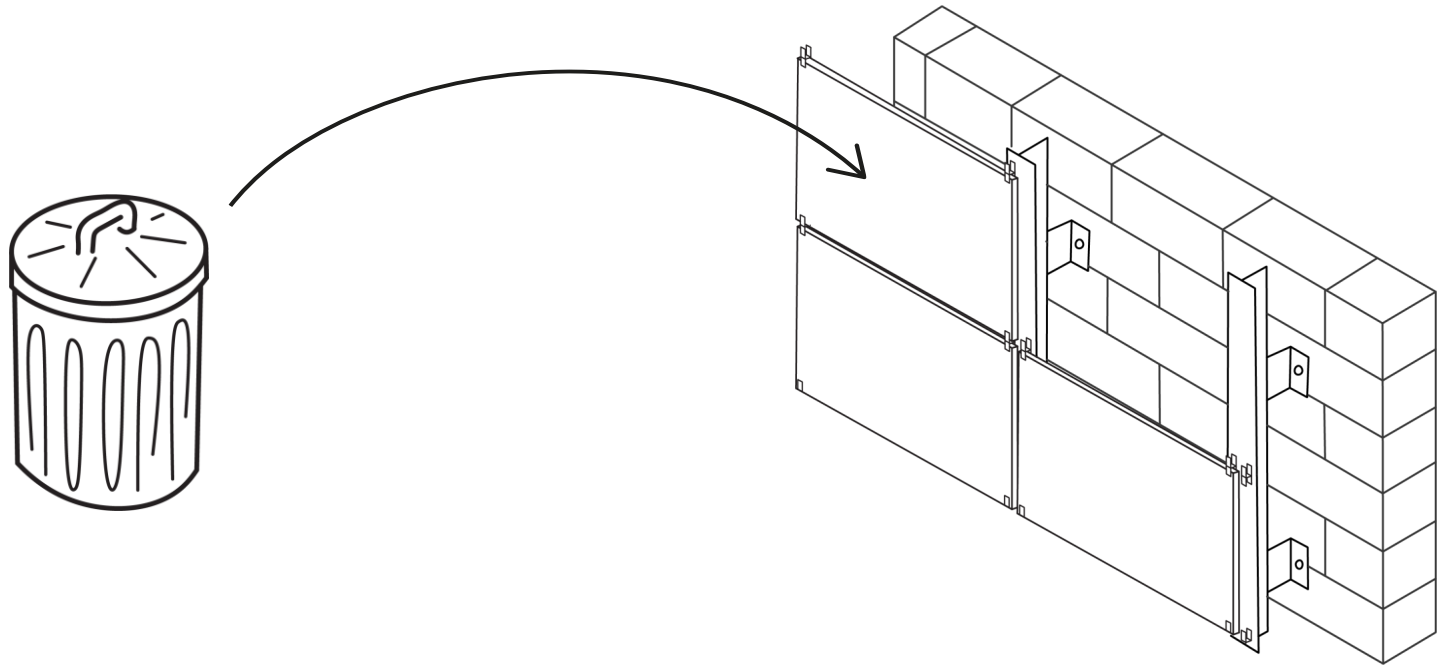
BIO-COMPOSITES FROM FOOD WASTE

Exploring the impact of waste sourced fillers from the food industry on the functional and mechanical characteristics of bio-composites for the possible application as a façade product

LARA NEUHAUS

THE IDEA



WHY IS THAT RELEVANT?

Depletion of
Fossil Resources

Construction Waste
going to Landfills

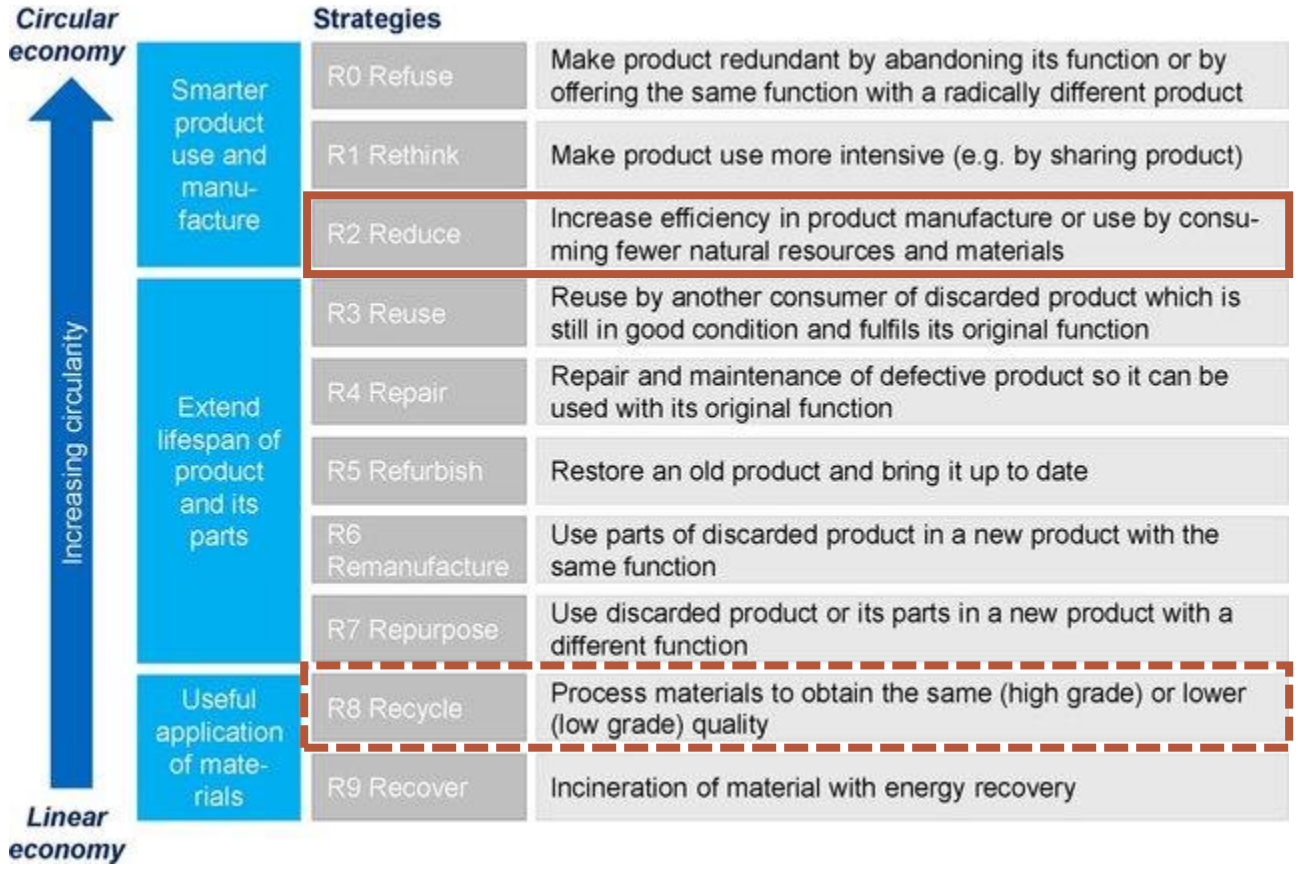
Emission of
Greenhouse-gases

Limited Renewable
Resources

WHY IS THAT RELEVANT?

The benefit of using waste:

- spare materials from landfill
- save on carbon emissions on new materials
- conserve renewable material sources

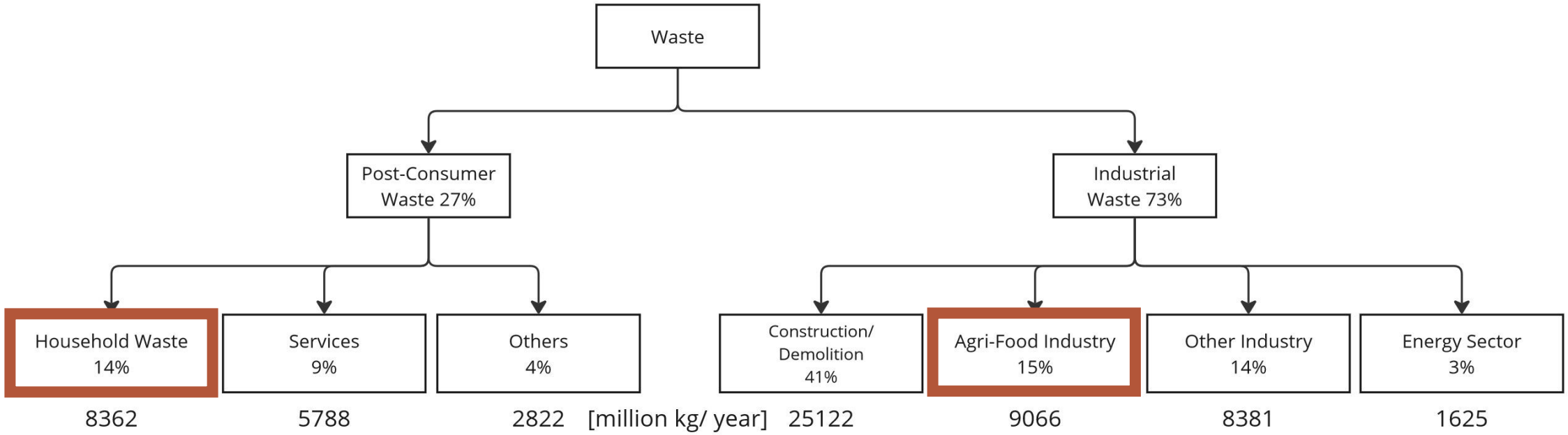


HOW COULD WE DO IT?

Which waste could be used for building materials?

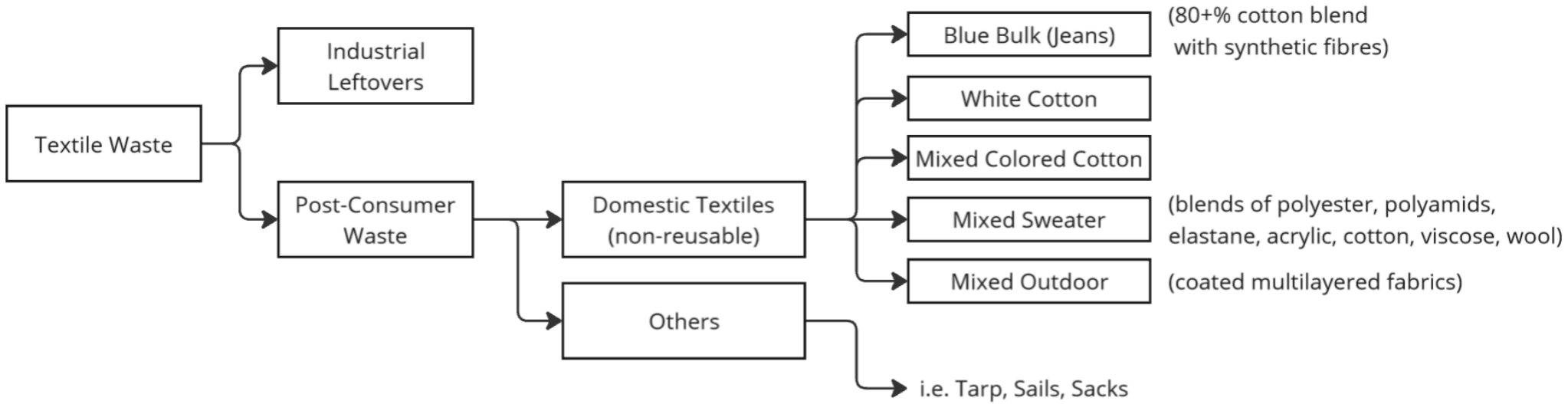
Which building-product could we make with it?

WASTE-STREAMS IN THE NETHERLANDS



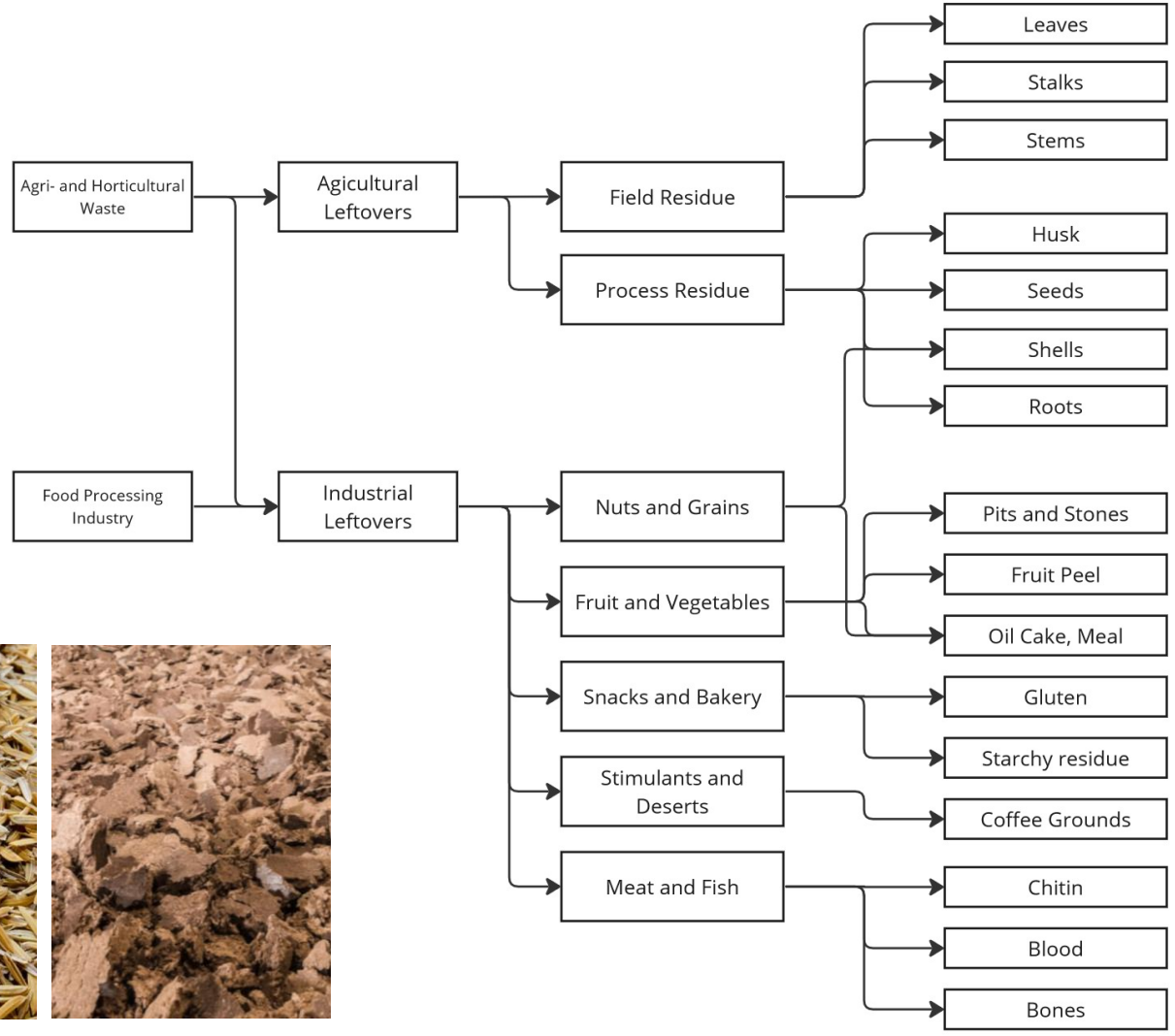
WASTE-STREAM: TEXTILES

- fibres
- variety of waste streams/ materials



WASTE-STREAMS: AGRI-FOOD WASTE

- yearly ~9million tonnes
- bio-based
- various shapes/forms
- steady quantity and quality



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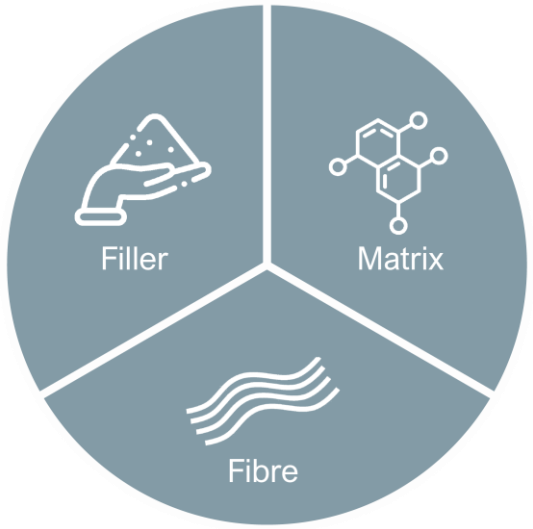
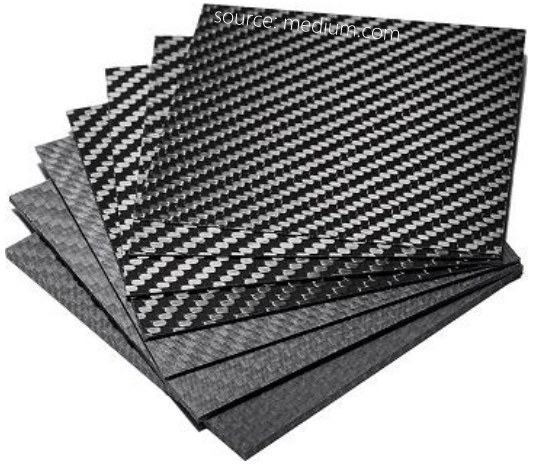
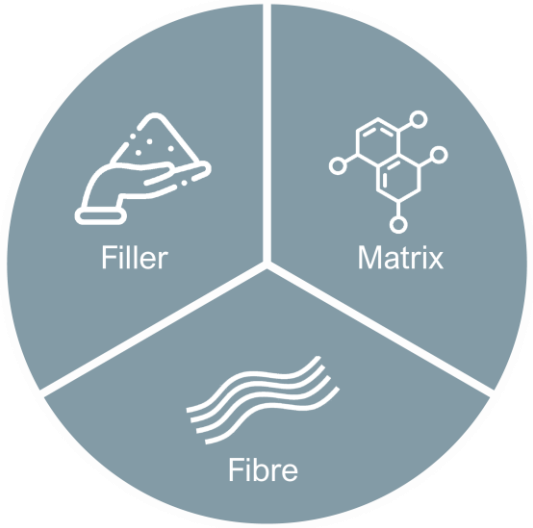
Which building-product could we make with it?

COMPOSITE MATERIALS





BIO-COMPOSITES

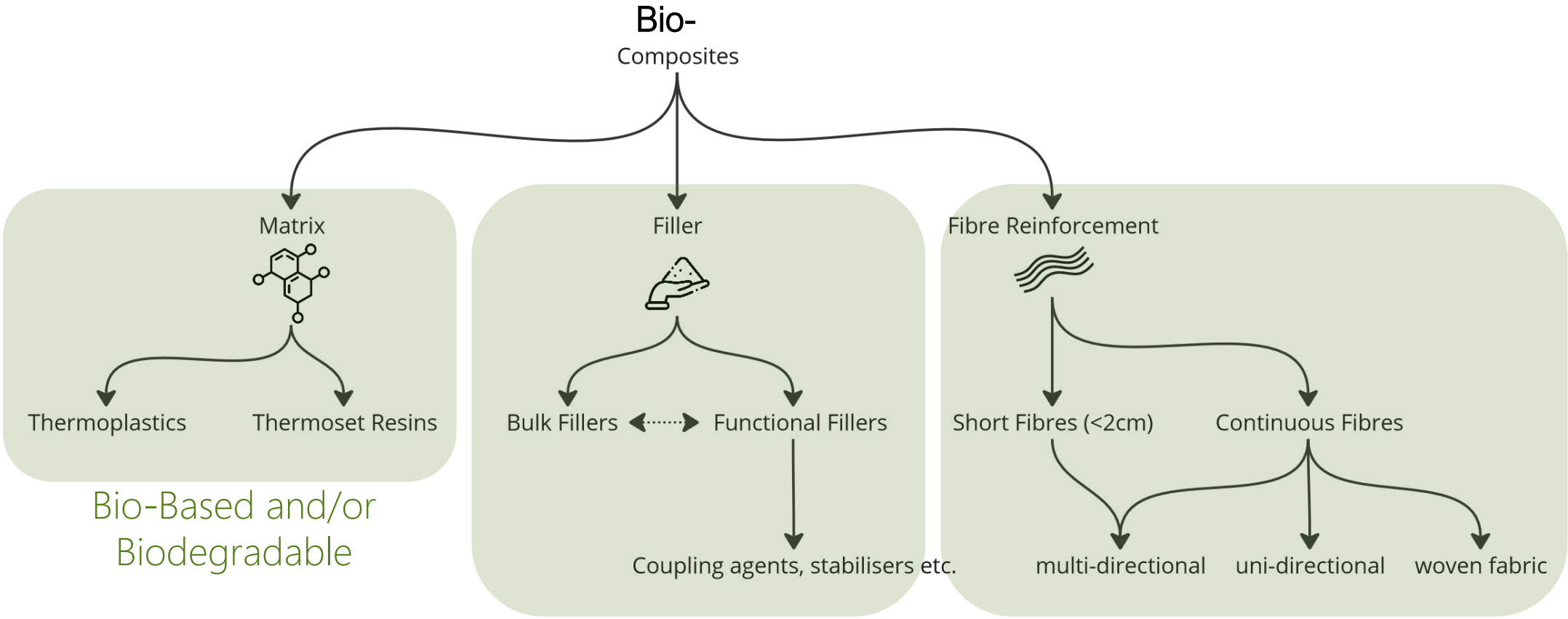



source: goldstab.com


source: natural-resources.canada.ca


source: plasticstoday.com

BIO-COMPOSITES



Bio-Based and/or Biodegradable

Bio-matter

Natural Fibre

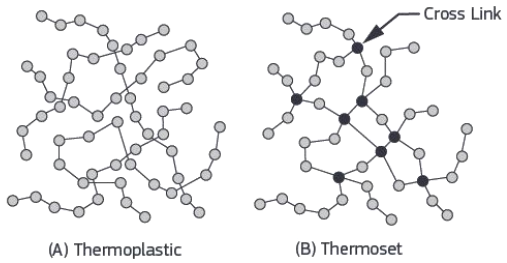
BIO-PLASTIC MATRICES

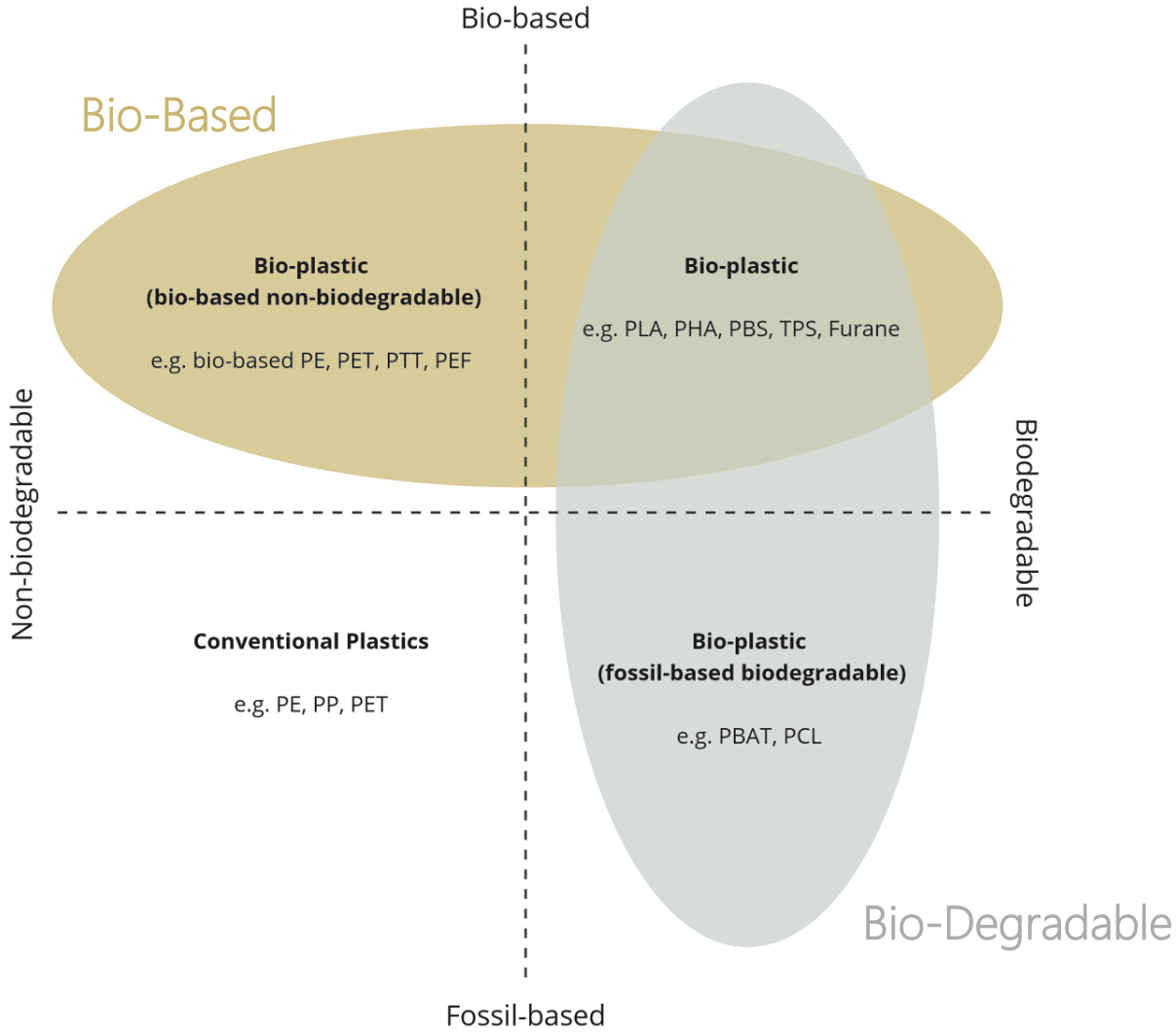
Thermoplastics: (Polypropylene (PP), Polystyrene (PS), Polylactic acid (PLA), PHA, TPS etc.):

- Melt at high temperatures
- Can be remelted

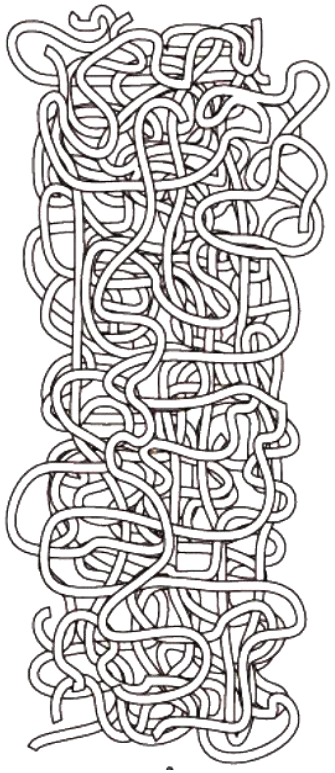
Thermoset Resins: (Polyurethane (PU), Epoxy, Silicone, Furan Resin)

- Liquid Resin solidify at raised temperatures
- Resistant to higher temperatures
- Not re-meltable

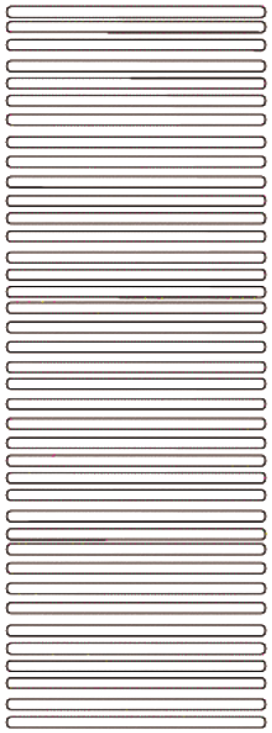




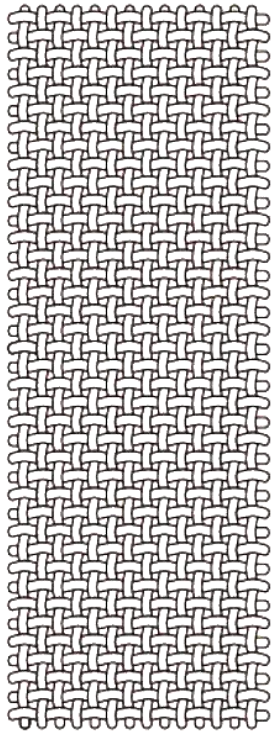
NATURAL FIBRES



Multi-directional



Uni-directional



Bi-directional, woven

Continuous Fibres

Short Fibres

Reed

Wheat Straw

FILLERS

Functional Fillers (<5wt%) used for:

- **Colouring** (pigments, colourants)
- **Fire resistance** (bromine, chlorine, borate and phosphorus)
- **UV resistance** (ultraviolet absorbers, stabilizers)
- **Ease of processing** (waxes, oils, clay, silica)
- **Electric conductivity** (metal powder, carbon particles)

Bulk Fillers (~40-60wt%):

- **Calcium carbonate** (mineral) - from limestone, marble or seashells
- **Kaolin** (mineral) - mined clay
- **Alumina trihydrate** and **Calcium sulphate** (mineral) - frequently used for their flame and smoke retarding properties and low cost

Bio-based alternatives?

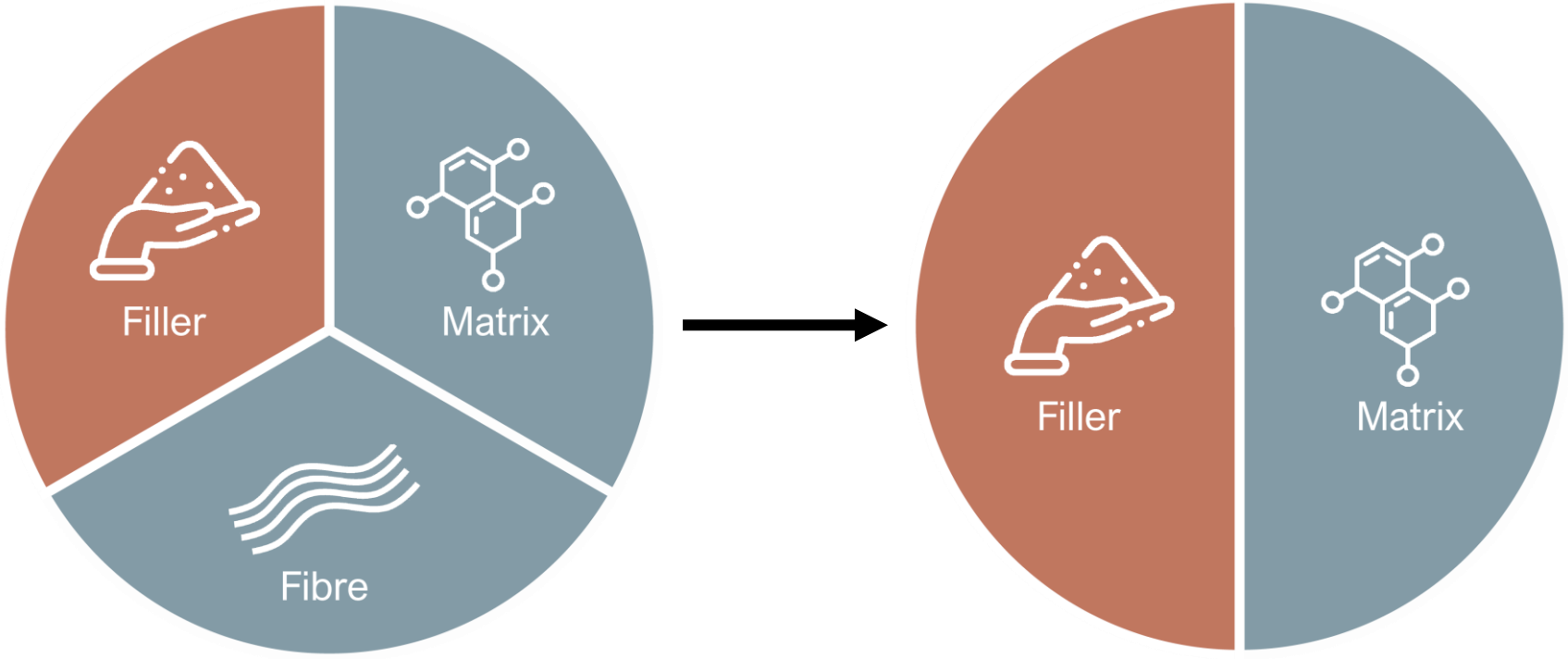
- Wood flour
- Biochar
- Waste-Based Biomatter ???

BIO-COMPOSITES AS A SOLUTION?

Potentials:

- Potential for **low embodied energy**
- Avoiding fossil resources by going **bio-based**
- Highly **engineerable**
- Can include **small particles** (waste)
- New aesthetics and **new design options**

BOUNDARY CONDITIONS

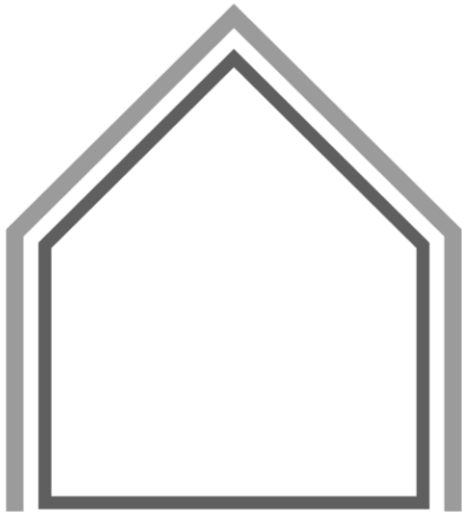


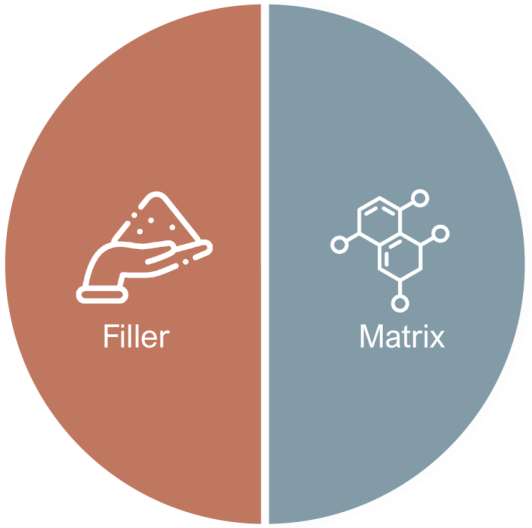
Mono-filler (no fibre)

RESEARCH QUESTION

100% Bio-Based

Partially Waste-Based





RESEARCH QUESTION

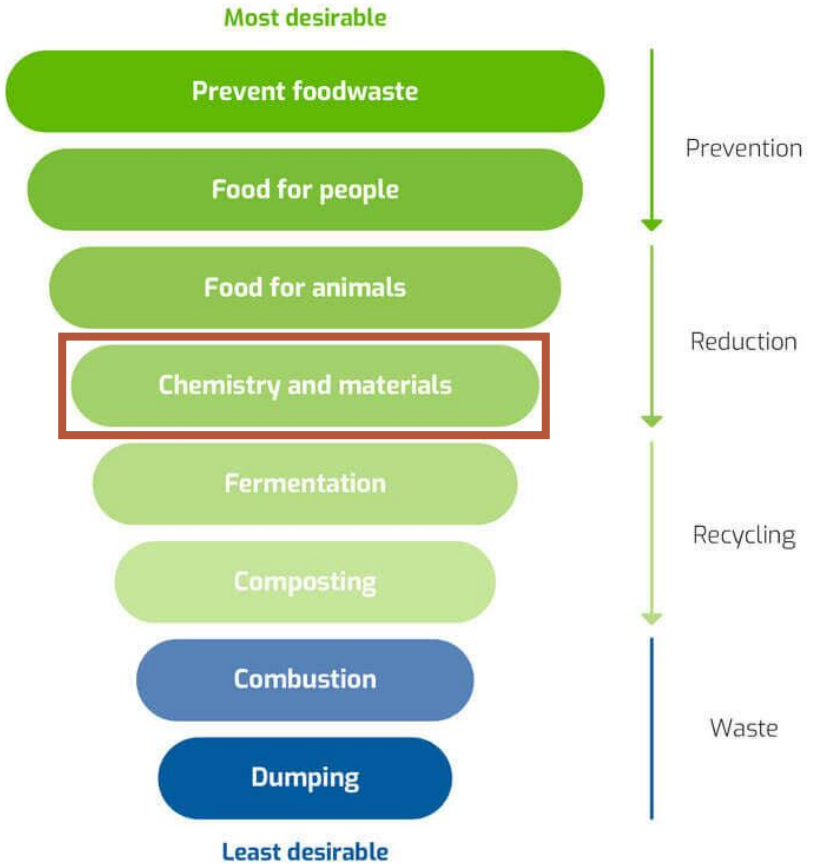
“HOW CAN WE INTEGRATE WASTE-BASED FILLERS INTO BIO-BASED COMPOSITE FAÇADE PANELS?”

THE WASTE

CRITERIA FOR WASTE STREAM SELECTION

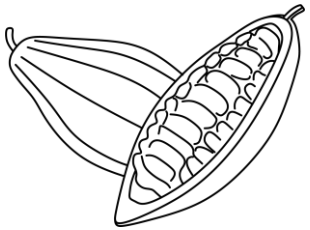
Selection Criteria

- **Locality** (Local availability of processes that produce waste in the Netherlands)
- **Usefulness** of the waste-stream to other functions
- Ease of **Processing** (How much pre-processing is needed and how easy is it to handle?)
- **Scalability** (How much is available, could a stable material flow be established?)



source: sonac.biz

THE SELECTION



1. Cacao-Shells, Raw

Source: Chocolate/Cocoa Industry

Current Uses: Soil Improver, Fuel Pellets

2. Cacao-Shells, Roasted

Source: Chocolate/Cocoa Industry

Current Uses: Soil Improver, Fuel Pellets

THE SELECTION

3. Spend Coffee Grounds

Source: Café Chains, Drinks and Dessert Industry

Current Uses: Composting, Biofuel

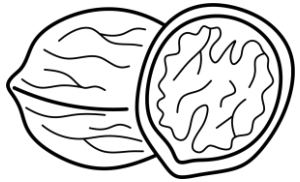
4. De-oiled Coffee Grounds

Source: Industrial Seller (caffe.inc)

Current Uses: Composting, Biofuel

THE SELECTION

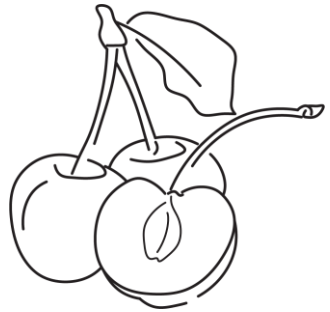
5. Walnut Shells



Source: Bakery and Snack Industry

Current Uses: Incineration, Gardening

6. Cherry Pits

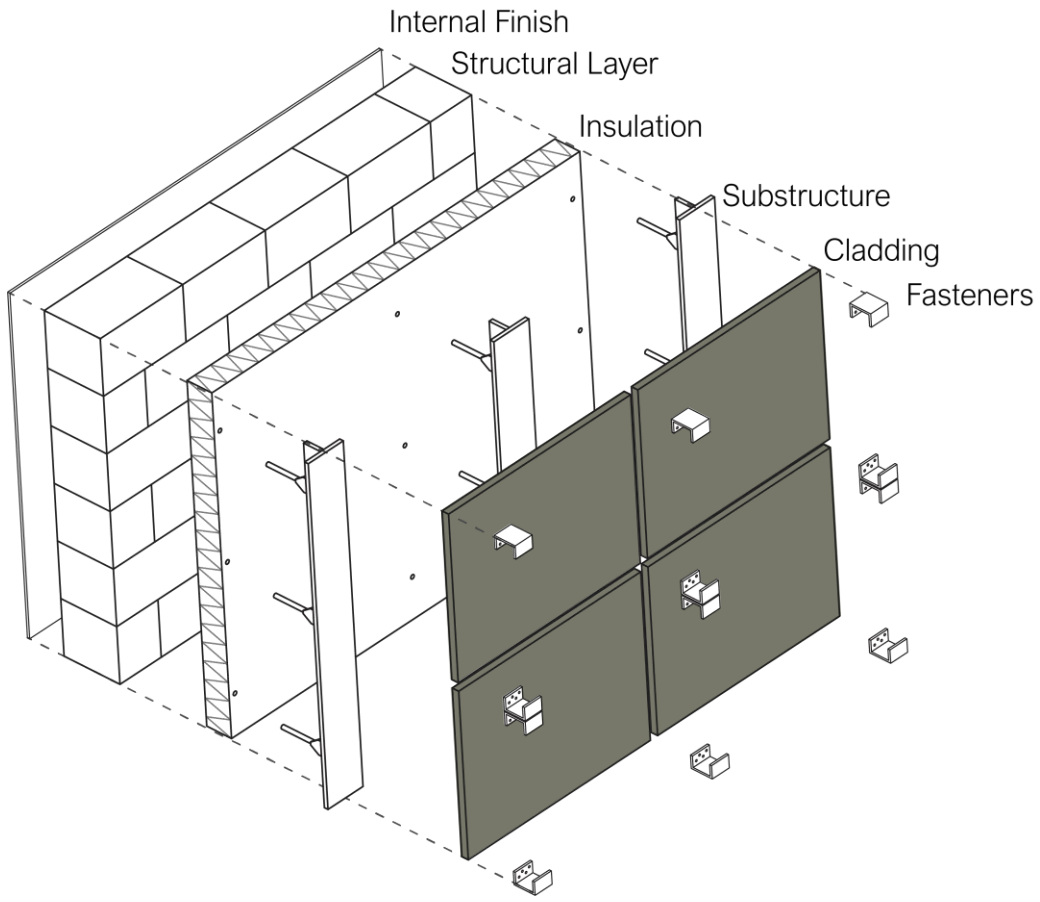


Source: Cultivator or Preserves/Jams Industry

Current Uses: Cosmetics, Incineration

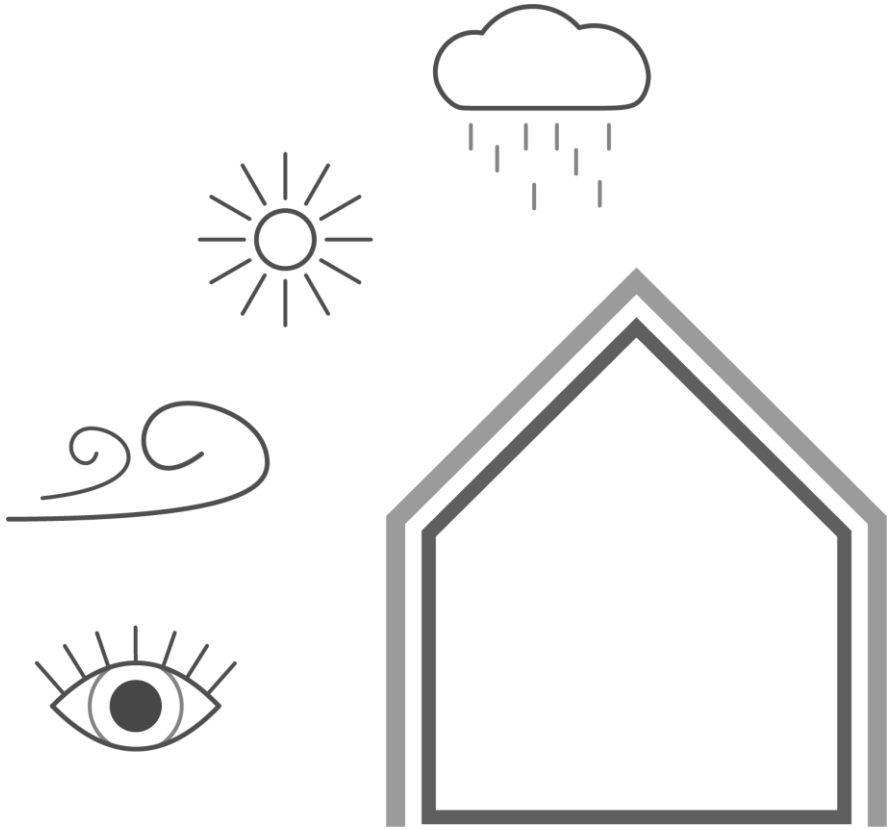
THE APPLICATION

RAINSCREEN FAÇADE CLADDING



RAINSCREEN FAÇADE CLADDING

Exposure:



Requirements:

- **Water/ Humidity** resistance
- Ability to take **wind-loads and self-weight**
- Ability to withstand **impacts** (nature, human caused, weather related)
- **Heat and UV** resistance

THE PHASES OF EXPLORATION

1

Comparing Waste sources as Fillers

Which waste materials have potential as fillers and why?

2

Integration into Composite

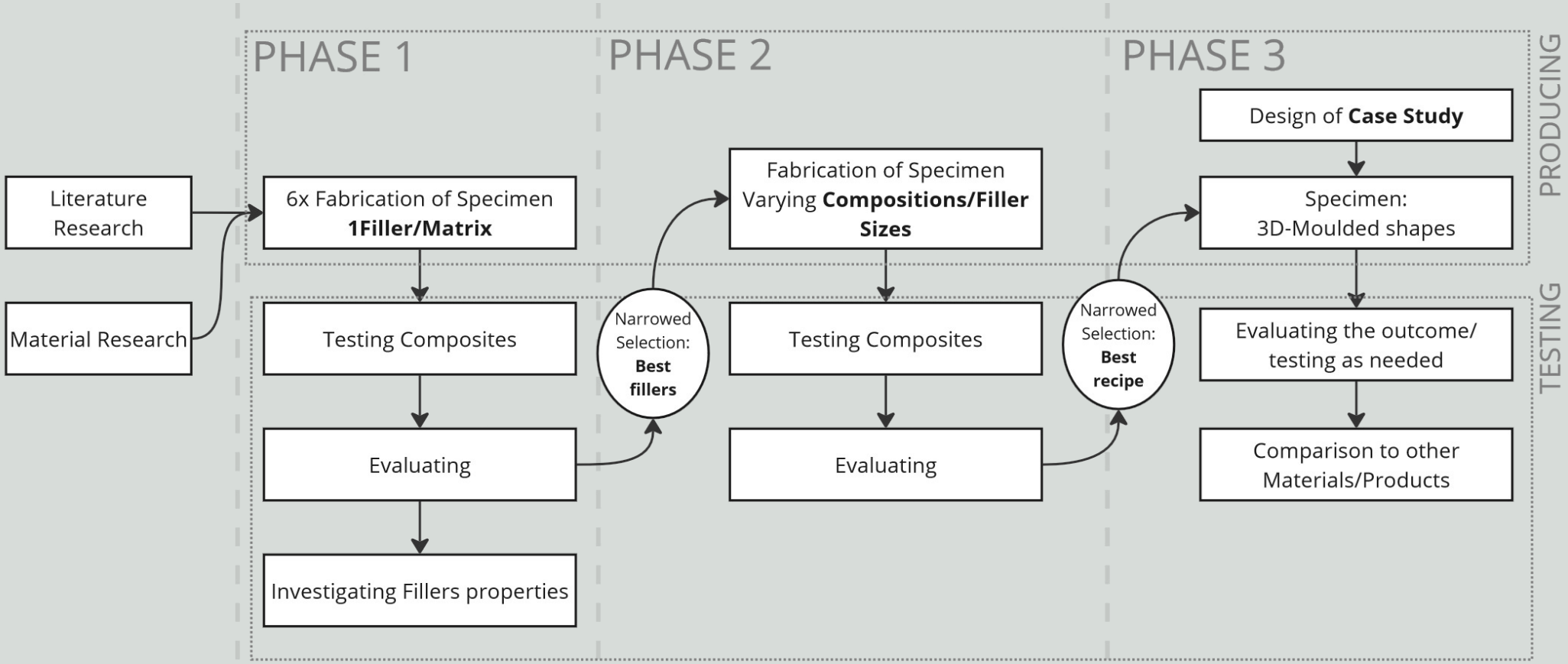
How can we implement the filler in the best way?

3

Composite Façade panelling

How does the material perform as façade panelling?

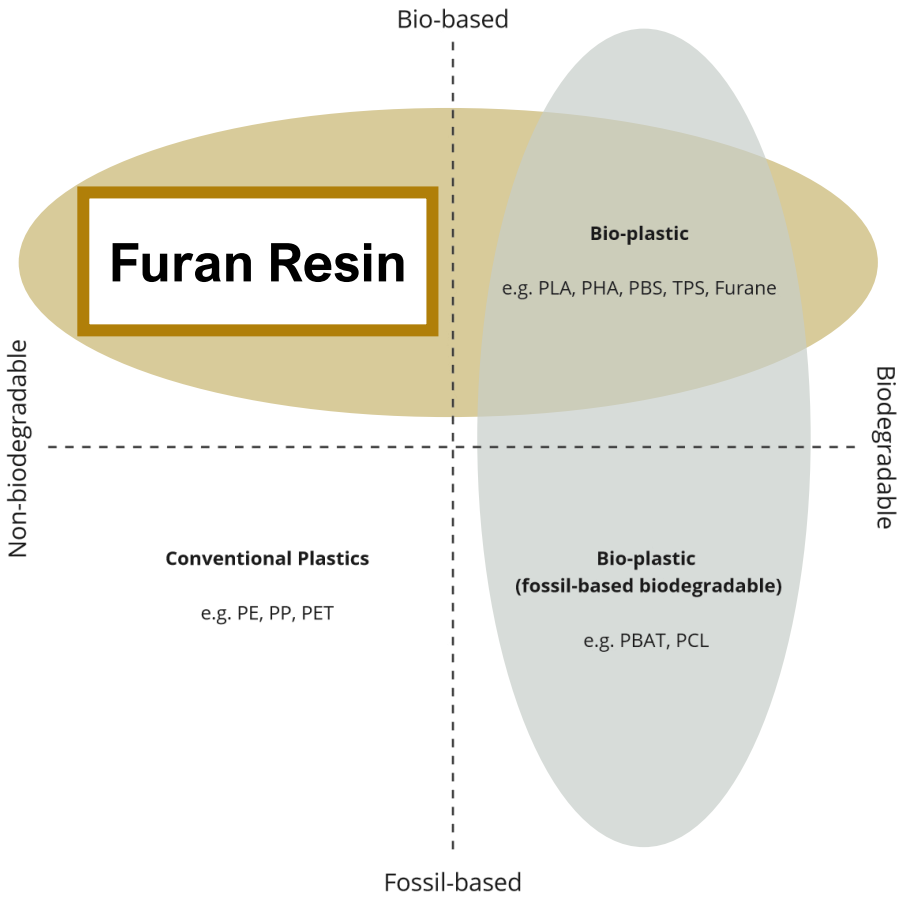
EXPERIMENTS

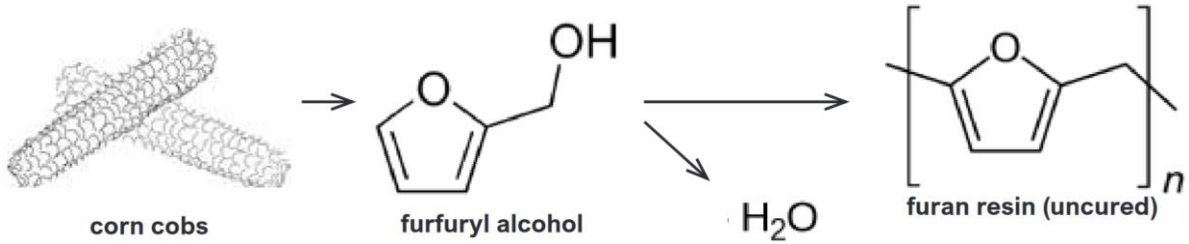


BOUNDARY CONDITIONS

BOUNDARY CONDITIONS: MATRIX

Matrix Choice:



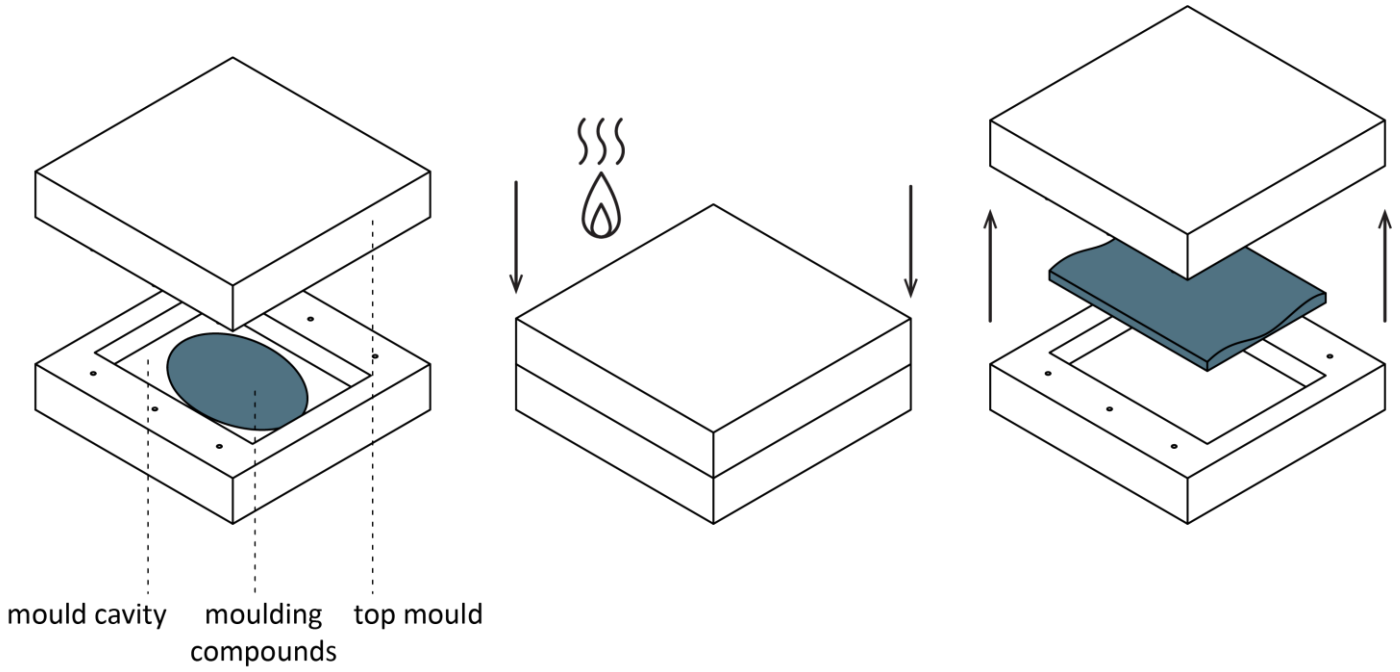


Furan Resin

- bio-based
- not bio-degradable
- dark in colour
- heat resistant

BOUNDARY CONDITIONS: MANUFACTURING METHOD

Manufacturing Technique: Bulk compression moulding



PHASE **1A**: COMPARING THE WASTE-FILLERS

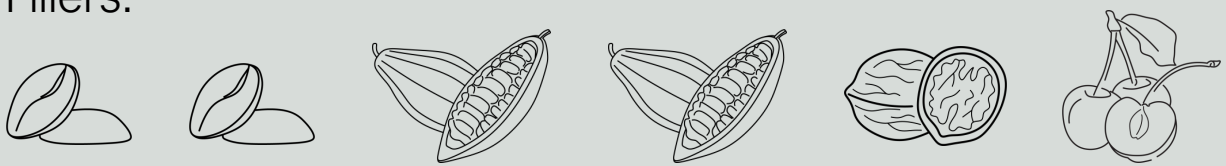
Question to be answered:
Which waste materials work well as fillers in a bio-composite?
How do the different materials compare?

Samples:
One plate of each filler type

Processing Method:
Compression moulding

Synthesis:

Fillers:



deoiled | spend coffee | roasted | raw cacao shells | walnut shells | cherry pits

Component	Description	Weight %
Resin	Furan resin	50
Filler	Powdered filler, **<125 µm**	45
Catalyst	HM1448 ((2-hydroxyethyl) ammonium nitrate)	3
Releasing Agent	Linseed oil	2

1A

PHASE **1A**: COMPARING THE WASTE-FILLERS

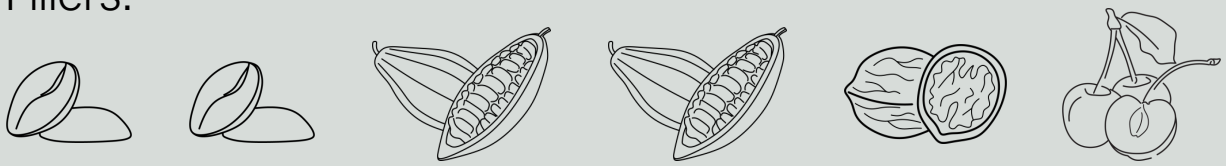
Criteria of evaluation:
Mechanical and functional Properties (testing),
Ease of material processing

Testing:

bending | impact | absorption | frost resistance

Synthesis:

Fillers:



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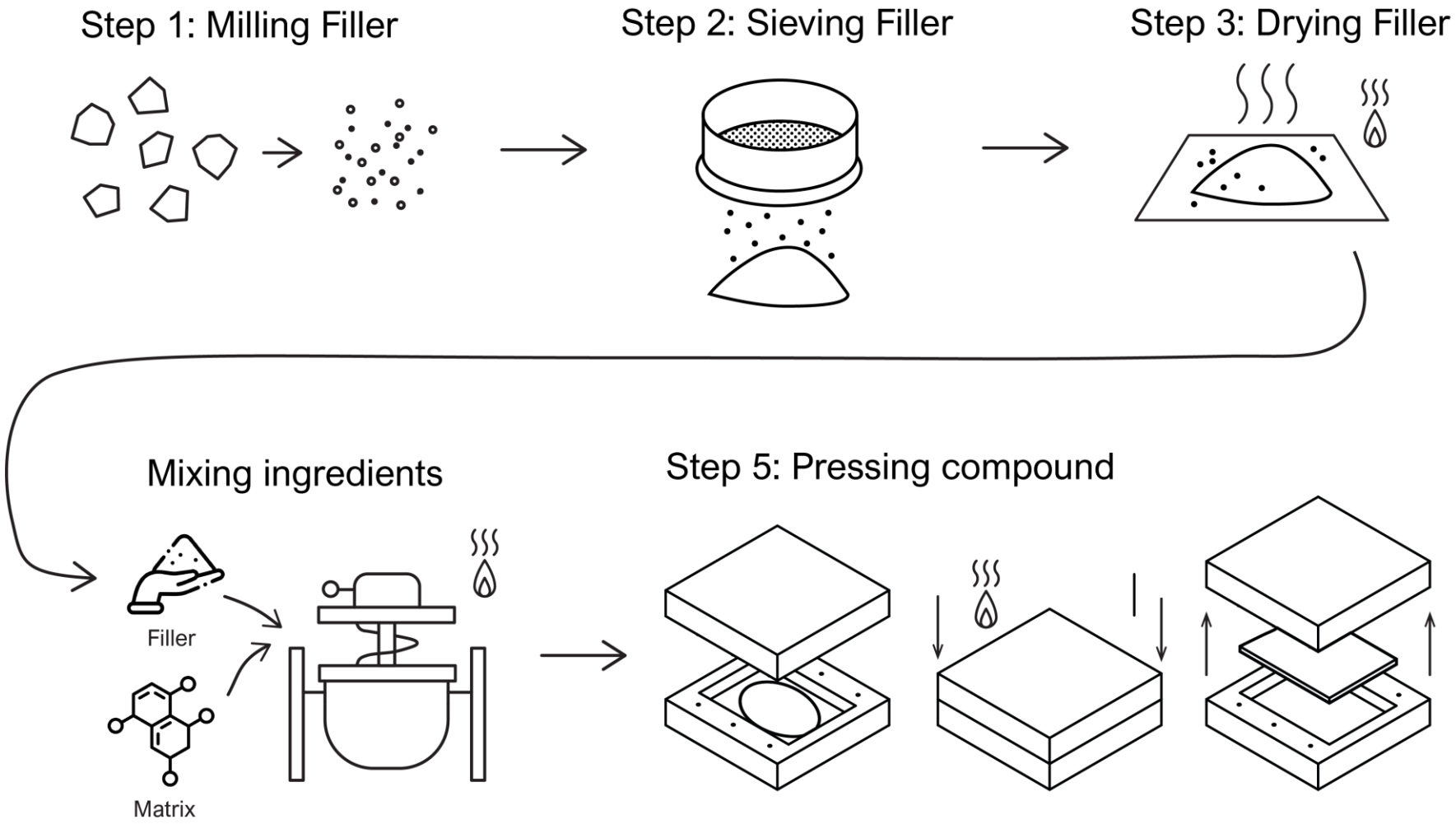
1A

SAMPLE PREPARATION



1A

SAMPLE PREPARATION

Step 1: Milling Filler Material

Step 2: Sieving Filler

Step 3: Drying Filler

at npsp 1A

SAMPLE PREPARATION

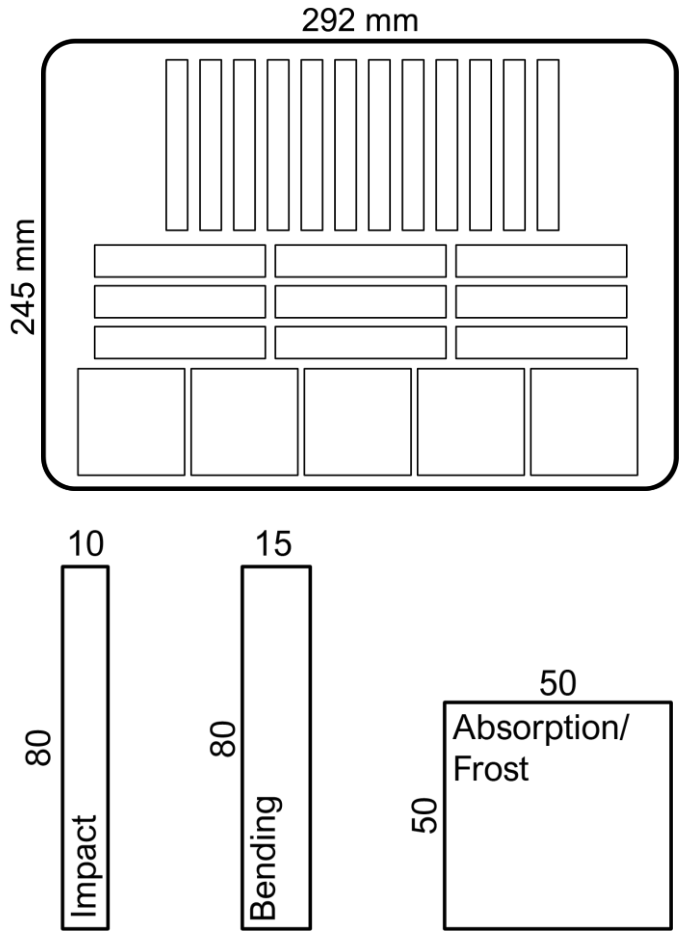
Step 4: Mixing

Step 5: Pressing

at npsp 1A

SAMPLE PREPARATION

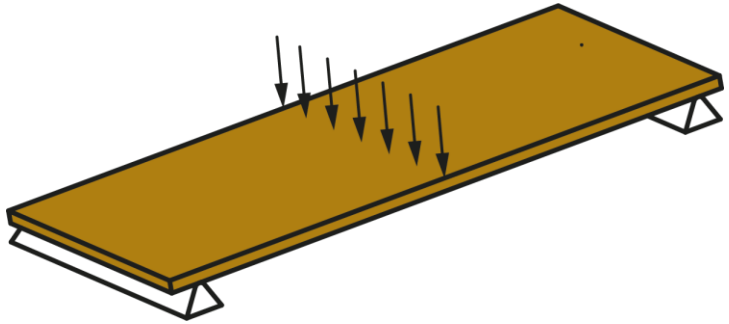
CNC-Cutting Samples



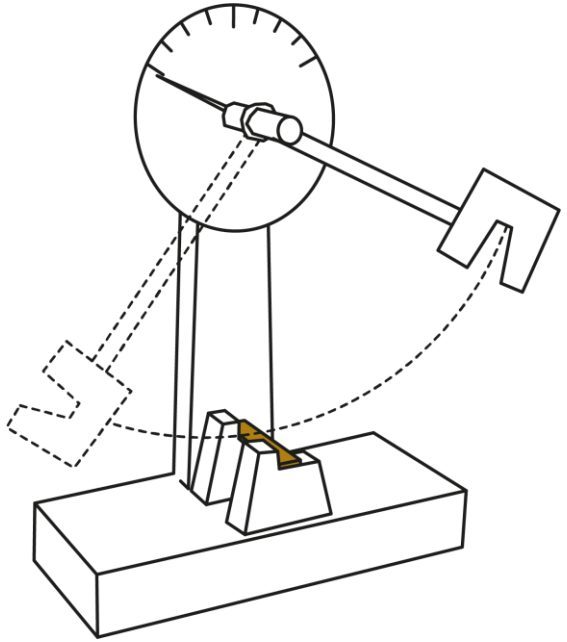
1A

PHASE 1A - TESTING

3-Point Bending (ISO 14125A)



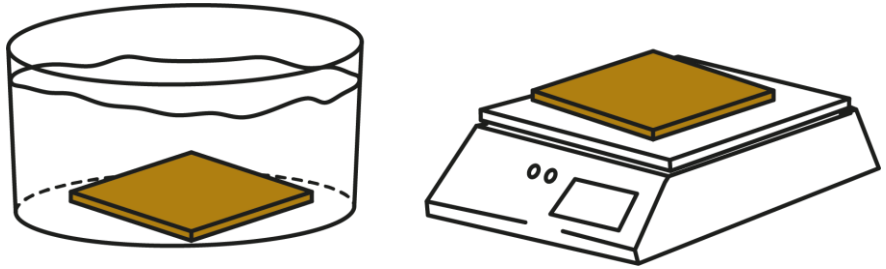
Charpy Impact test (ISO 179)



1A

PHASE 1A - TESTING

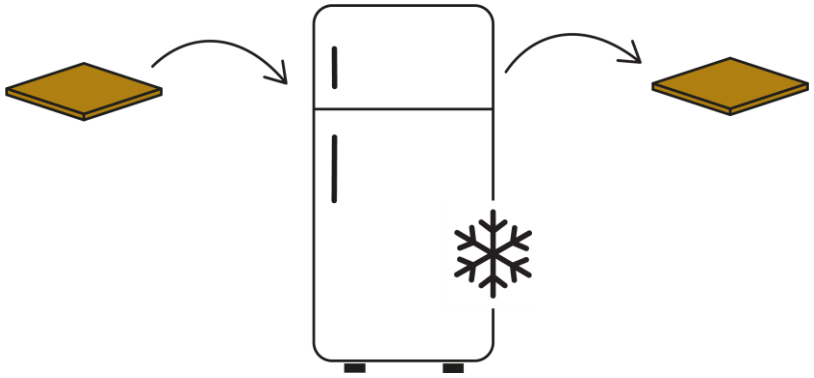
Water Absorption



Time intervals:

24h **x 28 days**

Frost Resistance



Time intervals:

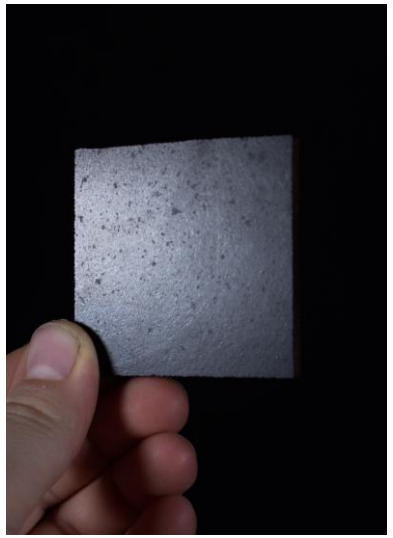
8h / **4h** **x 10 cycles**

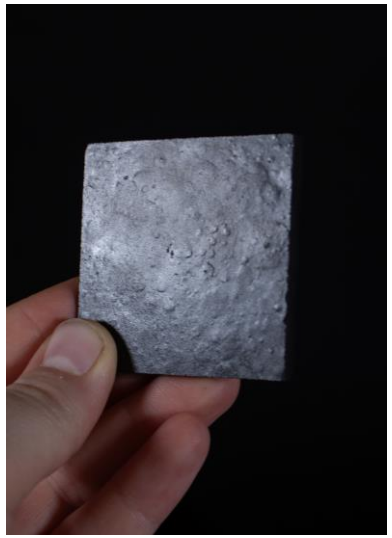
Freezing (-17°C) Thawing (20°C)

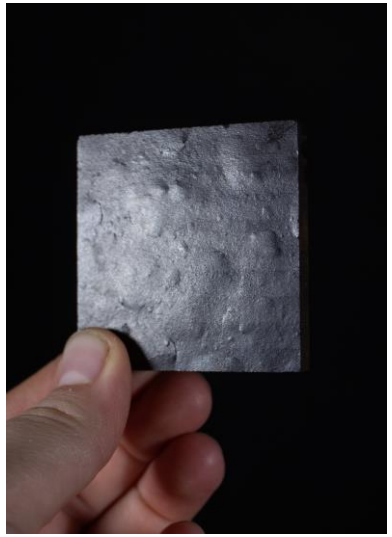
1A

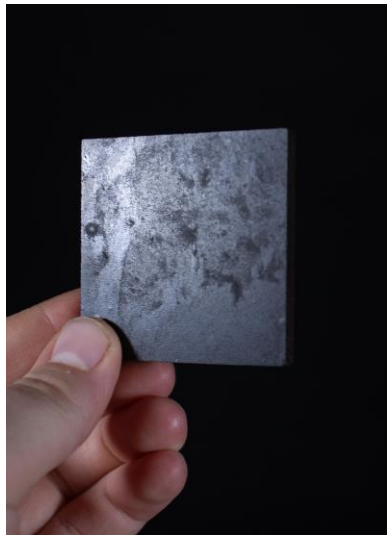
PHASE 1A - OUTCOME

Surface Texture



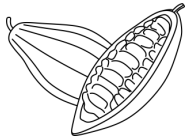




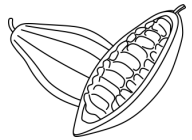


deoiled coffee

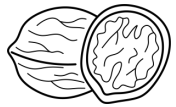
spend coffee



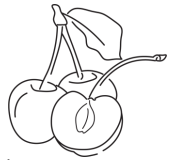
roasted cacao shells



raw cacao shells



walnut shells

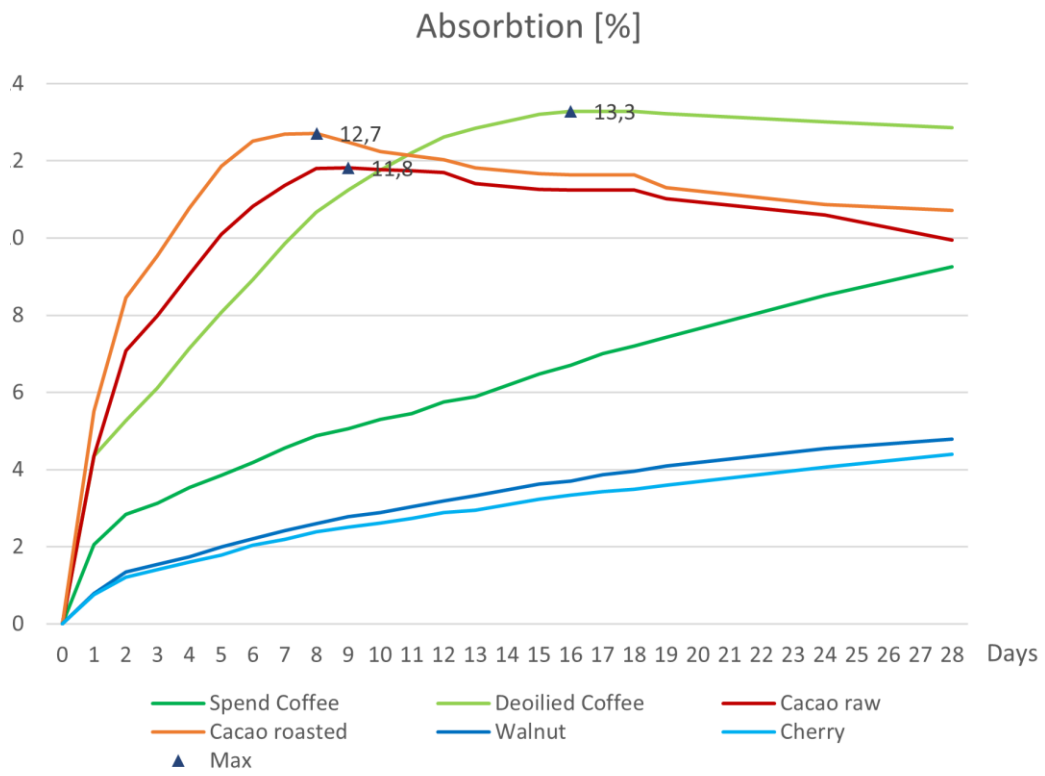


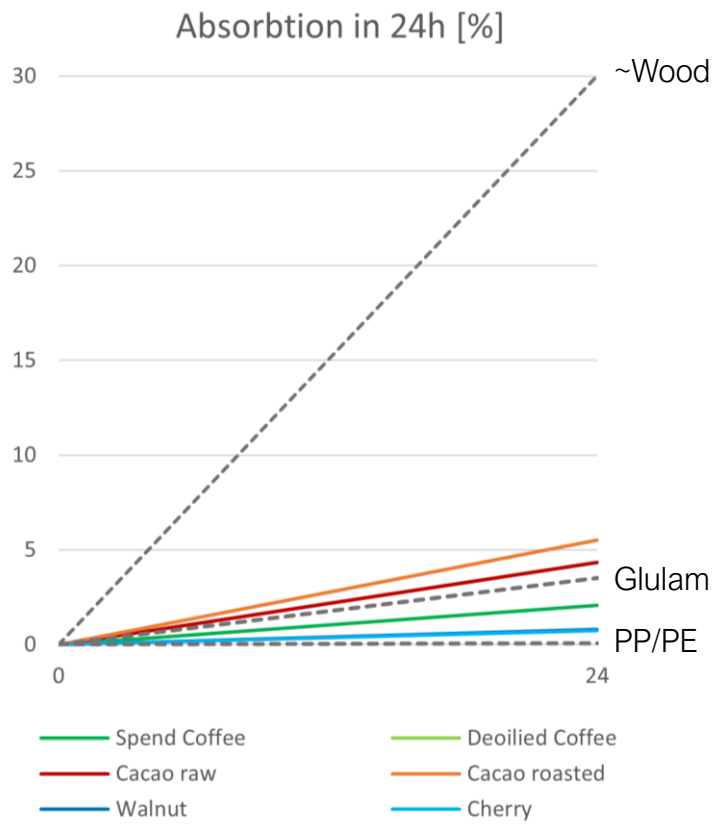
cherry pits

1A

PHASE 1A - OUTCOME

Absorption

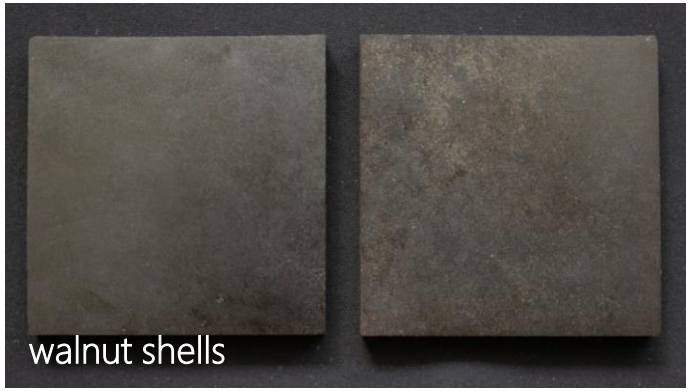


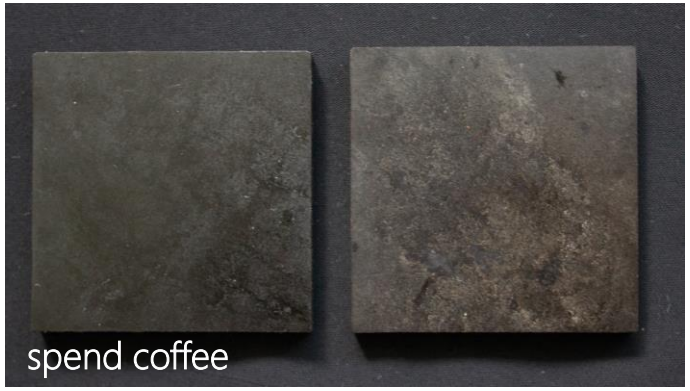


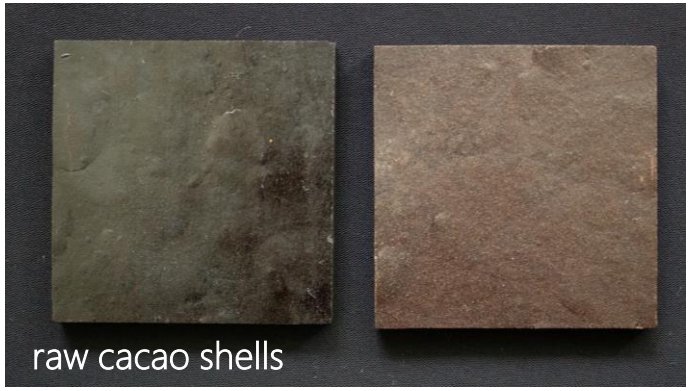
1A

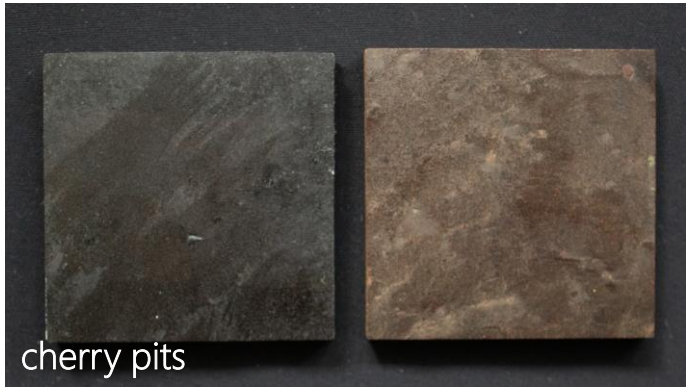
PHASE 1A - OUTCOME

Visible change after 10 freeze cycles (right)





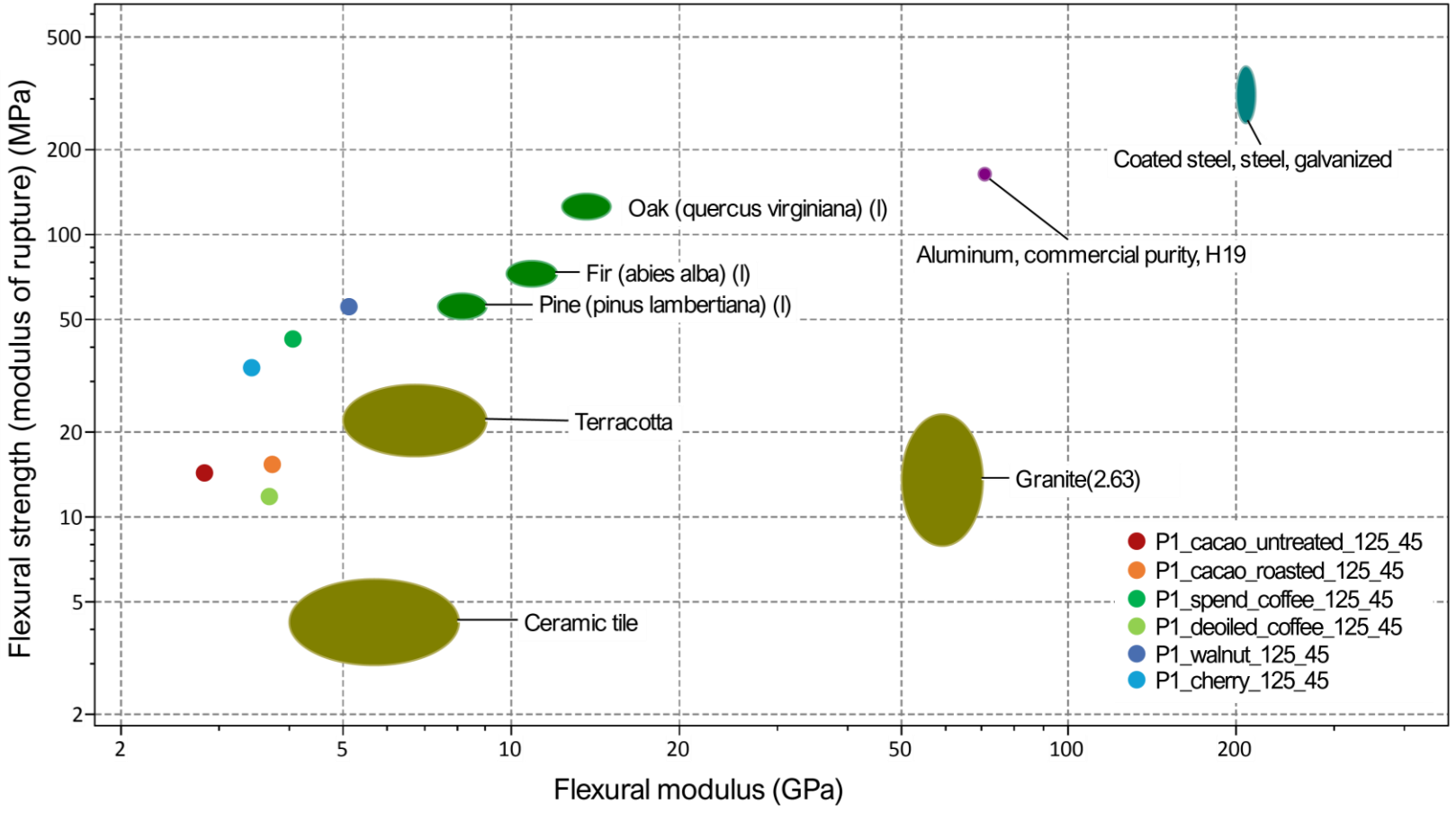




1A

PHASE 1A - OUTCOME

Mechanical Properties



1A

PHASE **1B**: COMPARING THE WASTE-FILLERS

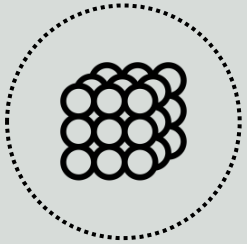
Question to be answered:
Which factors might influence filler compatibility?
What causes bumps and cracks?

Possible cause of Bubbles and cracks?

- Inadequate mixing
- Inherent moisture
- Thermal expansion mismatch with the resin
- Dispersion problem leading to air pockets

Wettability

Density



Powder analysis

Fracture analysis

1B

PHASE 1B - DENSITY

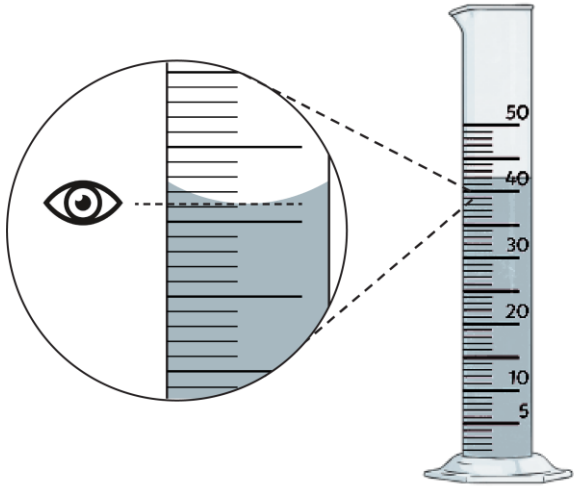
Measuring Material Volume/ Density

Filler	Average Measured Density [kg/m³]
Cacao, untreated	1070,1
Cacao, roasted	1100,0
Spend coffee grounds	1088,5
Deoiled coffee grounds	1117,3
Walnut shells	1469,6
Cherry pits	1145,1

Furan resin (TFC Biorez)	1210

Density [kg/m³] = W/(V_1- V_0)

V_1: Volume water + filler; V_0: Volume water

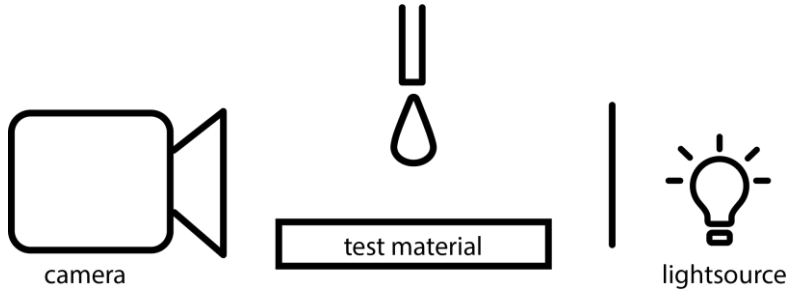


Material	Density [kg/m³]
Calcium carbonate	2650- 2710
Kaolin	2500- 2620
Oak (hardwood)	890- 1080
Pine (softwood)	360- 440
Aluminium	2680- 2740
Steel	7800-7900

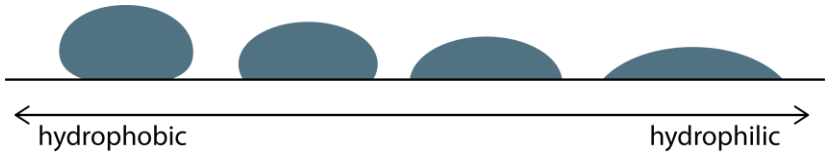
1B

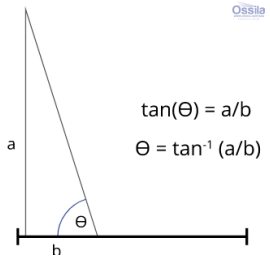
PHASE 1B – CONTACT ANGLE

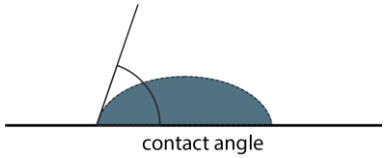
Testing Contact Angle of the powdered Filler

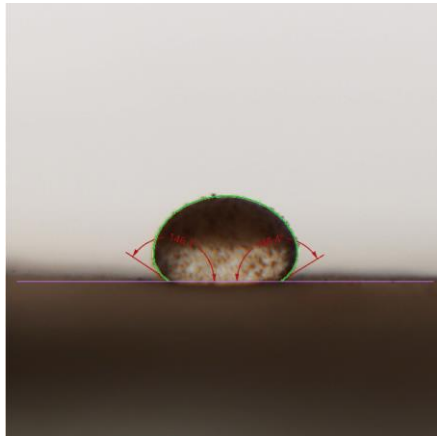


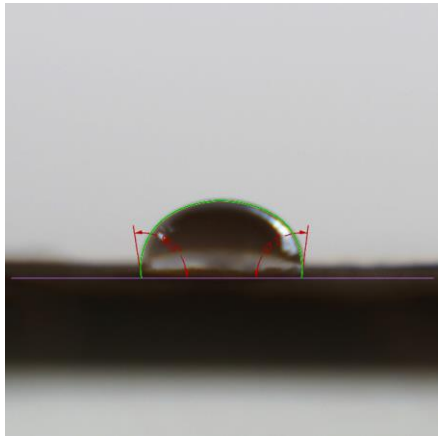
Filler	Contact angle	Deviation
Spend coffee	137,6°	9,7°
De-oiled coffee	122,5°	7,5°
Cacao, raw	126,9°	9,0°
Cacao, roasted	109,7°	8,2°
Walnut shell	100,7°	2,9°
Cherry pits	101,3°	5,3°







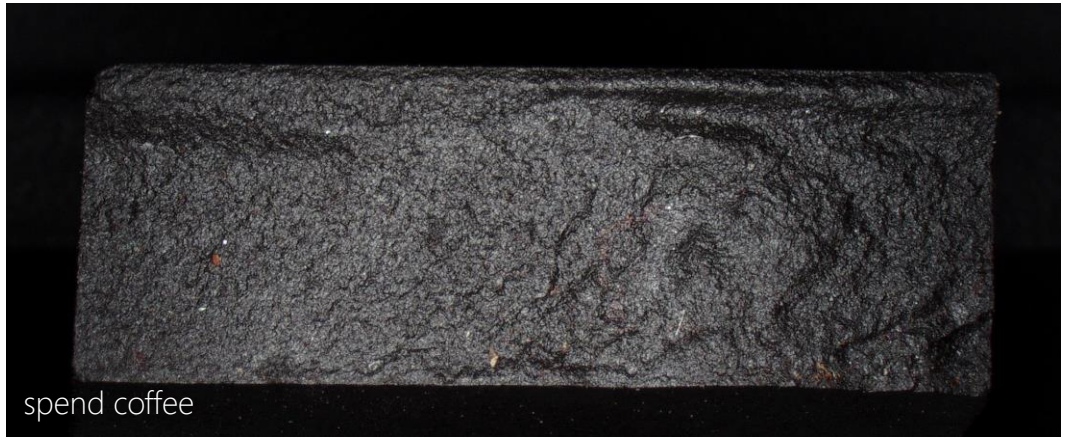


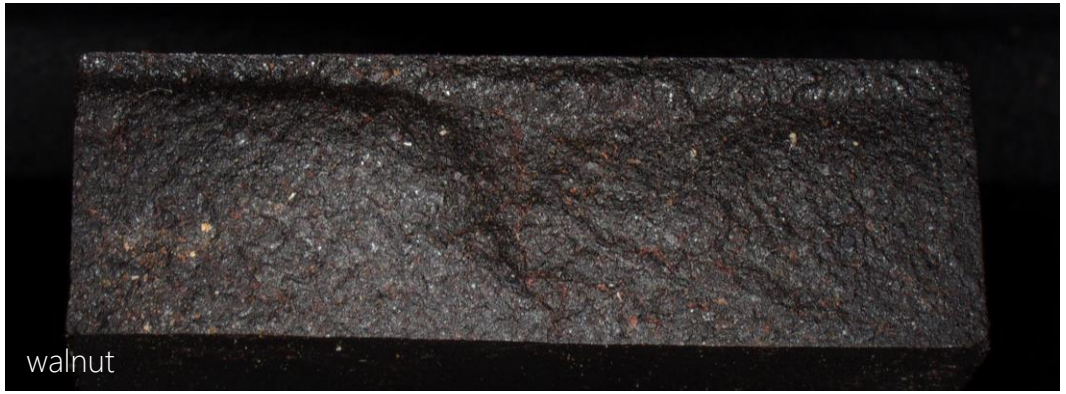


1B

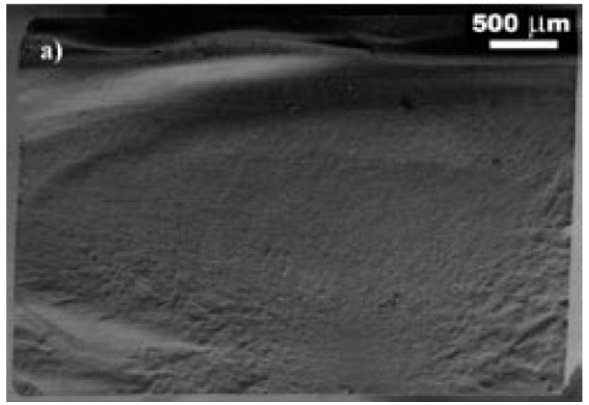
PHASE 1B – FRACTURE PATTERNS

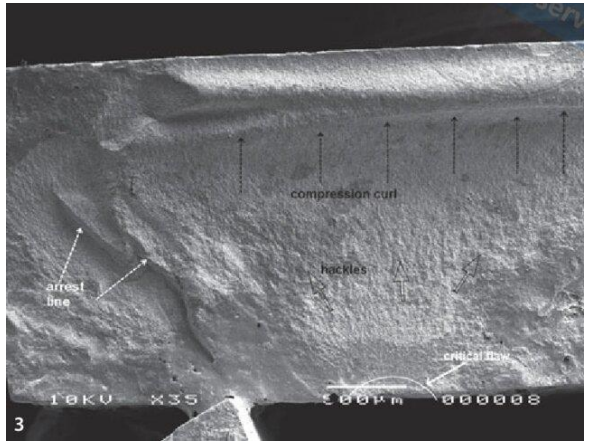
Failure mode:





Break patterns of high strength ceramics:



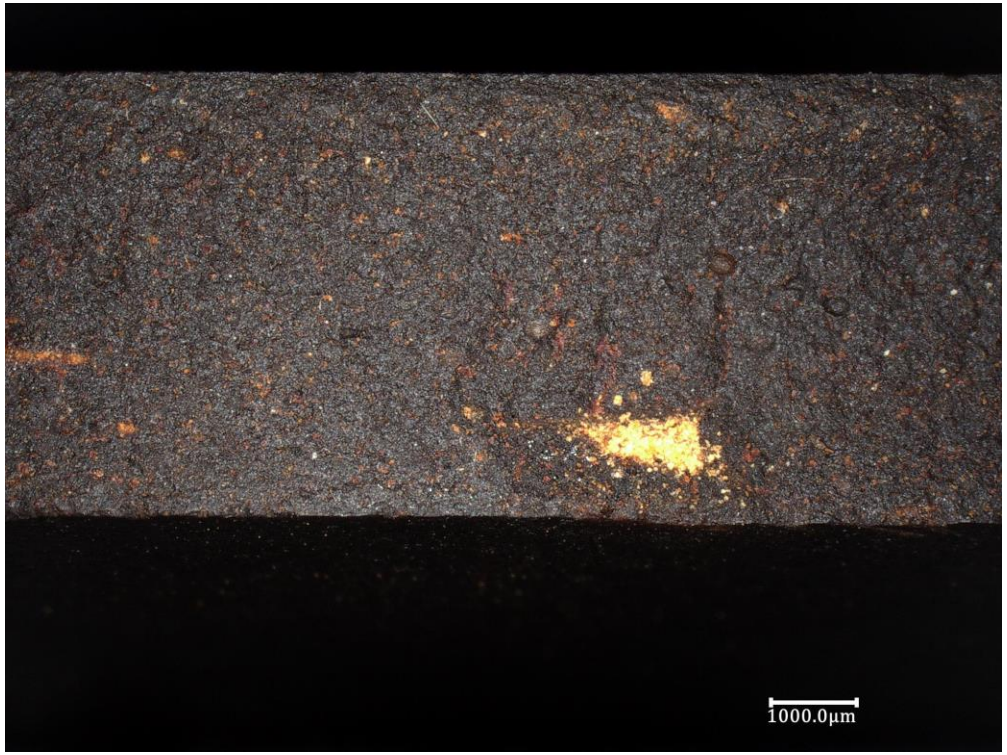


(top) Baudín & Bueno (2007); (bottom) Rizzante et al.(2020)

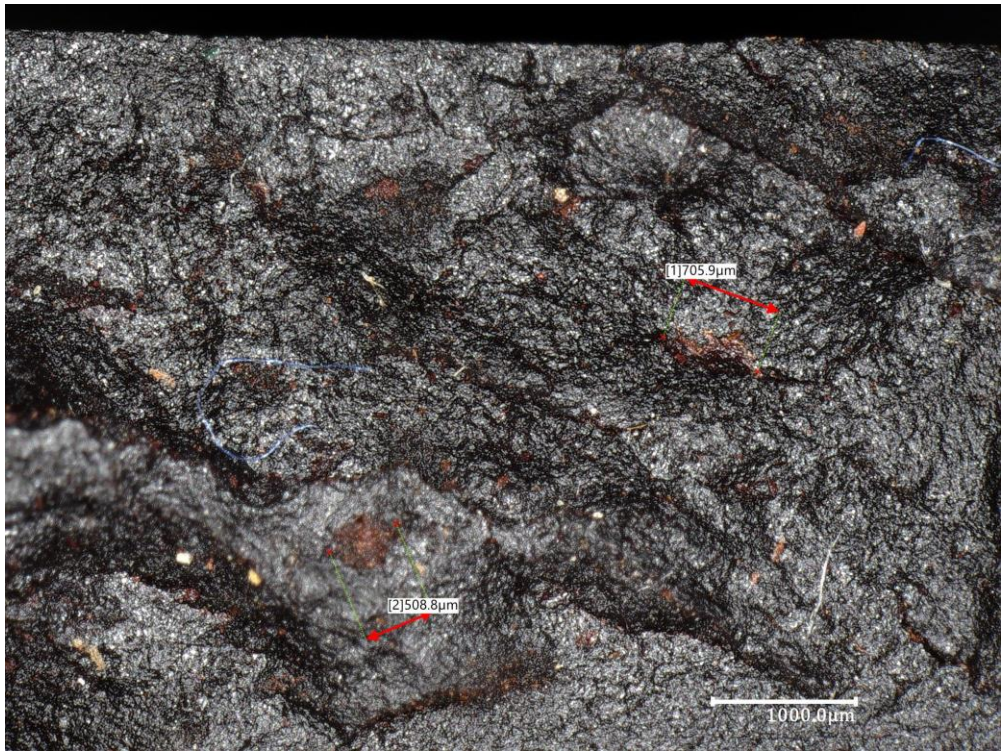
1B

PHASE 1B – FRACTURE PATTERNS

Mixing problems



Cherry pits

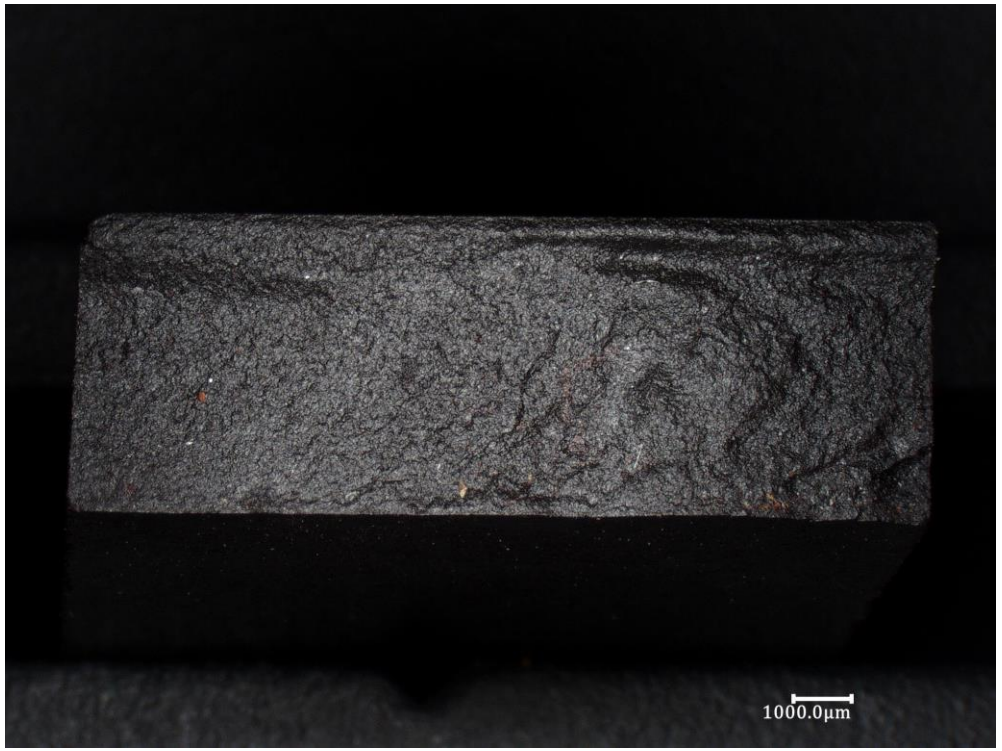


Deoiled coffee

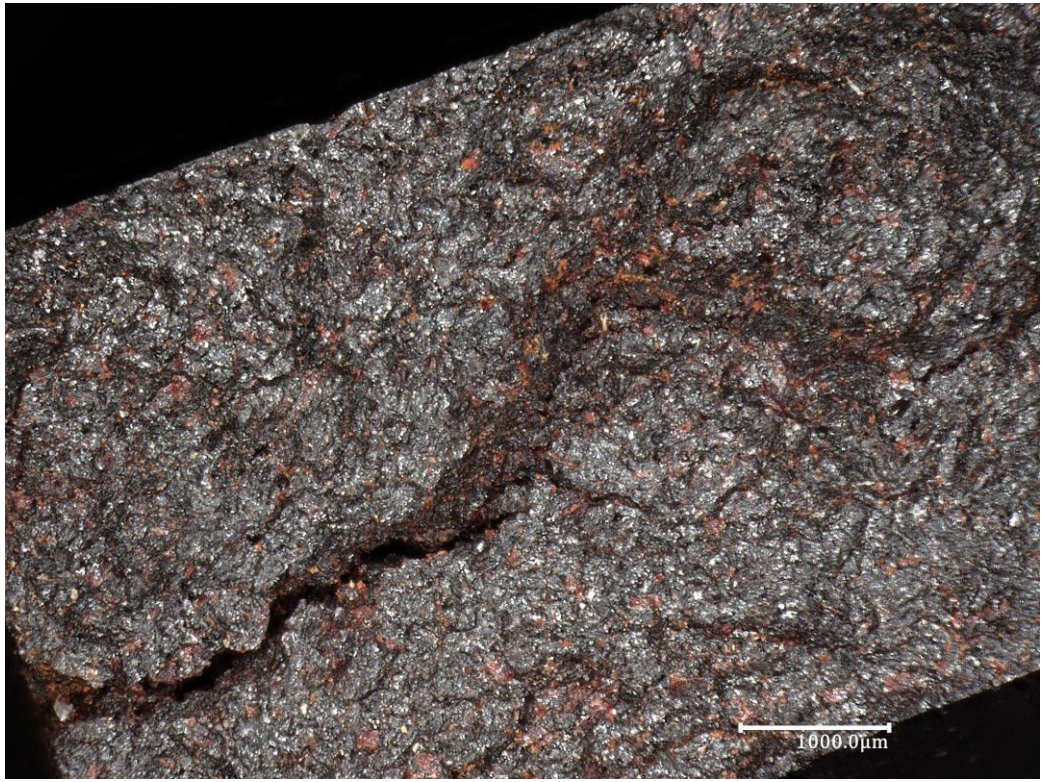
1B

PHASE 1B – FRACTURE PATTERNS

Surface smoothness



Spend coffee

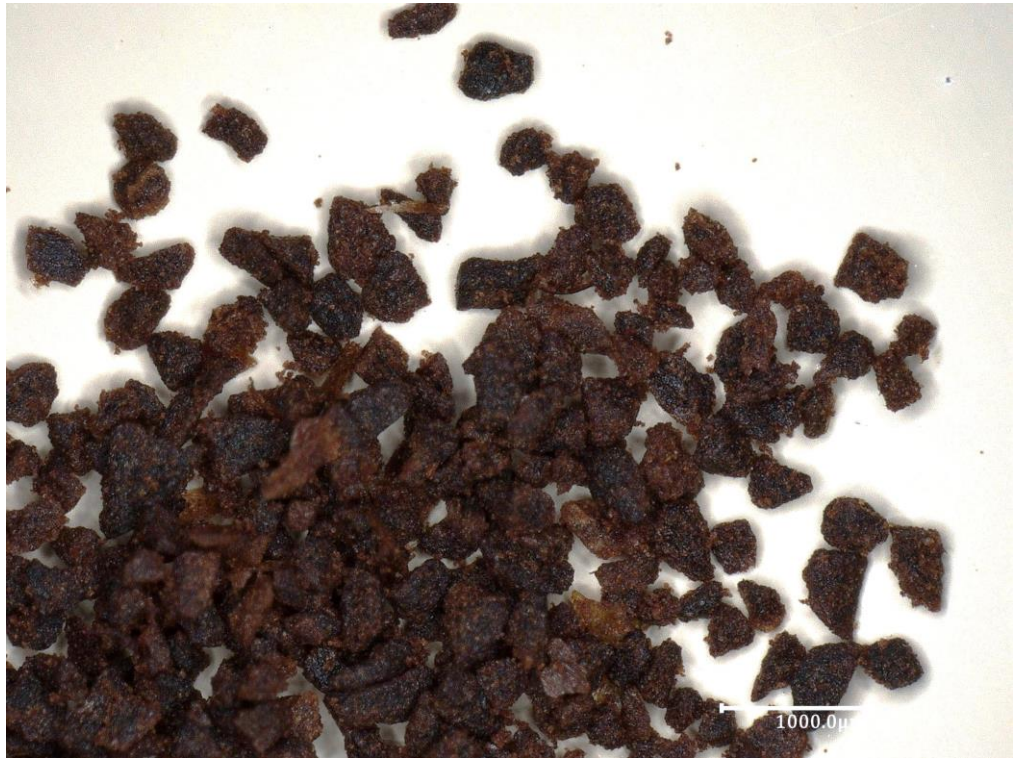


Raw cacao shells

1B

PHASE 1B – POWDER

Different particle shapes and size composition



coffee spend, <500µm

walnut, <500µm

1B

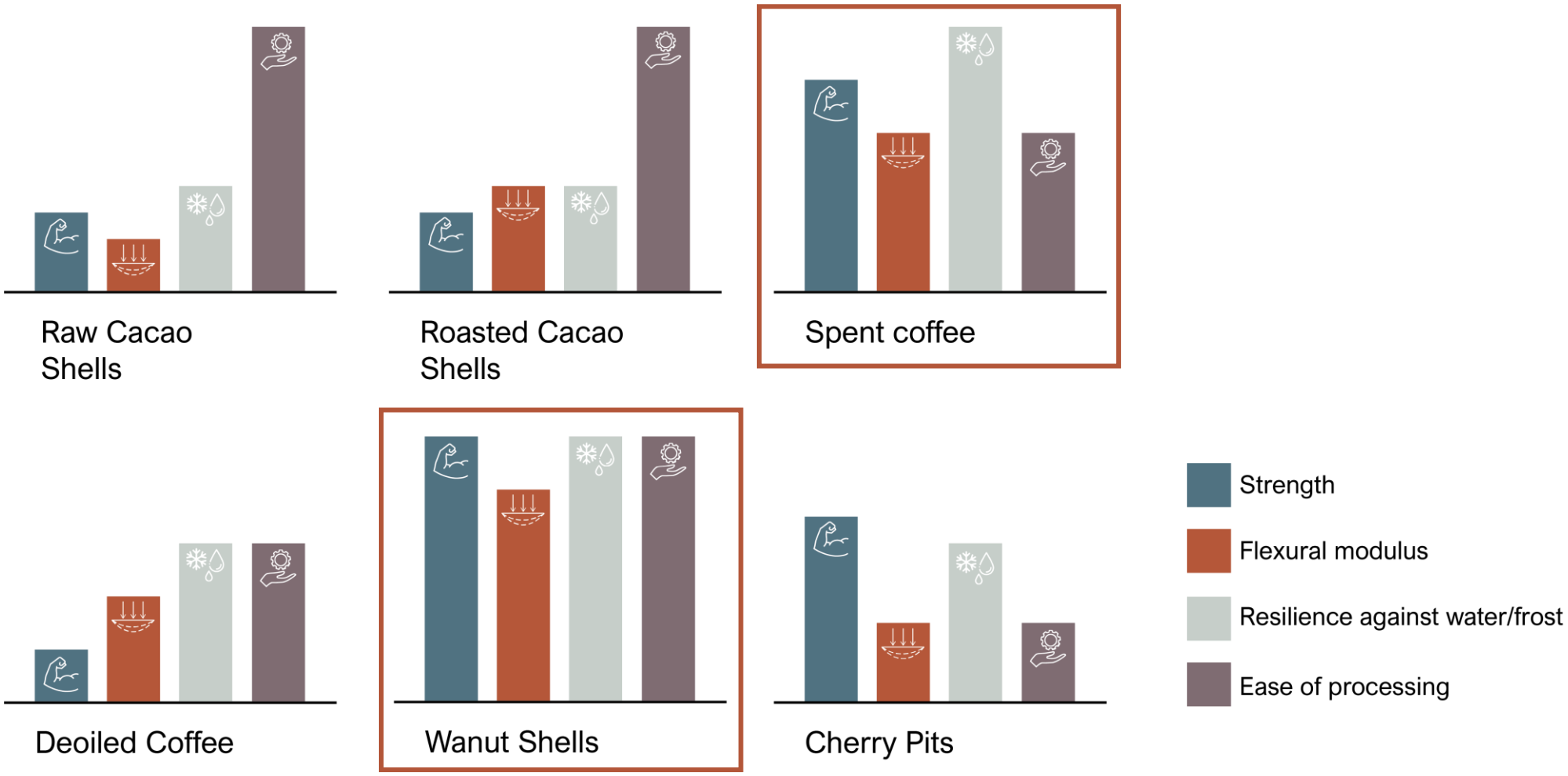
PHASE 1B - OUTCOME

Findings:

- Fracture behaviour comparable to **ceramics**
- Different **grain shapes** for different fillers
- Bio-based fillers are much more **lightweight** than mineral fillers
- All powders reacted **hydrophobic**
- The least hydrophobic the better mechanical performance was
- Cracks and bumps most likely not caused by dispersion problems or mixing issues.

1B

PHASE 1A - OUTCOME



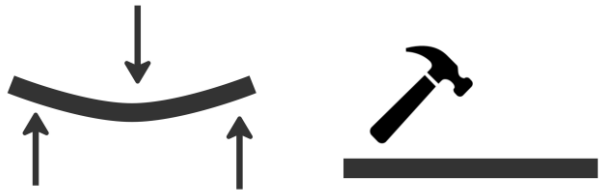
1A

PHASE 2: COMPOSITION AND GRAIN SIZE

Question to be answered:
How to integrate the fillers best regarding grain size and filler ratio?

Criteria for Evaluation:
A balance between:
- Mechanical properties
- Waste content
- Processability

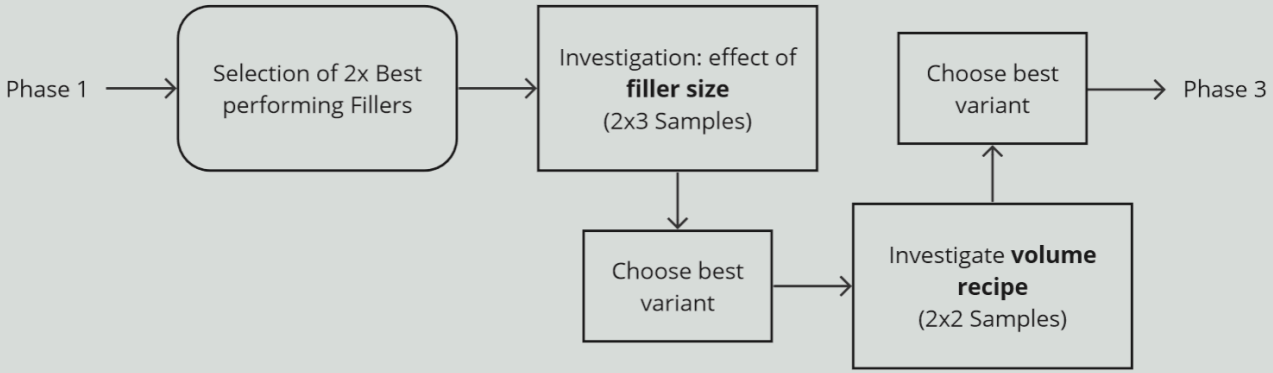
Tests:



bending impact

Synthesis:

Fillers: Spend coffee, Walnut shells



2

GRAIN SIZE

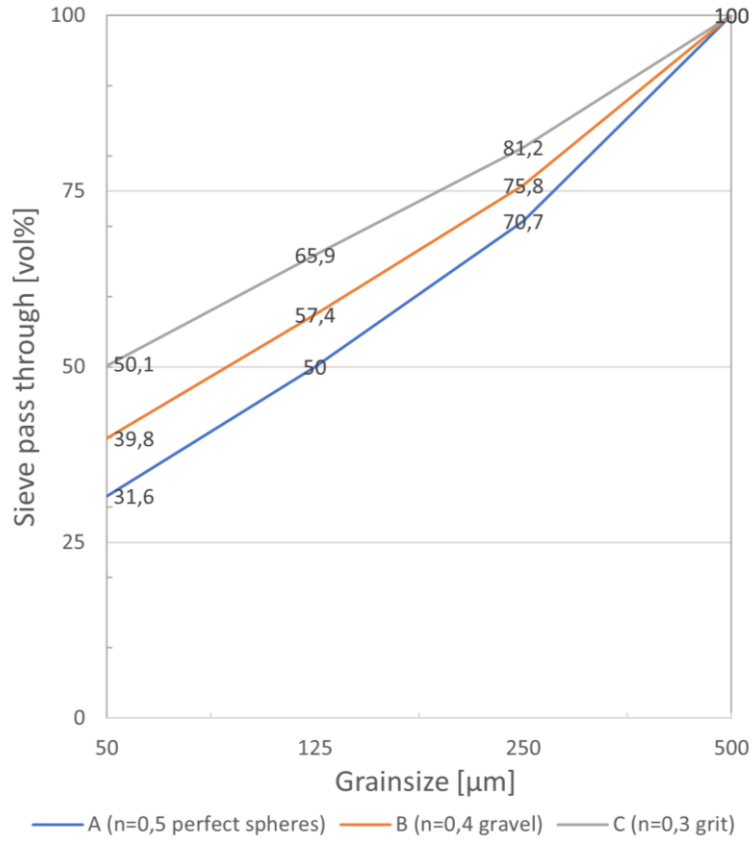
Samples:

45wt% Filler <125µm (from Phase 1)	45wt% Filler <250µm >125µm	45wt% Filler <500µm >250µm	45wt% Filler Fuller Ratio
125_45	250_45	500_45	blend_45

$$A = 100 \times (d/D)^n$$

A: sieve pass through [%]
d: grain size
D: biggest grain
n: factor for grain shape
(n=0.5 perfect sphere;
n=0.4 pebbles; n=0.3 grit)

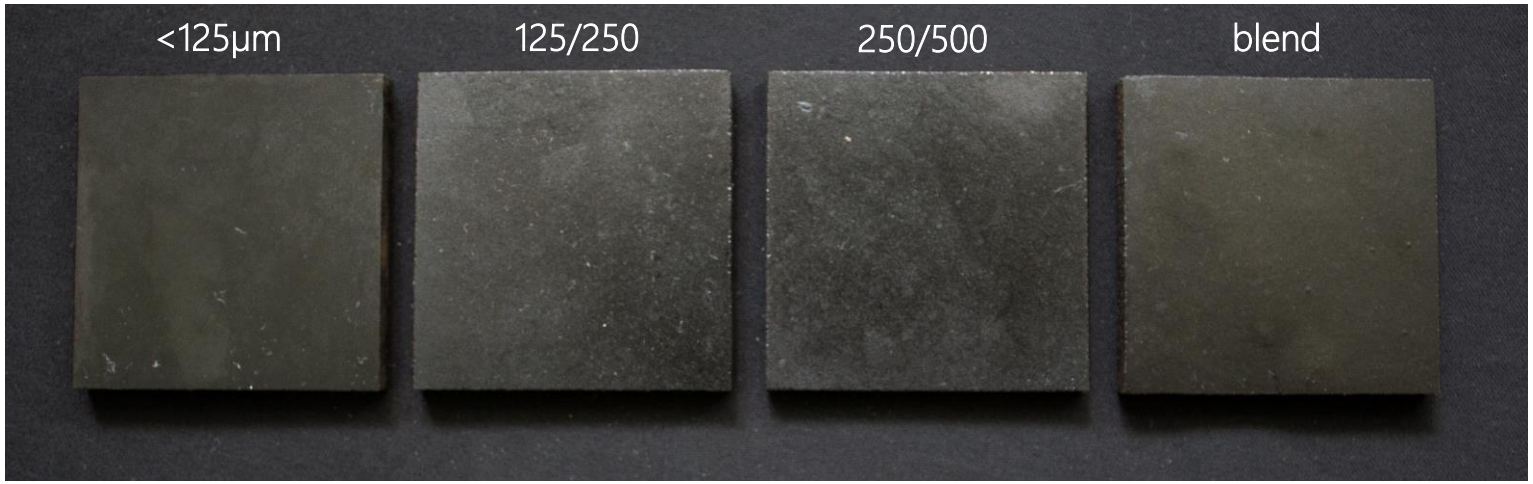
Walnut: n=0.35
Coffee: n=0.4

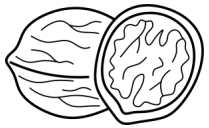


2

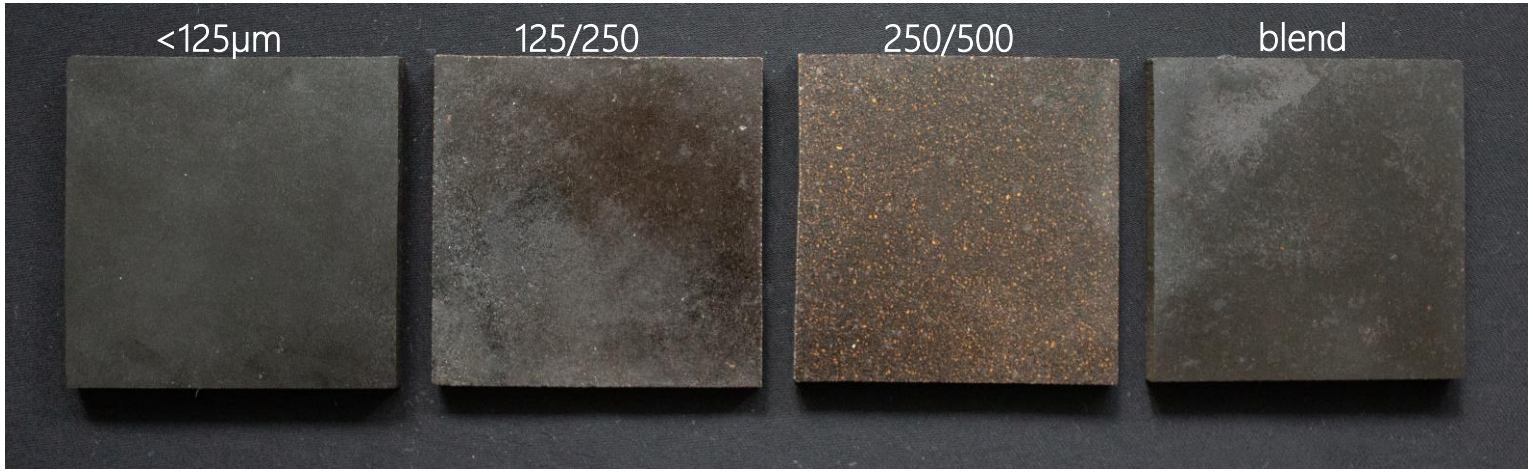
GRAIN SIZE - OUTCOME

Spend coffee





Walnut shells



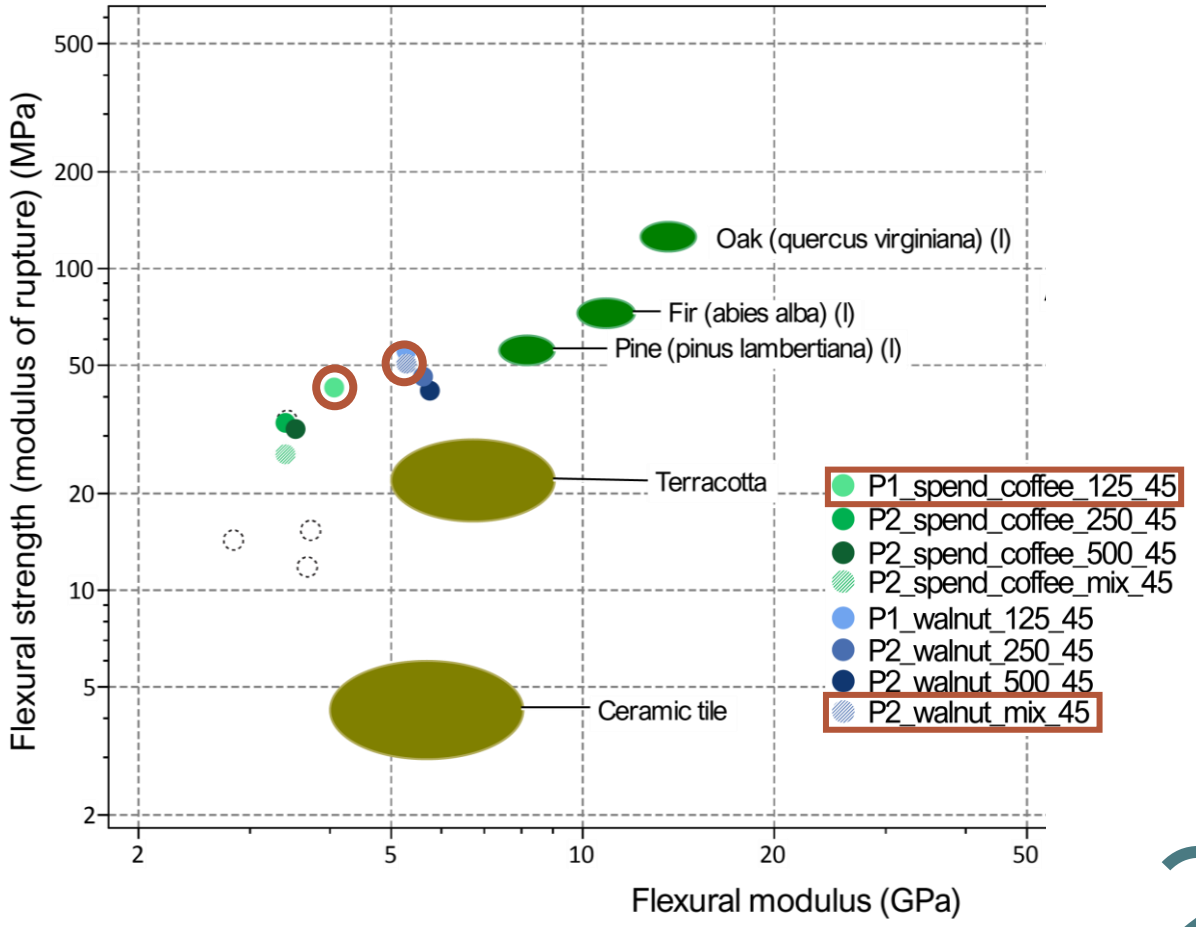
2

GRAIN SIZE - OUTCOME

Chosen grain sizes

Walnut: "blend"
Coffee: <125 µm

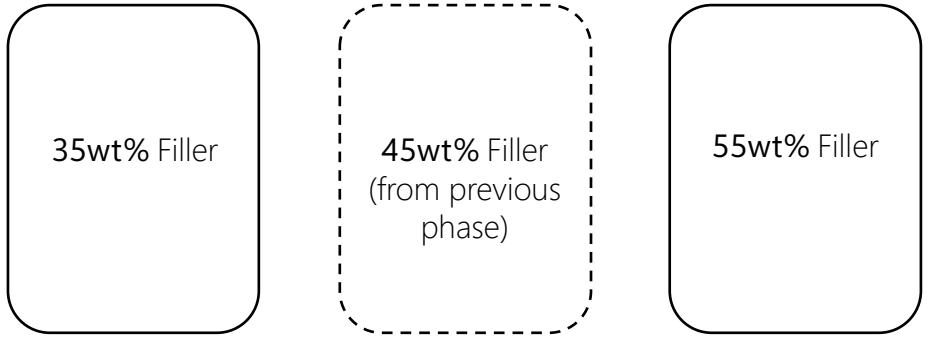
Sample plate	Bending strength [Mpa]	Stiffness [Gpa]	Impact res. [kJ/m²]
walnut_125_45 (P1)	58.71 (±8.37)	5.25	3.34 (±0.52)
walnut_250_45	49.96 (±3.88)	5.67	2.61 (±0.32)
walnut_500_45	41.70 (±2.02)	5.74	2.07 (±0.33)
walnut_blend_45	50.62 (±2.74)	5.23	2.26 (±0.45)
spent_coffee_125_45 (P1)	42.52 (±2.73)	4.12	2.35 (±0.47)
spent_coffee_250_45	33.23 (±3.11)	3.48	1.68 (±0.27)
spent_coffee_500_45	31.00 (±3.81)	3.64	1.79 (±0.46)
spent_coffee_blend_45	27.93 (±6.45)	3.42	1.41 (±0.12)



2

COMPOSITION

Samples:



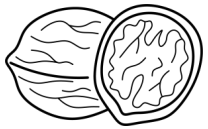
Grain sizes:

Walnut: "blend"
Coffee: <125 µm

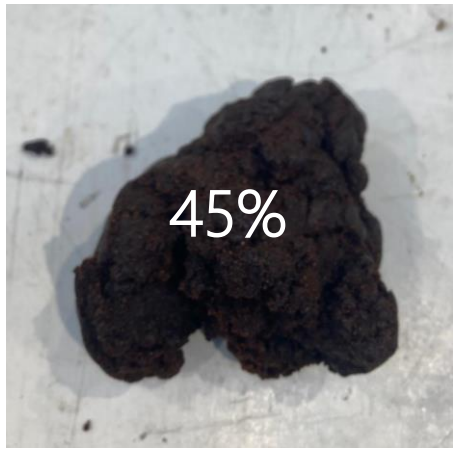
2

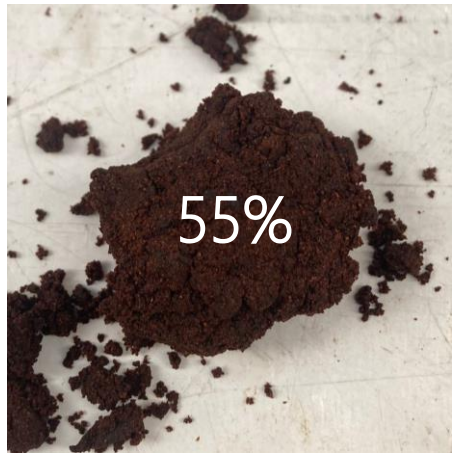
COMPOSITION - PROCESS

Spend coffee
(<125 µm)



Walnut shells
(size blend)

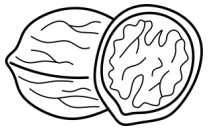




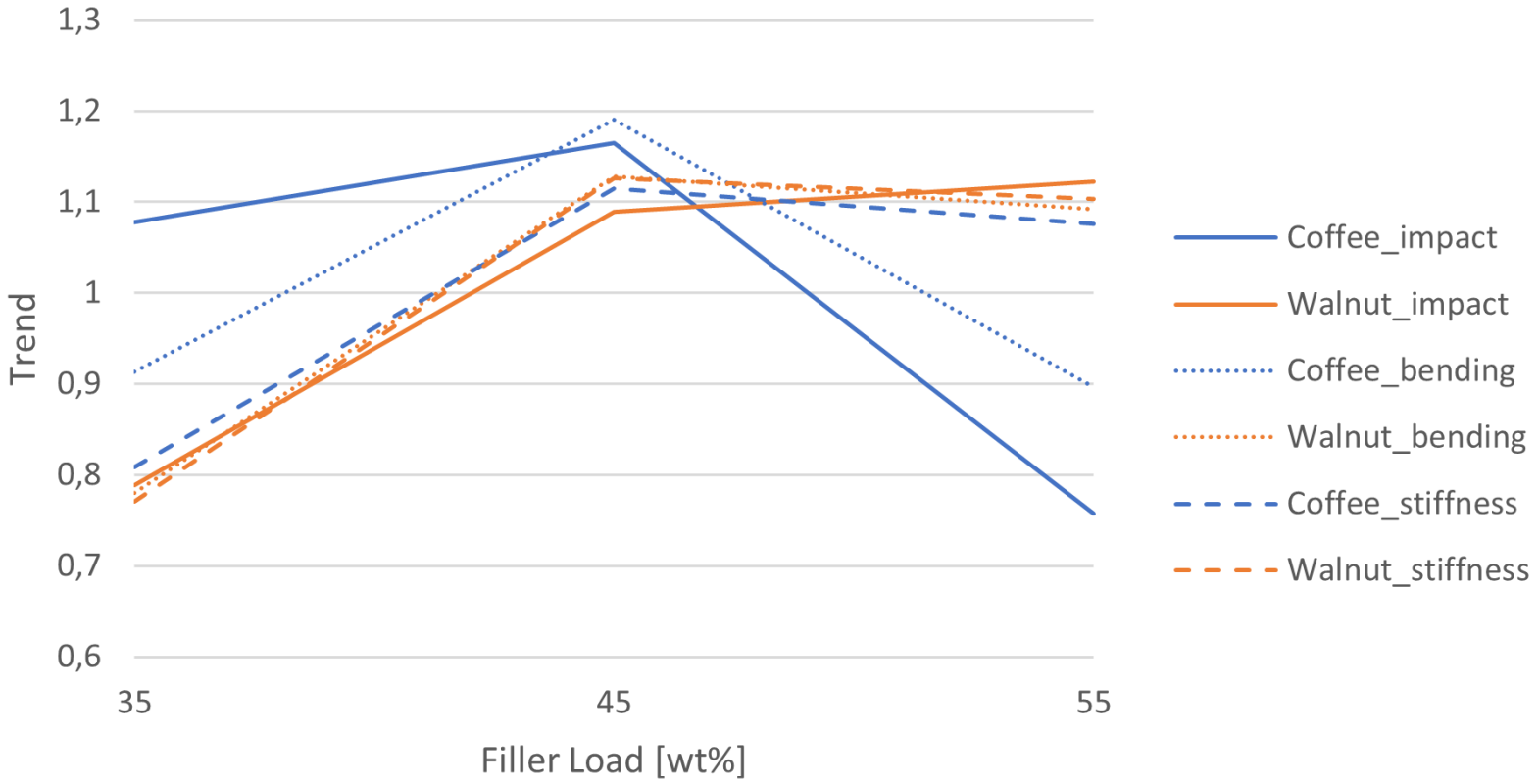
2

COMPOSITION - OUTCOME

Spend coffee
(<125 µm)



Walnut shells
(size blend)



2

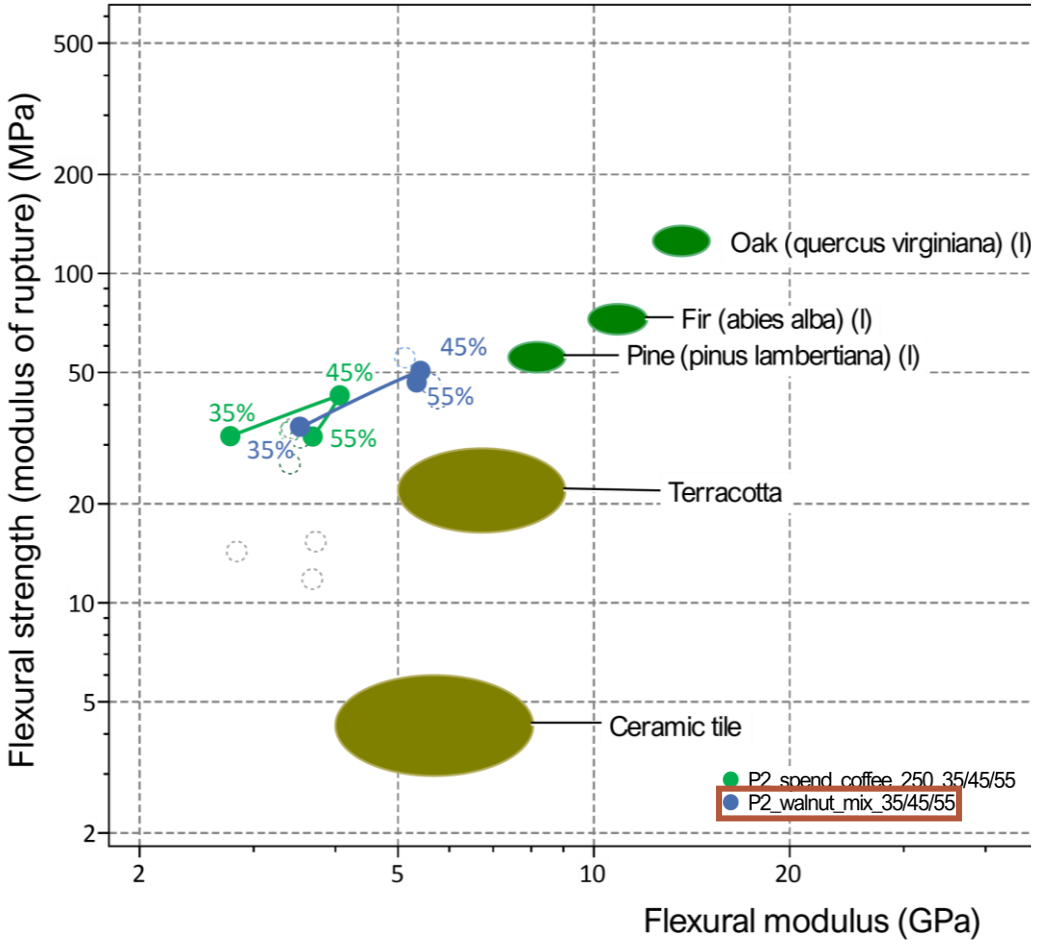
PHASE 2 - CONCLUSION

Best recipe

Walnut: mix_55%

- The mixed filler sizes worked out as expected
- Walnut shows more consistent results then coffee grounds

Sample plate	Bending strength [Mpa]	Stiffness [Gpa]	Impact res. [kJ/m²]
walnut_blend_35	35.01 (±3.06)	3.58	1.63 (±0.18)
walnut_blend_45	50.62 (±2.74)	5.23	2.26 (±0.45)
walnut_blend_55	48.98 (±2.49)	5.12	2.33 (±0.31)
spent_coffee_125_35	32.63 (±3.61)	2.98	2.18 (±0.45)
spent_coffee_125_45	42.52 (±2.73)	4.12	2.35 (±0.47)
spent_coffee_125_55	32.00 (±6.20)	3.97	1.53 (±0.32)



2

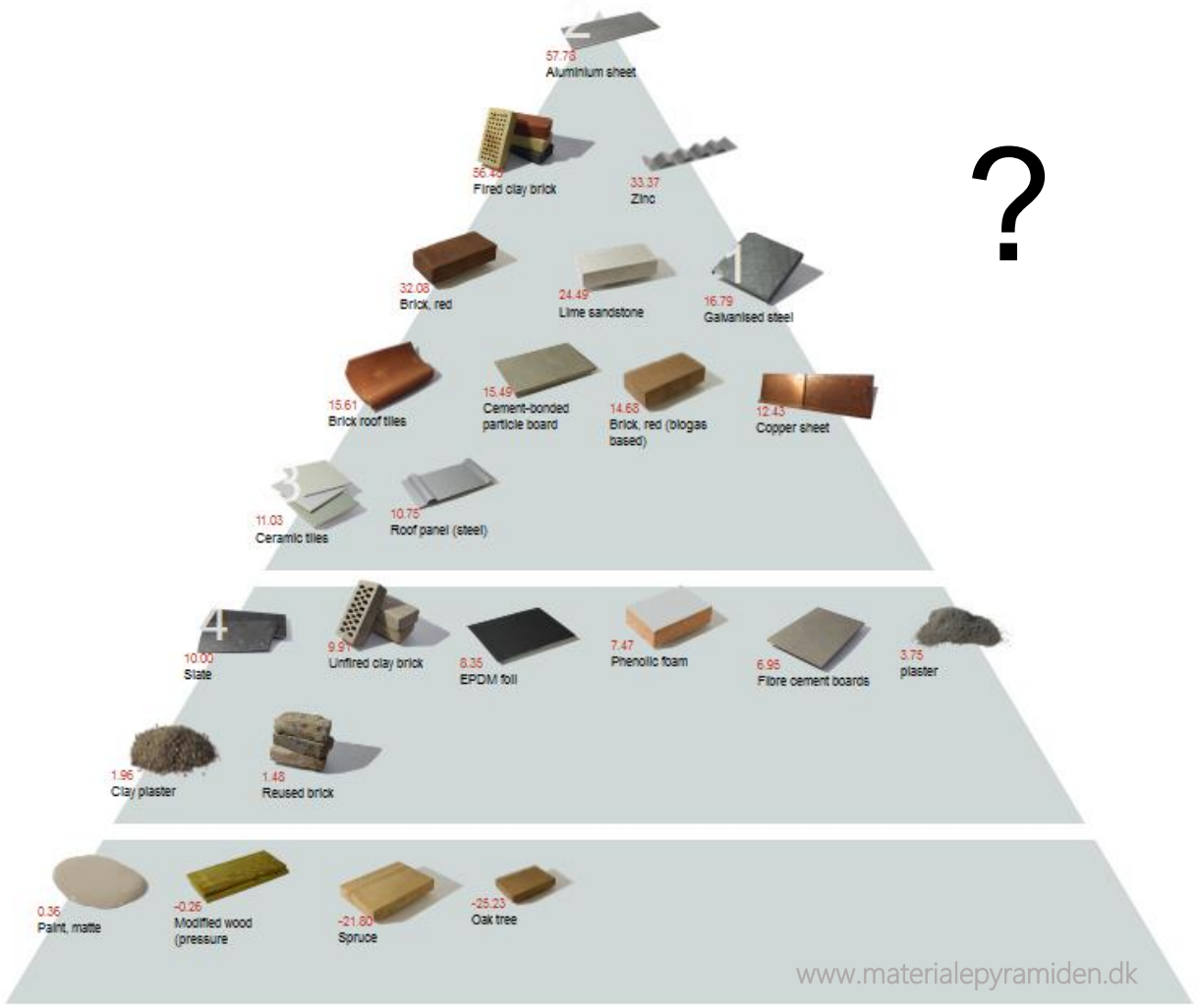
PHASE **3**: APPLICATION AND DESIGN

Objectives:

- Comparison of the composite in an application
- Determine if structural optimisation is possible
- Illustrate design options

3

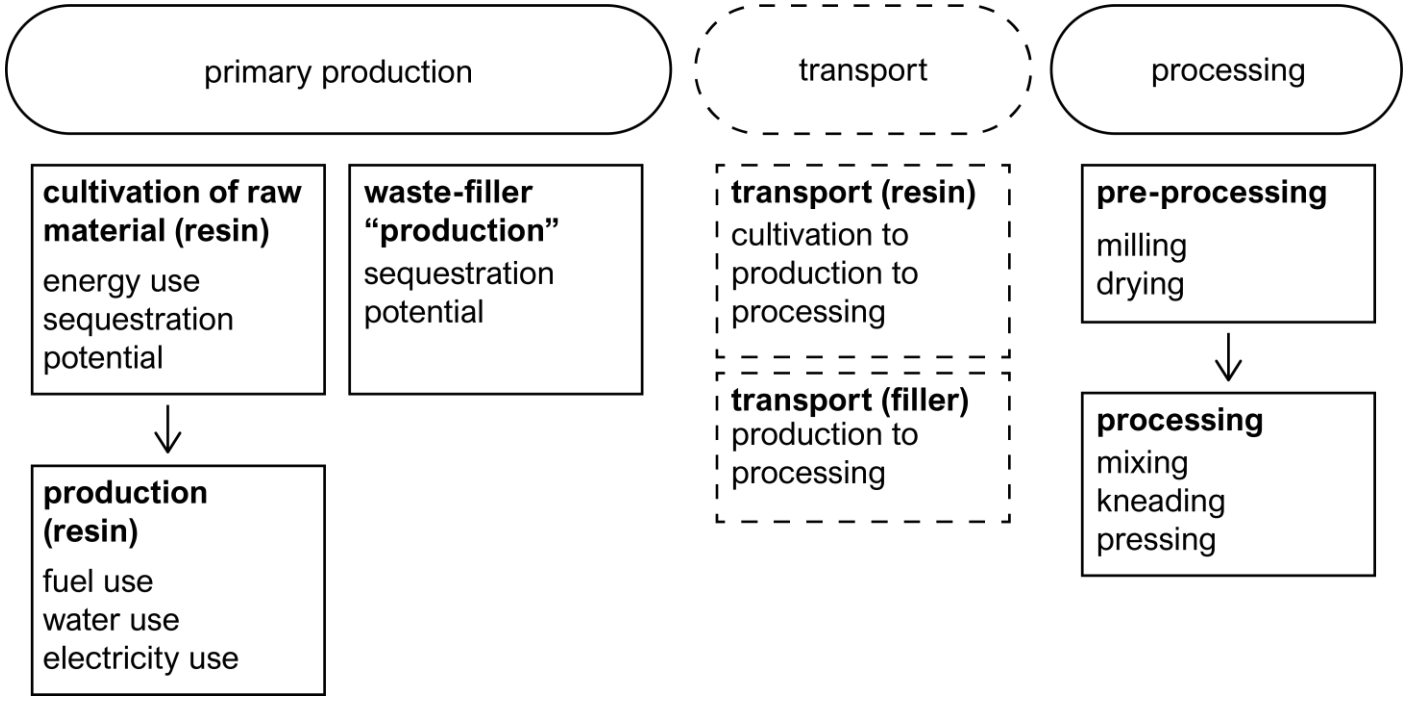
SUSTAINABILITY COMPARISON



?

3

SUSTAINABILITY COMPARISON



3

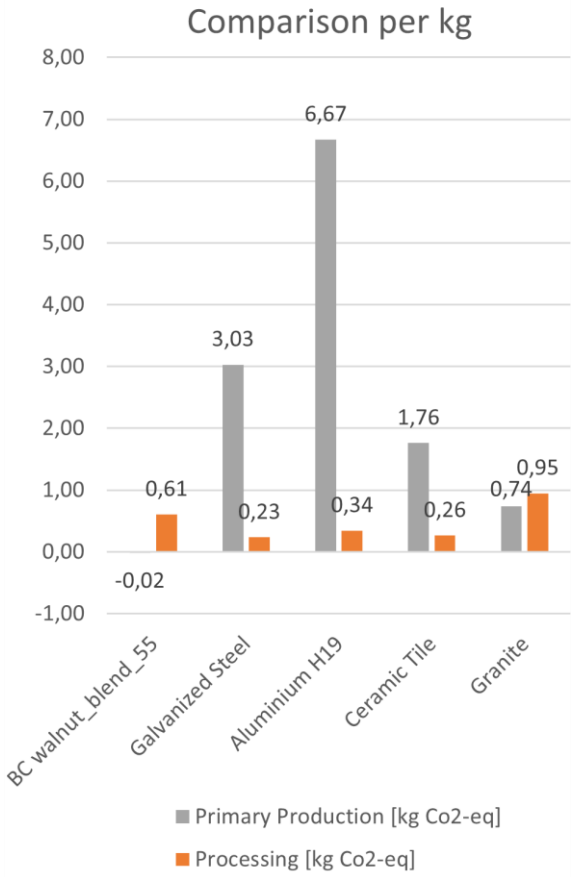
SUSTAINABILITY COMPARISON

Primary Production

Ingredient	Content [%]	Material Price [€]	CO2-eq [kg/kg]
Walnut Shells	55	(1.5)	-1.76
Furan Resin	41	3.2	2.13
Linseed Oil	2	6.14	2.69
Catalyst (HM1448)	2	10	1.18
Total	100	2.46	**-0.02**

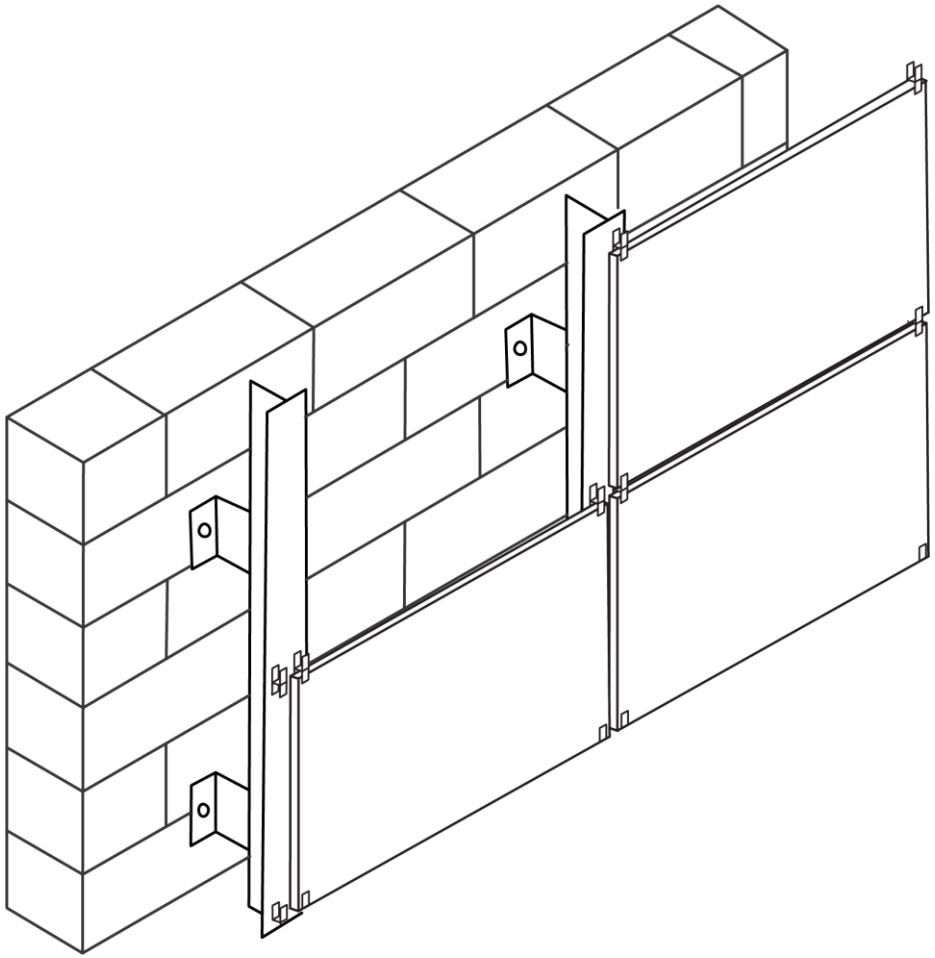
Processing

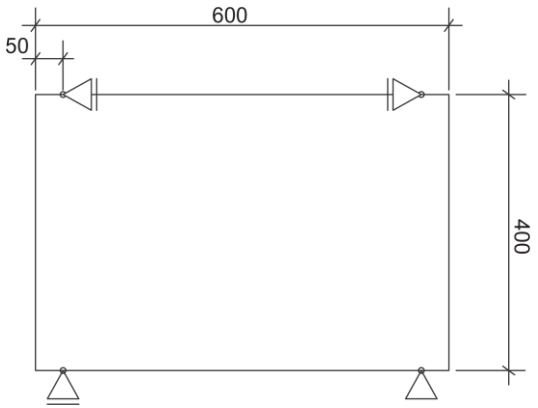
Processing step	Emissions (Energy) [kg CO2-eq/ kg composite]
Milling	0.059
Drying	0.426
Kneading	0.021
Moulding	0.099
Total	**0.605**

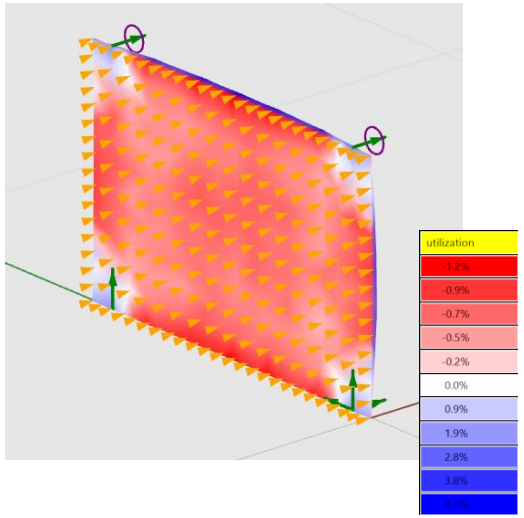


3

CASE STUDY

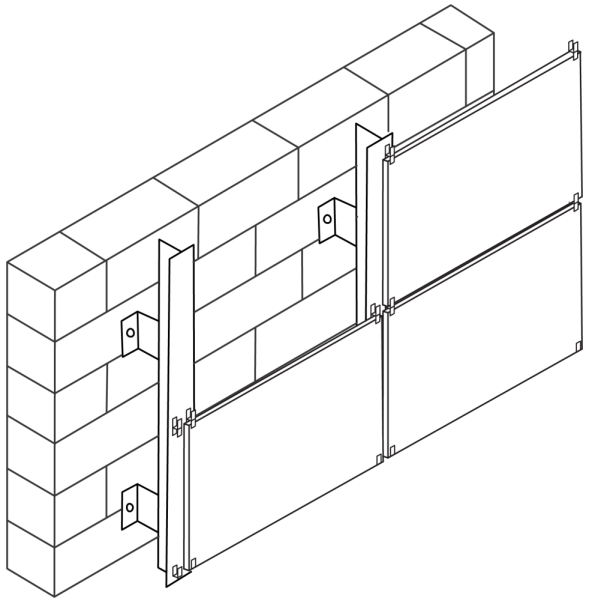


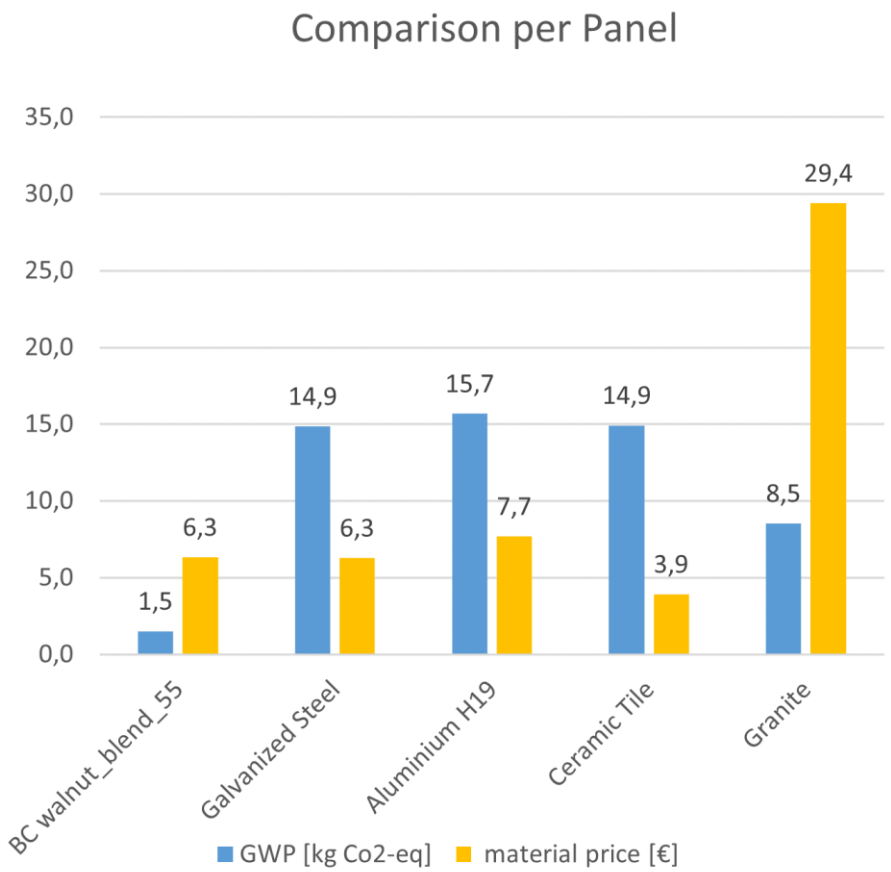




3

CASE STUDY - OUTCOME

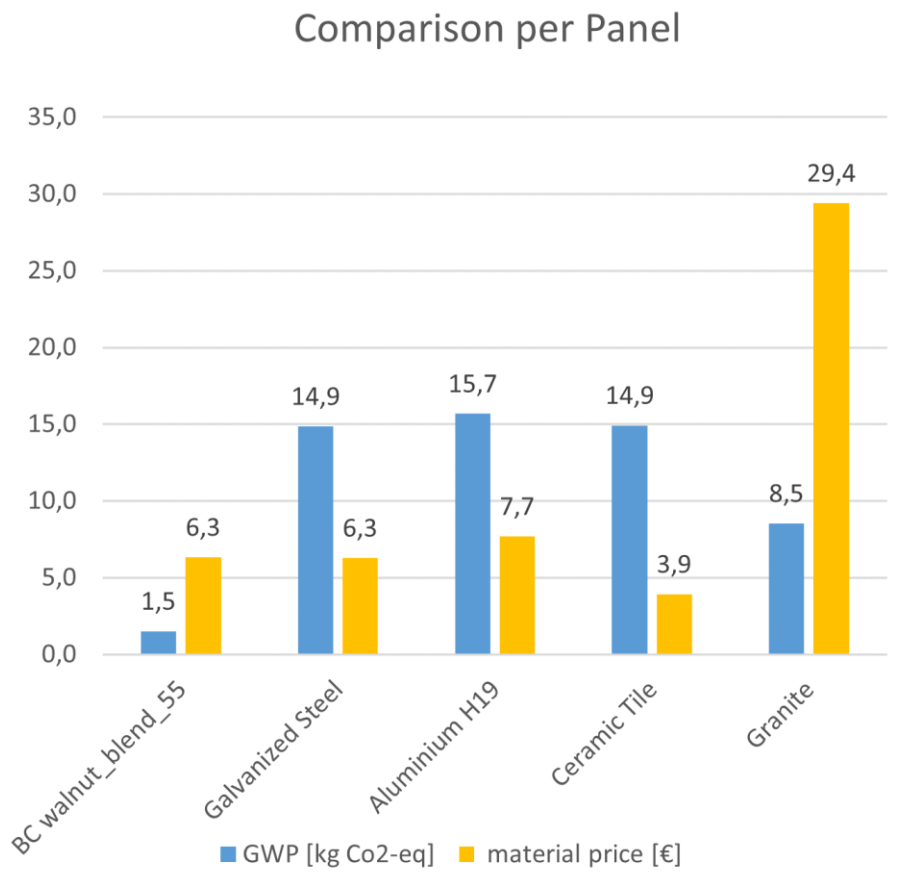




3

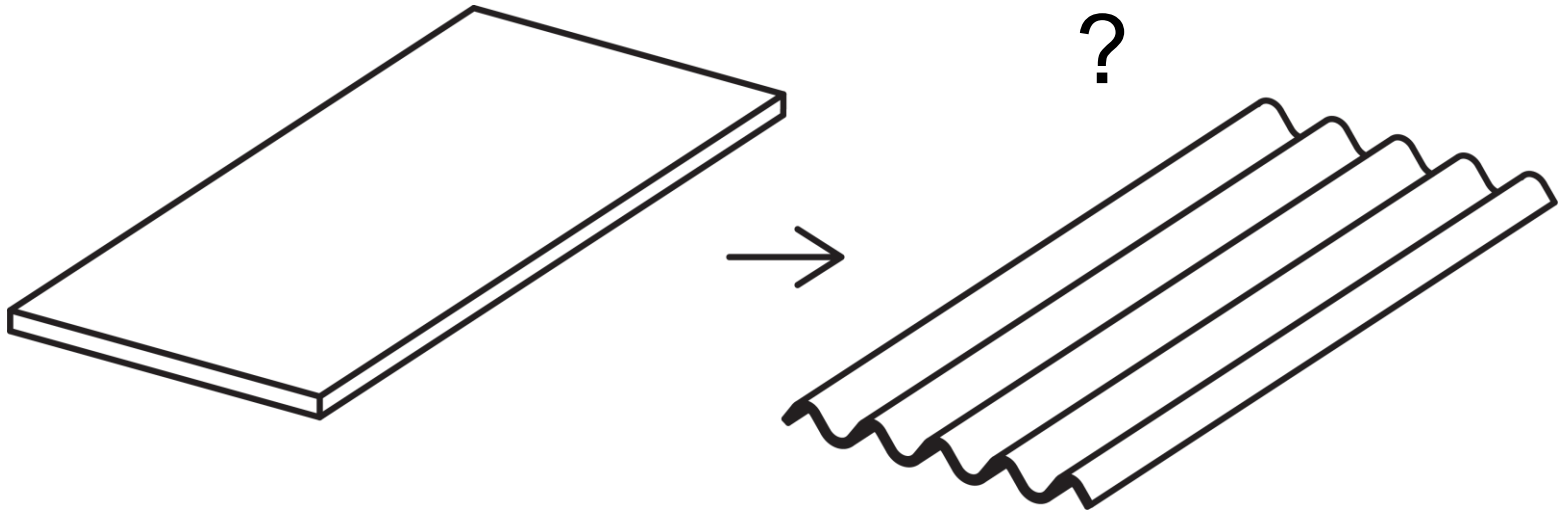
CASE STUDY - OUTCOME

Facade Panel	Thickness [mm]	Weight [kg]	Material Price [€]	GWP [kg CO2-eq]
Bio-Composite	11	3.54	8.7	0.6
Aluminium	5	3.29	11.3	23.1
Steel	3	5.69	7.8	18.6
Ceramic Tile	9	5.18	2.8	10.5
Granite	5	3.84	22.3	6.5



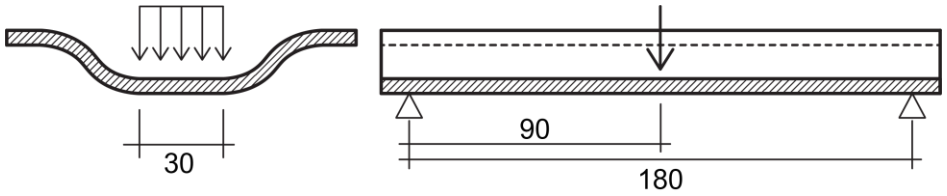
3

STRUCTURAL EFFICIENCY



3

STRUCTURAL EFFICIENCY



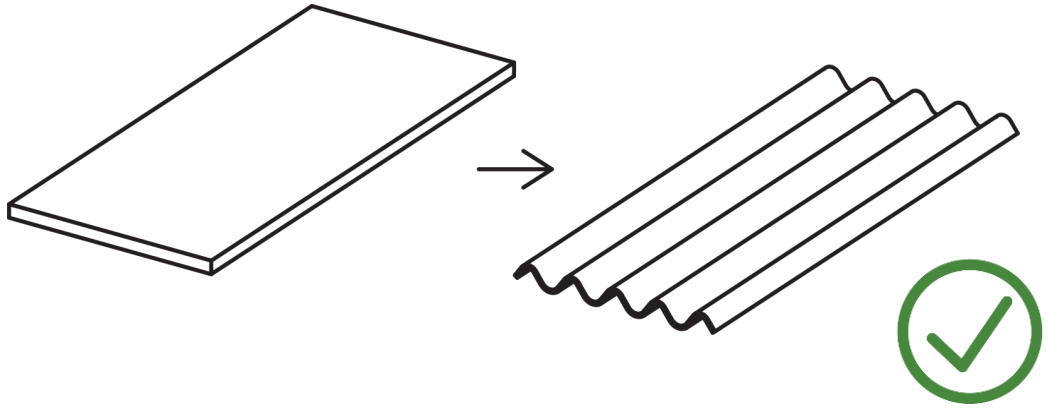
3

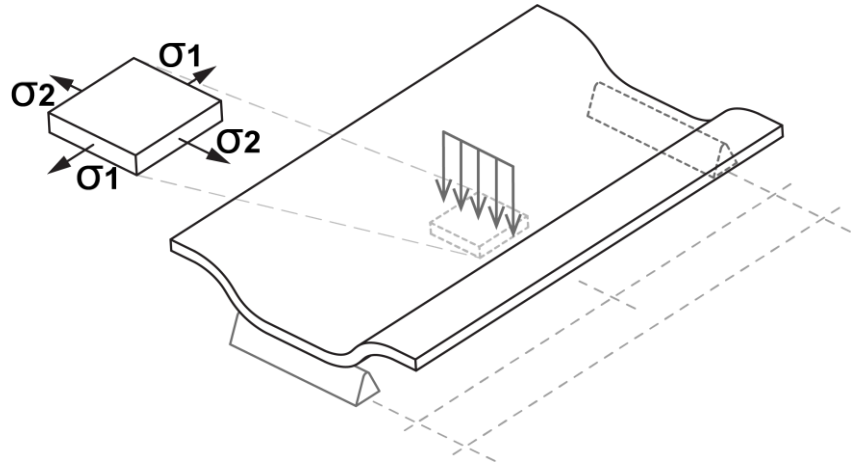
STRUCTURAL EFFICIENCY

3D Cross-section:
M_{max} = **0.102 kNm**

Equivalent Rectangular Cross-section:
M_{max} = **0.0304 kNm**

~3x higher



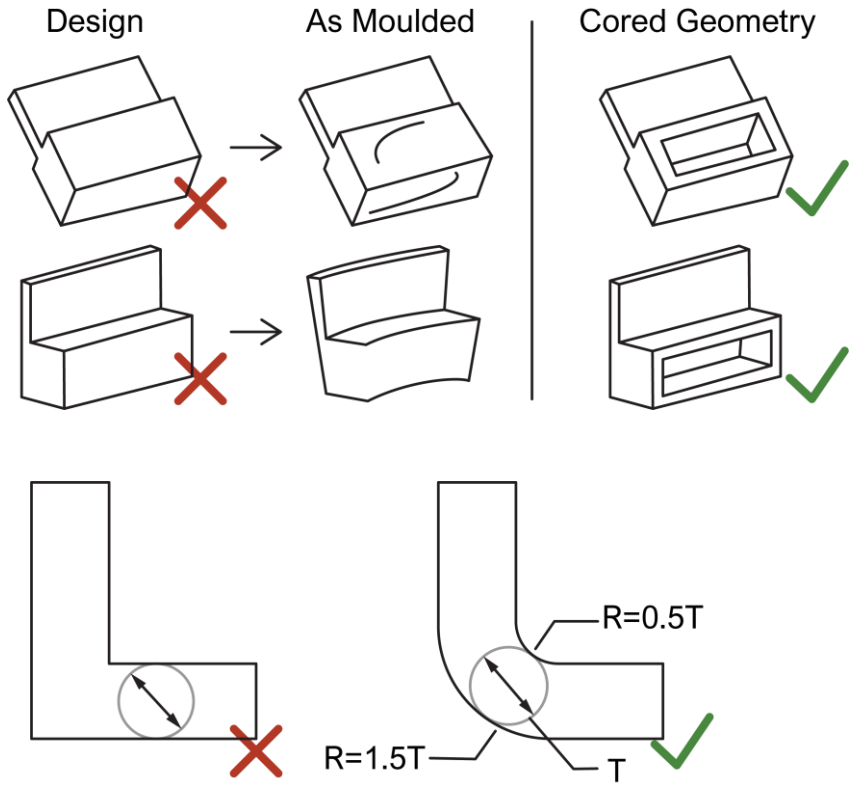


3

DESIGNING - MACHINEABILITY

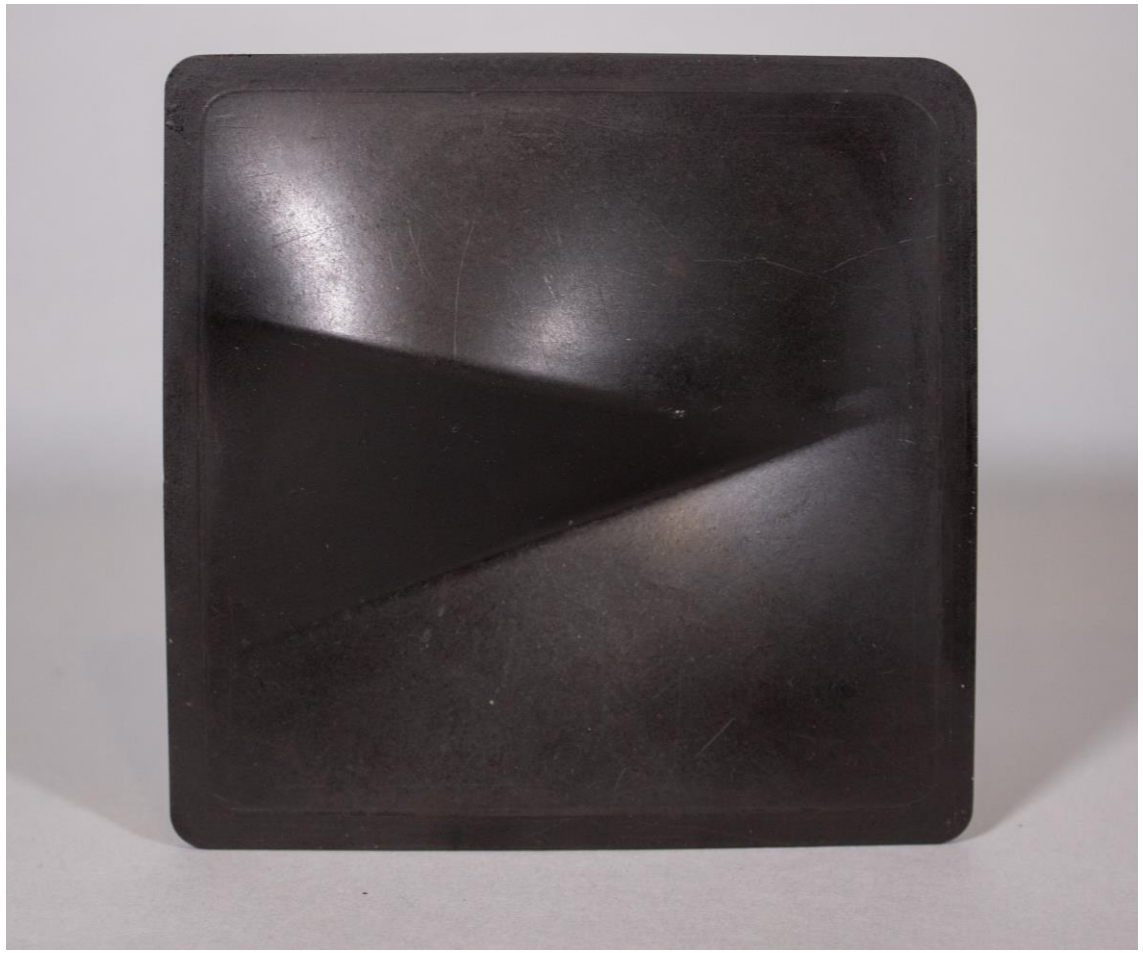
Machining

Moulding Rules



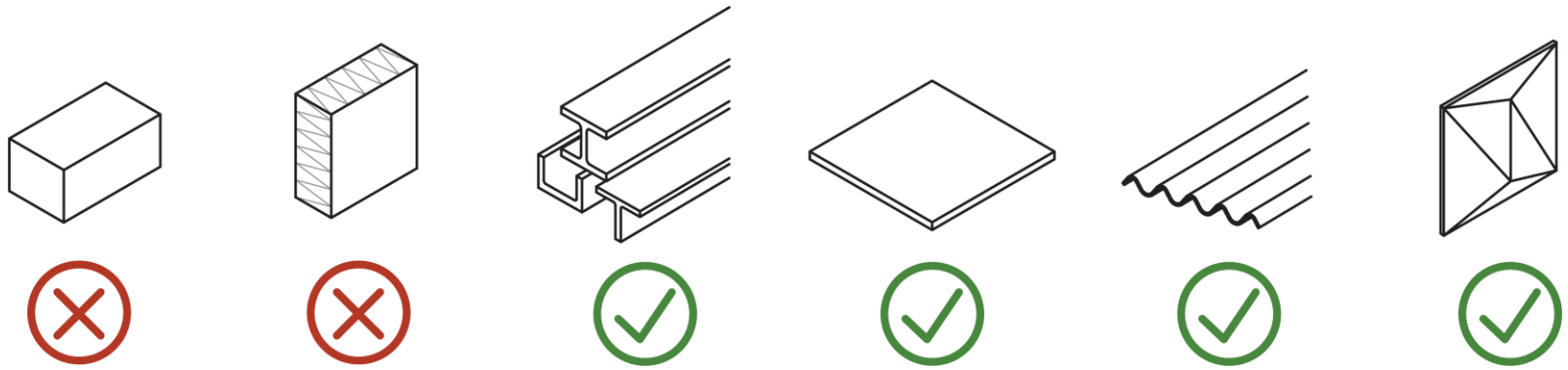
3

DESIGNING – CURVED SHAPES



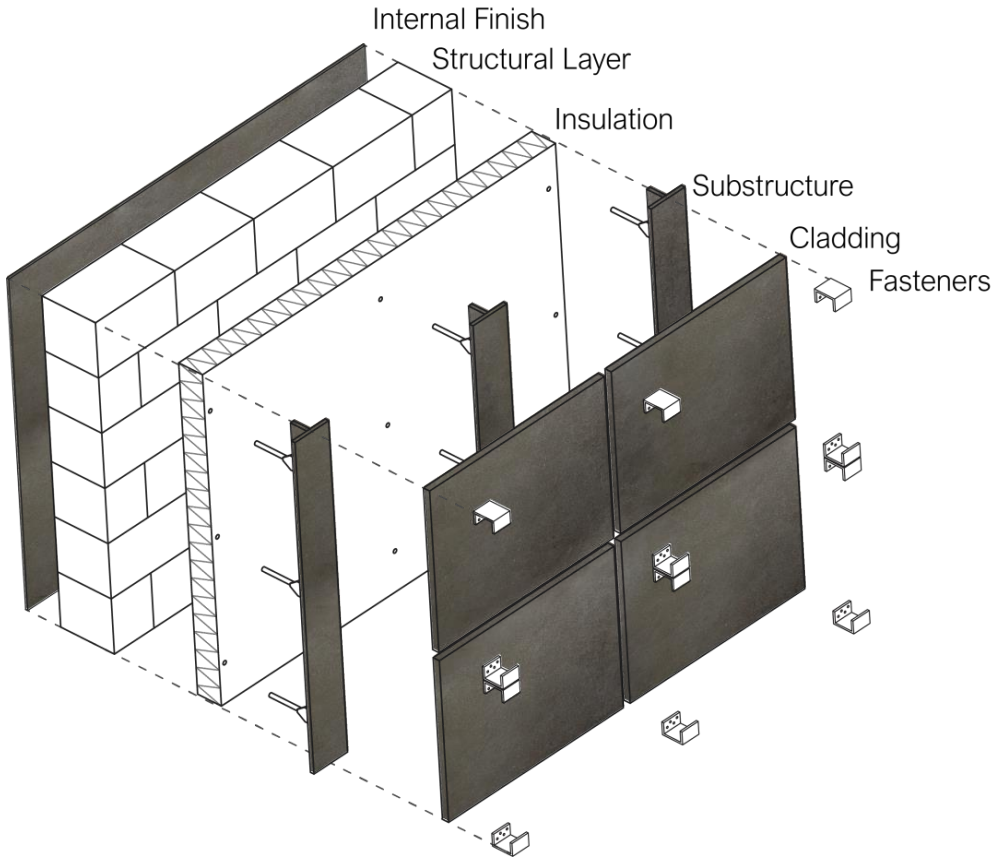
3

PHASE 3 - CONCLUSION



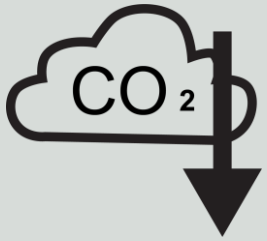
3

DESIGNING – ALTERNTIVE USES



3

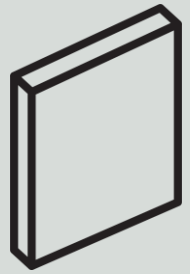
CONCLUSION



Sustainability

Resources

Integration



Application

QUESTIONS?