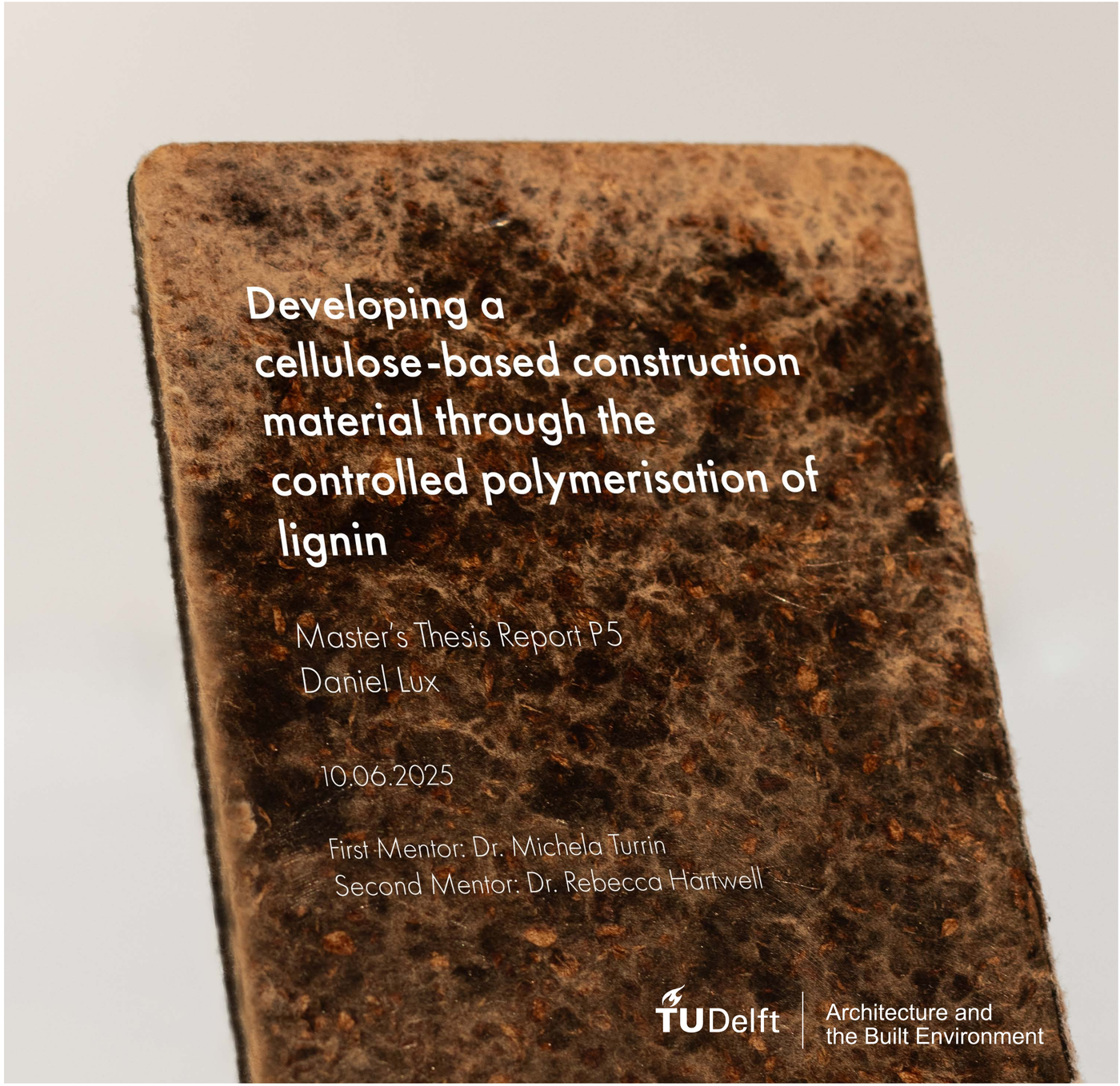
Daniel Lux

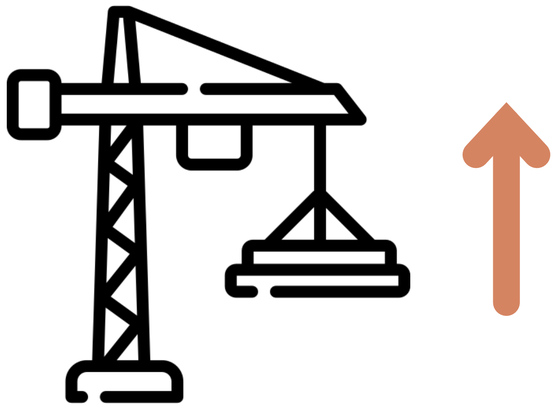
Wood without Trees

P5 Presentation

17.06.2025



Construction Demand

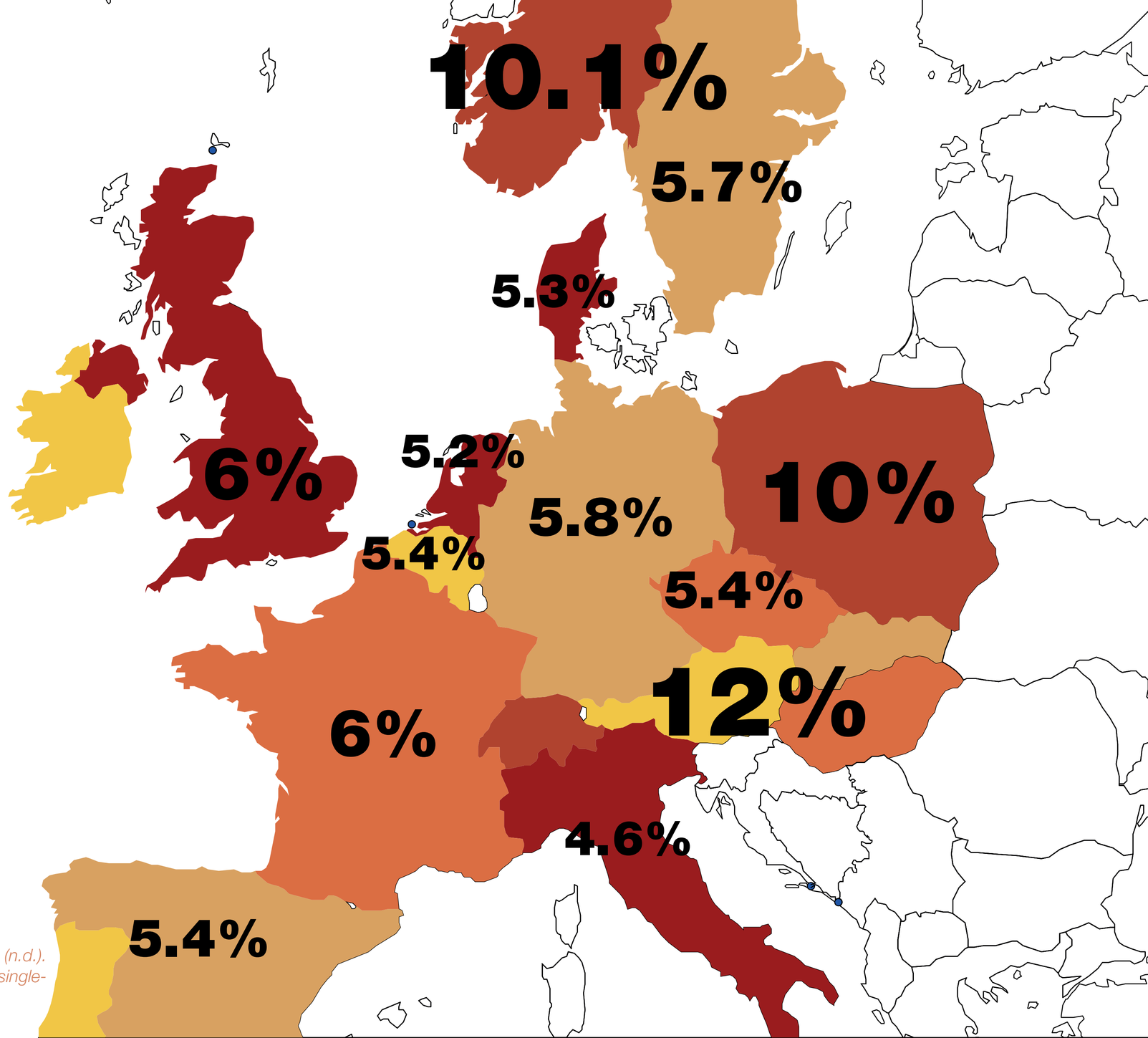


Construction Sector Size Per Nation

in % of GDP

EU

~9%*

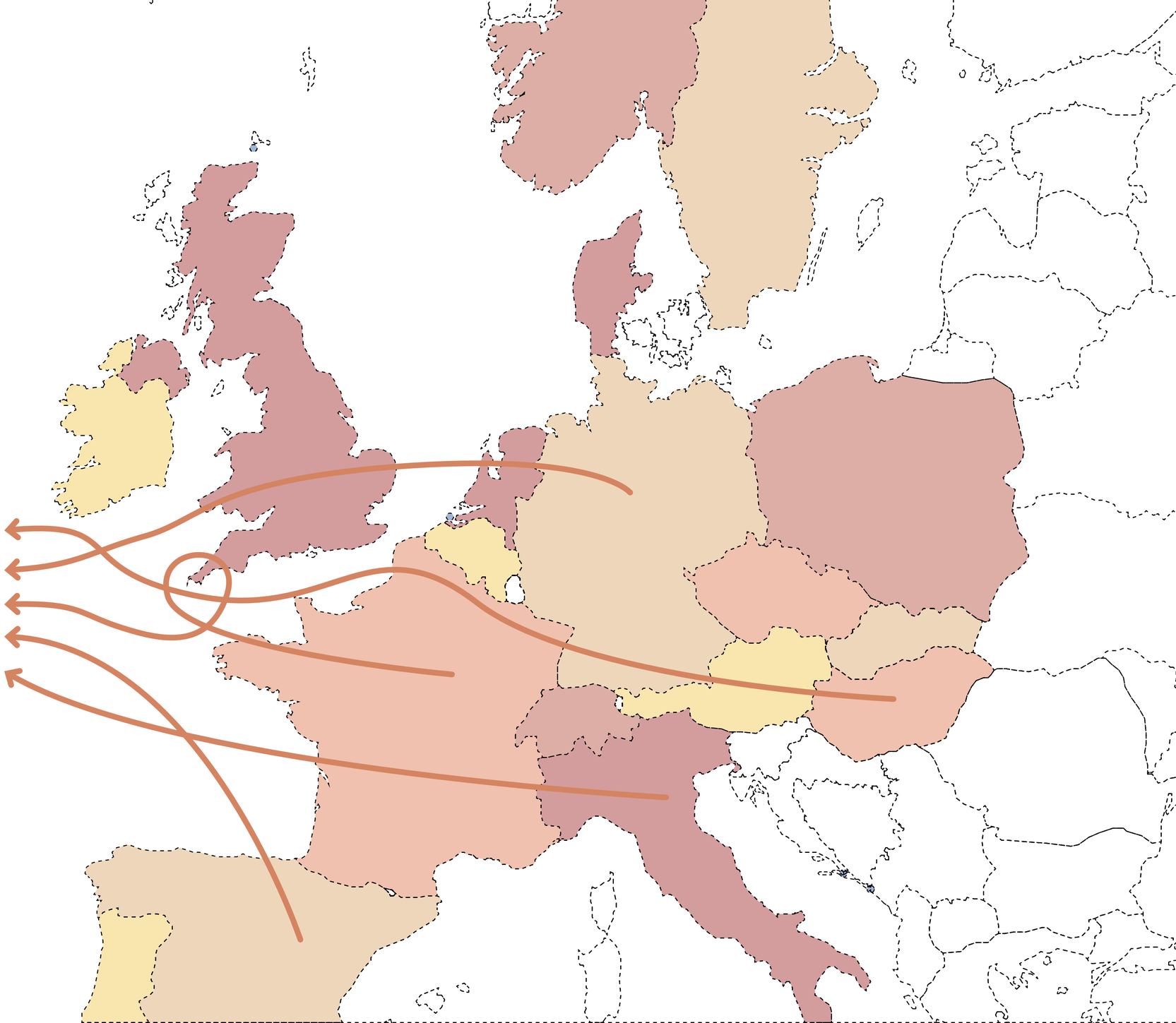


*Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs. (n.d.). Construction sector. European Commission. Retrieved June 12, 2025, from https://single-market-economy.ec.europa.eu/sectors/construction_en

Waste Production

Construction and Demolition Waste

Largest Waste-Stream of EU



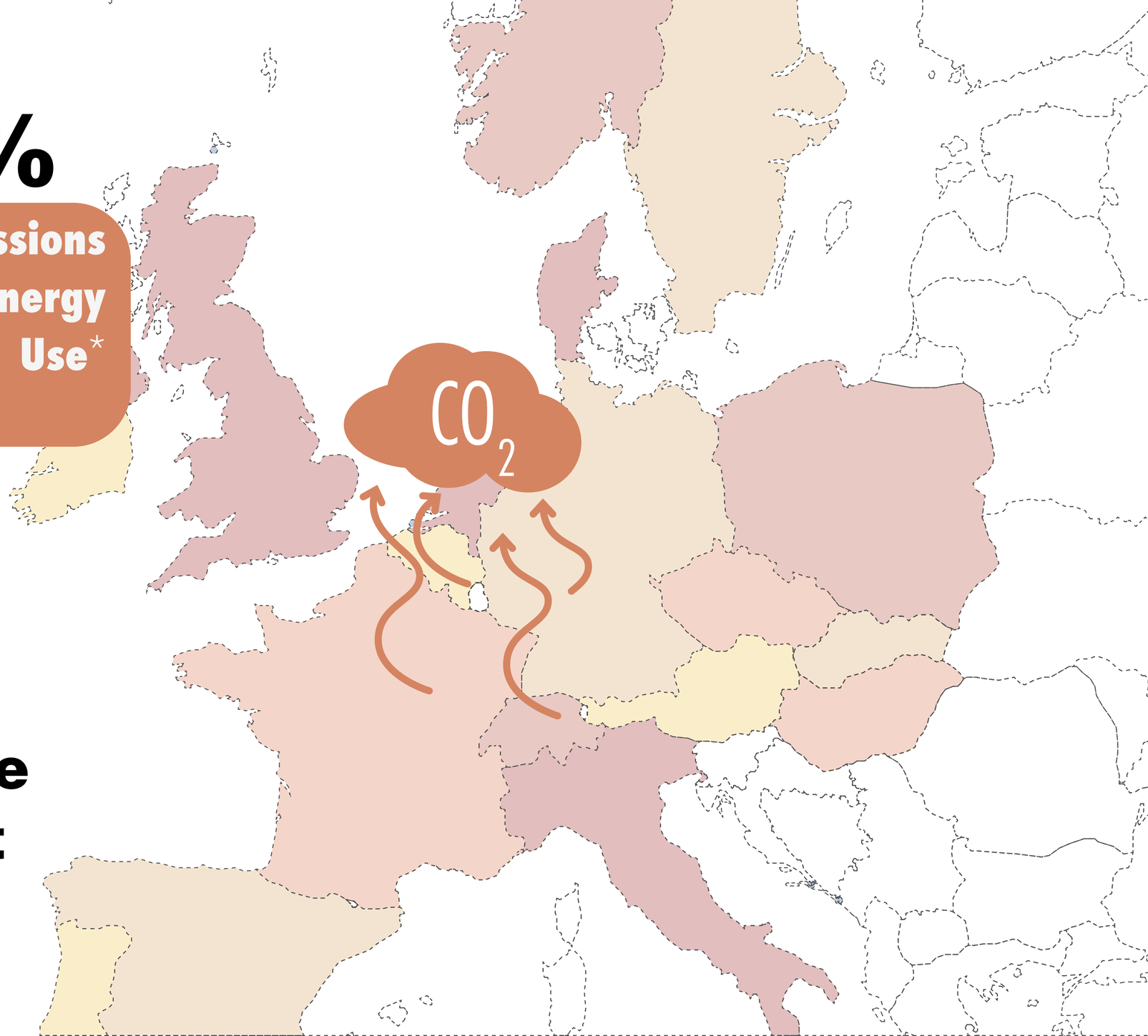
*(Source: European Commission, Circular Economy Action Plan, 2020)

50%

Consumption of Extracted Virgin Materials*

36%

Emissions from Energy Use*



Contributes to Major Challenges

↑ **Material Scarcity** & ↑ **Climate Impact**

*(Source: European Commission, Circular Economy Action Plan, 2020)

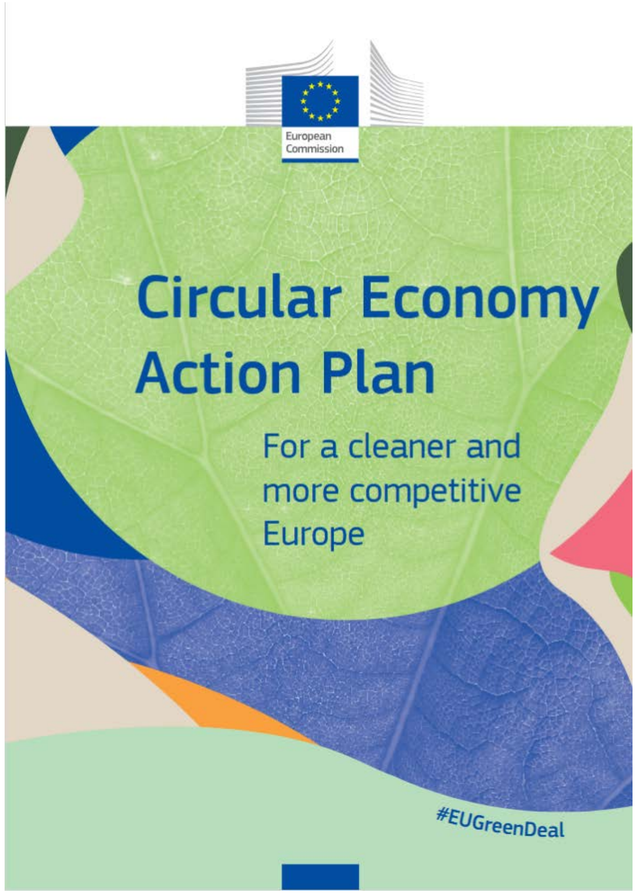


Image from: https://www.google.com/url?sa=i&url=https%3A%2F%2Fop.europa.eu%2Fde%2Fpublication-detail%2F-%2Fpublication%2F45cc30f6-cd57-11ea-adf7-01aa75ed71a1%2Flanguage-en&psig=AOvVaw3waOFdB8oGE2tJ-JwcXkwA&ust=1750327437215000&source=images&opi=89978449

Renewable Resources

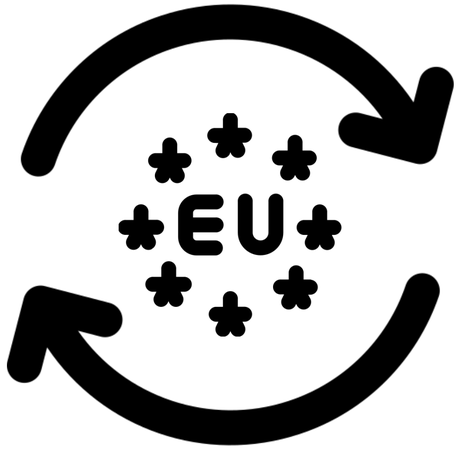
Lower embodied Carbon

Regenerable within a human timeframe

Renewable Resources

Lower embodied Carbon

Regenerable within a human timeframe



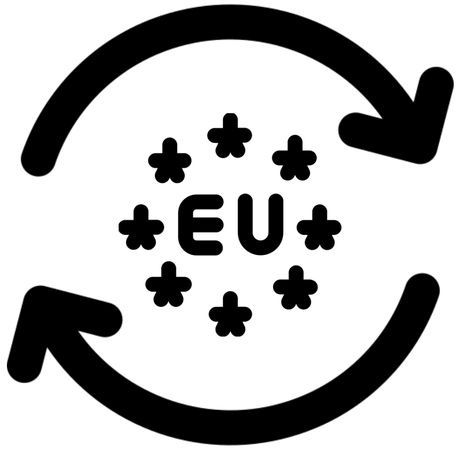
Circular Economy by 2050

Reduced Waste Production

Waste Utilisation

The global material consumption should be fully circular by 2050. All materials streams are closed circles. No waste! No greenhouse gas emmissions![1]

1 (Sustainable and Circular Construction | Interreg Europe, 2024)



Circular Economy by 2050

Reduced Waste Production

Waste Utilisation

The global material consumption should be fully circular by 2050. All materials streams are closed circles. No waste! No greenhouse gas emmissions![1]

Cellulose

Cellulose-containing waste, is almost immeasurable.
5 mill. tons of paper waste annually[2] in germany alone.

Lignin

50 -70 million tons of Lignin from the Kraft Process[3], and largely not utilized 98%[4] is being used for energy production

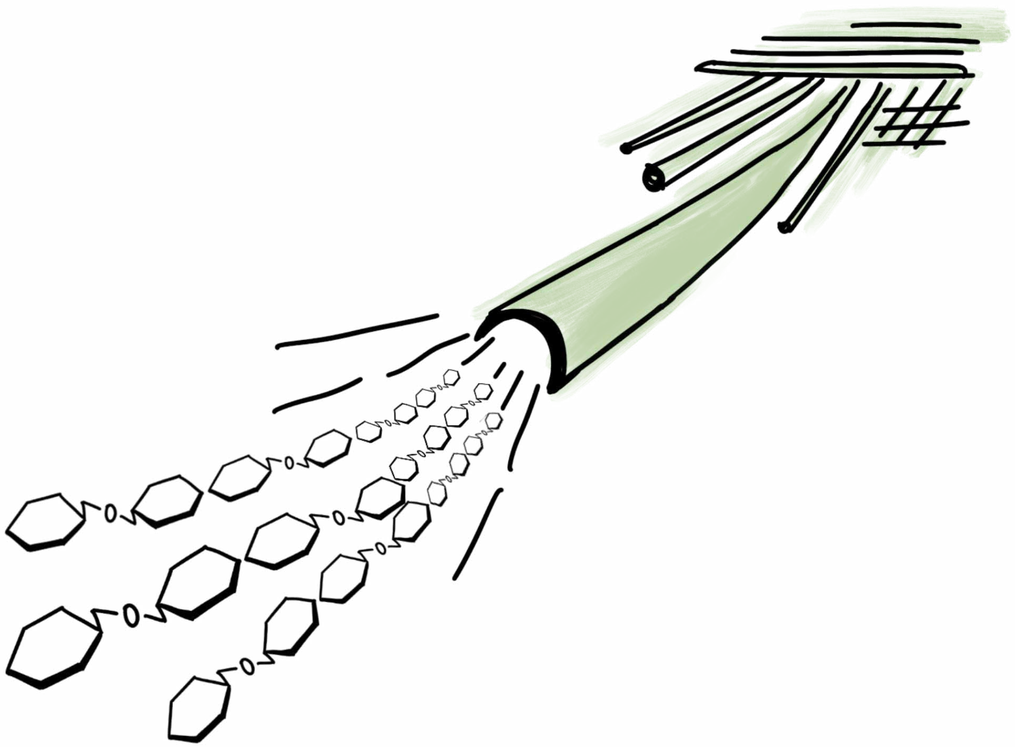
[2] (Waste Management in Germany 2023 – Facts, Data, Figures, 2023), [3](Bajwa et al., 2019), [4] (Global Lignin Market Report 2023-2033 with Profiles of 75+ Lignin Producers - ResearchAndMarkets.Com, 2023)

1 (Sustainable and Circular Construction | Interreg Europe, 2024)

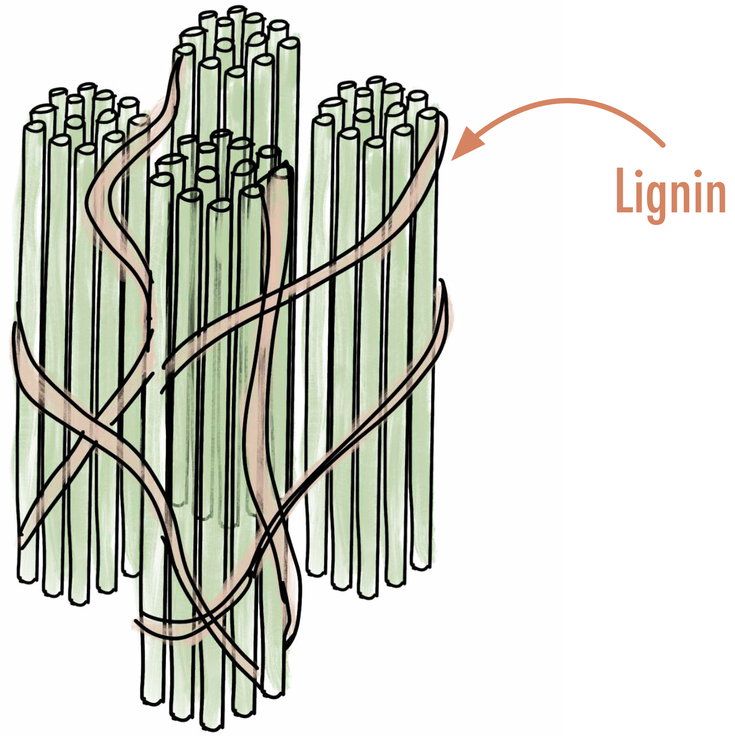
Isocell insulation material, from: https://www.isocell.com/en/product/zellulose

Three different lignin types, from: https://carboncredits.com/what-is-lignin-definition-uses-and-processes/

Cellulose Fibril



Cellulose Fibril



Crystalline cellulose of elementary fibrils:

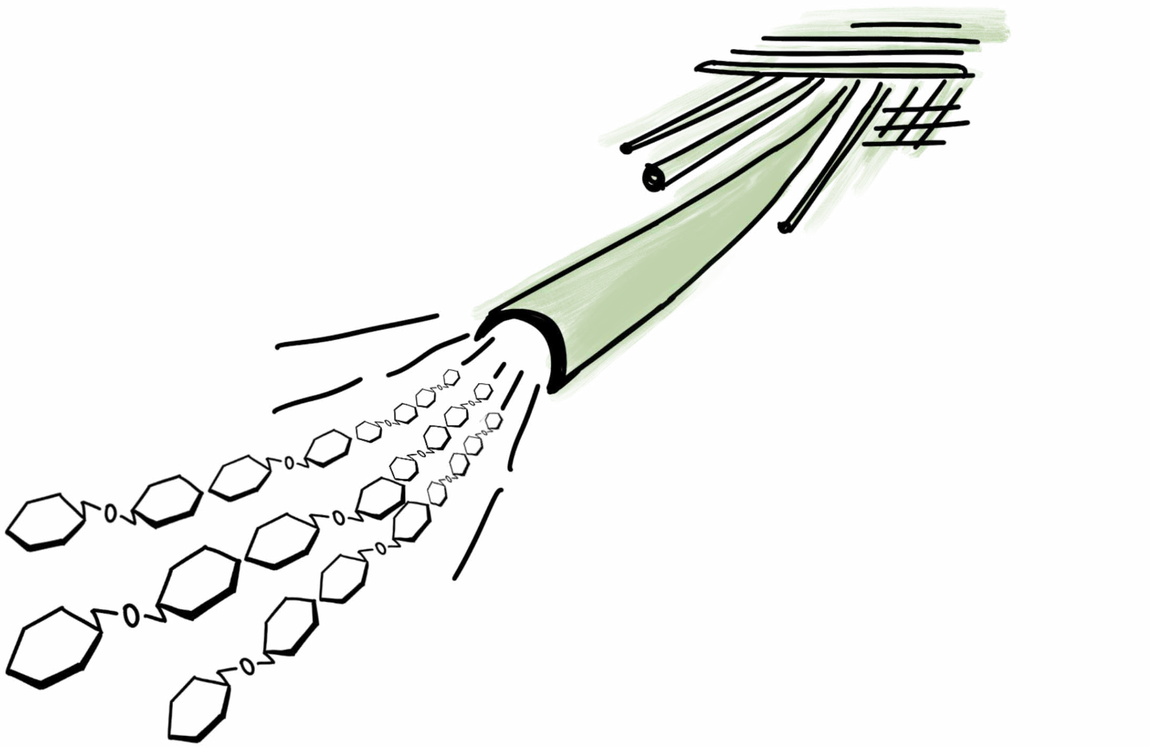
		Glass	Steel S275
Tensile strength	f_t: 7.5 - 7.7 GPa	7 GPa	430 MPa
E-Modulus	E: 140-150 GPa	50-125 GPa	210 GPa

Technical Lignin natural adhesive properties

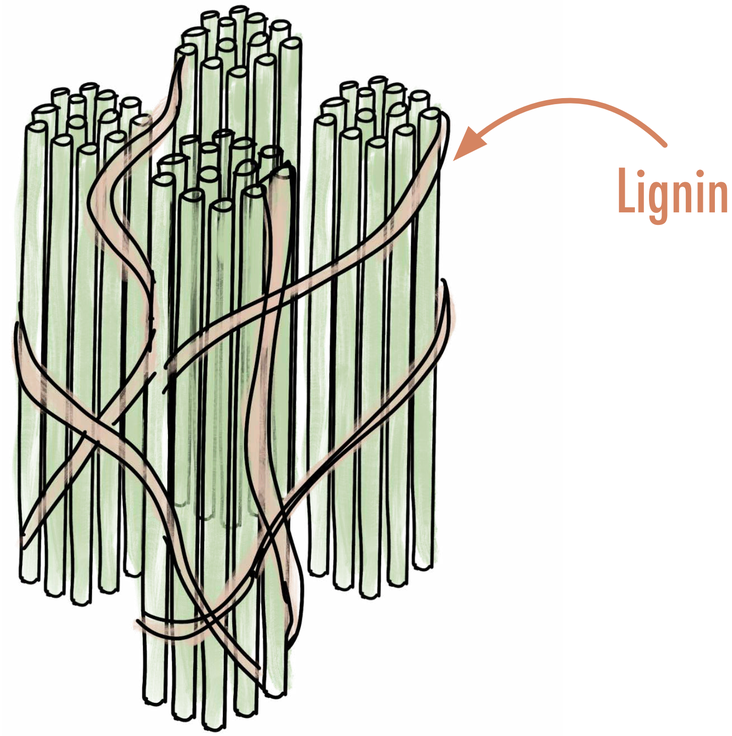
Cross-linking of polymers exhibits "exceptional adhesive properties"[1]

[1] Yan, L., Liu, H., Wang, R., Dai, L., Yuan, Z., & Si, C. (2025). Hot-pressing-assisted fabrication of high-lignin-content and self-crosslinked strong adhesives. Chemical Engineering Journal, 514, 163215. https://doi.org/10.1016/j.cej.2025.163215

Cellulose Fibril



Cellulose Fibril



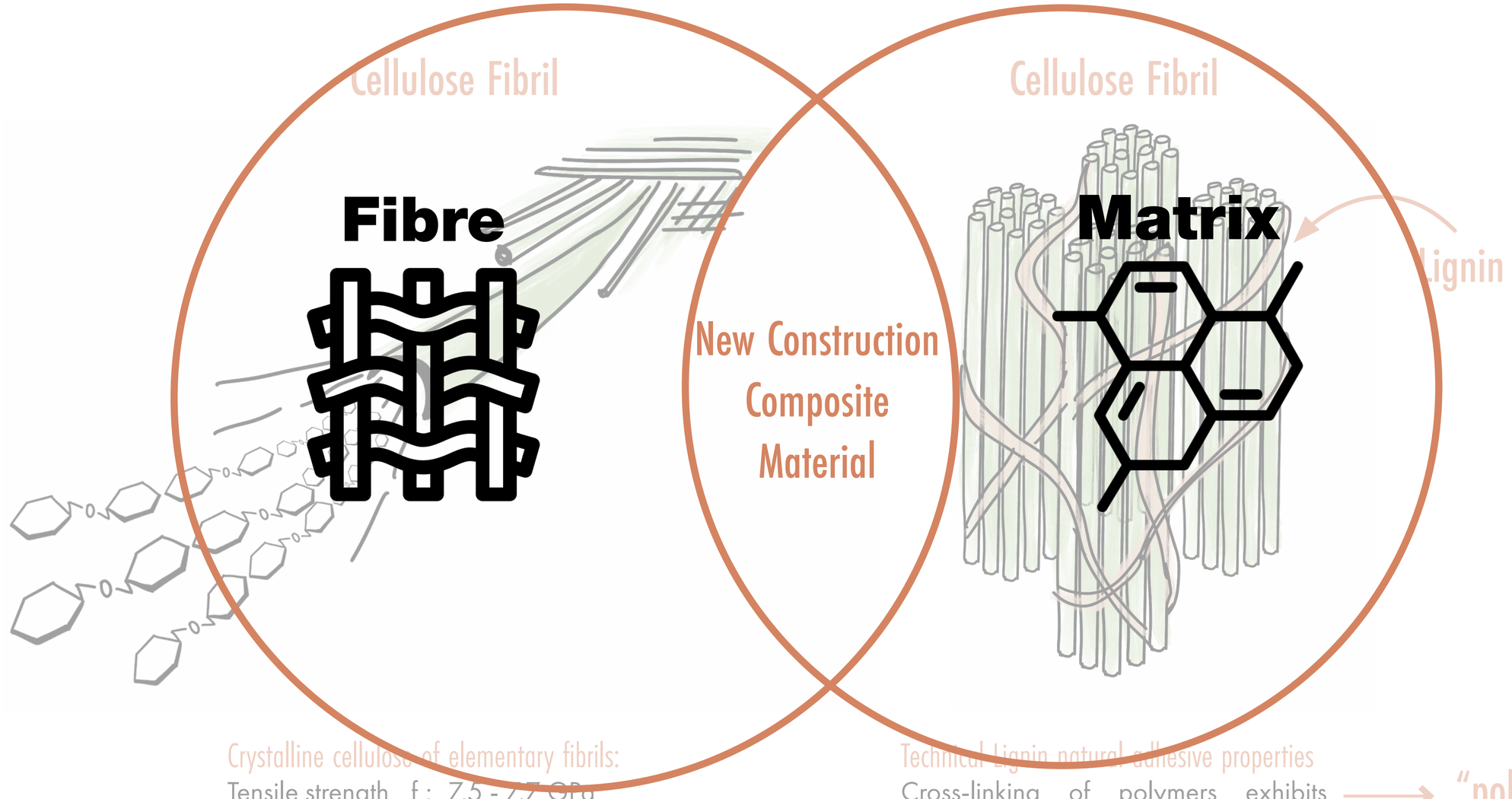
Crystalline cellulose of elementary fibrils:

		Glass	Steel S275
Tensile strength	f_t: 7.5 - 7.7 GPa	7 GPa	430 MPa
E-Modulus	E: 140-150 GPa	50-125 GPa	210 GPa

Technical Lignin natural adhesive properties

Cross-linking of polymers exhibits "exceptional adhesive properties"[1] → "polymerisation"

[1] Yan, L., Liu, H., Wang, R., Dai, L., Yuan, Z., & Si, C. (2025). Hot-pressing-assisted fabrication of high-lignin-content and self-crosslinked strong adhesives. Chemical Engineering Journal, 514, 163215. https://doi.org/10.1016/j.cej.2025.163215



Crystalline cellulose of elementary fibrils:

Tensile strength f_t: 7.5 - 7.7 GPa

E-Modulus E: 140-150 GPa

Technical Lignin natural adhesive properties

Cross-linking of polymers exhibits "exceptional adhesive properties"[1] → "polymerisation"

[1] Yan, L., Liu, H., Wang, R., Dai, L., Yuan, Z., & Si, C. (2025). Hot-pressing-assisted fabrication of high-lignin-content and self-crosslinked strong adhesives. Chemical Engineering Journal, 514, 163215. https://doi.org/10.1016/j.cej.2025.163215

Research Question:

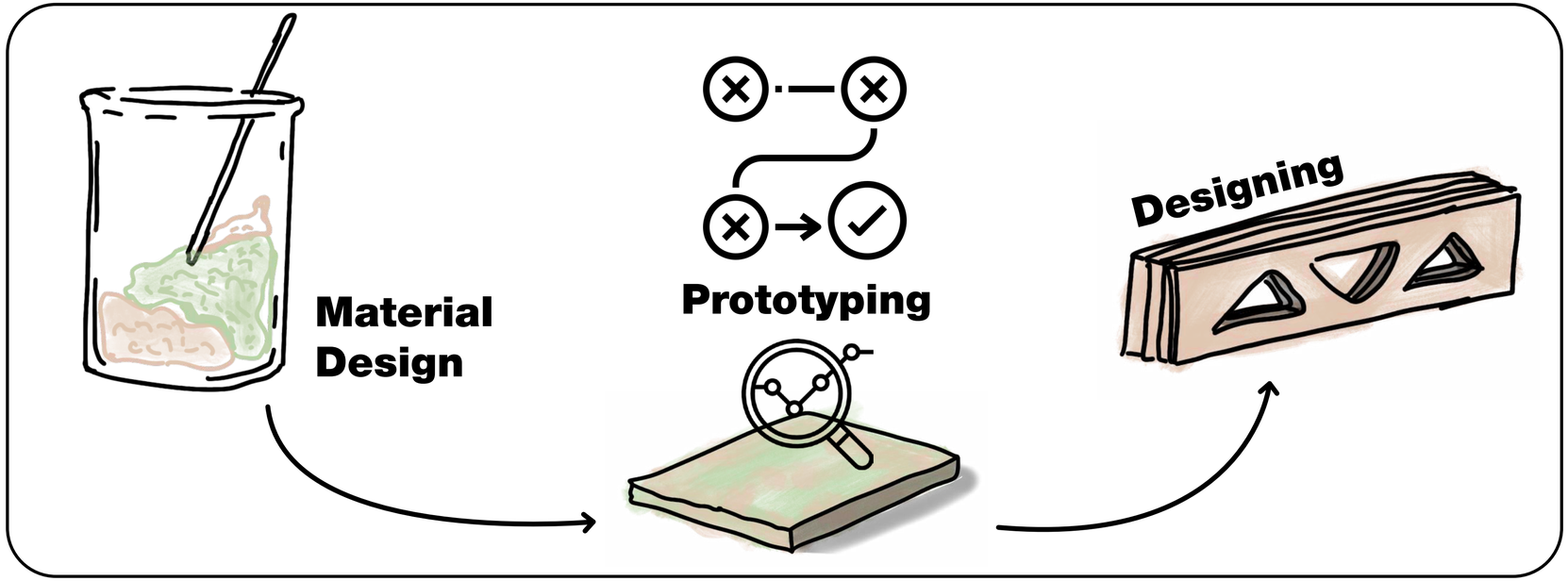
How can an optimised mixture and a suitable hot-press production method be developed that uses by-product-lignin and -cellulose, to utilize lignin’s natural binding properties through controlled polymerization?

Research Question:

How can an optimised mixture and a suitable hot-press production method be developed that uses by-product-lignin and -cellulose, to utilize lignin's natural binding properties through controlled polymerization?

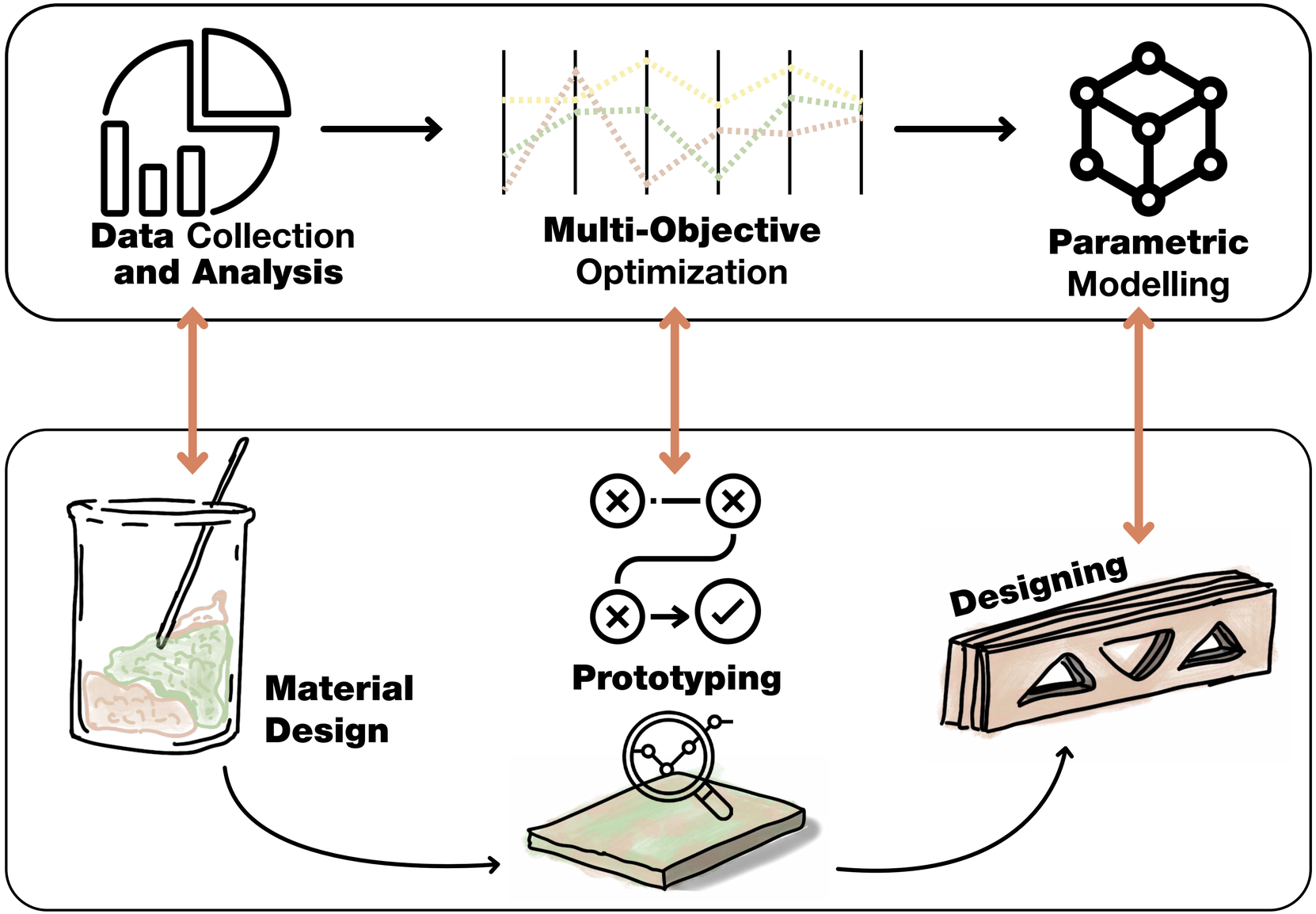
→ How to turn lignin into an adhesive?

MATERIAL DEVELOPMENT



COMPUTATIONAL INTEGRATION

MATERIAL DEVELOPMENT



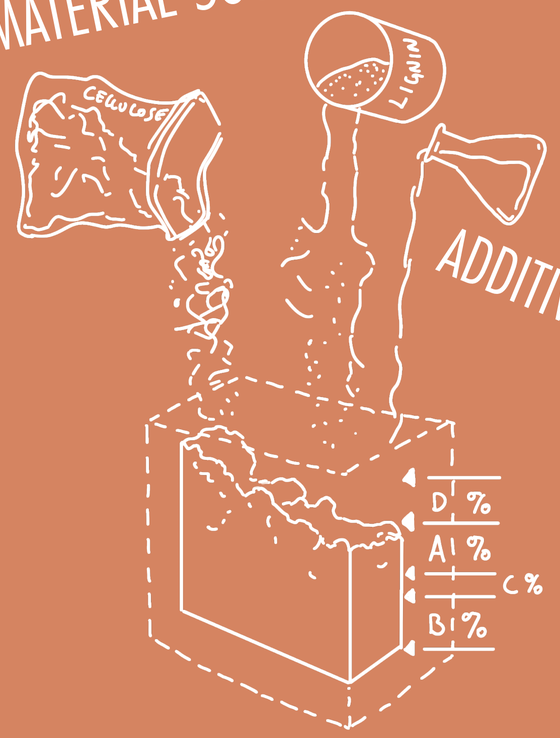
Project Process

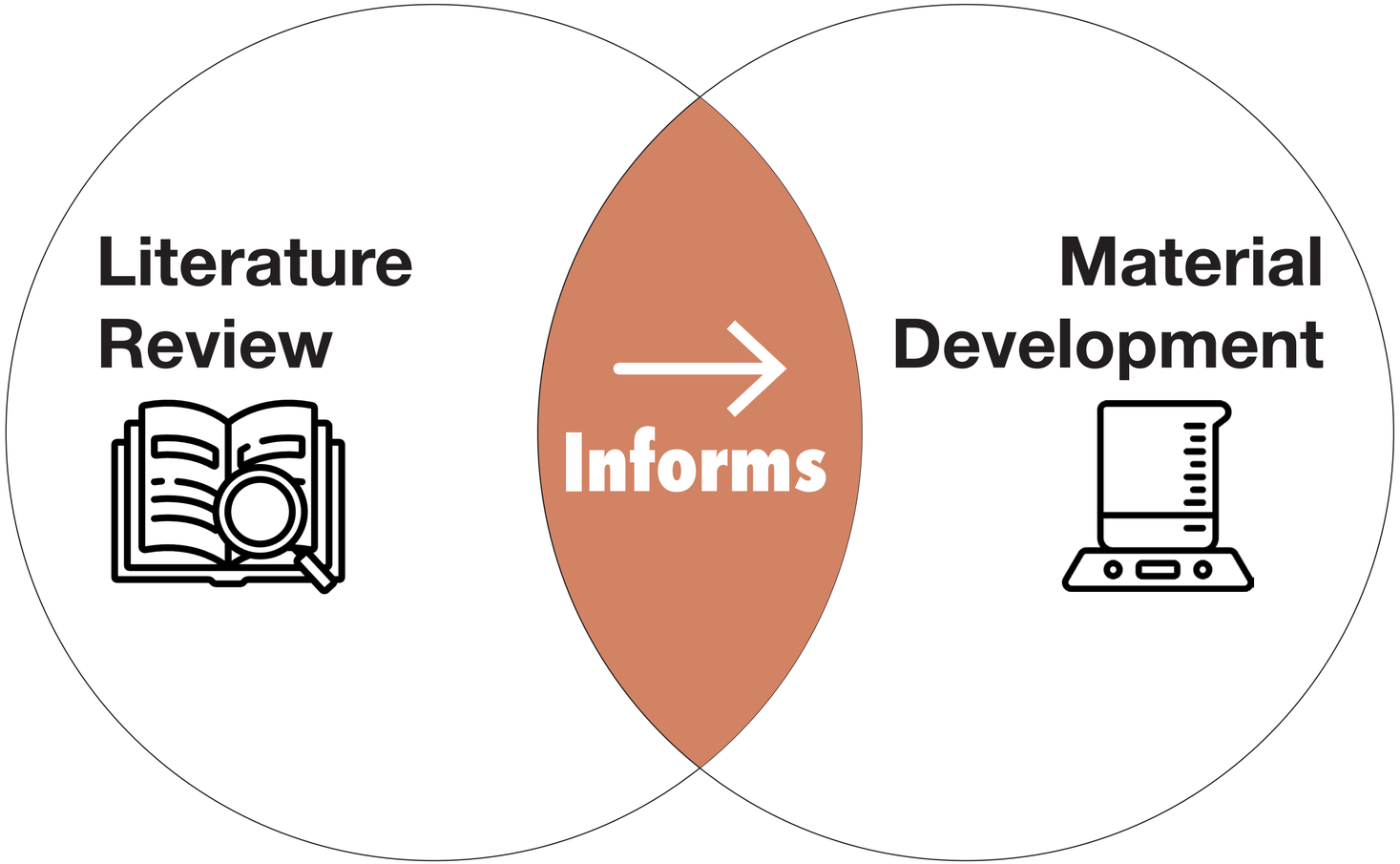
Literature Review

HOT-PRESSING PROCEDURE

PROCESSING CONDITIONS

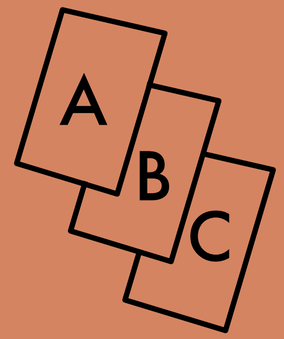
MATERIAL SOURCES



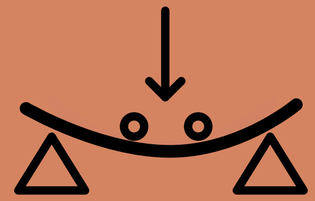


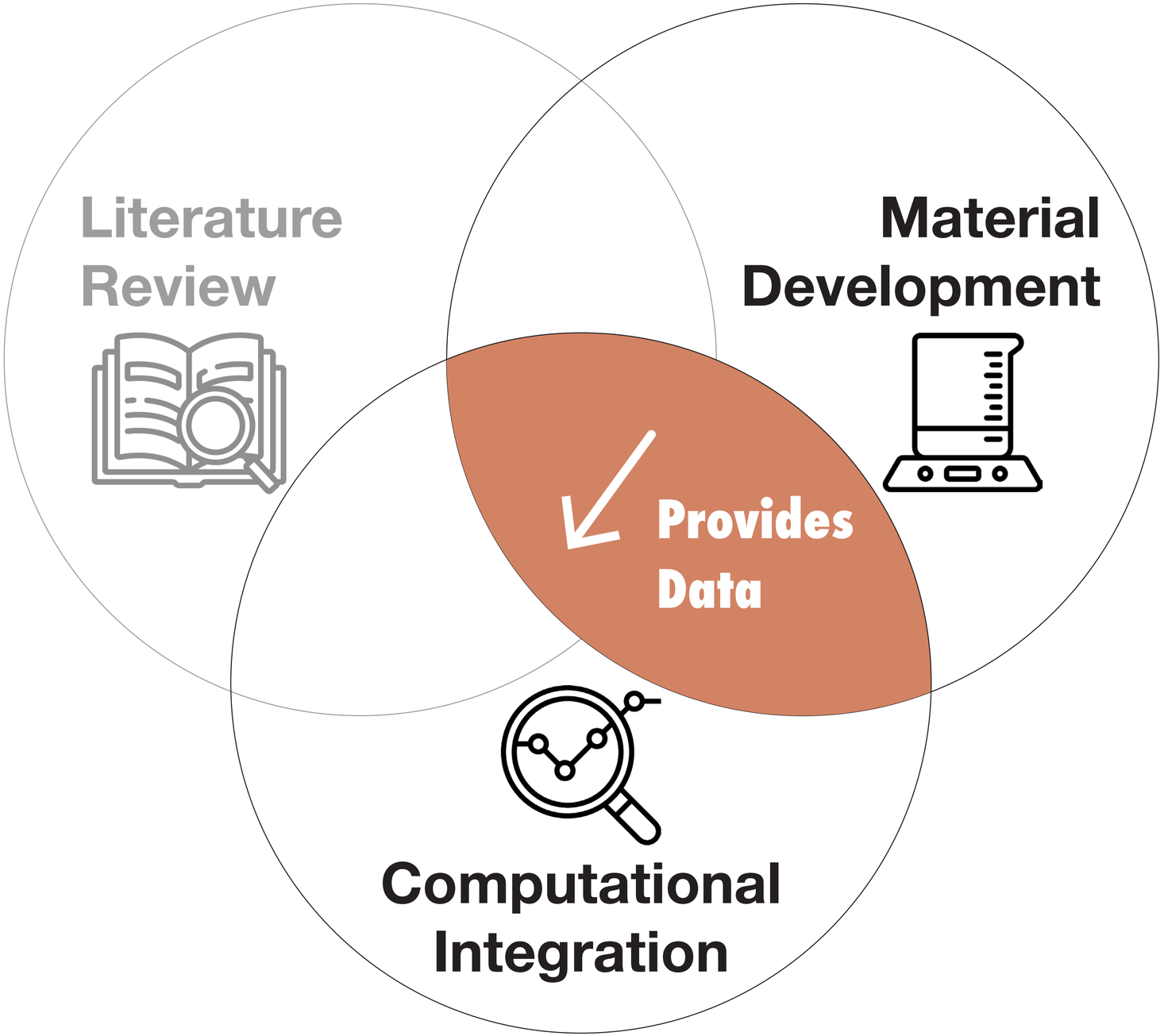
TRIALS

Production of Variations of Mixture and Pressing Conditions



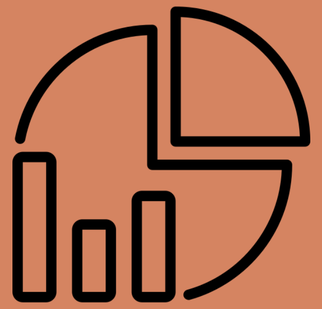
Mechanical Testing to Determine the Impact of the Variations



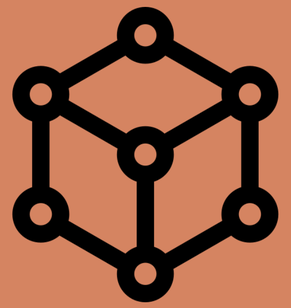


DATA ANALYSIS

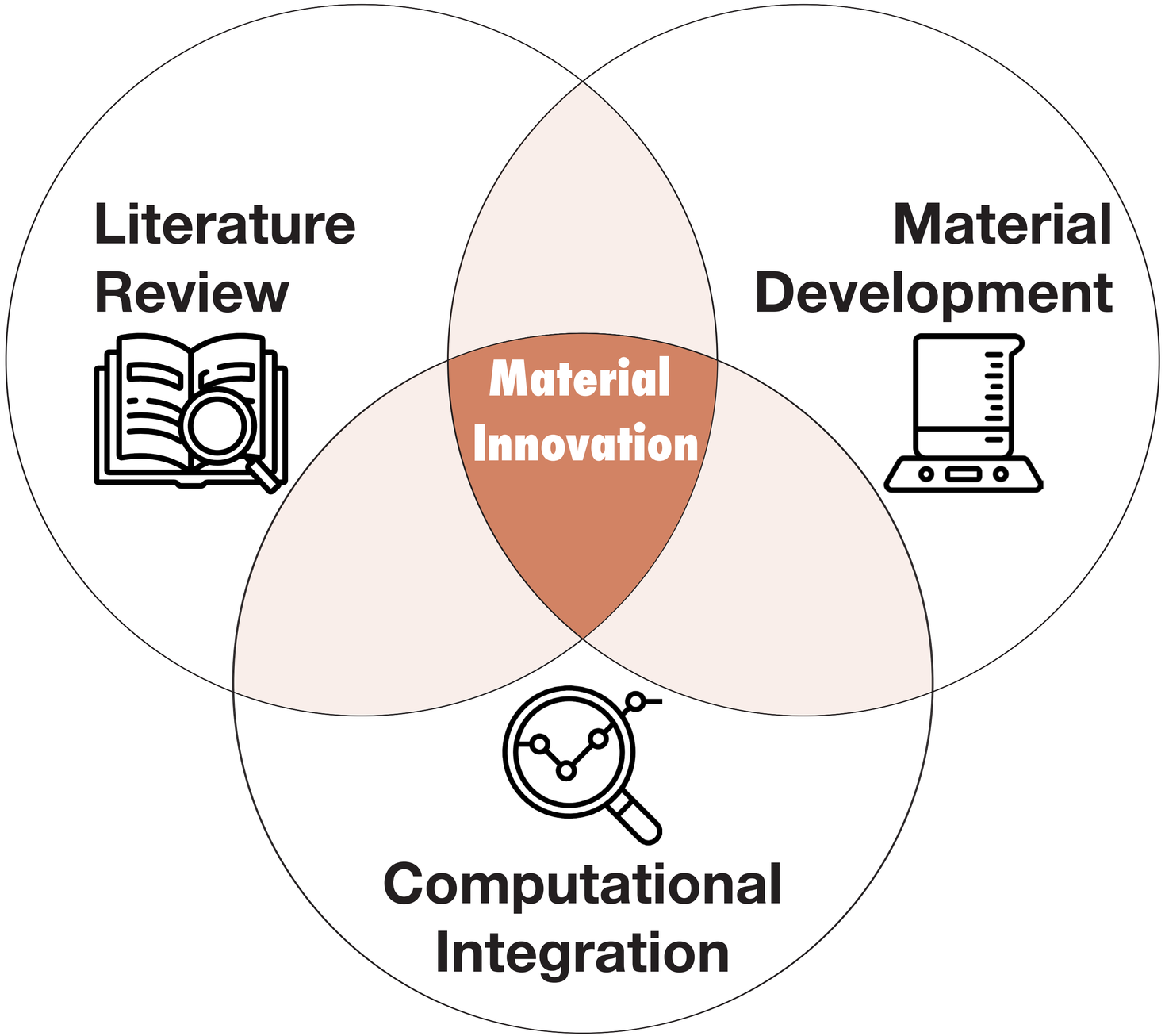
Extract Material Propteries

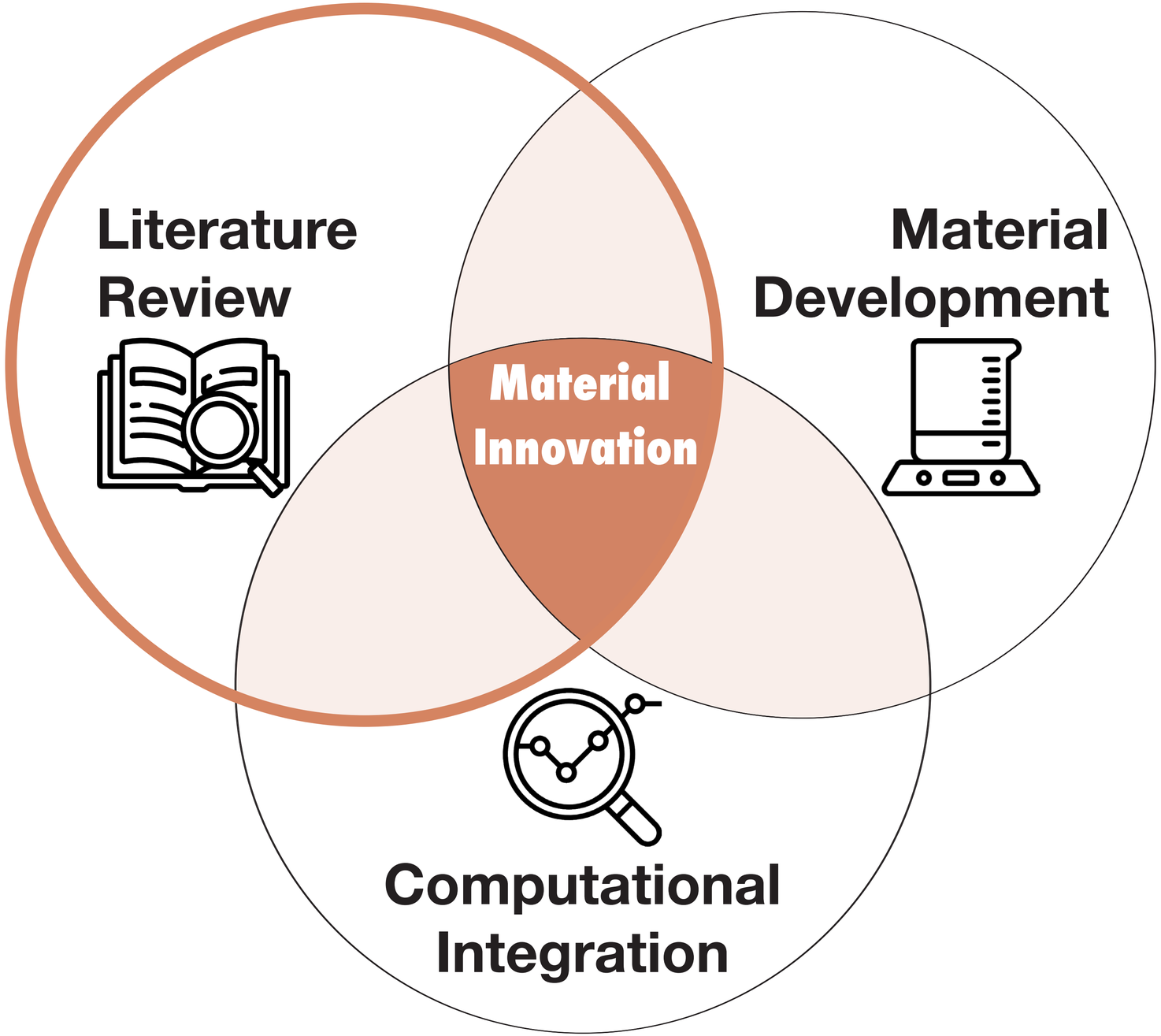


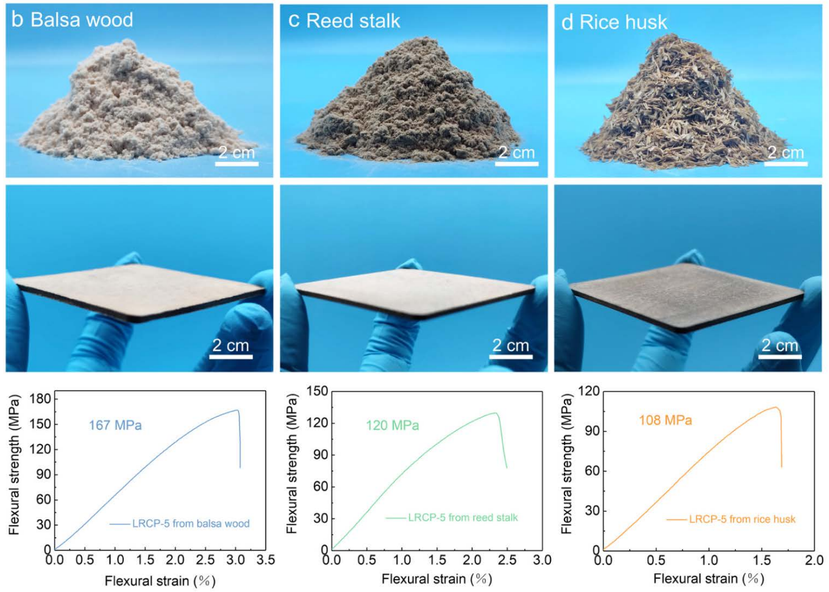
Define Relationships



Apply, Model, Predict

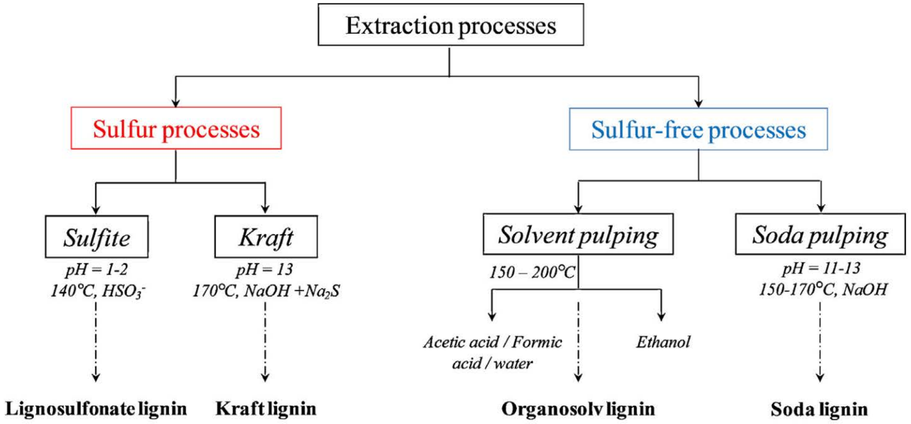

Literature Review
Material Development
Material Innovation
Computational Integration


Literature Review
Material Development
Material Innovation
Computational Integration

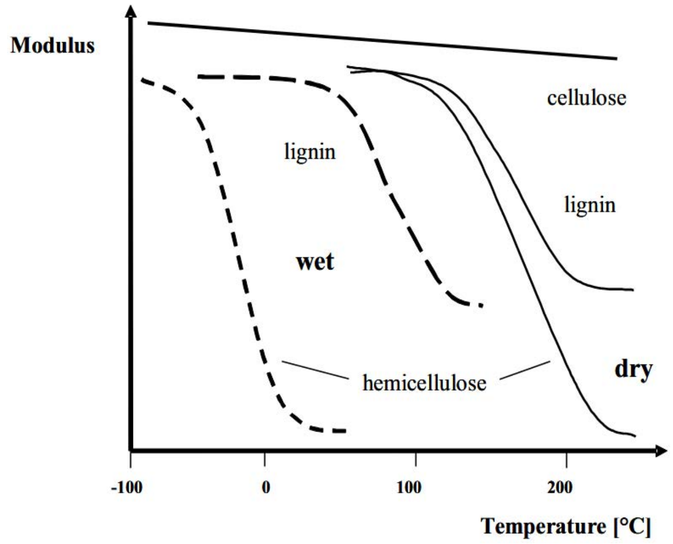


ced cellulose strategy. (a-d) LRCPs obtained from natural bamboo (a), balsa wood (b), reed stalk (c) and rice husk (d). Each al photo of the raw material, a digital photo of LRCP-5, and the flexural stress-strain curve of LRCP-5, respectively.

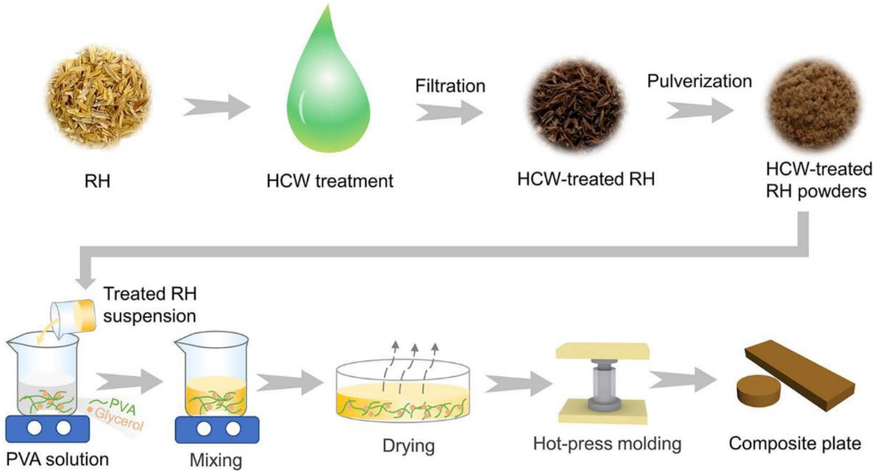
Mechanical Testing Results of LRCPs. From Qin et al. 2023



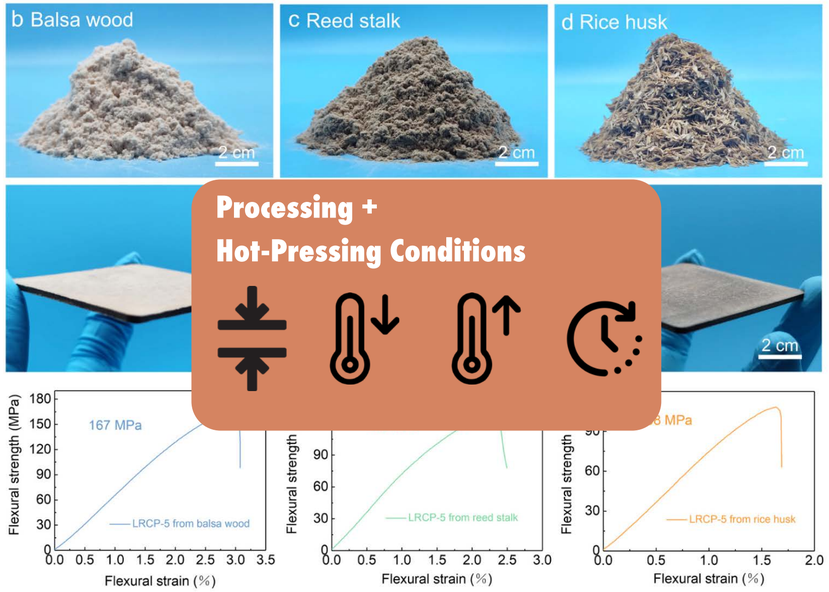
Lignin Extraction Process, from Laurichesse & Avérous, 2014



The glass-transition temperature of lignin as a function of moisture content, from Kuntar & Sernek, 2007

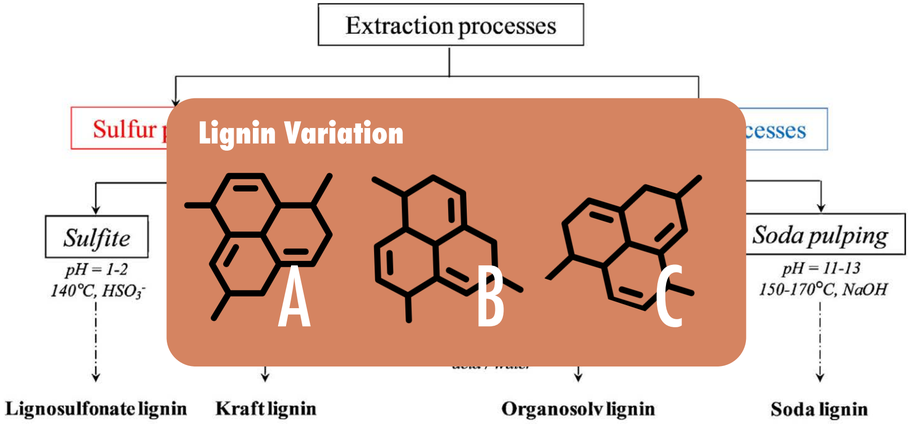


Rice Husk Composite Plate Propduction Process. From Qianli, 2022

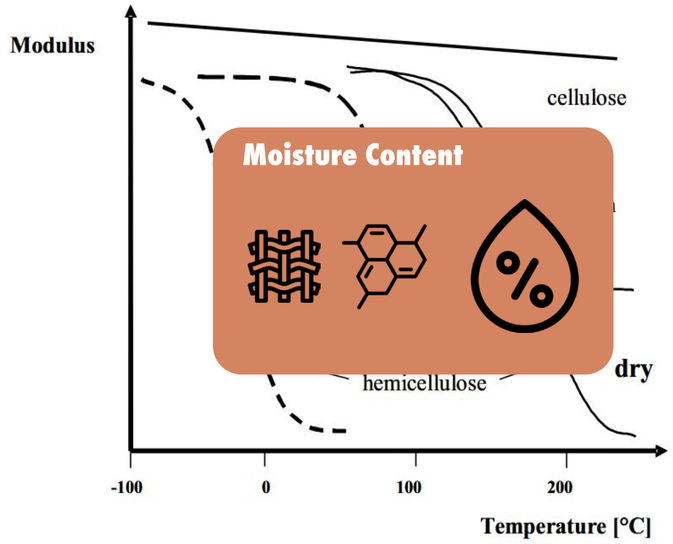


ced cellulose strategy. (a-d) LRCPs obtained from natural bamboo (a), balsa wood (b), reed stalk (c) and rice husk (d). Each al photo of the raw material, a digital photo of LRCP-5, and the flexural stress-strain curve of LRCP-5, respectively.

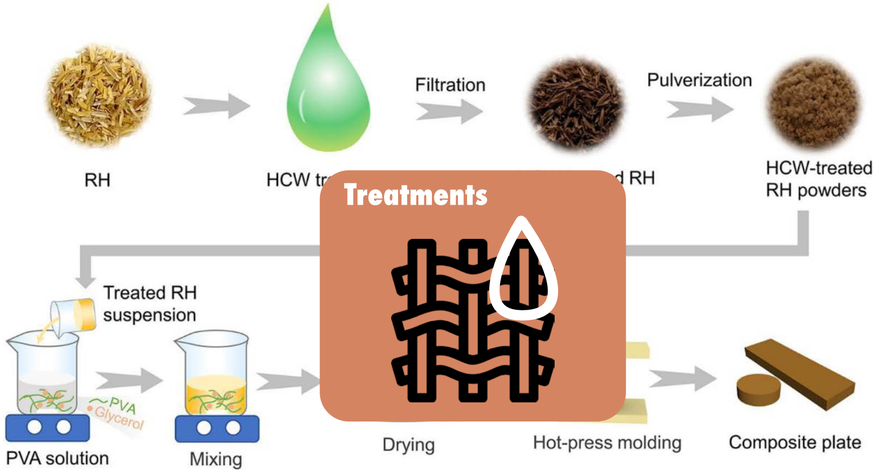
Mechanical Testing Results of LRCPs. From Qin et al. 2023



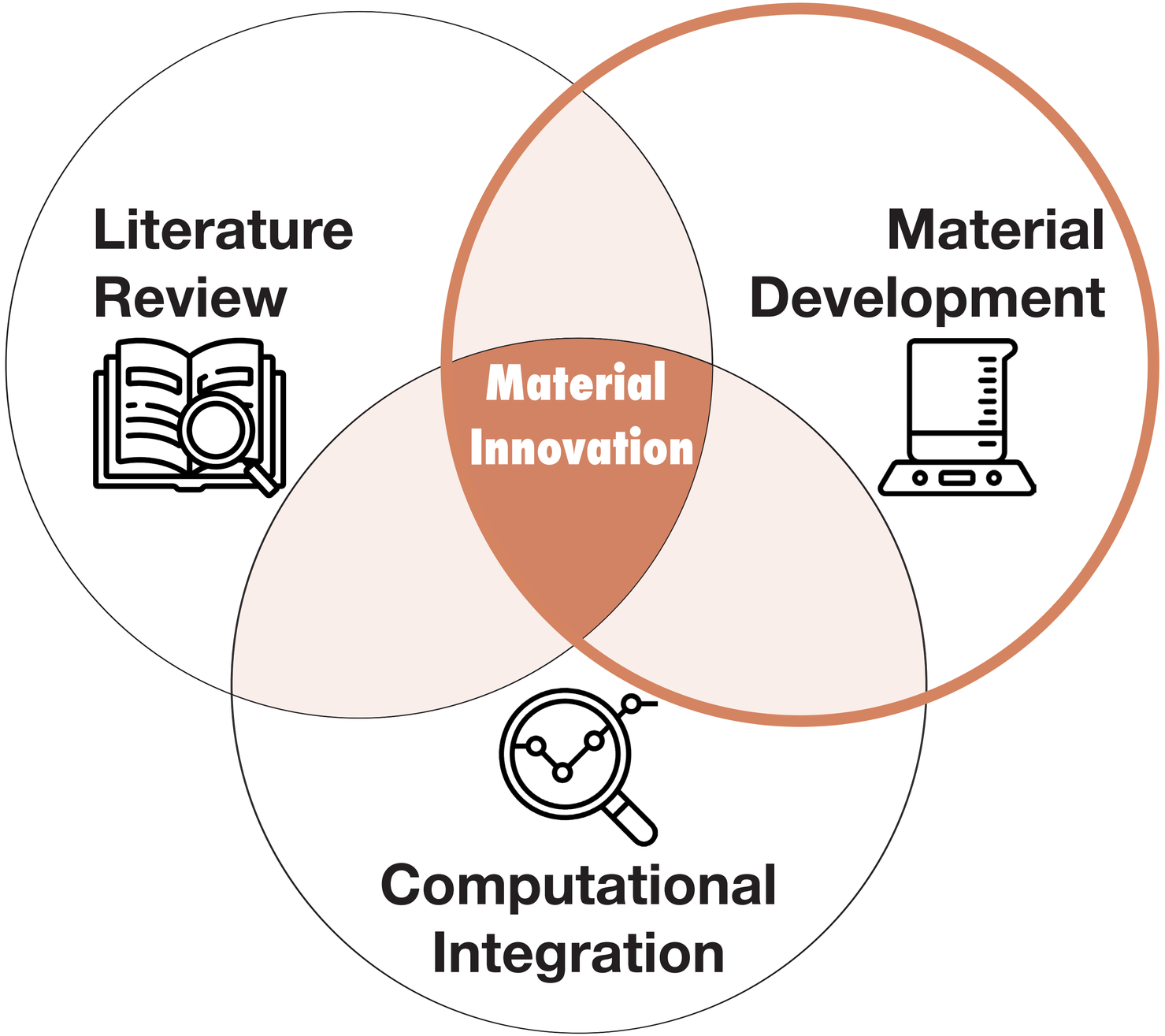
Lignin Extraction Process, from Laurichesse & Avérous, 2014



The glass-transition temperature of lignin as a function of moisture content, from Kuntar & Sernek, 2007

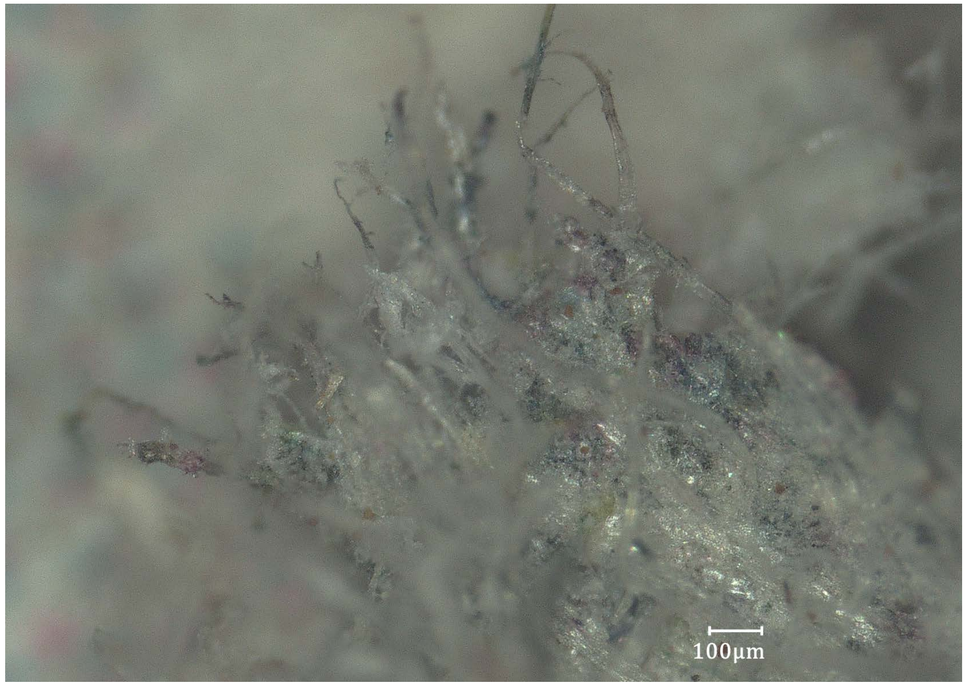


Rice Husk Composite Plate Propduction Process. From Qianli, 2022


Literature Review
Material Development
Material Innovation
Computational Integration

Material Constituents

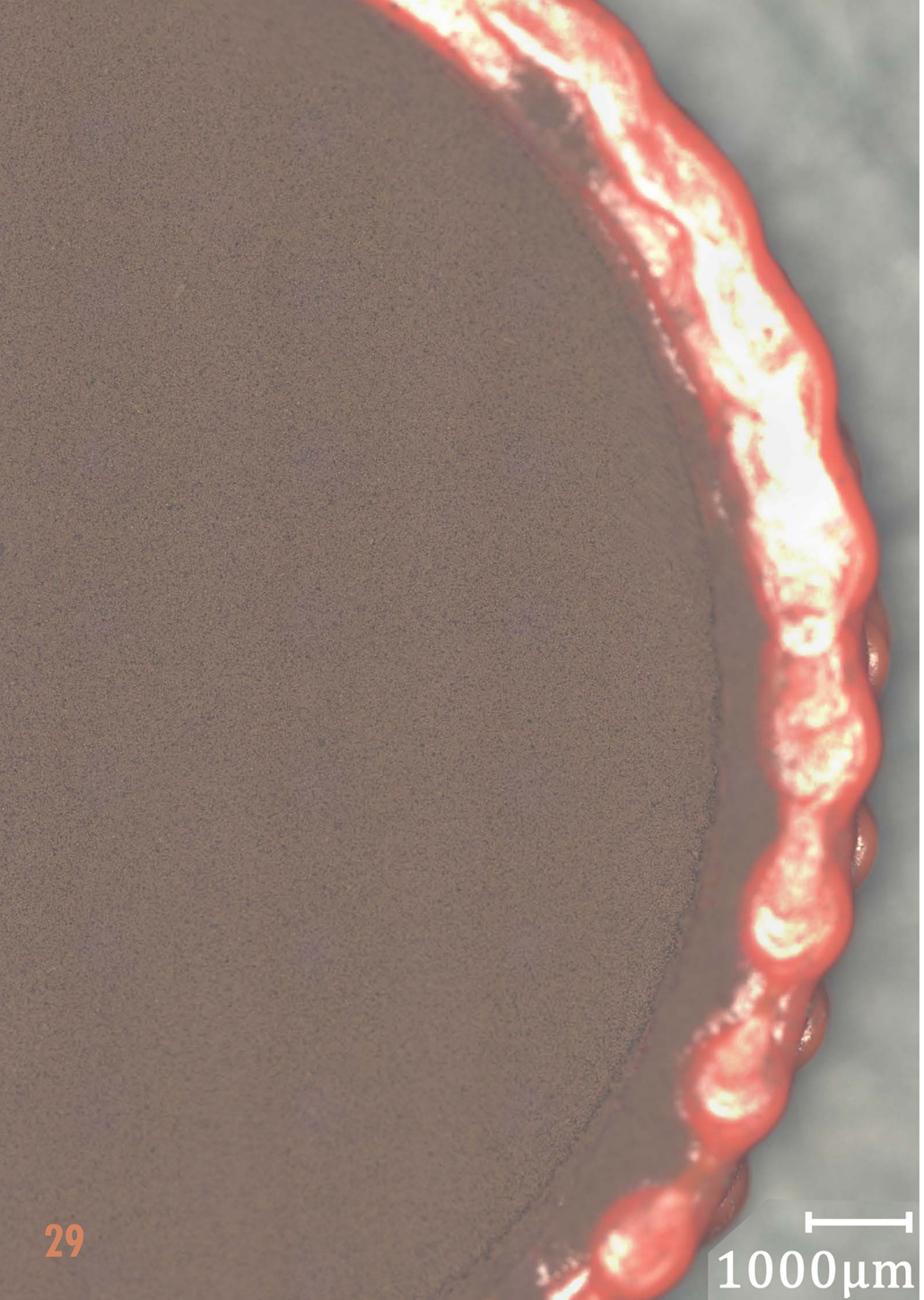
Cellulose



Shredded and untreated newspaper fibres
x150 magnification

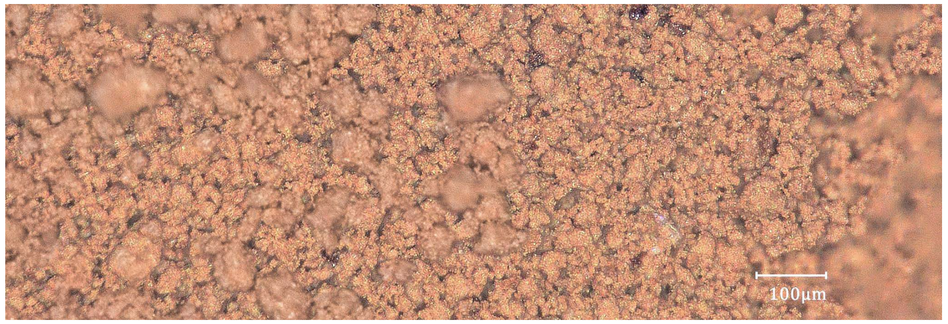
cellulose 40 – 70%, hemicellulose 10 – 40% and lignin 5 – 30%,

image sourcehttps://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.isocell.



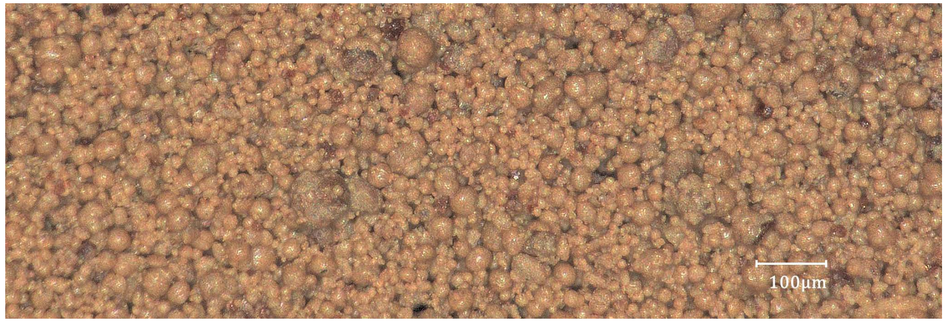
Material Constituents

Lignin



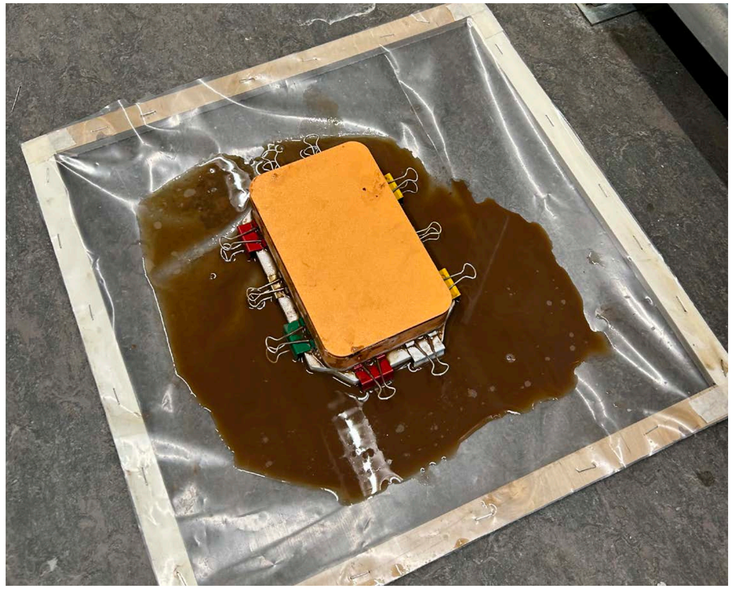
Kraft Lignin
x250 magnification

Organosolv Lignin
x250 magnification

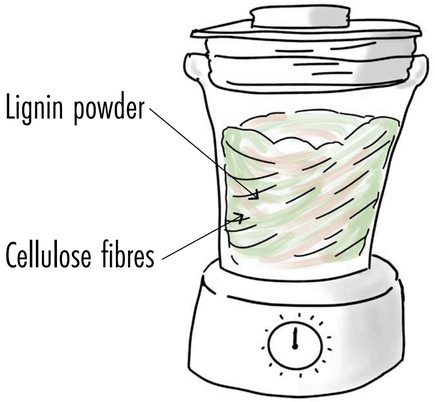


Soda Lignin
x250 magnification

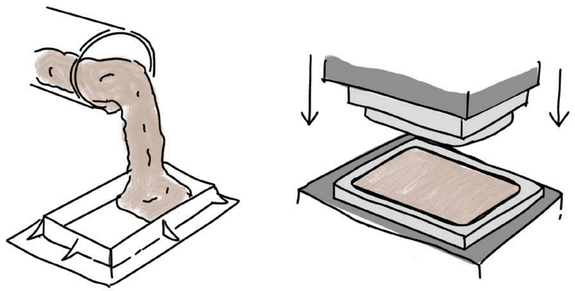
Trial and Error phase



Chosen production methods for experimental part



Material blend

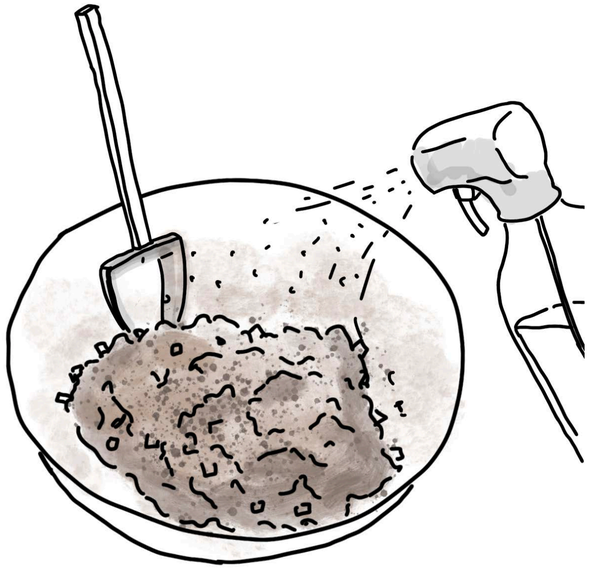


Moulding and hot-pressing

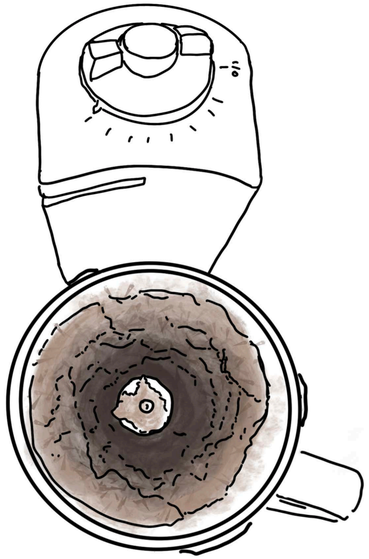
1. Mixing
2. Hot-Pressing
3. Post-Processing

1. Material Mixture

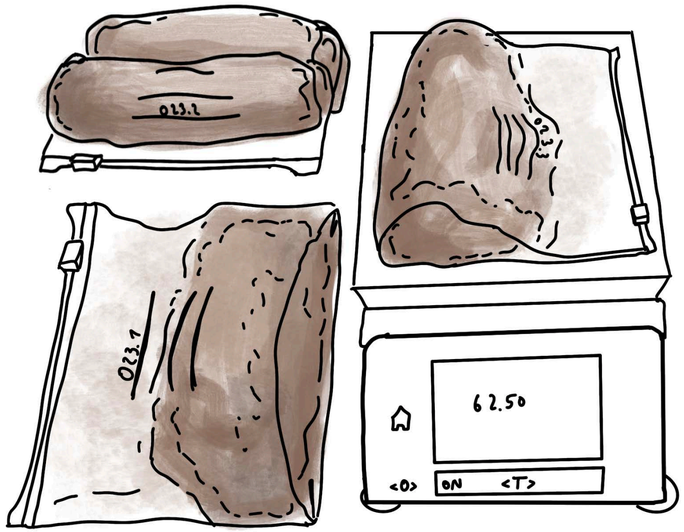
- Precision balance (±0.01 g)
- Kitchen Blender or Food processor
- Spray Bottle for distilled water
- Metal bowls for mixing
- Metal mortar for bowl
- Glass beaker 800ml
- Scraper or Spatula
- Drying oven
- Zip-lock bags
- Vacuum pump/ cleaner.



Combining constituents dry (total of 50g) and adding water to achieve moisture content X%.



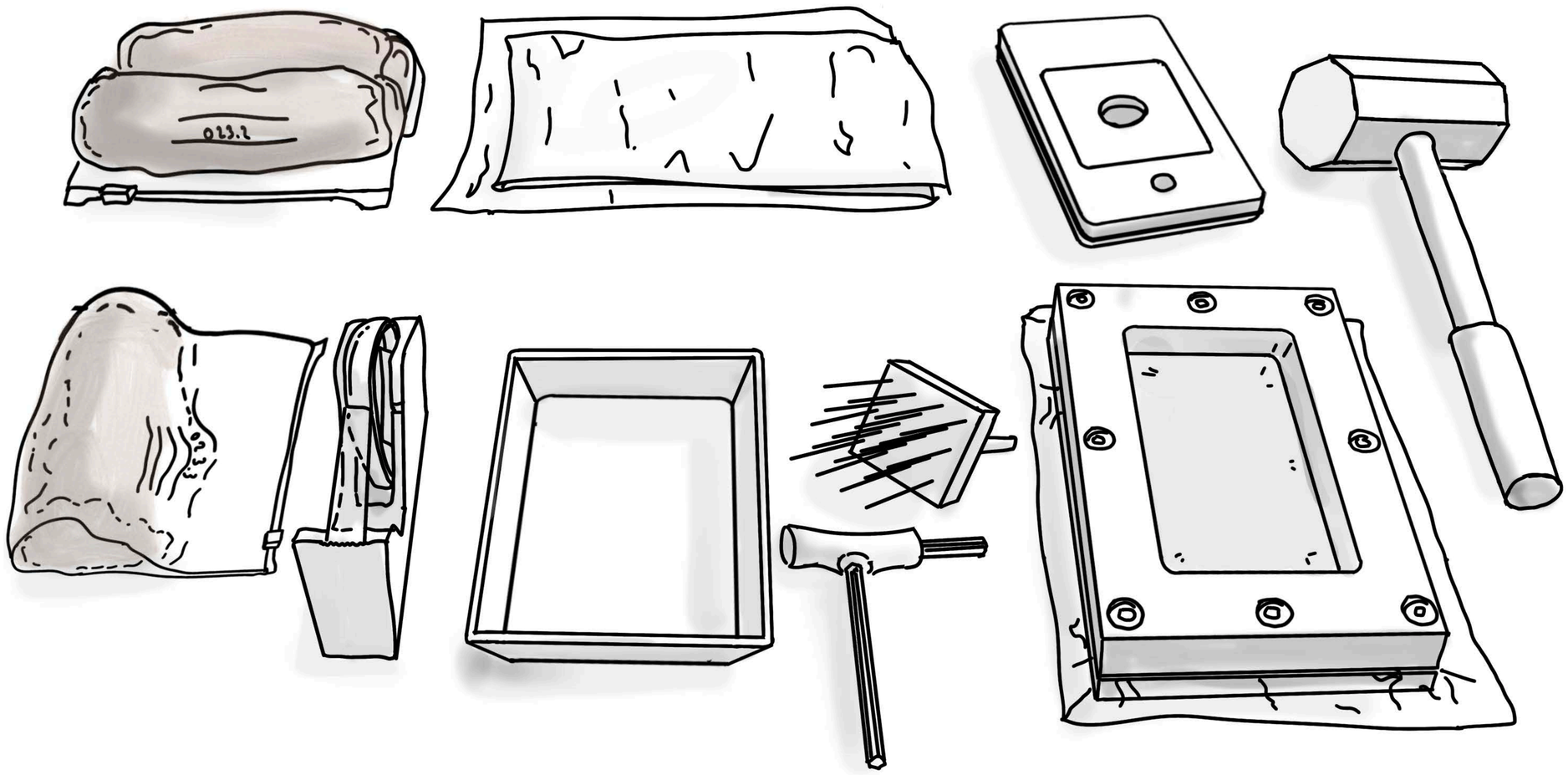
Blending materials until even distribution and even colour.



Weighing and packaging to maintain exact moisture content.

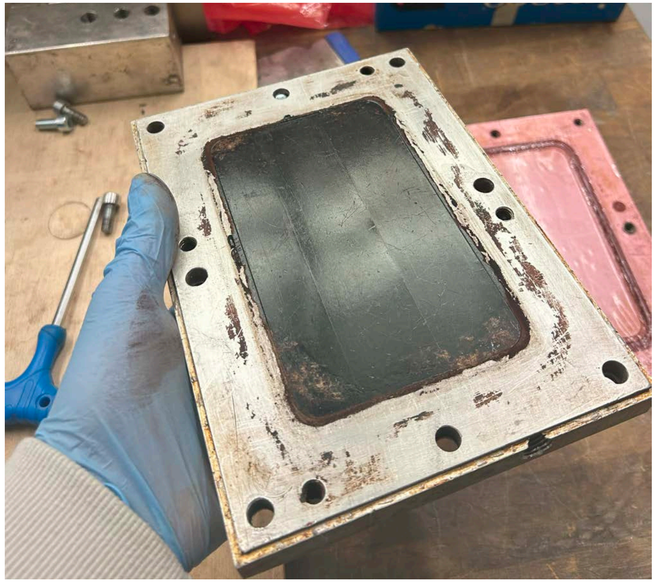
2. Hot-pressing

- Aluminium/ Steel mould (specimen: 150mm by 90mm)
- Unperforated releasefilm, FEP, Max. Temp. 240 °C
- M8 Screwdriver
- "Coffee Mixer"; Spiked tool to loosen and even out fibres in mould
- Heat Resistant Kapton Tape
- 3D printed funnel in size of the mould opening
- Cellulose/Lignin Mixture
- Rubber hammer



Preparing mixture in mould using the funnel and mixing tool.

Hot-pressing at specific conditions (time, pressure, temperature).



Removing plate from mould using rubber hammer.

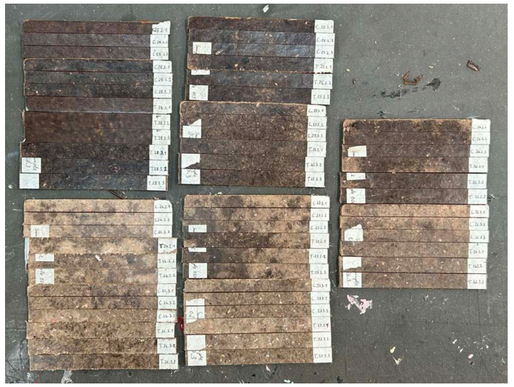
3. Post-processing

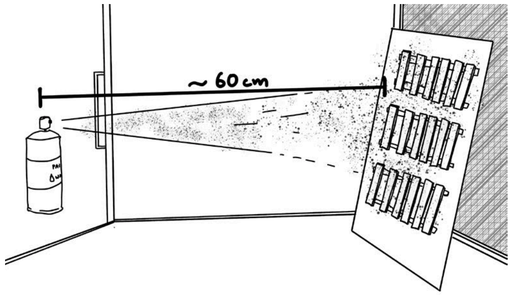
- Drying to prevent warping
- Cutting for mechanical tests
- Applying speckle pattern for DIC

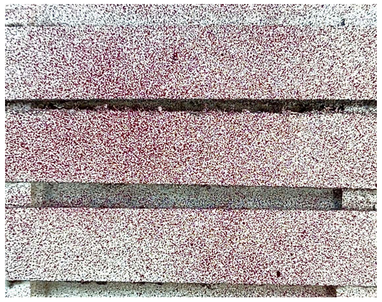
Required Eqiupment:

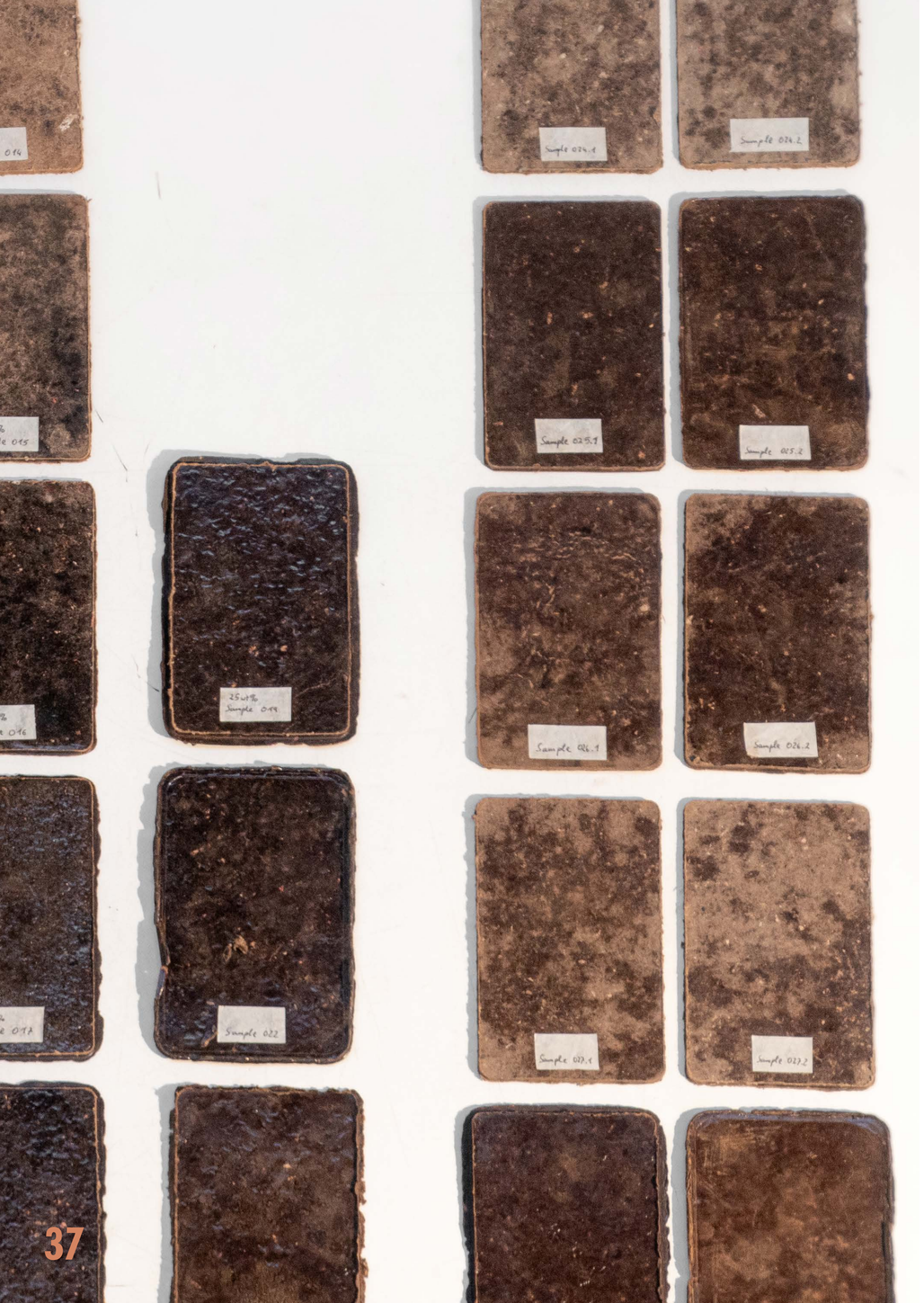
- Drying rack for samples
- Drying oven
- White and Black Spray-paint
- Band-saw

3d-printed drying rack

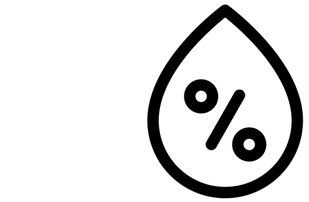




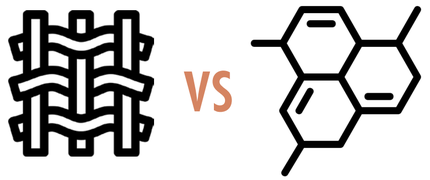




Mixture Variation Trials

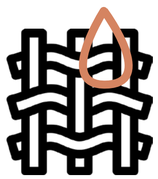


Moisture content variation,
at constant mixture ratio



Cellulose/Lignin ratio variation,
at constant moisture

Lignin Type Variation,
at constant mixture

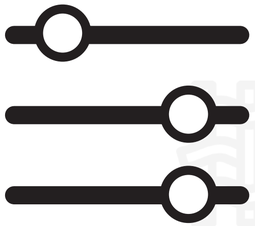


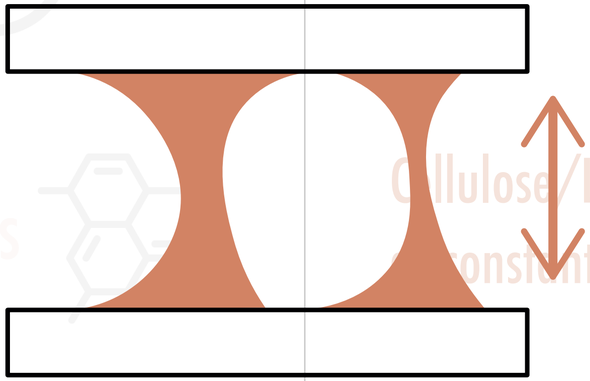
Cellulose Pre-treatment

Recyclability of hot-pressed plates

Mixture Variation Trials

Aim:





Adhesive qualities of Lignin

Moisture content variation,
at constant mixture ratio

Cellulose/Lignin ratio variation,
at constant moisture

Lignin Type Variation,
at constant mixture

Cellulose Pre-treatment

Moisture Trial

Mixture Profile

C - 20g | 30g - L Soda

Hot-Pressing Profile

2 MPa | 85 °C

60 °C | 15 min

Mositure

0 - 25 wt%

Moisture Trial

Mixture Profile

C - 20g | 30g - L Soda

Hot-Pressing Profile

2 MPa | 85 °C

60 °C | 15 min

Mositure

0 - 25 wt%

Qualifier: glossiness and colour

Moisture Trial

Mixture Profile

C - 20g | 30g - L Soda

Hot-Pressing Profile

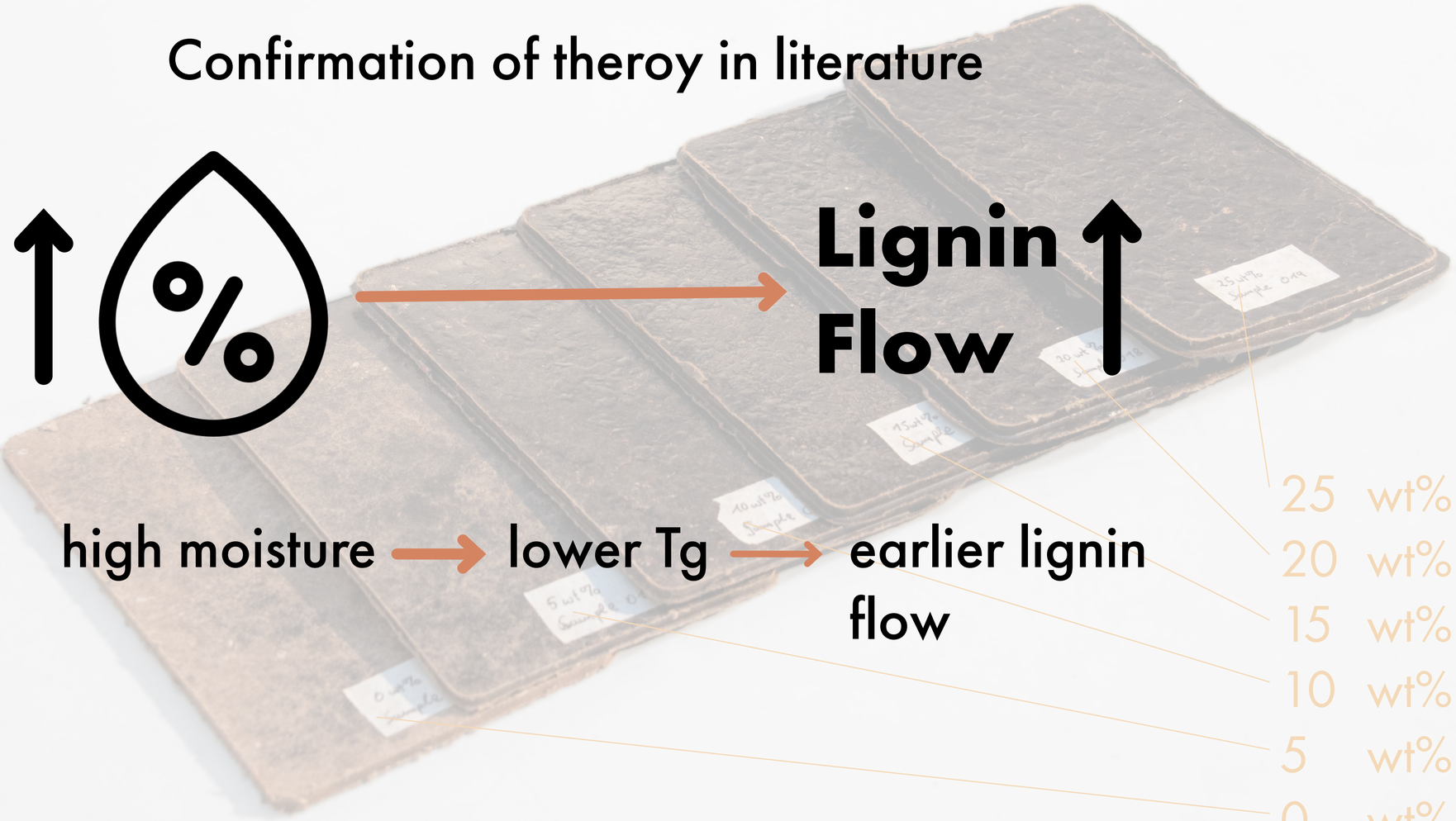
2 MPa | 85 °C

60 °C | 15 min

Mositure

0 - 25 wt%

Confirmation of theroy in literature



Moisture Trial

Mixture Profile

C - 30g | 20g - L Soda

Additional trial to test backwards-compatibility of moisture theory

5 wt%

Hot-Pressing Profile*

19 Mpa
2.2 Mpa
45°C
140 °C
15 min

10 wt%

Hot-Pressing Profile

19 Mpa
2.2 MPa
45°C
90 °C
15 min

25 wt%

Hot-Pressing Profile

19 MPa
2.2 MPa
45 °C
70 °C
15 min

Moisture Trial

Mixture Profile

C - 30g | 20g - L Soda

Additional trial to test backwards-compatibility of moisture theory

5 wt%

10 wt%

25 wt%

Theory is reproducible

Hot-Pressing Profile*

19 Mpa
2.2 Mpa
45°C
140 °C
15 min

Hot-Pressing Profile

19 Mpa
2.2 MPa
45°C
90 °C
15 min

Hot-Pressing Profile

19 MPa
2.2 MPa
45 °C
70 °C
15 min

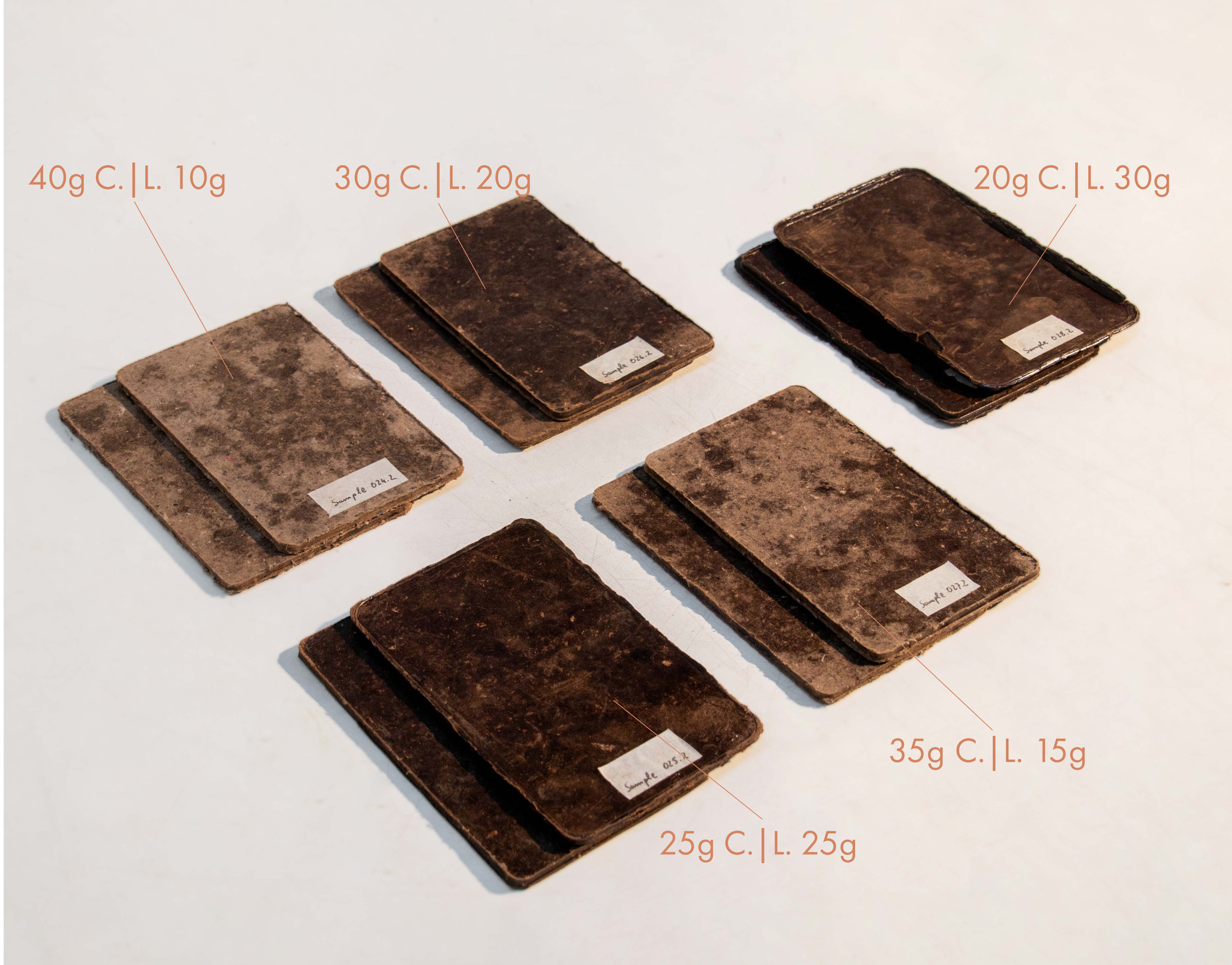
C/L ratio Trial

Hot-Pressing Profile

- 19 Mpa
- 2.2 Mpa
- 40°C
- 85 °C
- 15 min

Mixture Profile

- 20 - 40g ISO C.
- 20 - 40g Soda L.
- 25 wt%



C/L ratio Trial

Hot-Pressing Profile

19 Mpa
2.2 Mpa

85 °C

40°C

15 min

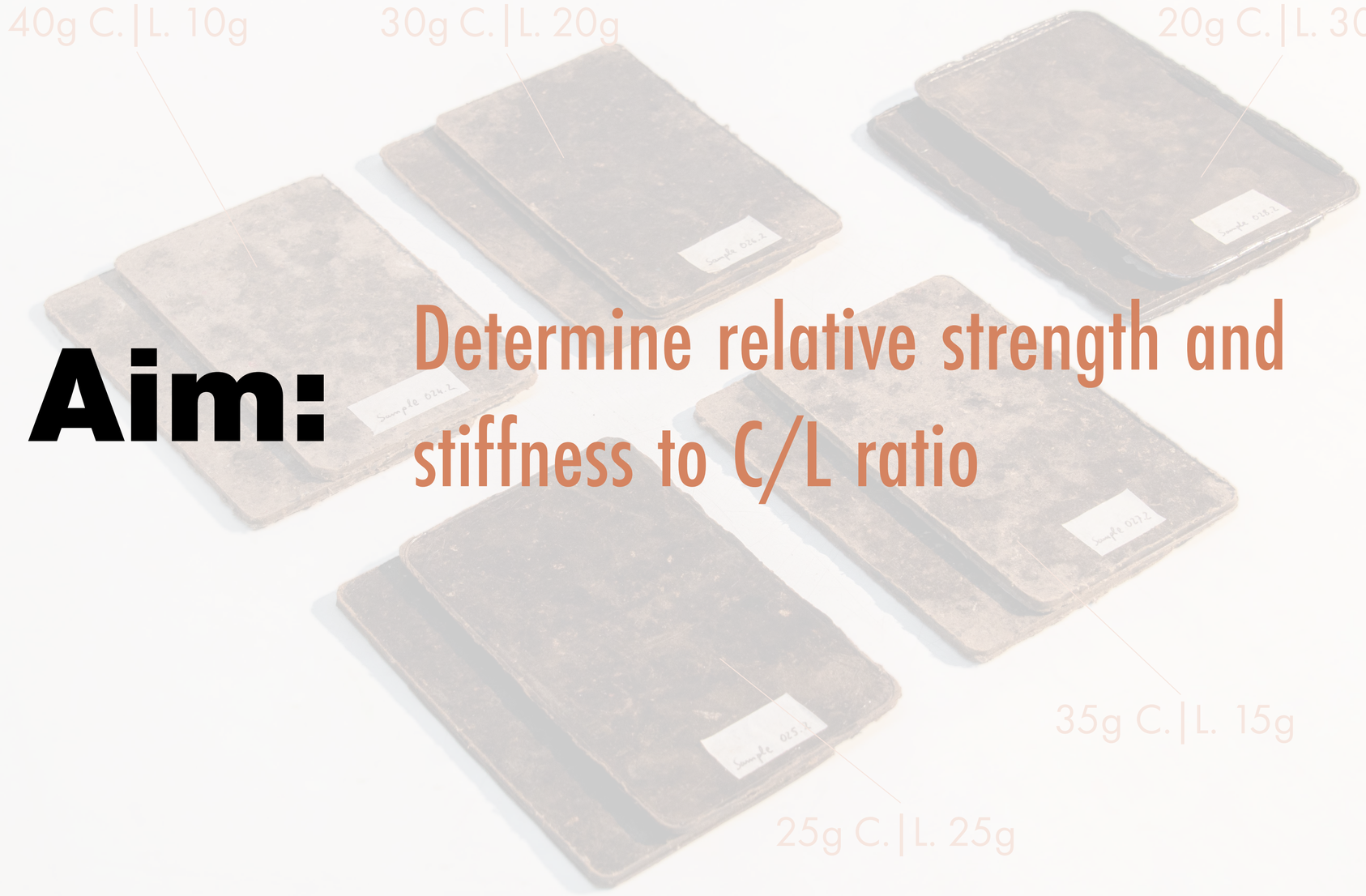
Mixture Profile

20 - 40g ISO C.

20 - 40g Soda L.

25 wt%

Aim: Determine relative strength and stiffness to C/L ratio



Lignin Variation Trial

Hot-Pressing Profile

- 19 Mpa
- 3.7 Mpa
- 140 °C
- 35°C
- 15 min

Mixture Profile

- 25g ISO C.
- 25g Lignin
- 10 wt%

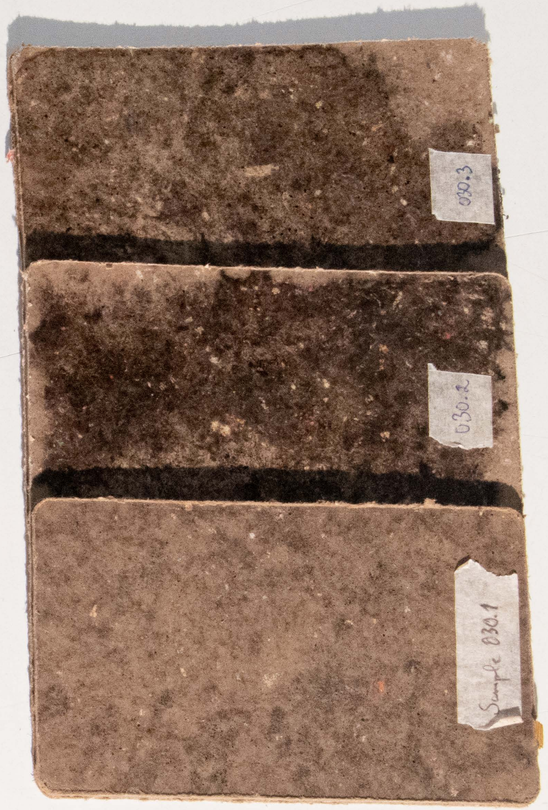
Kraft

(Material source: Softwoods)

Soda

(Material source: Straw, Baggase)

Organosolv



(Material source: Soft- or Hardwoods)

Lignin Variation Trial

Hot-Pressing Profile

19 Mpa
3.7 Mpa

140 °C

35°C

15 min

Mixture Profile

25g ISO C.

25g Lignin

10 wt%

Kraft

Soda (new)

Organosolv

Aim: Determine relative strength and stiffness to Lignin type

Cellulose Pre-treatment Trial

Hot-Pressing Profile

- 19 Mpa
- 3.7 Mpa
- 140 °C
- 35°C
- 15 min

Mixture Profile

- 25g ISO C.
- 25g Soda Lignin (new)
- 10 wt%

Cellulose Pre-treatment Trial

Hot-Pressing Profile

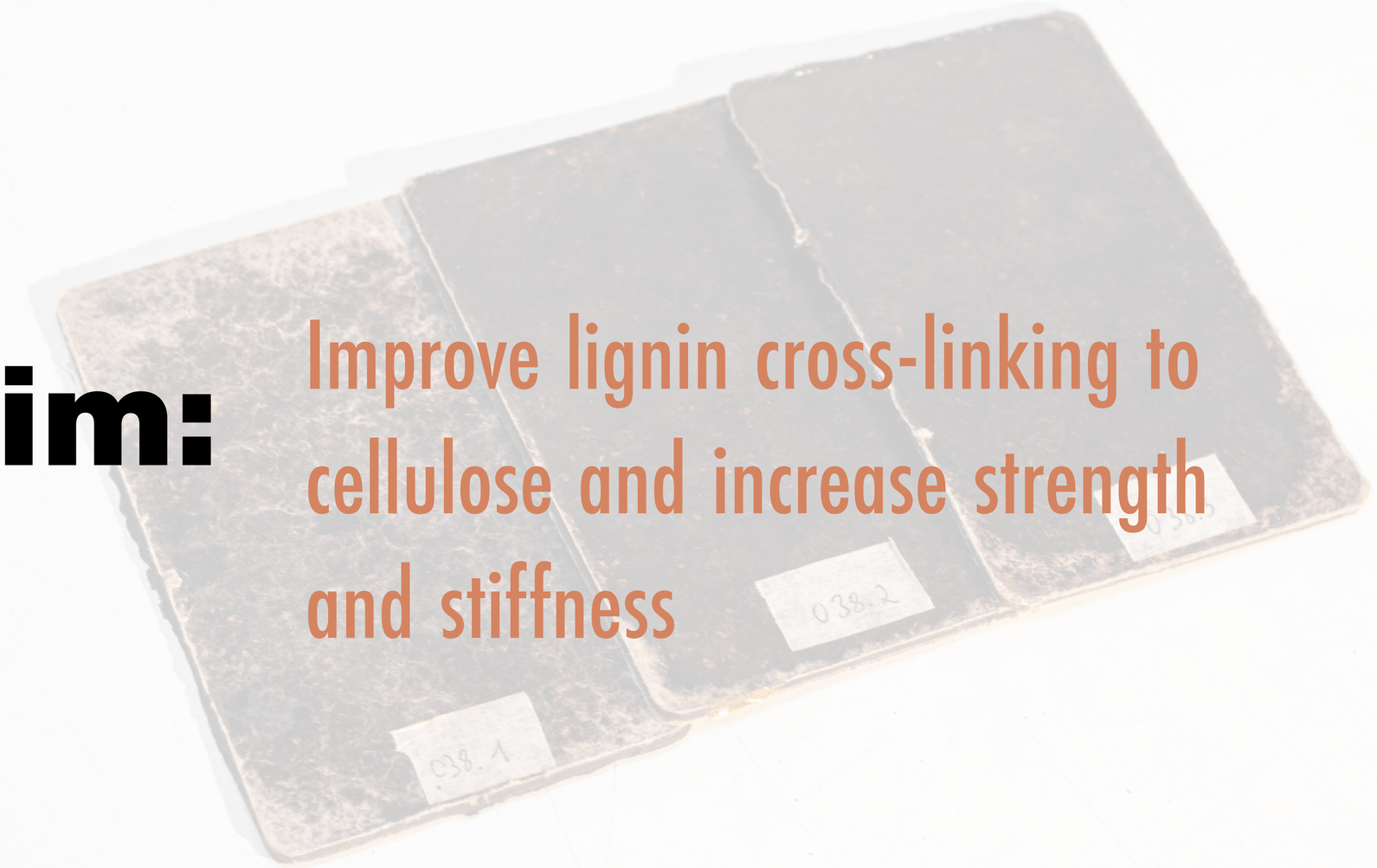
- 19 Mpa
- 3.7 Mpa
- 140 °C
- 35°C
- 15 min

Mixture Profile

- 25g ISO C.
- 25g Soda Lignin (new)
- 10 wt%

Aim:

Improve lignin cross-linking to cellulose and increase strength and stiffness



Cellulose Pre-treatment Trial

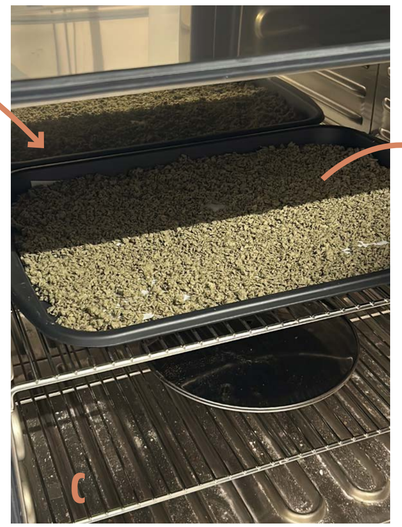
- Preparation of 5% NaOH Solution
- Soaking of Shredded newspaper for 6 to 9 hours
- Straining of Pulp
- Declumping and drying

Required Eqiupment:

- Large glass beakers ~ 1 litre
- Straining Cloth
- Drying Oven + Rack
- NaOH - Sodium Hydroxide

Result:

140g of newspaper -> 75g of dried, treated fibres.



Cellulose Pre-treatment Trial

- Preparation of 5% [illegible]
- Soaking of Shredded newspaper for 6 to 9 hours
- Straining of [illegible]
- Declumping and drying

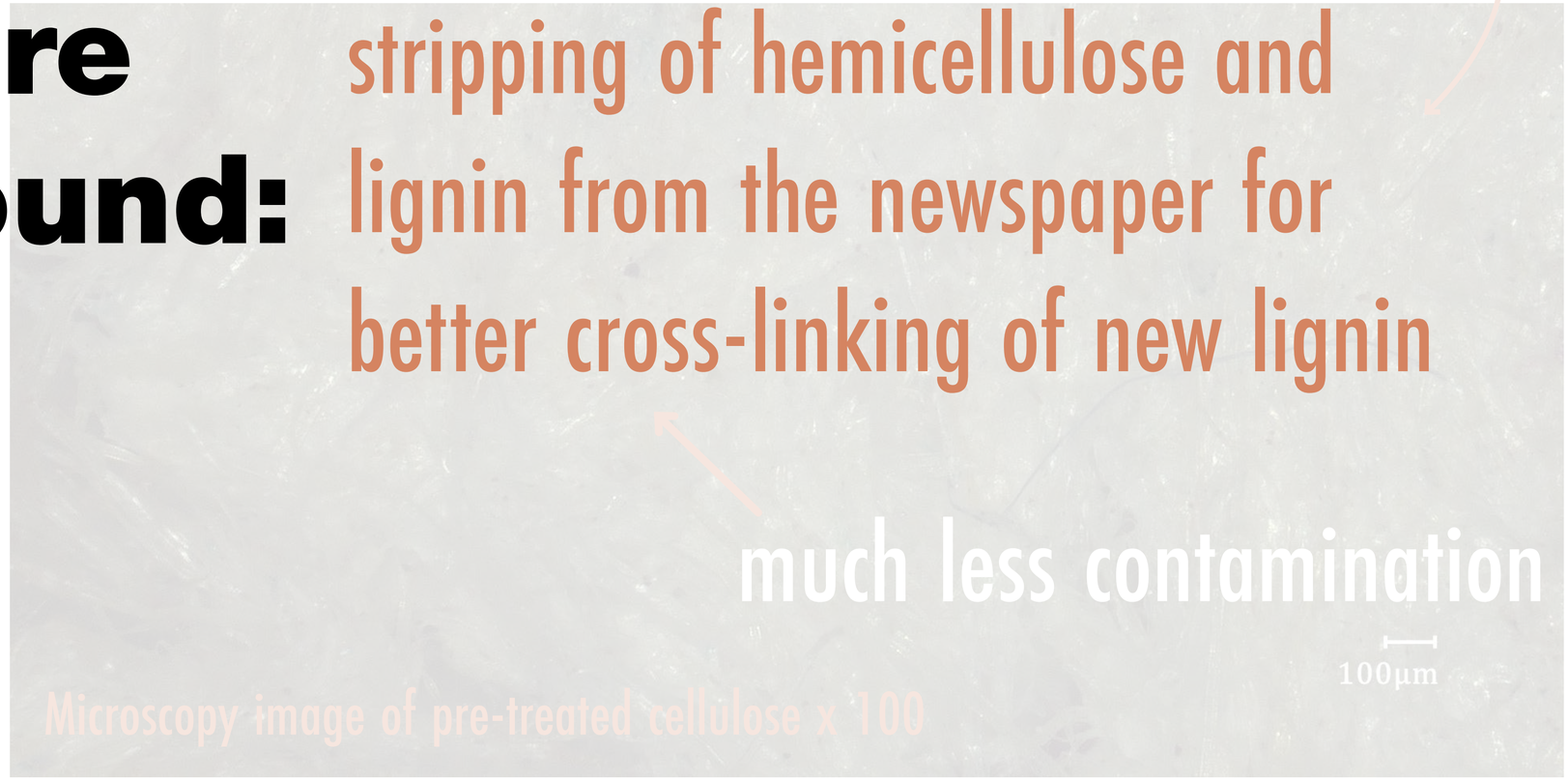
Required Eqiupment:

- Large glass beakers ~ 1 litre
- Straining Cloth
- Drying Oven + Rack
- NaOH - Sodium Hydroxide

Literature background:

stripping of hemicellulose and lignin from the newspaper for better cross-linking of new lignin

much less contamination



Microscopy image of pre-treated cellulose x 100

Material Recycling Trial

Hot-Pressing Profile

19 Mpa
3.7 Mpa

115 °C

60°C

15 min

Mixture Profile

50g (3:2)

10 wt%

Material Recycling Trial

Hot-Pressing Profile

19 Mpa
3.7 Mpa
115 °C
60°C
15 min

Mixture Profile

50g (3:2)
10 wt%

Aim:

Prove the re-softening possibilites of lignin

Scraps

Soaking

Wetted Scraps

Pulp

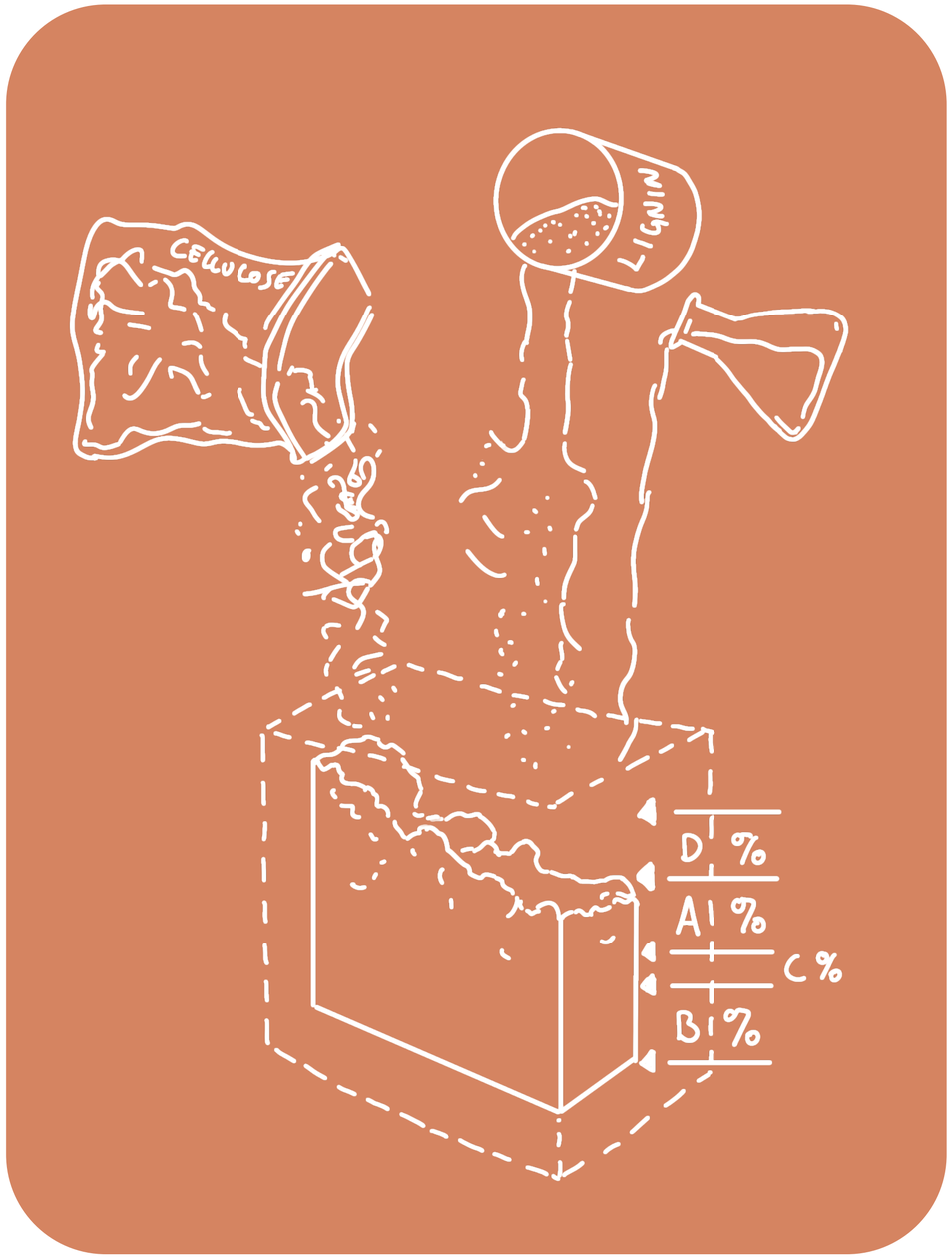
Straining

Dried pulp

Blending

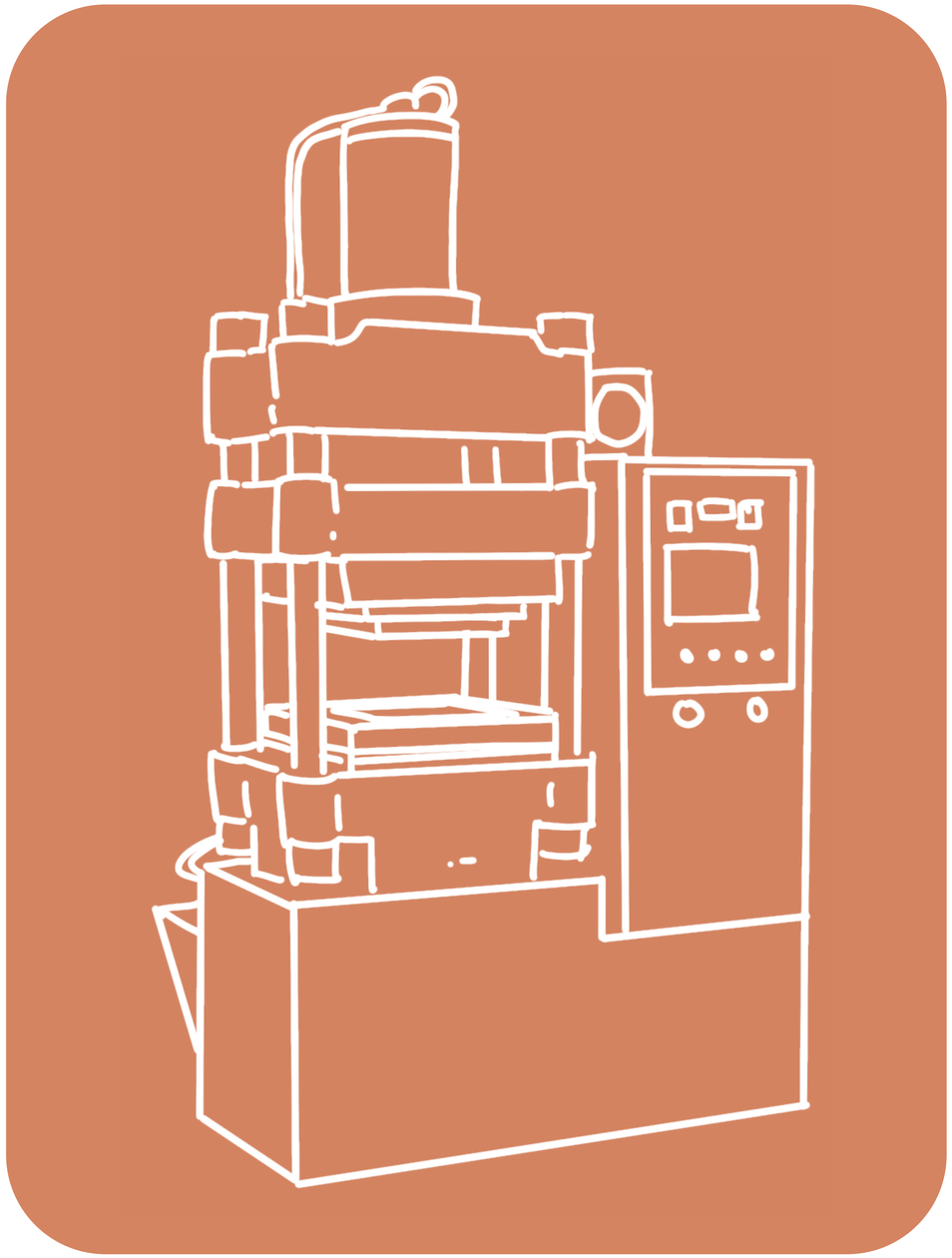
Pressing

Experimental Results



Mixture Development

- Dry-mixing using controlled adding of moisture - optimal 10 wt%
- 3:2 - 1:1 C/L ratio optimal (also economical)
- Organosolv lignin shows poor visual results
- Cellulose pre-treatment Samples show exceptional visual qualities.
- Recycling Trial succesfull, also exceptional visual qualities!



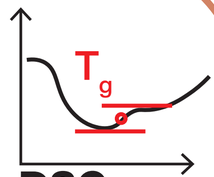
Hot-Pressing Process

- Pre-compression of 20MPa
- Heat to 120°C at 3MPa
- Hold at 120°C for 15min
- Cool to 35°C -> no blisters
- Direct bagging and controlled drying can reduce warping

Analysis Tools

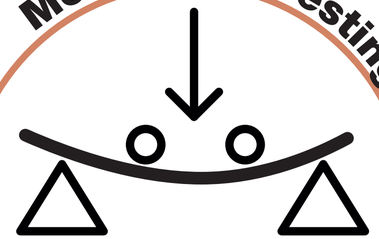
Micrscopy

Thermal Analyis



DSC

Mechanical Testing

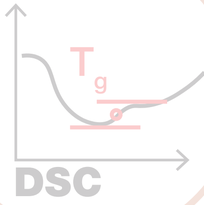


Compression
Bending
Tension

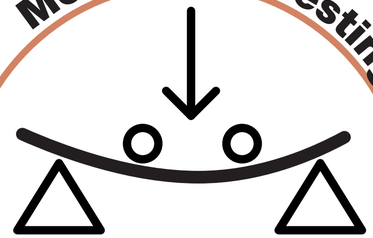
Analysis Tools

Micrscopy

Thermal Analyis

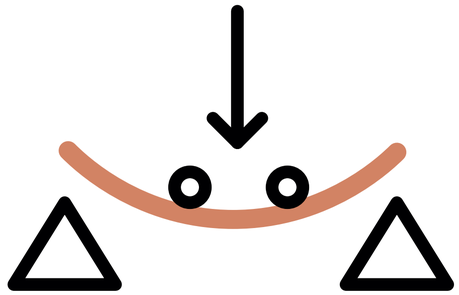


Mechanical Testing



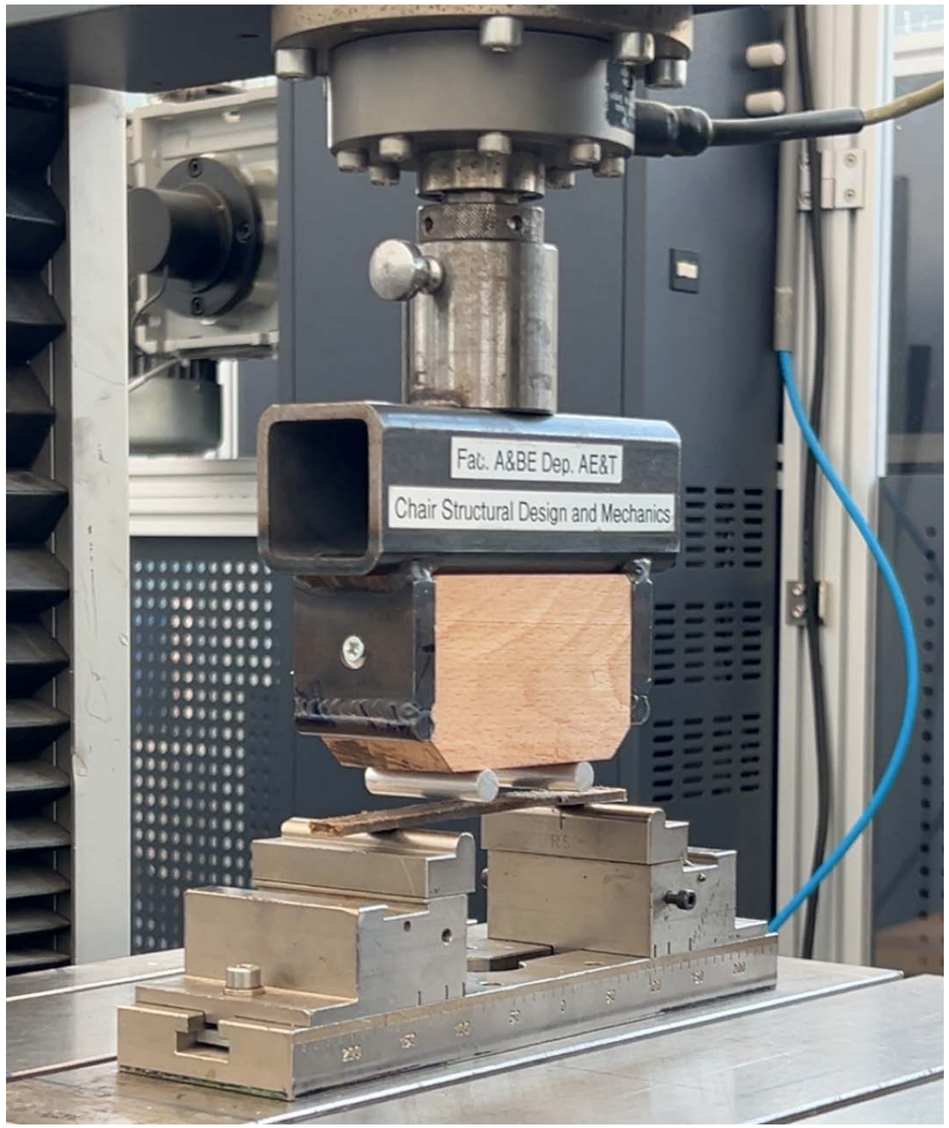
Compression
Bending
Tension

Four-Point Bending

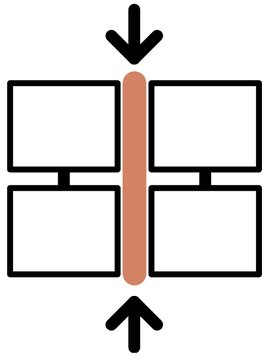


For determining:
Flexural Strength and Stiffness

@ TU Delft Mechanical Engineering - Mechanical Behaviour Laboratory

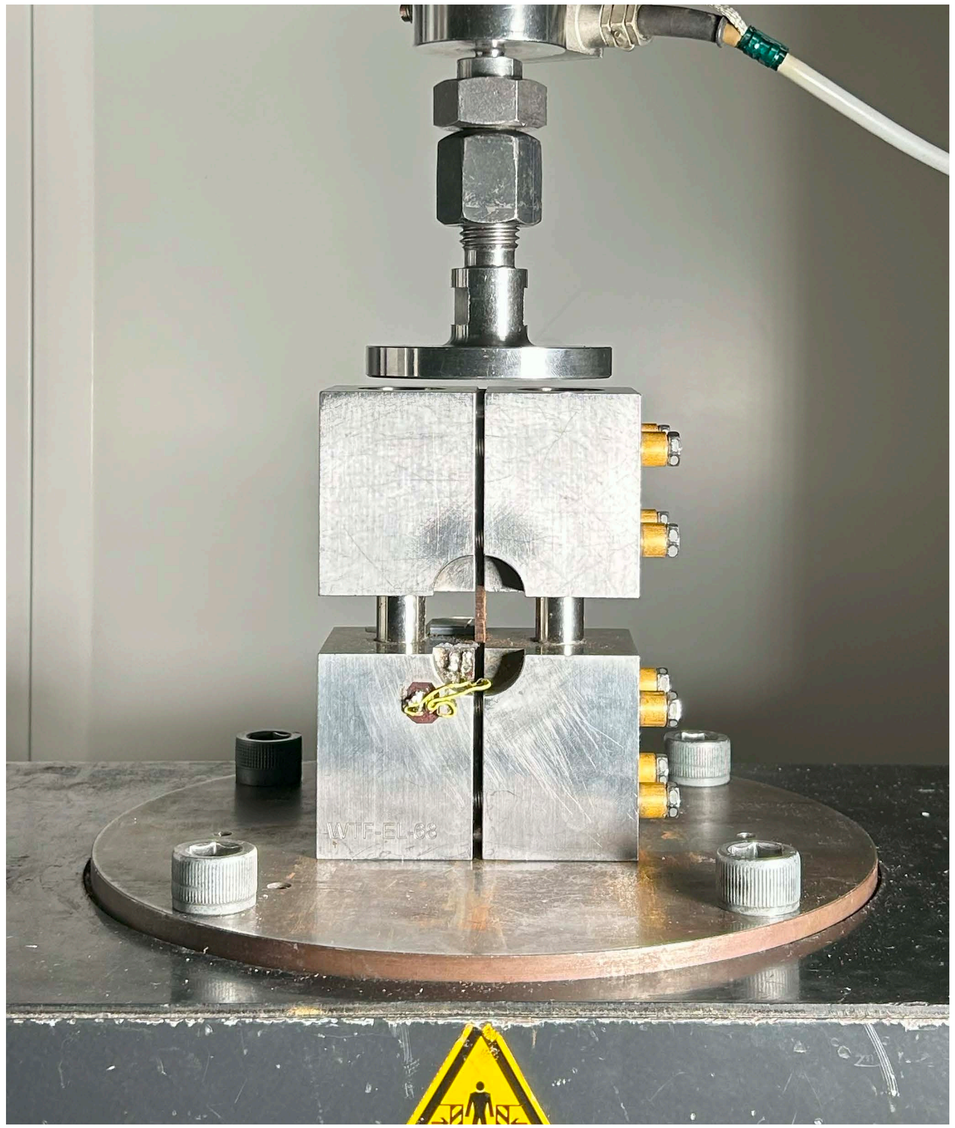


Compression



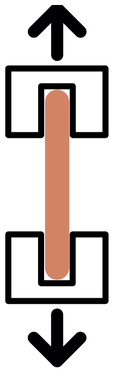
For determining:
Compressive Strength and Stiffness

@ TU Delft Aeropspace Engineering - DASML



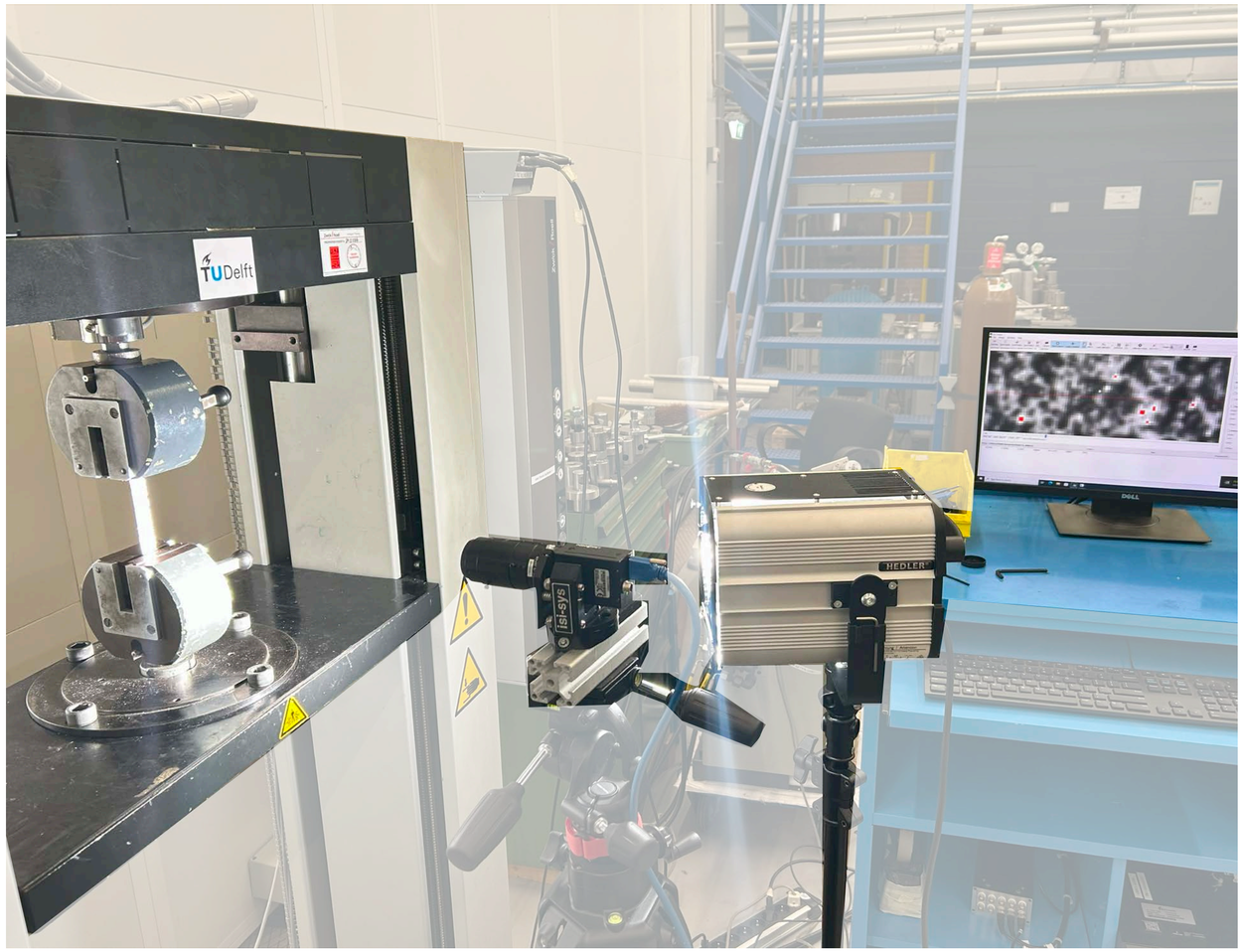
using ASTM D6641anti-buckling fixture

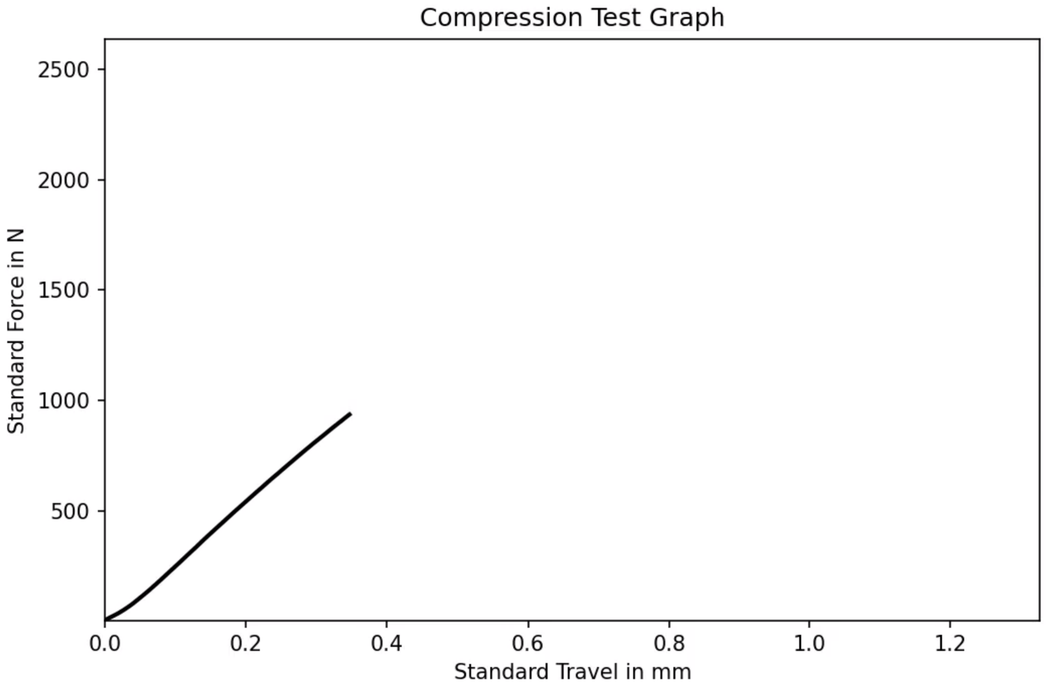
Tension + DIC

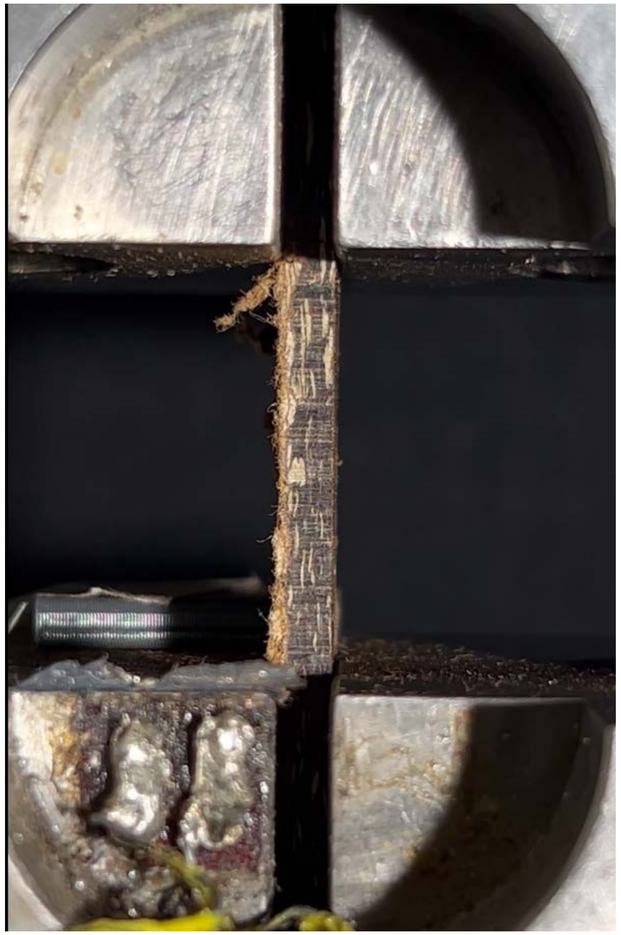


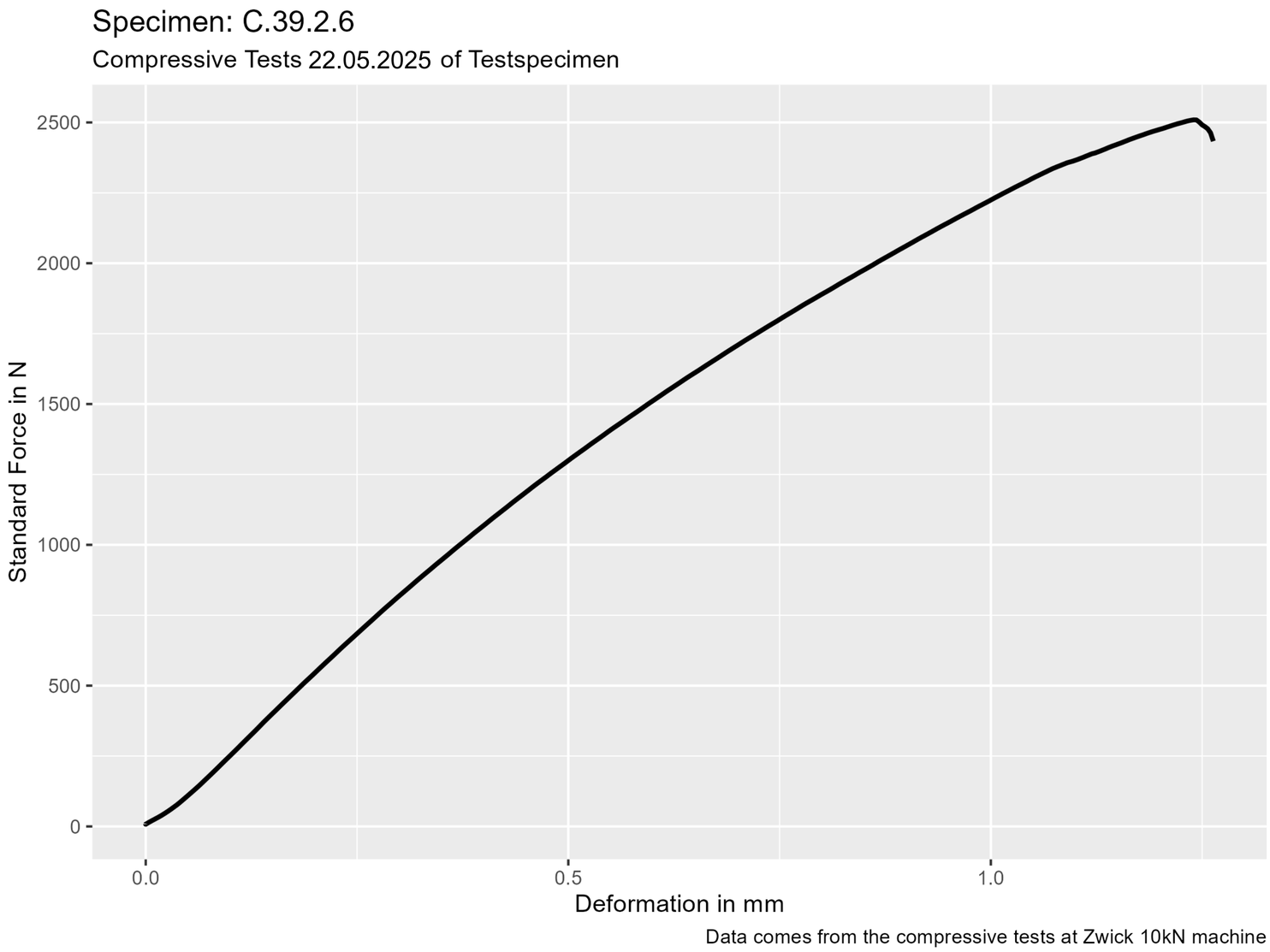
For determining:
Tensile Strength and Stiffness
+ lateral and longitudinal Strain
(for Poisson's ratio to Shear Modulus (G))

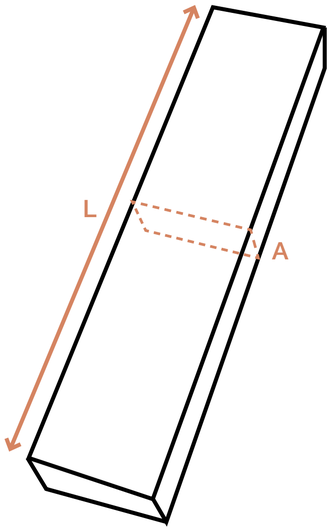
@ TU Delft Aeropspace Engineering - DASML

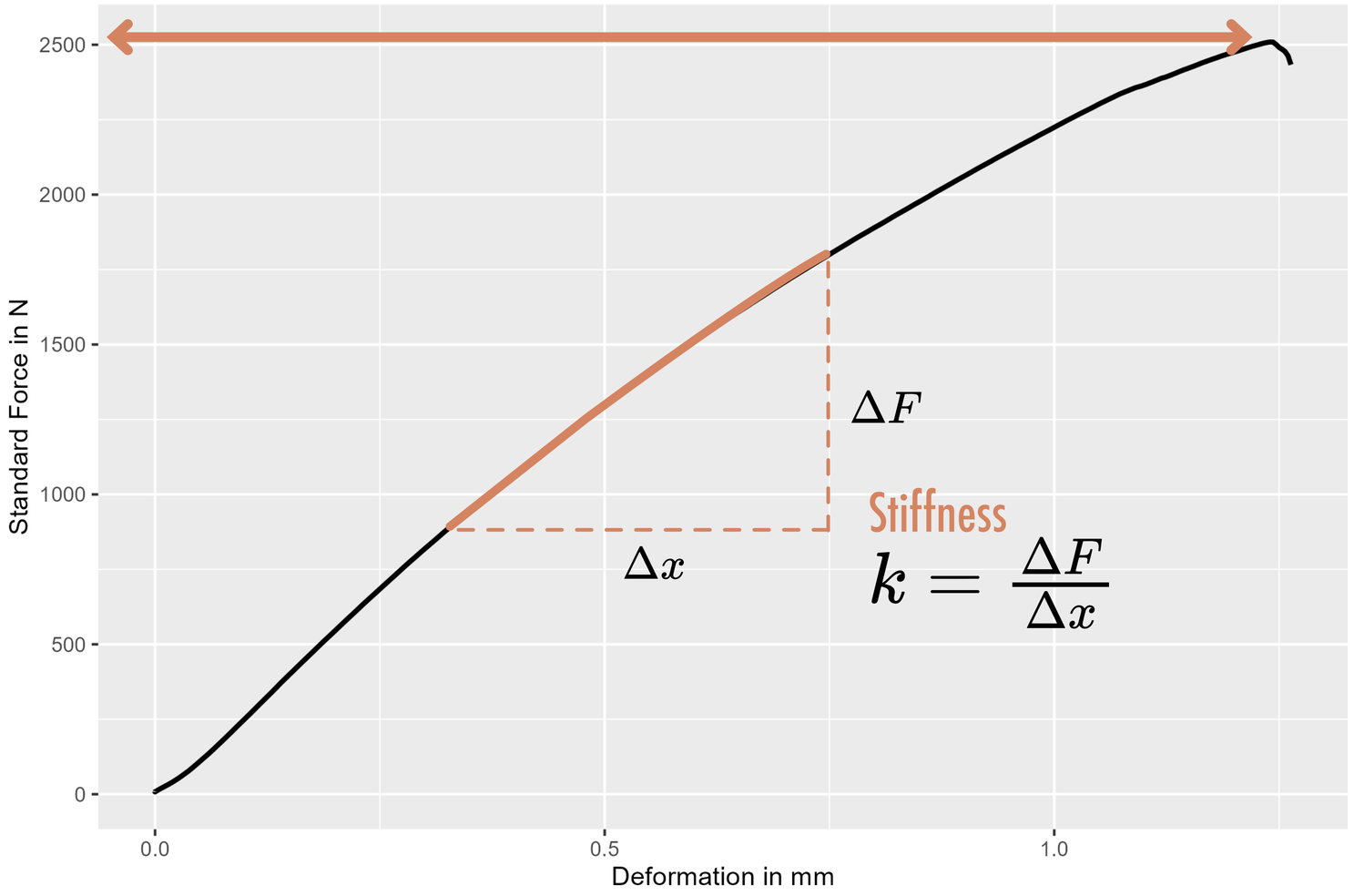



Compression Test Graph
Standard Force in N
2500
2000
1500
1000
500
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Standard Travel in mm




Specimen: C.39.2.6
Compressive Tests 22.05.2025 of Testspecimen
2500
2000
1500
1000
500
0
Standard Force in N
0.0
0.5
1.0
Deformation in mm
Data comes from the compressive tests at Zwick 10kN machine



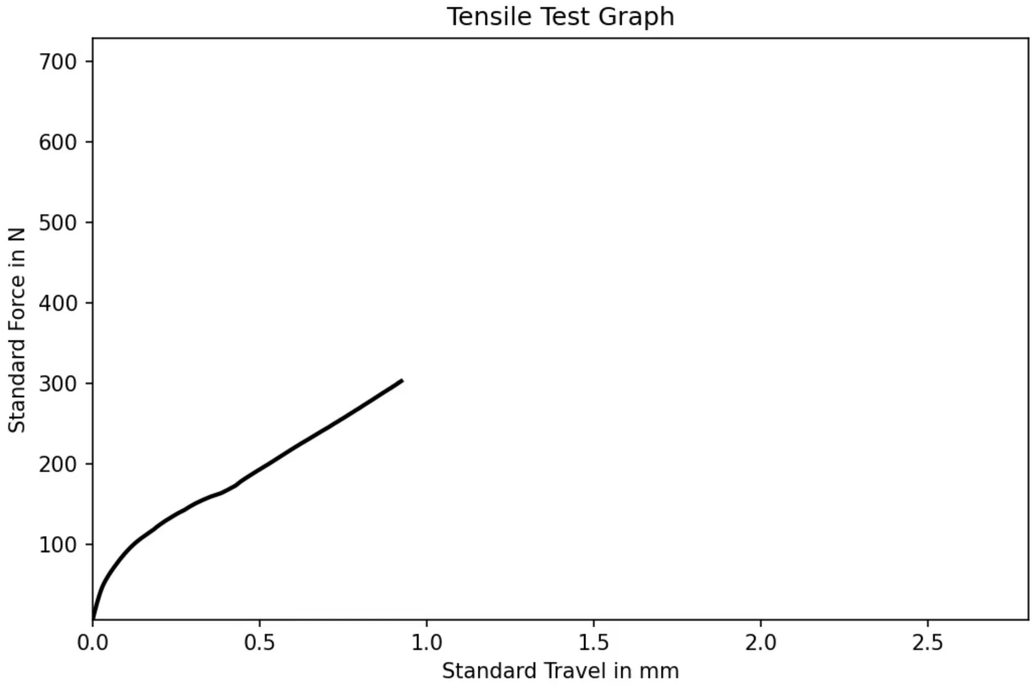


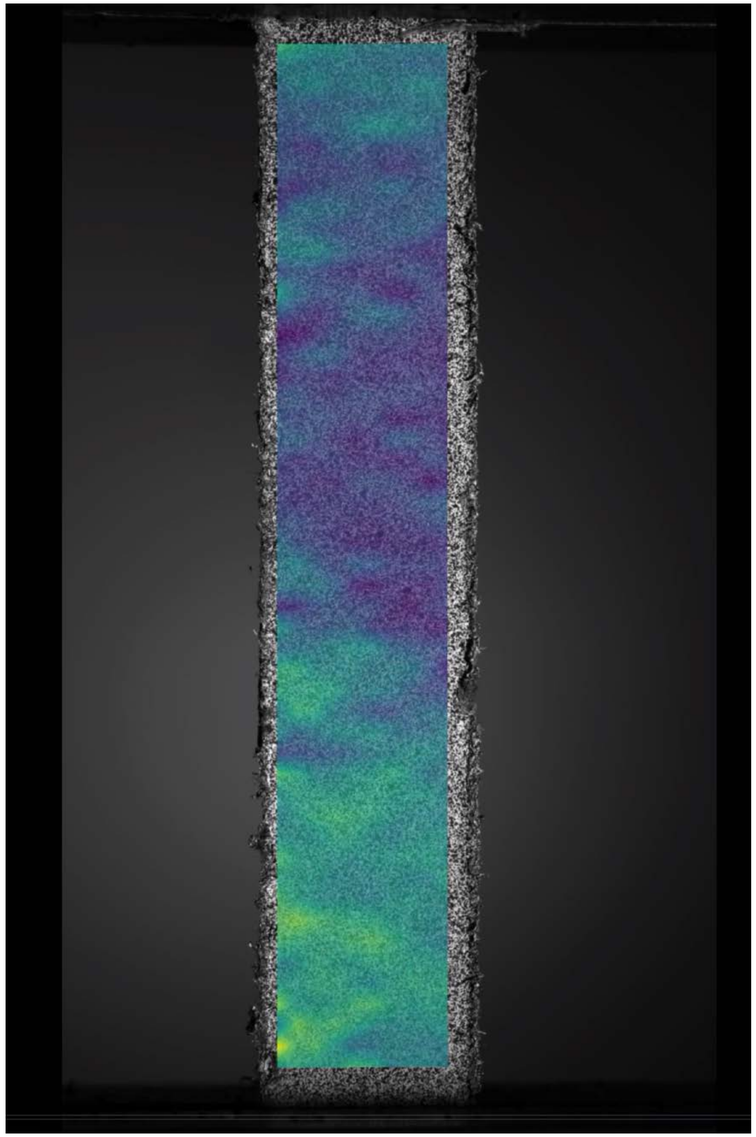
Compressive Strength

$$f_c = \frac{F_{max}}{A}$$

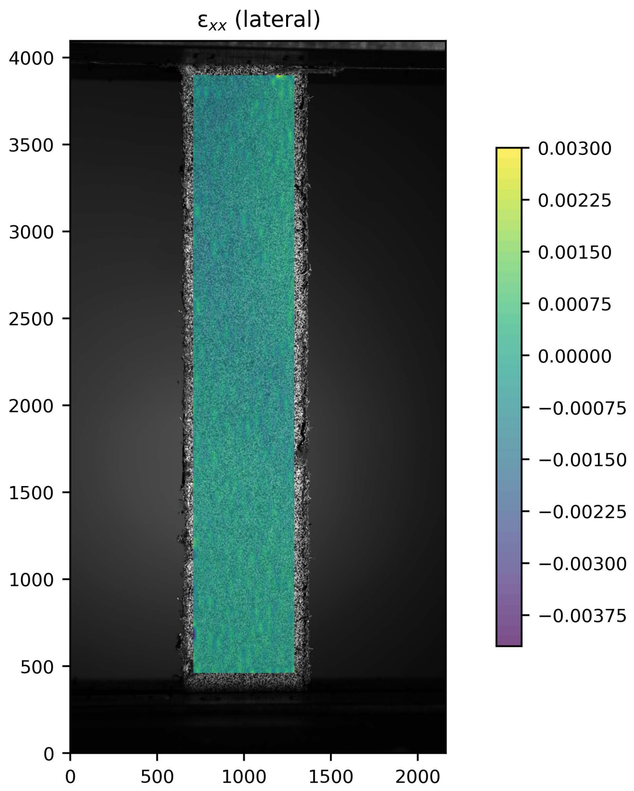
Compressive Modulus

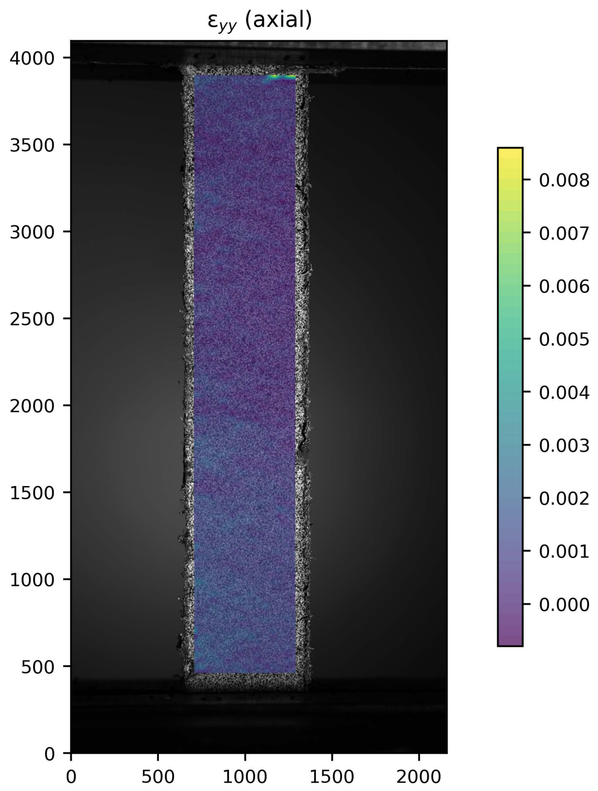
$$E_c = \frac{kL}{A}$$

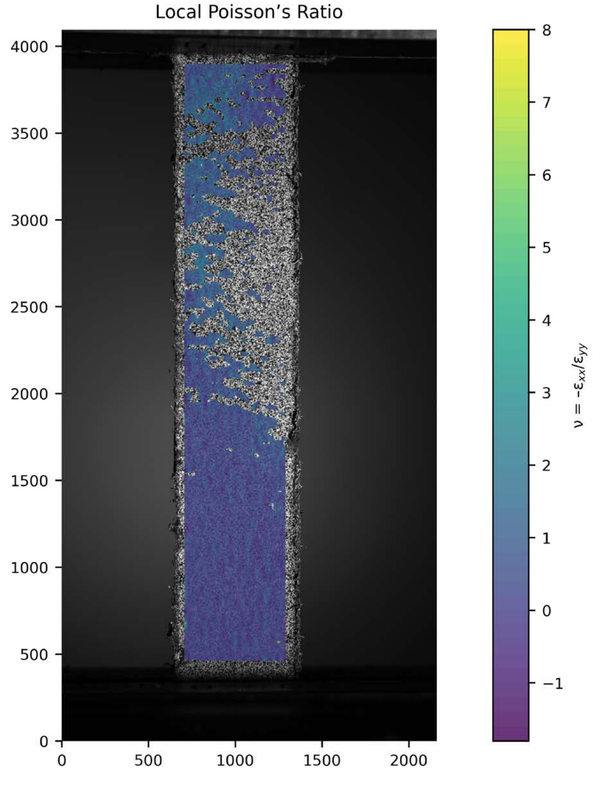

Tensile Test Graph
Standard Force in N
700
600
500
400
300
200
100
0.0
0.5
1.0
1.5
2.0
2.5
Standard Travel in mm

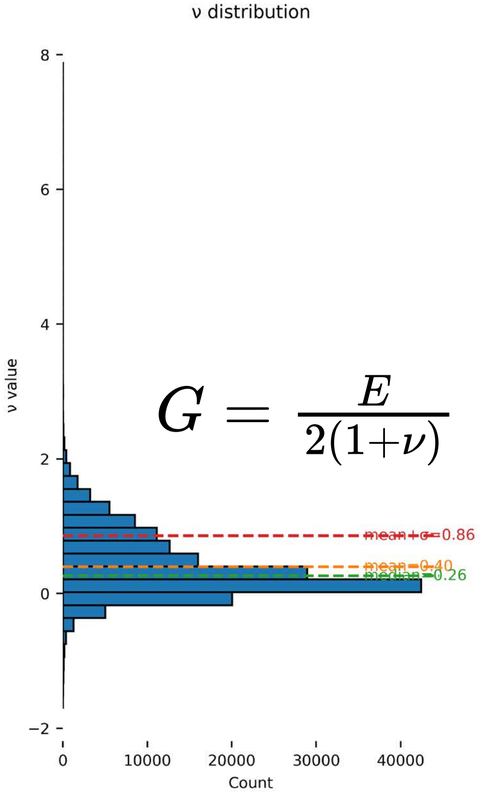


Determination of Poisson's Ratio

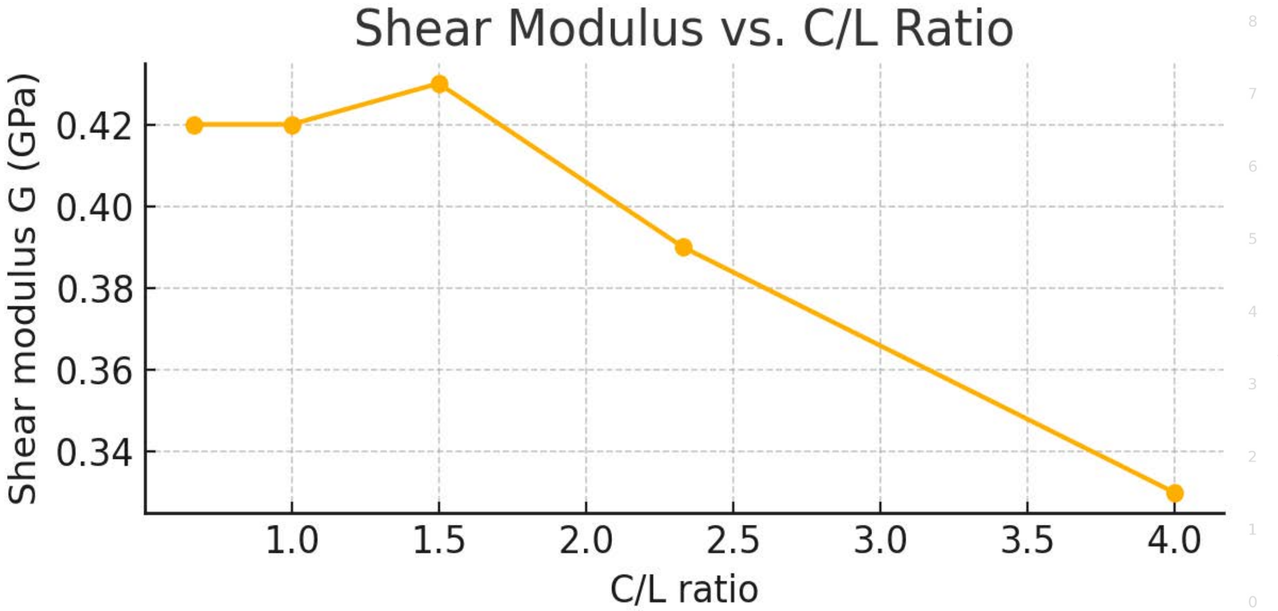








Determination of Poisson's Ratio



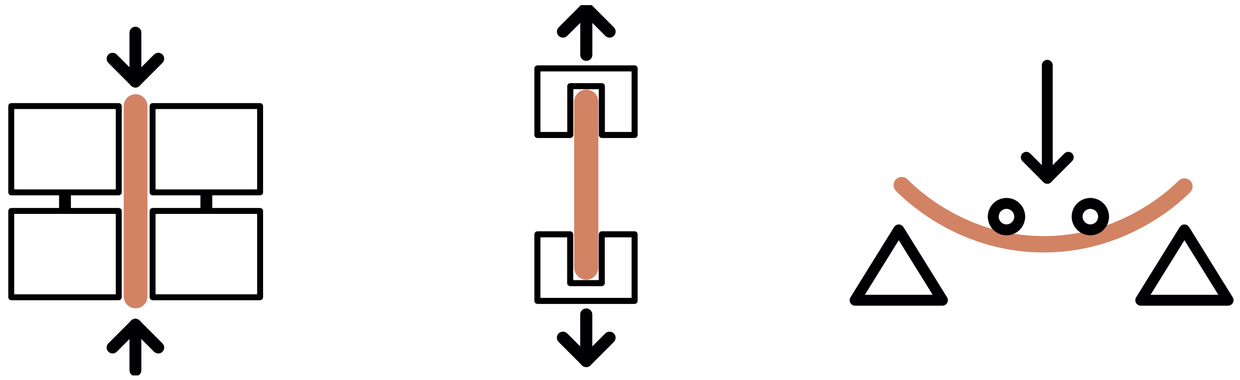
→ moderate internal cohesion, peak at C/L 3:2

e.g. MDF 0.2-0.6; Softwood (with grain) 0.6-1.2

$$G = \frac{E}{2(1+\nu)}$$

Tensile Test + DIC

Mechanical Testing Results



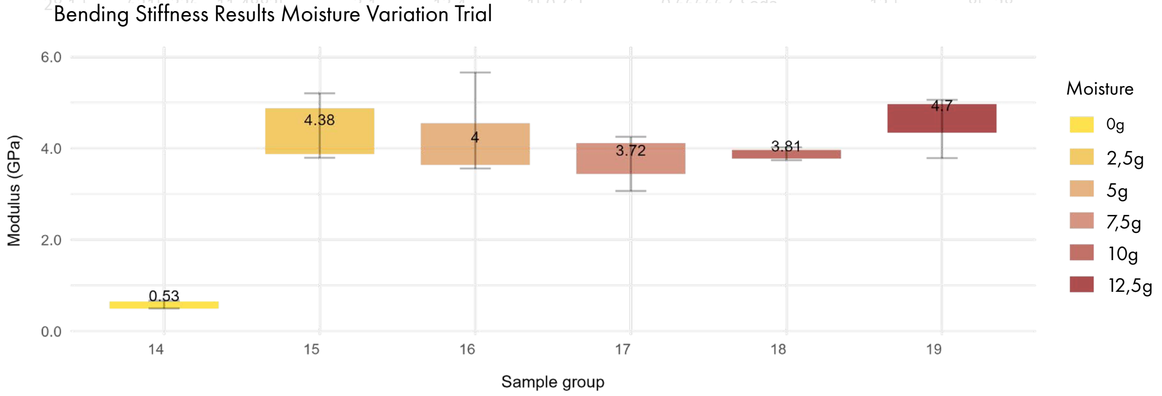
Type	ID	modulus	strength	thickness	width	L	Trial	C/L	Lignin	Moisture-Content	Pressing-temp.	ID_group
B	22.2	6265,322	11,55944	3,4	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	22.3	5013,124	11,10884	3,7	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	22.4	5997,309	12,59063	3,2	13,8	150	C-L	0,666667	Soda	12,5	85	22
B	22.5	5982,93	11,23988	3,3	13,9	150	C-L	0,666667	Soda	12,5	85	22
B	22.6	4714,929	12,5374	3,7	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	28.1.1	5101,026	8,70677	3,2	13,7	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.2	6110,462	10,29947	3,1	13,5	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.3	5589,53	9,100465	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.4	6527,995	7,59552	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.5	6215,326	11,48825	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.6	5290,872	8,867406	3,2	13,5	150	C-L	0,666667	Soda	12,5	85	28
B	25.1.1	6188,904	15,54374	3,7	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.2	5674,324	14,70073	3,6	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.3	6503,451	12,66391	3,7	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.4	5607,25	16,33841	3,4	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.5	5666,974	13,49964	3,7	13,6	150	C-L	1	Soda	12,5	85	25
B	25.1.6	7044,832	16,63206	3,2	13,3	150	C-L	1	Soda	12,5	85	25
B	27.1.1	6800,276	14,7554	3,3	13,2	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.2	5152,383	15,89623	3,3	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.3	7256,76	14,12752	3,4	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.4	5299,508	16,67117	3,3	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.5	8259,459	16,78037	3,4	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.6	9670,392	19,14852	3,3	12,9	150	C-L	2,333333	Soda	12,5	85	27
B	26.1.1	7517,785	14,55511	3,3	13,4	150	C-L	1,5	Soda	12,5	85	26
B	26.1.2	6522,592	16,8058	3,2	13,4	150	C-L	1,5	Soda	12,5	85	26
B	26.1.3	8244,057	16,01036	3,2	13,3	150	C-L	1,5	Soda	12,5	85	26
B	26.1.4	5128,713	15,05476	3,2	13,3	150	C-L	1,5	Soda	12,5	85	26
B	26.1.5	8611,443	22,78519	3,3	13,4	150	C-L	1,5	Soda	12,5	85	26
B	26.1.6	7927,4	22,23617	3,2	13,4	150	C-L	1,5	Soda	12,5	85	26
B	24.1.1	4767,761	9,510516	3,6	13,2	150	C-L	4	Soda	12,5	85	24
B	24.1.2	5229,5	9,207148	3,6	13,25	150	C-L	4	Soda	12,5	85	24
B	24.1.3	4236,728	7,758672	3,5	13,2	150	C-L	4	Soda	12,5	85	24
B	24.1.4	4623,934	10,29196	3,5	13,2	150	C-L	4	Soda	12,5	85	24
B	24.1.5	4769,64	11,98886	3,8	13,3	150	C-L	4	Soda	12,5	85	24
B	24.1.6	3989,662	8,649974	3,5	12,9	150	C-L	4	Soda	12,5	85	24
C	23.1	6311,049	19,1977	3,2	11,9	150	C-L	0,666667	Soda	12,5	85	23
C	23.2	7129,824	20,3512	3,3	12,1	150	C-L	0,666667	Soda	12,5	85	23
C	24.2.1	6873,97	10,17598	3,4	12,4	150	C-L	4	Soda	12,5	85	24
C	24.2.2	9212,007	20,47299	3,3	12,4	150	C-L	4	Soda	12,5	85	24
C	24.3.1	5572,161	14,66721	3,3	12,41	150	C-L	4	Soda	12,5	70	24
C	24.2.3	7852,884	28,76704	3,3	12,41	150	C-L	4	Soda	12,5	85	24
C	24.3.2	7019,717	14,55646	3,44	12,17	150	C-L	4	Soda	12,5	70	24
C	24.3.3	6022,323	15,70994	3,41	12,26	150	C-L	4	Soda	12,5	70	24
C	25.2.1	6951,605	41,44166	3,18	12,35	150	C-L	1	Soda	12,5	85	25
C	25.2.2	9935,626	32,52177	3,12	12,33	150	C-L	1	Soda	12,5	85	25
C	25.2.3	7923,521	24,6303	3,23	12,34	150	C-L	1	Soda	12,5	85	25
C	25.3.1	6536,127	25,18671	3,35	12,32	150	C-L	1	Soda	12,5	70	25
C	25.3.2	6660,878	15,12491	3,51	12,25	150	C-L	1	Soda	12,5	70	25
C	25.3.3	7076,884	17,14666	3,6	12,31	150	C-L	1	Soda	12,5	70	25
C	26.2.1	10559,65	34,29877	3	12,44	150	C-L	1,5	Soda	12,5	85	26
C	26.2.2	9922,856	40,11911	3,01	12,38	150	C-L	1,5	Soda	12,5	85	26
C	26.2.3	7589,371	41,15995	3,01	12,38	150	C-L	1,5	Soda	12,5	85	26
C	26.3.1	7438,504	18,114	3,06	12,31	150	C-L	1,5	Soda	12,5	70	26
C	26.3.2	8143,955	18,68327	3,13	12,16	150	C-L	1,5	Soda	12,5	70	26

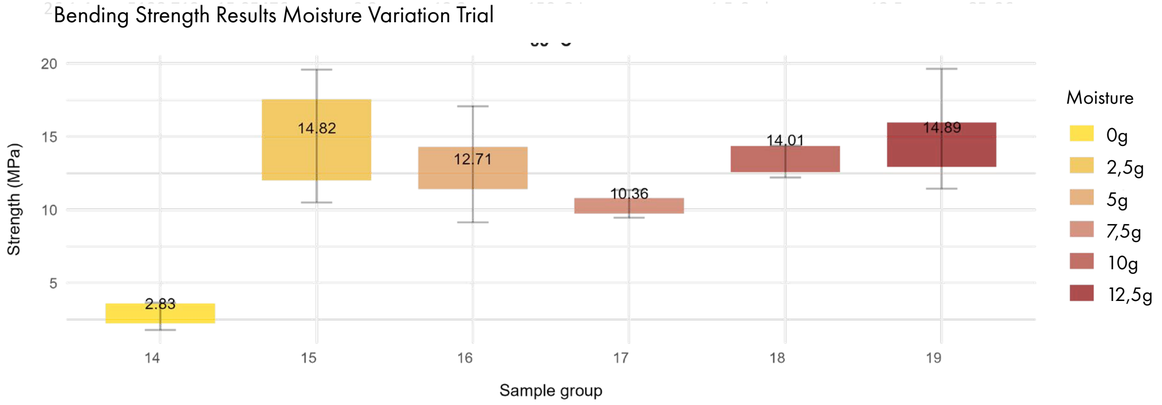
Mechanical Testing Results

- Material has asymmetric strain response due to:

$$E_c \neq E_t$$

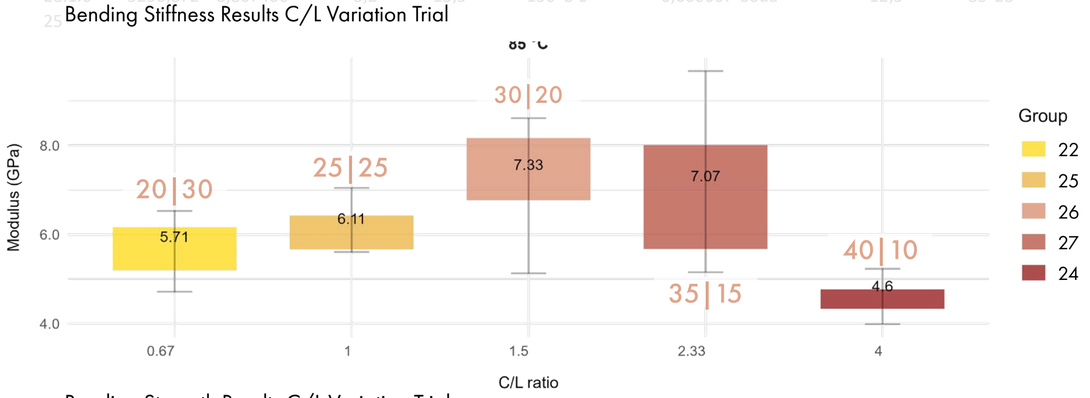
Mechanical Testing Results

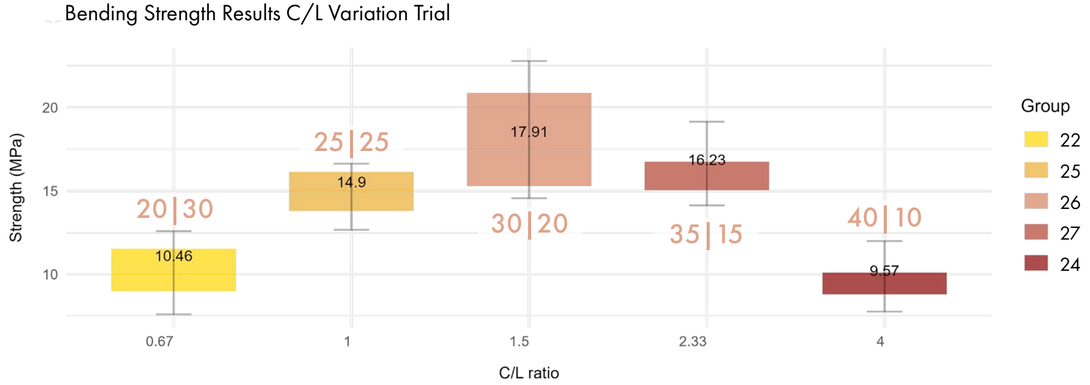




- Material has asymmetric strain response due to: $E_c \neq E_t$

- Moisture of 0wt% behaves the weakest, beyond “dip-and-recover”



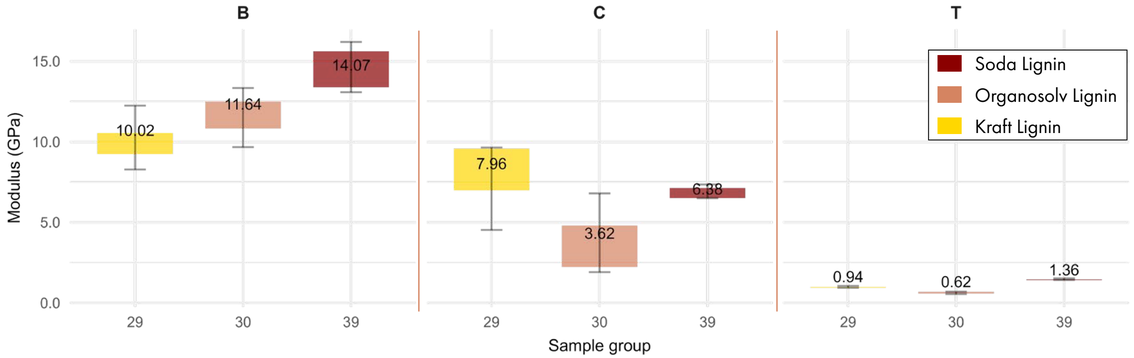


Mechanical Testing Results

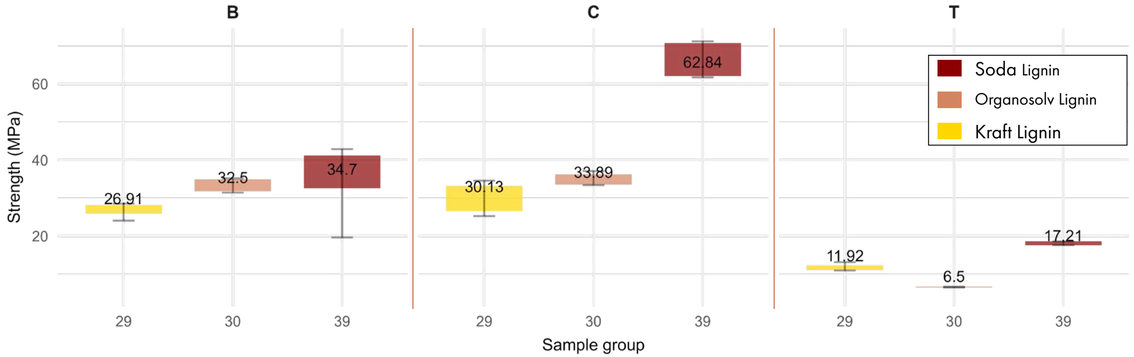
- Material has asymmetric strain response due to: $E_c \neq E_t$
- Moisture of 0wt% behaves the weakest, beyond “dip-and-recover”
- C/L mixtures 3:2 and 2:3 are the most promising

Type	ID	modulus	strength	thickness	width	L	Trial	C/L	Lignin	Moisture-Content	Pressing-temp.	ID_group
B	22.2	6265,322	11,55944	3,4	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	22.3	5013,124	11,10884	3,7	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	22.4	5997,309	12,59063	3,2	13,8	150	C-L	0,666667	Soda	12,5	85	22
B	22.5	5982,93	11,23988	3,3	13,9	150	C-L	0,666667	Soda	12,5	85	22
B	22.6	4714,929	12,5374	3,7	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	28.1.1	5101,026	8,70677	3,2	13,7	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.2	6110,462	10,29947	3,1	13,5	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.3	5589,53	9,100465	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.4	6527,995	7,59552	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28

Stiffness Results Lignin Variation Trial



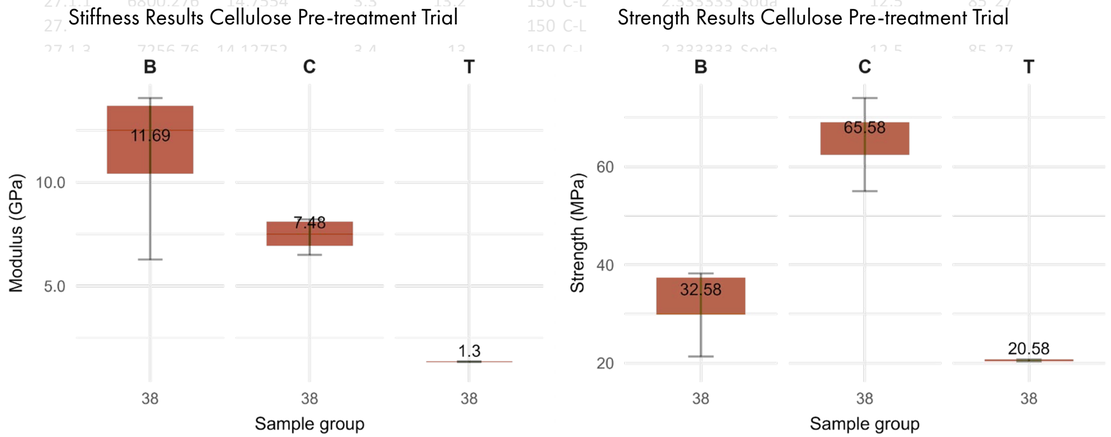
Strength Results Lignin Variation Trial



C	25.2.1	6951,605	41,44166	3,18	12,35	150	C-L	1	Soda	12,5	85	25
C	25.2.2	9935,626	32,52177	3,12	12,33	150	C-L	1	Soda	12,5	85	25
C	25.2.3	7923,521	24,6303	3,23	12,34	150	C-L	1	Soda	12,5	85	25
C	25.3.1	6536,127	25,18671	3,35	12,32	150	C-L	1	Soda	12,5	70	25
C	25.3.2	6660,878	15,12491	3,51	12,25	150	C-L	1	Soda	12,5	70	25
C	25.3.3	7076,884	17,14666	3,6	12,31	150	C-L	1	Soda	12,5	70	25
C	26.2.1	10559,65	34,29877	3	12,44	150	C-L	1,5	Soda	12,5	85	26
C	26.2.2	9922,856	40,11911	3,01	12,38	150	C-L	1,5	Soda	12,5	85	26
C	26.2.3	7589,371	41,15995	3,01	12,38	150	C-L	1,5	Soda	12,5	85	26
C	26.3.1	7438,504	18,114	3,06	12,31	150	C-L	1,5	Soda	12,5	70	26
C	26.3.2	8143,955	18,68327	3,13	12,16	150	C-L	1,5	Soda	12,5	70	26

Mechanical Testing Results

- Material has asymmetric strain response due to: $E_c \neq E_t$
- Moisture of 0wt% behaves the weakest, beyond “dip-and-recover”
- C/L mixtures 3:2 and 2:3 are the most promising
- Soda Lignin shows the best performance



Mechanical Testing Results

- Material has asymmetric strain response due to: $E_c \neq E_t$

- Moisture of 0wt% behaves the weakest, beyond "dip-and-recover"
- C/L mixtures 3:2 and 2:3 are the most promising
- Soda Lignin shows the best performance
- C-Pre-Treatment shows no significant performance improvements

Qualitative Material Propteries

Thickness

Lignin Flow

Compr. Force

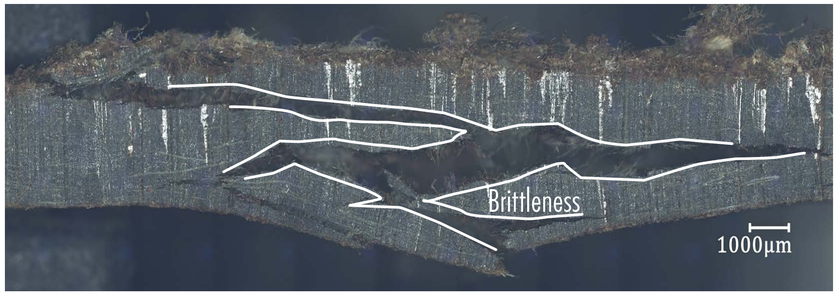
Warping

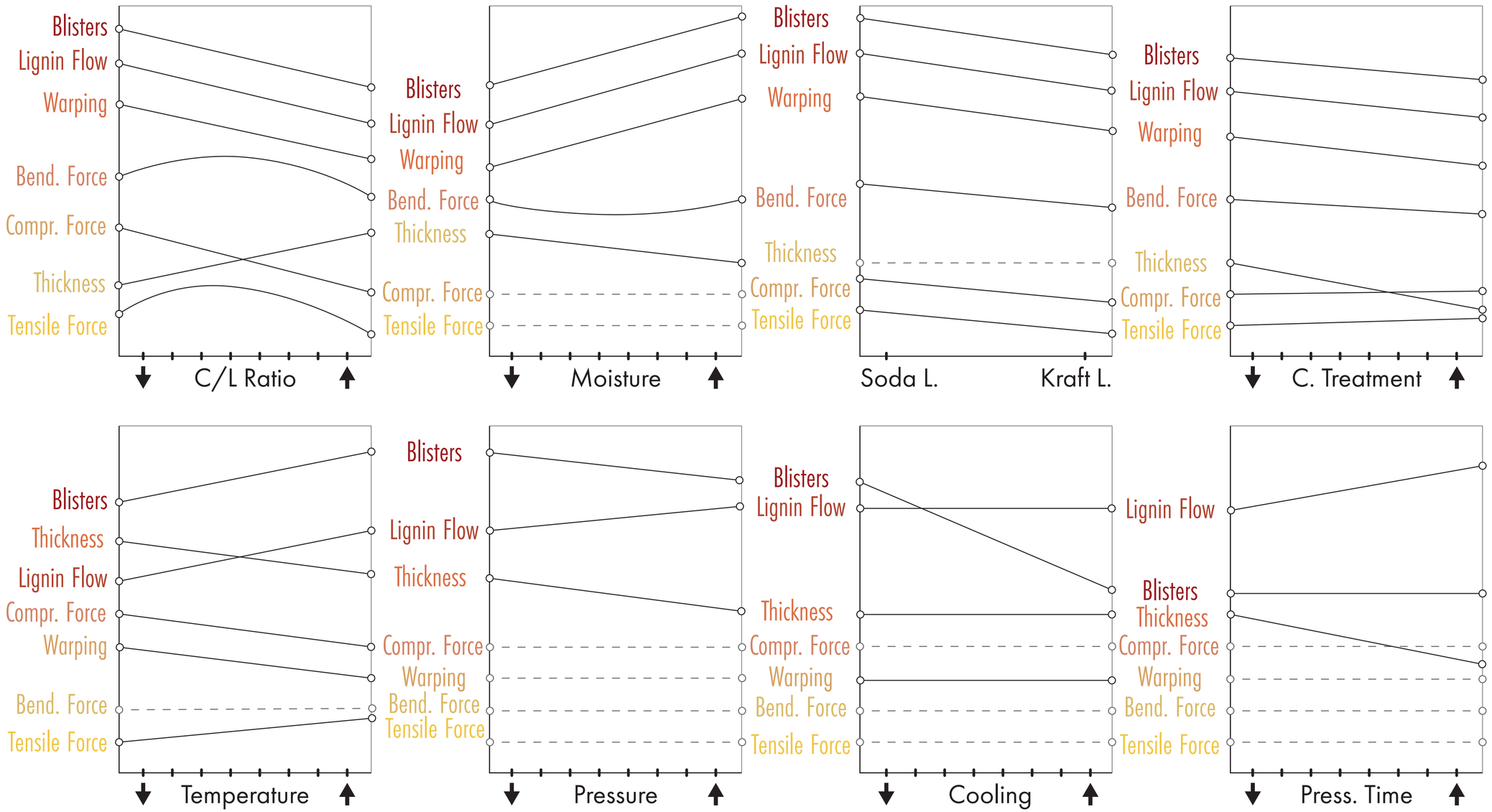
Bend. Force

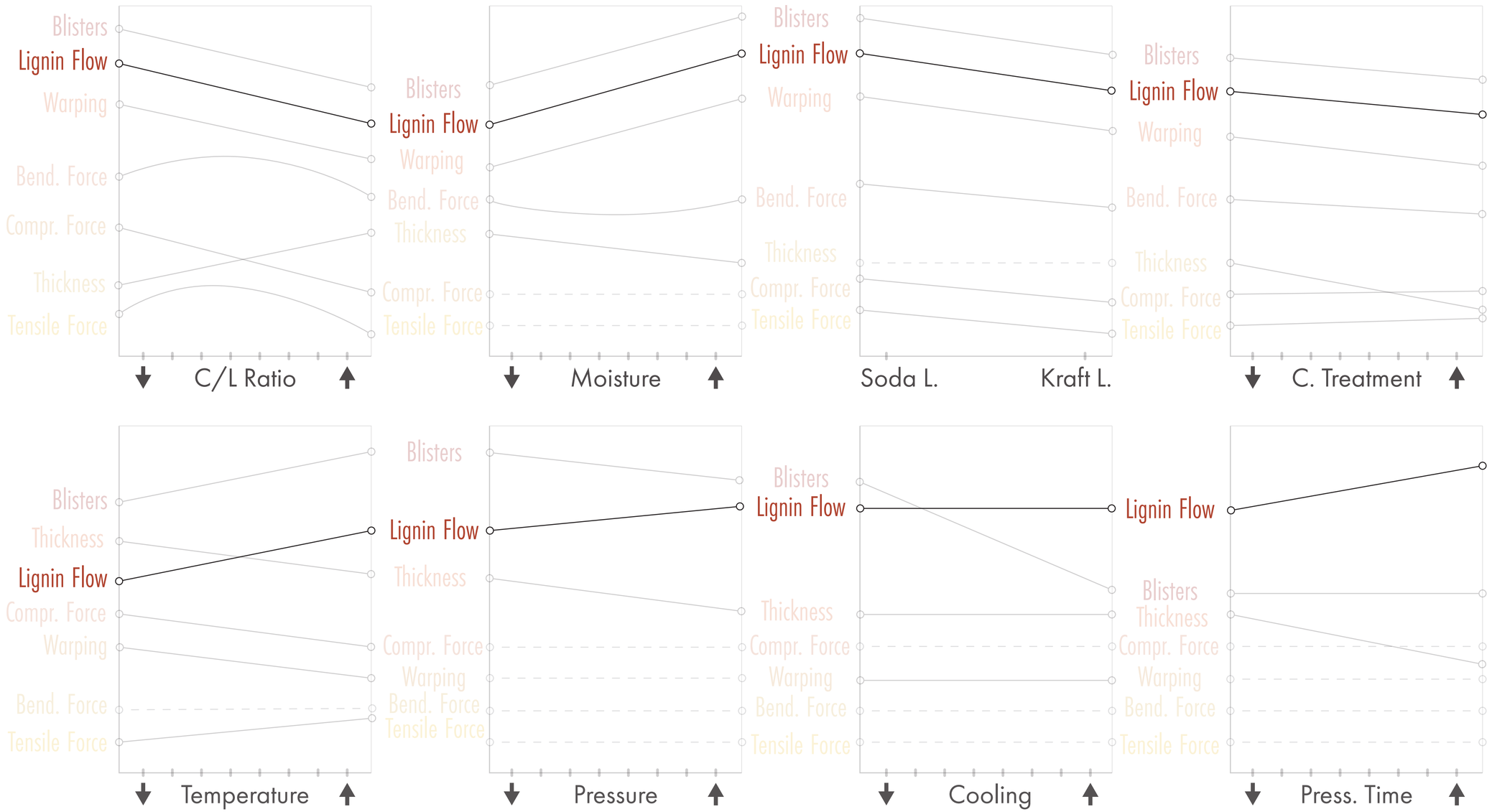
Tensile Force

Brittleness

Blisters




Blisters
Lignin Flow
Warping
Bend. Force
Compr. Force
Thickness
Tensile Force
C/L Ratio
Blisters
Lignin Flow
Warping
Bend. Force
Thickness
Compr. Force
Tensile Force
Moisture
Blisters
Lignin Flow
Warping
Bend. Force
Thickness
Compr. Force
Tensile Force
Soda L.
Kraft L.
Blisters
Lignin Flow
Warping
Bend. Force
Thickness
Compr. Force
Tensile Force
C. Treatment
Blisters
Thickness
Lignin Flow
Compr. Force
Warping
Bend. Force
Tensile Force
Temperature
Blisters
Lignin Flow
Thickness
Compr. Force
Warping
Bend. Force
Tensile Force
Pressure
Blisters
Lignin Flow
Thickness
Compr. Force
Warping
Bend. Force
Tensile Force
Cooling
Lignin Flow
Blisters
Thickness
Compr. Force
Warping
Bend. Force
Tensile Force
Press. Time


Blisters
Lignin Flow
Warping
Bend. Force
Compr. Force
Thickness
Tensile Force
C/L Ratio
Moisture
Soda L.
Kraft L.
C. Treatment
Temperature
Pressure
Cooling
Press. Time

Data Interpretation- Multidimensional Sacling(MDS)

Type	ID	modulus	strength	thickness	width	L	Trial	C/L	Lignin	Moisture-Content	Pressing-temp.	ID_group
B	22.2	6265,322	11,55944	3,4	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	22.3	5013,124	11,10884	3,7	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	22.4	5997,309	12,59063	3,2	13,8	150	C-L	0,666667	Soda	12,5	85	22
B	22.5	5982,93	11,23988	3,6	13,9	150	C-L	0,666667	Soda	12,5	85	22
B	22.6	4714,929	12,5374	3,1	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	28.1.1	5101,026	8,70677	3,2	13,7	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.2	6110,462	10,29947	3,1	13,5	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.3	5589,53	9,100465	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.4	6527,995	7,59552	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.5	6215,326	11,48825	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.6	5290,872	8,867406	3,2	13,5	150	C-L	0,666667	Soda	12,5	85	28
B	25.1.1	6188,904	15,54374	3,7	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.2	5674,324	14,70073	3,6	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.3	6503,451	12,66391	3,7	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.4	5607,25	16,33841	3,4	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.5	5666,974	13,49964	3,7	13,6	150	C-L	1	Soda	12,5	85	25
B	25.1.6	7044,832	16,63206	3,2	13,3	150	C-L	1	Soda	12,5	85	25
B	27.1.1	6800,276	14,7554	3,3	13,2	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.2	5152,383	15,89623	3,3	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.3	7256,76	14,12752	3,4	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.4	5299,508	16,67117	3,3	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.5	8259,459	16,78037	3,4	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.6	9670,392	19,14852	3,3	12,9	150	C-L	2,333333	Soda	12,5	85	27
B	26.1.1	7517,785	14,55511	3,3	13,4	150	C-L	1,5	Soda	12,5	85	26
B	26.1.2	6522,592	16,8058	3,2	13,4	150	C-L	1,5	Soda	12,5	85	26
B	26.1.3	8244,057	16,01036	3,2	13,3	150	C-L	1,5	Soda	12,5	85	26
B	26.1.4	5128,713	15,05476	3,2	13,3	150	C-L	1,5	Soda	12,5	85	26
B	26.1.5	8611,443	22,78519	3,3	13,4	150	C-L	1,5	Soda	12,5	85	26
B	26.1.6	7927,4	22,23617	3,2	13,4	150	C-L	1,5	Soda	12,5	85	26
B	24.1.1	4767,761	9,510516	3,6	13,2	150	C-L	4	Soda	12,5	85	24
B	24.1.2	5229,5	9,207148	3,6	13,25	150	C-L	4	Soda	12,5	85	24
B	24.1.3	4236,728	7,758672	3,5	13,2	150	C-L	4	Soda	12,5	85	24
B	24.1.4	4623,934	10,29196	3,5	13,2	150	C-L	4	Soda	12,5	85	24
B	24.1.5	4769,64	11,98886	3,8	13,3	150	C-L	4	Soda	12,5	85	24
B	24.1.6	3989,662	8,649974	3,5	12,9	150	C-L	4	Soda	12,5	85	24
C	23.1	6311,049	19,1977	3,2	11,9	150	C-L	0,666667	Soda	12,5	85	23
C	23.2	7129,824	20,3512	3,3	12,1	150	C-L	0,666667	Soda	12,5	85	23
C	24.2.1	6873,97	10,17598	3,4	12,4	150	C-L	4	Soda	12,5	85	24
C	24.2.2	9212,007	20,47299	3,3	12,4	150	C-L	4	Soda	12,5	85	24
C	24.3.1	5572,161	14,66721	3,3	12,41	150	C-L	4	Soda	12,5	70	24
C	24.2.3	7852,884	28,76704	3,3	12,41	150	C-L	4	Soda	12,5	85	24
C	24.3.2	7019,717	14,55646	3,44	12,17	150	C-L	4	Soda	12,5	70	24
C	24.3.3	6022,323	15,70994	3,41	12,26	150	C-L	4	Soda	12,5	70	24
C	25.2.1	6951,605	41,44166	3,18	12,35	150	C-L	1	Soda	12,5	85	25
C	25.2.2	9935,626	32,52177	3,12	12,33	150	C-L	1	Soda	12,5	85	25
C	25.2.3	7923,521	24,6303	3,23	12,34	150	C-L	1	Soda	12,5	85	25
C	25.3.1	6536,127	25,18671	3,35	12,32	150	C-L	1	Soda	12,5	70	25
C	25.3.2	6660,878	15,12491	3,51	12,25	150	C-L	1	Soda	12,5	70	25
C	25.3.3	7076,884	17,14666	3,6	12,31	150	C-L	1	Soda	12,5	70	25
C	26.2.1	10559,65	34,29877	3	12,44	150	C-L	1,5	Soda	12,5	85	26
C	26.2.2	9922,856	40,11911	3,01	12,38	150	C-L	1,5	Soda	12,5	85	26
C	26.2.3	7589,371	41,15995	3,01	12,38	150	C-L	1,5	Soda	12,5	85	26
C	26.3.1	7438,504	18,114	3,06	12,31	150	C-L	1,5	Soda	12,5	70	26
C	26.3.2	8143,955	18,68327	3,13	12,16	150	C-L	1,5	Soda	12,5	70	26

Aim

Distances among samples ~ dissimilarities

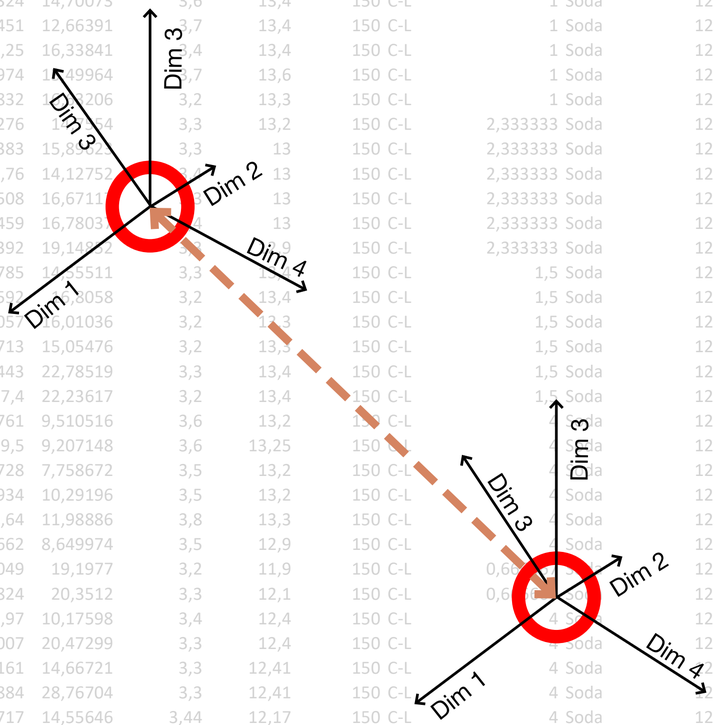
Fancy Math

Eigen-Decomposition

- Coordinates for a graph
- Percent of variation each axis accounts for
- Loading scores (to determine which variables have the largest effect)

Data Interpretation- Multidimensional Sacling(MDS)

Type	ID	modulus	strength	thickness	width	L	Trial	C/L	Lignin	Moisture-Content	Pressing-temp.	ID_group
B	22.2	6265,322	11,55944	3,4	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	22.3	5013,124	11,10884	3,7	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	22.4	5997,309	12,59063	3,2	13,8	150	C-L	0,666667	Soda	12,5	85	22
B	22.5	5982,93	11,23988	3,2	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	22.6	4714,929	12,5374	3,2	13,7	150	C-L	0,666667	Soda	12,5	85	22
B	28.1.1	5101,026	8,70677	3,2	13,7	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.2	6110,462	10,29947	3,1	13,5	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.3	5589,53	9,100465	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.4	6527,995	7,59552	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.5	6215,326	11,48825	3,1	13,4	150	C-L	0,666667	Soda	12,5	85	28
B	28.1.6	5290,872	8,867406	3,2	13,5	150	C-L	0,666667	Soda	12,5	85	28
B	25.1.1	6188,904	15,54374	3,7	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.2	5674,324	14,70073	3,6	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.3	6503,451	12,66391	3,7	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.4	5607,25	16,33841	3,4	13,4	150	C-L	1	Soda	12,5	85	25
B	25.1.5	5666,974	14,49964	3,7	13,6	150	C-L	1	Soda	12,5	85	25
B	25.1.6	7044,832	14,1206	3,2	13,3	150	C-L	1	Soda	12,5	85	25
B	27.1.1	6800,276	15,4564	3,3	13,2	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.2	5152,383	15,8[illegible]	3,3	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.3	7256,76	14,12752	3,[illegible]	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.4	5299,508	16,6711[illegible]	[illegible]	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.5	8259,459	16,7803[illegible]	[illegible]	13	150	C-L	2,333333	Soda	12,5	85	27
B	27.1.6	9670,392	19,14[illegible]	[illegible]	[illegible]	150	C-L	2,333333	Soda	12,5	85	27
B	26.1.1	7517,785	14,[illegible]5511	3,3	[illegible]	150	C-L	1,5	Soda	12,5	85	26
B	26.1.2	6522,592	[illegible],3058	3,2	13,4	150	C-L	1,5	Soda	12,5	85	26
B	26.1.3	8244,057	16,01036	3,2	13,3	150	C-L	1,5	Soda	12,5	85	26
B	26.1.4	5128,713	15,05476	3,2	13,5	150	C-L	1,5	Soda	12,5	85	26
B	26.1.5	8611,443	22,78519	3,3	13,4	150	C-L	1,5	Soda	12,5	85	26
B	26.1.6	7927,4	22,23617	3,2	13,4	150	C-L	1,5	Soda	12,5	85	26
B	24.1.1	4767,761	9,510516	3,6	13,2	150	C-L	[illegible]	Soda	12,5	85	24
B	24.1.2	5229,5	9,207148	3,6	13,25	150	[illegible]	[illegible]	Soda	12,5	85	24
B	24.1.3	4236,728	7,758672	3,5	13,2	150	C-L	[illegible]	Soda	12,5	85	24
B	24.1.4	4623,934	10,29196	3,5	13,2	150	C-L	4	Soda	12,5	85	24
B	24.1.5	4769,64	11,98886	3,8	13,3	150	C-L	4	Soda	12,5	85	24
B	24.1.6	3989,662	8,649974	3,5	12,9	150	C-L	4	Soda	12,5	85	24
C	23.1	6311,049	19,1977	3,2	11,9	150	C-L	0,66[illegible]	[illegible]	12,5	85	23
C	23.2	7129,824	20,3512	3,3	12,1	150	C-L	0,6[illegible]	[illegible]	12,5	85	23
C	24.2.1	6873,97	10,17598	3,4	12,4	150	C-L	4	Soda	12,5	85	24
C	24.2.2	9212,007	20,47299	3,3	12,4	150	C-L	4	Soda	12,5	85	24
C	24.3.1	5572,161	14,66721	3,3	12,41	150	C-L	4	Soda	12,5	70	24
C	24.2.3	7852,884	28,76704	3,3	12,41	150	C-L	4	Soda	12,5	85	24
C	24.3.2	7019,717	14,55646	3,44	12,17	150	C-L	4	Soda	12,5	70	24
C	24.3.3	6022,323	15,70994	3,41	12,26	150	C-L	4	Soda	12,5	70	24
C	25.2.1	6951,605	41,44166	3,18	12,35	150	C-L	1	Soda	12,5	85	25
C	25.2.2	9935,626	32,52177	3,12	12,33	150	C-L	1	Soda	12,5	85	25
C	25.2.3	7923,521	24,6303	3,23	12,34	150	C-L	1	Soda	12,5	85	25
C	25.3.1	6536,127	25,18671	3,35	12,32	150	C-L	1	Soda	12,5	70	25
C	25.3.2	6660,878	15,12491	3,51	12,25	150	C-L	1	Soda	12,5	70	25
C	25.3.3	7076,884	17,14666	3,6	12,31	150	C-L	1	Soda	12,5	70	25
C	26.2.1	10559,65	34,29877	3	12,44	150	C-L	1,5	Soda	12,5	85	26
C	26.2.2	9922,856	40,11911	3,01	12,38	150	C-L	1,5	Soda	12,5	85	26
C	26.2.3	7589,371	41,15995	3,01	12,38	150	C-L	1,5	Soda	12,5	85	26
C	26.3.1	7438,504	18,114	3,06	12,31	150	C-L	1,5	Soda	12,5	70	26
C	26.3.2	8143,955	18,68327	3,13	12,16	150	C-L	1,5	Soda	12,5	70	26



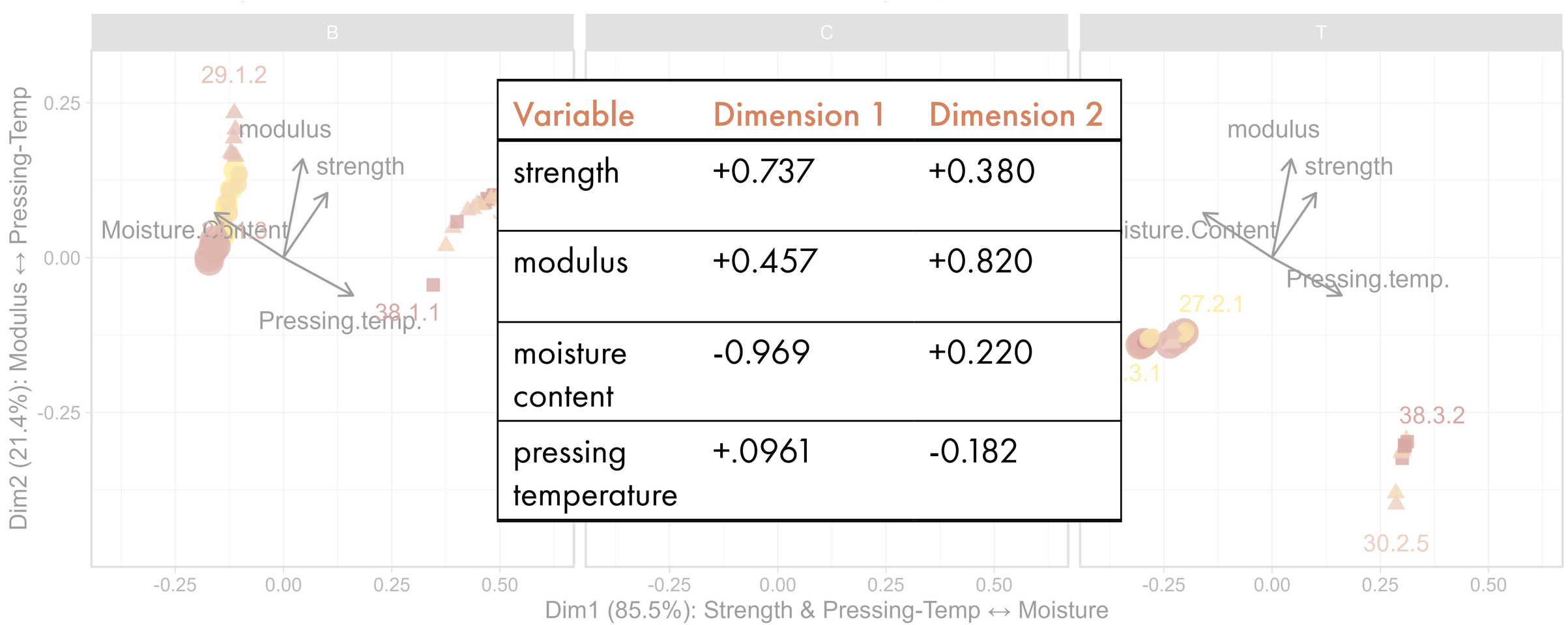
Aim

Distances among samples ~ dissimilarities

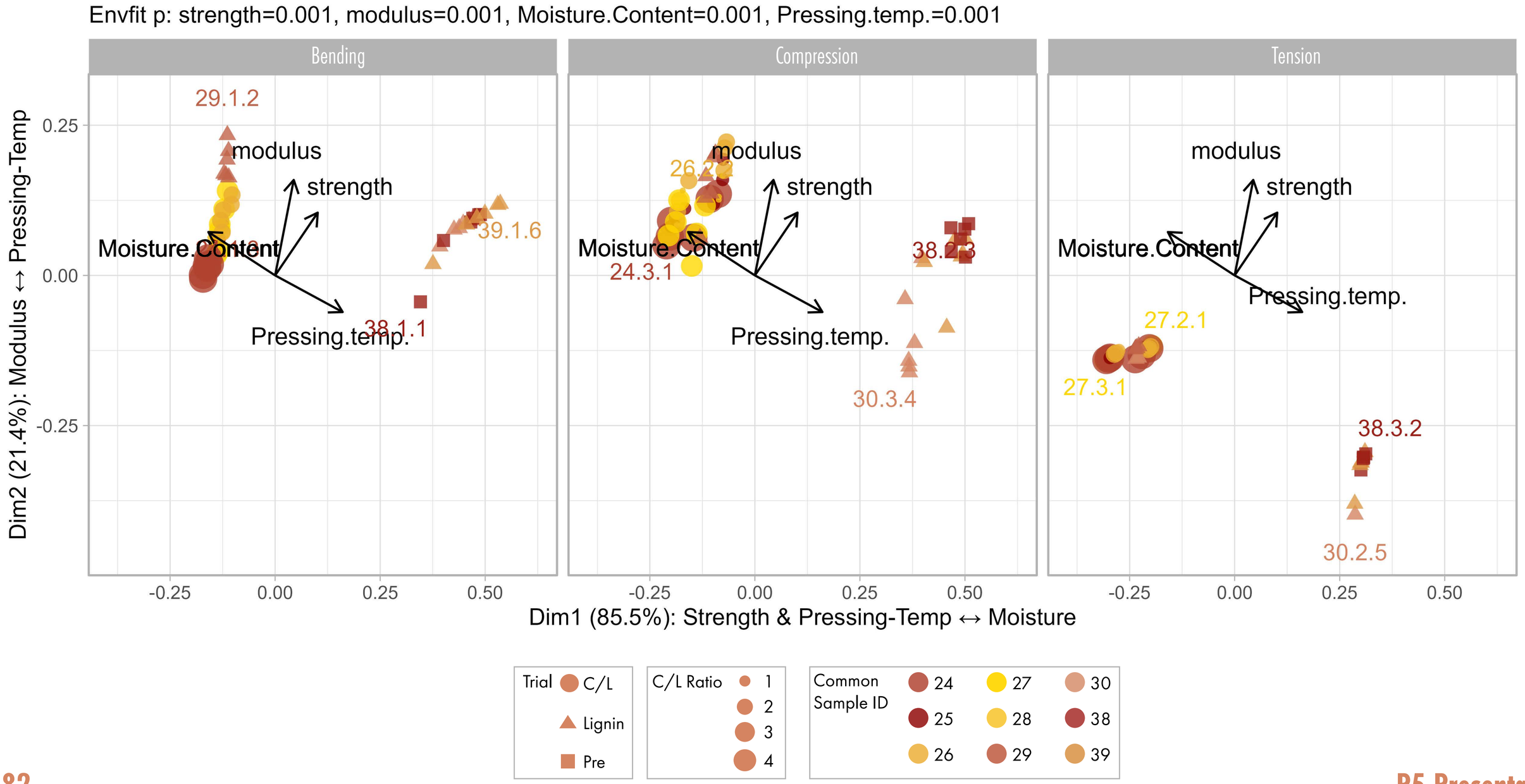
Fancy Math

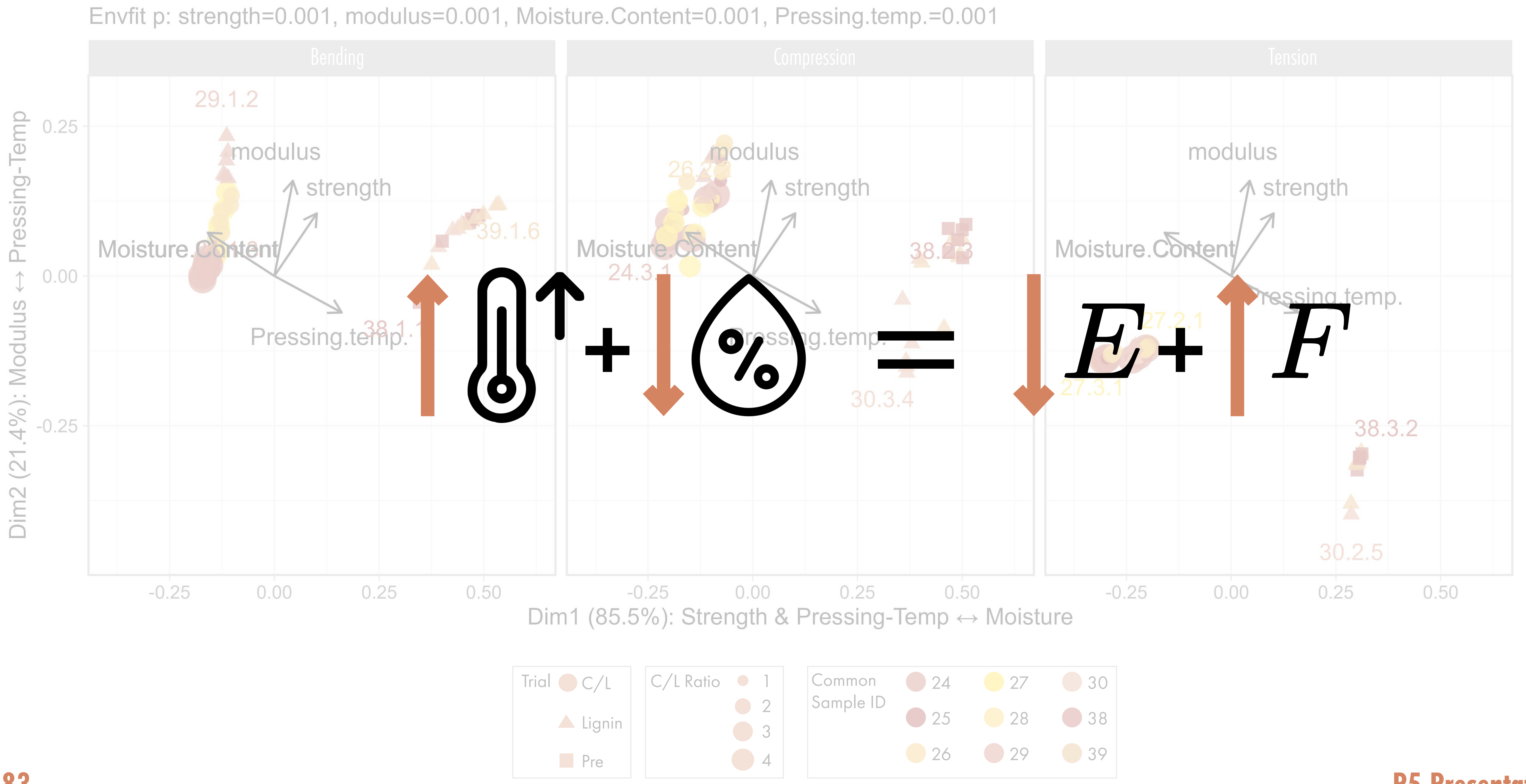
Eigen-Decomposition

- Coordinates for a graph
- Percent of variation each axis accounts for
- Loading scores (to determine which variables have the largest effect)

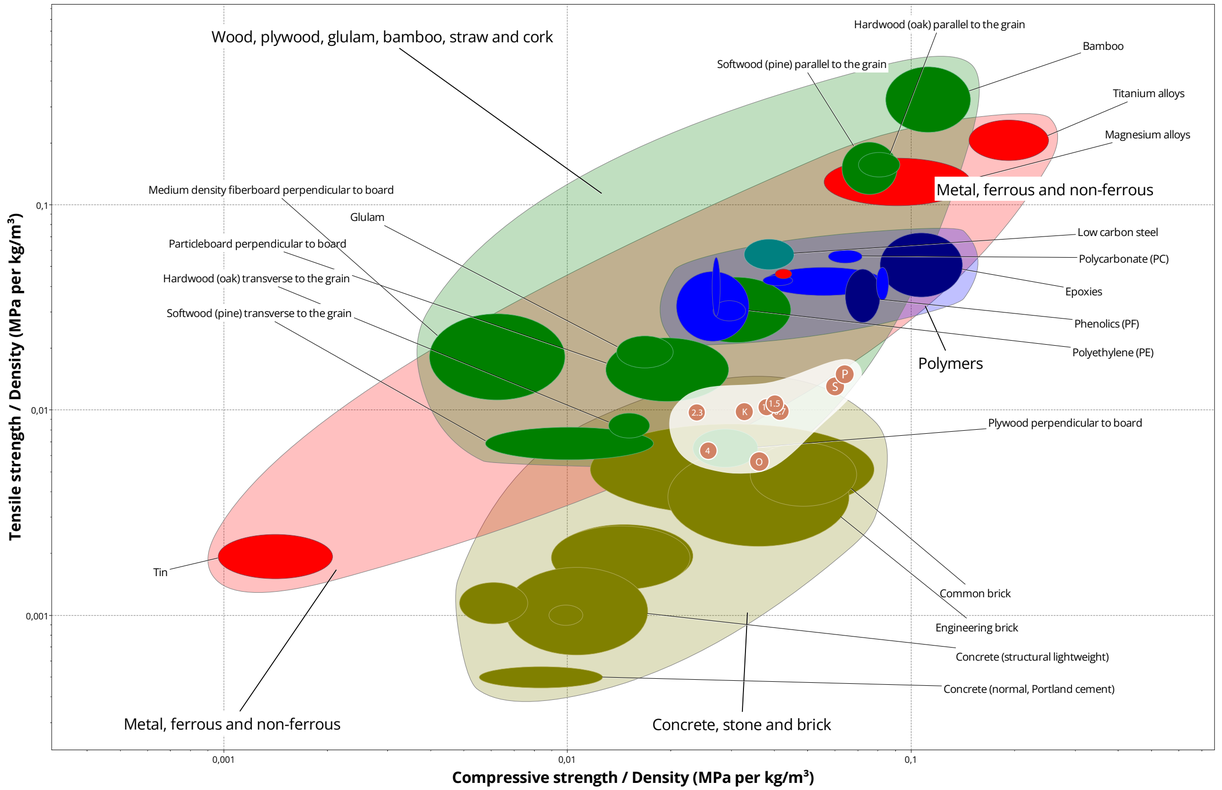


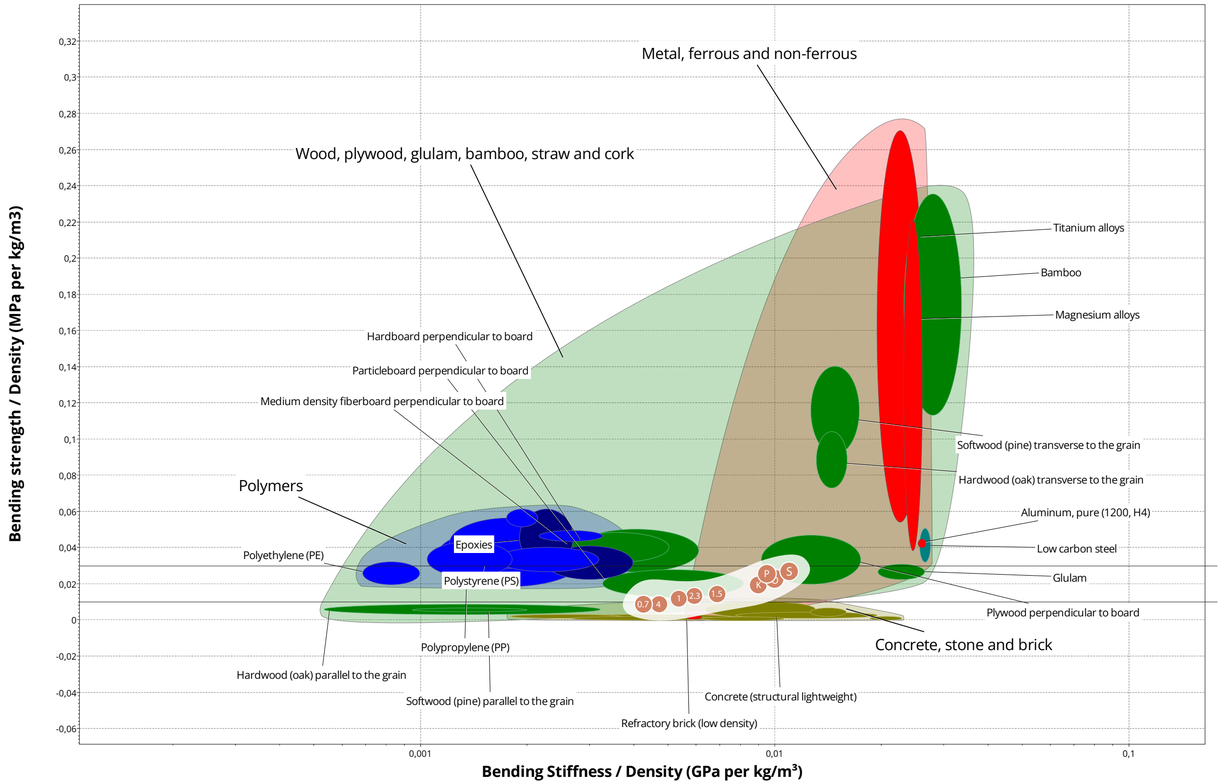
Variable	Dimension 1	Dimension 2
strength	+0.737	+0.380
modulus	+0.457	+0.820
moisture content	-0.969	+0.220
pressing temperature	+.0961	-0.182


Envfit p: strength=0.001, modulus=0.001, Moisture.Content=0.001, Pressing.temp.=0.001
Bending
Compression
Tension
Dim2 (21.4%): Modulus ↔ Pressing-Temp
Dim1 (85.5%): Strength & Pressing-Temp ↔ Moisture
0.25
0.00
-0.25
-0.25
0.00
0.25
0.50
modulus
strength
Moisture.Content
Pressing.temp.
29.1.2
39.1.6
38.1.1
24.3.1
30.3.4
27.2.1
27.3.1
38.3.2
30.2.5
Trial
C/L
Lignin
Pre
C/L Ratio
1
2
3
4
Common Sample ID
24
25
26
27
28
29
30
38
39

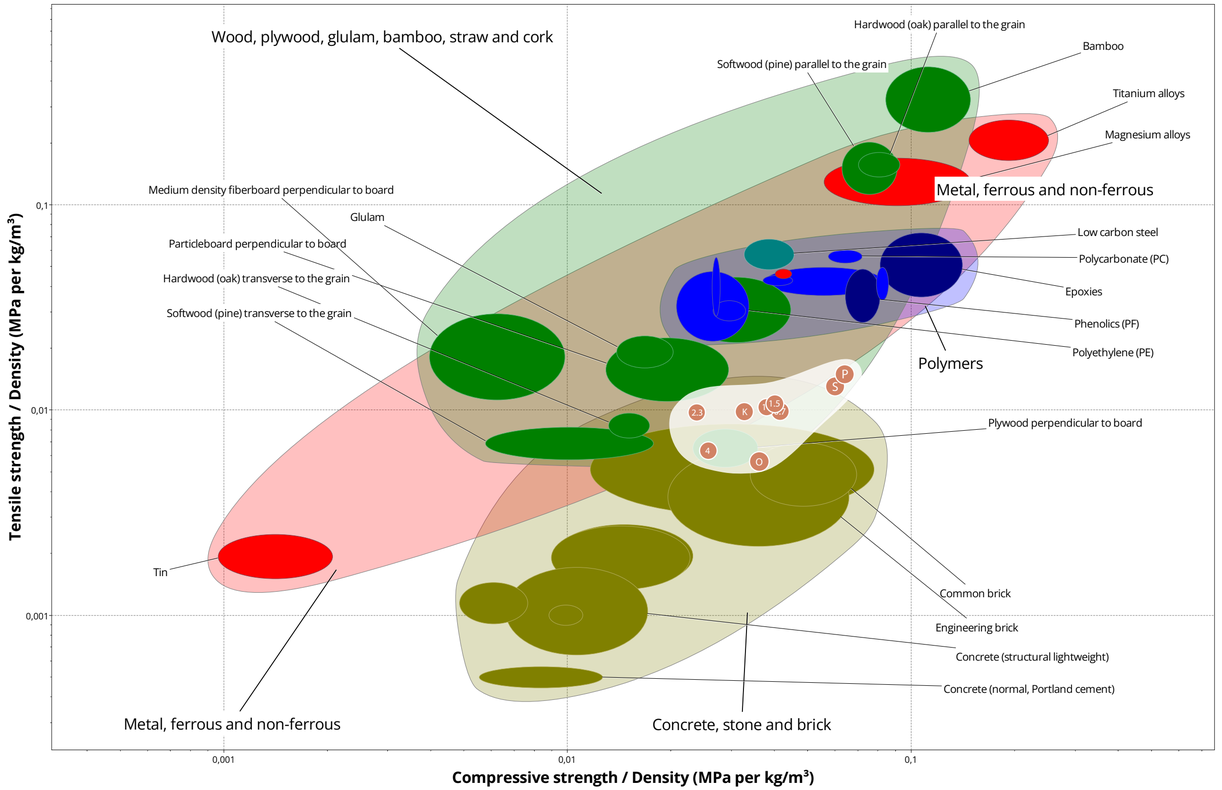

Envfit p: strength=0.001, modulus=0.001, Moisture.Content=0.001, Pressing.temp.=0.001
Bending
Compression
Tension
modulus
strength
Moisture.Content
Pressing.temp.
29.1.2
39.1.6
38.1.1
26.2.2
24.3.1
38.2.3
30.3.4
27.2.1
27.3.1
38.3.2
30.2.5
0.25
0.00
-0.25
0.50
Dim2 (21.4%): Modulus ↔ Pressing-Temp
Dim1 (85.5%): Strength & Pressing-Temp ↔ Moisture
Trial
C/L
Lignin
Pre
C/L Ratio
1
2
3
4
Common Sample ID
24
25
26
27
28
29
30
38
39
E
F

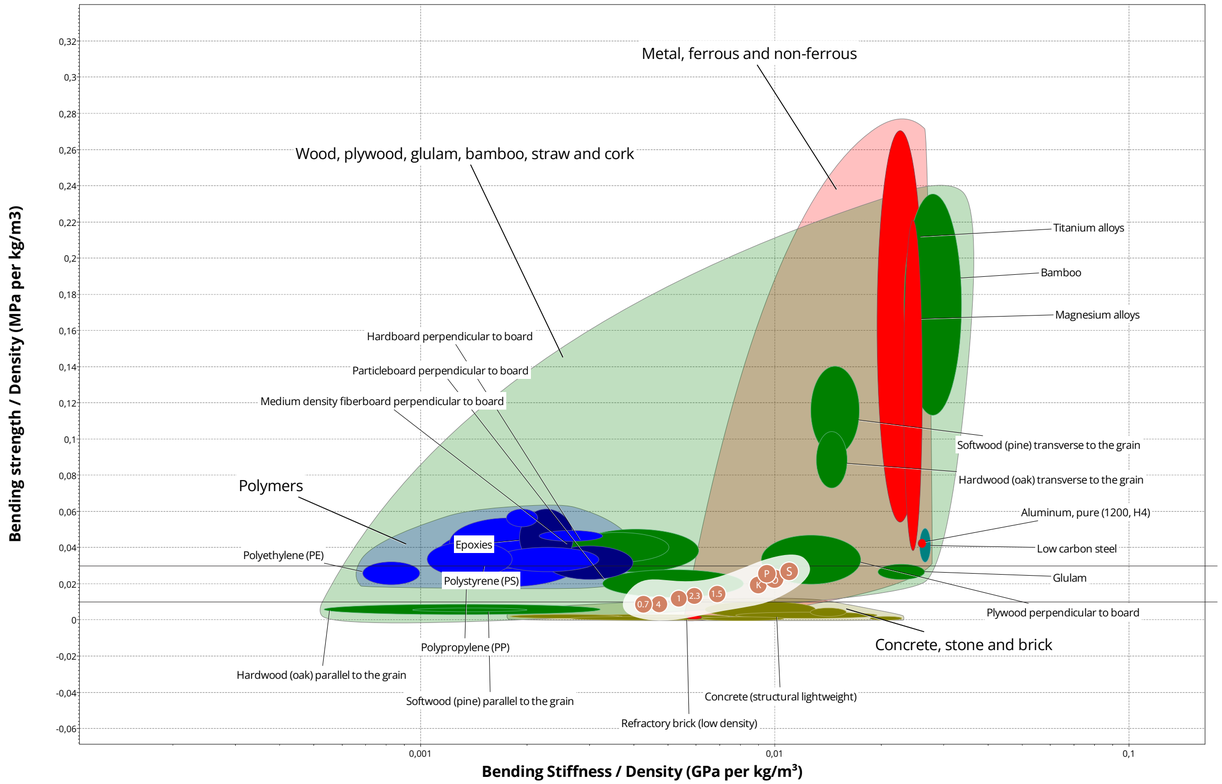
Result Comparison



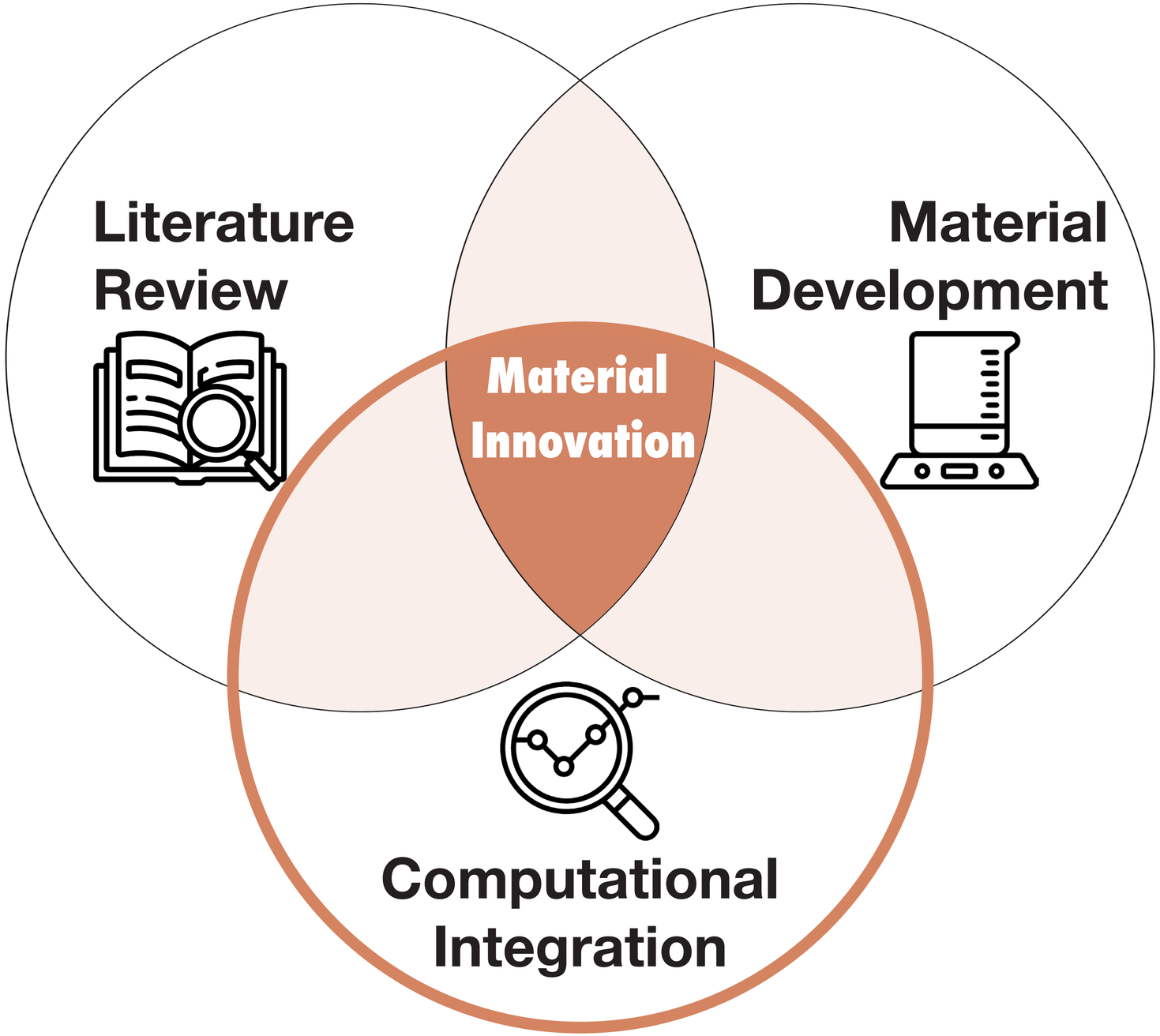


Result Comparison



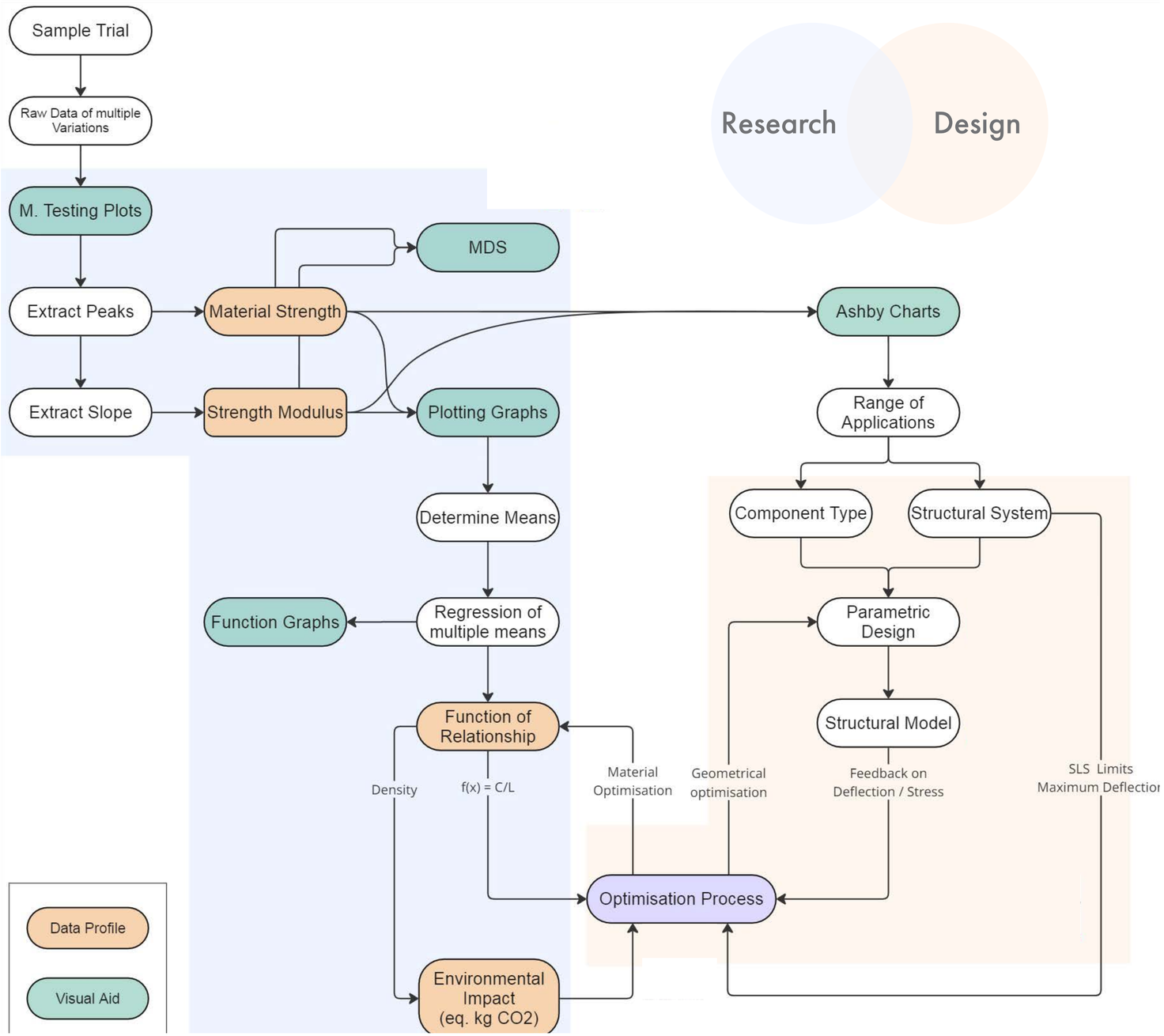


Density: 1230 kg/m³ -> could use some improvements


Literature Review
Material Development
Material Innovation
Computational Integration

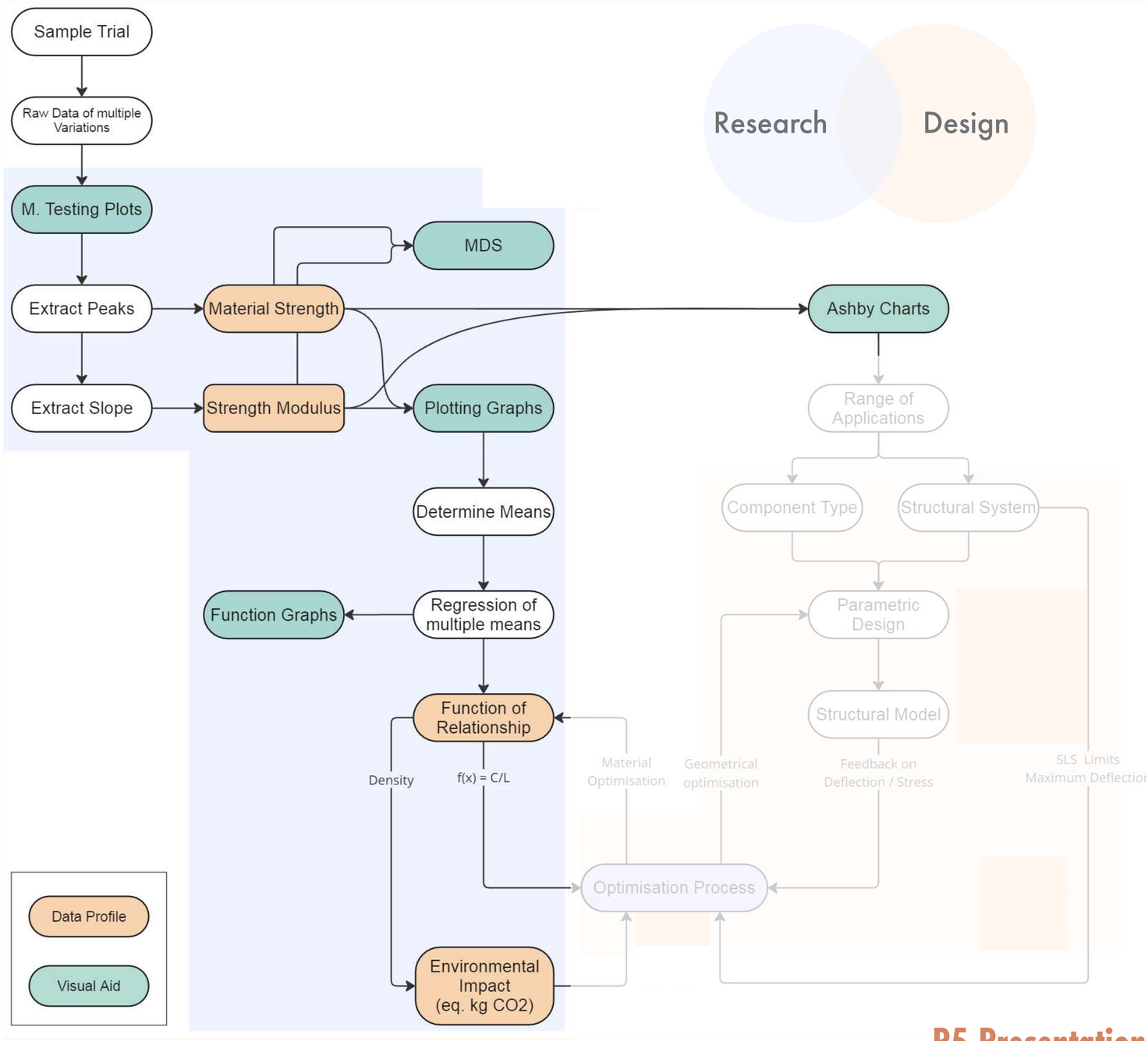
Computational Integration

Integration of Data Analysis with Component Design



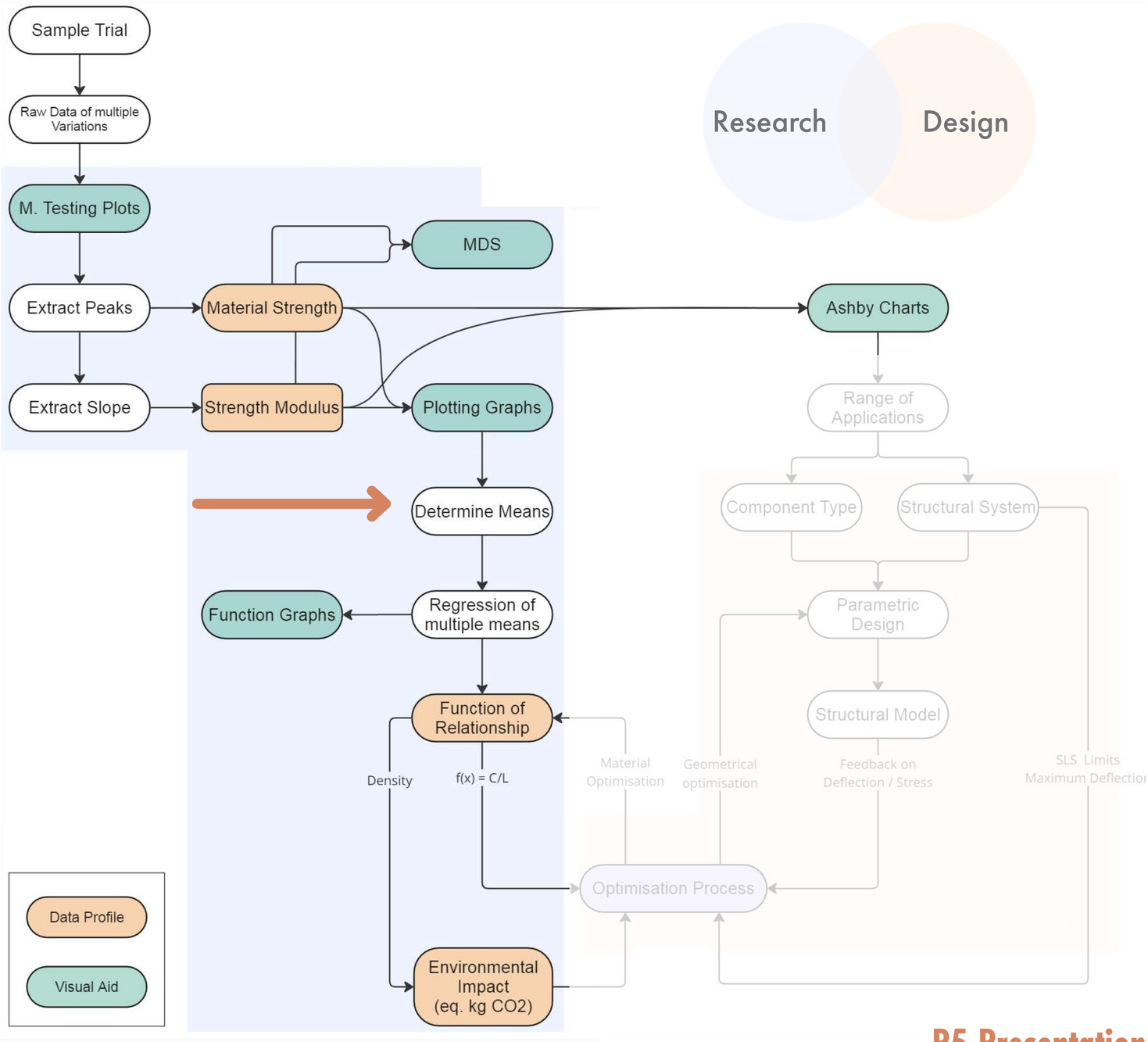
Computational Integration

Integration of Data Analysis with Component Design



Computational Integration

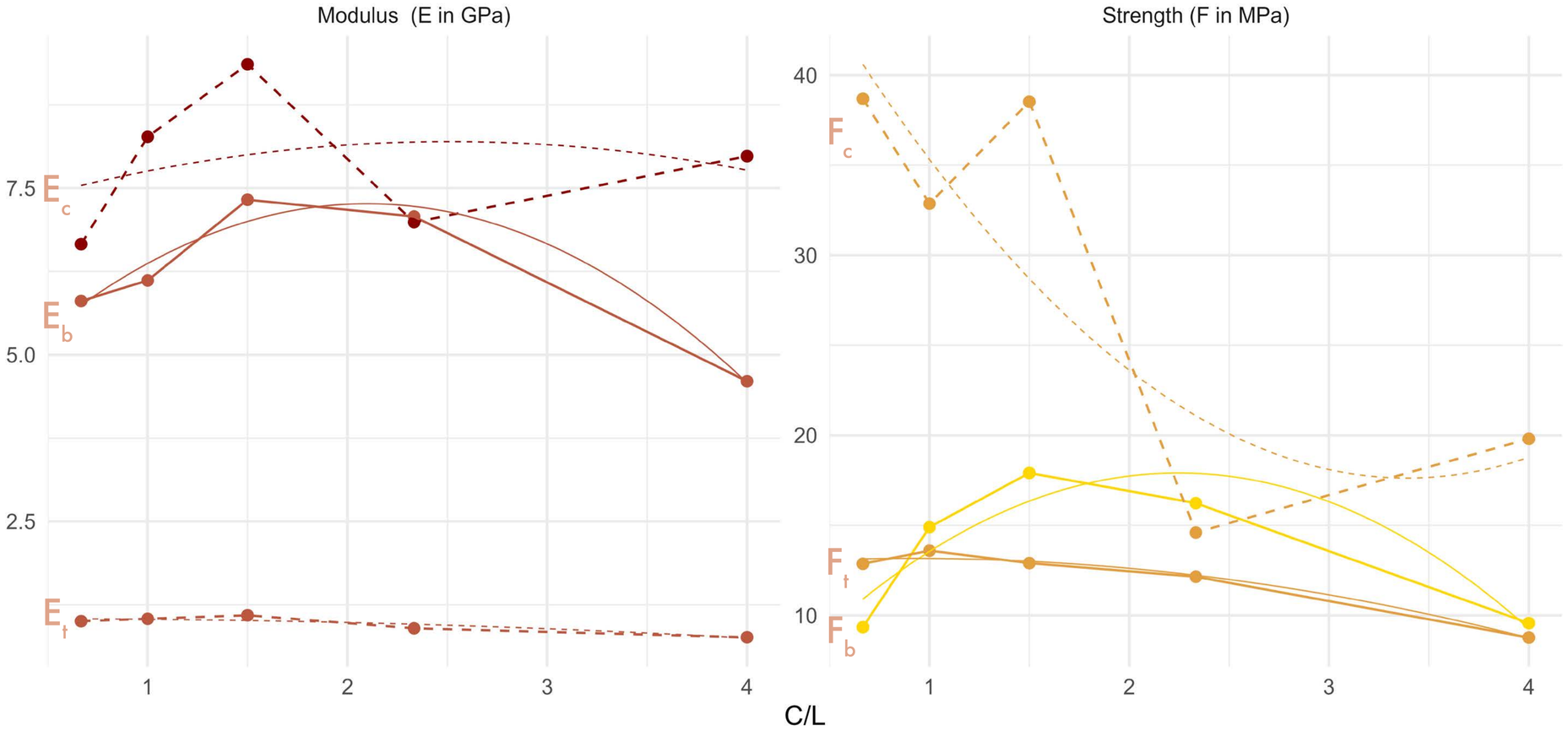
Integration of Data Analysis with Component Design



Regression C/L Trial

Results depict a quadratic relationship:

Polynomial 2nd Degree



Function	r^2 value	p value	Function of E/F to C-L
E_b	0.958	0.0419	$E_b(C/L) = 3.997 + 3.116 \times x + -0.742 \times x^2$
E_c	0.0544	0.946	$E_c(C/L) = 6.976 + 0.973 \times x + -0.194 \times x^2$
E_t	0.837	0.163	$E_t(C/L) = 1.035 + 0.02 \times x + -0.023 \times x^2$
F_b	0.845	0.155	$F_b(C/L) = 3.735 + 12.622 \times x + -2.81 \times x^2$
F_c	0.696	0.304	$F_c(C/L) = 53.228 + -20.999 \times x + 3.096 \times x^2$
F_t	0.981	0.0192	$F_t(C/L) = 12.783 + 0.839 \times x + -0.462 \times x^2$

Regression

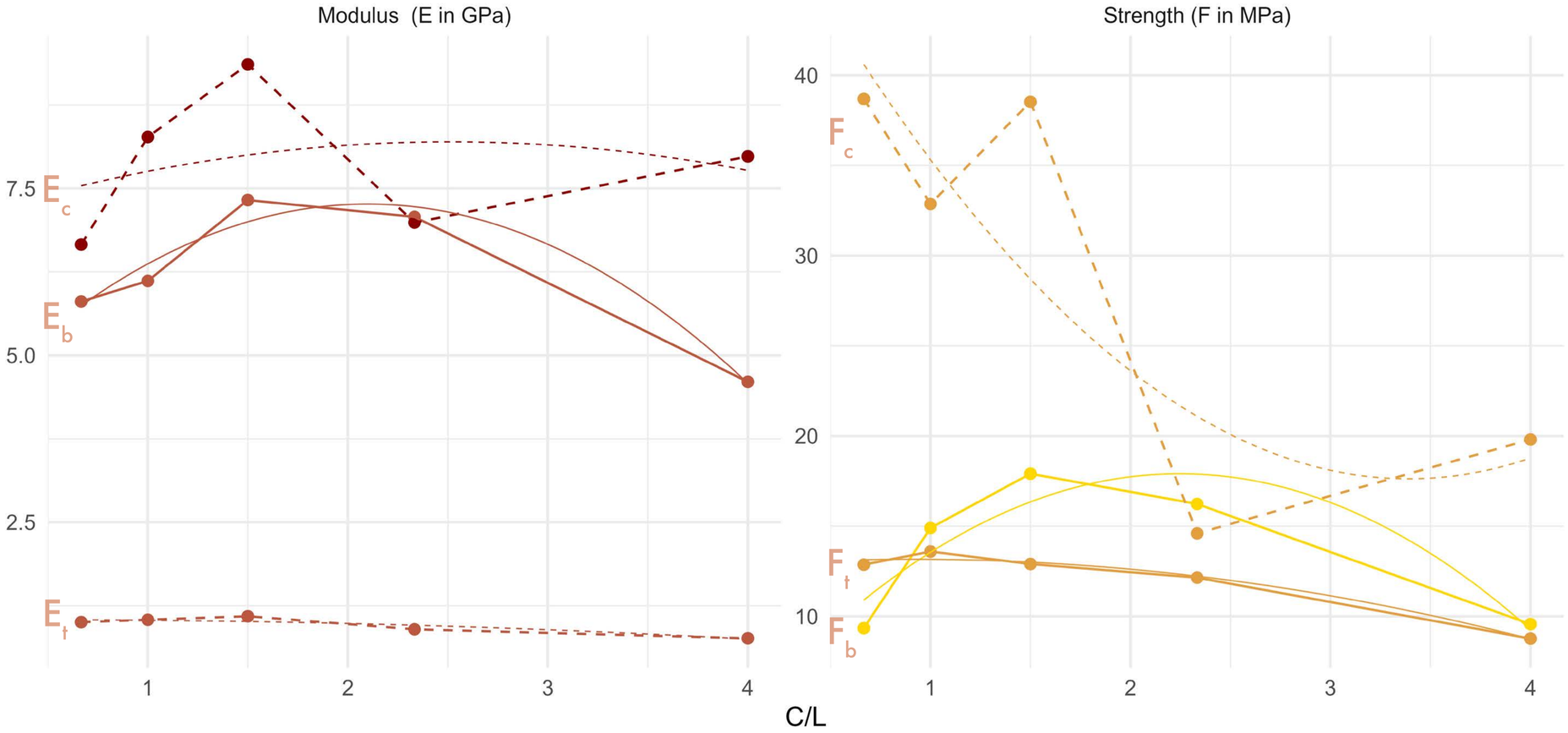
Results depict a quadratic relationship:

Polynomial 2nd Degree

statistical significance

$p \leq 0.05$ and high r^2

"Reliable effect and it explains a large share of variability"



Function	r^2 value	p value	Function of E/F to C-L
E_b	0.958	0.0419	$E_b(C/L) = 3.997 + 3.116 \times x + -0.742 \times x^2$
E_c	0.0544	0.946	$E_c(C/L) = 6.976 + 0.973 \times x + -0.194 \times x^2$
E_t	0.837	0.163	$E_t(C/L) = 1.035 + 0.02 \times x + -0.023 \times x^2$
F_b	0.845	0.155	$F_b(C/L) = 3.735 + 12.622 \times x + -2.81 \times x^2$
F_c	0.696	0.304	$F_c(C/L) = 53.228 + -20.999 \times x + 3.096 \times x^2$
F_t	0.981	0.0192	$F_t(C/L) = 12.783 + 0.839 \times x + -0.462 \times x^2$

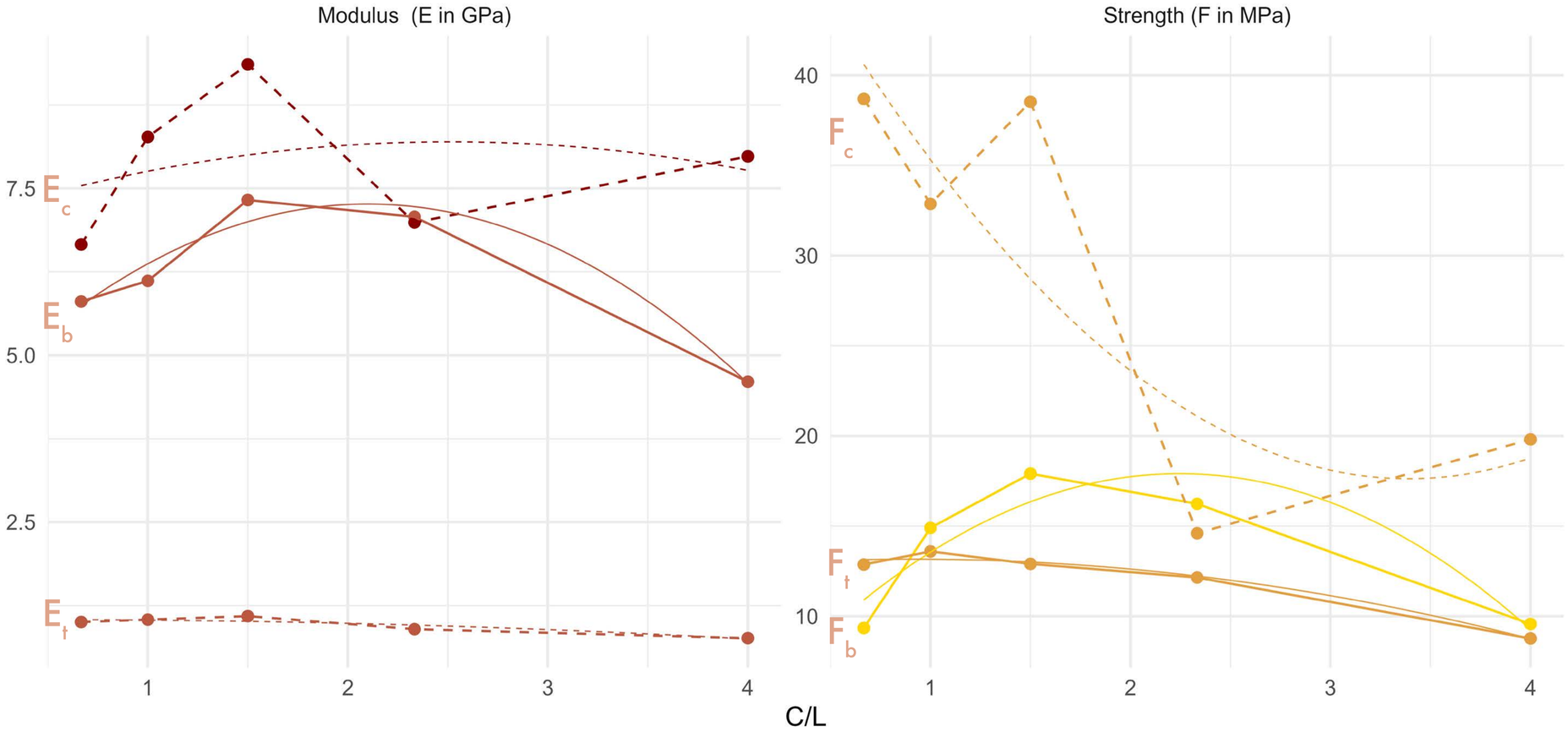
Regression

Results depict a quadratic relationship:

Polynomial 2nd Degree

statistical significance
$p \leq 0.05$ and high r^2

"Reliable effect and it explains a large share of variability"

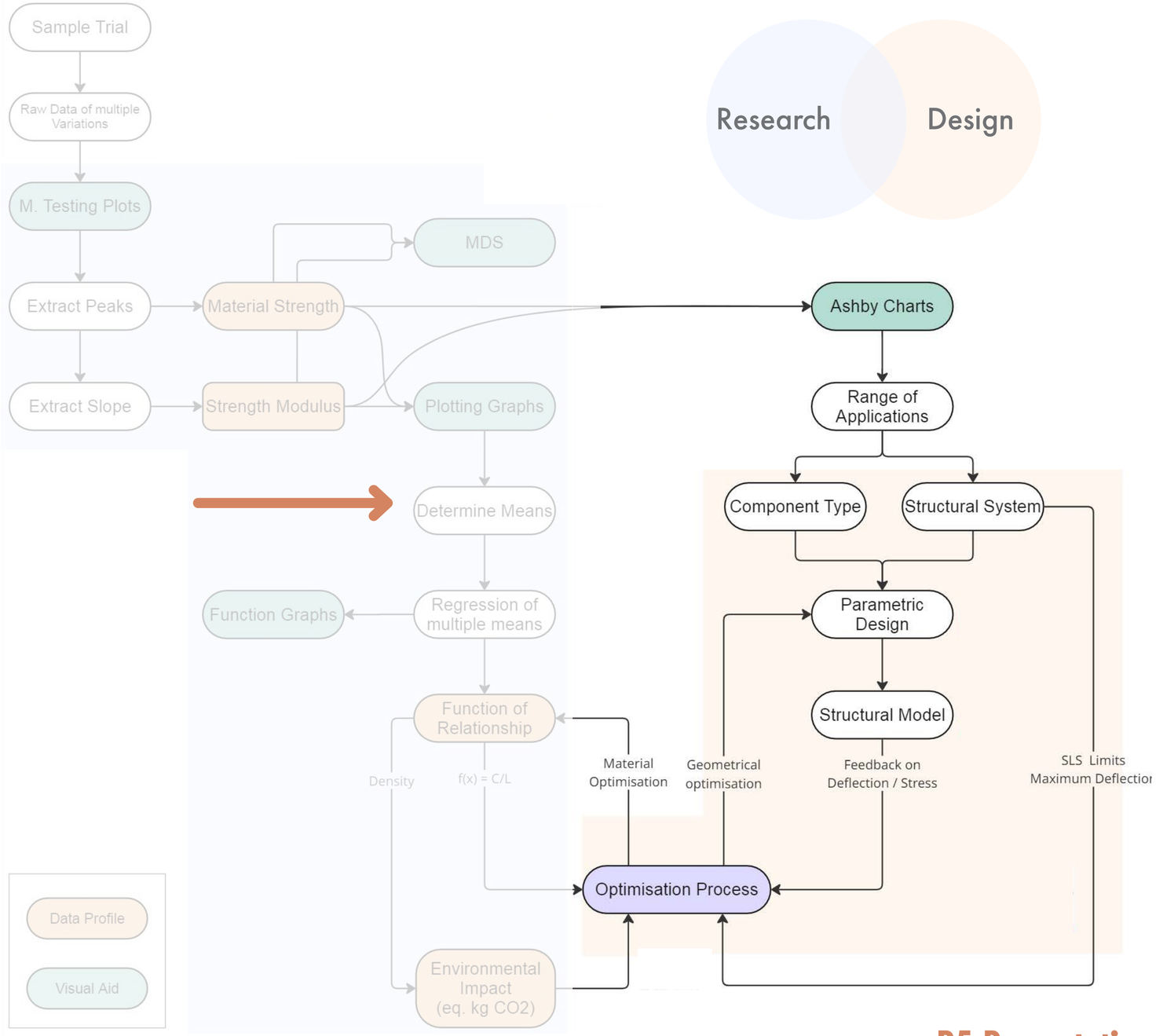


Function	r^2 value	p value	Function of E/F to C-L
E_b	0.958	0.0419	$E_b(C/L) = 3.997 + 3.116 \times x + -0.742 \times x^2$
E_c	0.0544	0.946	$E_c(C/L) = 6.976 + 0.973 \times x + -0.194 \times x^2$
E_t	0.837	0.163	$E_t(C/L) = 1.035 + 0.02 \times x + -0.023 \times x^2$
F_b	0.845	0.155	$F_b(C/L) = 3.735 + 12.622 \times x + -2.81 \times x^2$
F_c	0.696	0.304	$F_c(C/L) = 53.228 + -20.999 \times x + 3.096 \times x^2$
F_t	0.981	0.0192	$F_t(C/L) = 12.783 + 0.839 \times x + -0.462 \times x^2$

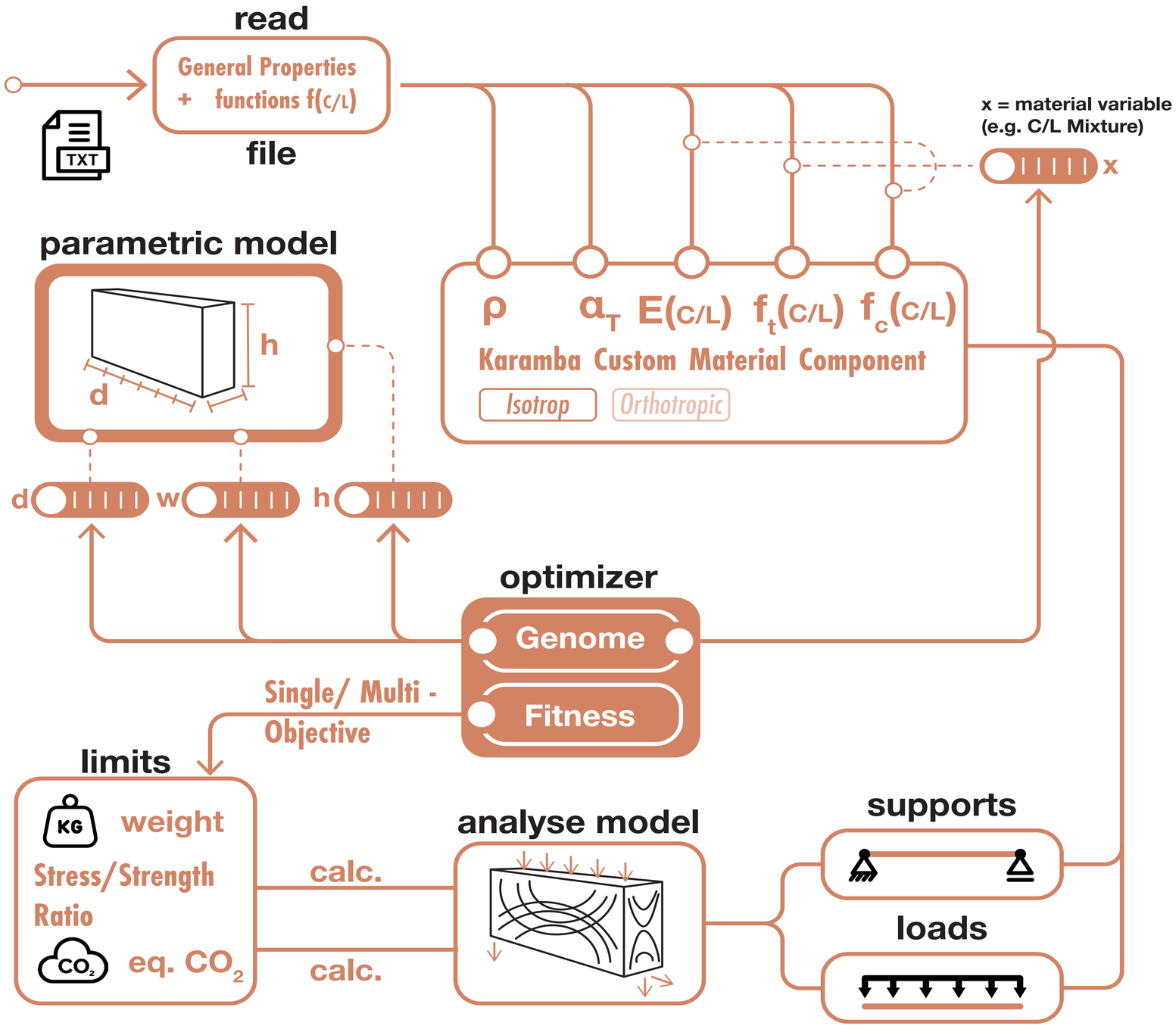
TXT

Computational Integration

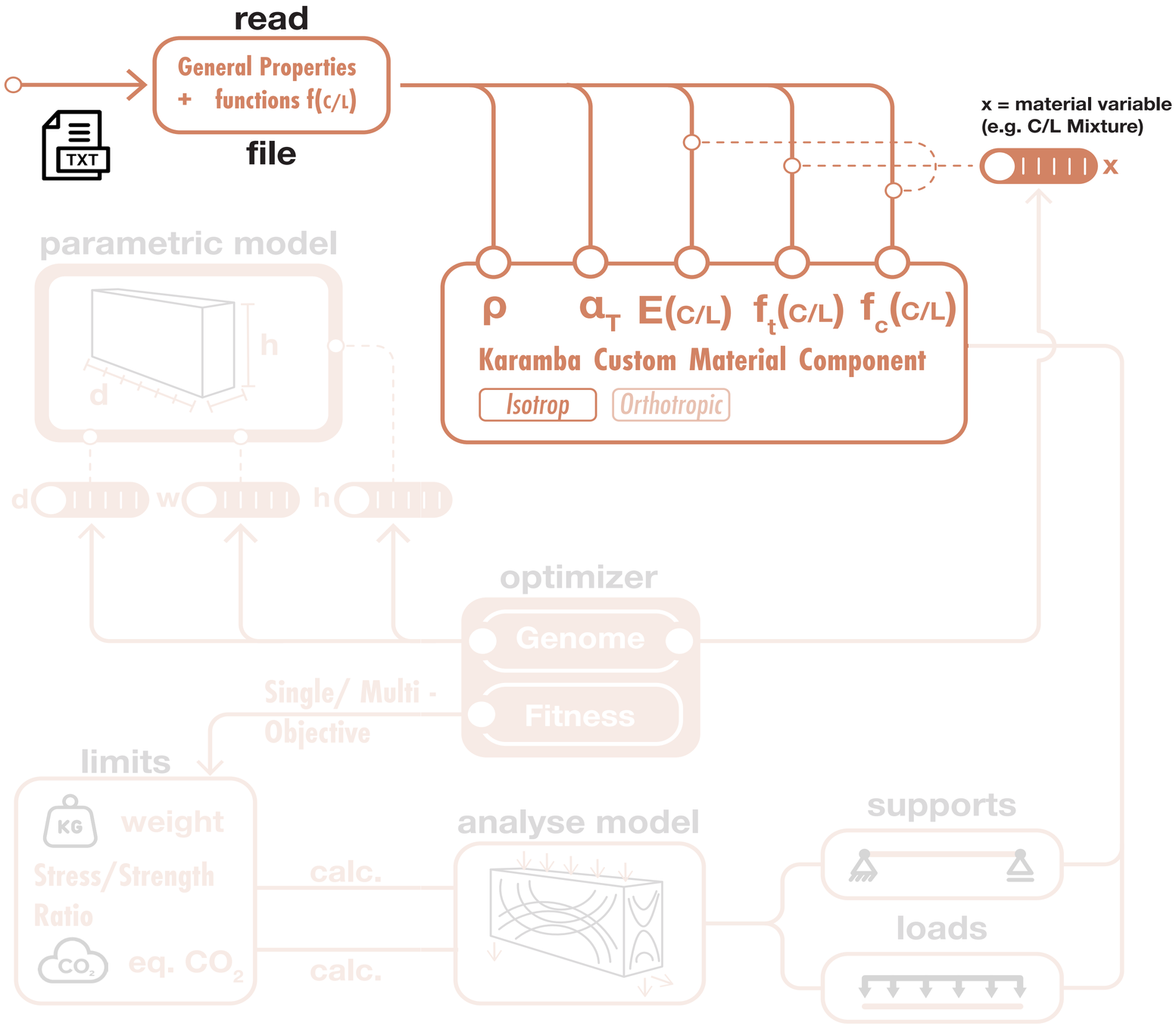
Integration of Data Analysis with Component Design



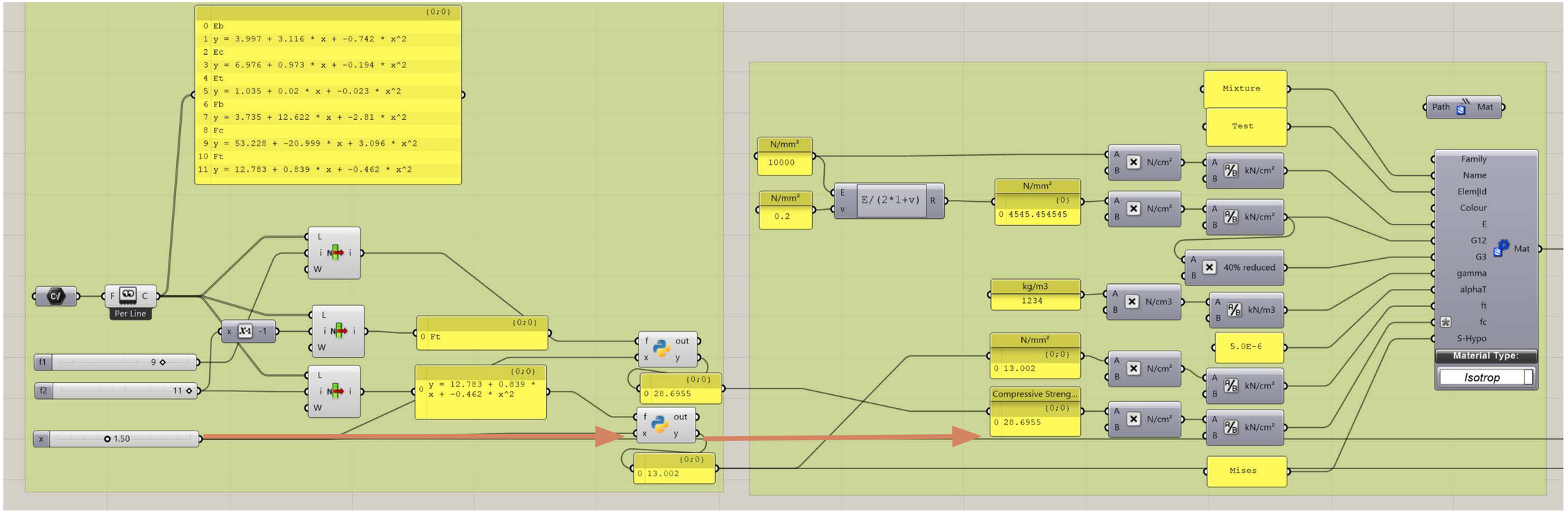
Continuation Grashopper Workflow



Grashopper Workflow



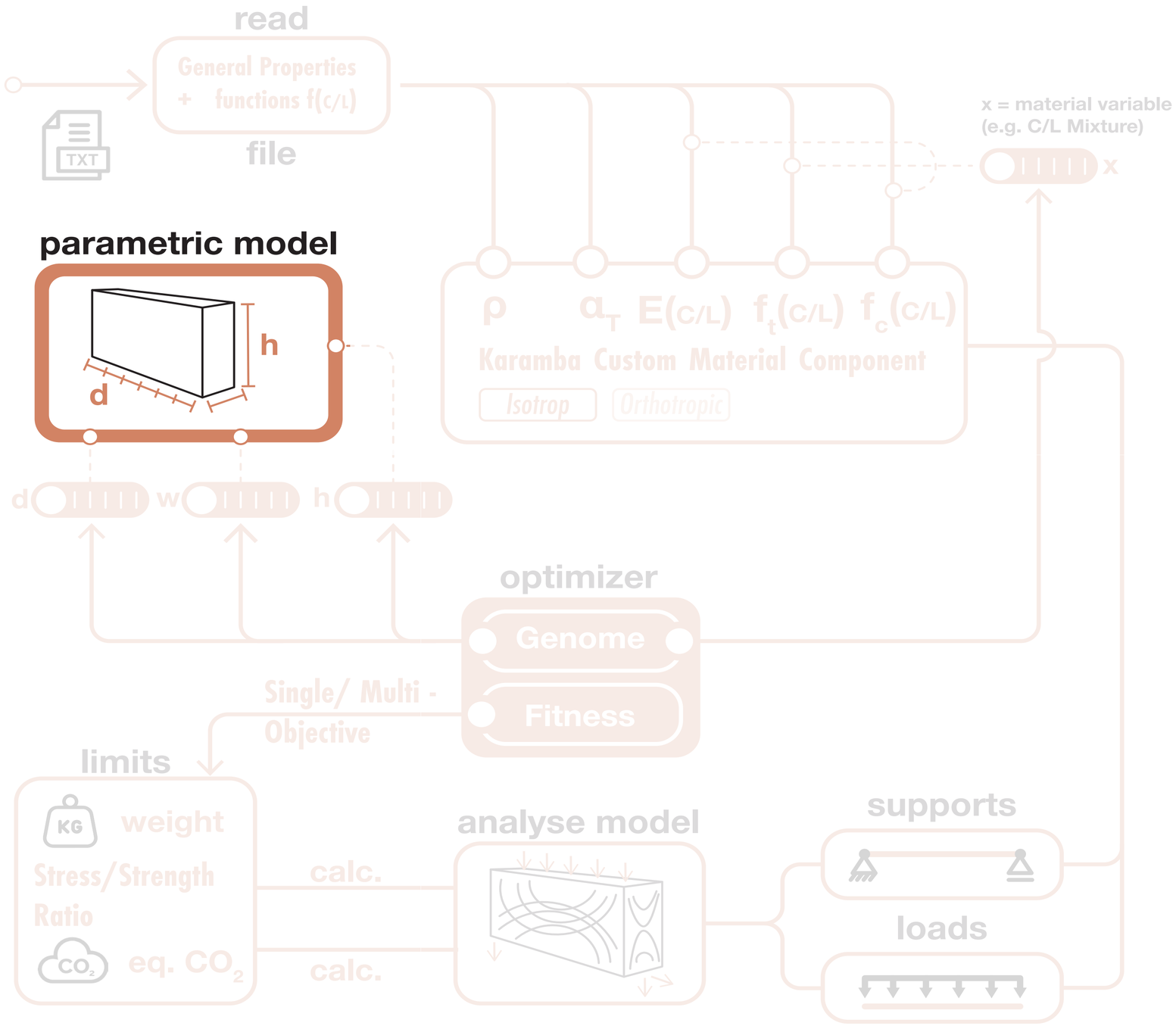
Import and reading of function file



Set variable X with Slider

Feed (F_C and F_T)into Karamba

Grashopper Workflow



Case Study: Finnjoist

- Replacement of the central web made of OSB(3).
- Matching of mechanical performance
- Structural adjustments based on material and process details

image and logo from: https://www.metsagroup.com/contentassets/bdd9a4385ba74645a0815d64c727455d/environmental_product_declaration_for_finnjoist.pdf

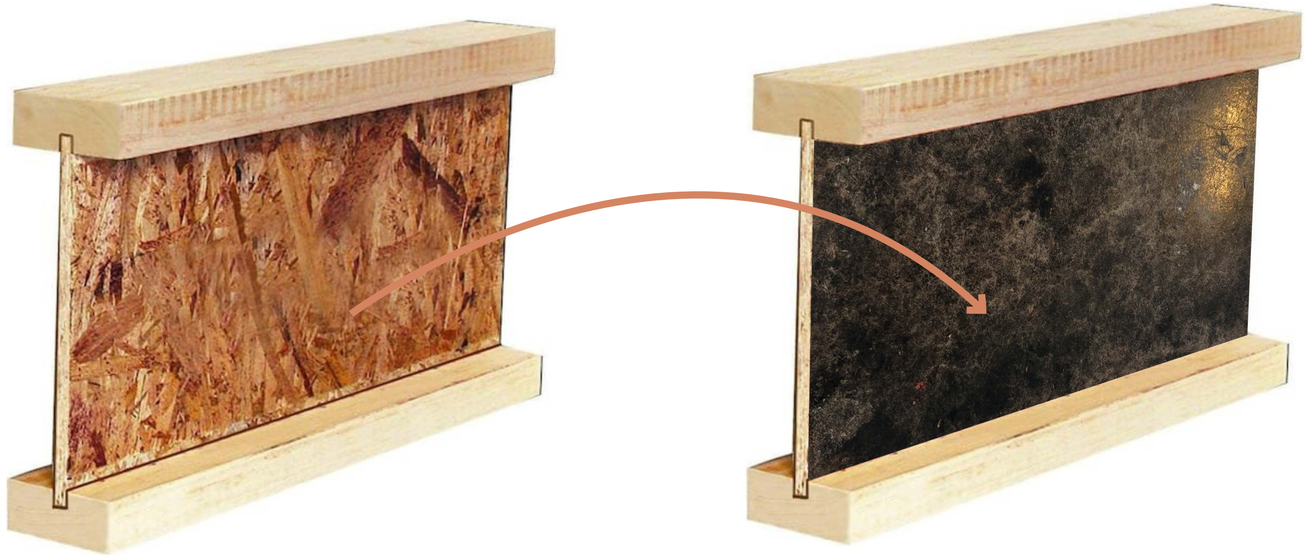
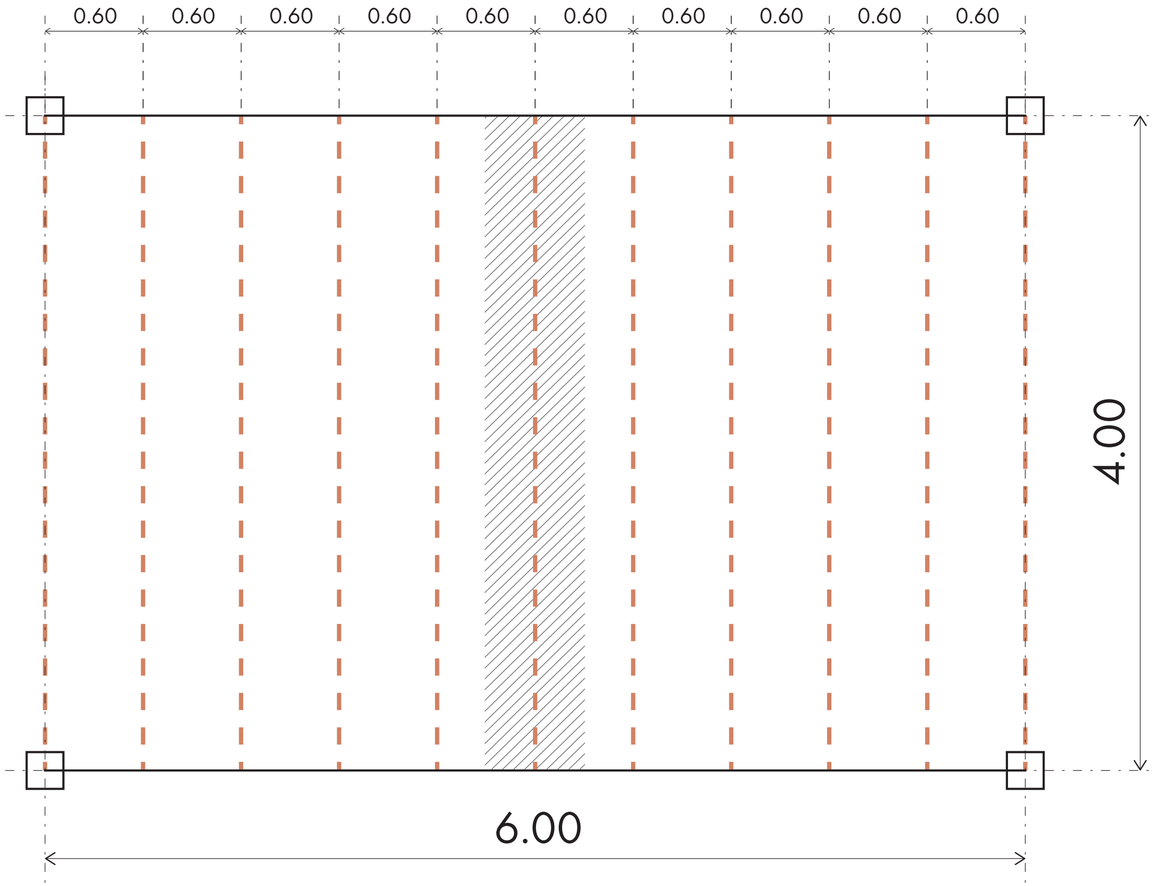


image from: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.homedepot.ca%2Fproduct%2F1001854928&psig=AOvVaw08vtlpbDeXu-NnMm-iYQuM&ust=1750326331826000&source=images&opi=89978449

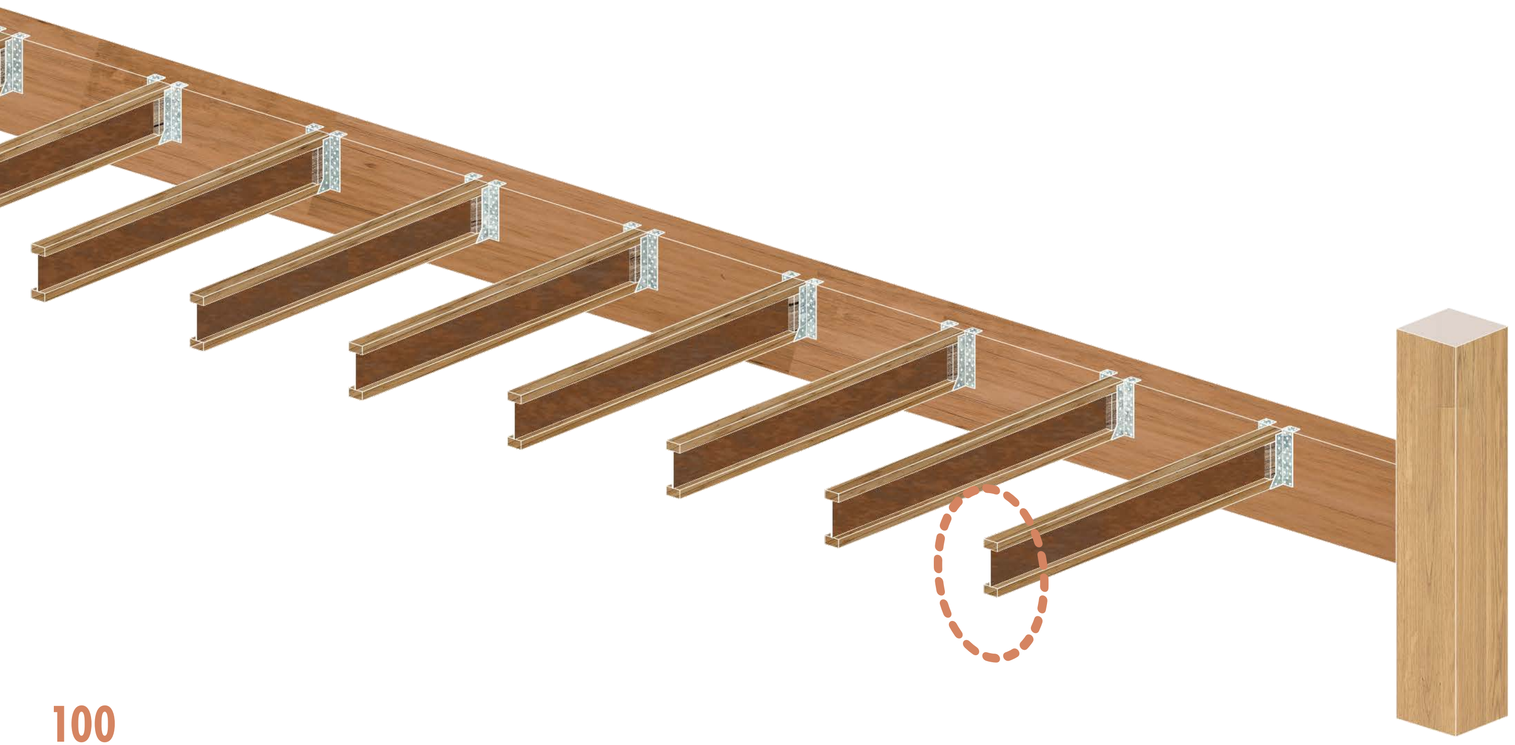
Structural System Requirements

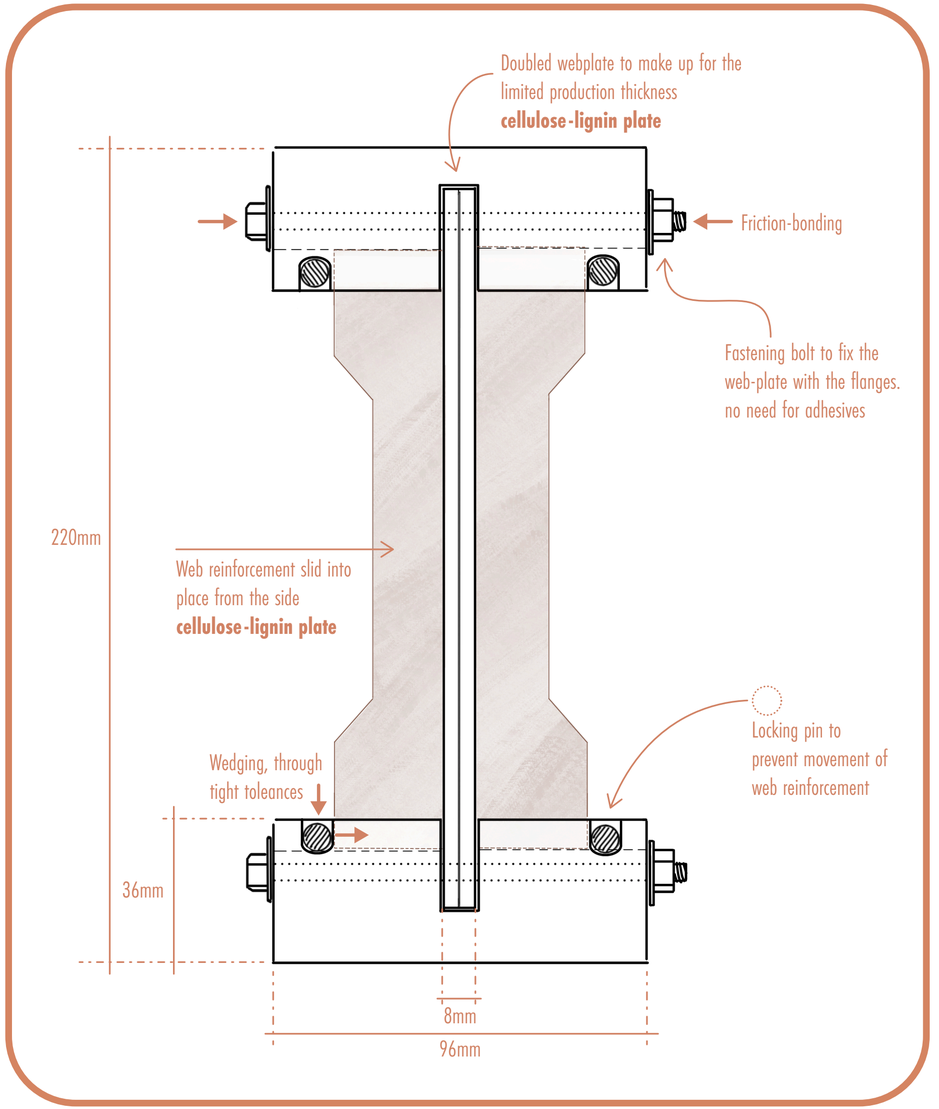
Type	Specification	Standard
Maximum deflection	≤ L/300; under characteristic (dead + live) loads	EN 1990:2002
Live load	2 kN/m² (residential area)	EN 1990-1-1:2002
Dead load	1.5 kN/m² (floor finishes, services, self-weight of joist and decking)	EN 1990-1-1:2002
Partial safety factors	γ_G = 1.35 (permanent), γ_Q =1.50 (variable)	EN 1991-1-1:2002
Minimum floor surface mass	200 kg/m² (to achieve $R_{n,}w \approx 50$ dB airborne sound insulation in a timber-framed floor)	EN ISO 12354-2:2017



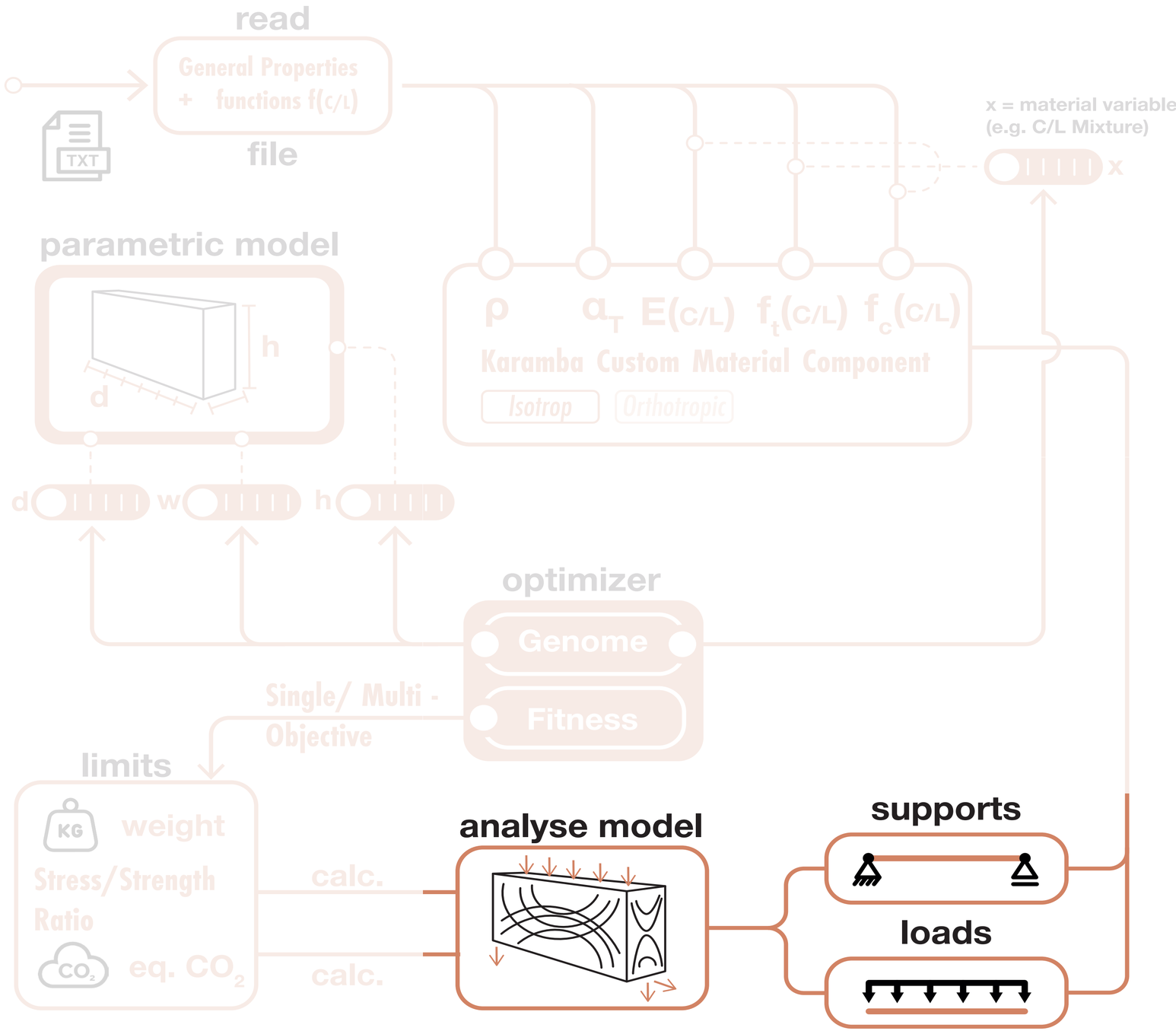
Cross-Section Adjustments

- No adhesives, glues irreversible connection
- Preserve standard joist connections
- Accommodate the limited production thickness of hot-press (~4mm)
- Accommodate low flexural modulus - Introduce buckling reinforcements

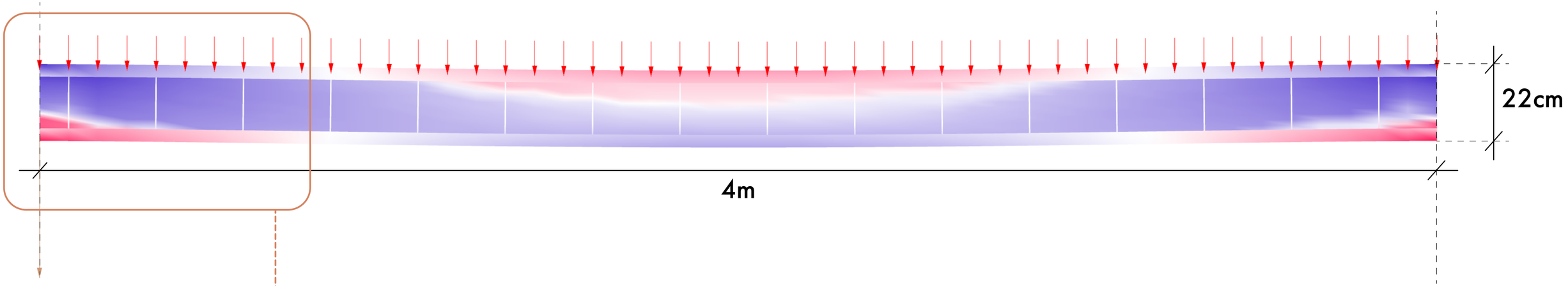


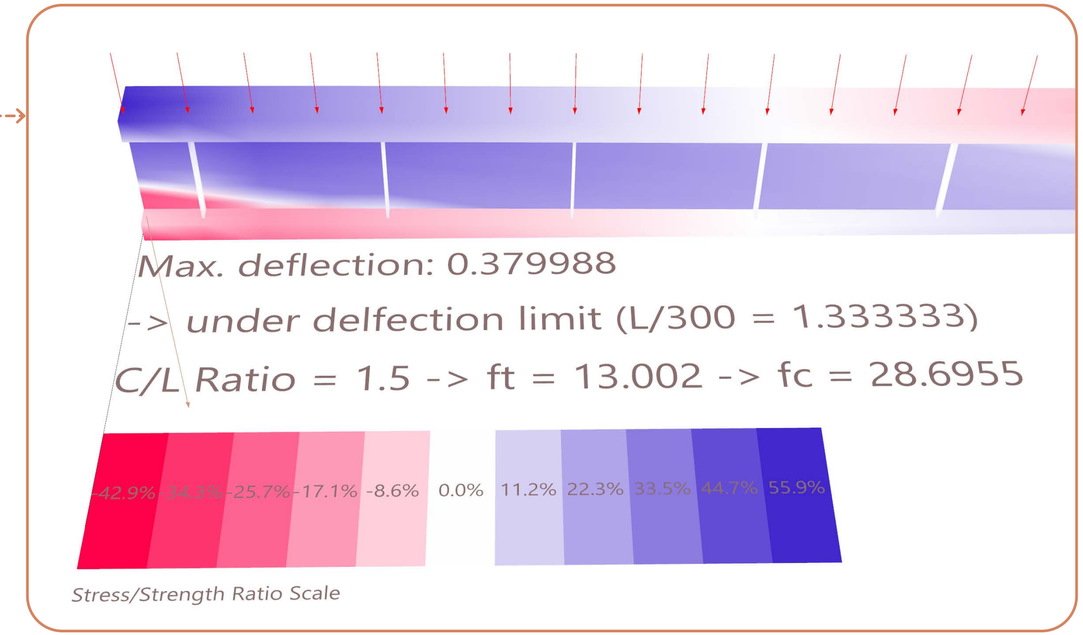


Grashopper Workflow



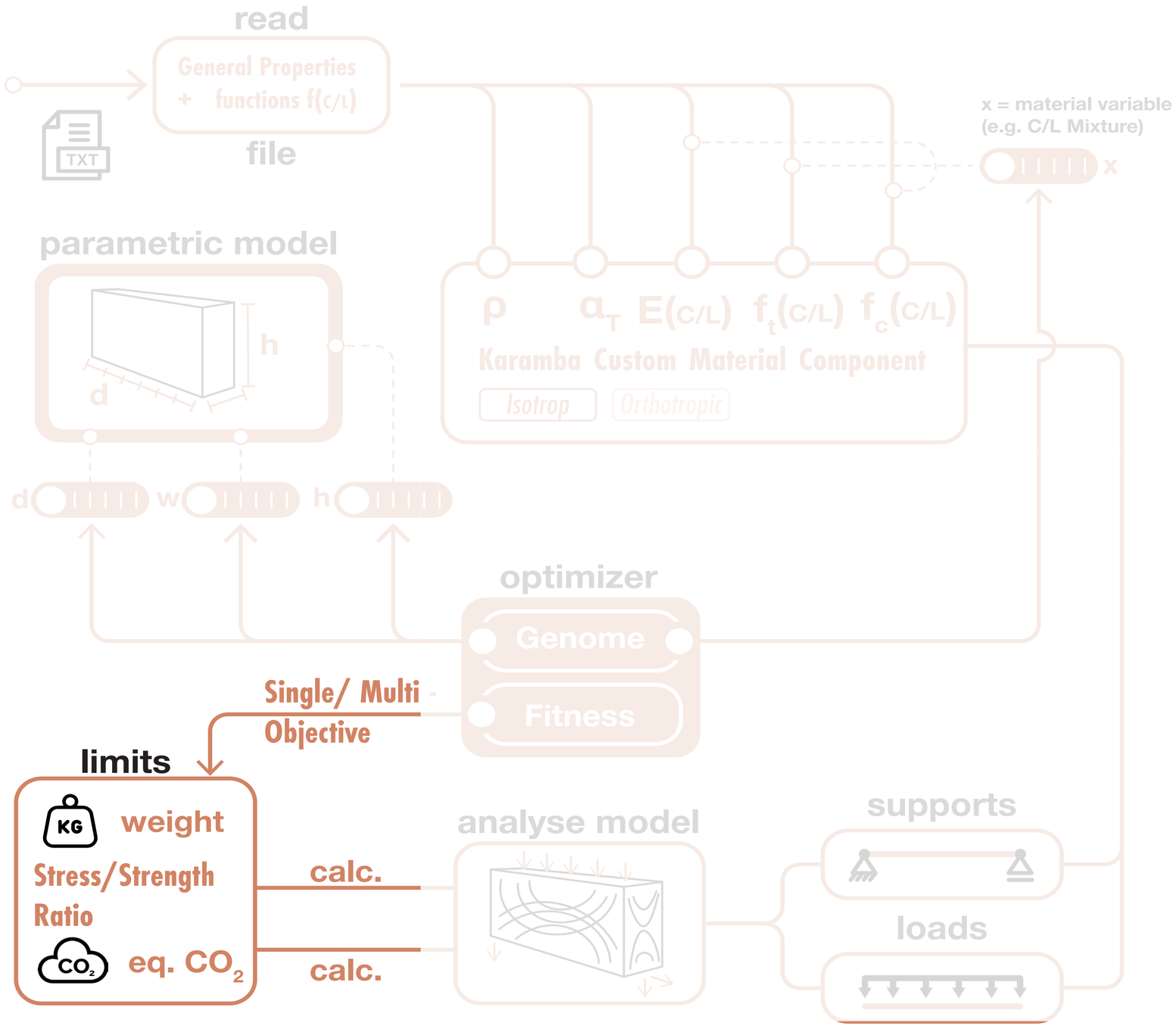
Modelling results



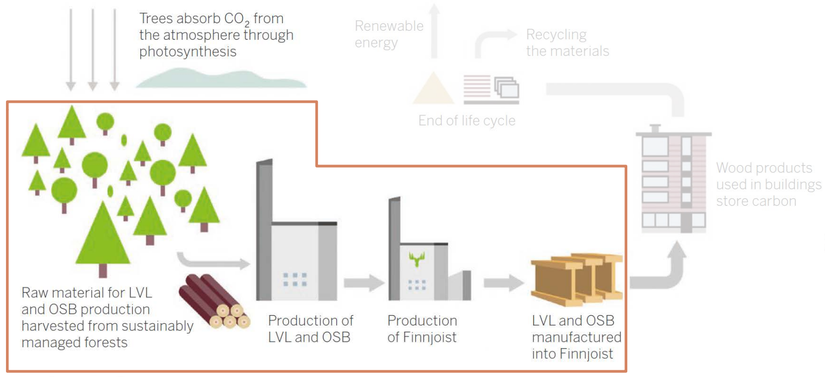


- Exemplary C/L ratio of 1.5 or 3 to 2.
- f_t = 13.0 MPa & f_c = 28.7 MPa
- Deflection limit satisfied
- 43% to 56% strength utilisation

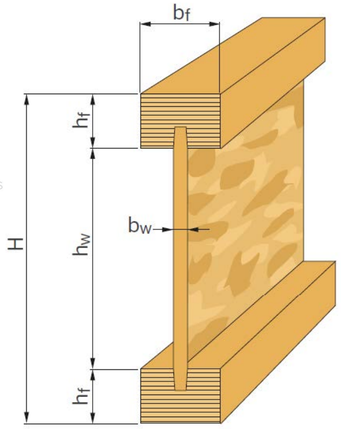
Grashopper Workflow



Environmental Impact



A1-A3



Environmental Information

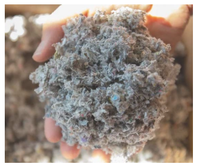
1 CORE ENVIRONMENTAL IMPACT INDICATORS - 1 KG OF FINNJOIST

Indicator	Unit	A1-A3
Global Warming Potential - total (GWP-total)*	kg CO_2 eq.	-1.04
Global Warming Potential - fossil fuels (GWP-fossil)	kg CO_2 eq.	0.581
Global Warming Potential - biogenic (GWP-biogenic)*	kg CO_2 eq.	-1.63
Global Warming Potential - land use and land use change	kg CO_2 eq.	$9.37 \cdot 10^{-4}$

images from: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.homedepot.ca%2Fproduct%2F1001854928&psig=AOvVaw08vtIpbDeXu-NnMm-iYQuM&ust=1750326331826000&source=images&opi=89978449

ISOCELL

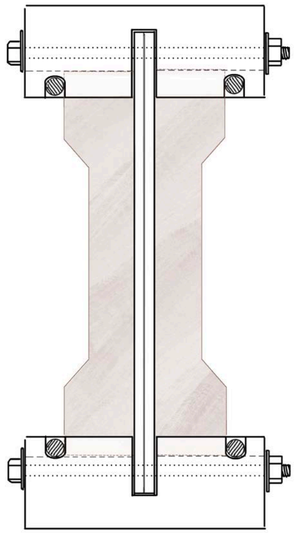
Kraft Lignin



LVL

Fasteners

+ Hot-Pressing Energy (Dutch Energy Mix)



4m of cellulose-lignin Finnjoist

Type	Equivalent kg CO_2	Amount	Source
Lignin	0.6 kg CO_2 /kg	4.97 kg	Bernier et al., 2013
Cellulose	-81.1kg CO_2 (65kg/kg)	7.46 kg	ISOCELL GmbH. (2014).
LVL	-693 kg CO_2/m^3	10.13 kg	Stora Enso. (2023)
Metal Fasteners	6.88 kg CO_2/1000kg	0.23 kg	Adolf Würth GmbH & Co. KG, 2024
Type	**Specification**		**Source**
Hot-pressing	6.1 kWh per m^2		Silva et al., 2020
Dutch Energy Mix	0.2685 kg CO_2/kWh		Statista, 2025
	Total kg CO_2 -19.02 (-0.9/kg)	Total weight: 22.80 kg	

Cellulose-lignin ratio:

0.6 = -0.72 kg eq. CO_2

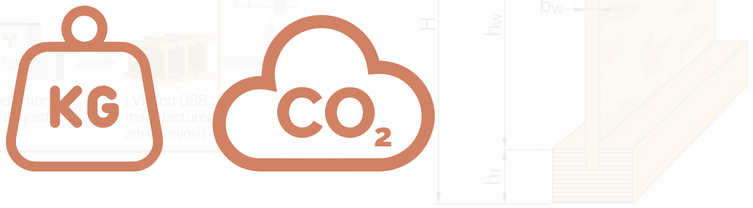
↓

Cellulose-lignin ratio:

4.0 = -1.06 kg eq. CO_2

LVL image from:https://www.vanhoorebeke.com/en/houtproducten/construction/lvl
Isocell Logo from: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.enning-daemmtechnik.de%2Fpartner.html&psig=AOvVaw2qxzitFlmK9KjMrwJqM5RP&ust=1750327061547000&source=images&opi=89978449
Cellulose and Lignin Image see reference on page 11
Metal Fasteners image from: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.melfast.com%2Fblog%2F2016%2F05%2F3-things-about-stainless-steel-fasteners-you-probably-dont-know&psig=AOvVaw2jkW-LDg8OqOaoENewTfAs&ust=1750327170290000&source=images&opi=89978449

Environmental Impact



14.0 kg 14.6 kg eq. CO_2

→ 100% Primary Timber

→ MUF Resisns for bonding - non recyclable

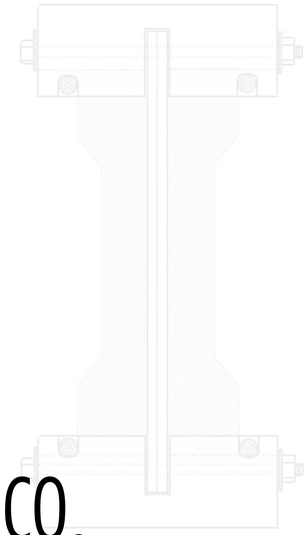
→ Formaldehyde emissions from OSB plates

22.8 kg -19.0 kg eq. CO_2

→ 45% Primary Timber

→ 55% Waste Cellulose/Lignin

→ No pot. harmful adhesives (e.g.formaldehyde)



Cellulose-lignin ratio:

0.4 = -0.72 kg eq. CO_2

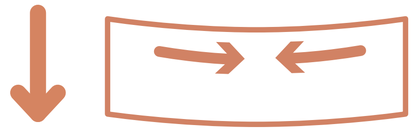
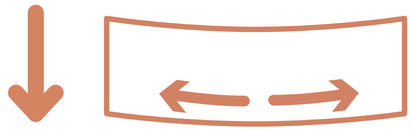
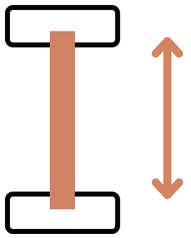
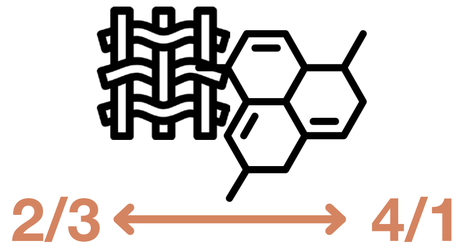
Cellulose-lignin ratio:

4.0 = -1.06 kg eq. CO_2

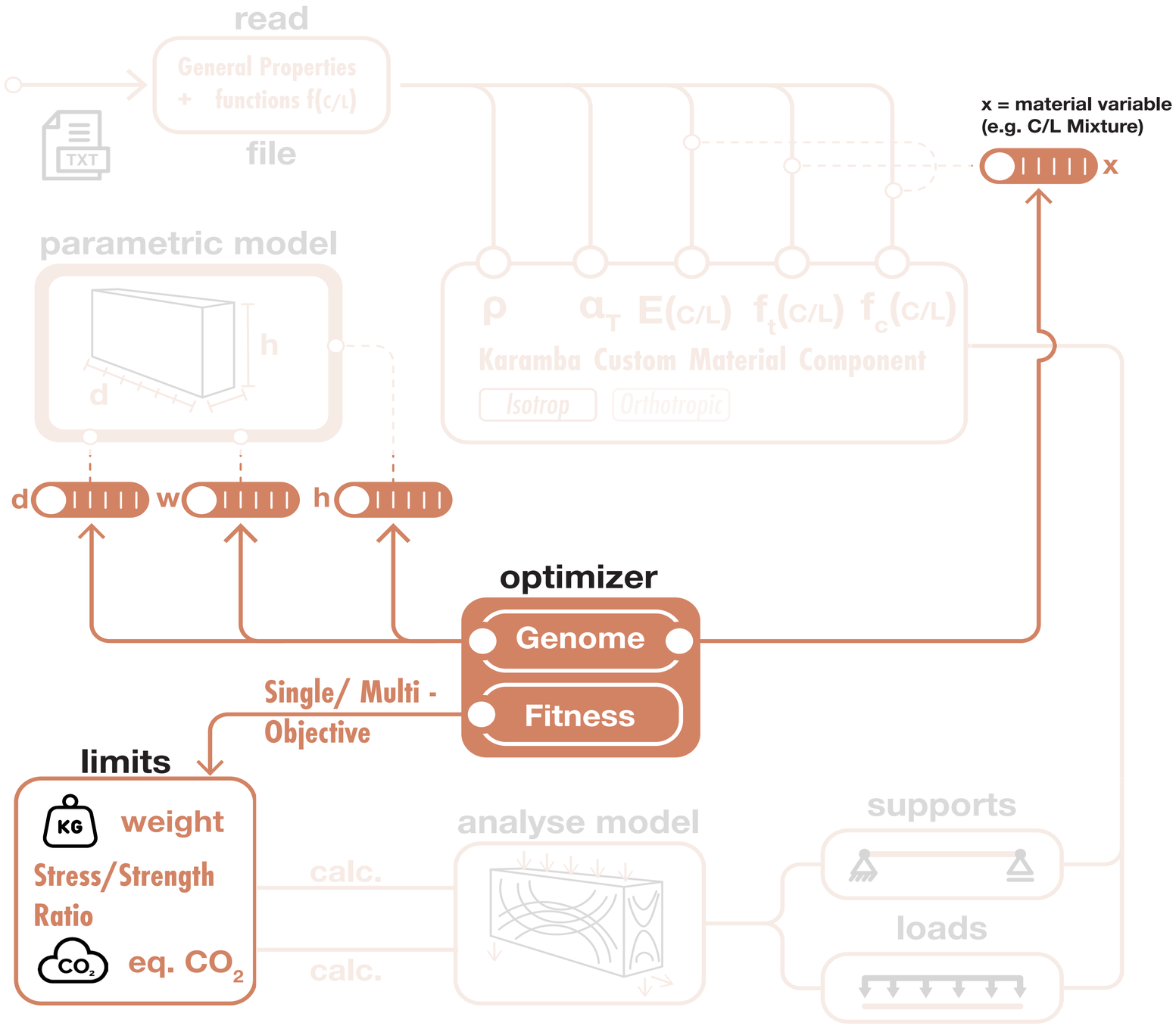
from:https://www.vanhoorebeke.com/en/houtproducten/construction/i

Optimisation outline

Walleci inputs

Fitness	Minimise equivalent CO2 emissions	Minimise weight	Minimise maximum compressive utilisation (red zone of stress/strength factor)	Minimise maximum tensile utilisation (blue zone of stress/strength factor)
				
Genomes	Web height (Finnjoist catalogue)	C/L ratio -> affecting f_t and f_c (0.66-4.00)		
				

Grashopper Workflow



Optimisation Results

60 generations with 20 individuals

Three solution that show the top ranking results per Fitness Objective

Selected Solution Information

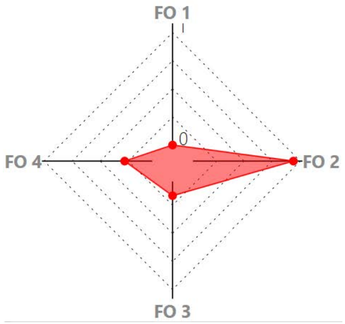
Solution: Gen. 20 | Ind. 2

FO1: Minimise CO2
Fitness Value: -35.61973
Fitness Rank: 0 / 1199

FO2: Minimise weight
Fitness Value: 37.964089
Fitness Rank: 1126 / 1199

FO3: Minimise tension zone
Fitness Value: 23.8
Fitness Rank: 198 / 1199

FO4: Minimise compression zone
Fitness Value: 41.4
Fitness Rank: 340 / 1199



Selected Solution Information

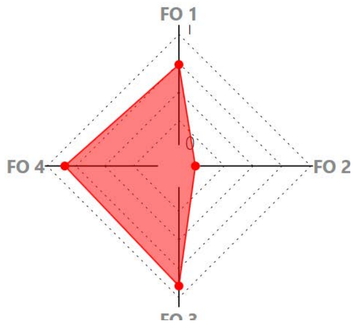
Solution: Gen. 2 | Ind. 4

FO1: Minimise CO2
Fitness Value: -22.527949
Fitness Rank: 885 / 1199

FO2: Minimise weight
Fitness Value: 22.421611
Fitness Rank: 0 / 1199

FO3: Minimise tension zone
Fitness Value: 53
Fitness Rank: 1078 / 1199

FO4: Minimise compression zone
Fitness Value: 80.5
Fitness Rank: 1015 / 1199



Selected Solution Information

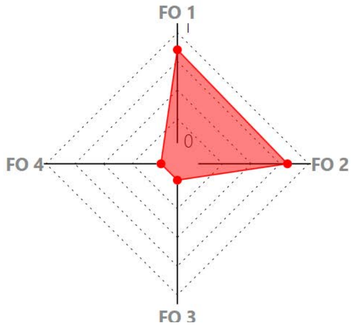
Solution: Gen. 0 | Ind. 10

FO1: Minimise CO2
Fitness Value: -19.934033
Fitness Rank: 1021 / 1199

FO2: Minimise weight
Fitness Value: 37.964088
Fitness Rank: 978 / 1199

FO3: Minimise tension zone
Fitness Value: 20.8
Fitness Rank: 0 / 1199

FO4: Minimise compression zone
Fitness Value: 27.8
Fitness Rank: 0 / 1199



Optimisation Results

60 generations with 20 individuals

Three solution that show the top ranking results per Fitness Objective

Selected Solution Information

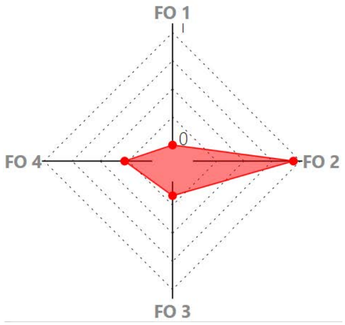
Solution: Gen. 20 | Ind. 2

FO1: Minimise CO2
Fitness Value: -35.61973
Fitness Rank: 0 / 1199

FO2: Minimise weight
Fitness Value: 37.964089
Fitness Rank: 1126 / 1199

FO3: Minimise tension zone
Fitness Value: 23.8
Fitness Rank: 198 / 1199

FO4: Minimise compression zone
Fitness Value: 41.4
Fitness Rank: 340 / 1199



Selected Solution Information

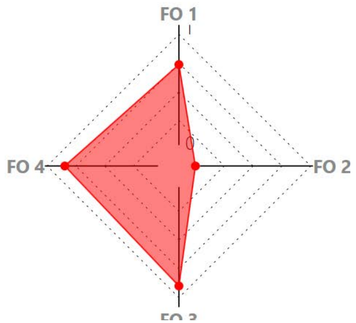
Solution: Gen. 2 | Ind. 4

FO1: Minimise CO2
Fitness Value: -22.527949
Fitness Rank: 885 / 1199

FO2: Minimise weight
Fitness Value: 22.421611
Fitness Rank: 0 / 1199

FO3: Minimise tension zone
Fitness Value: 53
Fitness Rank: 1078 / 1199

FO4: Minimise compression zone
Fitness Value: 80.5
Fitness Rank: 1015 / 1199



Selected Solution Information

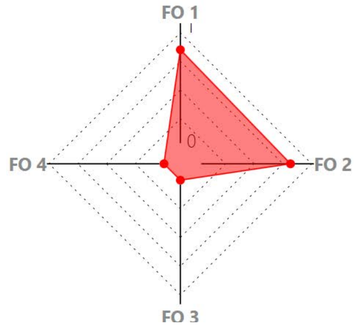
Solution: Gen. 0 | Ind. 10

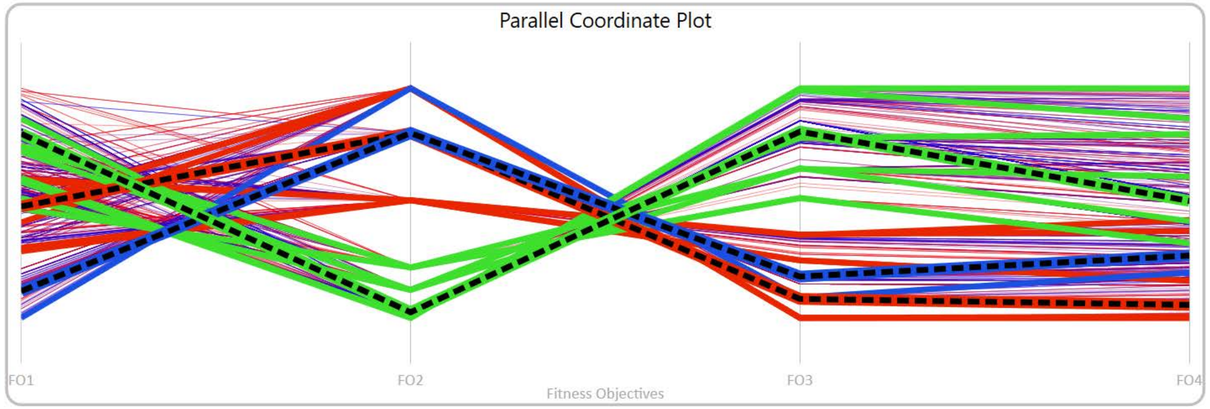
FO1: Minimise CO2
Fitness Value: -19.934033
Fitness Rank: 1021 / 1199

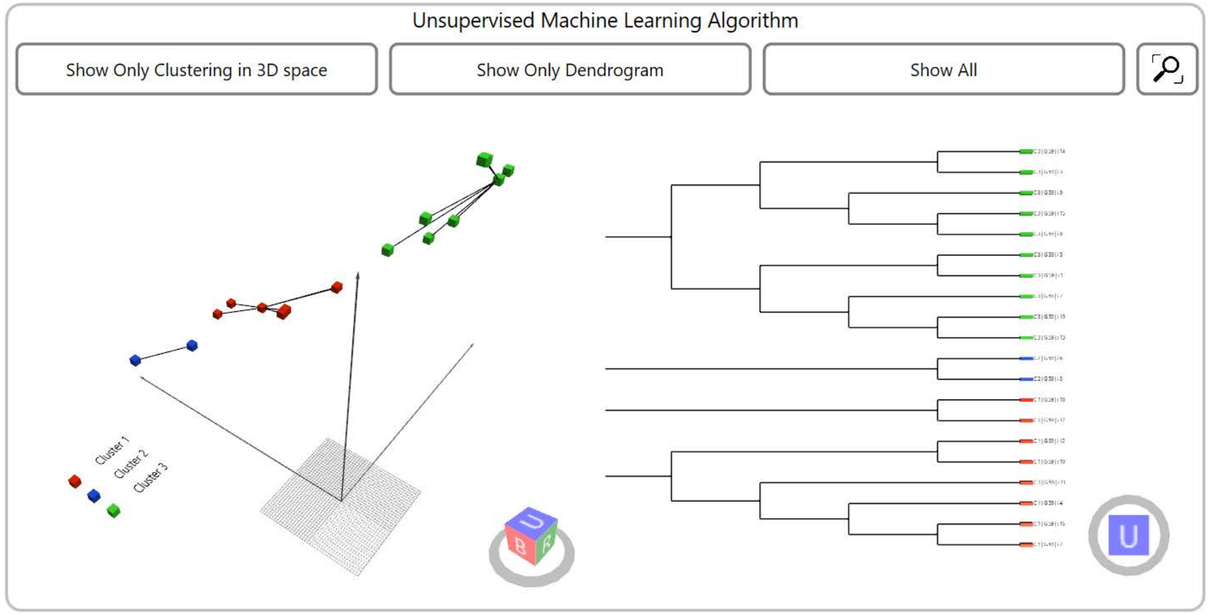
FO2: Minimise weight
Fitness Value: 37.964088
Fitness Rank: 978 / 1199

FO3: Minimise tension zone
Fitness Value: 20.8
Fitness Rank: 0 / 1199

FO4: Minimise compression zone
Fitness Value: 27.8
Fitness Rank: 0 / 1199





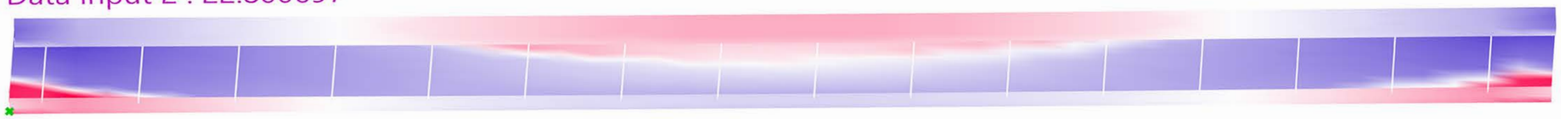


Gen: 59 | Ind: 11
FV. 1 : -25.547889
FV. 2 : 34.93141
FV. 3 : 23.6
FV. 4 : 31.7
Data input 1 : -25.547889
Data input 2 : 34.93141

Genome:
Height: 380mm - C/L ratio: 1.71

Gen: 59 | Ind: 14
FV. 1 : -18.982479
FV. 2 : 22.800697
FV. 3 : 48.3
FV. 4 : 62.9
Data input 1 : -18.982479
Data input 2 : 22.800697

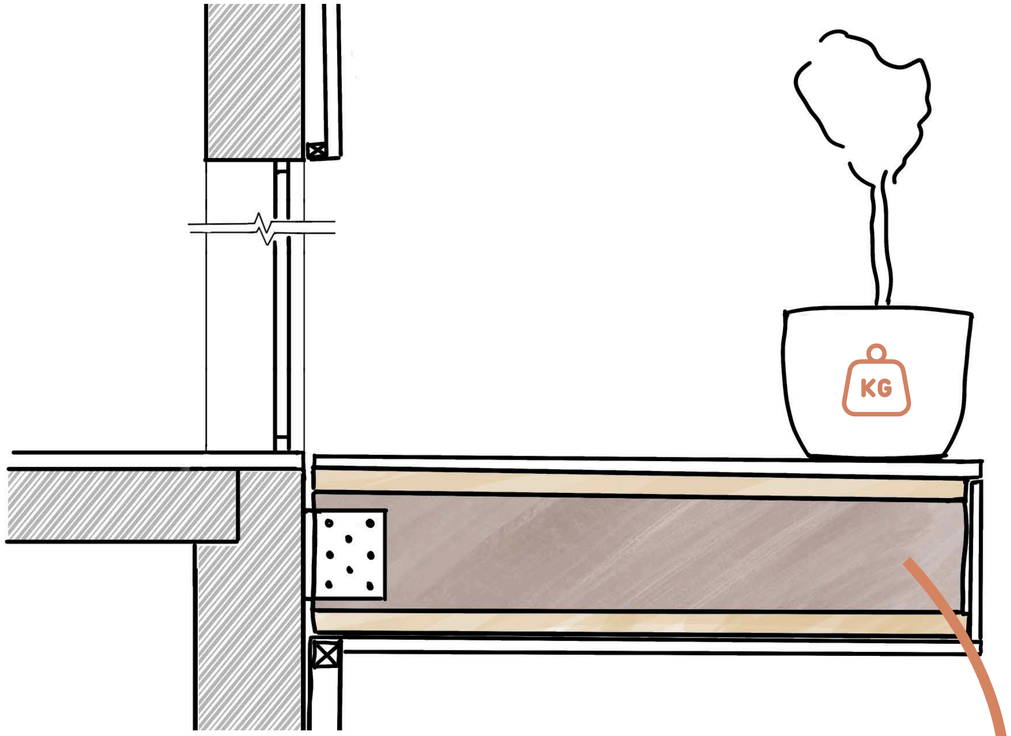
Genome:
Height: 200mm - C/L ratio: 1.49



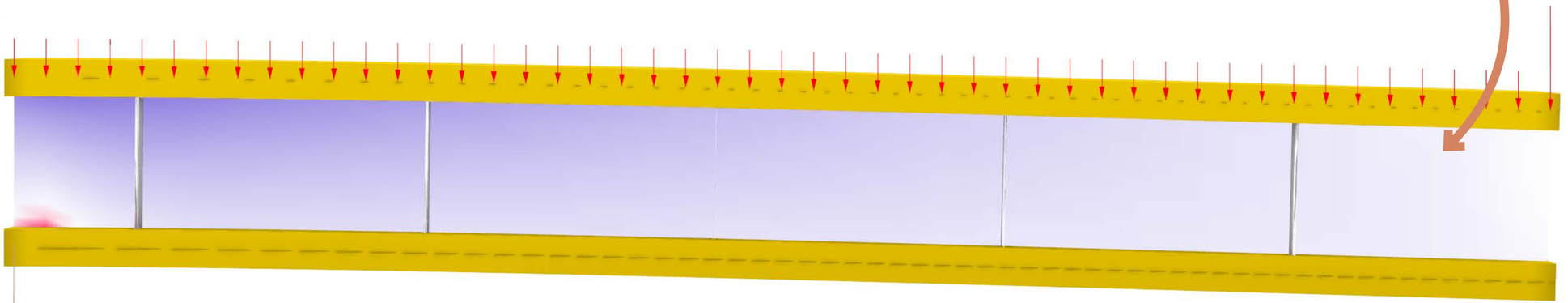
Gen: 59 | Ind: 6
FV. 1 : -33.200437
FV. 2 : 34.931411
FV. 3 : 26.9
FV. 4 : 46.5
Data input 1 : -33.200437
Data input 2 : 34.931411

Genome:
Height: 360mm - C/L ratio: 3.98

Component customisation

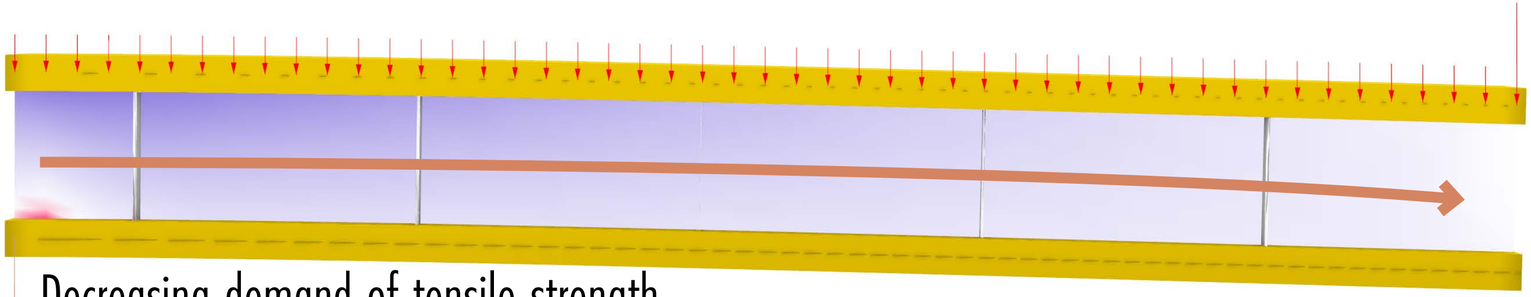


Non-uniform load distribution



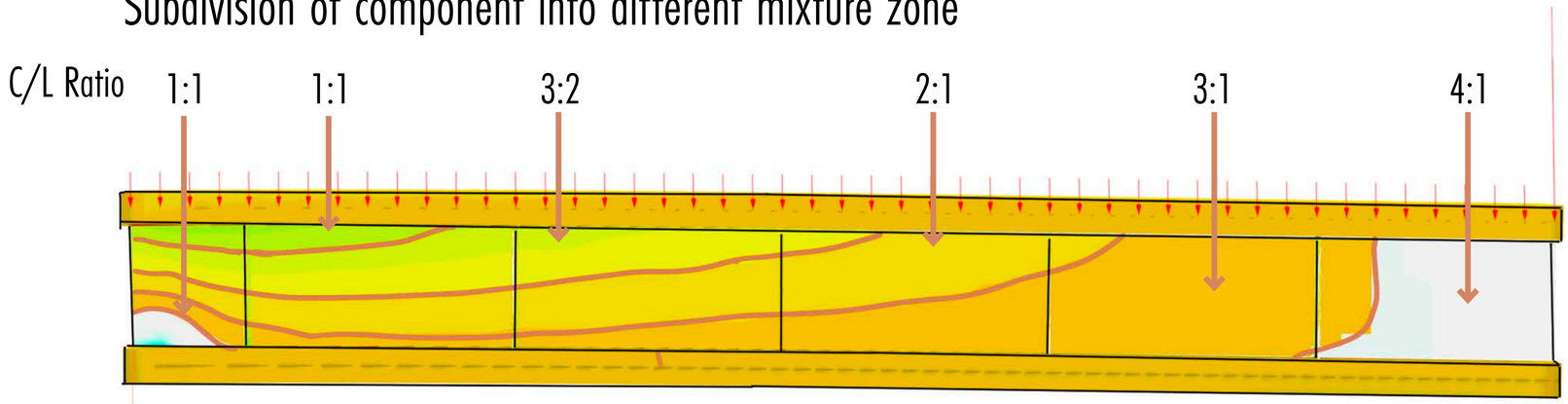
Principal stress 1 is tensile, optimise for tensile perfromance

Component customisation



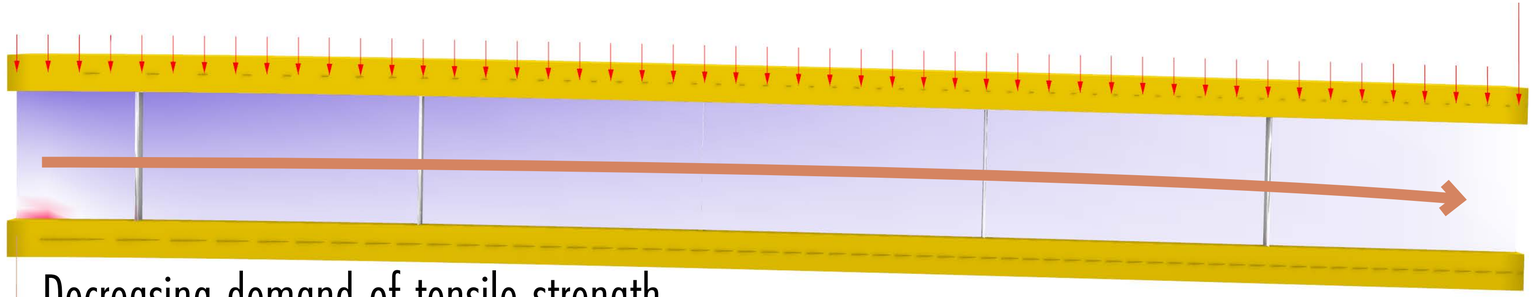
Decreasing demand of tensile strength

Subdivision of component into different mixture zone



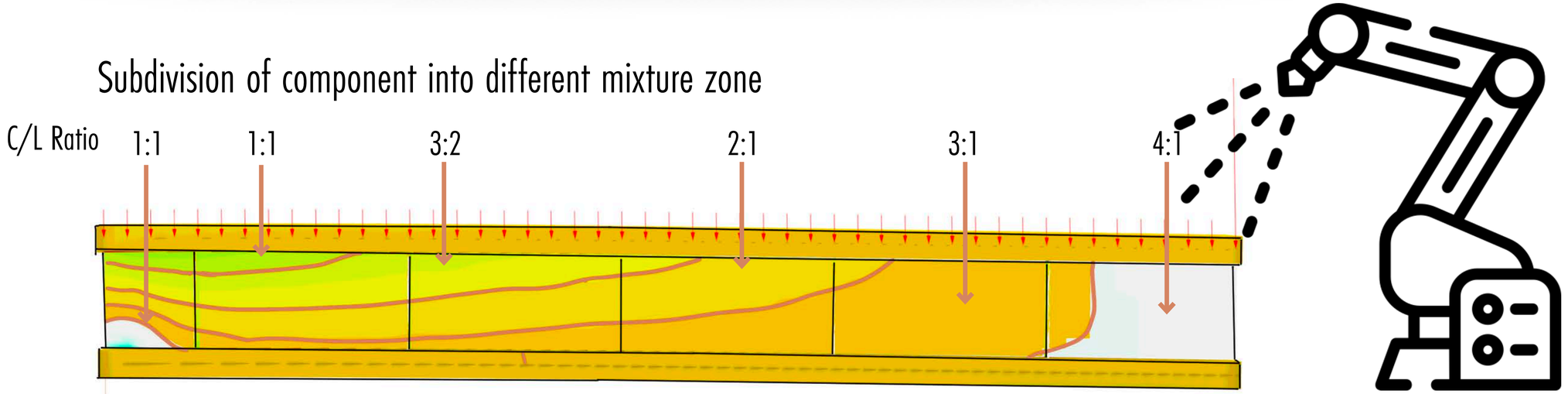
Decreasing lignin content with less demand

Component customisation



Decreasing demand of tensile strength

Subdivision of component into different mixture zone

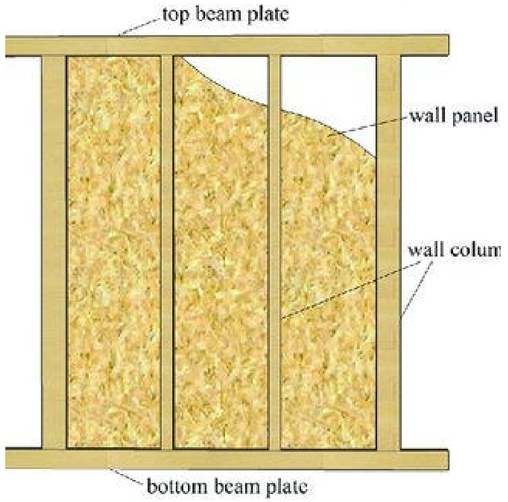


Decreasing lignin content with less demand

Future Application

Simple Plated Production

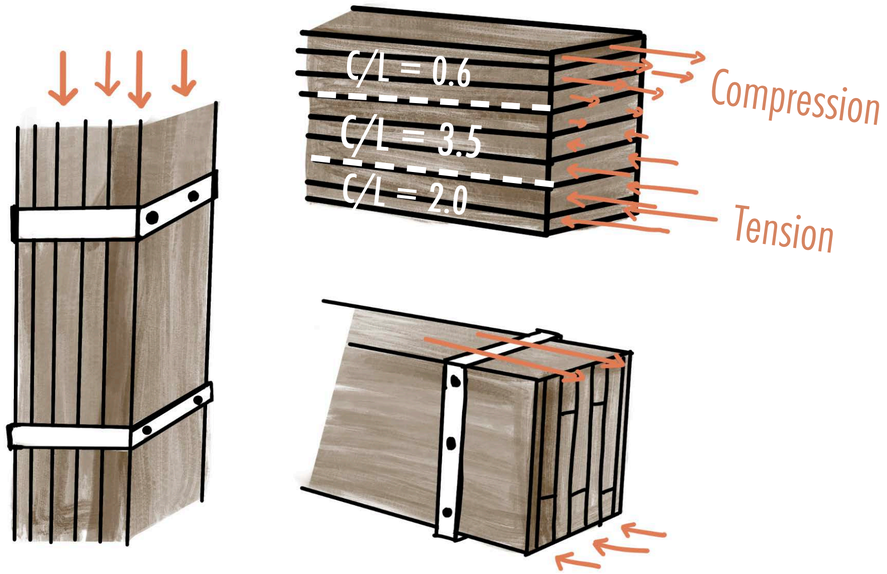
Shear Wall Framing

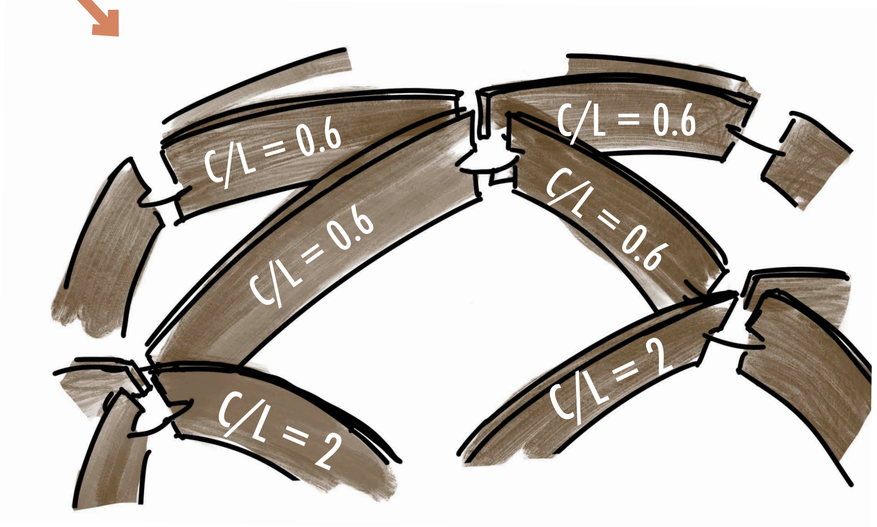


Customised Mould

Additive Layering

Mixture adjustment based on load





Discrete Elements with customised mixtures

Future Application

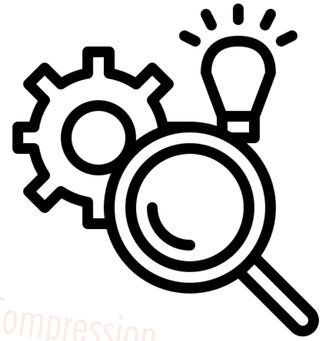
Simple Plated Production

Shear Wall Framing

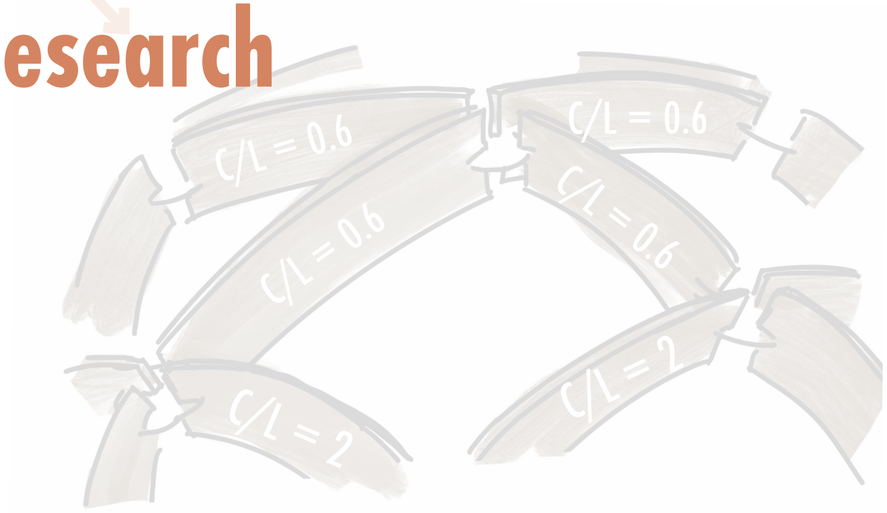
Customised Mould

Additive Layering

Mixture adjustment based on load

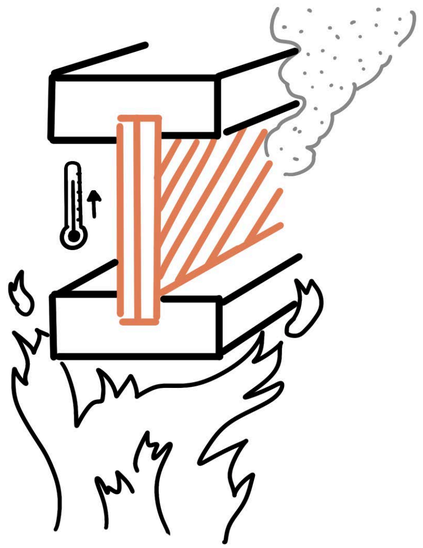


Future Design Research

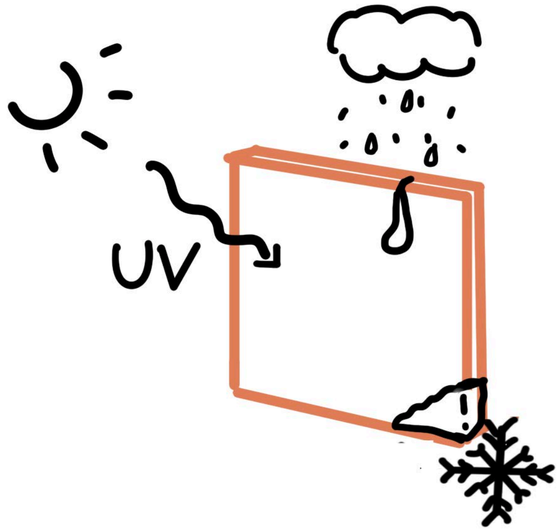


Discrete Elements with customised mixtures

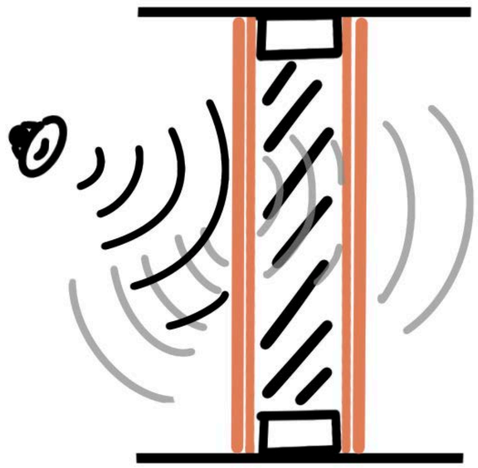
Further Investigation and Improvements



Thermal and Fire Behaviour



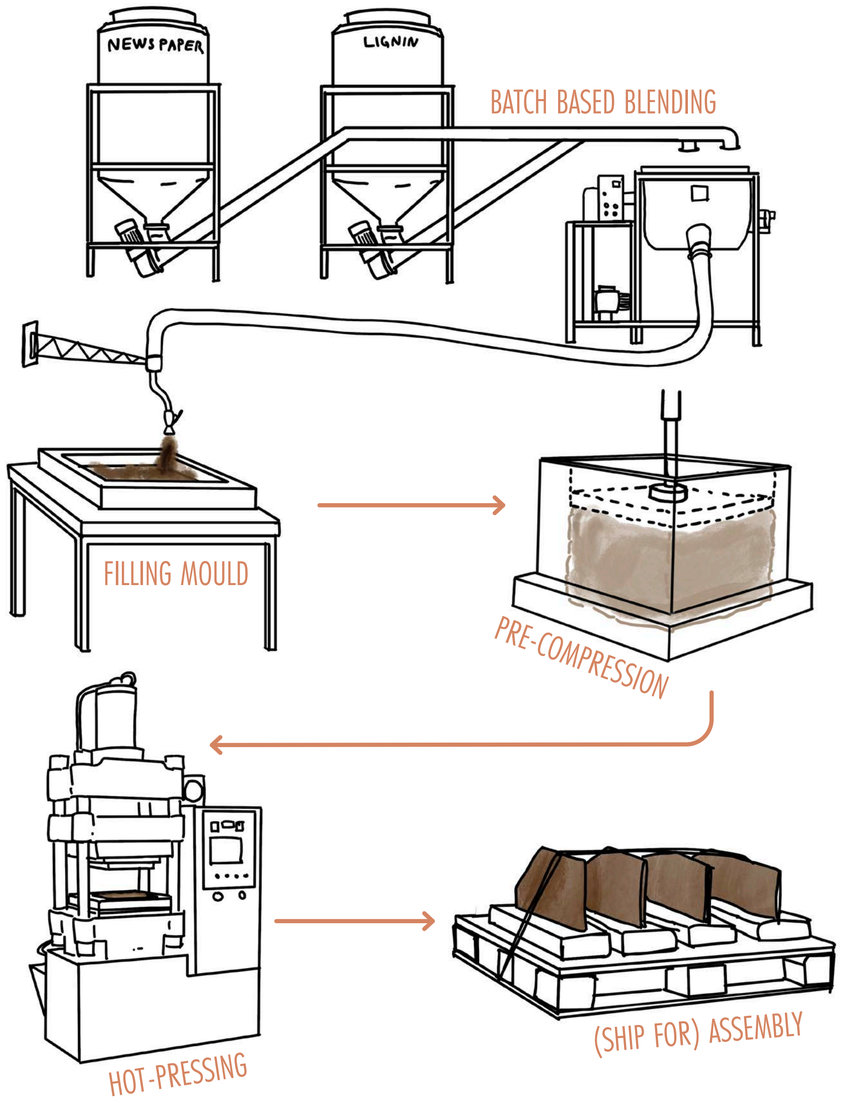
Environmental Response



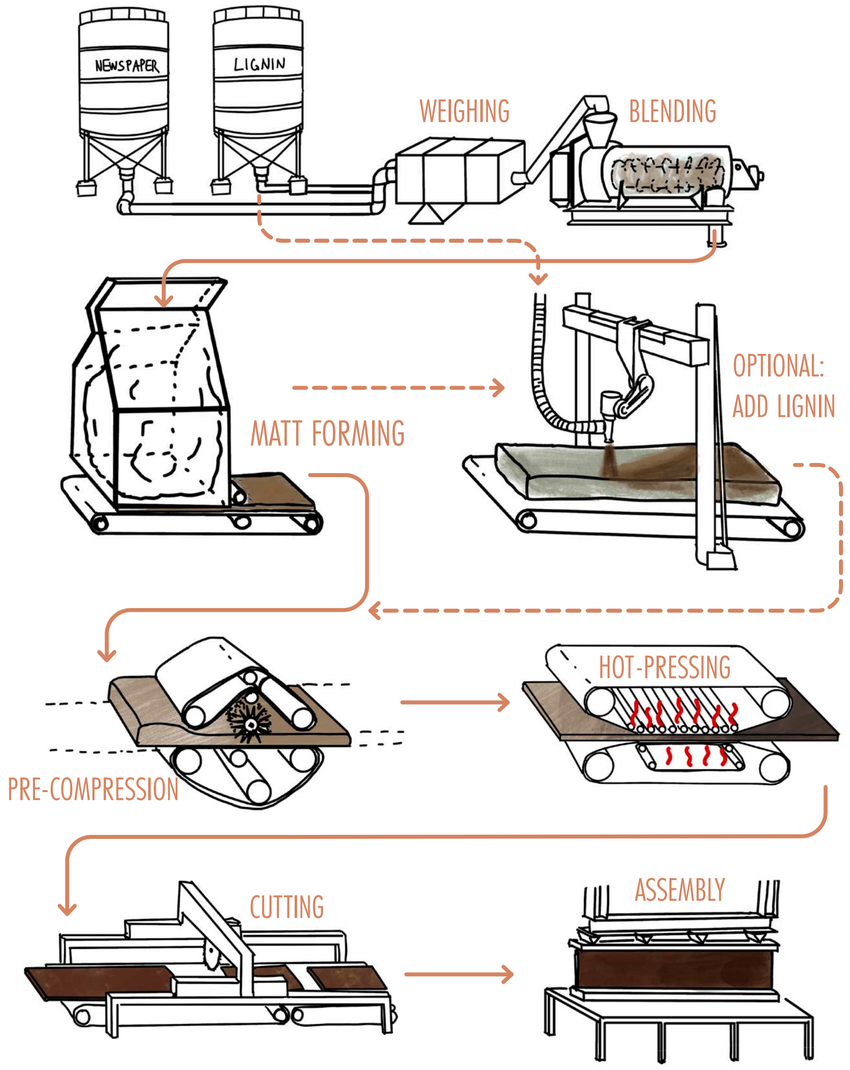
Indoor Performance

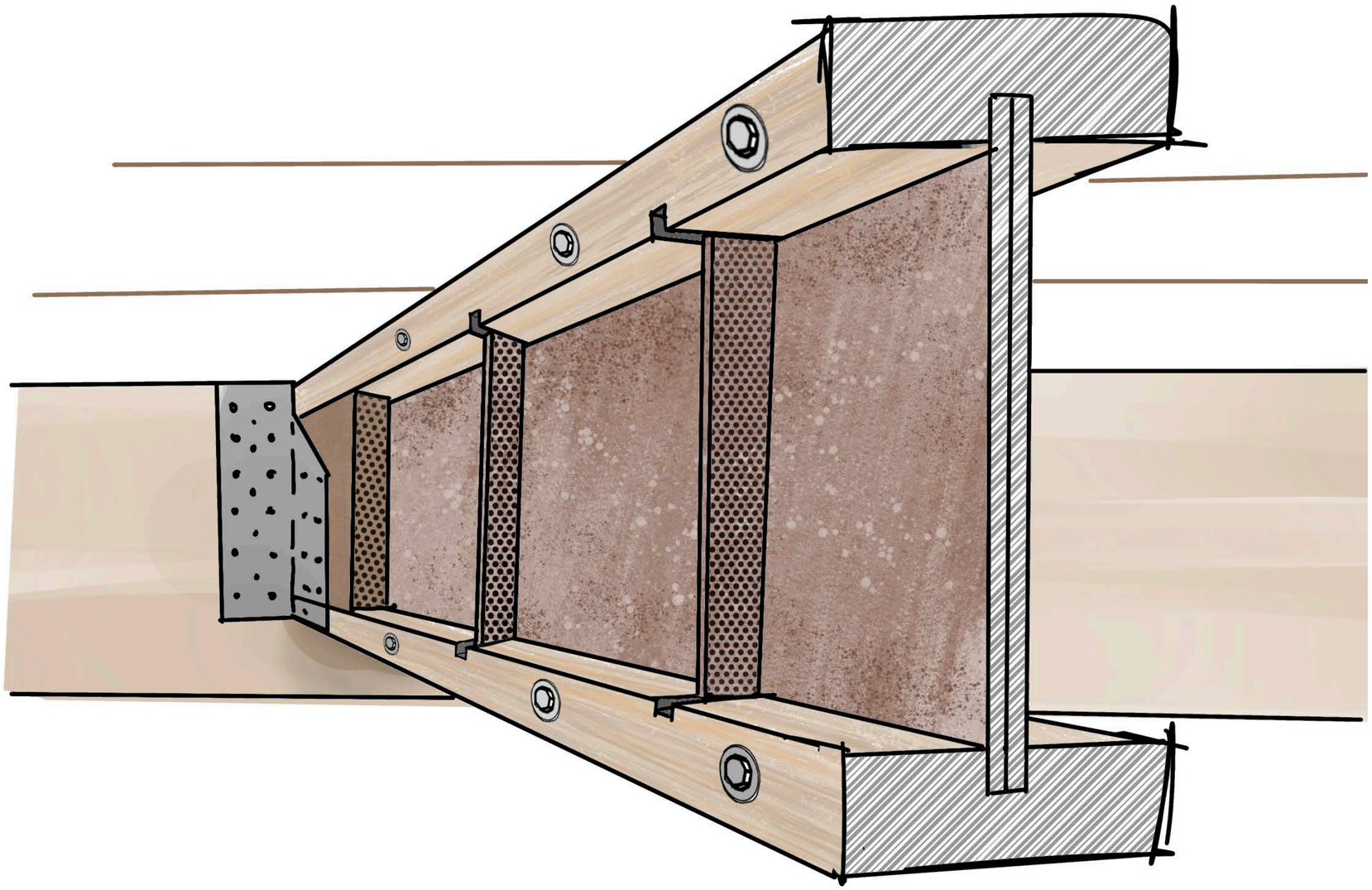
Large Scale Production Process

Individual Hot-pressing



Continuous Plate Production





Conclusion

Research Question:

How can an optimised mixture and a suitable hot-press production method be developed that uses by-product-lignin and -cellulose, to utilize lignin's natural binding properties through controlled polymerization?

→ how to turn lignin into an adhesive?

Research Question:

How can an optimised mixture and a suitable hot-press production method be developed that uses by-product-lignin and cellulose, to utilize lignin's natural binding properties through controlled polymerization?

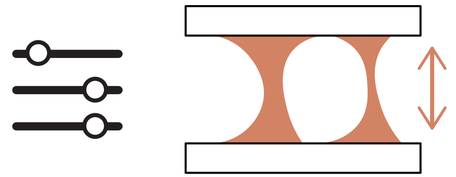
→ how to turn lignin into an adhesive?

Mixture Design
Production Method

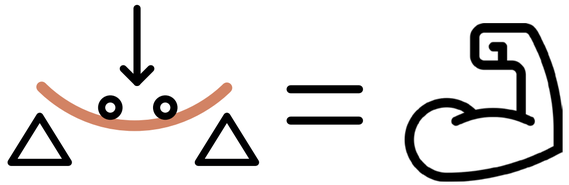
Material Development

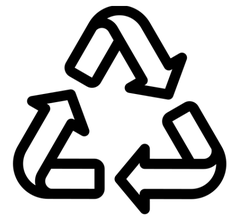
Cellulose and Lignin Image see reference on page 11

Performance

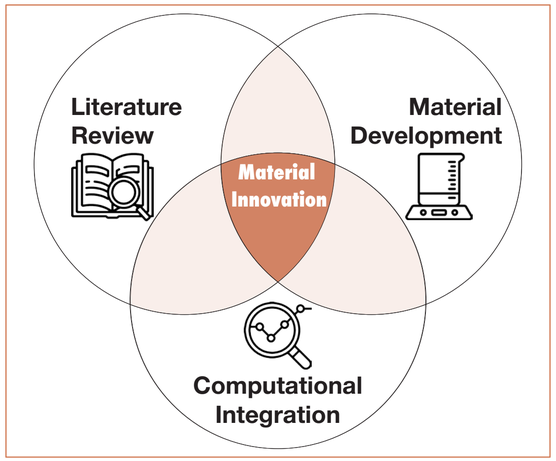


Adhesive qualities of Lignin

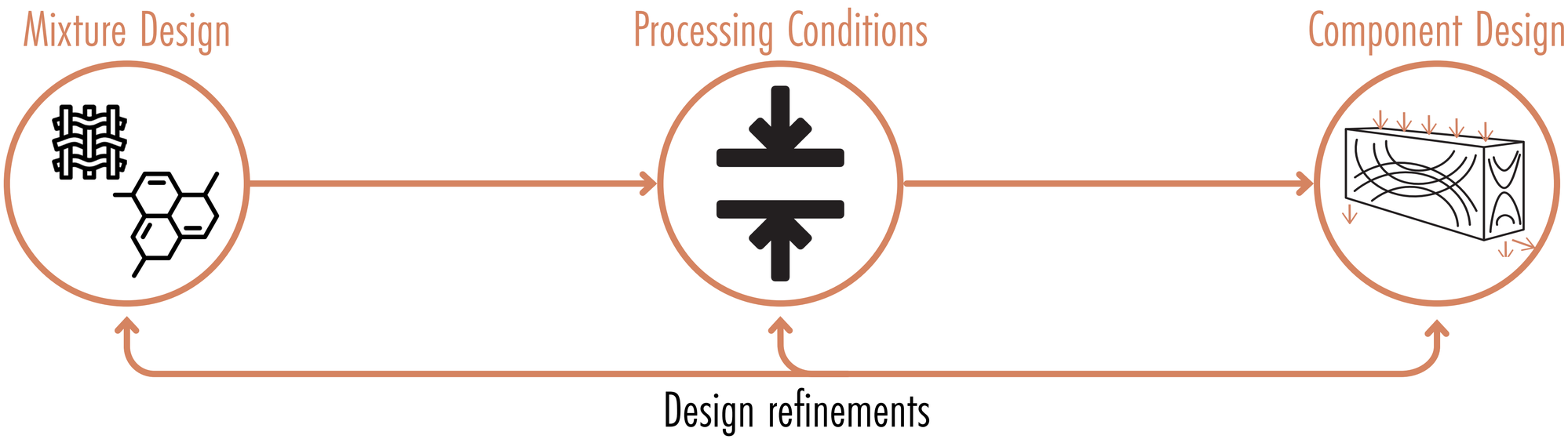




Control mechanisms



Level of Control



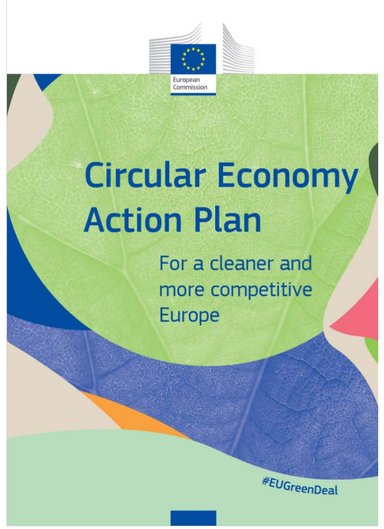


Image from: https://www.google.com/url?sa=i&url=https%3A%2F%2Fop.europa.eu%2Fde%2Fpublication-detail%2F-%2Fpublication%2F45cc30f6-cd57-11ea-adf7-01aa75ed71a1%2Flanguage-en&psig=AOvVaw3waOFdB8oGE2tJ-JwcXkwA&ust=1750327437215000&source=images&opi=89978449

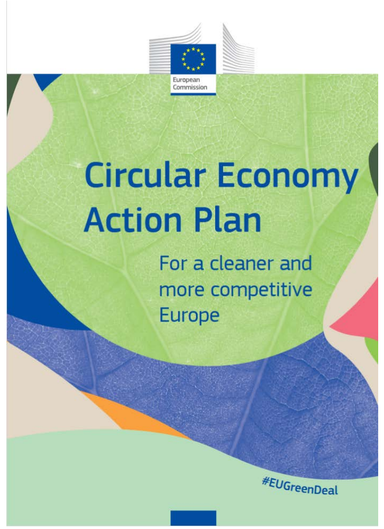


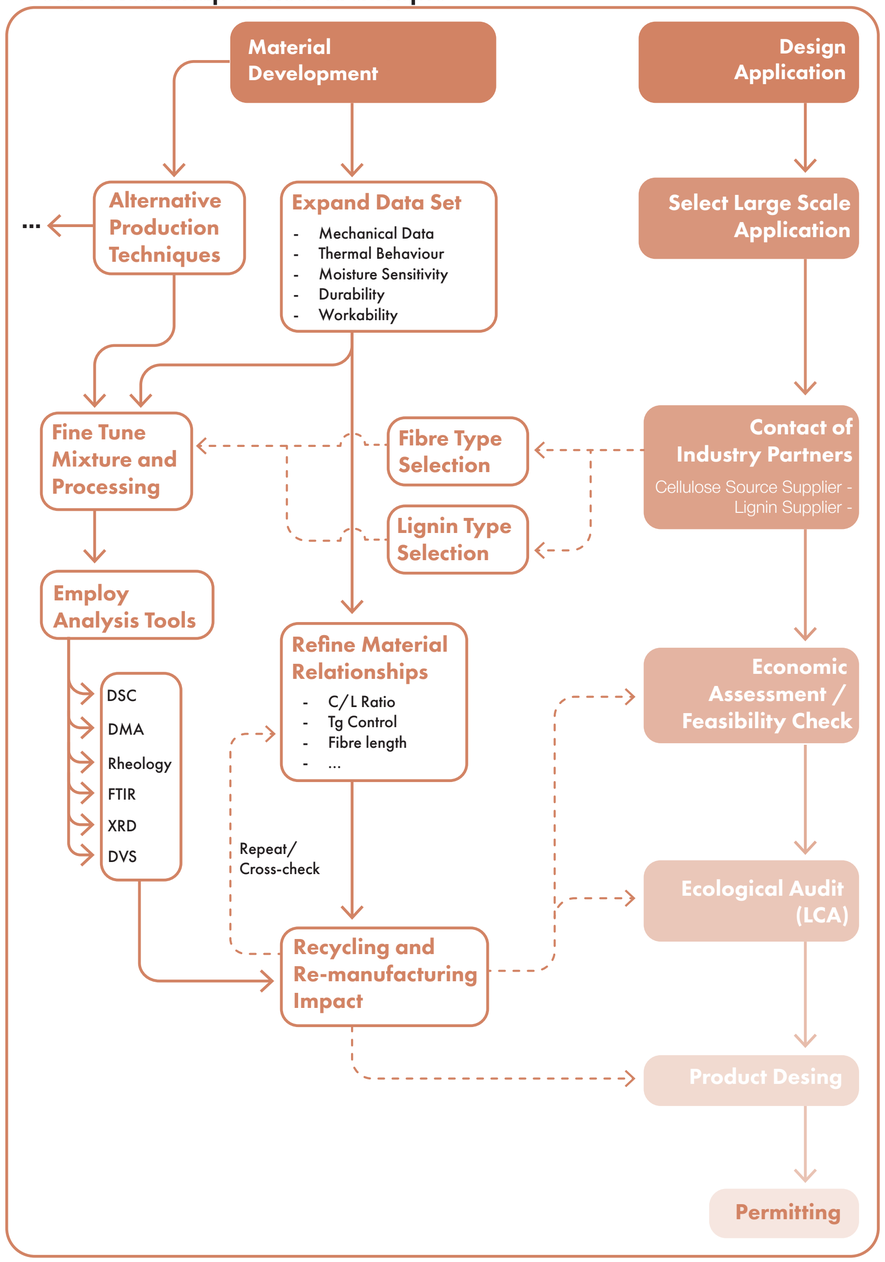
Image from: https://www.google.com/url?sa=i&url=https%3A%2F%2Fop.europa.eu%2Fde%2Fpublication-detail%2F-%2Fpublication%2F45cc30f6-cd57-11ea-adf7-01aa75ed71a1%2Flanguage-en&psig=AOvVaw3waOFdB8oGE2tJ-JwcXkwA&ust=1750327437215000&source=images&opi=89978449

↓ Material Scarcity & ↓ Climate Impact

Project Suggestions

- Perform more material variations and expand the dataset for more accurate models
- Exploration of additives for improved performance and processing
- Involvement of industry partners to detail the resource chains and environmental implications
- Develop further production techniques past hot-pressing (e.g. palletisation and 3d-printing)
- Deepen knowledge on the recyclability and performance changes after re-processing

Future Roadmap of Research Topic




Thank
You!

Pictogram Reference List

Some Figures have been designed using resources from Flaticon.com see Table below:

Icon Title	Author	Used on Page:	Flaticon URL
Weather	Ivan Abirawa	20,26,39-53,57,83	https://www.flaticon.com/free-icon/weather_13936209
Cell	Nadiinko	14,26,37,39-53,56,73-75, 104, 106,121	https://www.flaticon.com/free-icon/cell_4299855
Horizontal Merge	Freepik	20,26,39-53,57, 104, 122	https://www.flaticon.com/free-icon/horizontal-merge_80716
Textile	Freepik	14,26,37,39-53,56,73-75, 104, 106,121, 122	https://www.flaticon.com/free-icon/textile_5482820
Humidity	Freepik	26,37,39-53,56,72-75,83	https://www.flaticon.com/free-icon/humidity_8678233
Time	Ilham Fitrotul Hayat	20,26,39-56,57,	https://www.flaticon.com/free-icon/time_3395452
Recycle Sign	Hilmy Abiyyu A.	121,125	https://www.flaticon.com/free-icon/recycle-sign_4361302?term=recycle-sign&page=1&position=44&origin=search&related_id=4361302
Time	Ilham Fitrotul Hayat	20,39-53,57	https://www.flaticon.com/free-icon/time_3395452?term=time&page=1&position=35&origin=search&related_id=3395452
Success	Parzival' 1997	17,18	https://www.flaticon.com/free-icon/success_7508545?term=trial+and+error&page=1&position=3&origin=search&related_id=7508545
Pie Chart	bsd	18,22	https://www.flaticon.com/free-icon/pie-chart_8972636?term=pie+chart+data&page=1&position=2&origin=search&related_id=8972636
3D-Modeling	Freepik	18,22	https://www.flaticon.com/free-icon/3d-modeling_12008058?term=modeling+cube&page=1&position=31&origin=search&related_id=12008058
TXT-file	Freepik	92,94,95,97, 101,103, 107	https://www.flaticon.com/free-icon/txt-file_104647
Weight	Freepik	94,95,97, 101, 103, 105, 106, 107, 110, 111	https://www.flaticon.com/free-icon/weight_847345?term=weight&page=1&position=1&origin=search&related_id=847345
Carbon Dioxide	Freepik	94,95,97, 101, 103, 105, 106, 107, 110	https://www.flaticon.com/free-icon/carbon-dioxide_550250?term=co2&page=1&position=20&origin=search&related_id=550250
Microscope	Iconir	59	https://www.flaticon.com/free-icon/microscope_18922227
Robotic Arm	Freepik	113,125	https://www.flaticon.com/free-icon/robotic-arm_2823691
Construction	Freepik	2	https://www.flaticon.com/free-icon/construction_2204128
Factory	srip	125	https://www.flaticon.com/free-icon/factory_1098423
Database	The Chohans Brand	125	https://www.flaticon.com/free-icon/database_9542653
Circle	Jagat Icon	9	https://www.flaticon.com/free-icon/circle_3839944
EU	Wahyu Adam	3,9	https://www.flaticon.com/free-icon/european-union_3503210?term=eu&page=1&position=53&origin=search&related_id=3503210
Erlenmeyer Flask	Fahrul Oktaviana	10	https://www.flaticon.com/free-icon/erlenmeyer-flask_17184399?term=beaker&page=1&position=55&origin=search&related_id=17184399
Newspaper	Freepik	10	https://www.flaticon.com/free-icon/newspaper_10290333
Research	Freepik	20, 21 , 22, 23, 24, 27, 86, 122	https://www.flaticon.com/free-icon/research_1321070?term=literature&page=1&position=6&origin=search&related_id=1321070
Weighing Scale	juicy_fish	21, 22, 23, 24, 27, 86, 122,125	https://www.flaticon.com/free-icon/weighing-scale_4906768?term=beaker&page=1&position=27&origin=search&related_id=4906768
Analysis	mynamepong	17, 18, 22, 23, 24, 27, 86,122	https://www.flaticon.com/free-icon/analysis_809497
Biceps	Freeepik	121	https://www.flaticon.com/free-icon/biceps_3120798?term=strong&page=1&position=9&origin=search&related_id=3120798
Research & Development	Iconixar	115	https://www.flaticon.com/free-icon/research-and-development_4599811?term=research&page=1&position=1&origin=search&related_id=4599811
Check	Kiranshastry	120	https://www.flaticon.com/free-icon/checked_709510?term=check&page=1&position=7&origin=search&related_id=709510