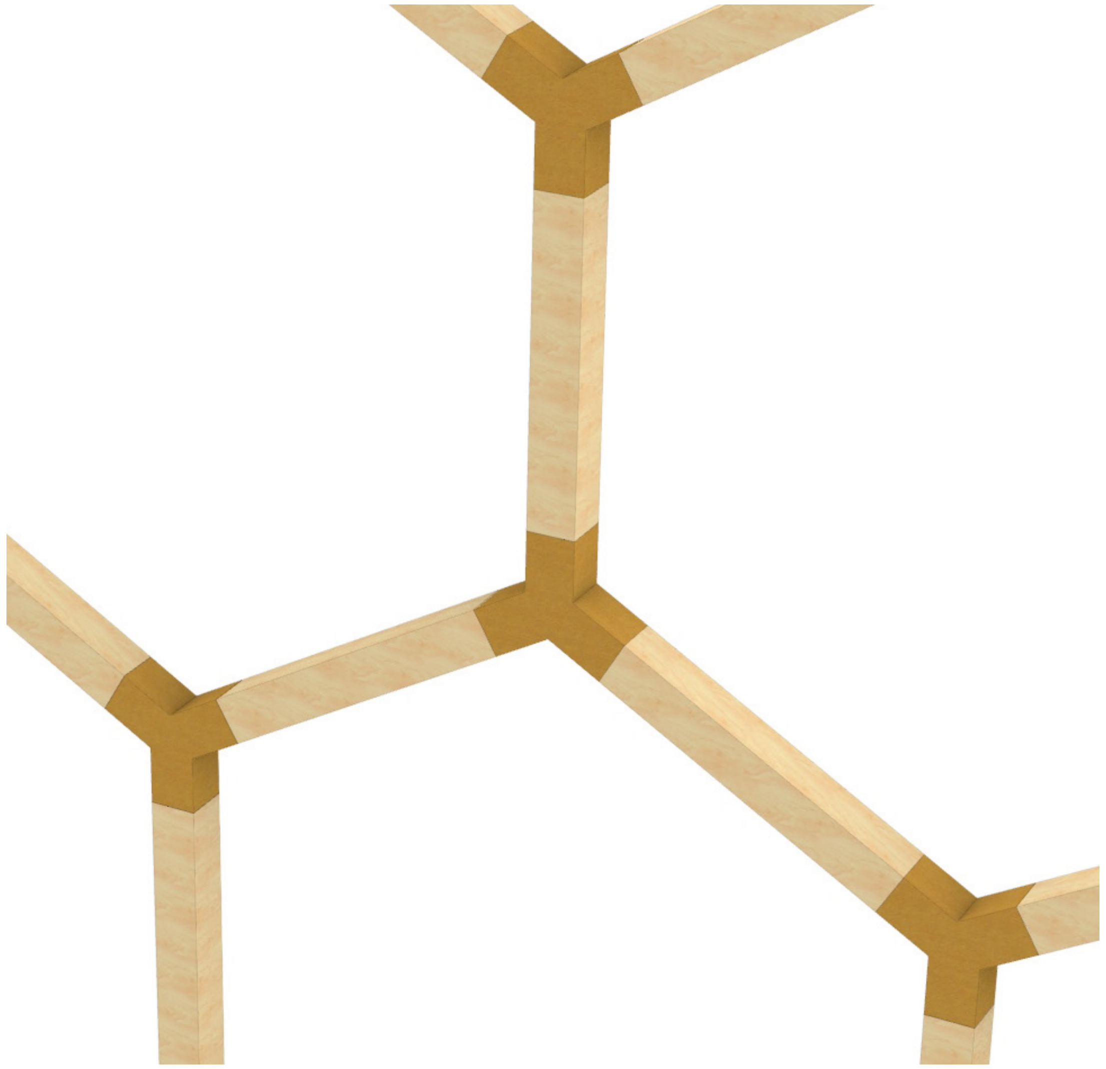
v0.1 - Plywood



v3.3

Final design

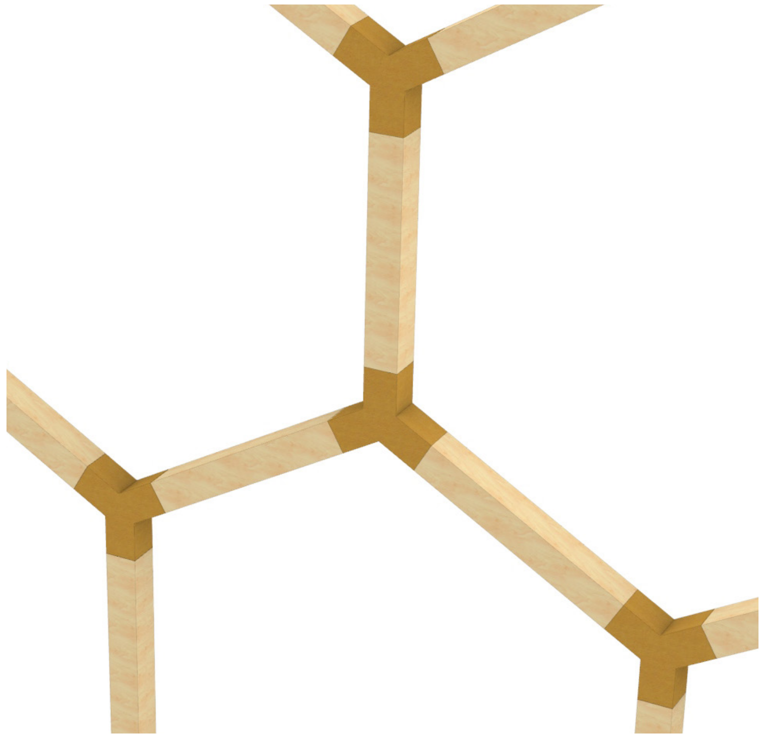
Optimising the connection



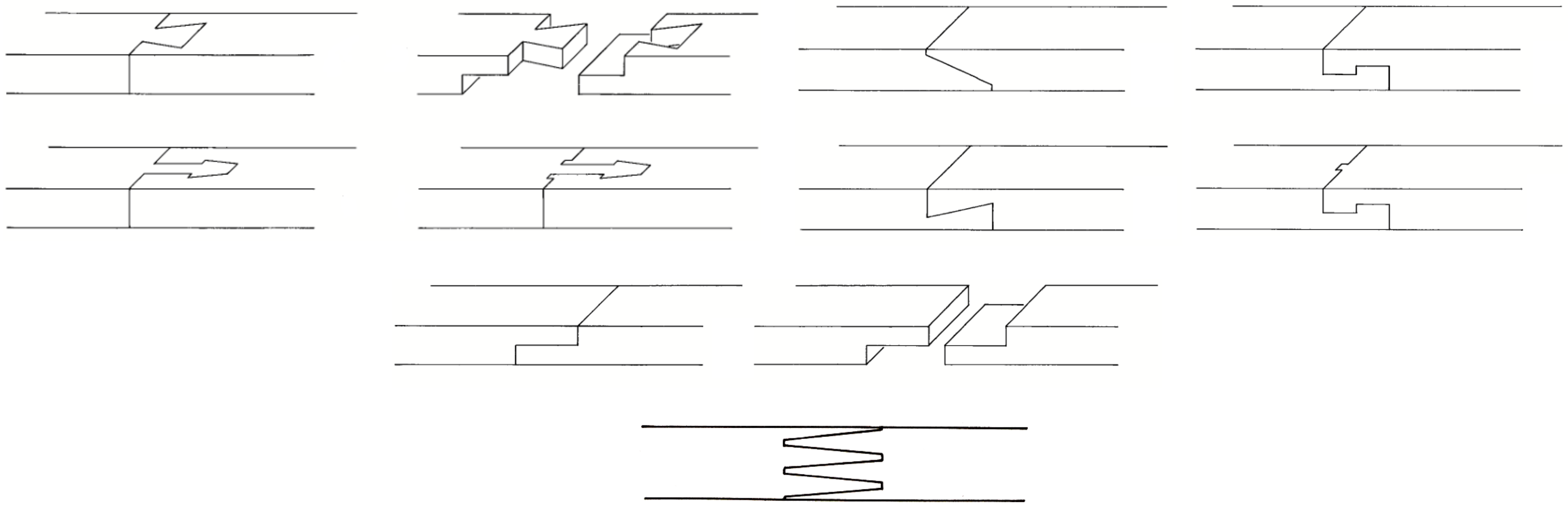
Butt-jointed pieces of wood (Zwerger, 1997)

Final design

Optimising the connection



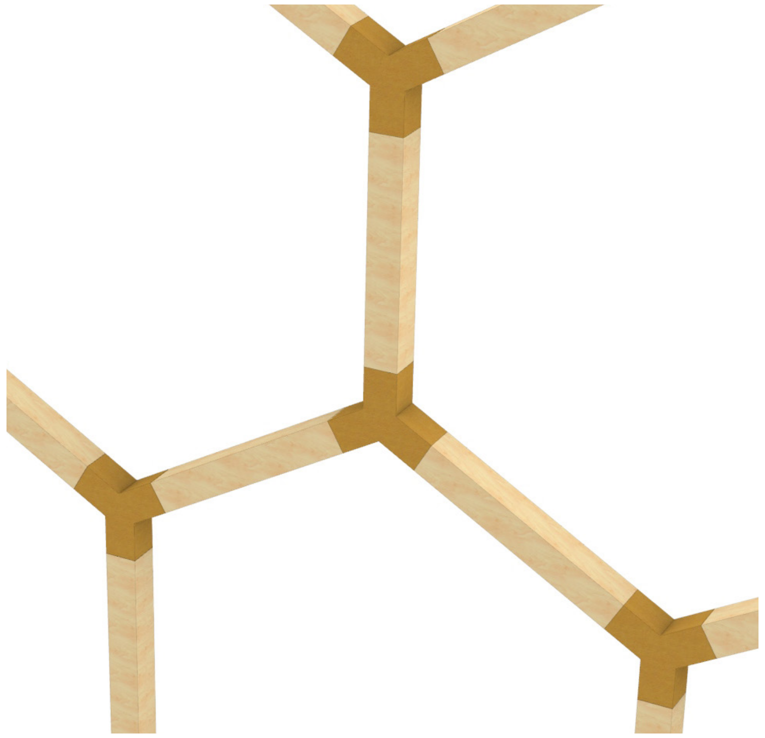
Butt-jointed pieces of wood (Zwerger, 1997)



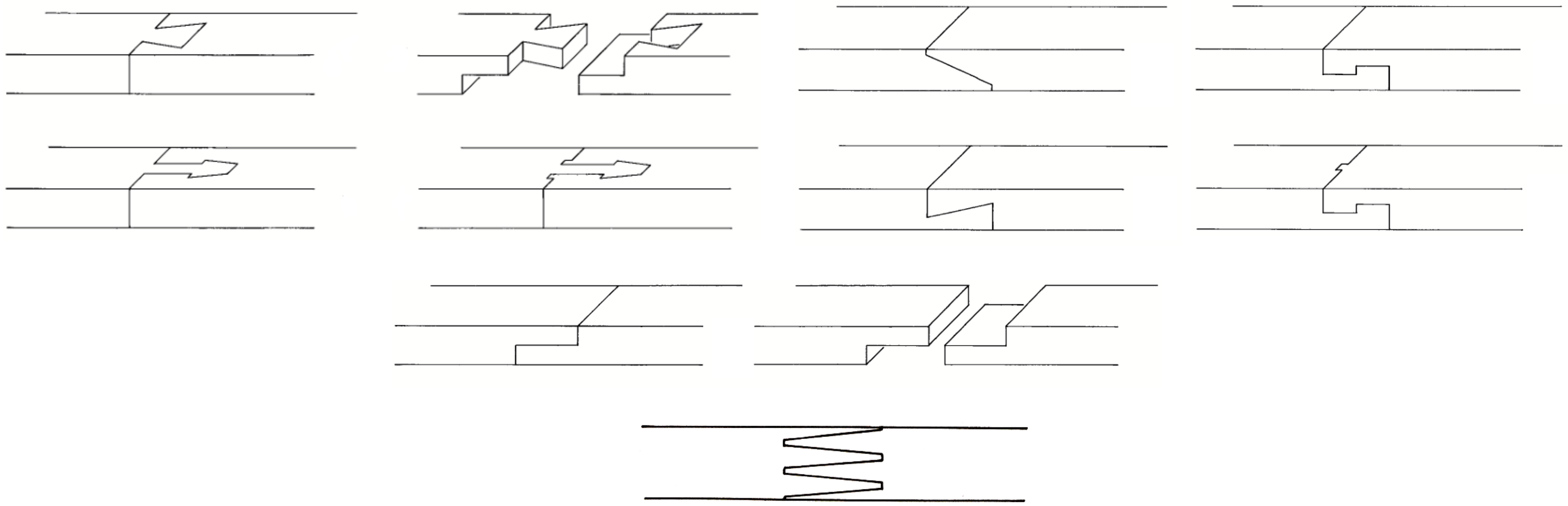
Various types of connections (Zwerger, 1997; Martin, 1977)

Final design

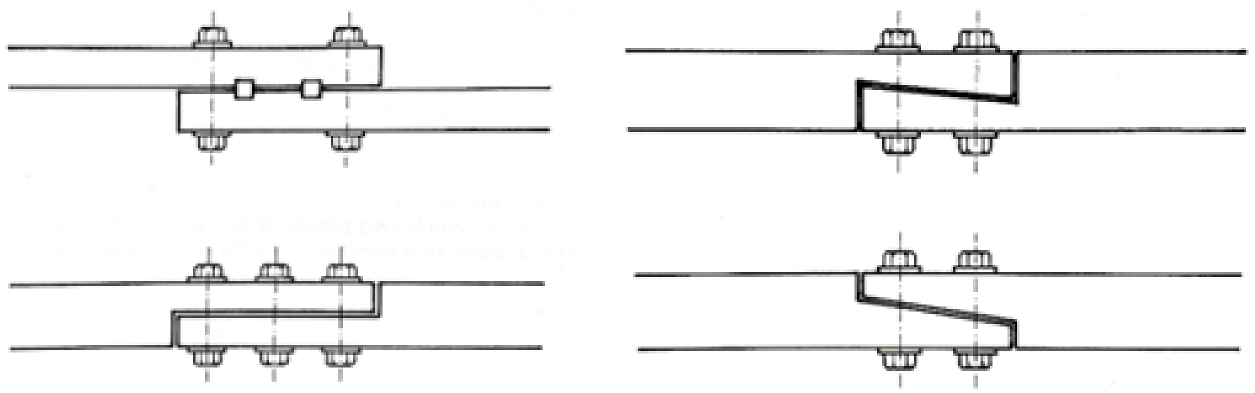
Optimising the connection



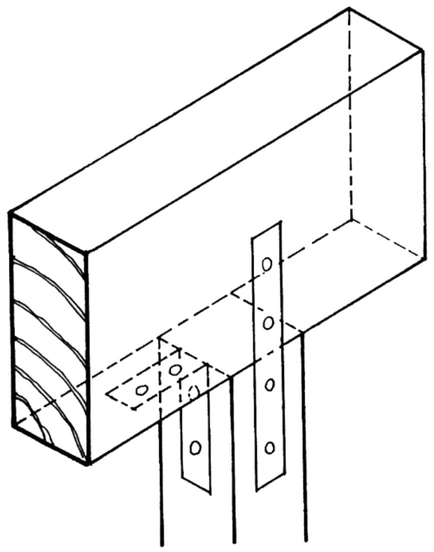
Butt-jointed pieces of wood (Zwerger, 1997)



Various types of connections (Zwerger, 1997; Martin, 1977)



Bolted lapped joints (Martin, 1977)



Example of an external connector (Martin, 1977)

Final design

Optimising the connection

> Design study by Kromoser et al. (2021)

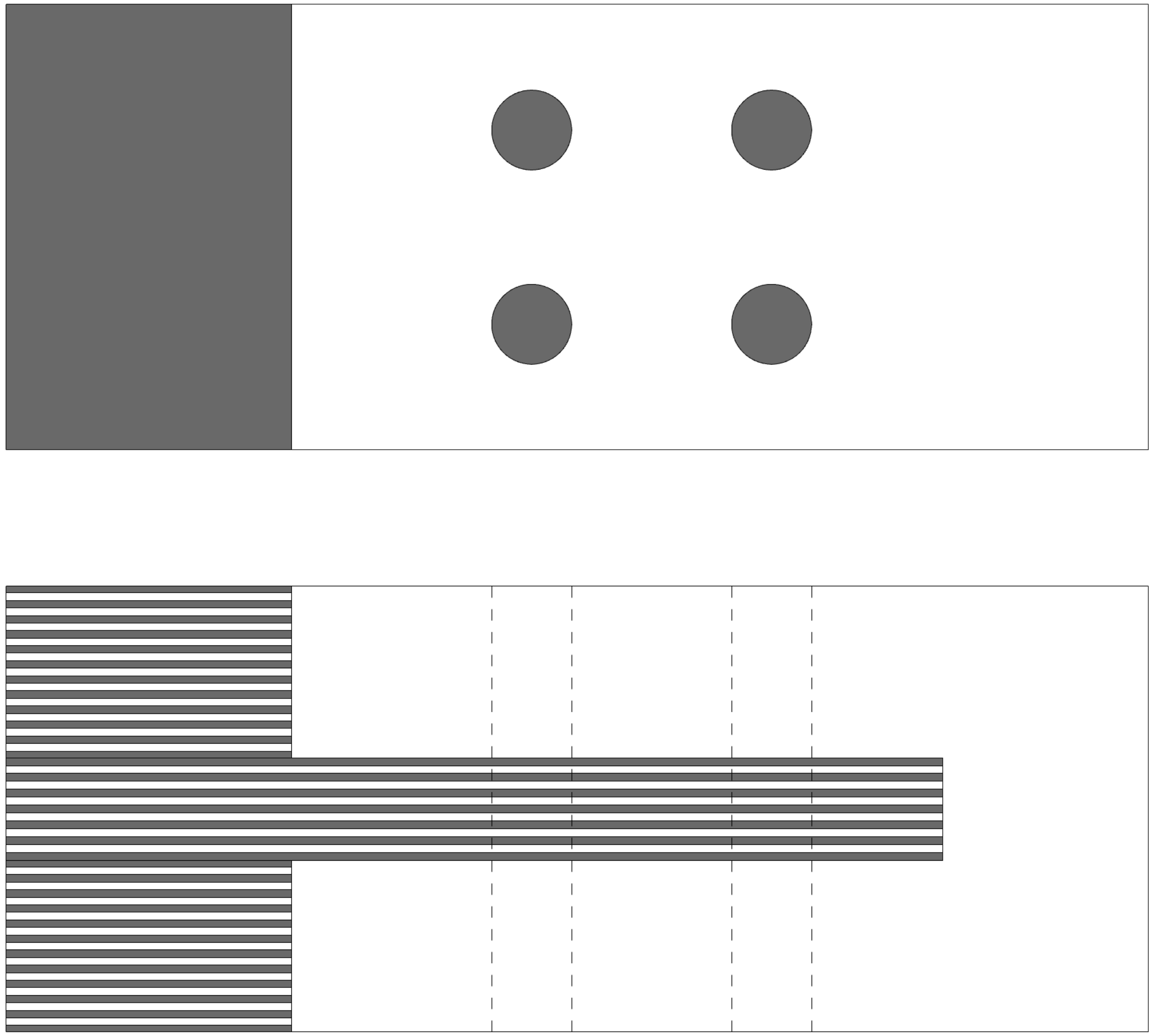
> Completely wooden load bearing structure

Wooden load bearing structure with wooden nodes (Kromoser et al., 2021)

Final design

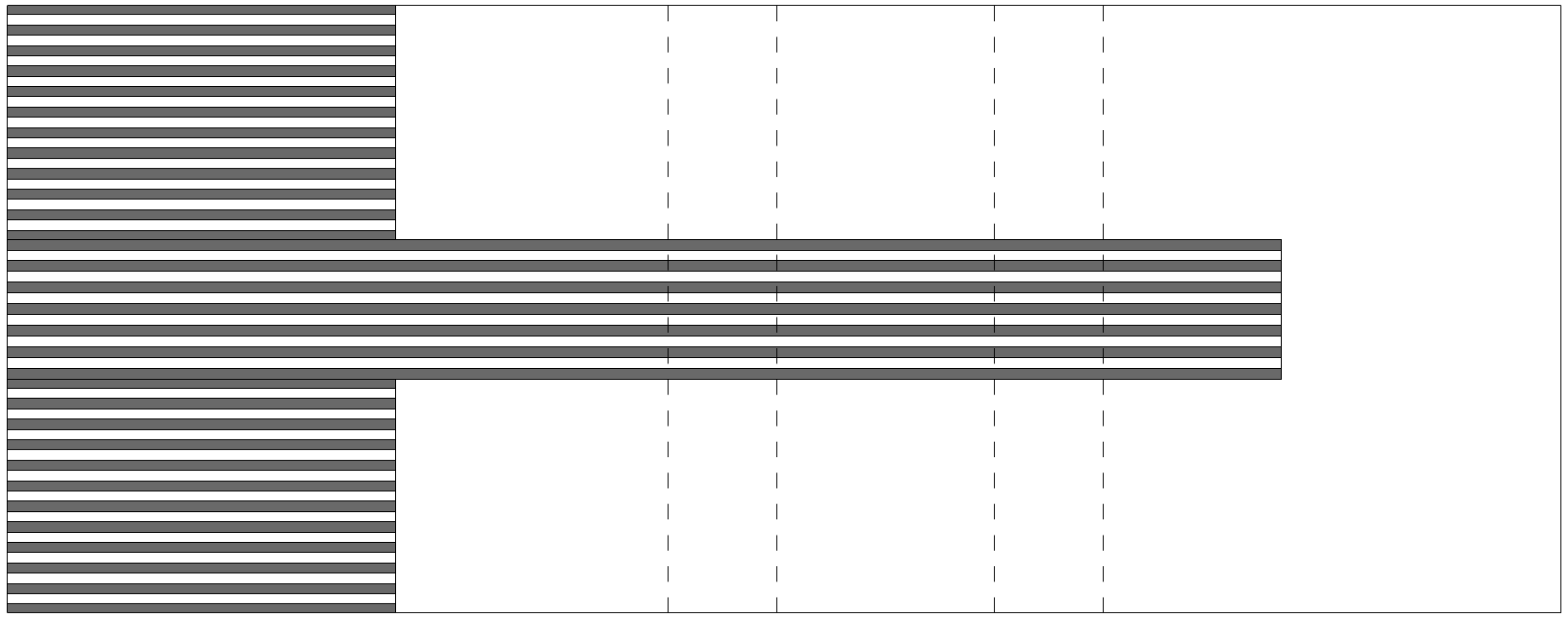
Optimising the connection

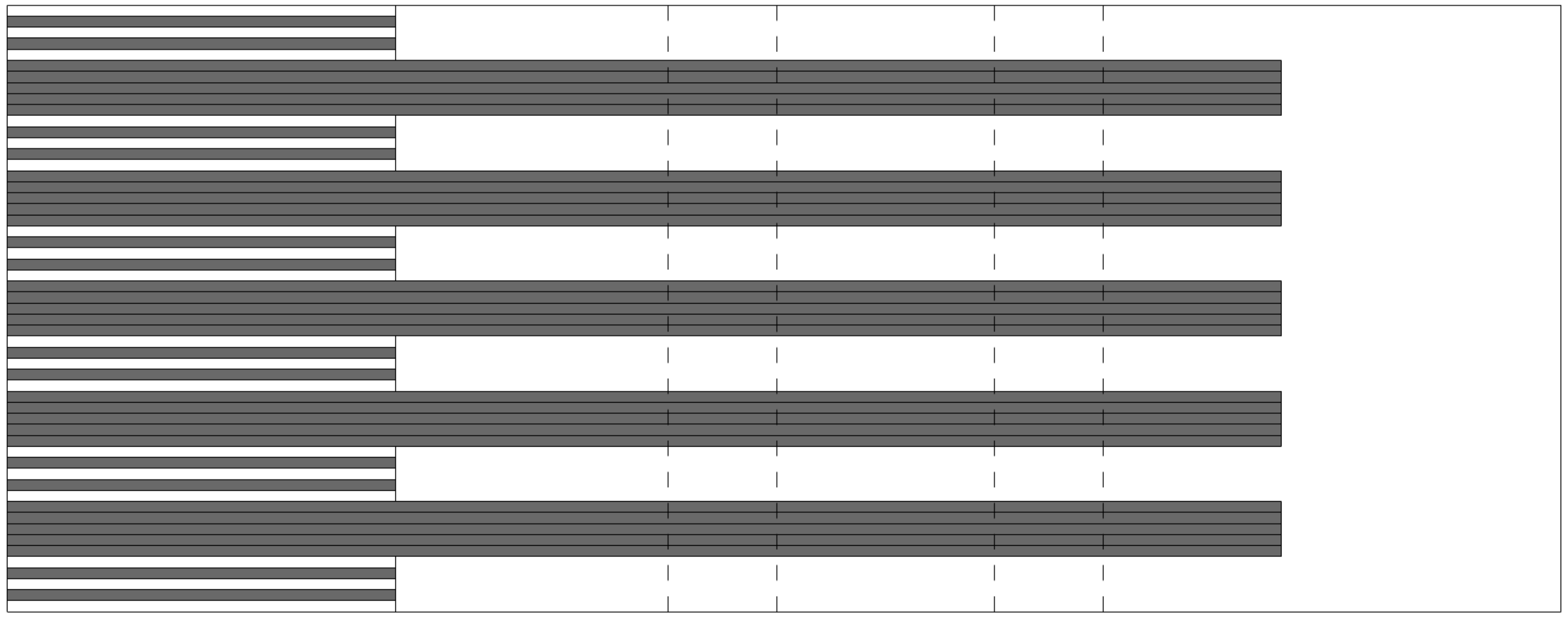
Wooden connection node (Kromoser et al., 2021)



Final design

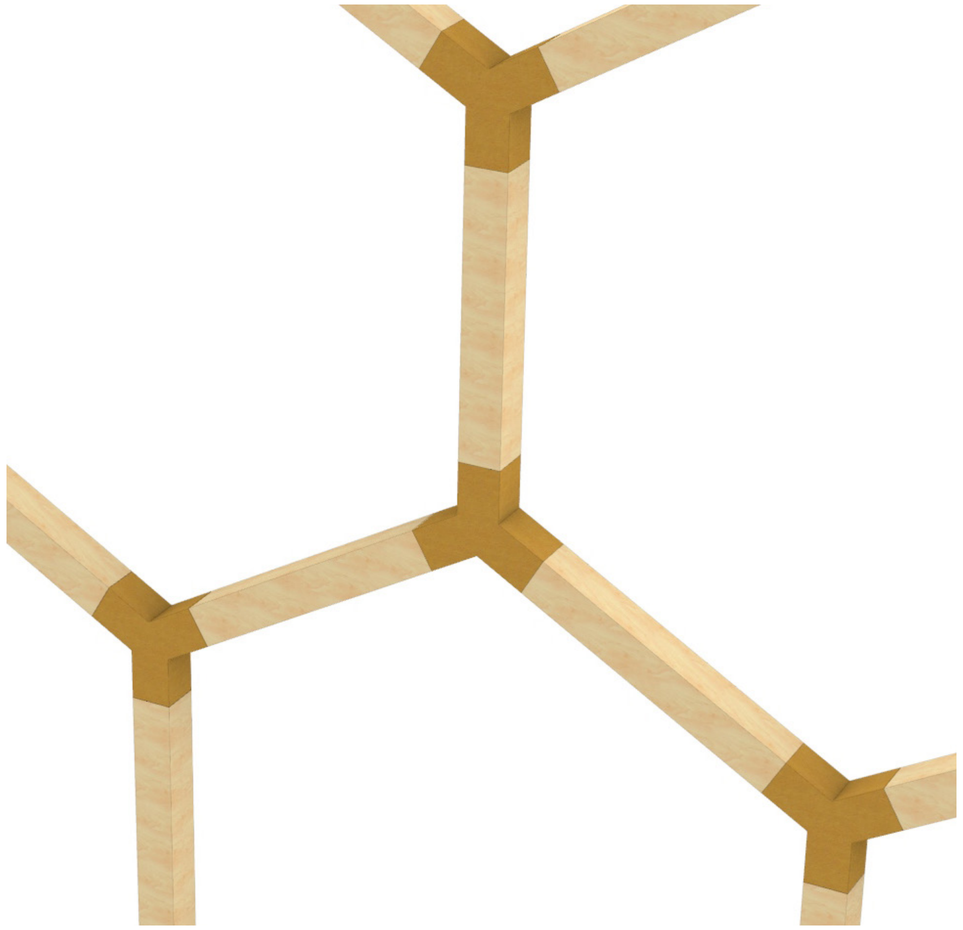
Optimising the connection

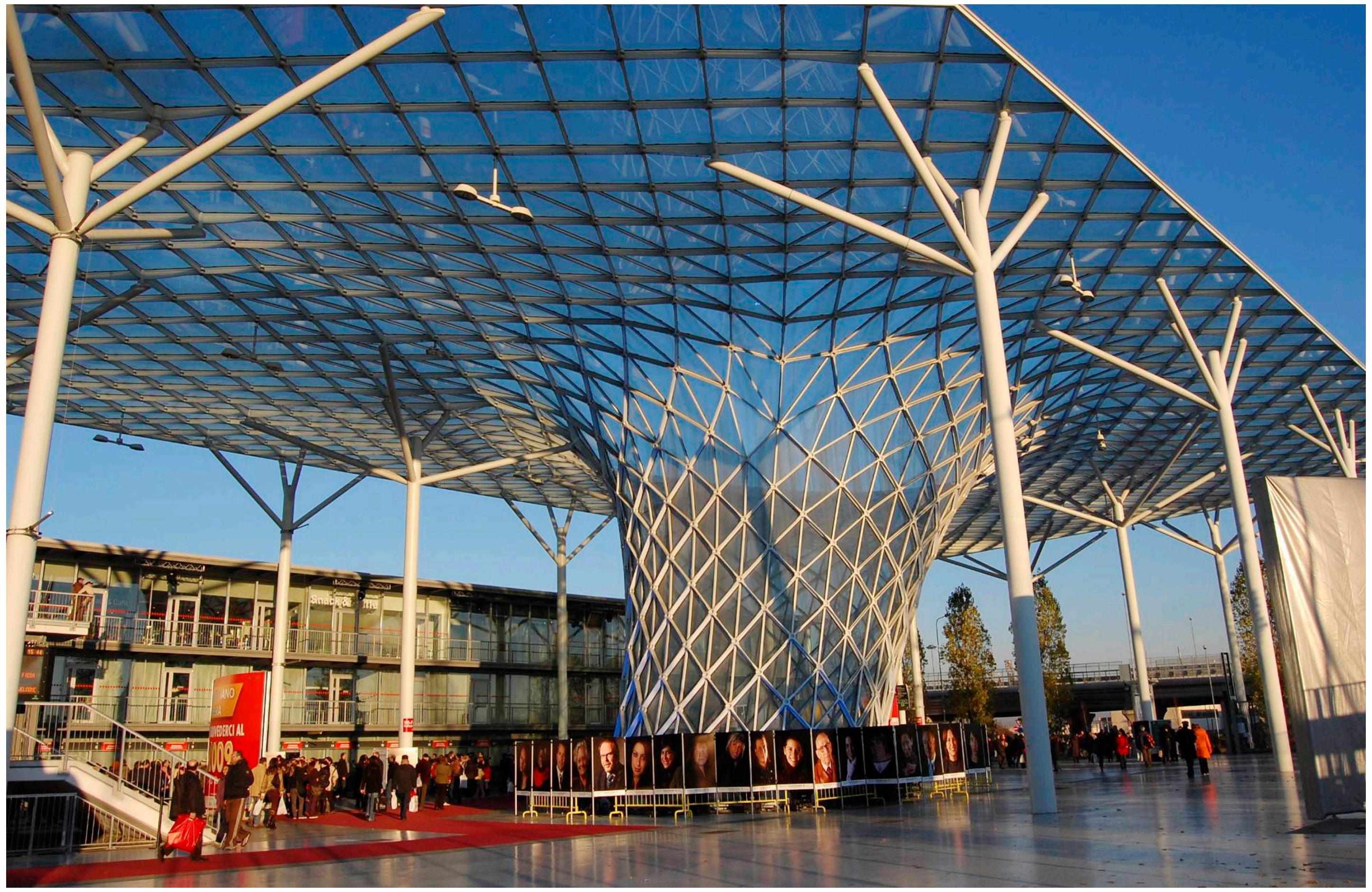




Final design

From 2D to 3D

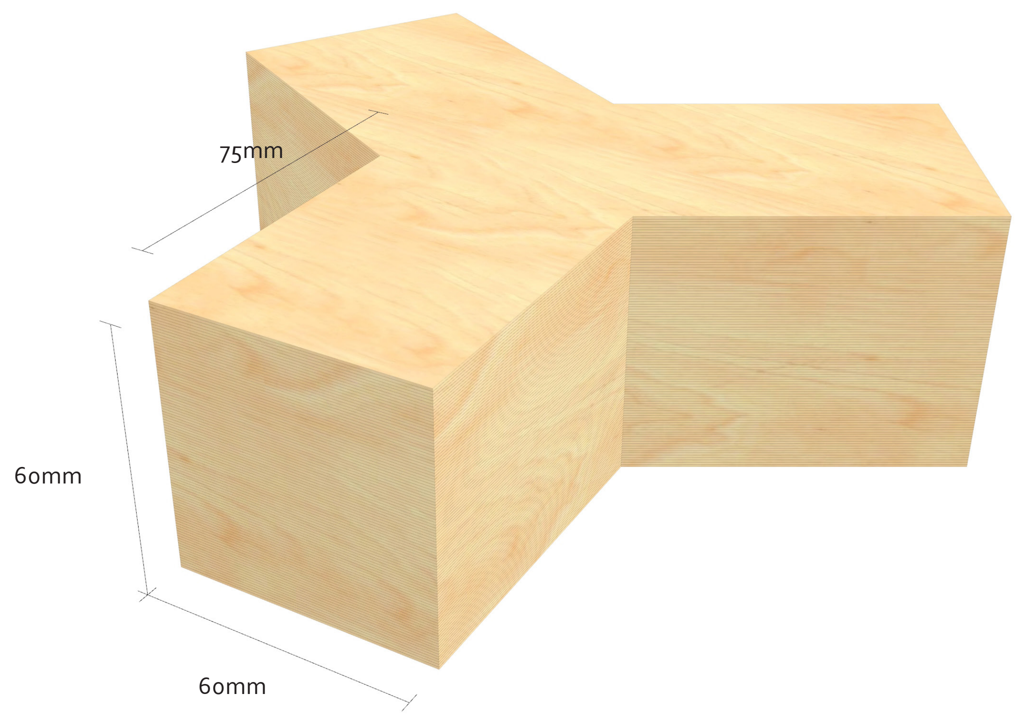


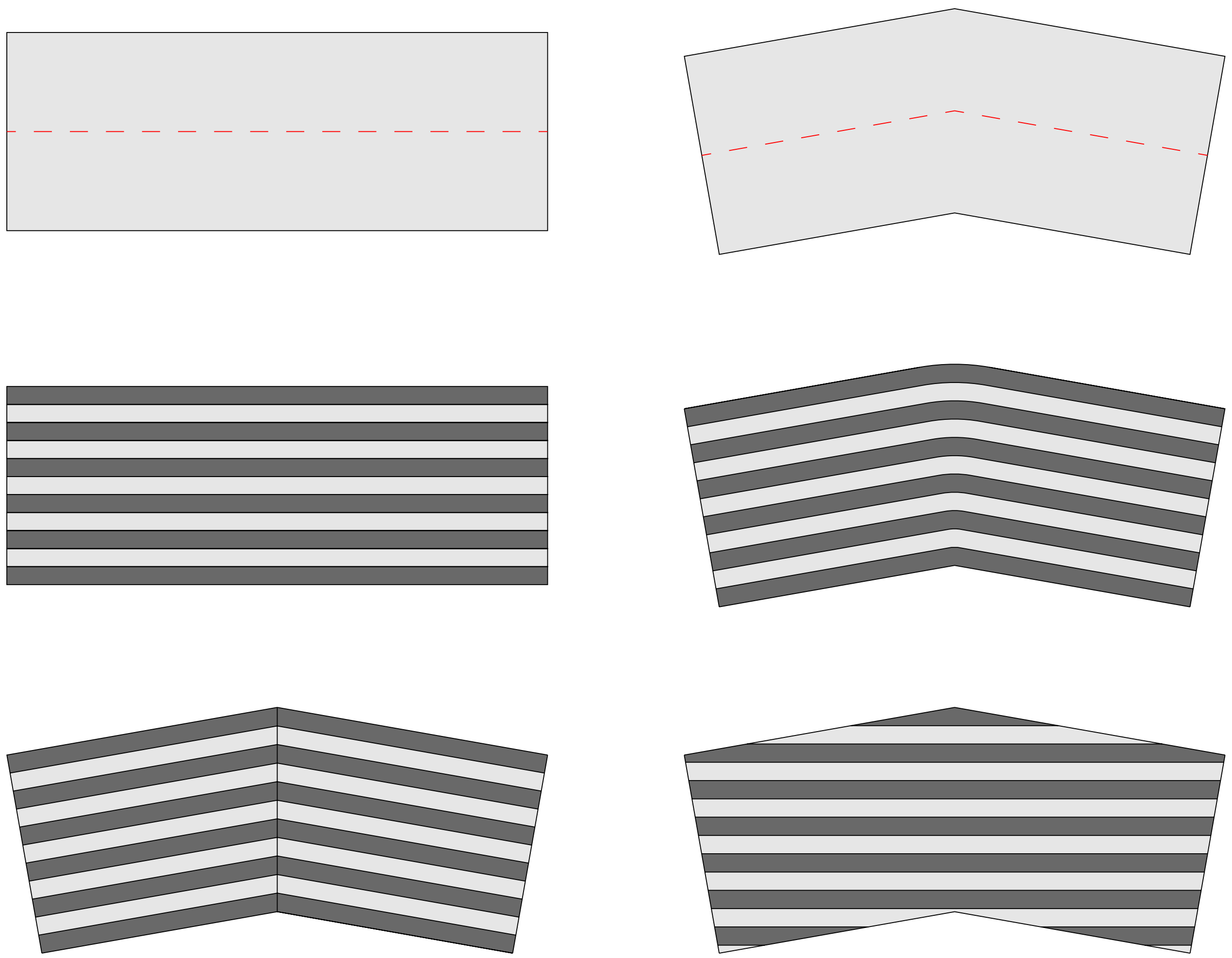


The New Fair, Milan (Itinari, 2019)

Final design

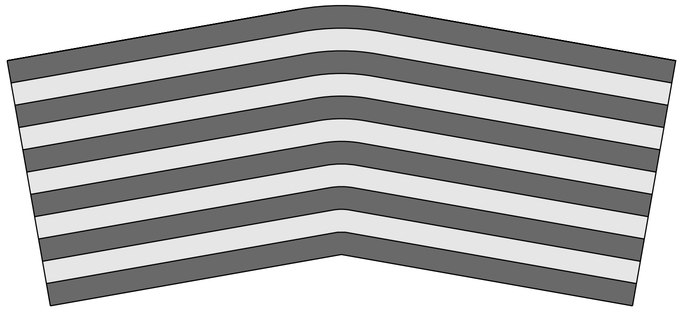
From 2D to 3D

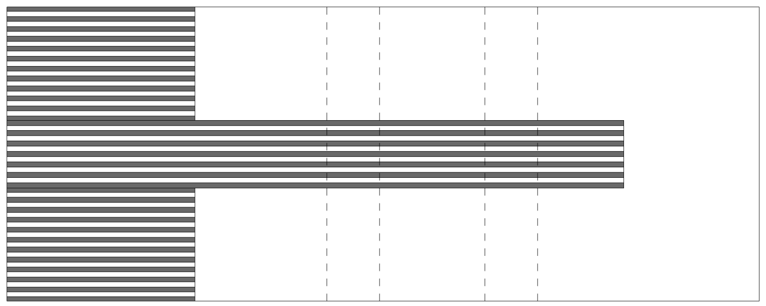


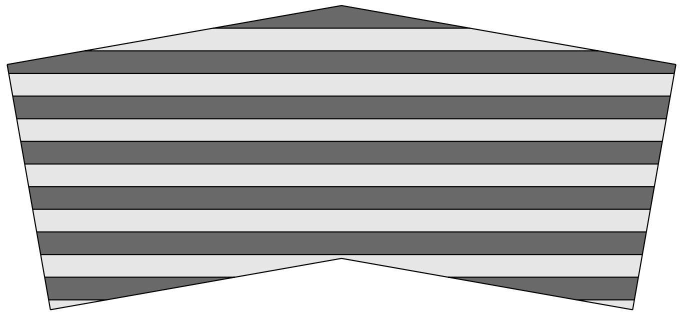


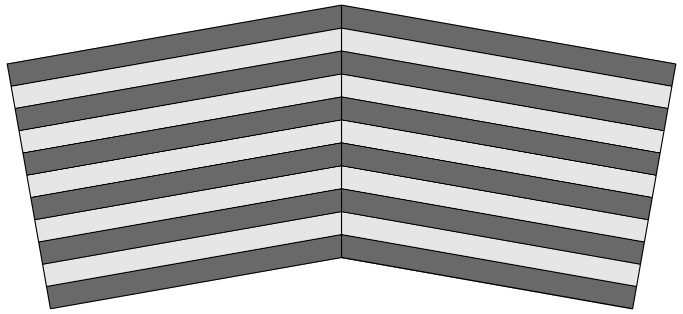
Final design

From 2D to 3D



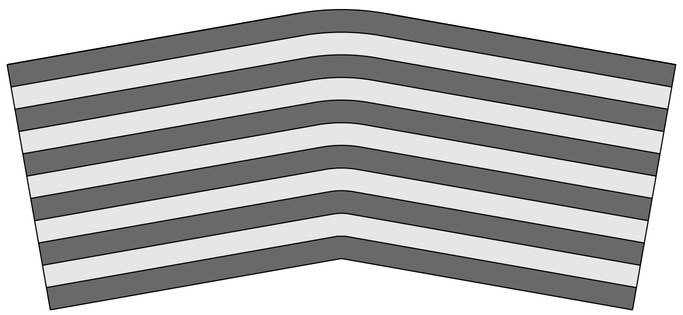


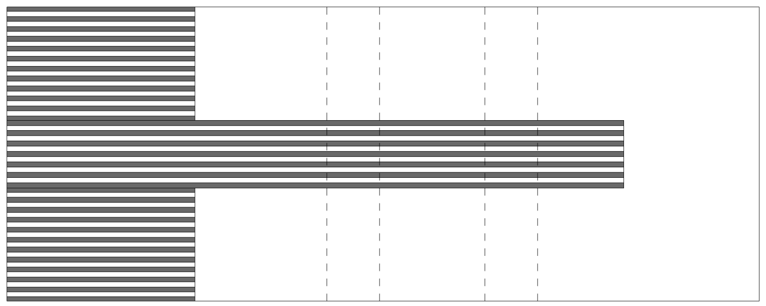


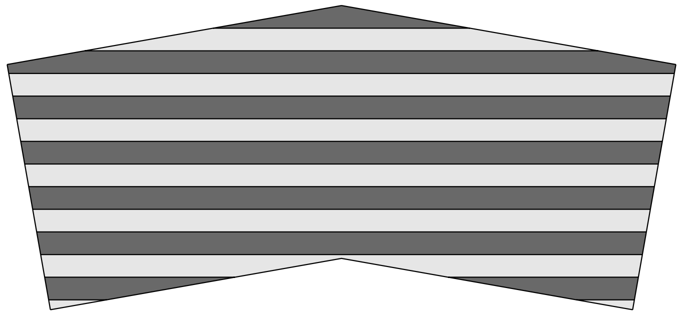


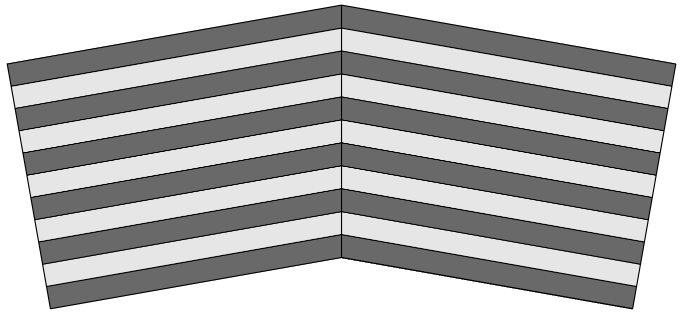
Final design

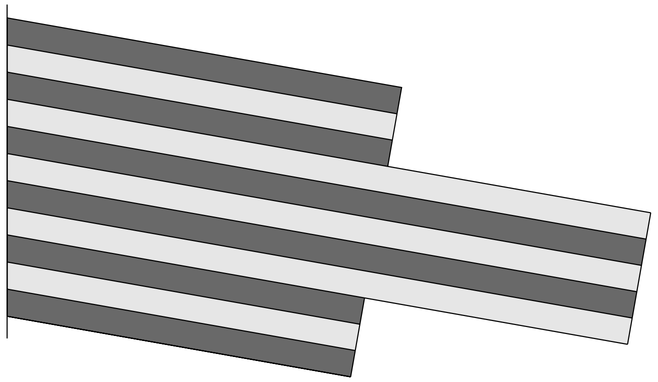
From 2D to 3D











Final design

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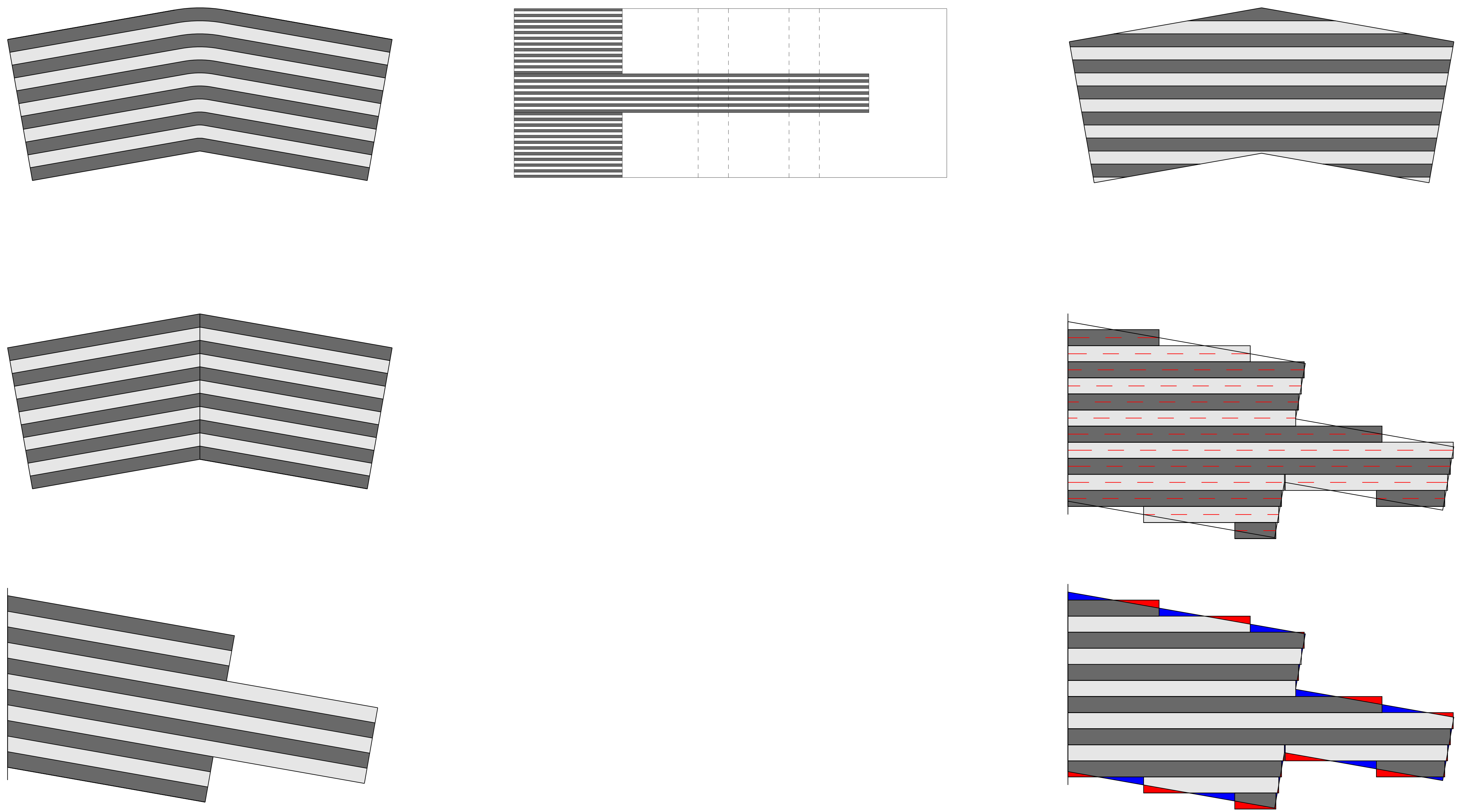
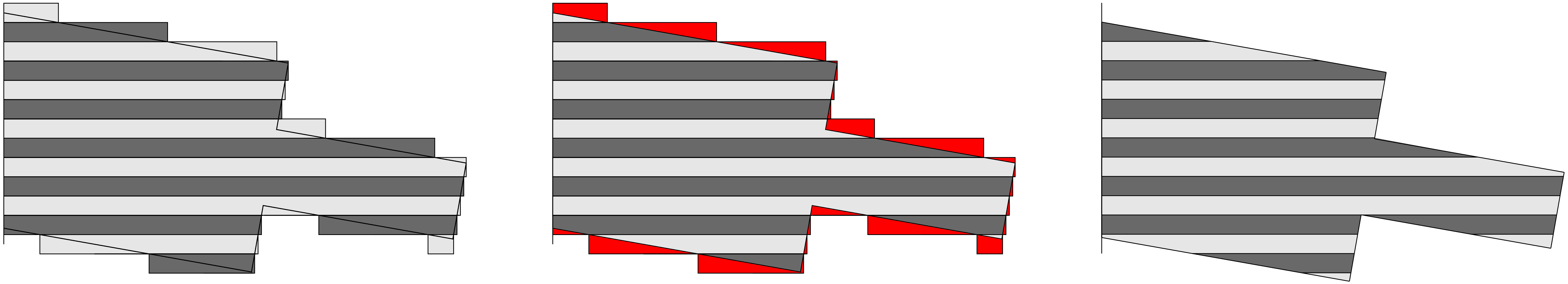
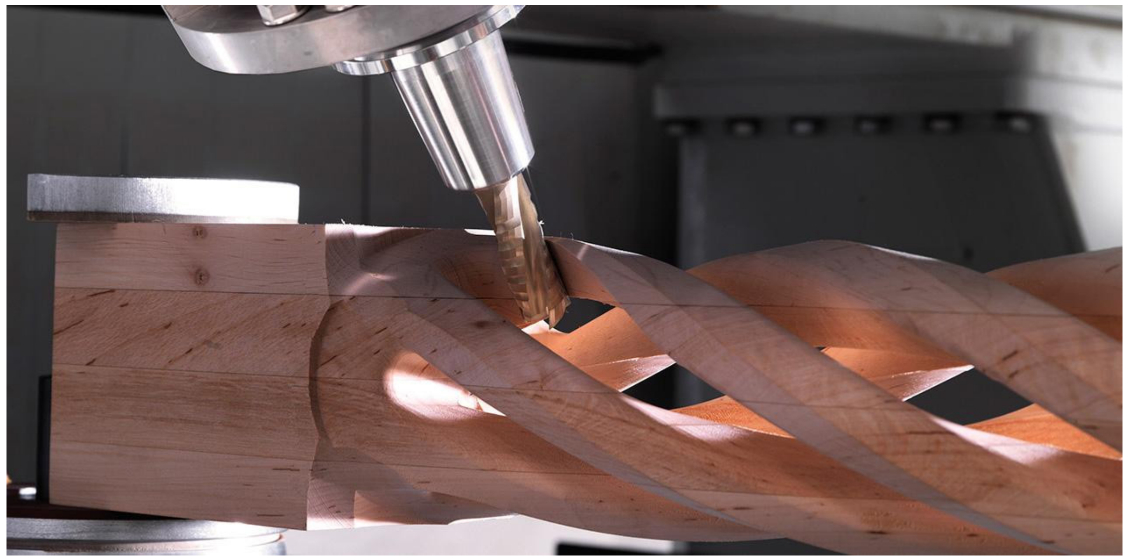


Final design

From 2D to 3D

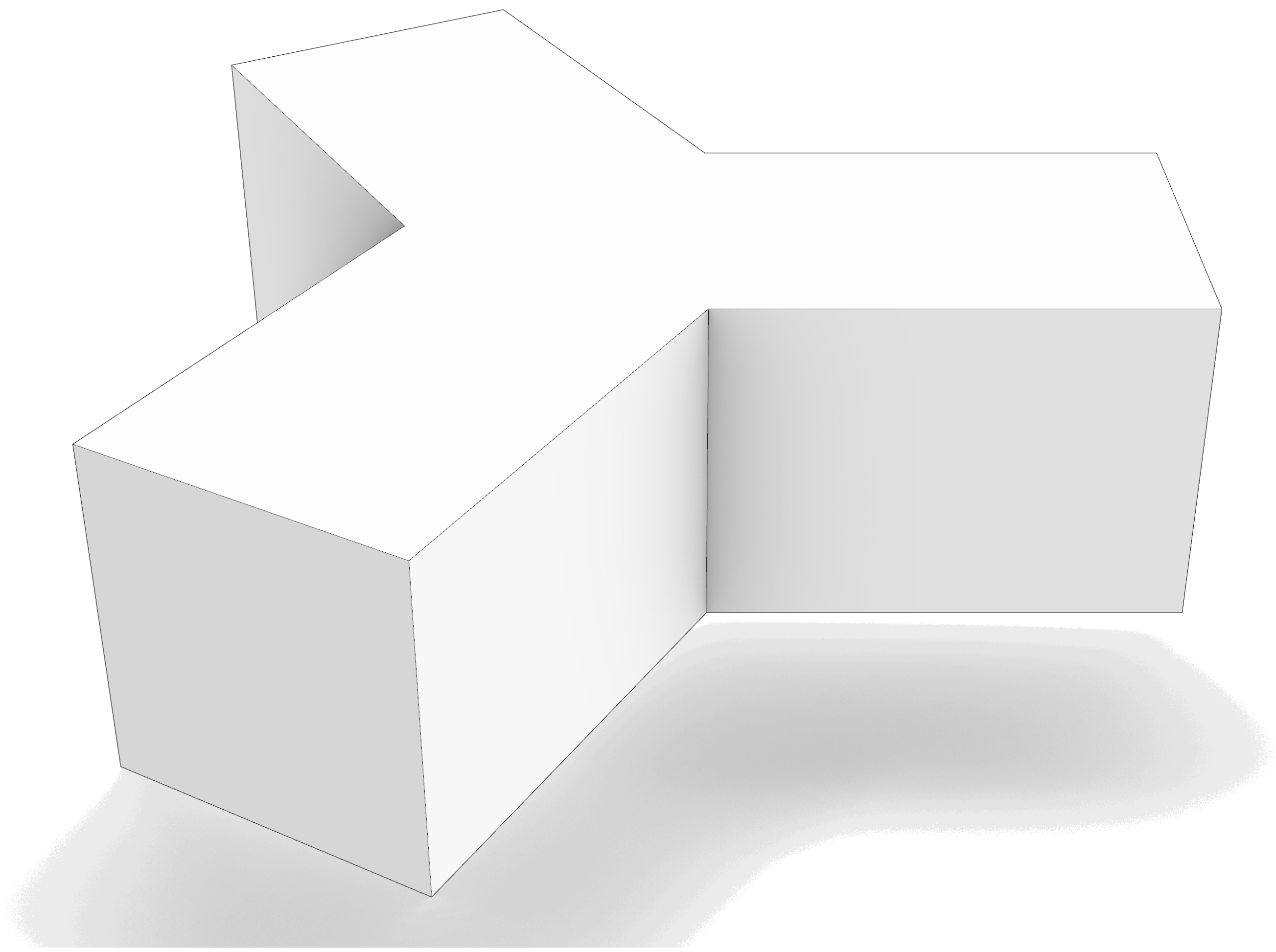


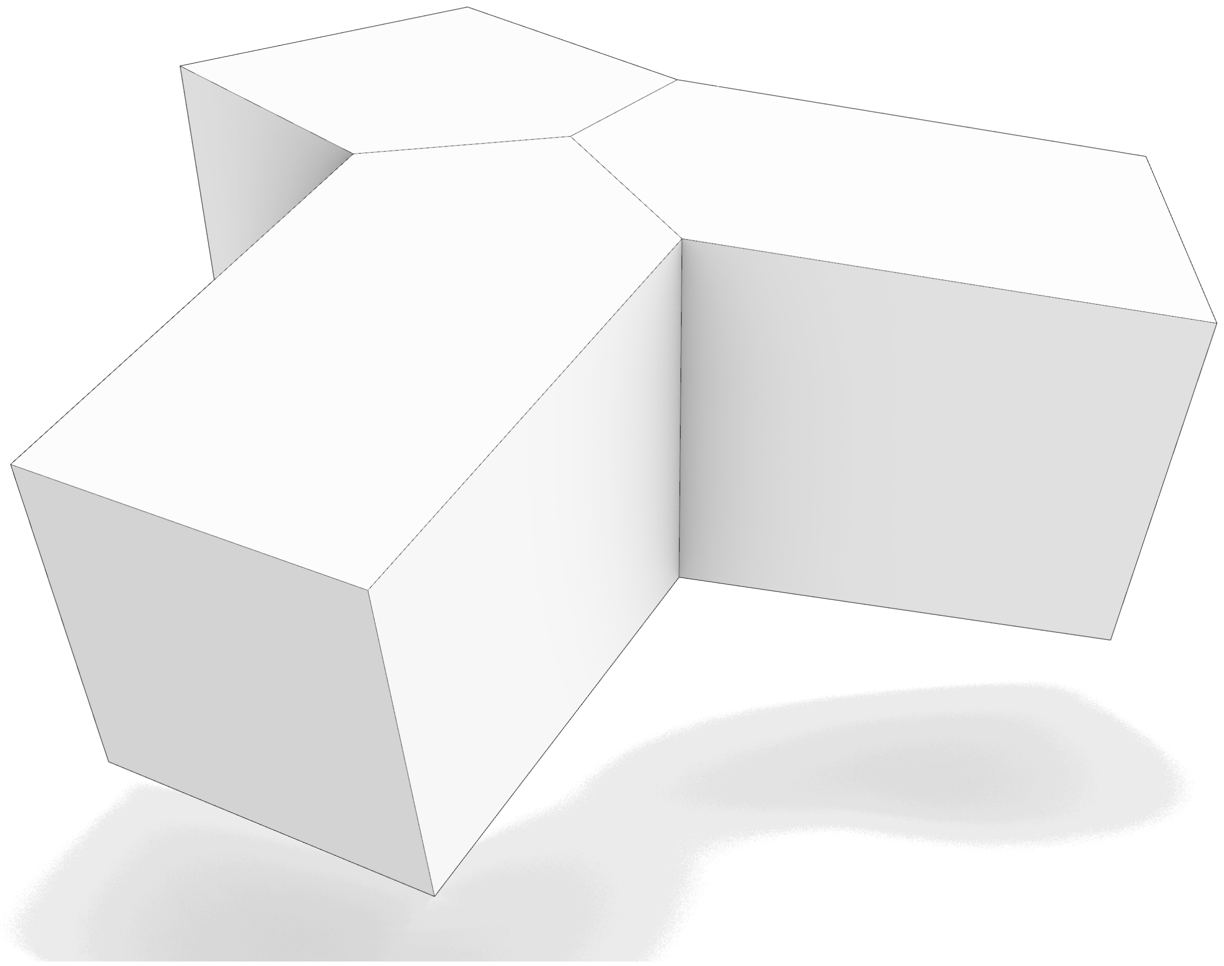


CNC milling process (Haco, n.d.)

Final design

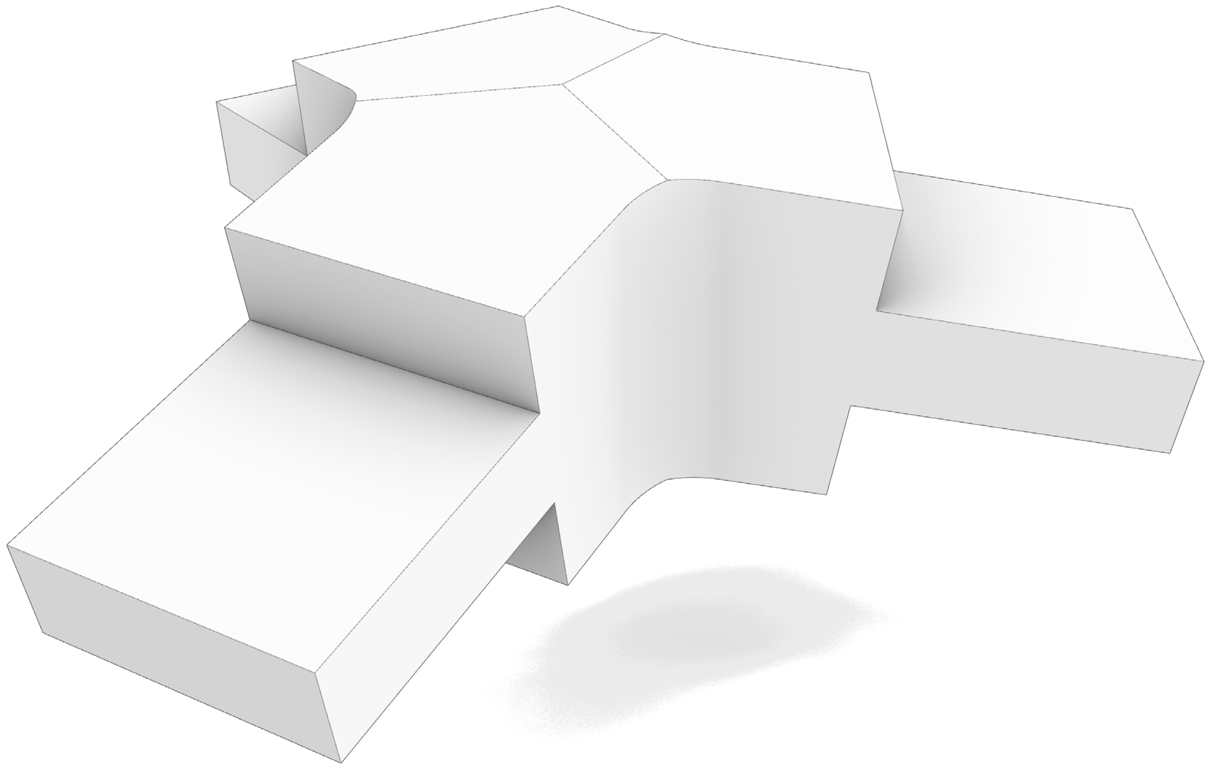
From 2D to 3D

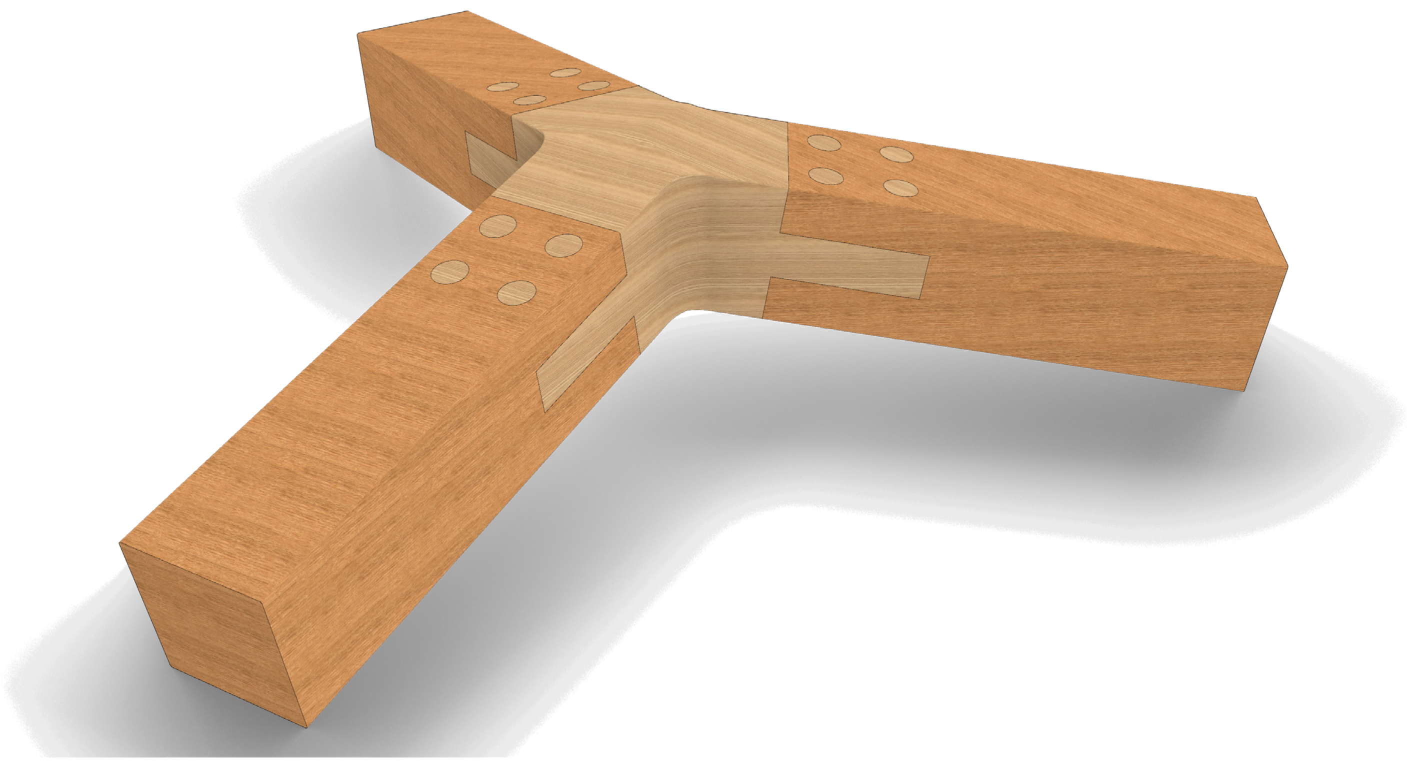




Final design

From 2D to 3D





Final design

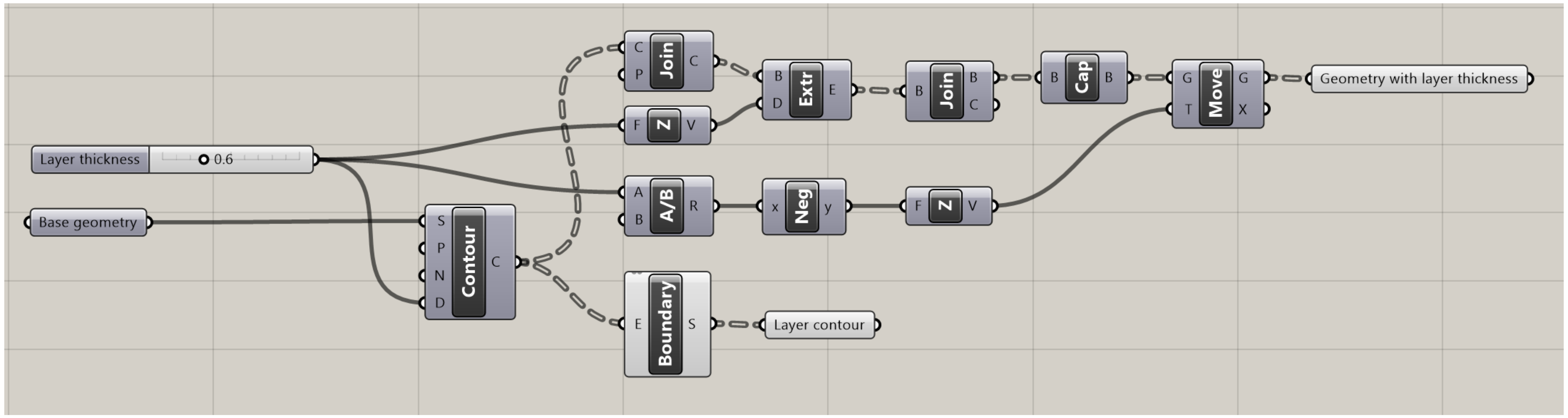
From 2D to 3D

Rhinoceros®
NURBS modeling for Windows

(Rhino3D, z.d.)

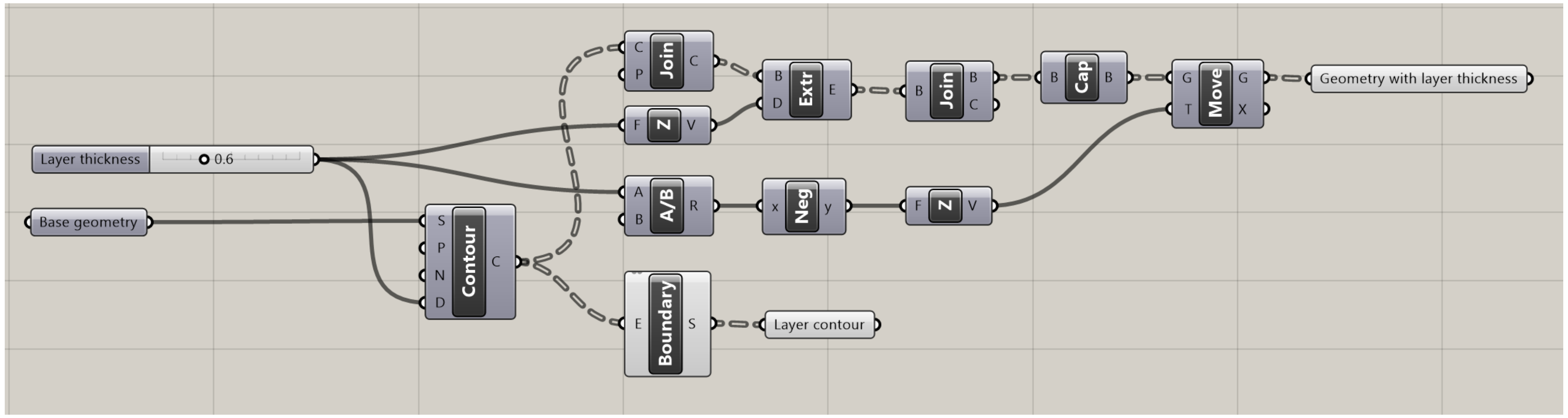
+

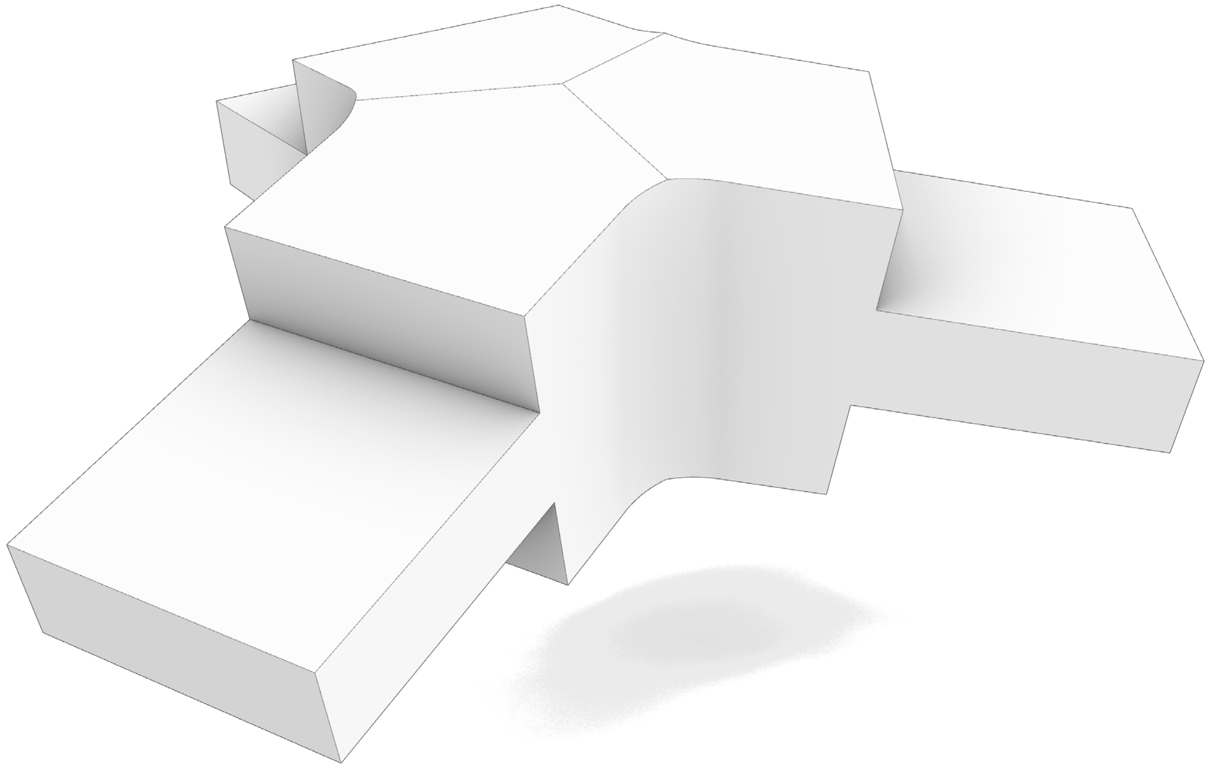
grasshopper

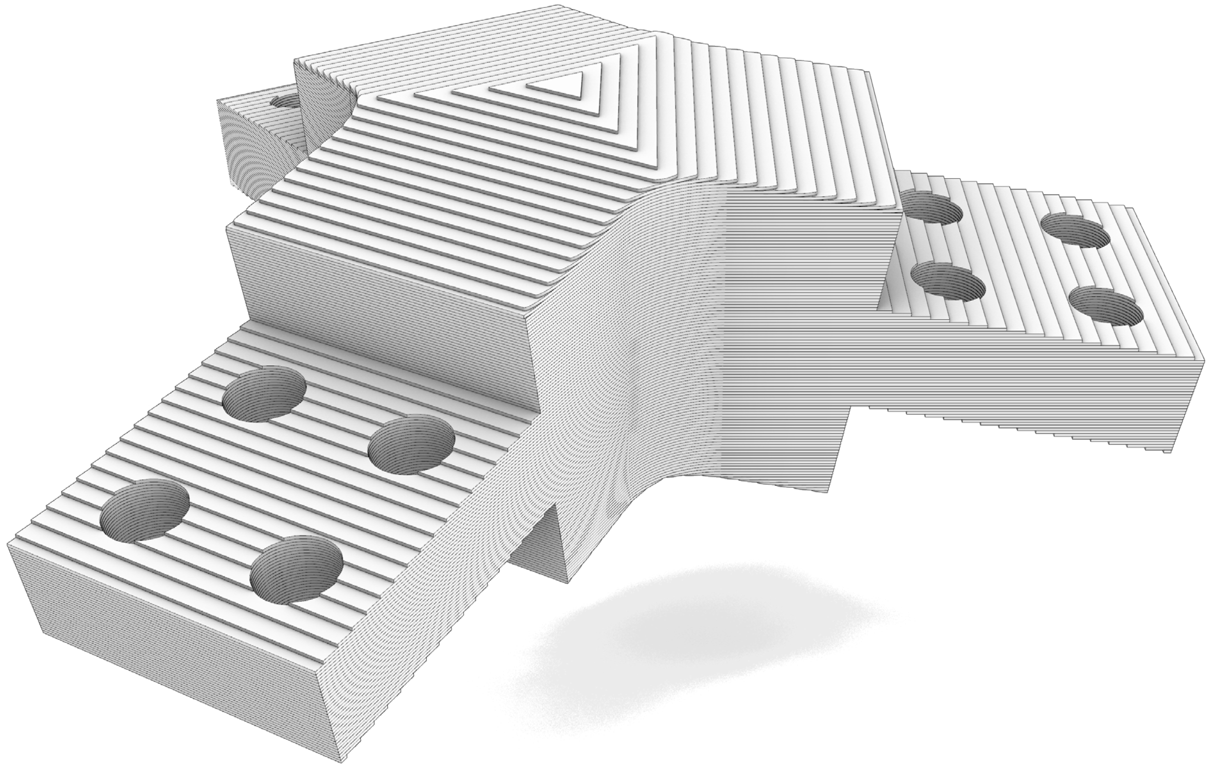


Final design

From 2D to 3D

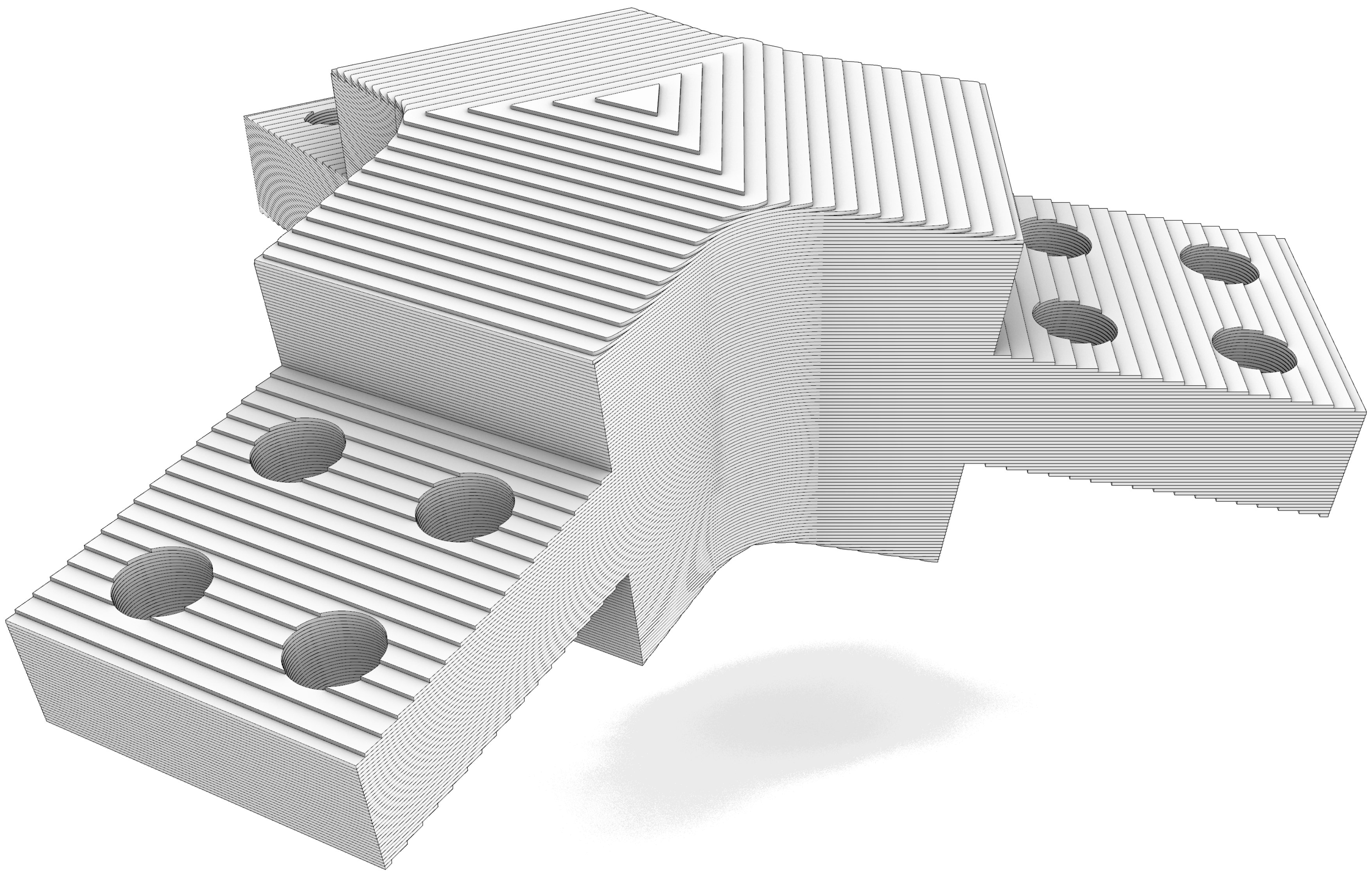






Final design

From 2D to 3D



Conclusions

What are the advantages and limitations of manufacturing wooden elements using Laminated Object Manufacturing (LOM)?

Advantages

> Individual grain direction
> Optimise stress distribution in material
> Cutting before lamination reduces waste

Limitations

> Segmented layers complicates lamination process
> Still a lack of knowledge about real-life performance of process and products

Conclusions

What are the design parameters for constructing a solid wooden connection element using Laminated Object Manufacturing (LOM)?

> Grain direction

> Layer segmentation

> Possibility for hybrid structures

Conclusions

What methods can be used to create reliable connections between a wood-LOM produced node and a timber structure?

> Regular wood-on-wood connections are usable

> Wood-LOM has potential to enhance performance by optimising layer structure

> Further research needed in performance benefits

Conclusions

How can Layer Object Manufacturing technology be used to create wooden nodes for timber structures?

This research:

> Showed possibilities and considerations for using wood in LOM

> Showed design flexibility by using wood-LOM

> Explored effects of design choices on the structural performance

> Provided potential for optimizing structural connections with layer structure

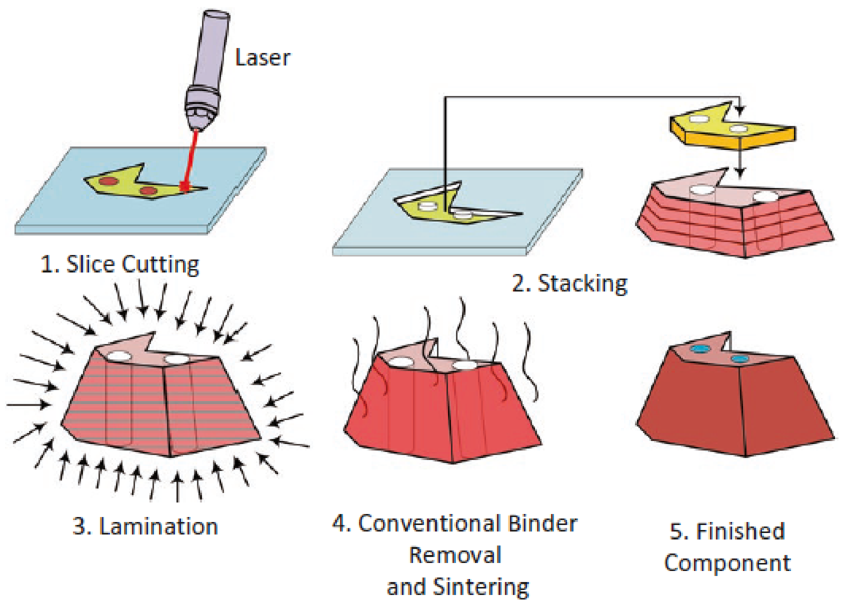
Recommendations

Optimise separate cutting + stacking process

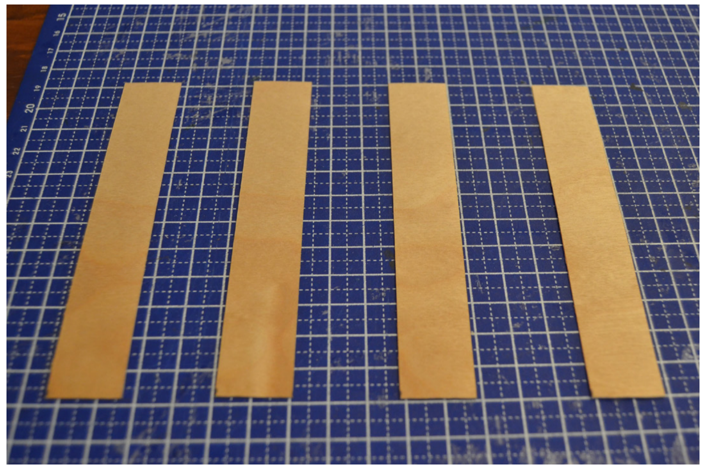
Mitigate effects of glue on small parts

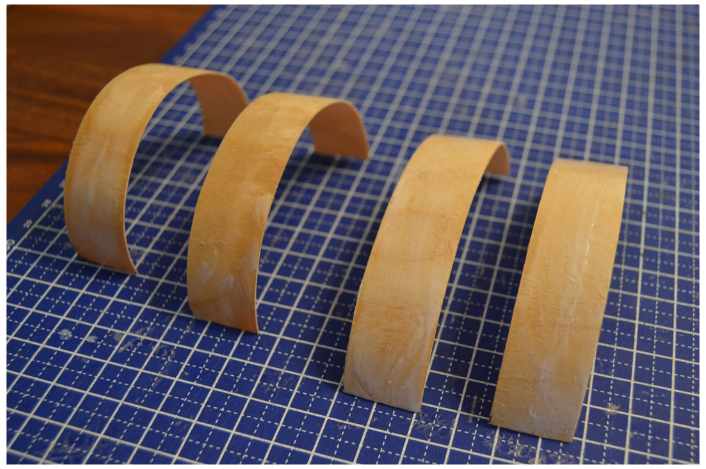
Explore

> More materials
> Other material hybrids
> Other layer structures
> Simulate multiple planes of forces



Stacking process (Gibson et al., 2016)





Questions?

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