

Interlocking glued Solid timber from Reclaimed Stocks

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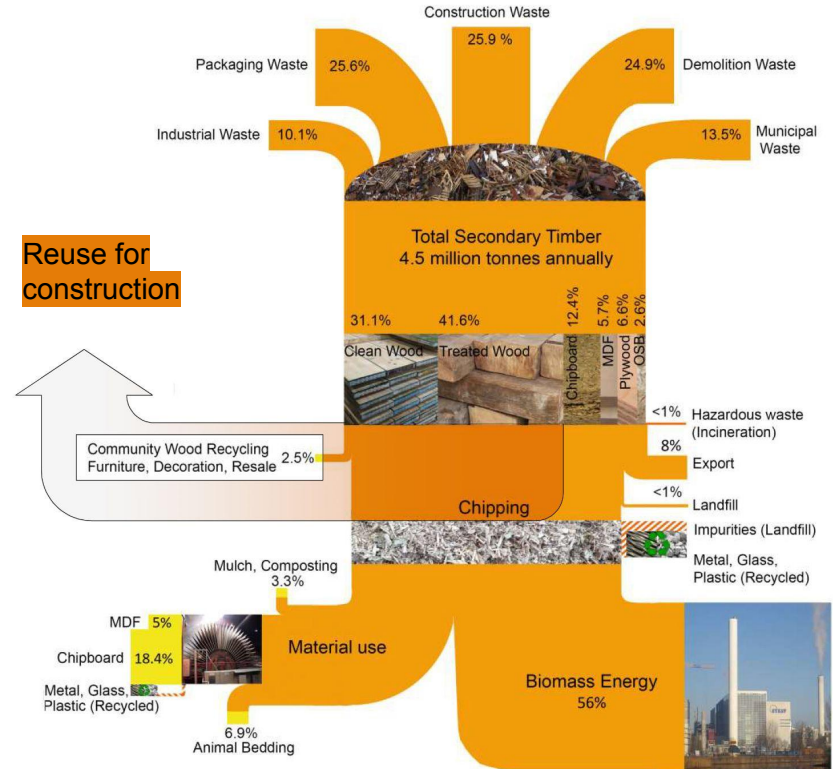
Industry partners: Sss-ovo/Lorrin Brassier

Why Reclaimed timber?



Future

- Heading Towards Carbon Neutrality by 2050(FAO)
- France's 2022: 50% Natural Materials in New Buildings
- the push for sustainable construction materials raises the crucial issue of sourcing additional wood
- a 37% increase in the consumption of primary processed wood products by 2050 in a business-as-usual (FAO)
- additional 8% growth in a bioeconomic scenario as mass timber and man-made cellulose fibers, as substitutes for non-renewable materials like concrete and steel.
- Forestry Value Chain: Essential for Sustainable Wood Production

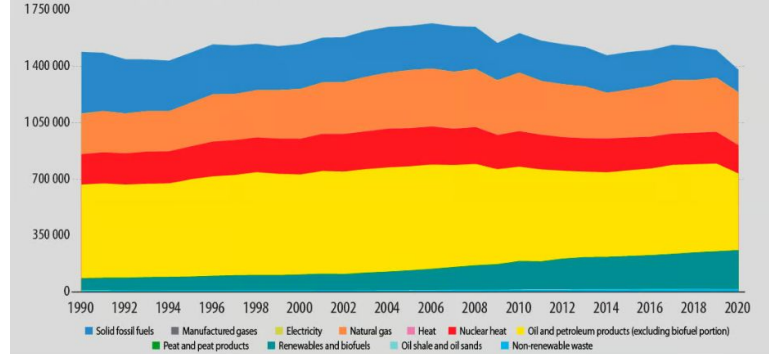


Present

- EU Renewable Energy Directive retains **woody biomass as renewable** despite opposition.
- Concerns include **carbon emissions and forest impact**, leading to significant public and scientific opposition.
- Legal loopholes exist in forest protection regulations due to weak monitoring and enforcement.
- Dutch Parliament **ceased subsidies** for biomass heat plants in **February 2021 to prevent unsustainable construction**.

Gross available energy by product

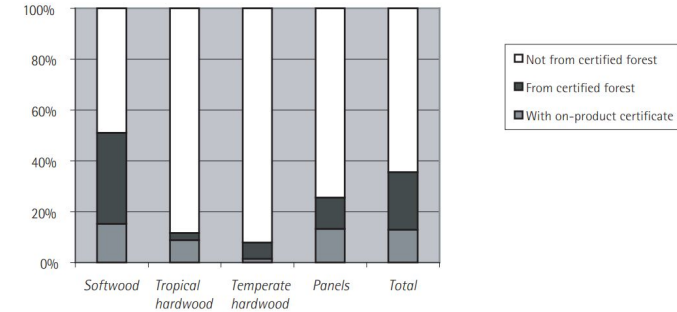
EU (1990-2020), Thousand tonnes of oil equivalent



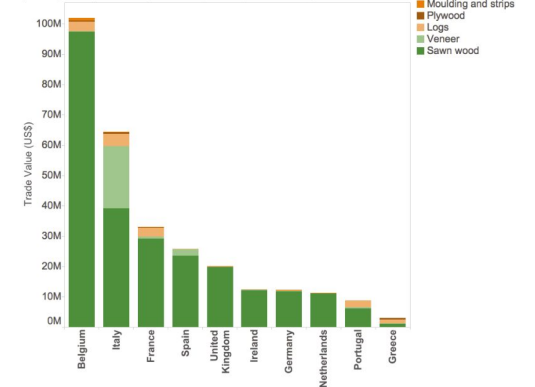
Past

- Indonesia and Malaysia collectively supplied around 40% of Netherlands' timber imports in 2006.
- Approximately 80% of tropical timber imported by the Netherlands is illegally sourced.
- Environmental risks of uncertified timber include illegal logging and deforestation.
- Social risks include poor labor conditions, human rights violations, and land rights disputes.

Figure 1. Timber with certificate and timber sourced from certified forest, per product group, as a percentage of total Dutch timber consumption in 2005

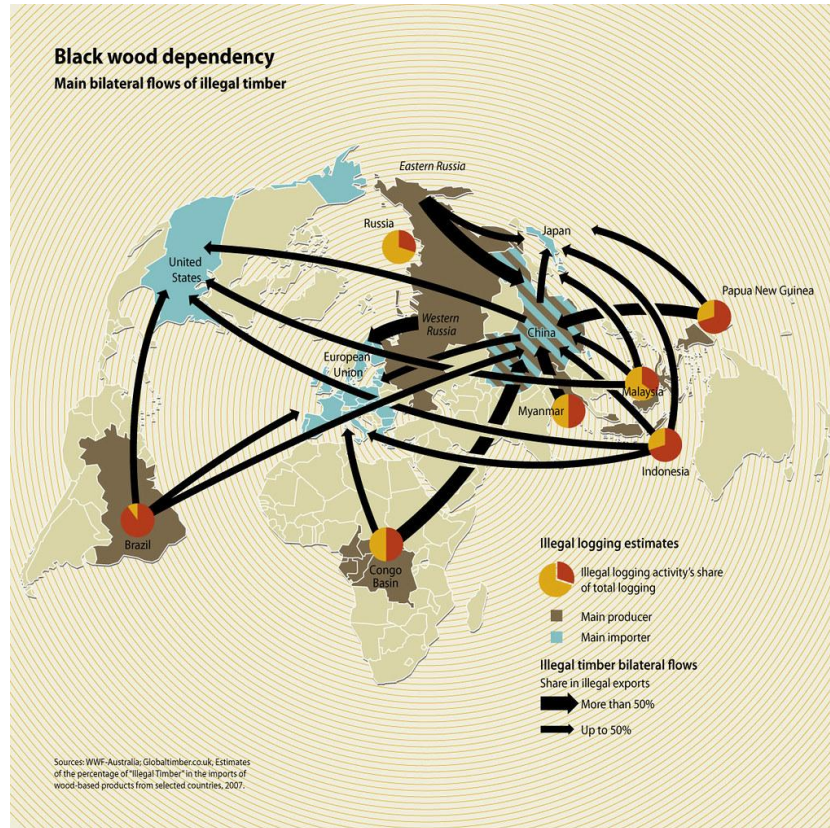


Top ten EU Member State importers of timber products from Cameroon in 2015 (showing the top 5 timber products imported by value in USD)



Data from UN Comtrade 2017 and compiled by Forest Trends 2017.

Sourcing timber illegally



Why Reclaimed timber ?

- A **high Demand** is expected in the future,
- **the laws** for using wood for biomass energy is matter of **change** due to the carbon emission research.
- The value of the timber exist in the new and reclaimed stocks has a value for EU region and beyond

Cascading flow for recycling timber

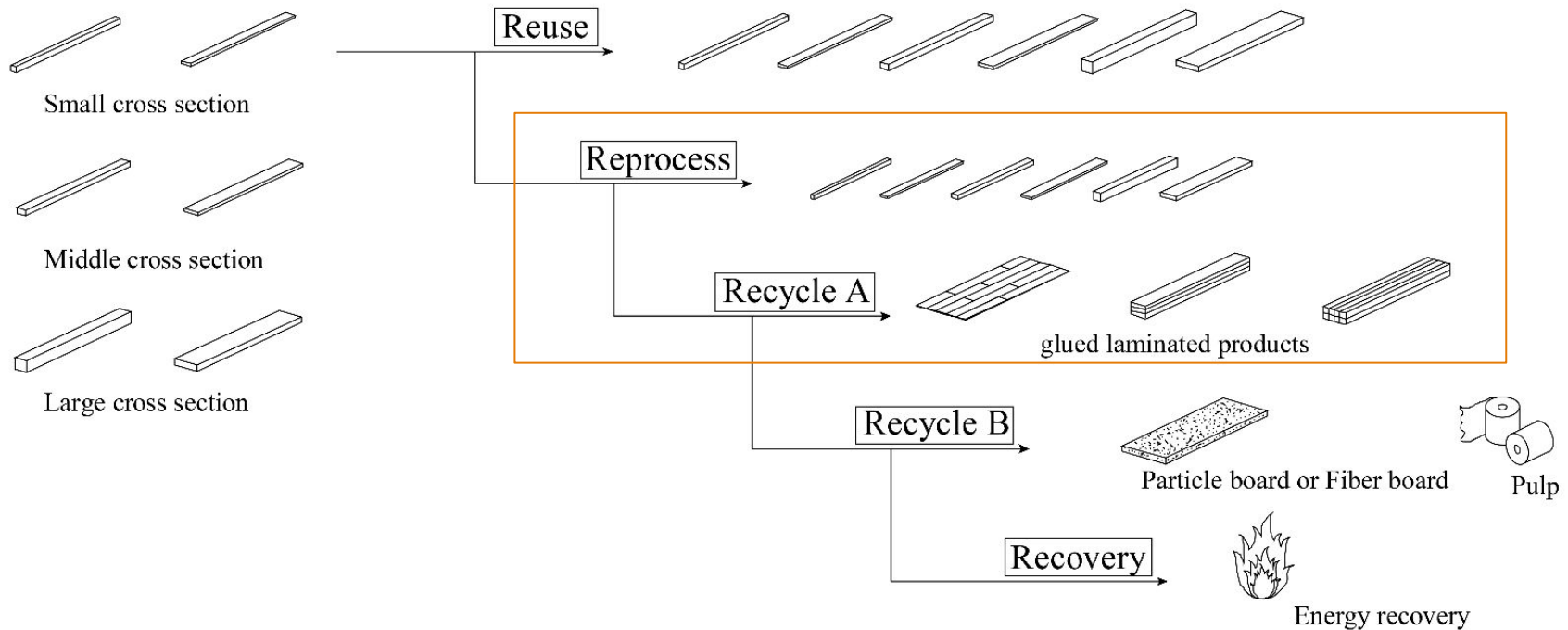


Figure 2. An example of a cascading flow for timber members from a deconstructed building (Sakaguchi 2014). Image courtesy of Daishi Sakaguchi.

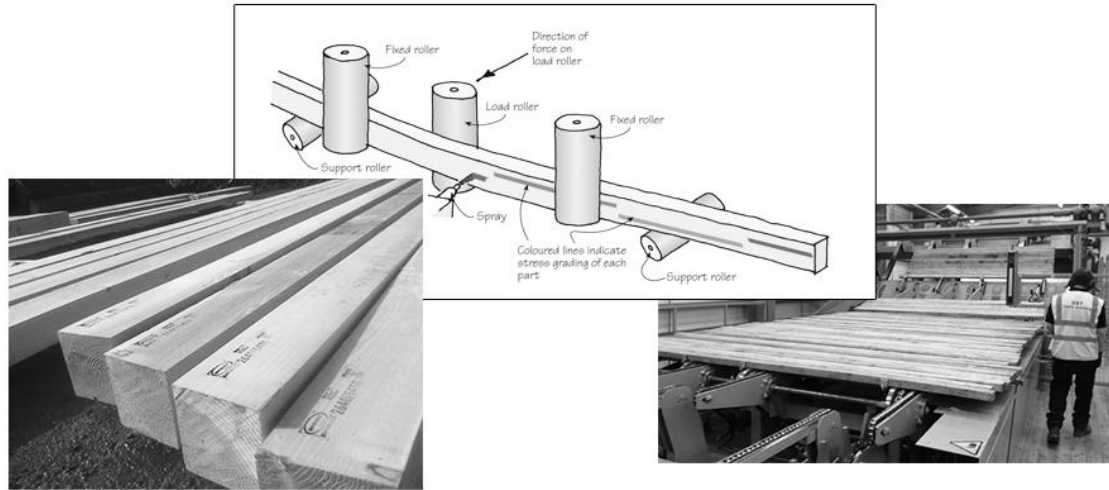
Discourse

1

Rethinking Timber Reuse vs. Recycling

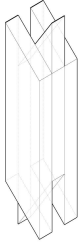


Using machine-graded timber since the 1950s, which has lower safety margins, raises concerns about reusing demolished timbers for structures due to possible strength loss, suggesting recycling as a more sustainable choice.

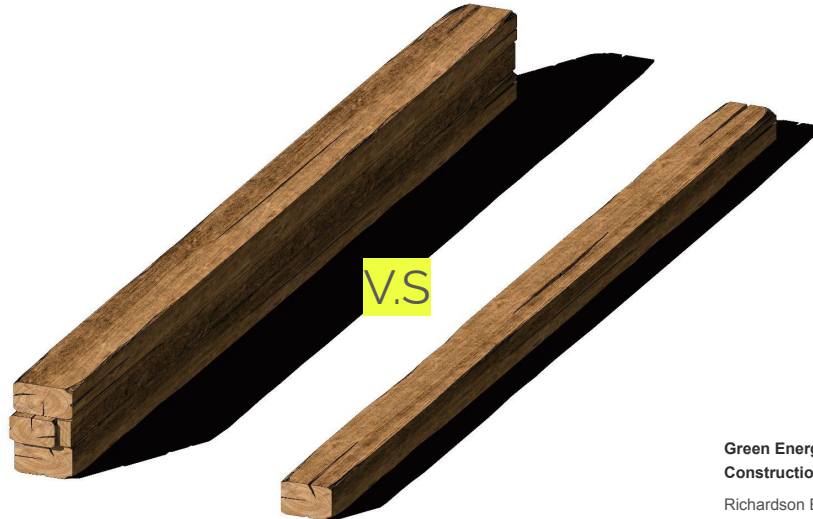


2

Element V.S Bundle of Elements!

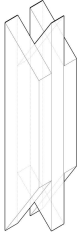


Therefore, the use of reclaimed timber is governed by the concept of its structural capacity. Since each element undergoes a certain amount of degradation, using an aggregation of these elements will provide structural elements with better performance

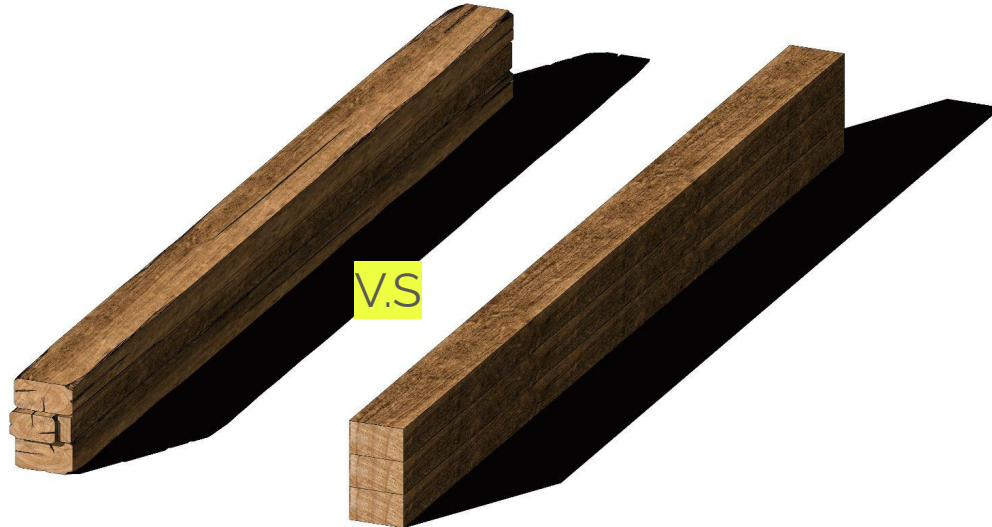


3

Newly sawn timber > reclaimed timber (Glulam)

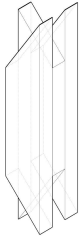


still the making structural elements, from newly cut timber has better performance than using reclaimed timber, but research has proven that glulam from reclaimed timber still satisfy the structural need in the construction market Patlakas et al. 2019



4

Unlocking Market Growth

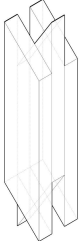


Sustainably sourced wood products are more expensive, causing mass timber buildings to cost 5-15% more than conventional ones. This significant cost increase limits widespread adoption. However, considering engineered timber from reclaimed timber can offer a solution with lower costs than newly sourced timber, helping support market growth (Mayencourt & Mueller, 2020).

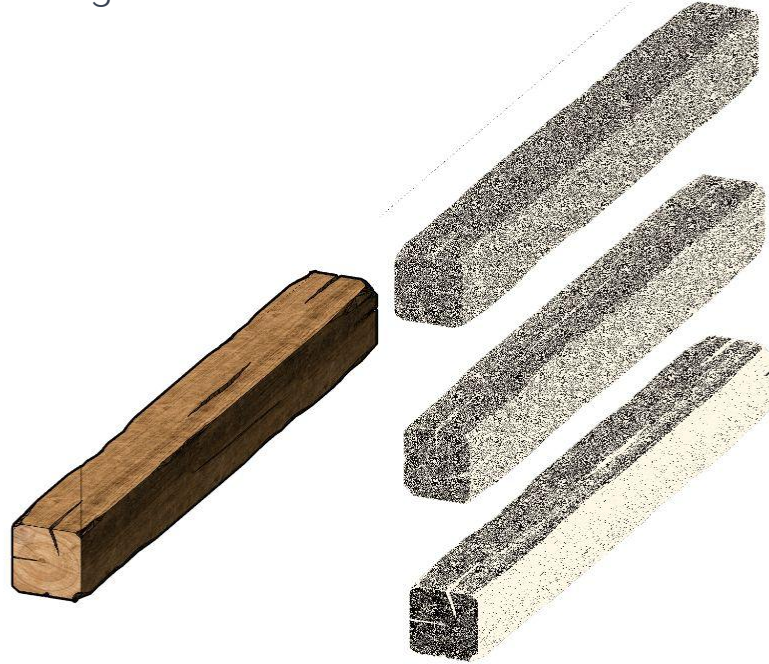


5

Density + Geometrical properties

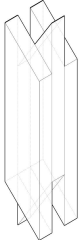


To design strong glulam from reclaimed wood, we need to check the wood's density, age, and structure alongside its geometric data

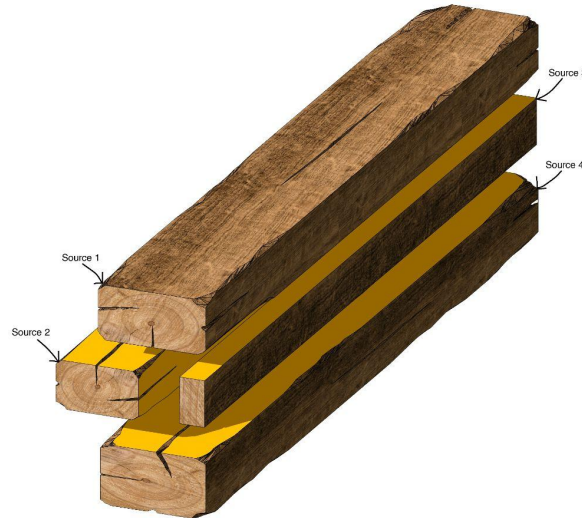


6

Multi source => Bonding Problem !

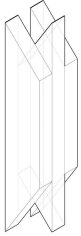


The evaluation results in a matrix of data, which the literature shows can be used directly to assess designing for optimum strength. The first question is linked to the essence of the salvaged material, the sourcing of the material, and the possibility of creating glulam from different wood species (Palma & Fink, 2013).

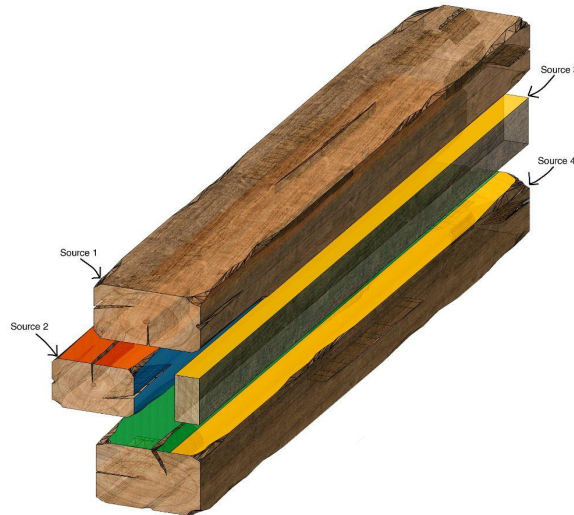


7

Better glued joint = Similar face treatment Chemical + physical (sanded or planared)



Various factors can impact how structural elements fit together. Reclaimed timber diverse wood types and surface treatments can affect bonding strength, requiring attention to glue compatibility, wood chemicals, pH, and surface smoothness to prevent weak bonds and damage (Palma & Fink, 2013).



State of art of EPW

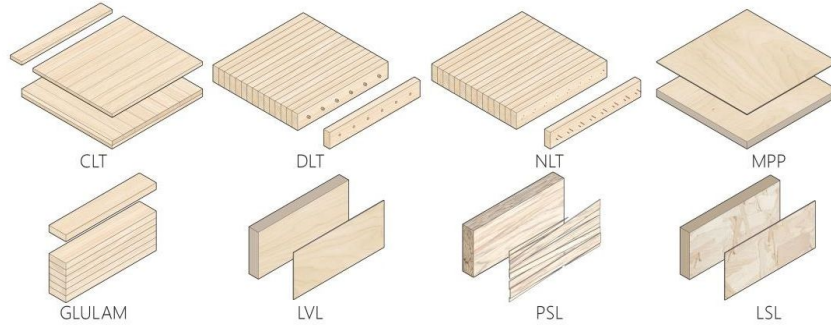
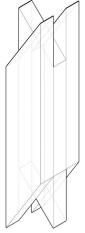
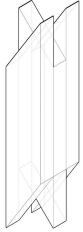


Figure 1. Main species of mass timber.

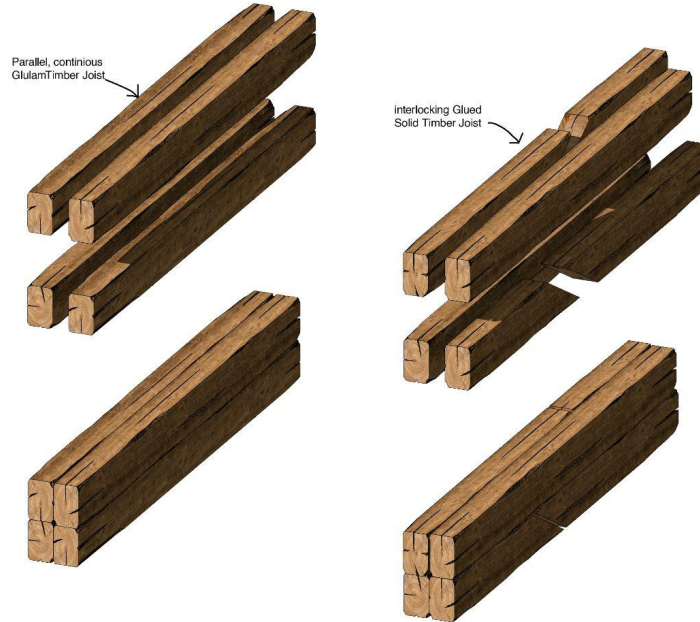
Glulam	Wooden planks	Glue	Parallel	
CLT	Wooden planks	Glue	Orthogonal	
IGST	Wooden planks	GLUE	Parallel Orthogonal	
Non-glued types:				
DLT	Wooden planks	Dowels	Parallel Orthogonal	
NLT	Wooden planks	Nails	Parallel Orthogonal	
Structural Composite Lumber types:				
LVL	Veneers	Glue	Parallel Orthogonal	
PSL	Wooden strands	Glue	Parallel	
LSL	Wooden strands	Glue	Parallel Orthogonal Random	

9

1:4 Slope edge , simple joint = increase the strength

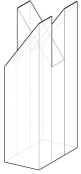


Most research on reclaimed materials focuses on straight structural parts, overlooking factors like joint shape, cost, and environmental impact (Patlakas et al., 2019).



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Problem statement



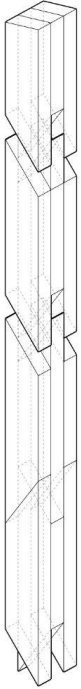
Moving to carbon-neutral construction will likely raise demand for engineered timber, putting pressure on the wooden materials industry and increasing costs for Mass Timber structures, which are already 15% more expensive than concrete buildings. However, creating mass timber structures from reclaimed timber could be an important alternative, despite lacking comprehensive design and production methods.

11



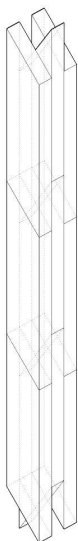
The goal of project is to find methods To help structural designer and craftsmen to make IGST structural elements from reclaimed timber stocks.

Research Question:



Main research question

How can we create interlocking glued Solid timber structural components from reclaimed element stocks?



Sub-Questions:

Preparing the Inventory

How to evaluate the timber in the stocks, with simple techniques

Matching algorithm

How to optimize the quality and quantity of the produced elements by controlling the matching process between design and stock?

Environmental Impact

How to calculate the environmental impact of the resulting component and compare it with glulam from newly sawn timber, or combination from both?

Manufacturing

What to workflow needed to manufacture the designed structural component?

Design assignment

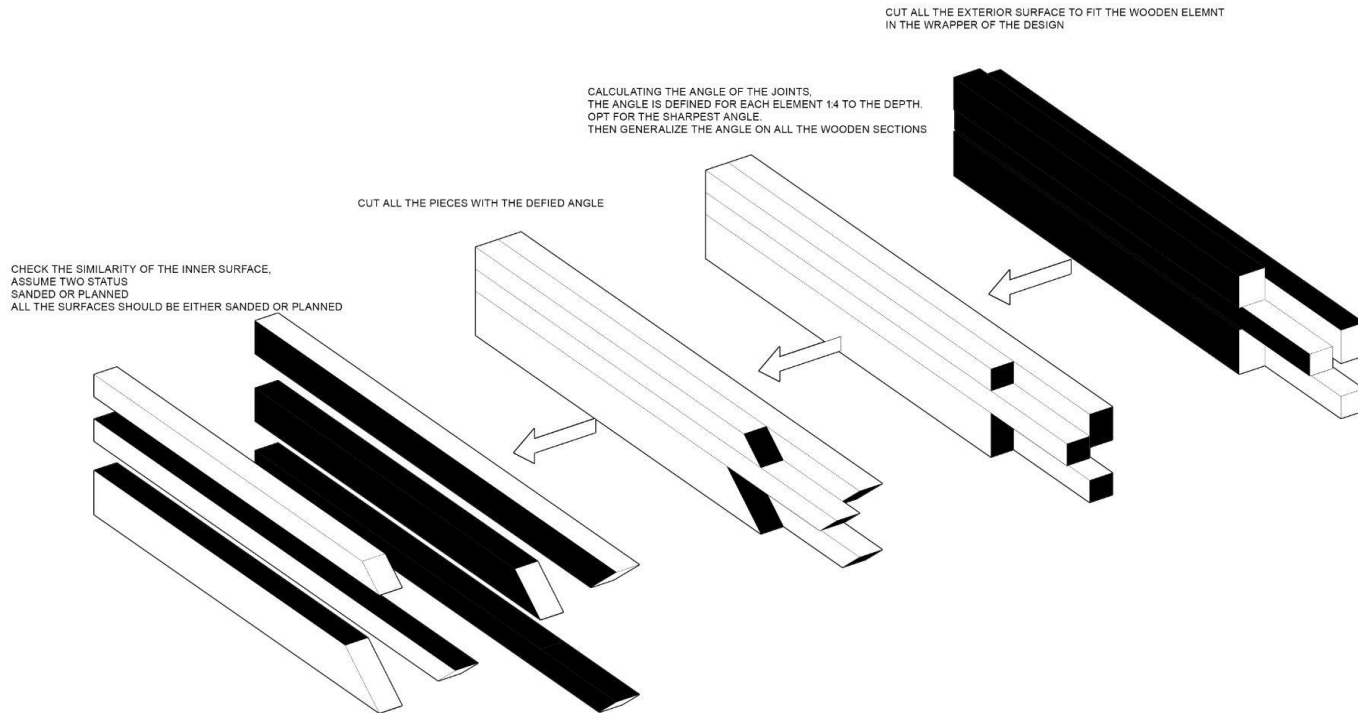
Case study A:
A single Beam
Suitable Method: MILP



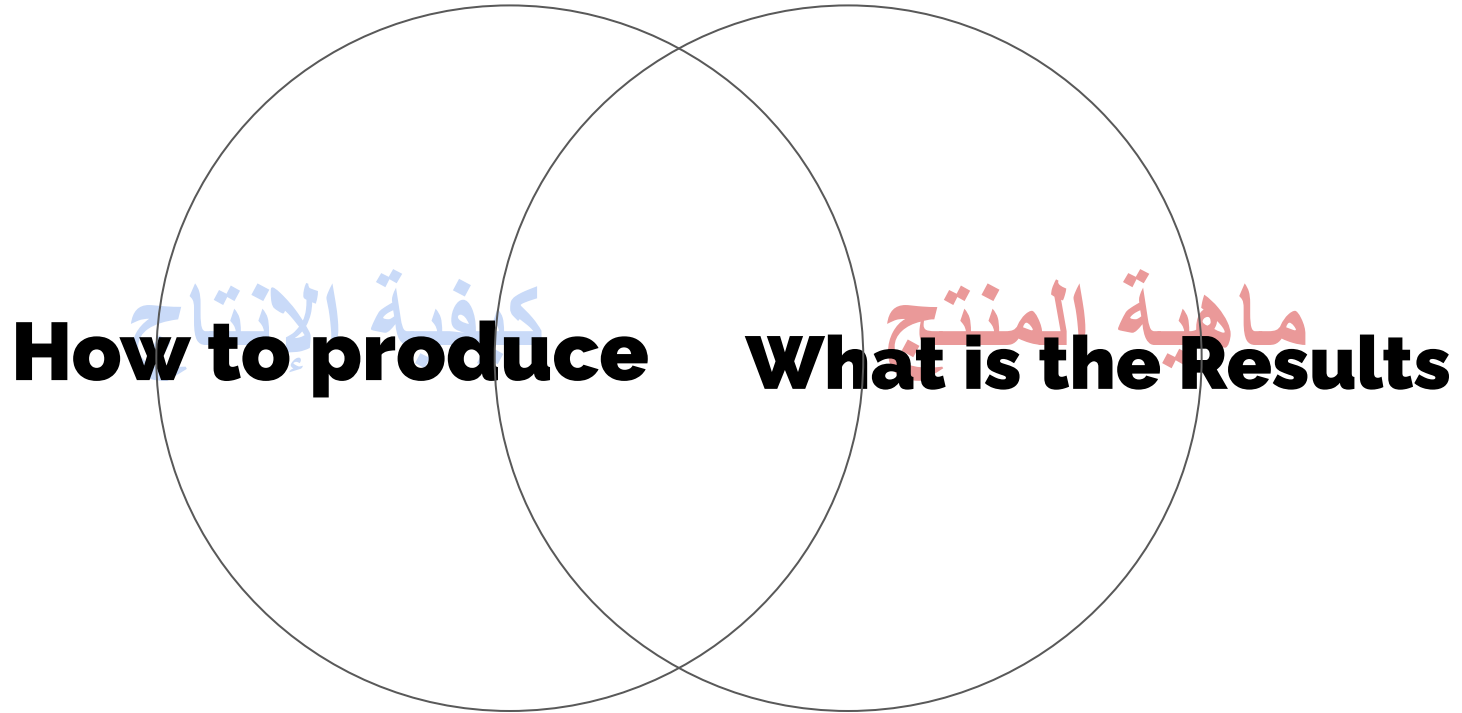
Case study B:
A collection of Beam
Suitable methods: Hungarian Algorithm



From Design to workshop workflow



How to proceed with the concepts



How to proceed with the concepts

How to produce

كيفية الإنتاج

ما هي النتائج
What is the Results

How to produce IGST from Reclaimed timber

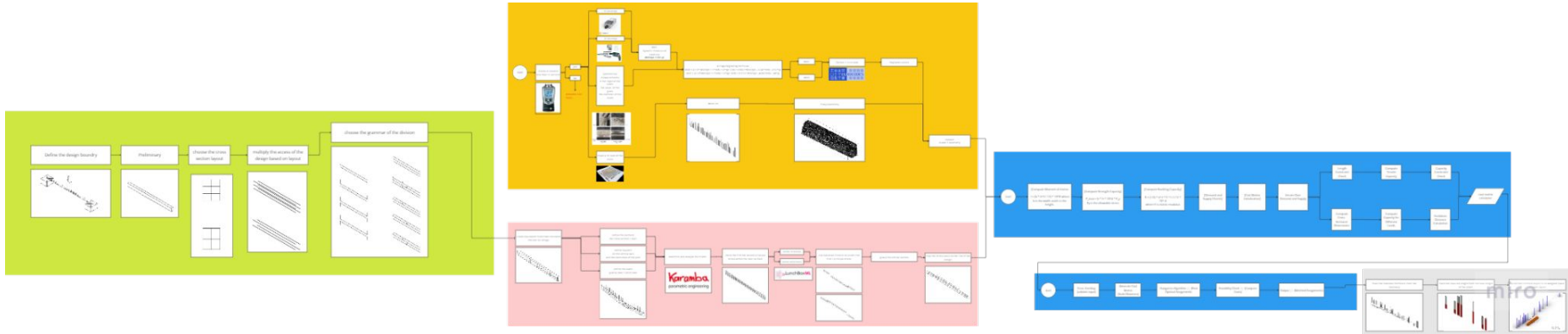
تصميم
Design

التشييد
Regrading

البنية
structure

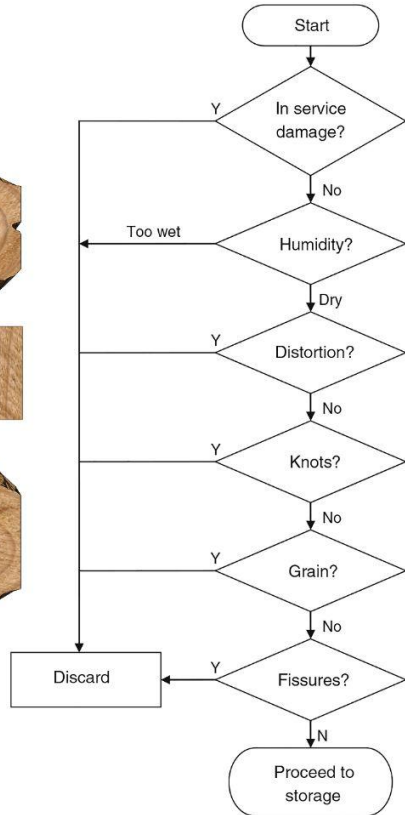
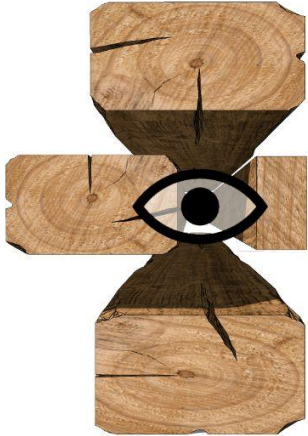
مطابقة
Matching

workflows(Layout -structural - matching -visualization)



تصنيف Regrading

Visual Grading methodology



Discard if more than **35 nail** holes per meter. Holes and notches up to 15 mm wide are fine, except on narrow edge. *Notches up to 25 mm near end are okay*; can be machined out if needed

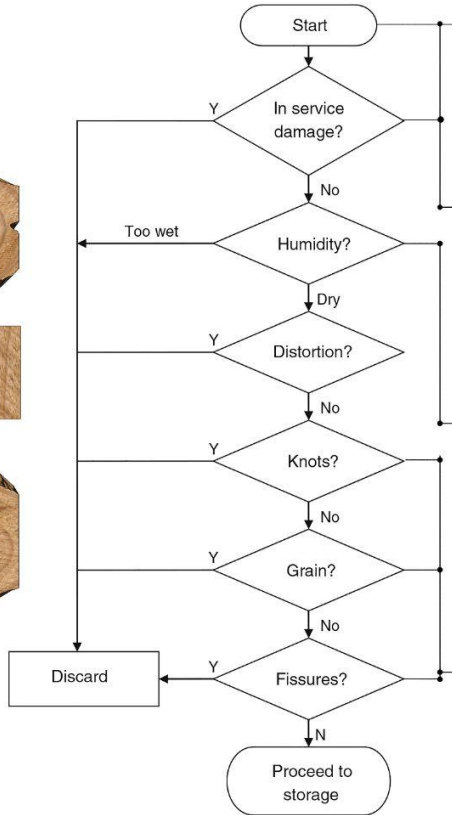
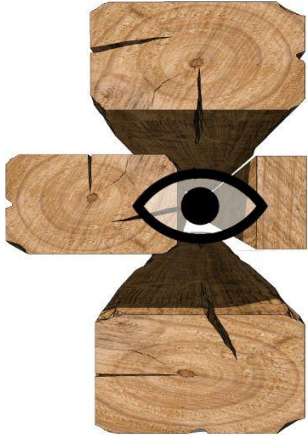
If a joist has recently been removed from its 'in-service' position, it should feel dry to the touch. Any timber feeling wet or damp could indicate rot and should be rejected.

Bow—Not more than 20 mm over a length of 2 m
Spring—Not more than 12 mm over a length of 2 m
Twist—Not more than 2 mm per 25 mm width over a length of 2 m
 If all of these conditions are met, the joist is a 'Yes'; if not then it is a 'No' and must be rejected.

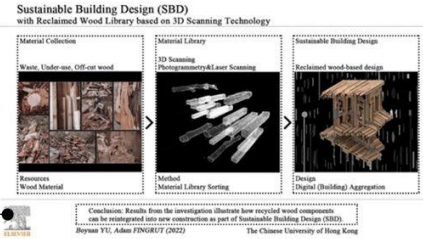
Any knots wider than **30 mm on the surface of the timber and within a quarter of the joist's width** from the edge are **not allowed**. If knots violate this rule, the joist is considered failed and rejected.

The slope of the clear grain must **not exceed 1 in 6**. There can be unlimited fissures, but **none should be longer than 600 mm per meter**. Timbers failing this rule are rejected. No wane is permitted on the reclaimed joist according to the visual grade.

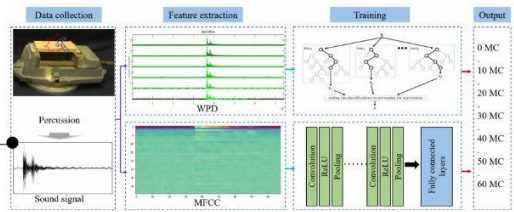
Visual Grading methodology



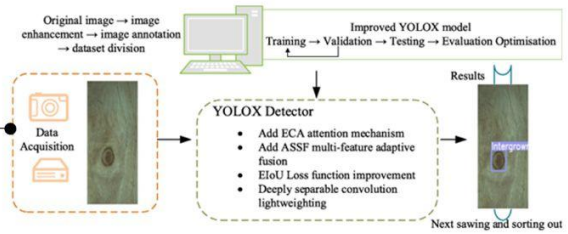
An analysis of timber sections and deep learning for wood species classification
 de Geus A, Silva S, Souza J
 Multimedia Tools and Applications (2020) 79(45-46) 34513-34529



Sustainable building design (SBD) with reclaimed wood library constructed in collaboration with 3D scanning technology in the UK
 Yu B, Fingrut A
 Resources, Conservation and Recycling (2022) 186



Timber moisture detection using wavelet packet decomposition and convolutional neural network
 Yuan C, Zhang J, Kong Q
 Smart Materials and Structures (2021) 30(3) 035022

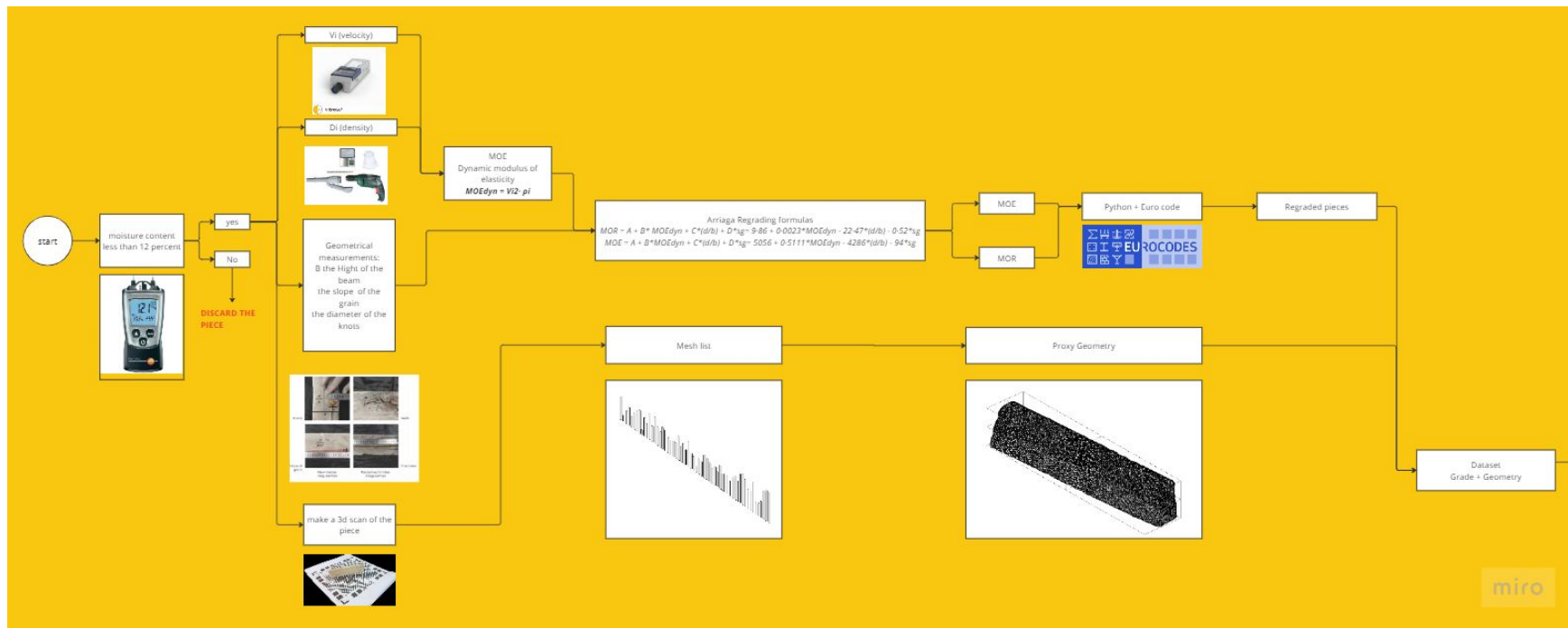


Detection method of timber defects based on target detection algorithm
 Li D, Zhang Z, Deng L
 Measurement (2022) 203 111937

Literature focus

How can we utilize **visual grading**, along with **mechanical material characteristics**, to re-grade reclaimed timber according to the Eurocode?

From stock to a grade workflow



Visual characteristics

Measure width (b)

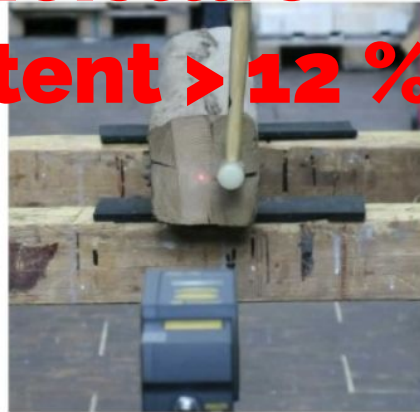
Measure height (h)

Length (L)

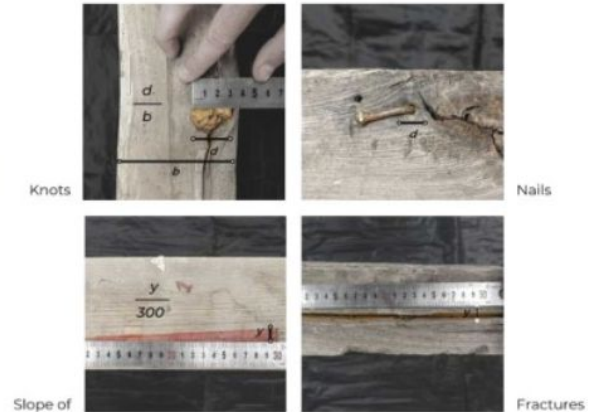
knots diameters ratio(D)

Slope of grain

**Moisture
content > 12 %**



Polytec 100 laser doppler
vibrometer



Knots

Nails

Slope of
grain

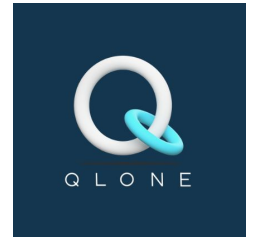
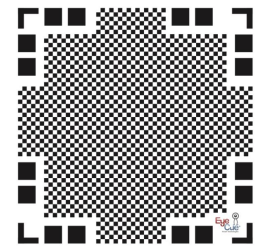
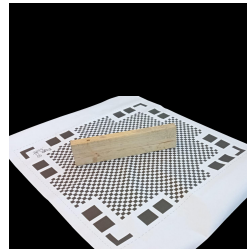
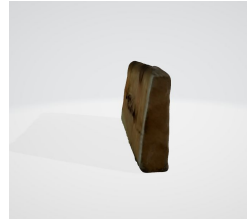
New timber
irregularities

Reclaimed timber
irregularities

Fractures

A 3d scan of the reclaimed pieces

- Using Qlone app on the phone
- create an obj file with the materials
- create a data set of meshes



Measuring Vi and Di

To get Vi



or



Micro second timer

To get pi



or

$$\rho = \frac{m}{V}$$

$$MOEdyn = Vi^2 \cdot \rho_i$$

$$MOR = A + B \cdot MOEdyn + C \cdot (d/b) + D \cdot sg = 9.86 + 0.0023 \cdot MOEdyn - 22.47 \cdot (d/b) - 0.52 \cdot sg$$

$$MOE = A + B \cdot MOEdyn + C \cdot (d/b) + D \cdot sg = 5056 + 0.5111 \cdot MOEdyn - 4286 \cdot (d/b) - 94 \cdot sg$$

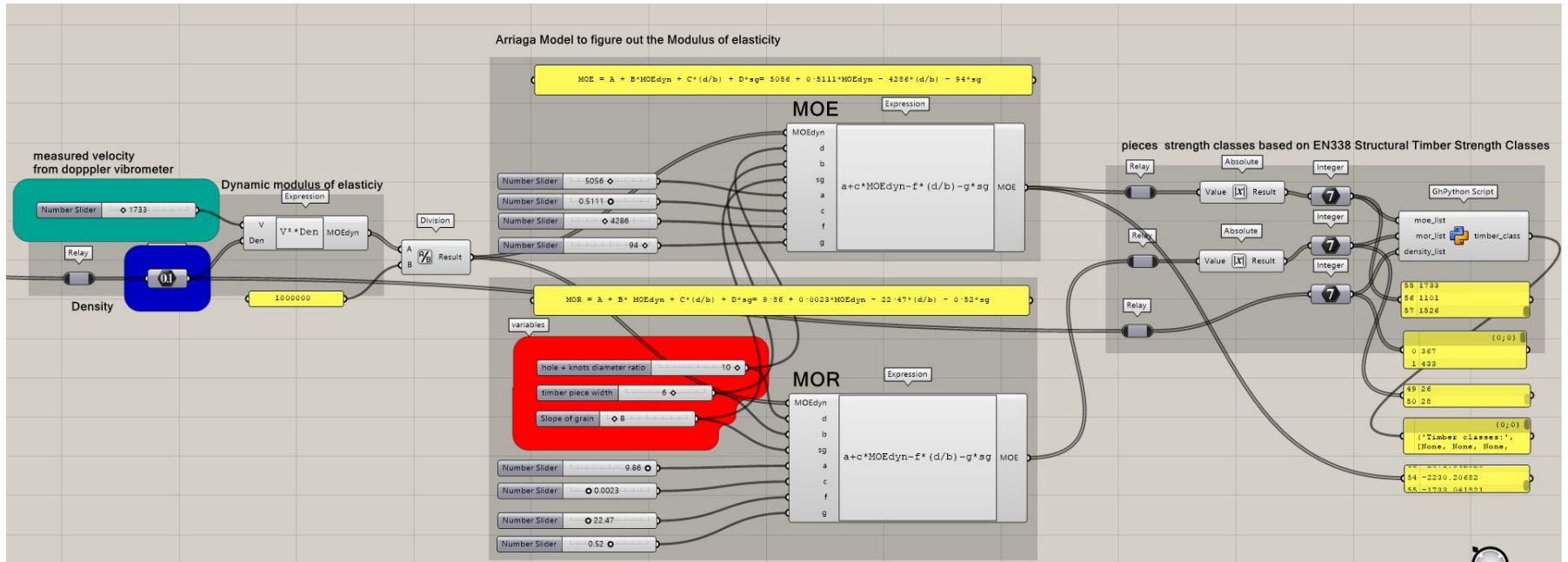
Classes from the eurocode

Table 1 — Strength classes - Characteristic values

		Poplar and softwood species												Hardwood species					
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	D30	D35	D40	D50	D60	D70
Stiffness properties (in kN/mm ²)																			
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16	10	10	11	14	17	20
5% modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7	8,0	8,7	9,4	11,8	14,3	16,8
Mean modulus of elasticity perpendicular	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53	0,64	0,69	0,75	0,93	1,13	1,33
Mean shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00	0,60	0,65	0,70	0,88	1,06	1,25
Density (in kg/m ³)																			
Density	ρ_k	290	310	320	330	340	350	370	380	400	420	440	460	530	560	590	650	700	900
Mean density	ρ_{mean}	350	370	380	390	410	420	450	460	480	500	520	550	640	670	700	780	840	1080
NOTE																			
a Values given above for tension strength, compression strength, shear strength, 5% modulus of elasticity, mean modulus of elasticity perpendicular to grain and mean shear modulus, have been calculated using the equations given in annex A																			
b The tabulated properties are compatible with timber at a moisture content consistent with a temperature of 20°C and a relative humidity of 65%																			
c Timber conforming to classes C45 and C50 may not be readily available.																			



Using grasshopper to input the data



A snippet of the data set used

Timber piece	Section		Length	Moisture content	Knots diameter ratio d/b	Slope of grain	Density	MOE ^{dyn}	species
	B cm	H cm							
A	8	12	100	20	0.3	12	530	0.64	oak
B	20	7	60	12	0.4	5	350	0.73	spurce
C	8	10	35	8	0.1	8	480	0.35	oak
D	4.5	4.5	95	5	0.34	12	317	0.24	fir
...

Insert the eurocode classes values as ranges in python

The image shows a Grasshopper Python Script Editor window with a Python script for determining timber classes based on EN338 Structural Timber Strength Classes. The script defines class boundaries and iterates through a list of MOE values to assign them to the appropriate timber class.

```
def determine_timber_class(moe):
    # Define your class boundaries based on grading standards
    class_boundaries = {
        'C14': ('moe_min': 0.22, 'moe_max': 0.26, 'mor_min': 1, 'mor_max': 30, 'density_min': 280, 'density_max': 300),
        'C16': ('moe_min': 0.27, 'moe_max': 0.30, 'mor_min': 1, 'mor_max': 30, 'density_min': 310, 'density_max': 319),
        'C18': ('moe_min': 0.31, 'moe_max': 0.32, 'mor_min': 1, 'mor_max': 30, 'density_min': 320, 'density_max': 329),
        'C20': ('moe_min': 0.32, 'moe_max': 0.33, 'mor_min': 16, 'mor_max': 18, 'density_min': 330, 'density_max': 339),
        'C22': ('moe_min': 0.34, 'moe_max': 0.36, 'mor_min': 18, 'mor_max': 24, 'density_min': 340, 'density_max': 349),
        'C24': ('moe_min': 0.36, 'moe_max': 0.37, 'mor_min': 24, 'mor_max': 27, 'density_min': 350, 'density_max': 359),
        'C27': ('moe_min': 0.37, 'moe_max': 0.38, 'mor_min': 27, 'mor_max': 30, 'density_min': 370, 'density_max': 379),
        'C30': ('moe_min': 0.39, 'moe_max': 0.40, 'mor_min': 30, 'mor_max': 35, 'density_min': 380, 'density_max': 399),
        'C35': ('moe_min': 0.41, 'moe_max': 0.43, 'mor_min': 35, 'mor_max': 40, 'density_min': 400, 'density_max': 419),
        'C40': ('moe_min': 0.44, 'moe_max': 0.47, 'mor_min': 1, 'mor_max': 30, 'density_min': 420, 'density_max': 439),
        'C45': ('moe_min': 0.48, 'moe_max': 0.50, 'mor_min': 1, 'mor_max': 30, 'density_min': 440, 'density_max': 459),
        'C50': ('moe_min': 0.51, 'moe_max': 0.53, 'mor_min': 1, 'mor_max': 30, 'density_min': 460, 'density_max': 529),
        'D30': ('moe_min': 0.54, 'moe_max': 0.64, 'mor_min': 16, 'mor_max': 18, 'density_min': 530, 'density_max': 559),
        'D35': ('moe_min': 0.65, 'moe_max': 0.69, 'mor_min': 18, 'mor_max': 24, 'density_min': 560, 'density_max': 589),
        'D40': ('moe_min': 0.70, 'moe_max': 0.75, 'mor_min': 24, 'mor_max': 27, 'density_min': 590, 'density_max': 649),
        'D45': ('moe_min': 0.76, 'moe_max': 0.93, 'mor_min': 27, 'mor_max': 30, 'density_min': 650, 'density_max': 699),
        'D50': ('moe_min': 0.94, 'moe_max': 1.13, 'mor_min': 30, 'mor_max': 35, 'density_min': 700, 'density_max': 899),
        'D60': ('moe_min': 1.16, 'moe_max': 1.33, 'mor_min': 30, 'mor_max': 35, 'density_min': 900, 'density_max': 1000),
    }
    # Define other classes as needed
    # Example: 'C13': ('moe_min': ..., 'moe_max': ..., 'mor_min': ..., 'mor_max': ..., 'density_min': ..., 'density_max': ...),
    # Example: 'C20': (...),
    # Example: 'C22': (...),
    # ...

    # Check which class the timber belongs to
    for timber_class, boundaries in class_boundaries.items():
        if boundaries['moe_min'] <= moe <= boundaries['moe_max']:
            return timber_class
    # If the timber doesn't fit into any class, return None
    return None

# Input list from Grasshopper
# Assuming this is the input list received from Grasshopper containing actual values
moe_list = moe_list # Get the MOE list from Grasshopper

# Output list to store the timber classes
timber_classes = []

# Iterate over each MOE value
for moe in moe_list:
    timber_class = determine_timber_class(moe)
    timber_classes.append(timber_class)

# Output list to store the timber classes
timber_classes = []

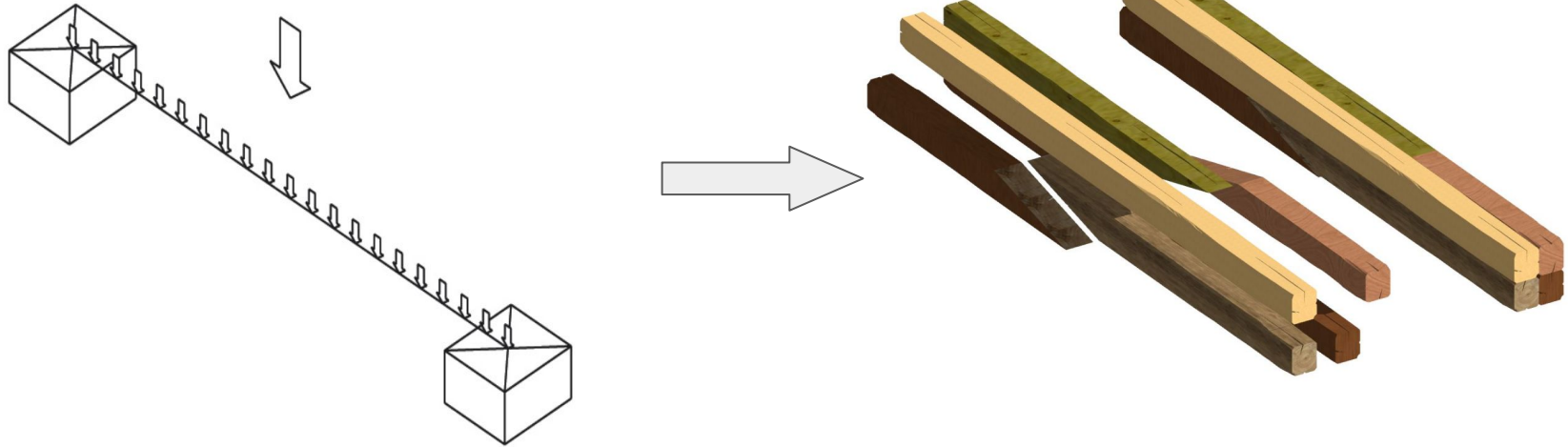
# Iterate over each MOE value
for moe in moe_list:
    timber_class = determine_timber_class(moe)
    timber_classes.append(timber_class)

# Output the timber classes list with enumeration
print("Timber classes:")
for index, timber_class in enumerate(timber_classes):
```

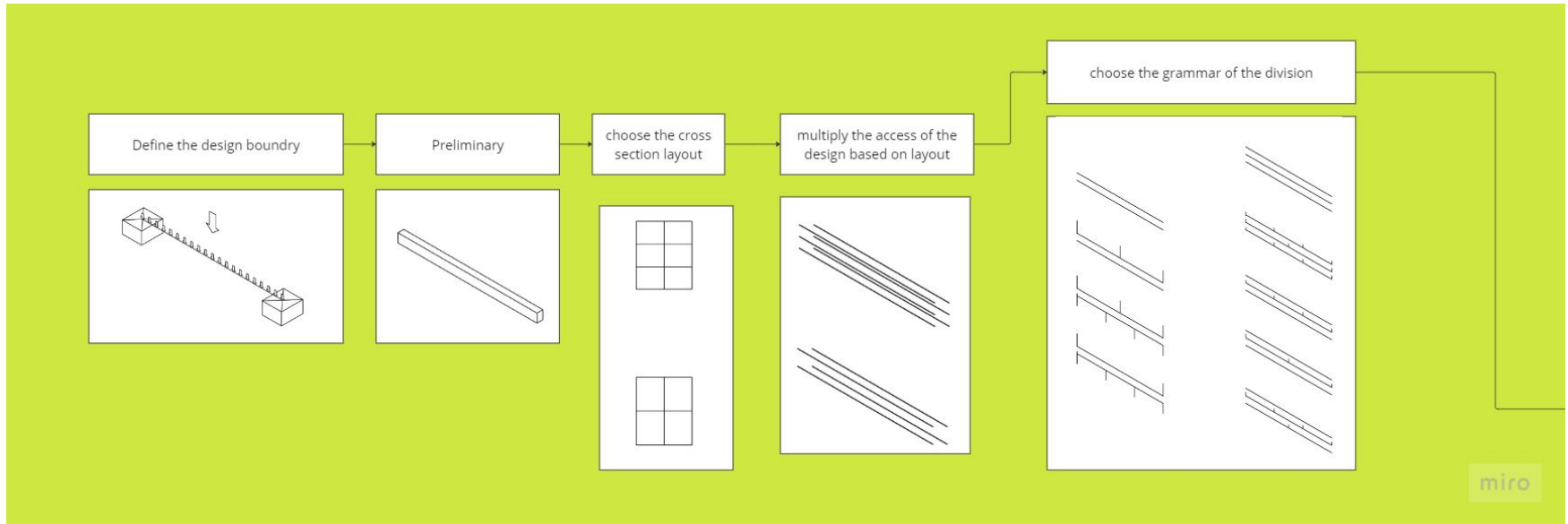
The screenshot also shows a Grasshopper canvas with a Python script component and a List Item component. The List Item component displays the output of the Python script, which is a list of timber classes: D60 and D40.

تصميم
Design

From design boundaries to ISGT

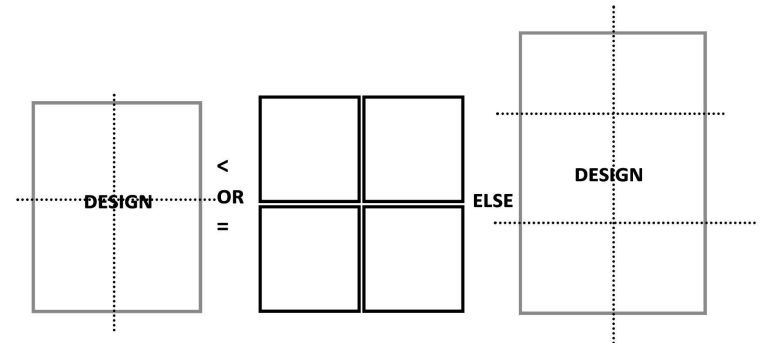
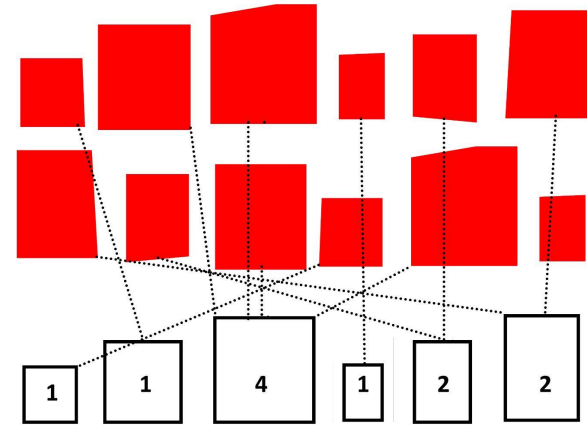


From a design constraint to a layout

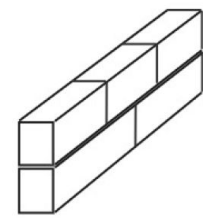
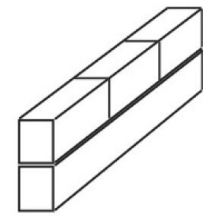
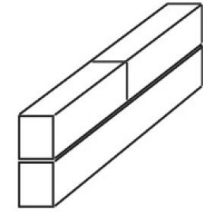
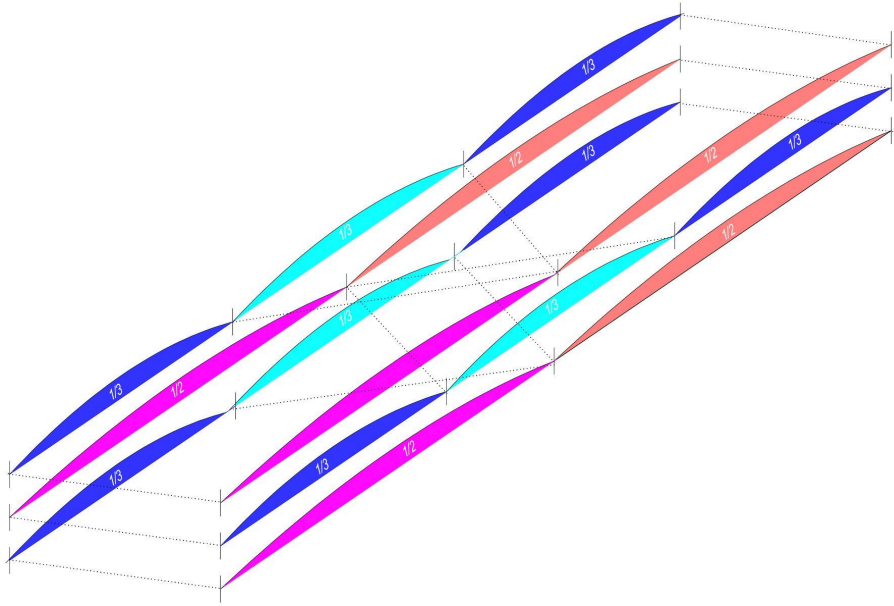


From a design constraint to a layout

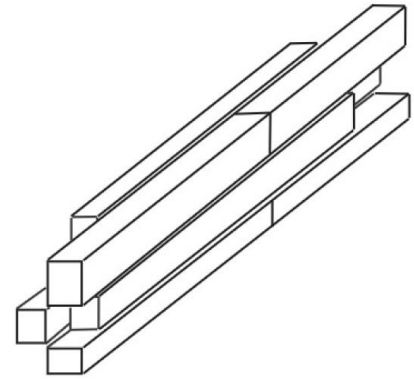
- We conservatively discretize the areas of the sections.
- We calculate the mode (Mod) and the mean of the discretized areas dataset.
- If the area of the preliminary section is less than or equal to four times the area of the mode, we choose the four-lamella layout.
- Otherwise, we choose the six-lamella layout



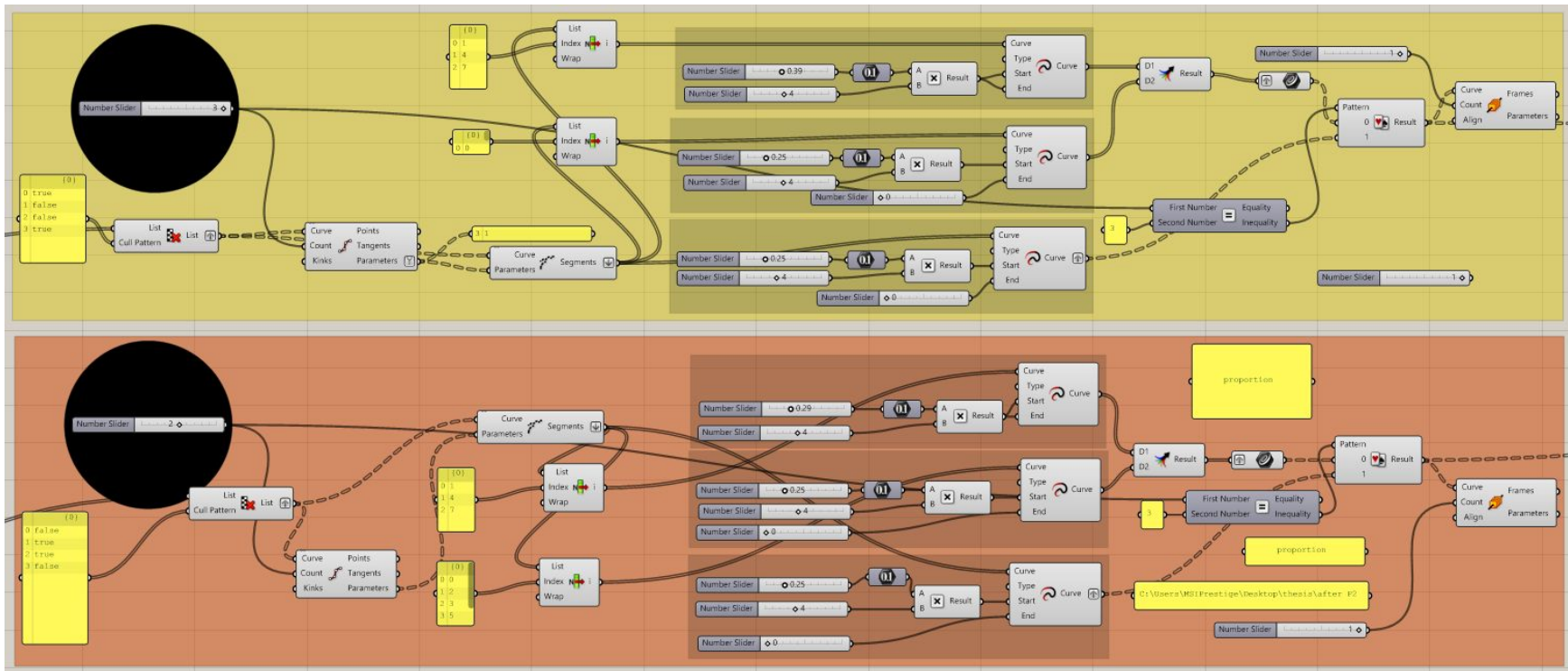
From a design constraint to a layout



1: 1/2	1/2: 1
1: 1/3	1/3: 1
1/2: 1/3	1/3: 1/3

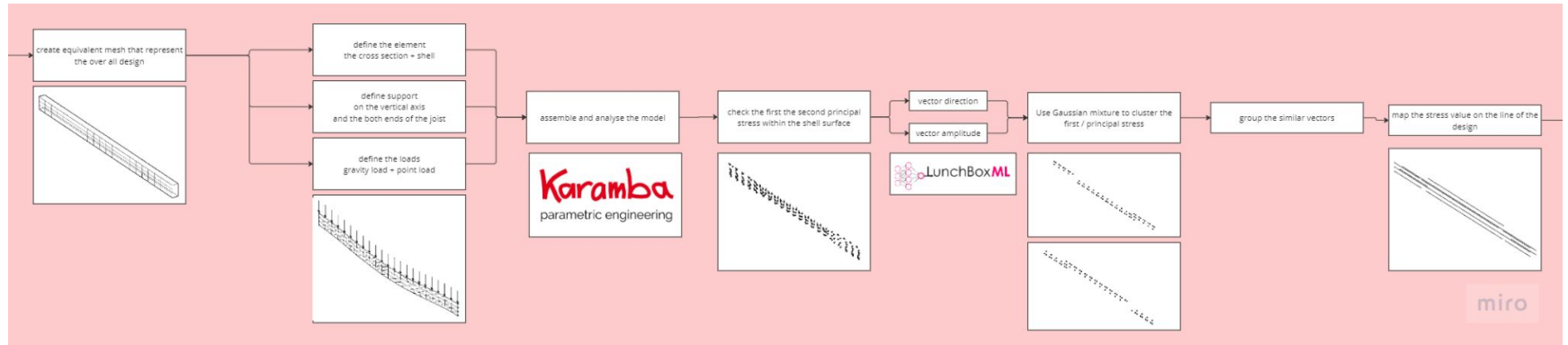


Using a simple grasshopper code to do the division

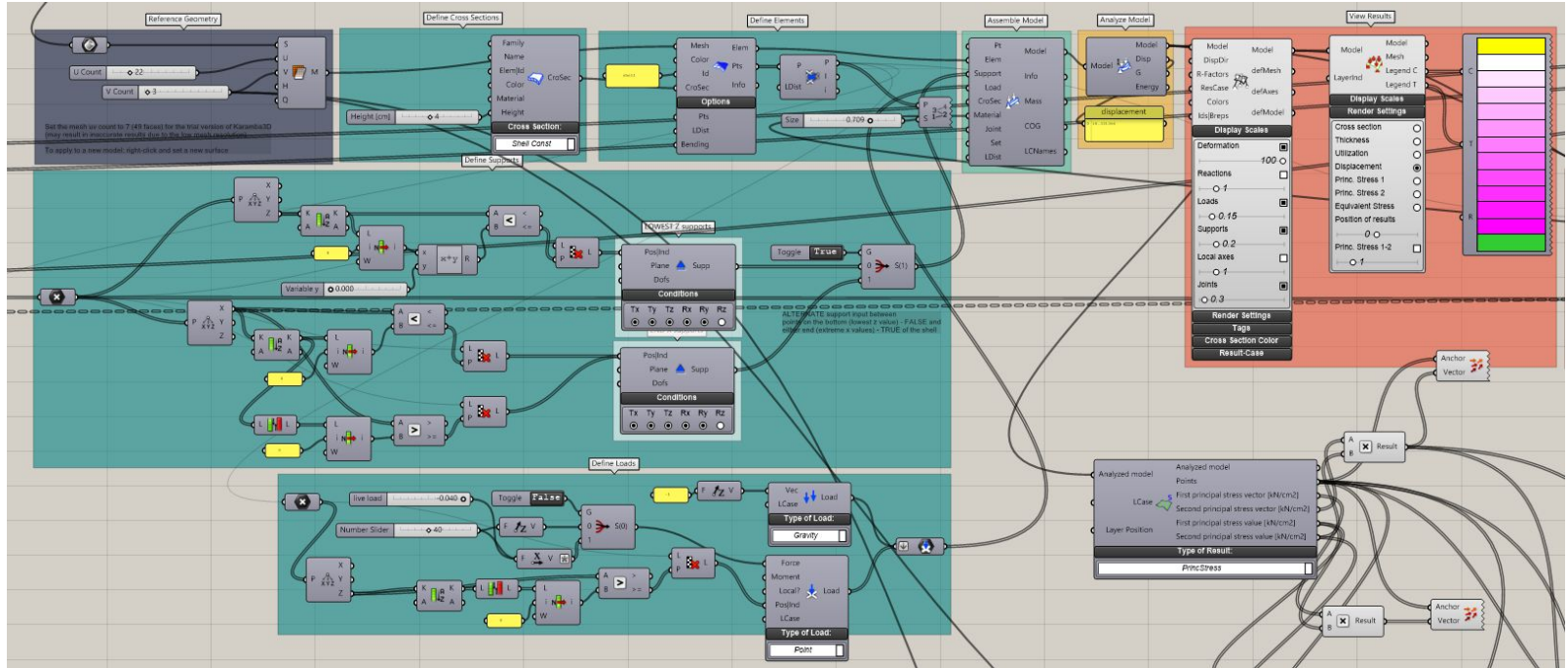


البناء
structure

From Line to a structural demand



5 workflows (Layout - structural - matching - visualization)



From principal stress to a structural layout

CREATE A SURFACE MESH THAT REPRESENT A SECTION OF THE BEAM
- DEFINE THE LOAD CONDITIONS (GRAVITY LOAD + POINT LOAD)
- DEFINE THE SUPPORT

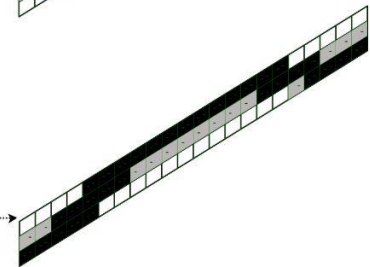
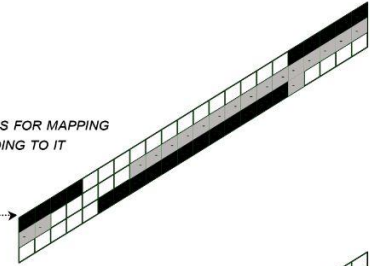
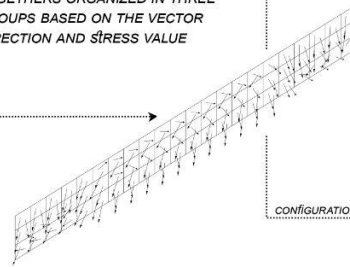
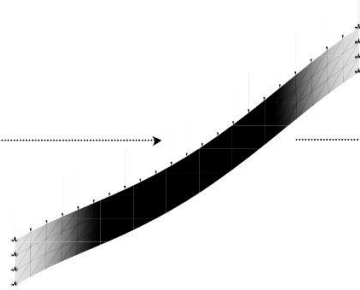
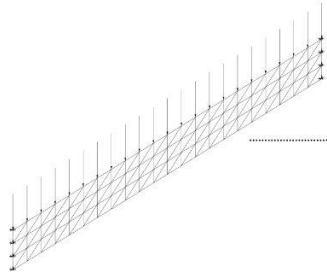
- RUN THE SOLVER AND CHECK THE DEFLECTION

- CHECK THE STRESSES WITHIN THE MESH UNITS
- GET THE VECTORES OF THE FIRST AND SECOND PRINCIPLE VECTORS
- USE K MEANS CLUSTERING TO GROUP ALL THE SIMILAR VECTORS TOGETHER ORGANIZED IN THREE GROUPS BASED ON THE VECTOR DIRECTION AND STRESS VALUE

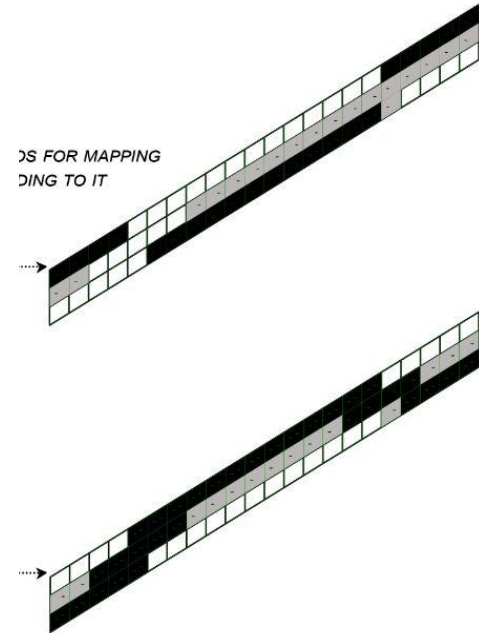
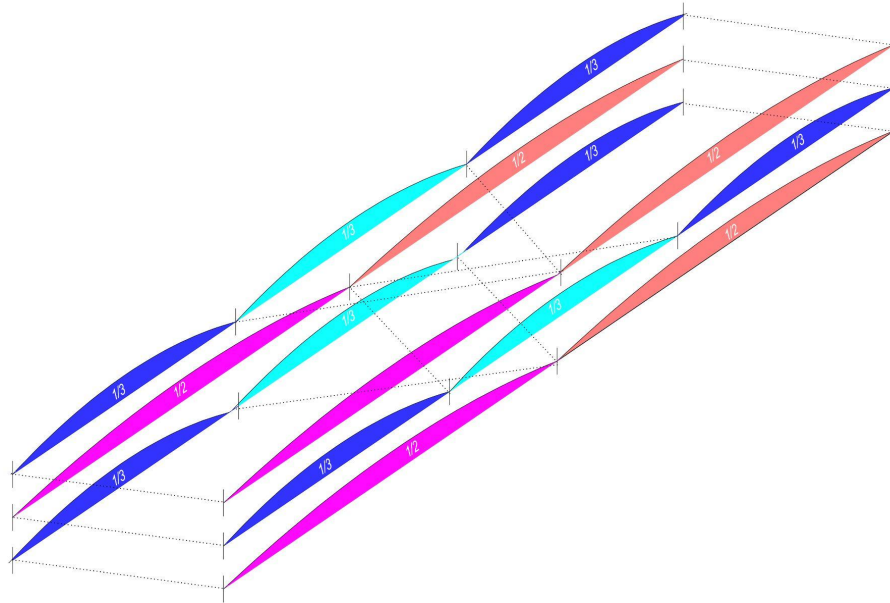
WE GET TWO SCENARIOS FOR MAPPING THE ELEMENTS ACCORDING TO IT STRENGTH

CONFIGURATION 1

CONFIGURATION 2

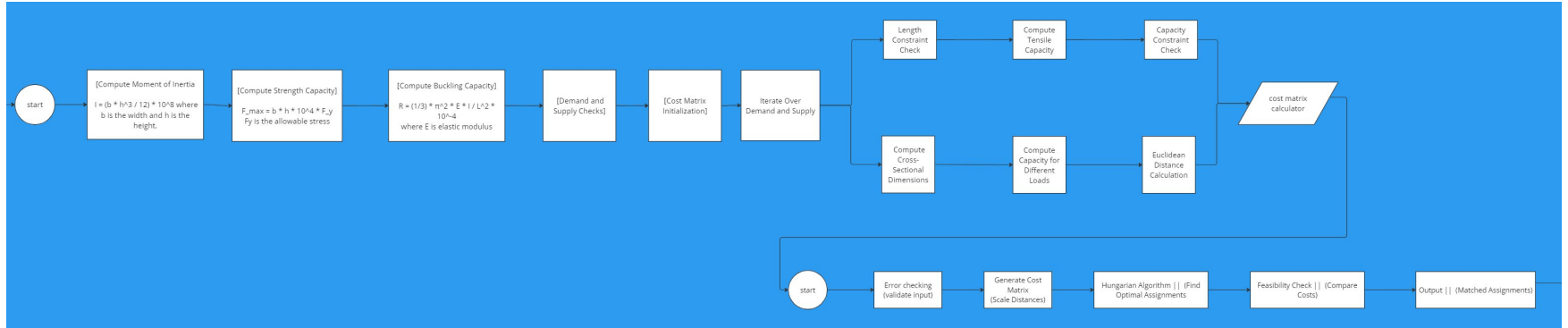


Map the stresses from the mesh to the linear layout



مطابقة Matching

5 workflows (Layout - structural - matching - visualization)



Creating the matching cost

The code calculates the cost matrix for assigning structural beams to different loads and lengths, considering constraints like length and capacity. It uses functions to compute beam properties and iterates through demand-supply combinations to determine costs, eventually converting the result into a Grasshopper data tree structure.

The image displays a Grasshopper Python Script Editor window with a C# script titled "C# Matching backend". The script defines three functions for calculating beam properties: moment of inertia, strength capacity, and buckling capacity. It then iterates through demand and supply combinations to calculate a cost matrix.

```
Grasshopper Python Script Editor
File Edit Tools Mode Help
Test OK

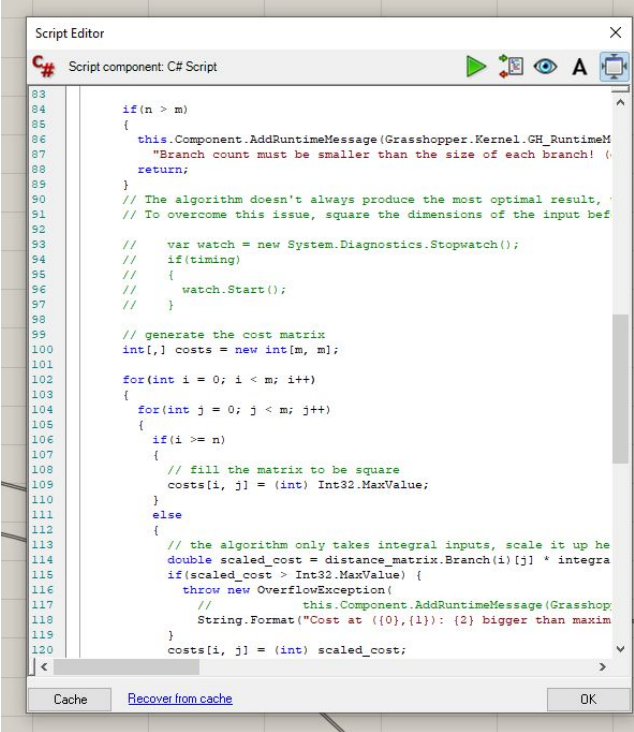
3 import System
4 from System.Collections.Generic import List
5 import math
6
7 from ghpythonlib.treehelpers import list_to_tree, tree_to_list
8 #####
9
10 def compute_moment_of_inertia(b,h):
11     """# input: b,h in meter
12     """# return: I in cm^4
13     """# return: (b^3*pow(h,3)/12)*1e8
14
15 def compute_strength_capacity(b,h,Fy):
16     """# input: b,h in meter;
17     """# Fy in kN/cm^2: allowable stress
18     """# return: Fmax in kN
19     """# return: b*h*1e4*Fy
20
21 def compute_buckling_capacity(b,h,L,E):
22     """# input: b,h,L in meter, E in kN/cm^2
23     """# return: buckling capacity R in kN
24     """# I = compute_moment_of_inertia(b,h)
25     """# return: (1.0/3)*pow(math.pi,2)*E*I/pow(L,2)*1e-4
26     """#
27     #####
28
29 demand_num = len(demand_lengths)
30 supply_num = len(supply_lengths)
31 assert demand_num <= supply_num, 'demand_num ({} > supply_num ({}).format(demand_num, supply_num)
32 assert len(demand_loads) == demand_num
33 assert len(supply_cross_sec_xs) == supply_num
34 assert len(supply_cross_sec_ys) == supply_num
35
36 cost_matrix = [[0.0 for _ in range(supply_num)] for _ in range(demand_num)]
37
38 for i in range(demand_num):
```

The script is connected to a Grasshopper canvas. A "C# Matching backend" component has several inputs: demand_lengths, supply_lengths, demand_loads, supply_cross_sec_xs, supply_cross_sec_ys, allowable_stress, elastic_modulus, and penalty. The output is a cost_matrix. This cost_matrix is then processed by a "distance_matrix" component (using an external dll), which also takes an integral_scale and a penalty input. The output of the distance_matrix is a matched_A2B_ids component, which is then processed by a "7" component (likely a list length or index component) and finally a "1.9318e6" component (likely a multiplier or scaling factor).

Using Hungarian Algorithm to solve the matching

The provided C# script implements the Hungarian Algorithm within Grasshopper for Rhino to solve assignment problems efficiently. It takes input parameters such as a distance matrix representing task-resource costs, scales the costs, and finds the optimal assignment. After validating the total cost against a penalty threshold, it outputs the matched assignments and total cost.

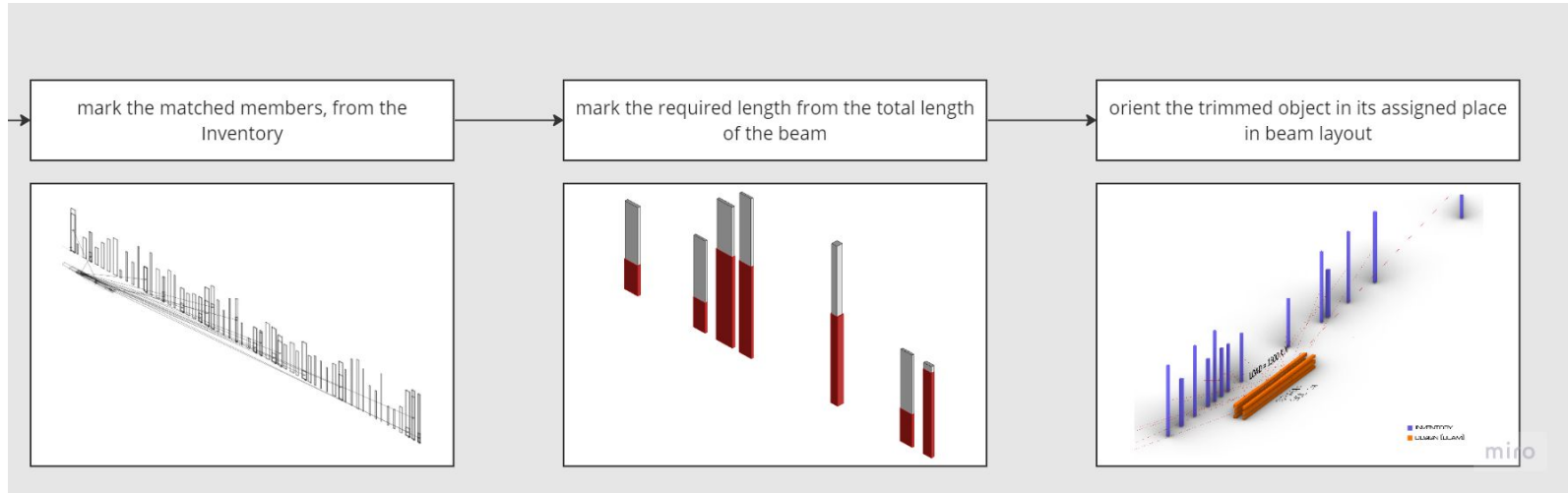
Code source for the hungarian algorithm:
https://github.com/yijiangh/algorithmic_circular_design



```
Script Editor
C# Script component: C# Script

83
84     if(n > m)
85     {
86         this.Component.AddRuntimeMessage(Grasshopper.Kernel.GH_RuntimeM
87             "Branch count must be smaller than the size of each branch! (
88         return;
89     }
90     // The algorithm doesn't always produce the most optimal result,
91     // To overcome this issue, square the dimensions of the input bef
92
93     //     var watch = new System.Diagnostics.Stopwatch();
94     //     if(timing)
95     //     {
96         //         watch.Start();
97     //     }
98
99     // generate the cost matrix
100    int[,] costs = new int[m, m];
101
102    for(int i = 0; i < m; i++)
103    {
104        for(int j = 0; j < m; j++)
105        {
106            if(i >= n)
107            {
108                // fill the matrix to be square
109                costs[i, j] = (int) Int32.MaxValue;
110            }
111            else
112            {
113                // the algorithm only takes integral inputs, scale it up he
114                double scaled_cost = distance_matrix.Branch(i)[j] * integra
115                if(scaled_cost > Int32.MaxValue) {
116                    throw new OverflowException(
117                        //         this.Component.AddRuntimeMessage(Grasshop
118                        String.Format("Cost at {(0},{1)}: {2} bigger than maxim
119                }
120                costs[i, j] = (int) scaled_cost;
121            }
122        }
123    }
124
125    Cache    Recover from cache    OK
```

5 workflows (Layout - structural - matching - visualization)



Creating the matching cost



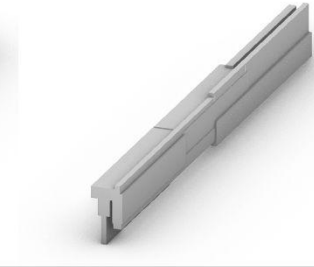
Frame 0000, Value = 1.00



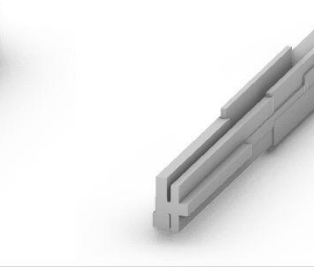
Frame 0001, Value = 100.00



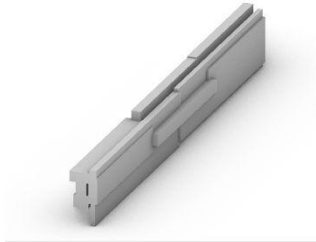
Frame 0002, Value = 200.00



Frame 0003, Value = 300.00



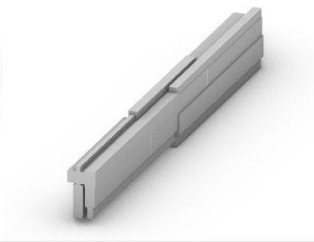
Frame 0004, Value = 400.00



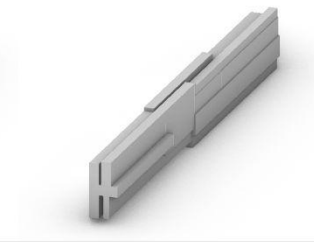
Frame 0005, Value = 500.00



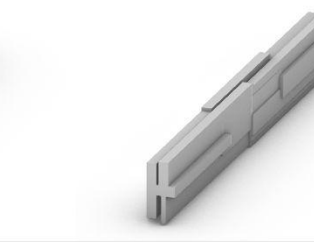
Frame 0006, Value = 600.00



Frame 0007, Value = 700.00

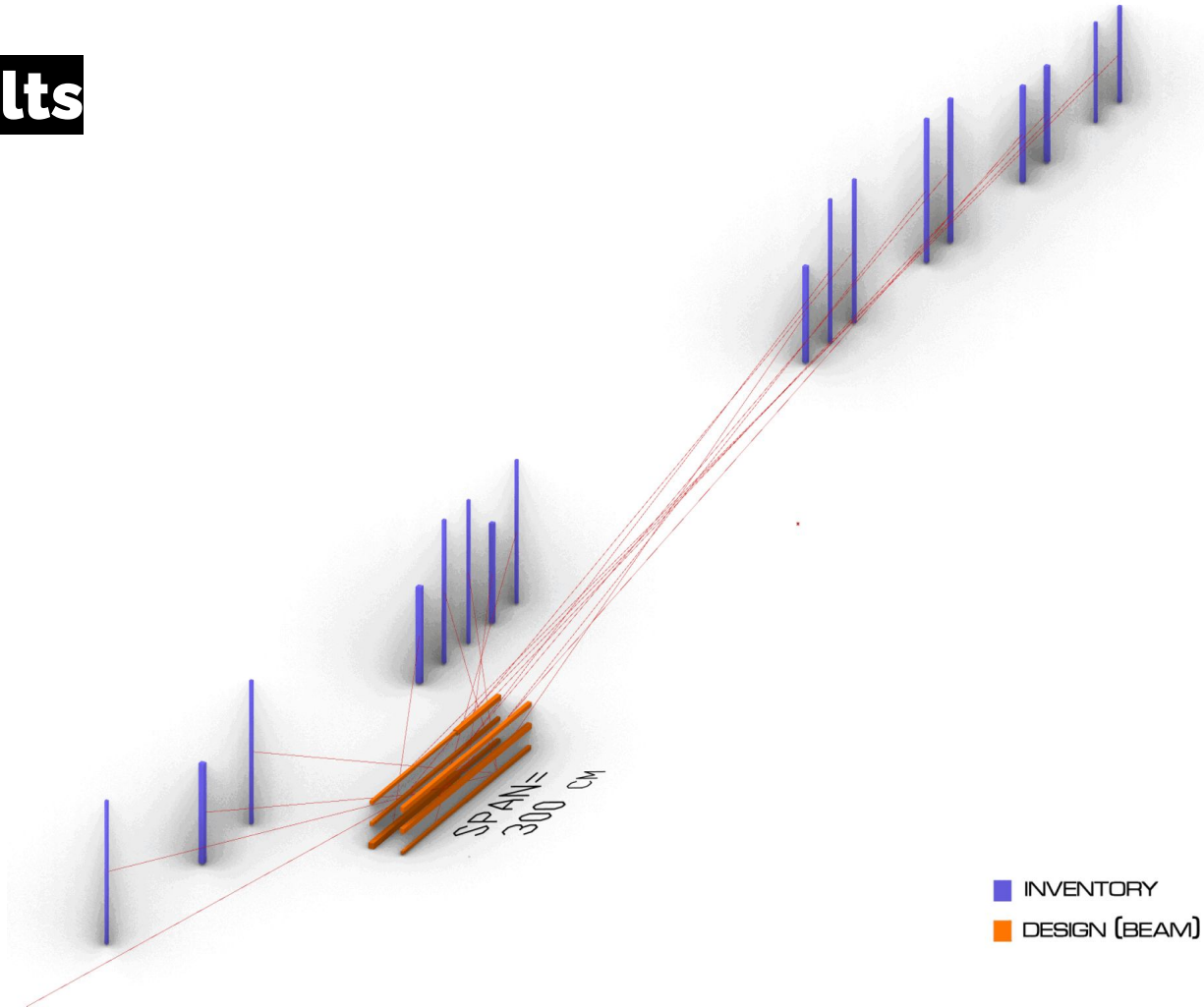


Frame 0008, Value = 800.00



Frame 0009, Value = 900.00

Results



المرحلة الأولى من التجارب

First phase of tests

How to proceed with the concepts

كيفية الإنتاج
How to produce

ماهية المنتج
What is the Results

How to proceed with the concepts

What is the Product

**IGST with different
configuration**

**IGST from different
Timber species**

How to proceed with the concepts

**IGST from different
Timber species**



**Hardwood/
Hardwood**

**Softwood/
Hardwood**

**Softwood/
Softwood**

Collecting the timber



Prins
Bernhardlaan 6,
2628 BX Delft



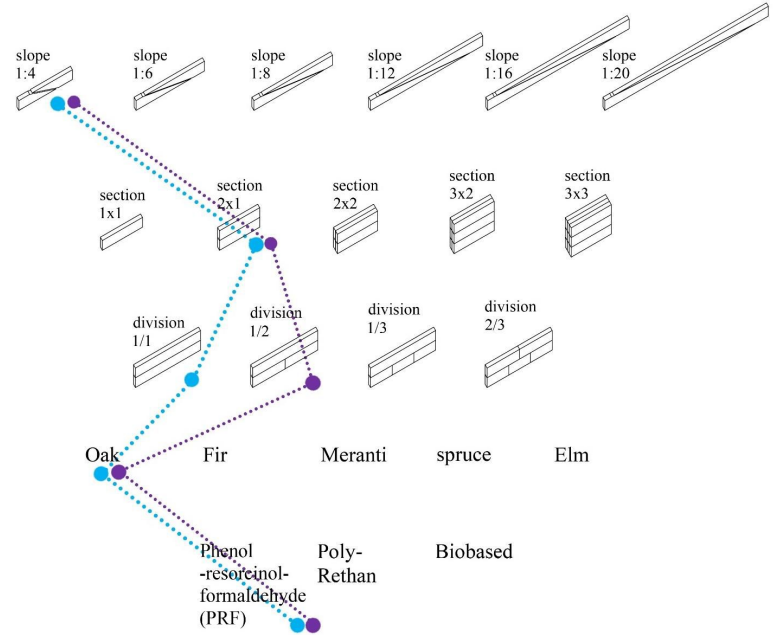
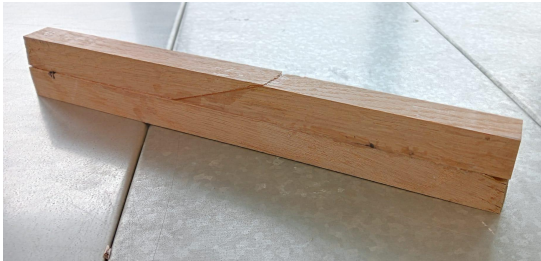
Julianala
an 134,
2628 BL
Delft



Van Hasseltlaan
2625 HS

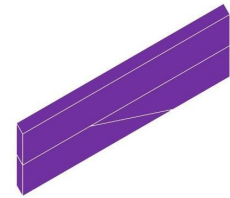
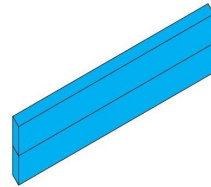


Sample 3, 4

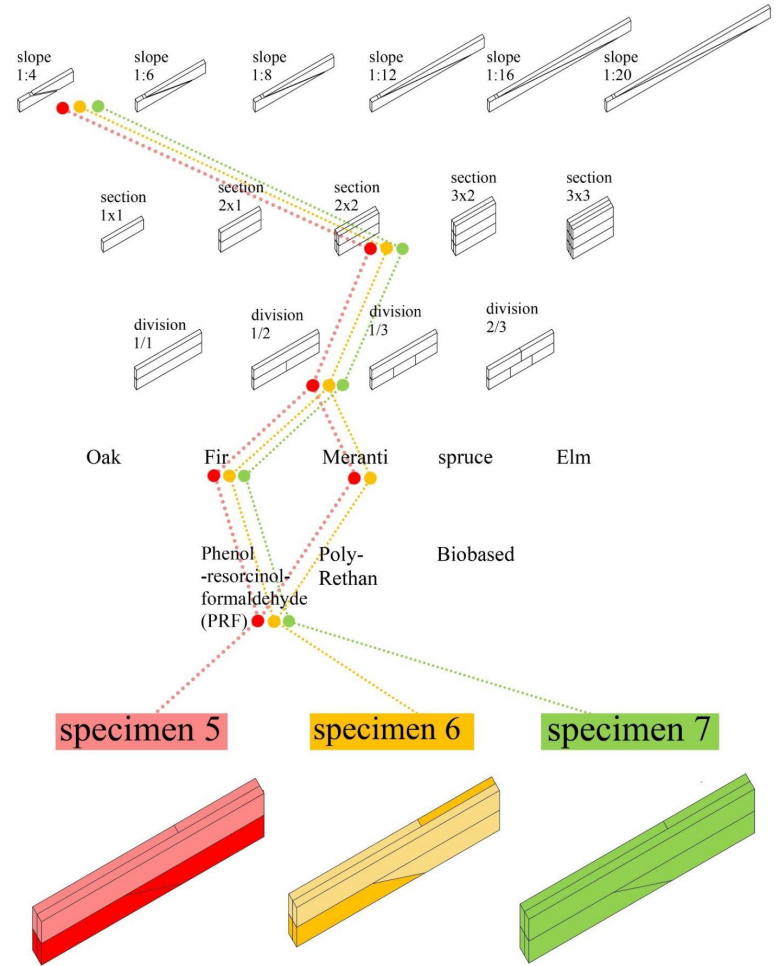
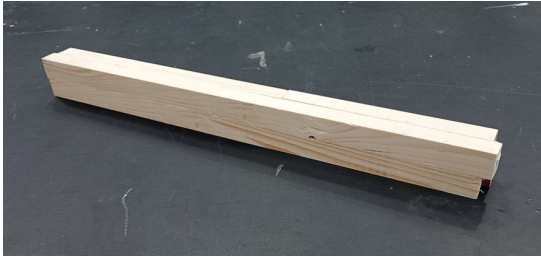


specimen 3

specimen 4



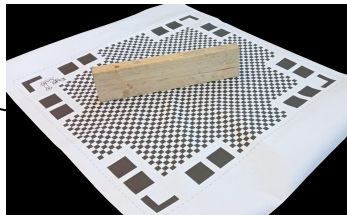
Sample 5,6,7



Manufacturing the specimens



Collecting the timber



Scanning and grading



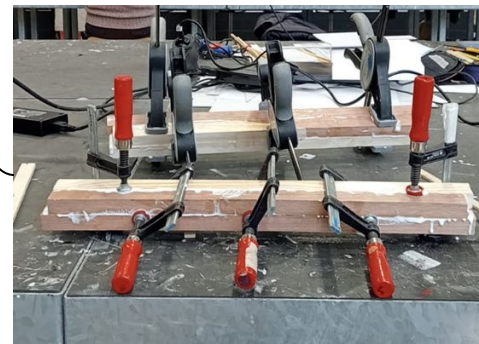
assembly



Cutting and cleaning

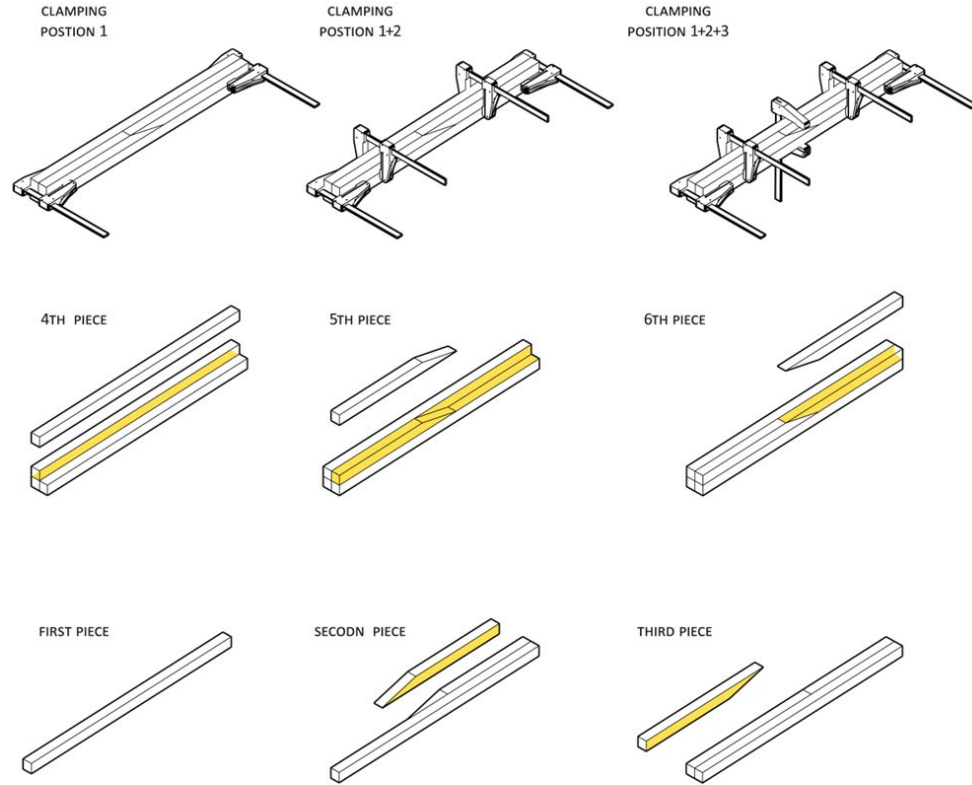


Glueing the first two sample



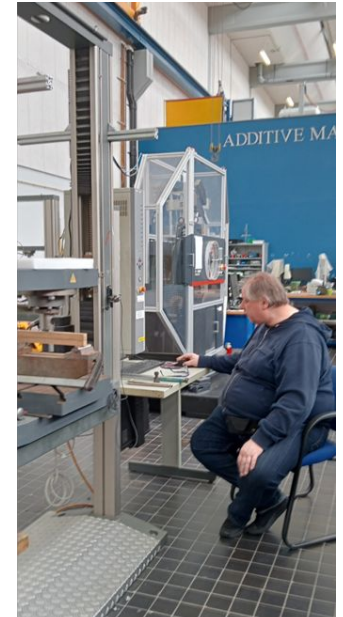
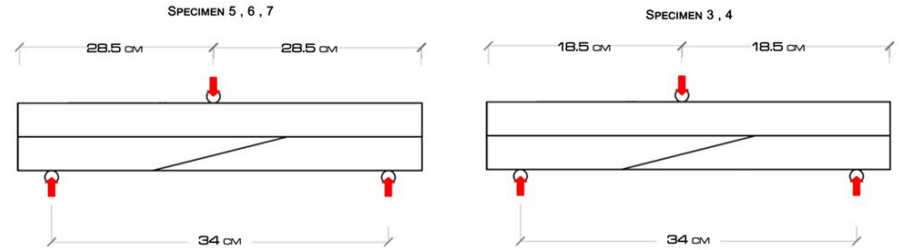
Glueing the first two sample

Assembly sequence:



Mechanical test

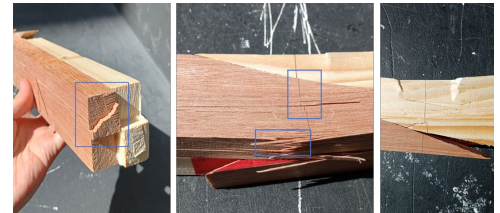
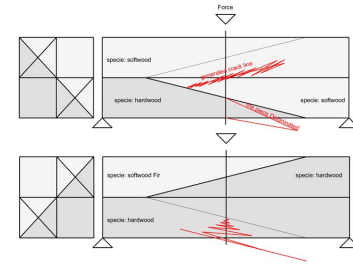
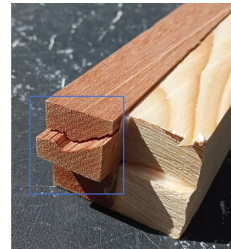
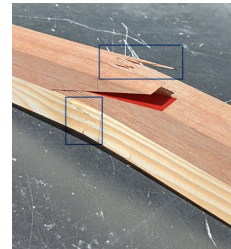
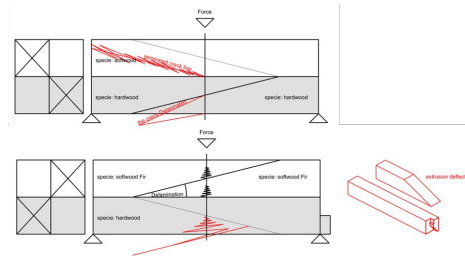
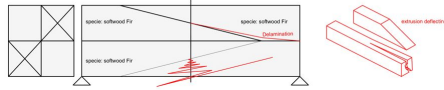
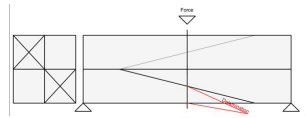
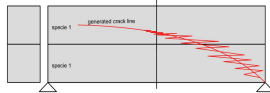
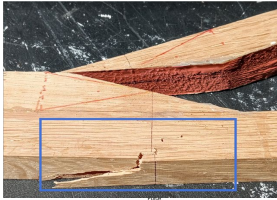
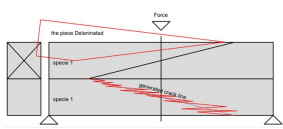
The 3-point bending mechanical test occurred in the 3ME faculty, in the lab of material mechanical behaviour, with the assistance of Dr. ir. F.A. Veer. The test utilized a low- and high-temperature tensile and fatigue testing machine with a span of 34 cm between the supports, a cylindrical pressure head with a diameter of 6 cm, and a pressure speed of 5 mm per second.



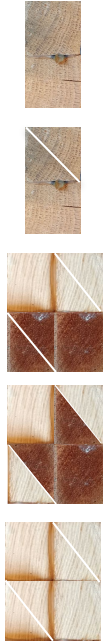
Mechanical test



Failures observations



Failures observations



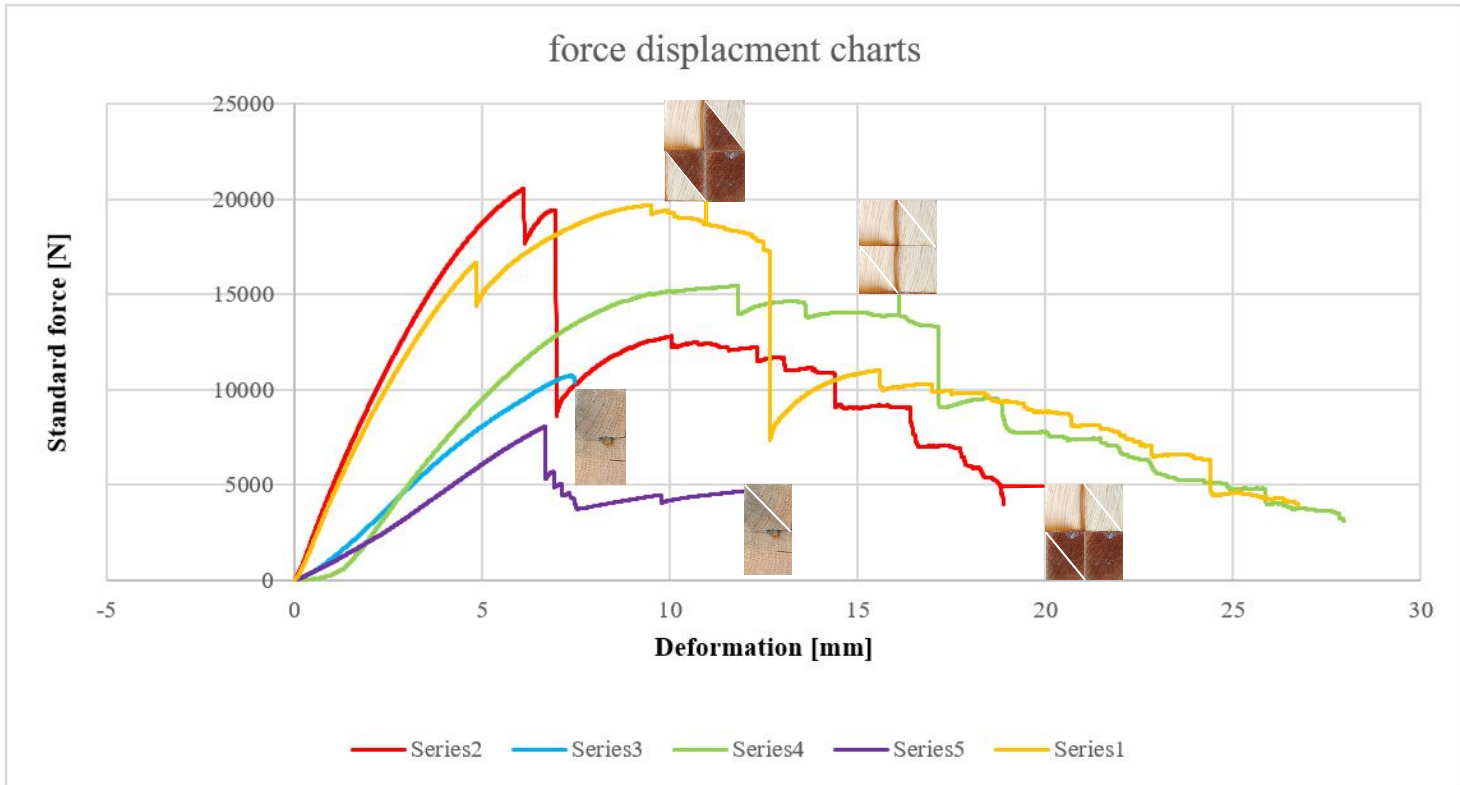
	CRACK IN THE MIDDLE	CRACK AT THE SUPPORT	LAMELLAS DELAMINATIONS	SCARF JOINT DELAMINATION	FIBER EXTRUSION	FIBER SPLIT	PHOTO
Specimen 3		X					
Specimen 4	X		X				
Specimen 5	X			X	X		
Specimen 6	X			X	X		
Specimen 7	X		X	X		X	

Breaking test results



	F_{\max}	dL at F_{\max}	F_{Break}	dL at break	a_0	b_0	S_0
	N	mm	N	mm	mm	mm	mm ²
Specimen 3	10739.19	7.363589	10363.42	7.445922	100	100	10000
Specimen 4	8088.012	6.674073	4688.503	11.99171	100	100	10000
Specimen 5	20574.39	6.110257	3984.609	18.87277	100	100	10000
Specimen 6	19697.14	9.479986	3933.534	26.73088	100	100	10000
Specimen 7	15463.81	11.81508	3092.065	27.96162	100	100	10000

Results



Results:

- Except for Specimen 3, all specimens show a sudden drop in applied force after lower lamella breakage due to lamination issues and specimen anatomy.
- Following the drop, pieces exhibit non-linear elastic behavior as strain transitions from lower to upper lamella. This behavior is most evident in Specimens 5 and 6, where lower lamella is mostly hardwood. Specimen 4 shows less clear non-linear elastic behavior, while Specimen 7, made of a single piece with uniform stiffness, does not exhibit prominent non-linear elastic behavior.
- Specimen 5 displays the highest stiffness, enduring over two tons before breaking, while Specimen 6 remains in the elastic range for a longer period despite reaching higher deformation values before failure.
- Specimen 7 experiences the longest period of plastic deformation before failure.

Key consideration(Glue)

- Careful consideration of glue selection and application is crucial, focusing on the type and quantity of adhesive used in the lamination process.
- Positioning of clamps and surface treatment techniques are equally important factors impacting specimen performance.

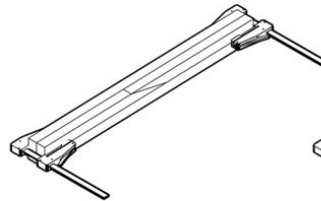
The type of glue used for the previous experiment



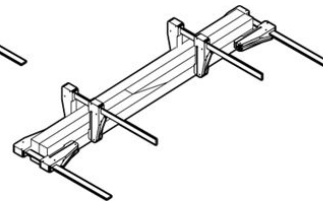
The proposed glue for future experiments



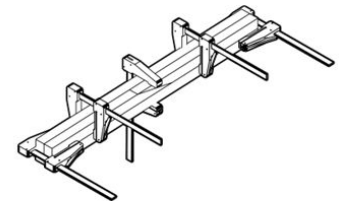
CLAMPING POSITION 1



CLAMPING POSITION 1+2

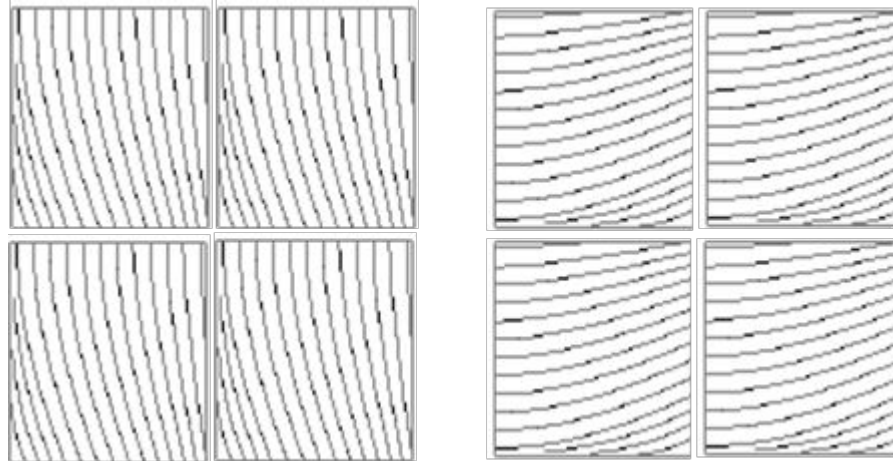


CLAMPING POSITION 1+2+3



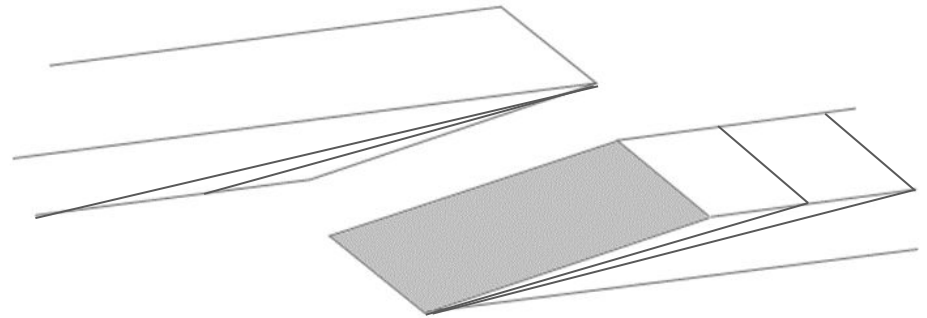
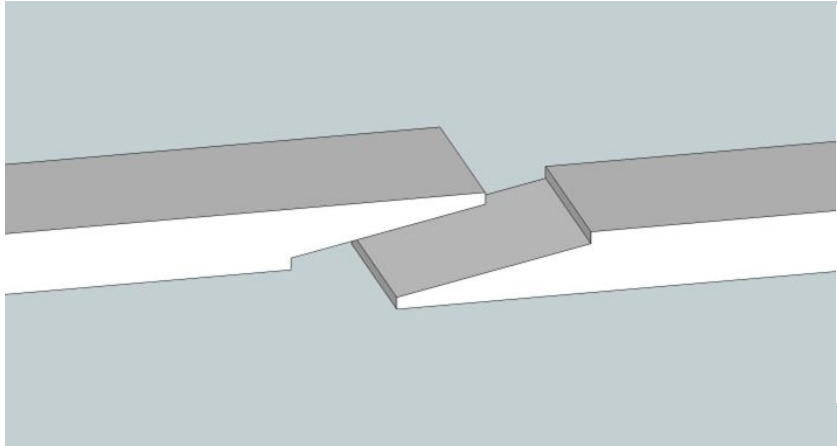
Key consideration (grain)

- Grain orientation is critical, especially in four-lamella specimens.
- Tearing of fibers in the lower lamella due to compression forces can occur.
- To prevent this, avoid diagonal grain orientation in the lower lamella.
- Promoting uniform grain direction across all lamellas enhances structural integrity.

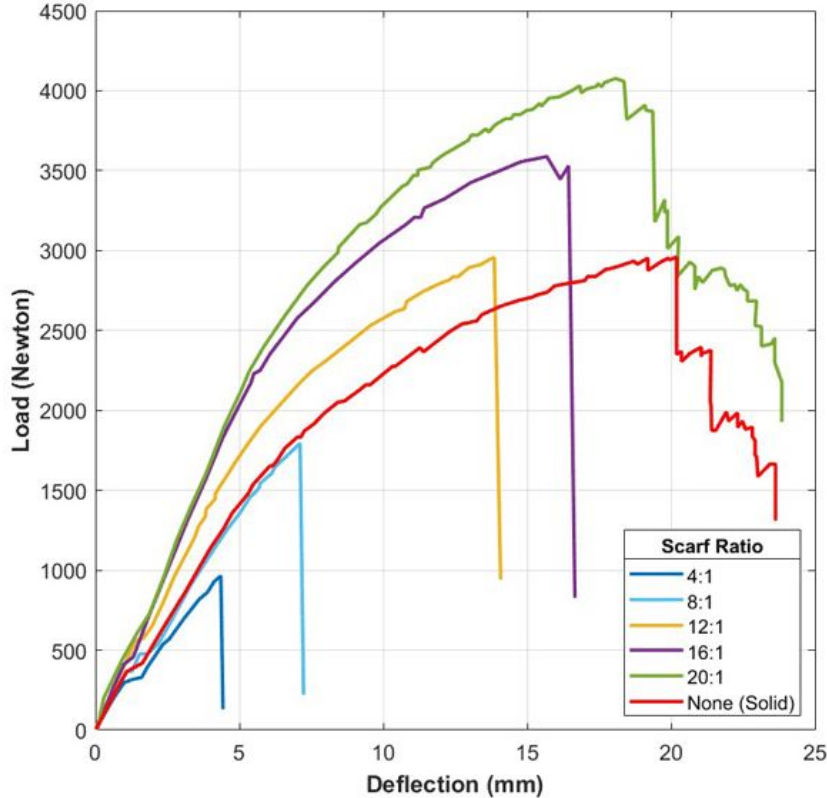


Key consideration(slope)

- Enhancing scarf joints is crucial to minimize delamination.
- Using a nipped scarf joint instead of a plane scarf joint can improve connection integrity.
- This modification reduces the risk of delamination, enhancing overall structural robustness.



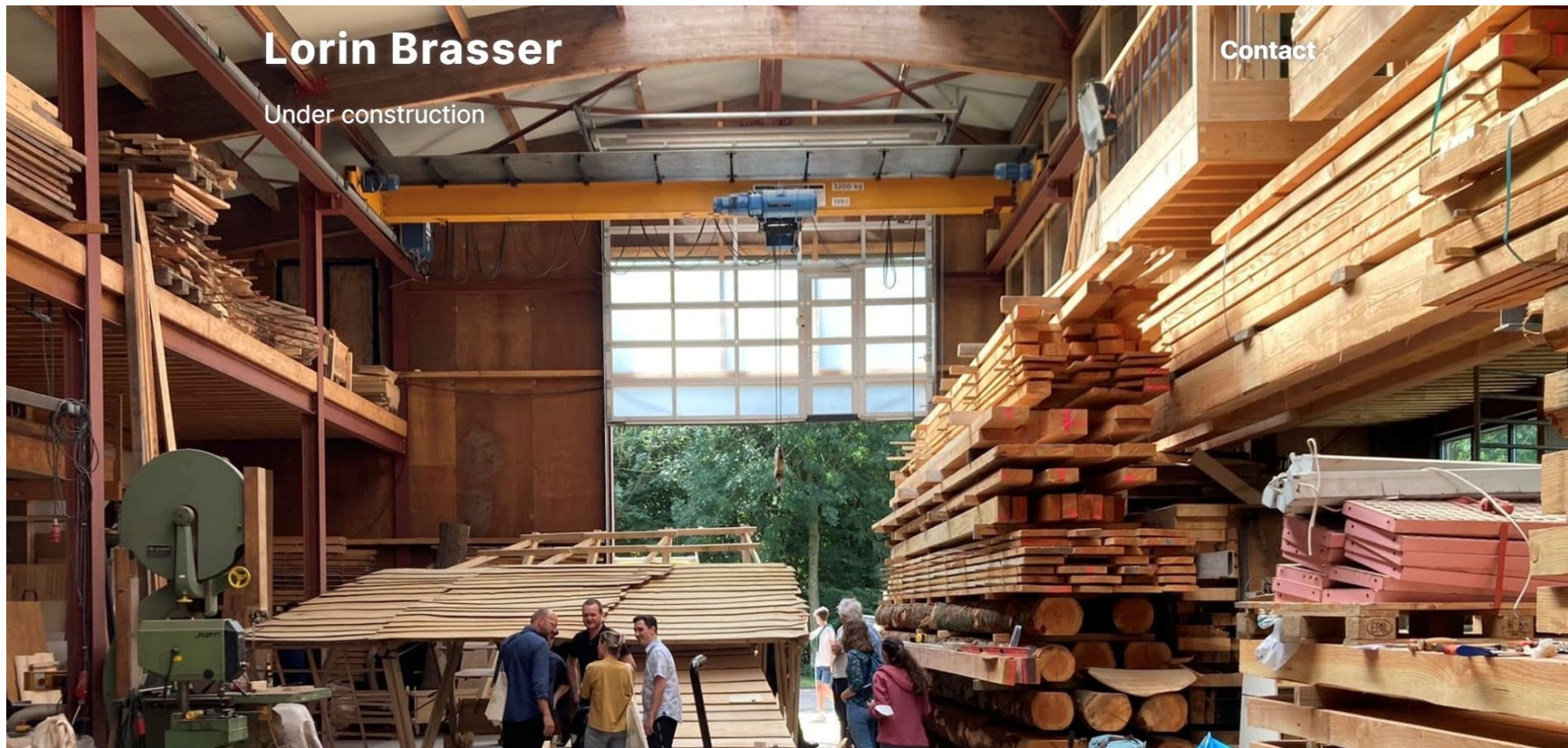
Key consideration(slope)



Mechanical Properties		Ultimate Flexural Strength (MPa)	Young's Modulus (MPa)
ABS Yachts (2017)		66.00	10,000
ISO 12215-5 (2019)		77.00	12,060
Experimental	Solid Timber	73.51	11,980
	4:1 Scarf	18.28	8,045
	8:1 Scarf	38.86	10,270
	12:1 Scarf	48.72	12,379
	16:1 Scarf	93.43	14,486
	20:1 Scarf	96.11	15,250

المرحلة الثانية من التجارب
second phase of tests

Second phase of experiments



Lorin Brassler

Under construction

Contact

Second phase of experiments

What is the Product

**IGST with different
configuration**

**IGST from different
Timber species**

Second phase of experiments

From design
constraints to layout
Workflow

The results of first
phase experimen
Scarf joint and Glue

IGST with different
configuration

1/1

1/2

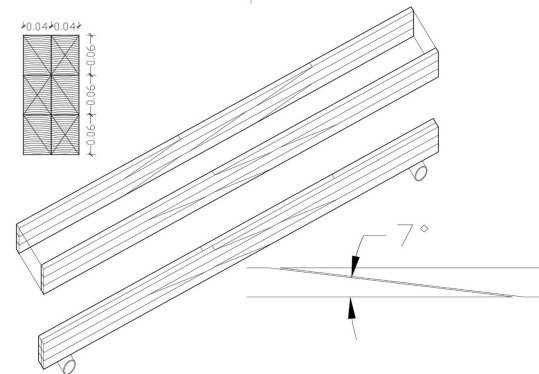
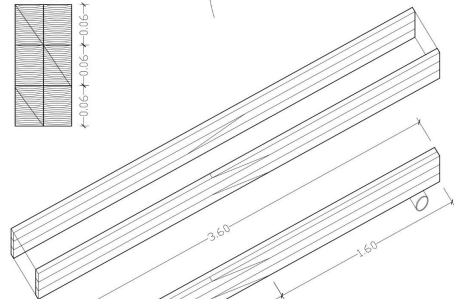
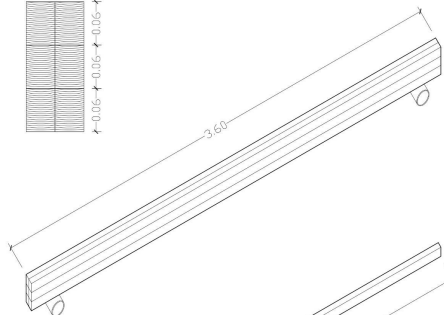
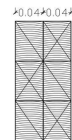
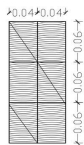
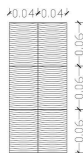
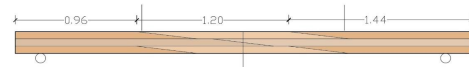
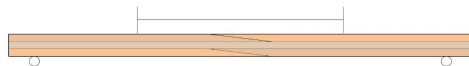
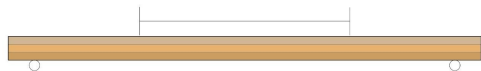
2/3

division ratio

division ratio

division ratio

Developing specimens:



1/1

1/2

2/3

division ratio

division ratio

division ratio

No of piece = 6

No of piece = 3

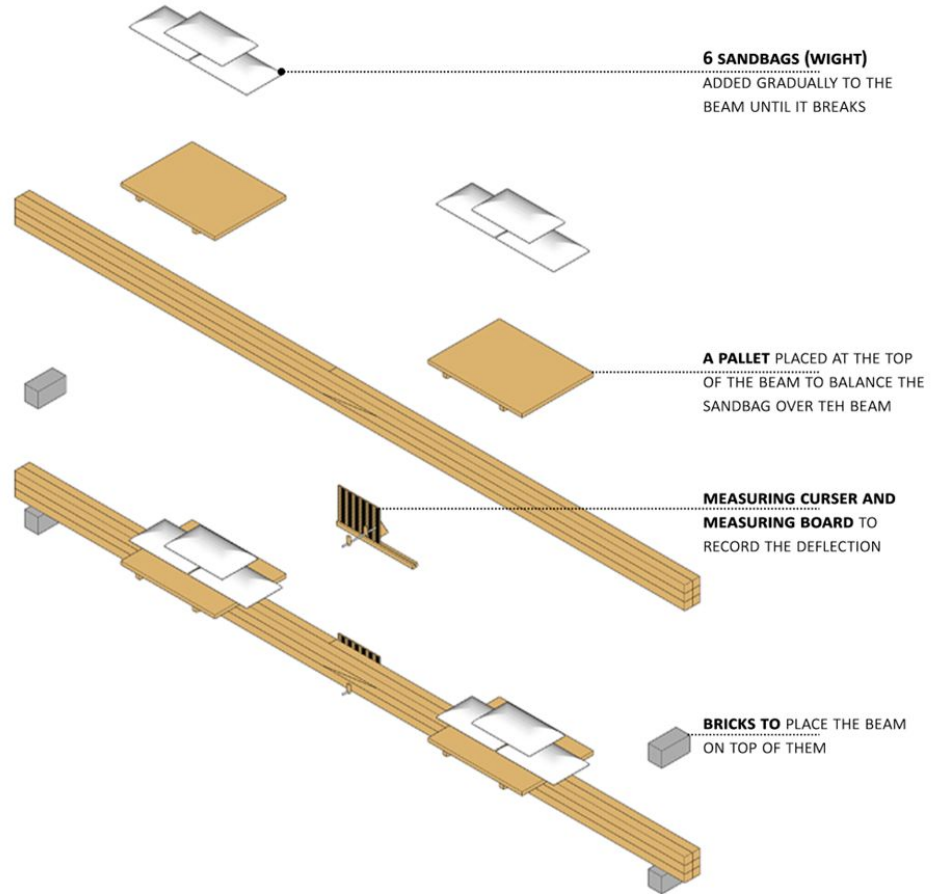
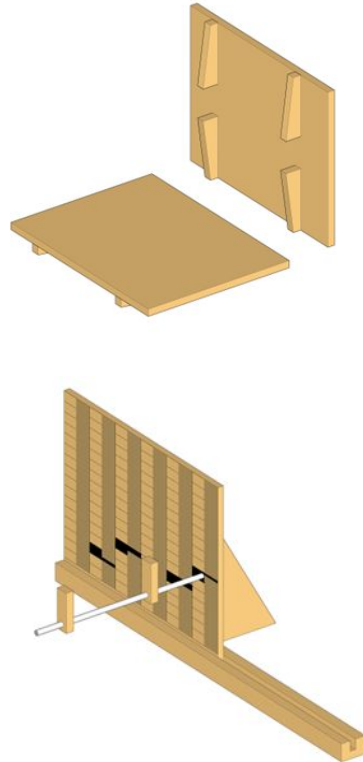
No of piece = 6

No of piece = 3

No of piece = 3

No of piece = 6

Experiments setting



Hypothesis

We hypothesize that in interlocking solid glued timber beams made from reclaimed stocks, **increasing the number of lamellas and joints will increase strength**. Additionally, the placement and slope ratio of the joints will significantly impact beam performance and strength

- How does the **number of lamellas** affect the strength of interlocking solid glued timber beams produced from reclaimed stocks?
- How do the **quantity and placement of joints** influence the overall strength of these beams?

On site Visual grading



CONTINUOUS GRAIN
(PREFERRED)



RAIN INTEREPTED BY BIG
KNOTS (AVOIDED)



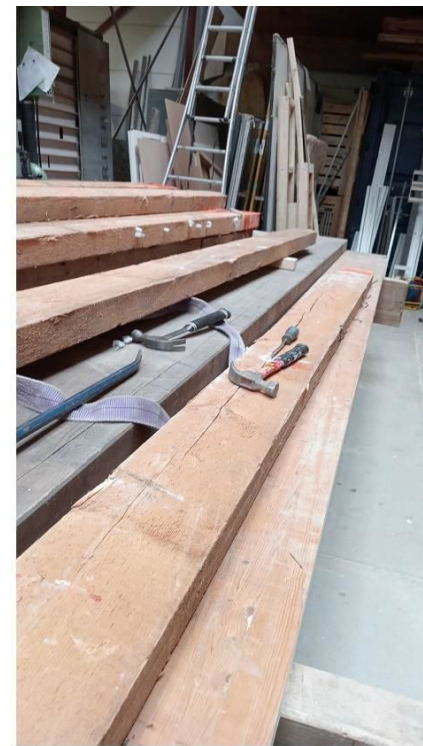
AVOIDED ROT



SEPERATING THE CHOSEN PIECES FROM THE VISUAL FIELD-GRADING



RUSTY SCREWS STUCK INSIDE THE FIBERS



DURING THE PROCESS OF CLEANING

Cutting and Planning



USING THE
VERTICAL WALL
SAWY TO CUT
THE PIECES



USING THE
PLANNER TO
PLAIN THE
PIECES IN SHAPE

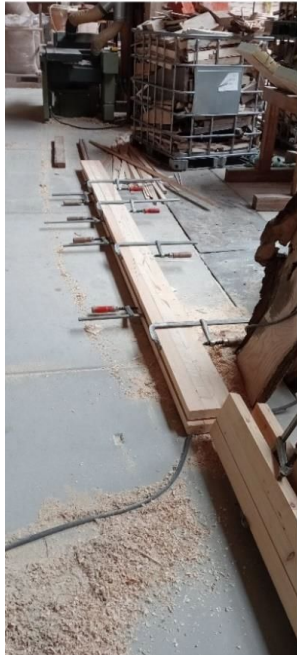


USING TH TABLE
SAW TO CUT THE
BIGGER PIECES



BUNNDLE OF
LAMELLA READY
FOR LAMINATING

Dry fitting



AGGREGATE THE DRY
FITTED PIECES
CLAMPS TO MOVE IT
TO THE WORKING
BENCH



PLACING THE PIECES
ON THE WORKING
BENCHES AND
PLANNING THE THE
CUT



CHECKING THE
MOISTURE CONTENT
BEFORE LAMINATING

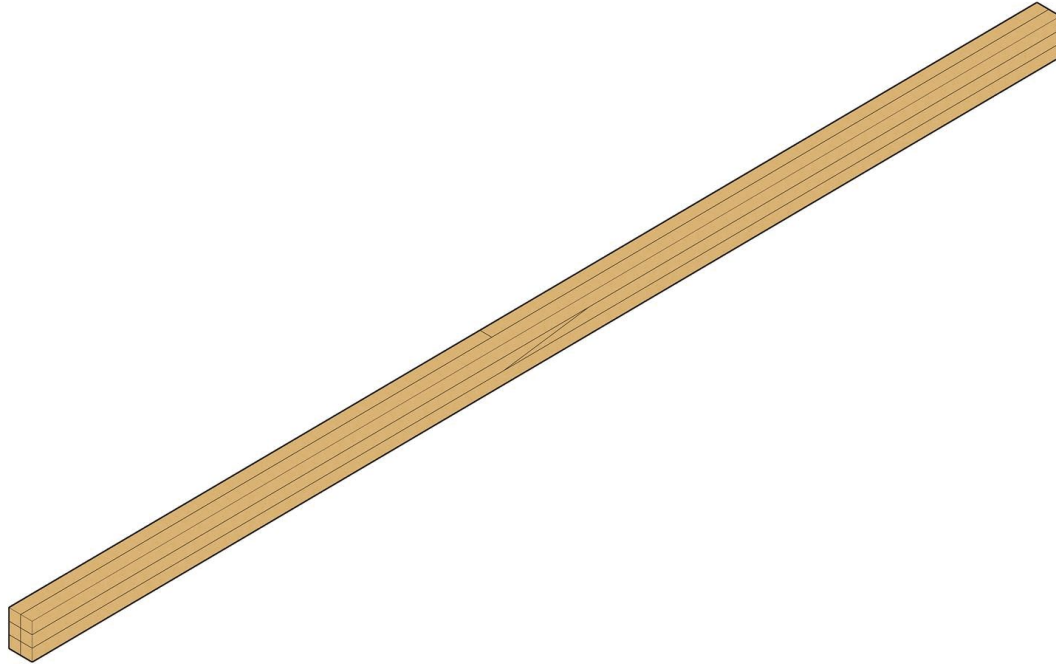


DRY FITTING , AND
DOUBLE CHECL THE
SIZE OF THE PIECES

Preparing for Lamination



Preparing for Lamination



READY TO TEST

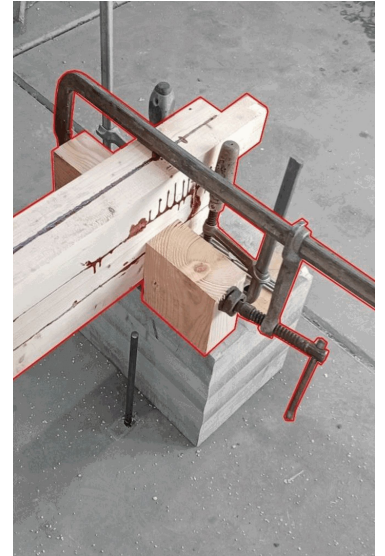
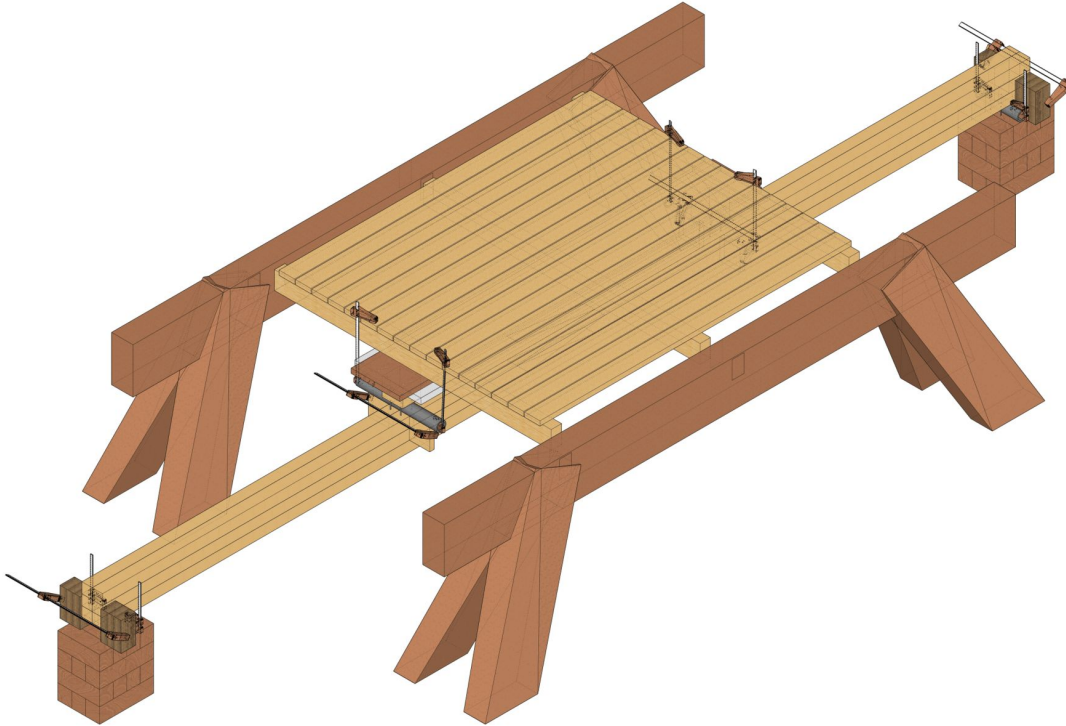
10 minutes + 10 Minutes



Drying 5 hours to one day



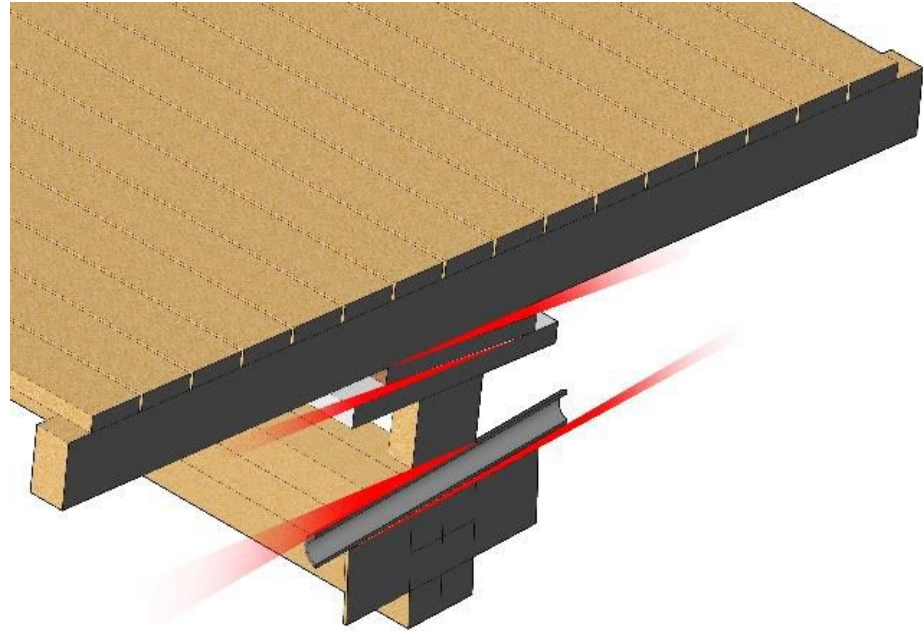
PREPARING AND BALANCING THE TEST SETTING



Using sand bags the loads



Tolerance and movement, an accurate



Sand bags gets torn through the process



Using water tank for the load



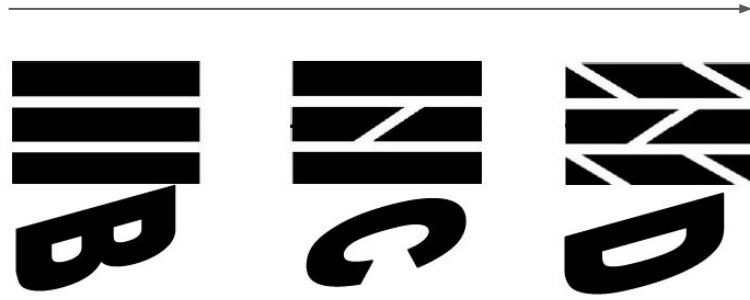
Using water tank for the load



PREPARING AND BALANCING THE TEST SETTING

Specimen	P	a	E	I	L	#DIV/0!	Inst SLS	Stat SLS	Max measured def
D	10000	1.2	11000000000	0.000038	3.6	0.039617225	0.0072	0.012	0.015
	4000	1.2	11000000000	0.000038	3.6	0.01584689	0.0072	0.012	none
C	10000	1.2	11000000000	0.000038	3.6	0.039617225	0.0072	0.012	0.016
	4200	1.2	11000000000	0.000038	3.6	0.016639234	0.0072	0.012	
A	10000	1.2	11000000000	0.000038	3.6	0.039617225	0.0072	0.012	0.021
	5200	1.2	11000000000	0.000038	3.6	0.020600957	0.0072	0.012	0.015

REASONING

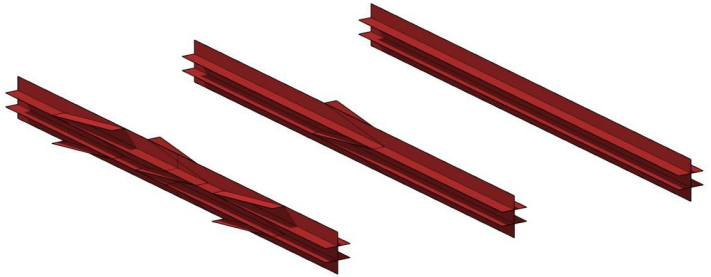


C24	C24
C24	C24
C24	C24

C20	C20
C16	C14
C24	C24

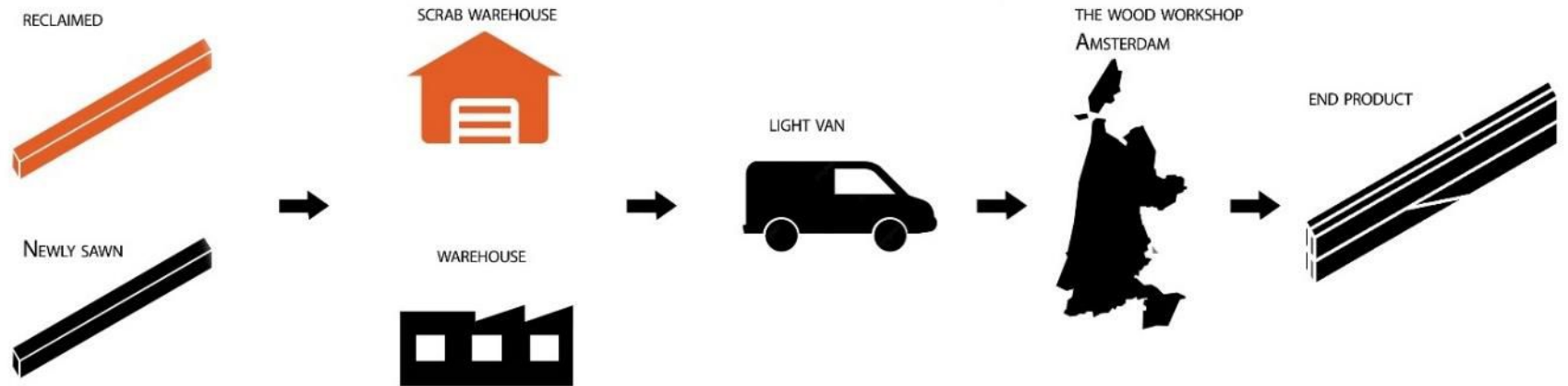
?

C12	C20
C14	C14
C20	C24



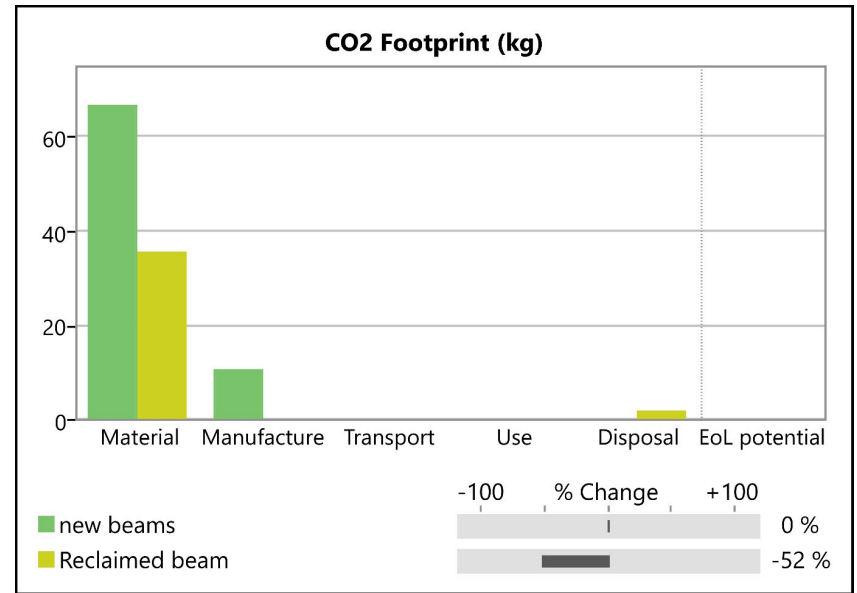
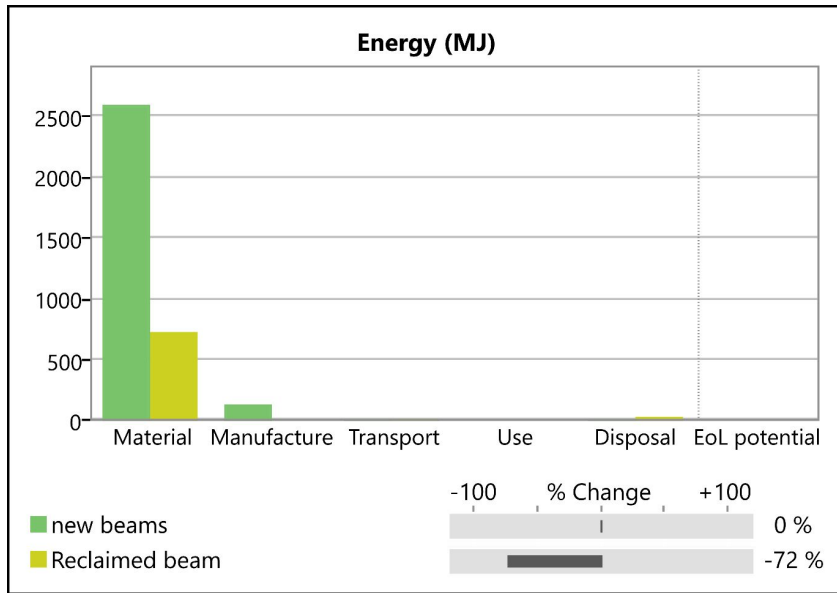
Environmental impact reclaimed vs New

Defining a simple scenario that represent both source

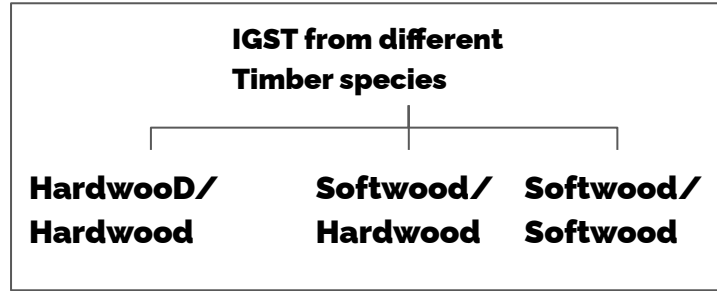


Environmental impact reclaimed vs New

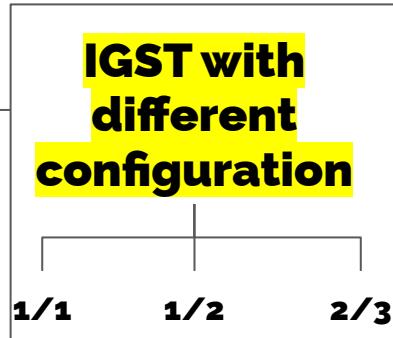
Using Granta Edupack Eco_Audit tool



conclusion:



From design
constraints to
layout Workflow



The results of first
phase experimen
Scarf joint and Glue

**Structure Demand
workflow**

conclusion:

From Literature

- Reclaimed timber has significant potential to fill the gap in structural materials due to current environmental challenges.
- The key aspect of using reclaimed timber is the regrading process; more tools and methods adopted by salvagers enable its structural use.
- IGST timber shows great potential as an engineered wood product (EWP), especially with larger sections allowing for wider spans than current EWPs.
- Despite the simple manufacturing techniques of IGST, optimizing production is complex, involving factors like the number of lamellas, slope of the scarf joint, timber species, and glue type.
- Literature indicates that for low-density timber like spruce, a higher slope for the scarf joint is preferable, ideally avoiding an 8:1 slope ratio.
- The number of lamellas is also crucial; more lamellas in the section typically provide better strength, though further investigation is needed.

conclusion:

From workflows:

- The developed workflow successfully selected the right piece from a dataset of regraded elements based on load and length demand.
- However, it does not optimize the overall IGST performance, as it needs to consider the slope of the scarf joint and the effect of the glue used.
- Integrating these factors and environmental impact calculations into the computational process would provide a more comprehensive analysis.
- Including all these parameters requires a more complex parametric model and a matching algorithm that can consider multiple aspects for accurate results.

conclusion:

From first phase experiment:

- Laminating different timber species can improve structural performance.
- However, delamination at the scarf joint with two timber species is a major issue. The connection should be modified by adjusting the slope or using a nibbed scarf joint, which requires more precise cutting.
- Future research should include FEA to analyze force distribution within the joist, helping to understand why failures like extrusion occur in specific locations.

conclusion:

From second phase experiment:

- Initial results of the 4-point bending test show that having more elements in a joist positively impacts beam performance.
- A homogeneous grade along the section improves performance, but splitting into smaller sections can cause waste.
- Using larger sections to manufacture IGST minimizes waste from regrading.
- Improved structural performance with more pieces may be due to the increased glue, which strengthens the fibers.
- The first three elements used epoxy resin-based glue, which is strong but hinders circularity. We are now testing a new piece with bio-based glue.
- Controlled destructive tests are essential to check the ULS of SLS beams. DIY testing systems have many flaws, affecting reliability and worker safety.
- The experiments will be extended to understand the potential of IGST with different glues and compare it with other EWP.

شکرا
Thank you