TU Delft
BK Bouwkunde

P5 Presentation | Master Thesis Dissertation
AR3B025 Building Technology Graduation Studio

Engineering Biocomposites

Circularity in Facade Cladding Systems with Complex Geometries

Samanwita Ghosh
| 5577640 MSc Building Technology

P5 Presentation | Master Thesis Dissertation

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Circularity in Facade Cladding Systems with Complex Geometries

Samanwita Ghosh

| 5577640 MSc Building Technology

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Engineering Biocomposites

Circularity in Facade Cladding Systems with Complex Geometries

Architectural
Façade & **Products**
Research Group

Sustainable Architectural
Materials & **Structures**
Research Group

under the guidance of

Dr Olga Ioannou
Building Product Innovation

&

Dr Mauro Overend
Structural Design & Mechanics


Foster + Partners
MOL Headquarters, Budapest
U.S. GREEN BUILDING COUNCIL
PLATINUM
USGBC
CODE FOR A SUSTAINABLE BUILT ENVIRONMENT
BREEAM

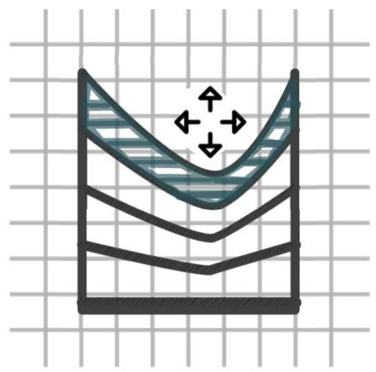
“

.... The **complex & challenging form** of the building is predominantly **constructed from flat and easy-to-manufacture panels** while **keeping** the **curve only where** they are truly **needed**.

”

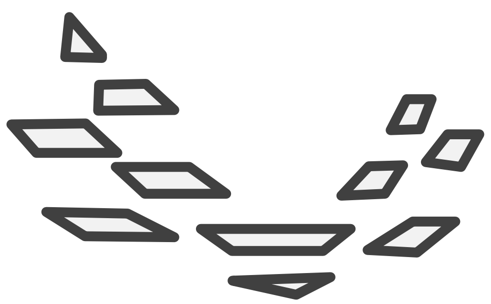
Complex Geometry & Fabrication of MOL Facade
(Applied R+D Group Foster + Partners, 2022)

Convention



'panelisation'

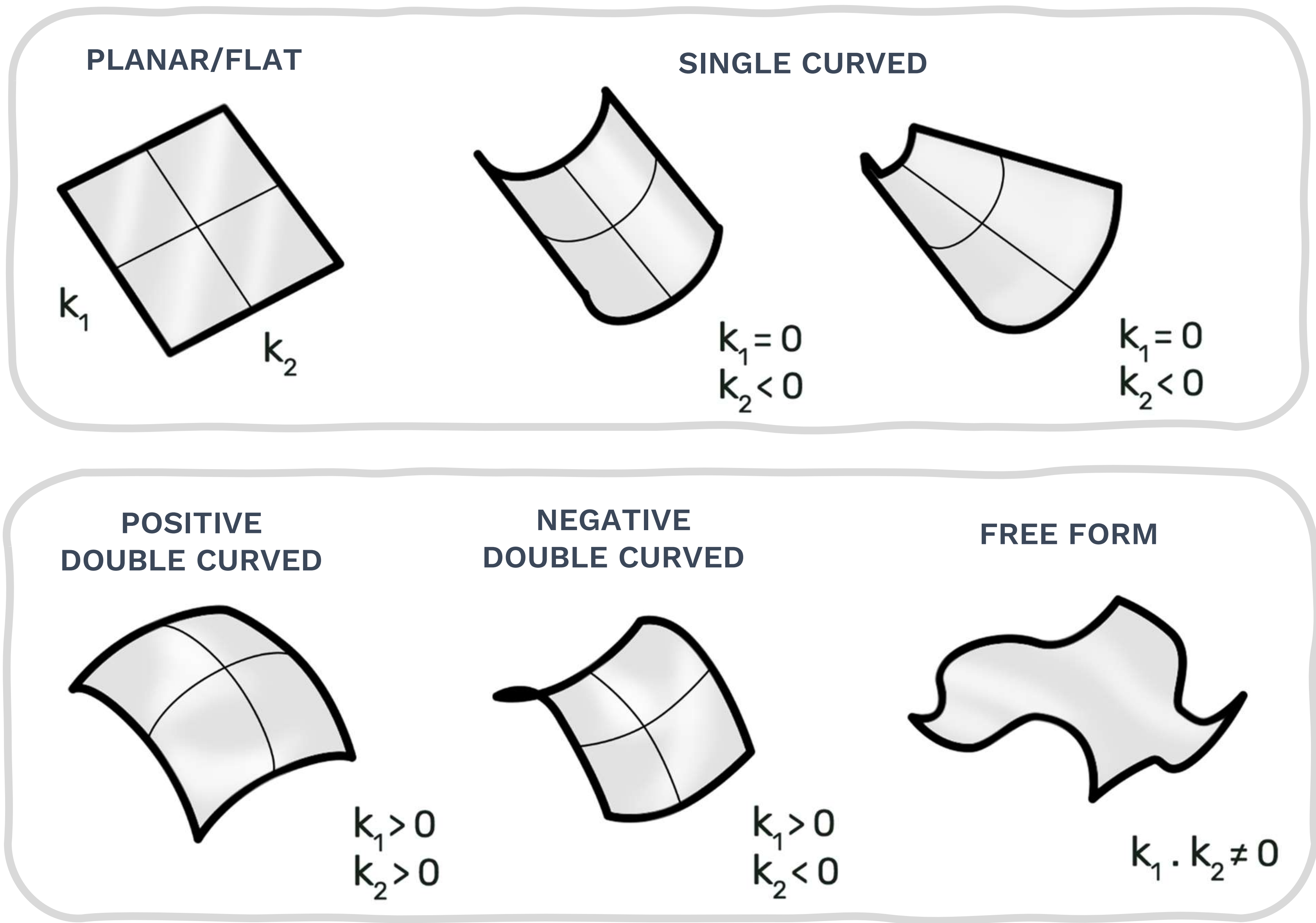
(Pantazis et. al, 2019)



complexity optimised

'rationalisation'

(Lee & Kim, 2012)



⇨ **Developable** Surfaces

⇨ **Non-Developable** Surfaces

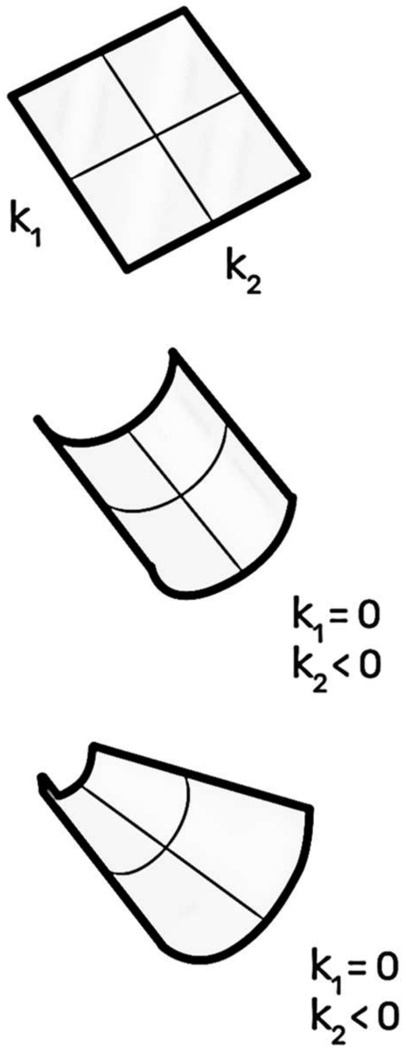
'surface typology'

(Pronk & Dominicus, 2012; Henriksen et al., 2015; Correa et al., 2021)

Illustrations: Own

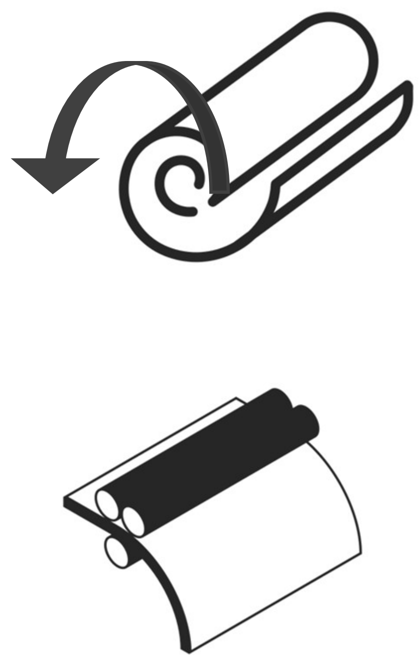
Developables

The materials display developability, geometric ability to fold & transform flat without distortion



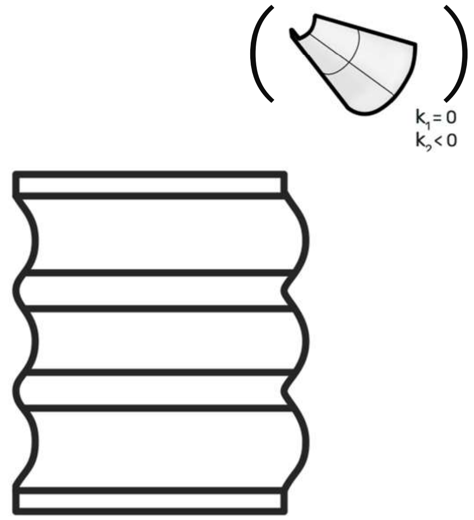
‘developable surfaces’

(Euler, 1772)



‘ease of manufacturing’ sheet metals

(Pottmann et al., 2008)



Aluminium

Most Favoured for Complex Profiles

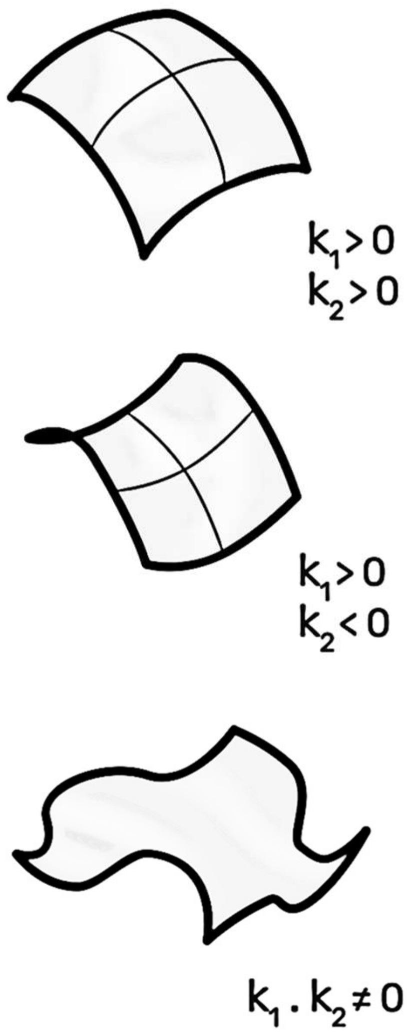
⅓ Steel Weight

High Reuse Potential

Icons: The Noun Project; Illustrations: Own

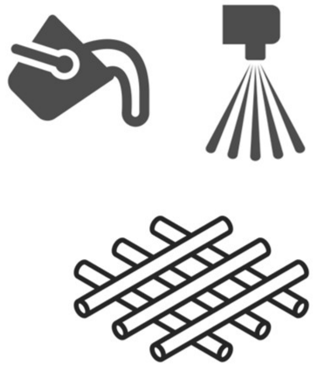
Non-Developables

The materials that can’t be folded & transformed back without distortion

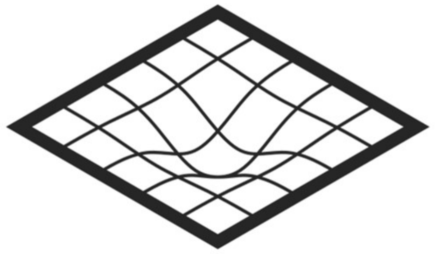


‘non developable surfaces’

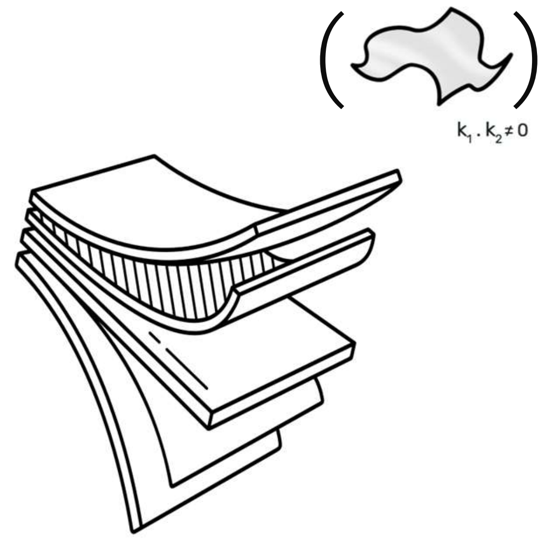
Rationalized Often



FIBRE-REINFORCED POLYMERS



high resource consumption
mould manufacturing

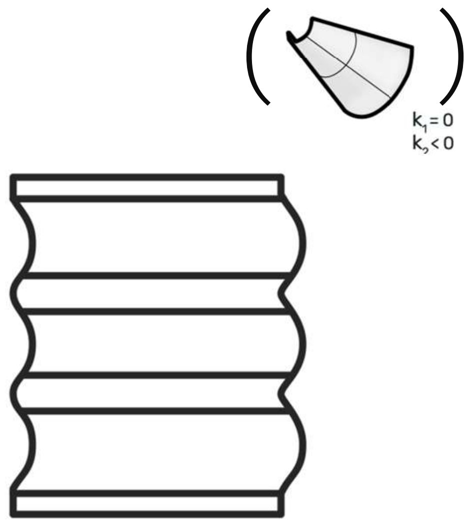


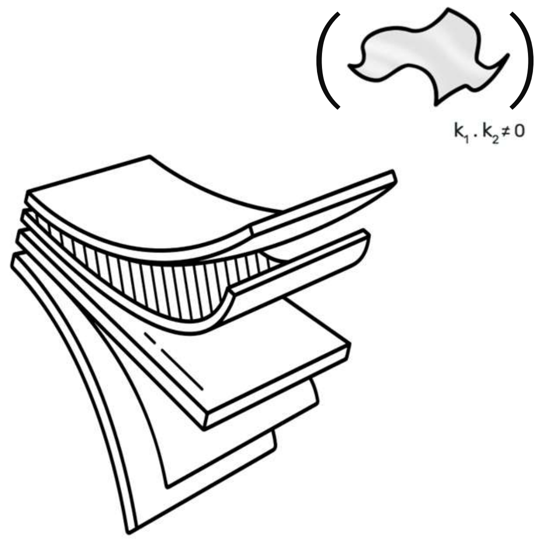
Glass-FRP

AEC Largest Consumer :
37% Market Share
>90% of all FRP’s were GFRP

Icons: The Noun Project; Illustrations: Own

Convention





Aluminium

1.1 Giga Tonnes CO_2 (2021)
+ Electrical Consumption

(IEA, 2022)

sheet-formable
high reuse potential

developable material

GFRP

'**2.5** T CO_2/glass fibre ton'
$1/3^{RD}$ of Production is Waste

(EuCia, 2022; Qureshi, 2022)

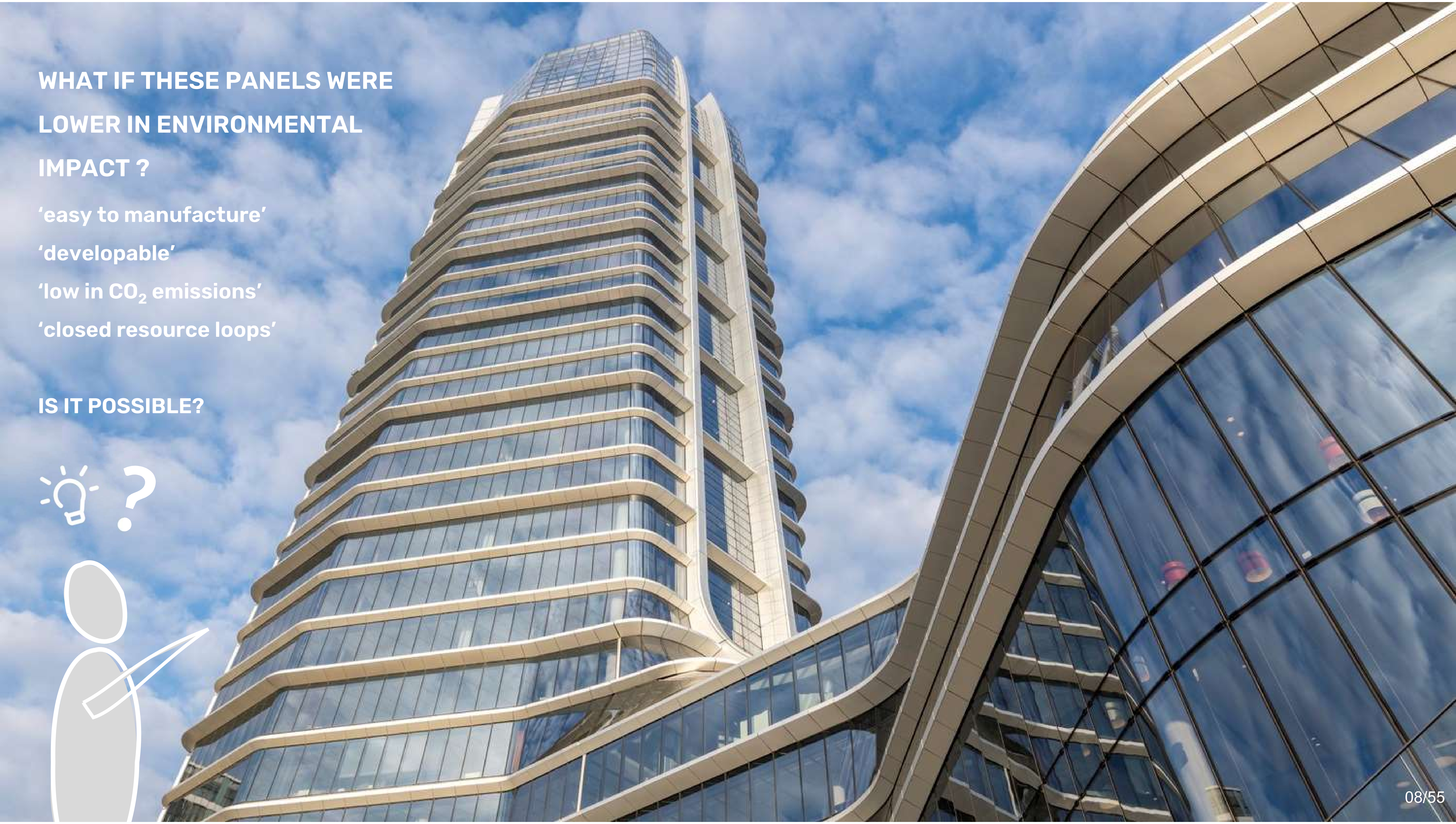
formwork dependent
high production waste

mouldable material

Alternatives to Conventional Materials

Need for Transitioning
to a Circular Built Environment

Icons: The Noun Project; Illustrations: Own


WHAT IF THESE PANELS WERE
LOWER IN ENVIRONMENTAL
IMPACT ?
‘easy to manufacture’
‘developable’
‘low in CO_2 emissions’
‘closed resource loops’
IS IT POSSIBLE?
?

Opportunity & Gaps

Natural Fibre Reinforced Polymeric Composites

Despite extensive academic studies

Competence in Mechanical Properties
Low Eco-Impact, Local Production
Carbon Sequestering, Renewable Origins
Biodegradable

NFRP Façade Products

"do not exist yet"

(Fiore et al., 2015)
(Mugahed Amran et al. 2018)
(Vinay et al. 2022)
(Qureshi, 2022)

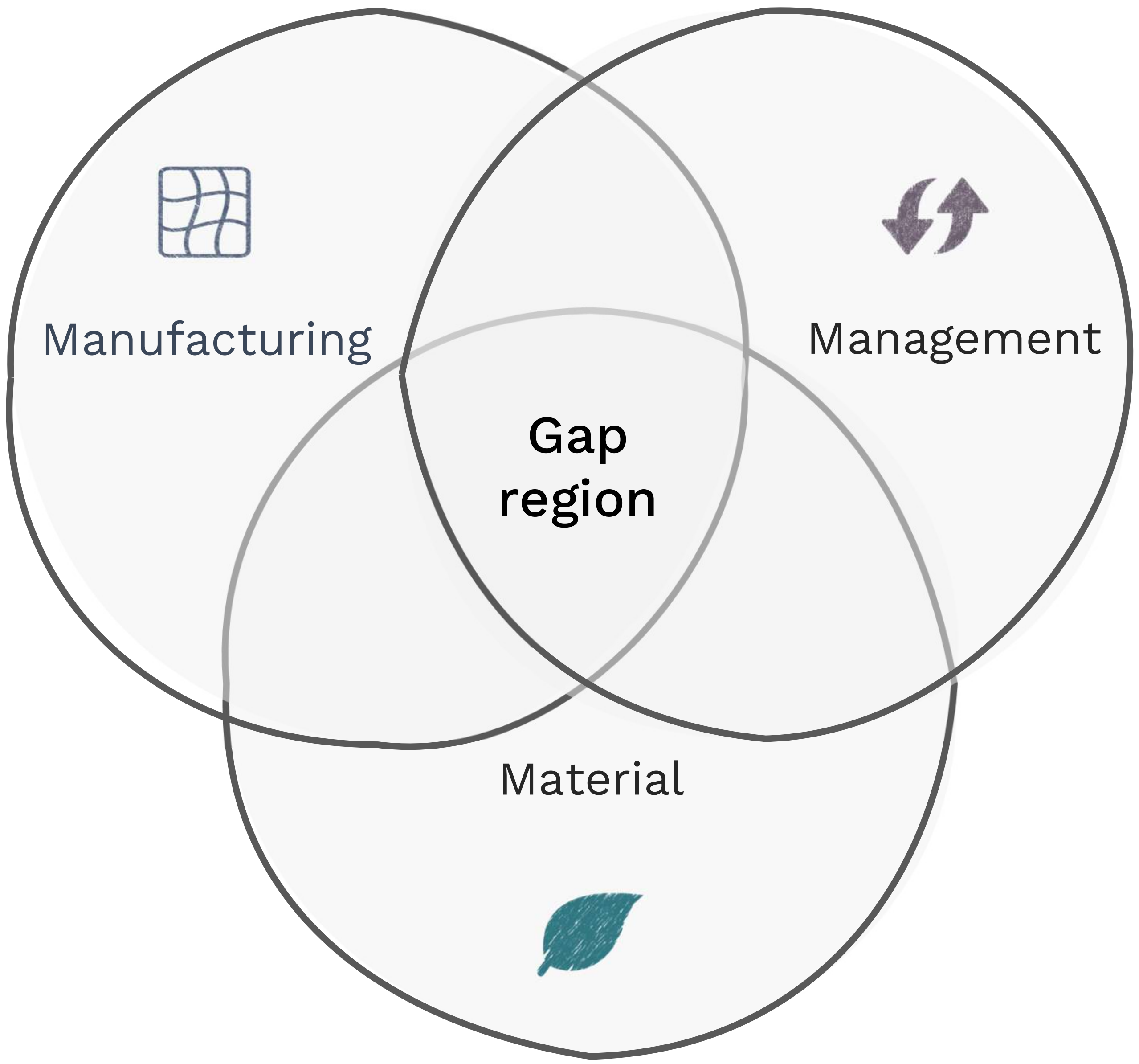
'developability in fibrous biocomposites'

"not proven yet"

(Tomas, 1996)
(Chanda & Bhattacharyya, 2022)

Relevant Domains

For circular façade product with NFRP, these domains need addressal



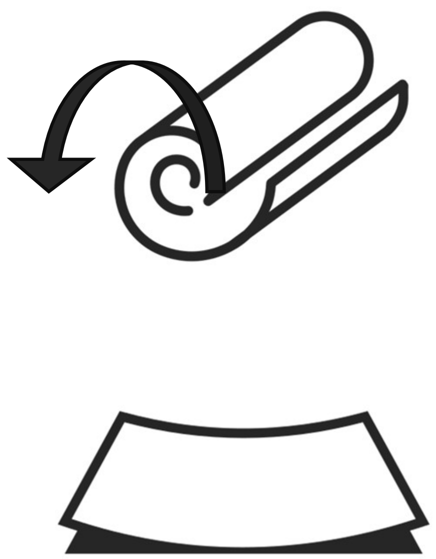
fully renewable origins ?

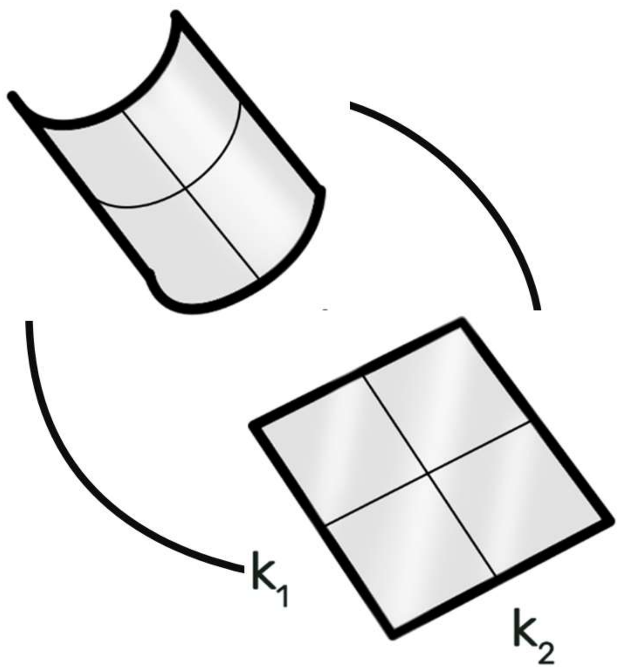
viable for panel manufacturing ?

suitable for multiple use cycles ?

(Dahy, 2019)

Addressing the Gap





***'promote** 100% biobased'*

(Joustra & Bessai, 2021)

Redefining Conventional
Façade Material Choices

(H. Dahy, 2019)

***'prove** developability'*

(Tomas, 1996)

Ability to Reshape without Distortion
Intensifies product use

(Cramer, 2017)

***'preserve** value'*

(Joustra & Bessai, 2021)

*'**product integrity** > material integrity'*

(Joustra & Bessai, 2021)

MATERIAL

MANUFACTURING

MANAGEMENT

Research Question

> "How to engineer a fibre-reinforced biocomposite façade cladding panel for complex geometries?"

1. Literature Review
2. System Design
3. Iterative Analysis

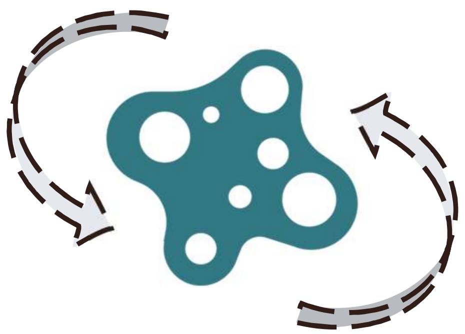
Material Review

Natural Fibre Reinforced Composite Parameters for Cladding Applications

reinforcement

Bast Fibres
Flax
Jute, Kenaf
Hemp

matrix



Biomass Derived Thermoplastics
PLA PHA
TPS PA11

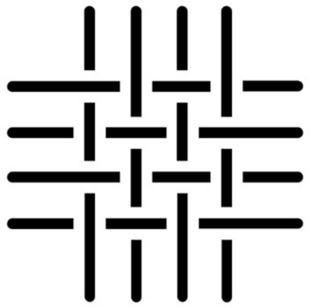
architecture

Woven Textiles
2D Weaves
Textiles

'100% biobased'
Fully biomass derived feedstocks

'developability'
thermoplastics allow reforming, unlike thermosets

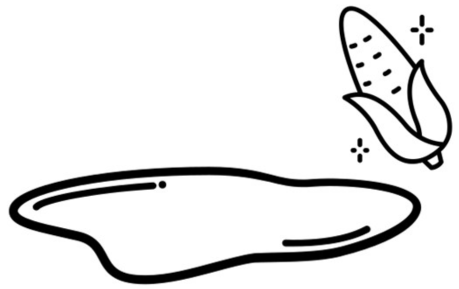
Selection + Sourcing



Flax (Natural Fibre)

'strongest natural fibre, local to EU'
343 -1500 MPa Tensile Strength
(Linen)

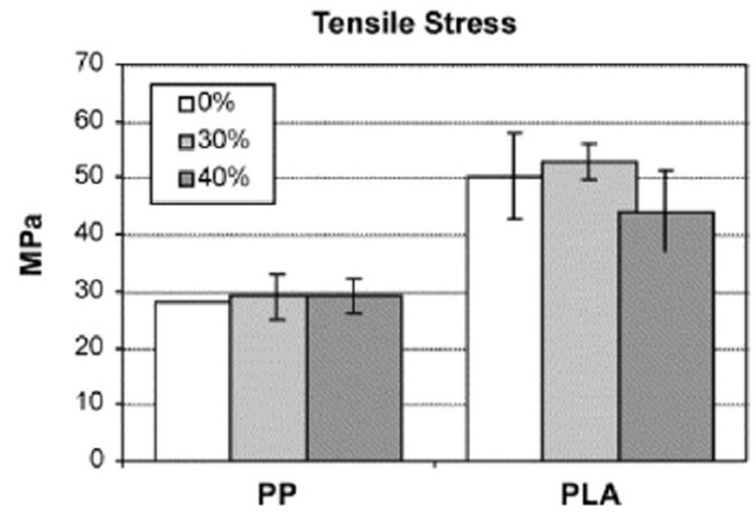
(Llyod, 1996; Mohanty et al., 2005)



PLA (Bioplastic)

'100% bio-sourced & biodegradable'
Tg = 65-70 C, compatible with Flax
Biobased Thermoplastic

(Morales et al. 2017; Dahy, 2019)

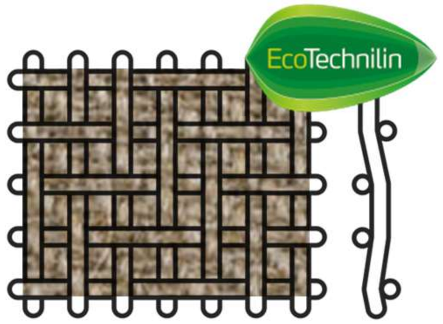


Flax + PLA

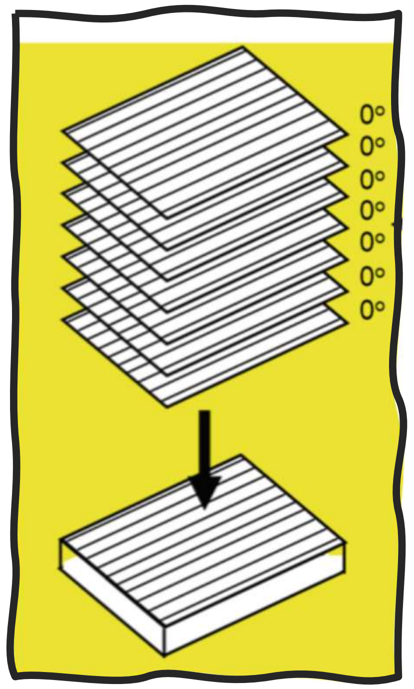
'PLA+flax 50% stronger than PP+flax'
higher strength than petro-based
Outperforms other combinations

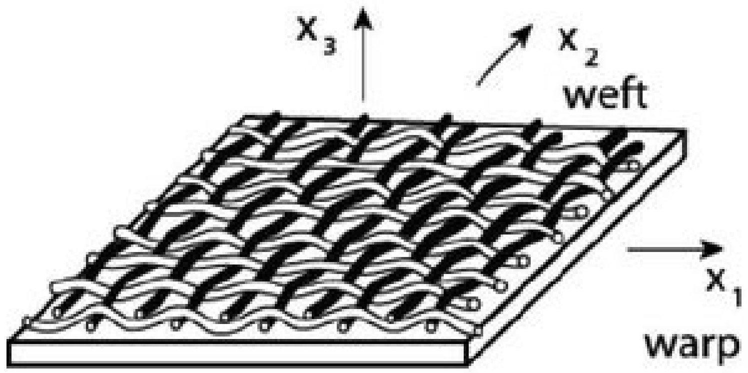
(Oksman et al., 2003; Manral et al. 2020)

Configuration



'2x2 Twill Weave Flax Fabric'
Warp Strength = Weft Strength
Pliable, High Drapability
High Impact Resistance



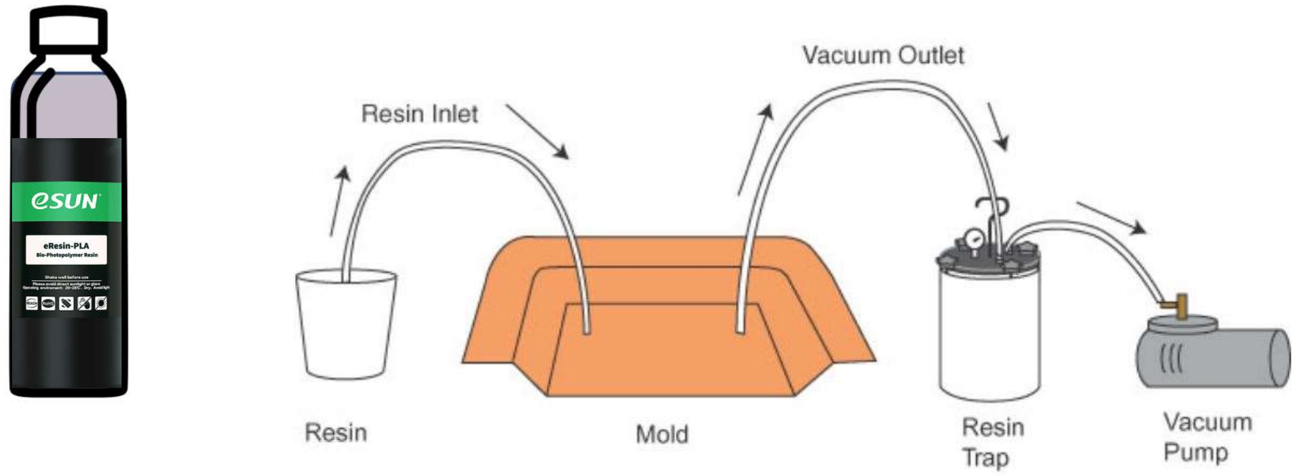


'Unidirectional Layup'

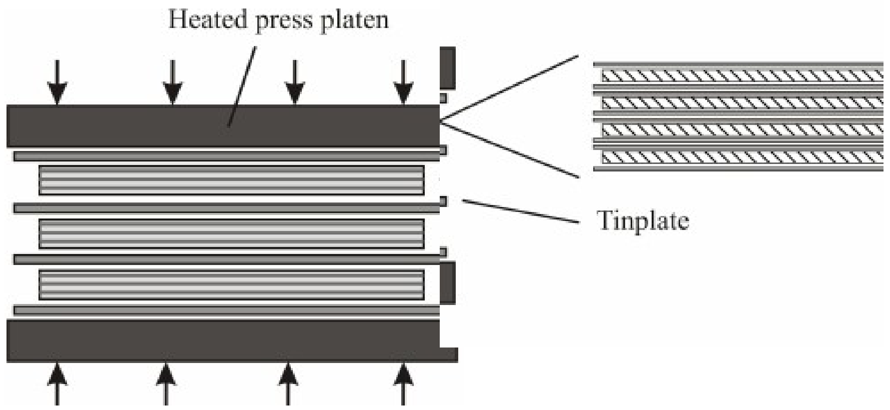
Twill Weave is Directionless
(Kazmi et al., 2023)

Consolidation

'Vacuum Assisted Resin Transfer Moulding'

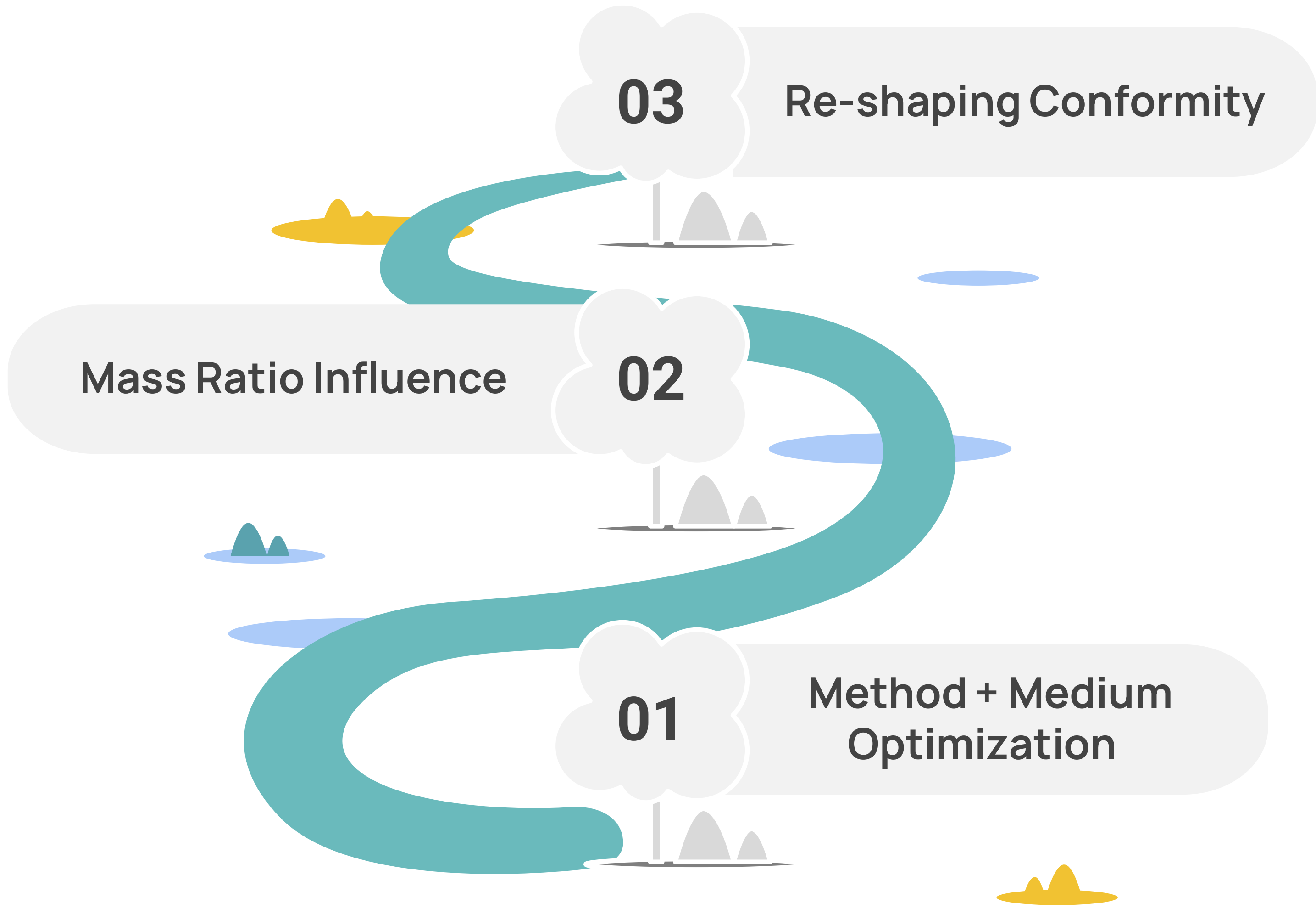


'Resin Film Infusion' & Hydraulic Hot Press



Design of Experiments

Experimental Road Map to System Design



Hypothesis 3

Is a **novel reshaping strategy feasible** for biocomposites?

If so, what are the **impacts** on mechanical properties?

Hypothesis 2

Do variations in **Flax-PLA mass ratios** influence **Exp1** process & resultant **composite traits ?**

Hypothesis 1

Which **method-medium combination** yields **optimal** sheet **consolidation** & minimal resource consumption ?

Design of Experiment 1

Which method-medium combination is optimum?

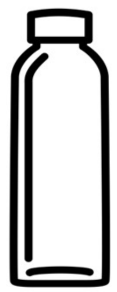
Experiment 1A

Experiment 1

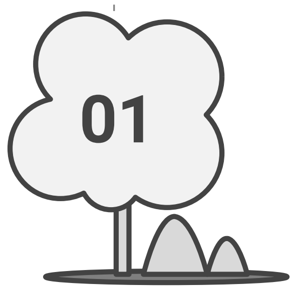
Experiment 1B

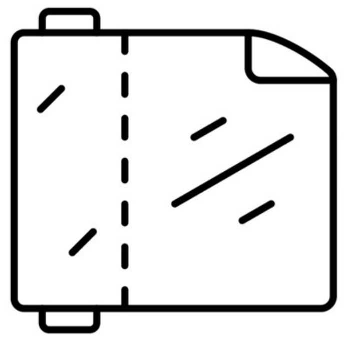
Favourable Outcome

Settings:



'Vacuum Assisted Resin Transfer Moulding'





'Resin Film Infusion' Hydraulic Hot Press

Response Variables: Consolidation, Texture Quality, Time – Cost – Skill Required, Waste Generated, Viability for Sheet Material

Experiment 1A

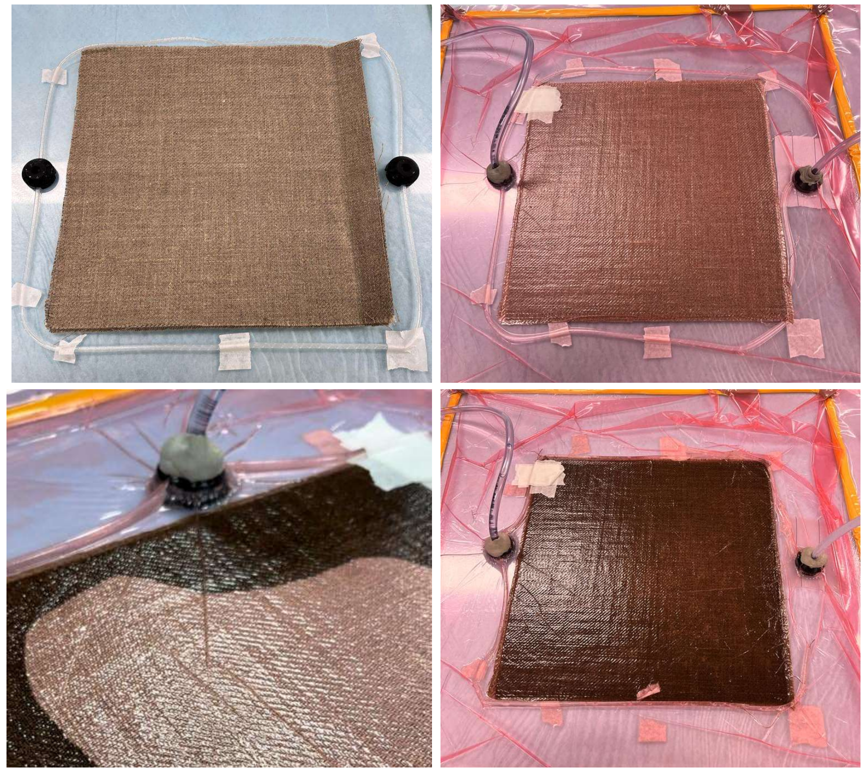
Vacuum Assisted Resin Transfer with PLA Photopolymer Resin

Vacuum Bagging Essentials + Resin Infusion Kit

Technical Twill Flax Fabric   Bio-photopolymer Resin

setup

Previous Work at TU Delft
(N. Merhi, 2022)



VARTM + UV Curing
24 hours   48 hours

procedure

Production at Think Lab, TU Delft
(S. Ghosh, 2023)

Time Required = **72+ Hours**
Cost & Skill Required = **High**

response variables

Consolidation = **Poor**
Surface Quality = **Uncured**
Waste Generated = **High Consumables**

Experiment 1B

Resin Film Infusion with PLA Film



Fontjine Lab Press + PHI Hydraulic Press
Steel Mould Plates + Silicone Rubber

Technical Twill Flax Fabric

PLA Film Resin

setup

Reviewed Literature

(Morales et al., 2017; Kazmi et al., 2023)

npsp


165 °C Heated Contact + 20 °C Cold Press
165 °C for 8 mins + 2.5 Tons 20 °C for 5 mins

procedure

Production at NPSP, Amsterdam Sloterdijk

Under supervision of Willem Bottger

Time Required = **15 Mins**
Cost & Skill Required = **Low**

response variables

Consolidation = Excellent Impregnation
Surface Quality = **Smooth, Cured**
Consumable = **Zero Waste Generated**

Experiment 1 Response

Which method-medium combination is optimum?

Factors & Settings

Direct comparison between
2 predetermined combinations:

VARTM with Polyol Resin vs Hot Pressing with Film.
* Constraint = Each PLA medium was specific to a technique

Under a high temperature – low pressure profile,

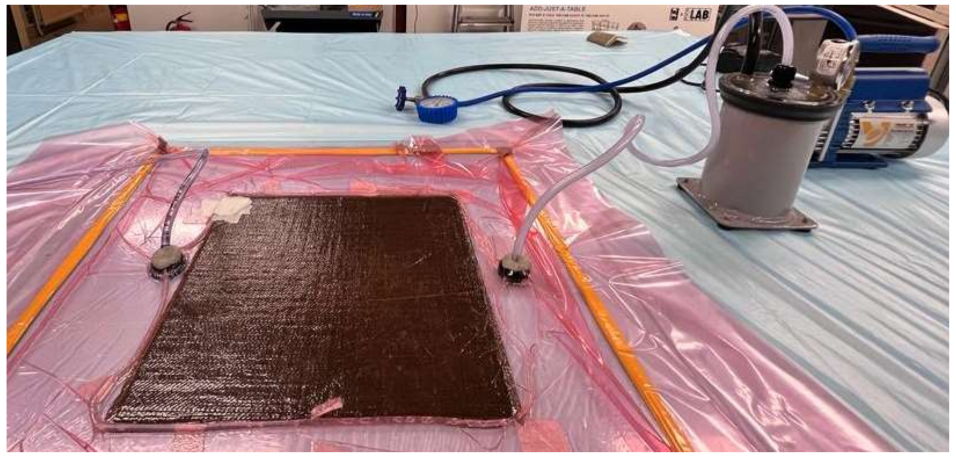
in < 15 minutes,

a stiff, bendable sheet

with 100% PLA fibre impregnation,

with **zero waste** and **optimal texture** and appearance.

VARTM + Polyol PLA Resin



Film Stacking Hydraulic Press+ PLA Film

Resin Film Infusion with PLA Film was better in all aspects.

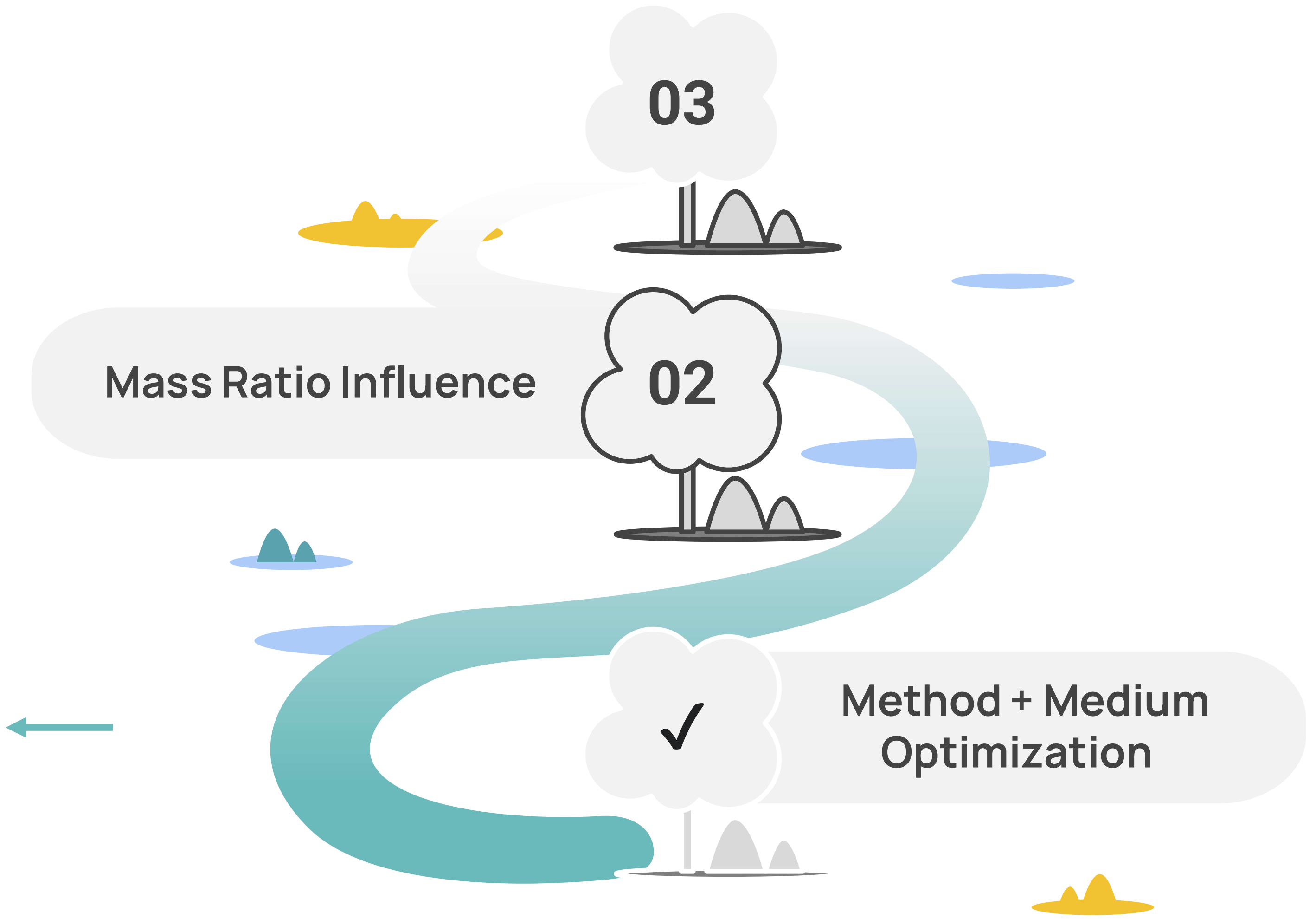
Hypothesis 2

Varying Fibre-Polymer Mass Ratios & Flax Lamina

Hypothesis 2

Do variations in **Flax-PLA mass ratios** and **lamina layers** influence **RFI** process & resultant **composite traits ?**

Input Experiment 1 Outcome



PLA Film + Resin Film Infusion

Design of Experiment 2

Influence of the permutations in mass ratios and fibre lamina plies

Settings

C 473	**4** Lamina; **7**0 % Flax : **3**0 % PLA
C 673	**6** Lamina; **7**0 % Flax : **3**0 % PLA
C 464	**4** Lamina; **6**0 % Flax : **4**0 % PLA
C 664	**6** Lamina; **6**0 % Flax : **4**0 % PLA

Mass Ratio + Lamina Count

4 Layer Flax, 70:30 Ratio

--------	16 PLA
=======	1 Flax
--------	8 PLA
=======	1 Flax
--------	8 PLA
=======	1 Flax
--------	8 PLA
=======	1 Flax
--------	16 PLA

4 Layer Flax, 60:40 Ratio

--------	20 PLA
=======	1 Flax
--------	16 PLA
=======	1 Flax
--------	16 PLA
=======	1 Flax
--------	16 PLA
=======	1 Flax
--------	20 PLA

6 Layer Flax, 70:30 Ratio

--------	21 PLA
=======	1 Flax
--------	8 PLA
=======	1 Flax
--------	8 PLA
=======	1 Flax
--------	8 PLA
=======	1 Flax
--------	8 PLA
=======	1 Flax
--------	8 PLA
=======	1 Flax
--------	21 PLA

6 Layer Flax, 60:40 Ratio

--------	20 PLA
=======	1 Flax
--------	18 PLA
=======	1 Flax
--------	18 PLA
=======	1 Flax
--------	18 PLA
=======	1 Flax
--------	18 PLA
=======	1 Flax
--------	18 PLA
=======	1 Flax
--------	20 PLA

Method + Medium

npsp

Production at NPSP
Supervised by Willem Bottger

165 °C Heated Contact + 20 °C Cold Press

resin film infusion
165 °C for 8 mins + 2.5 Tons 20 °C for 5 mins

(Salman et al., 2007; Kazmi et al., 2023)

Experiment 2

Responses

Observed Outcomes: Time-Temp-Pressure requirements for required for perfect consolidation, along with appearances & texture.

4 Layers ; **70:30** **C-473**

8 mins | 2.5 Ton | Coarse

6 Layers ; **70:30** **C-673**

8 mins | 5 Ton | Coarse

4 Layers ; **60:40** **C-464**

12 mins | 2.5 Ton | Smooth

6 Layers ; **60:40** **C-664**

12 mins | 5 Ton | Smooth

varying outcomes

Verified Literature

(Morales et al., 2017; Kazmi et al., 2023)

5 Ton — **6** Lamina

12 mins — **60:40** Ratio

Smooth — **40%** PLA

Specimen Preparation

Varying Fibre-Polymer Mass Ratios & Flax Lamina

+	corner 1	corner 2	corner 3	corner 4	Avg (mm)
473	2.02	2.01	2.00	2.01	**2.01**
673	3.05	3.08	3.00	3.03	**3.04**
464	2.60	2.80	2.80	3.00	**2.80**
664	4.60	4.50	4.60	4.30	**4.47**

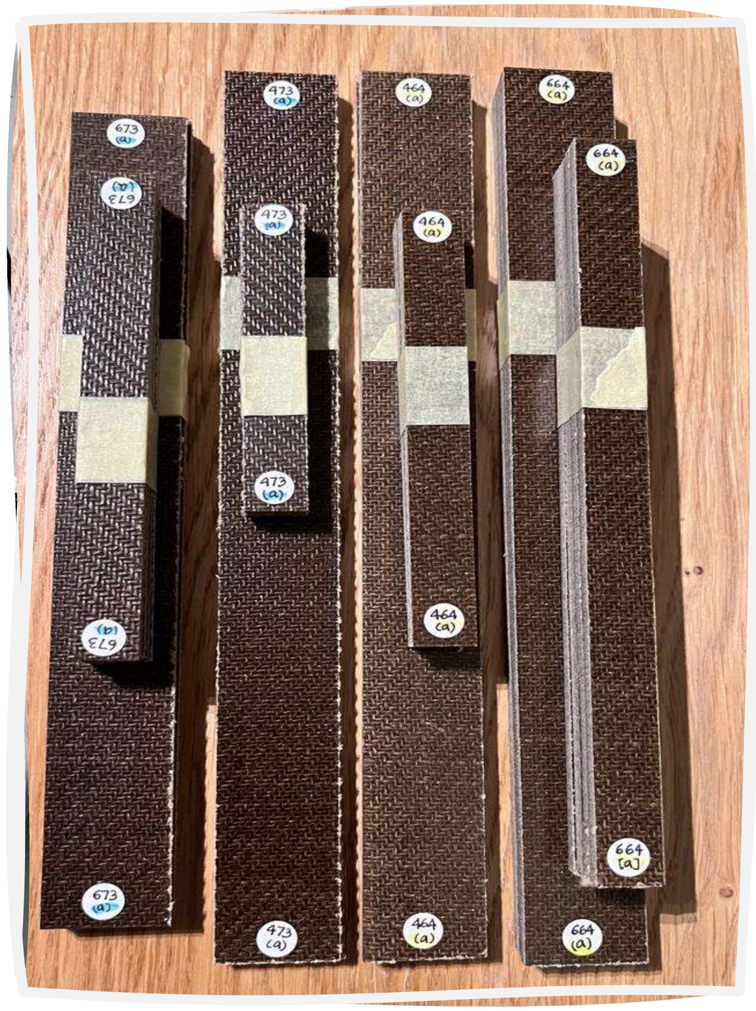
Flexural Test Specimens
According to **ASTM Code D7264**
Width of Specimen = 13 mm
Test Span = 32 * Thickness
Length of Specimen = 1.2 * Test Span

Tensile Test Specimens

According to **ASTM Code D3039**
Width of Specimen = 25 mm
Length of Specimen = 250 mm

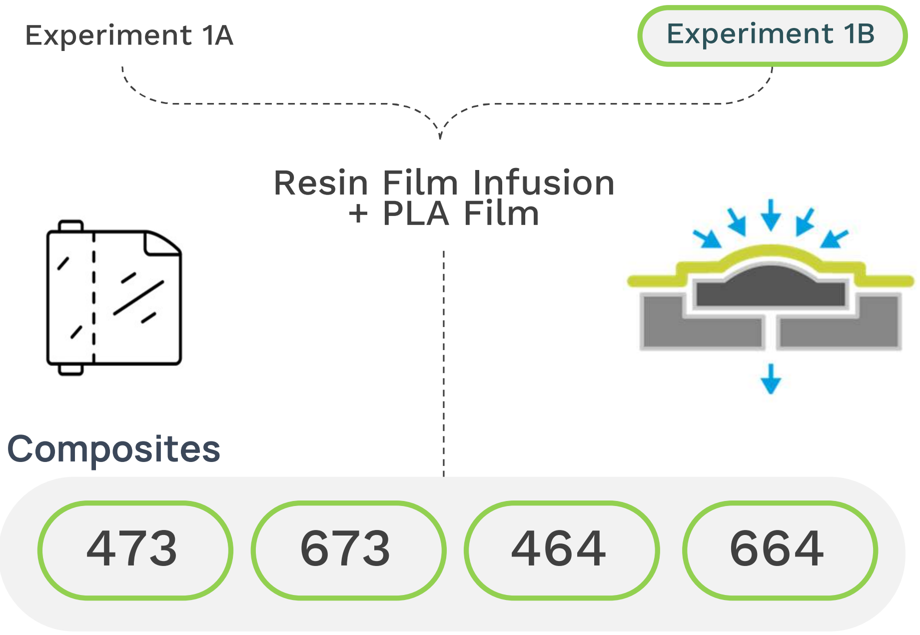
measurements

Per ASTM Codes



machining

Under Supervision of Technician Chris at Wood Workshop, TU Delft



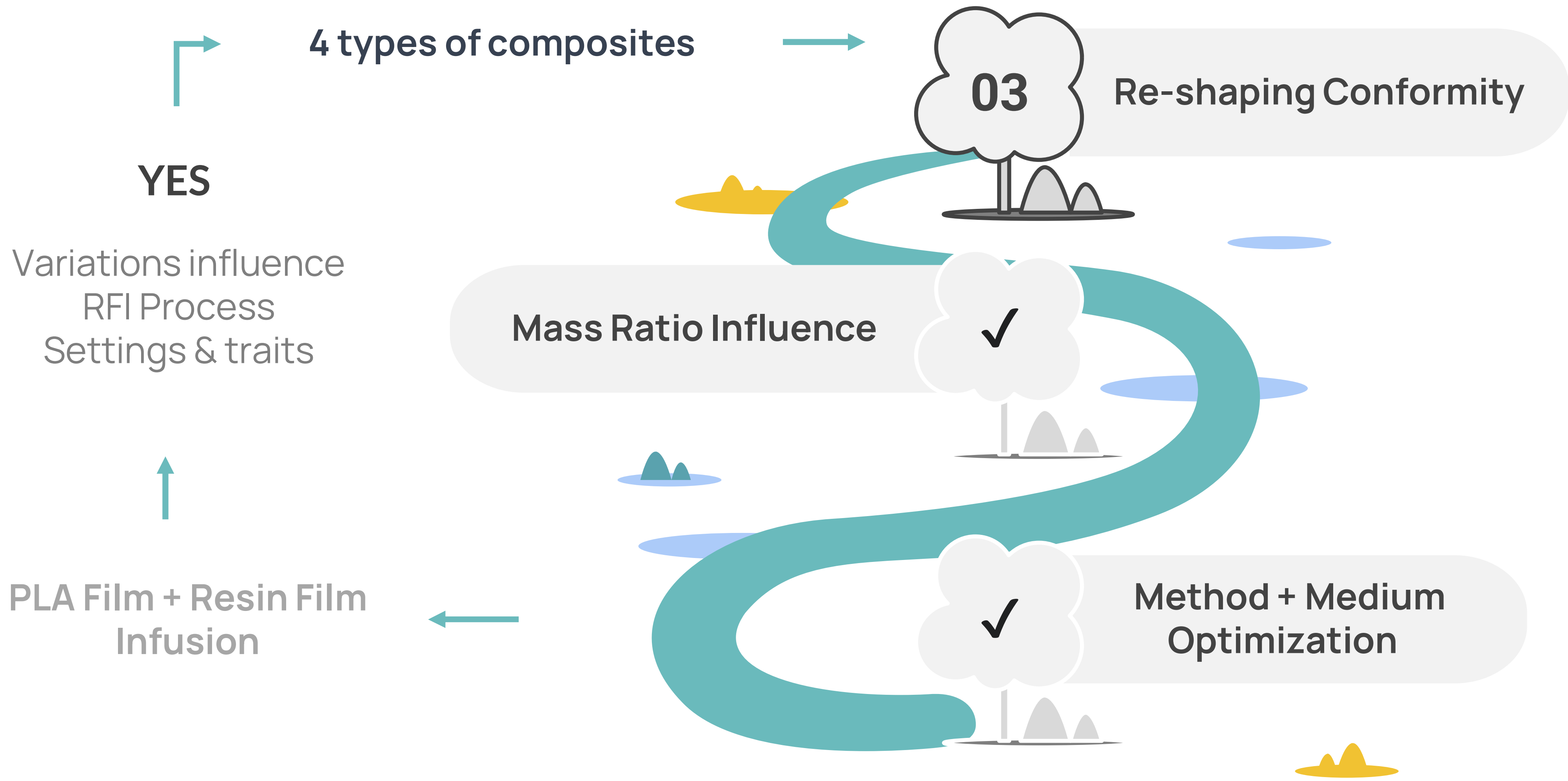
Flexural Test Specimens

Tensile Test Specimens

4 Tensile Specimens Each

4 Flexural Specimens Each

Hypothesis 3



Hypothesis 3

Is a **novel reshaping strategy feasible** for biocomposites?

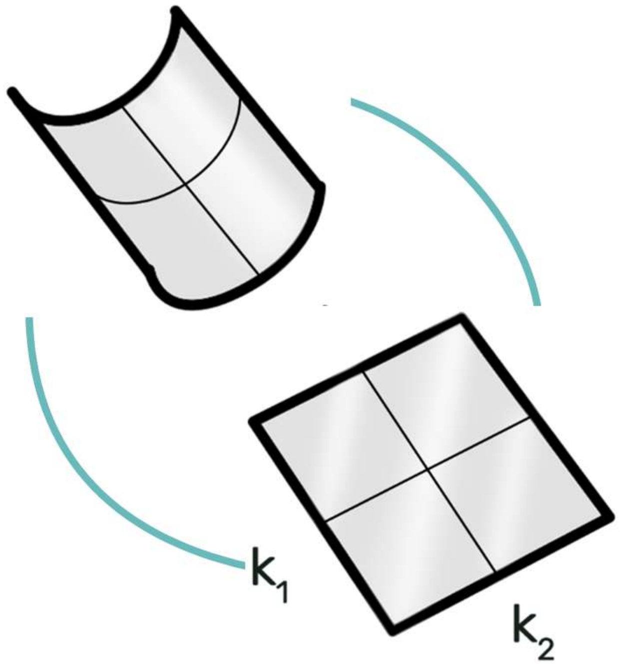
If so, what are the **impacts** on mechanical properties?

Design of Experiment 3

Hypothesis 3

Is it feasible to prove developability /reshaping in biocomposites?

*'**Developability**', the geometric ability to be formed by folding 2D plane & transforming it back without distortion.*

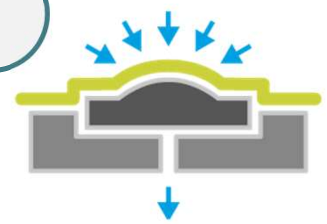


Novel Reshaping Strategy with 473, 673, 464, 664

Experiment 1A

Experiment 1B

Resin Film Infusion + PLA Film



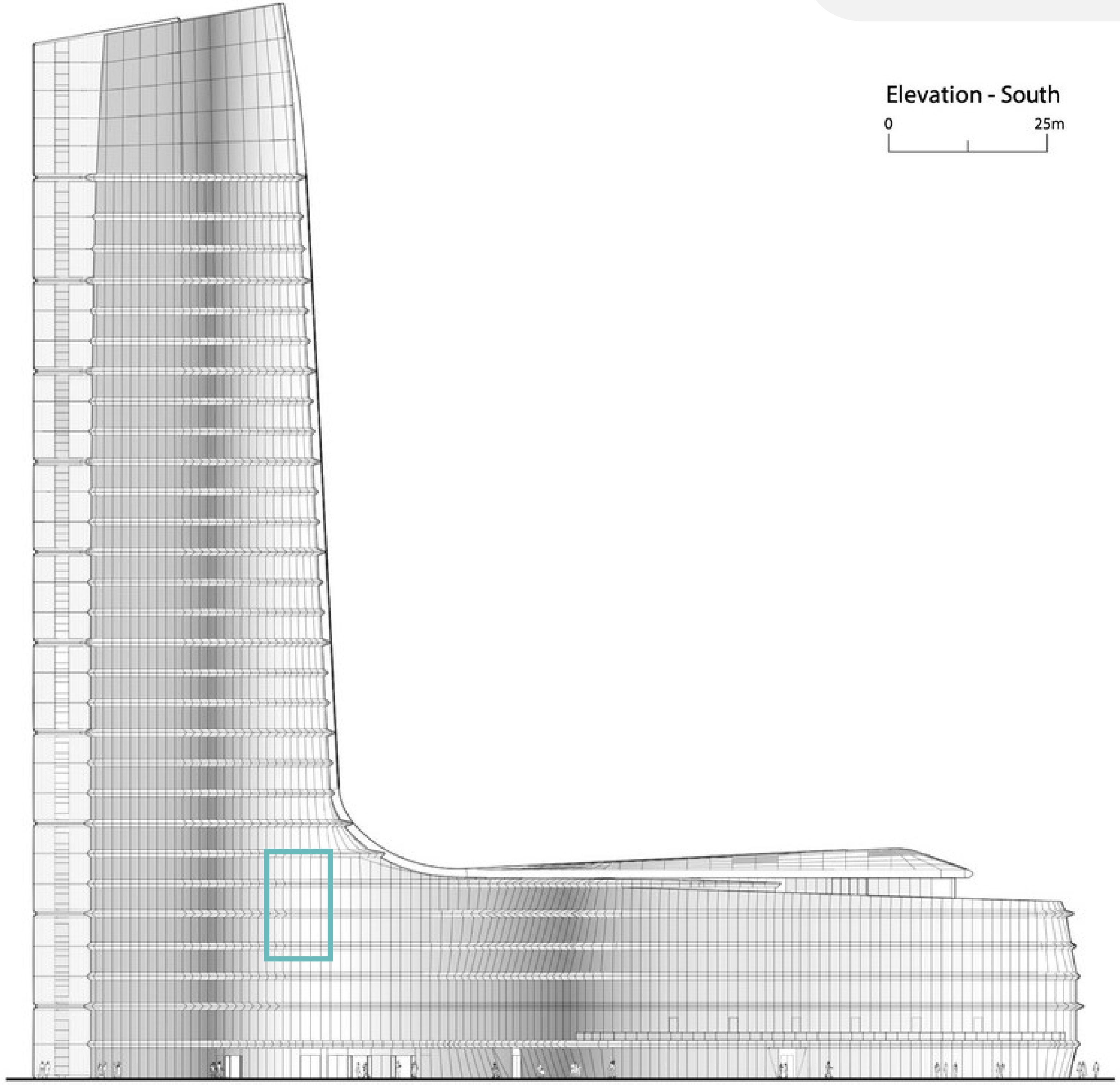
Factors & Settings

473 | 673 | 464 | 664

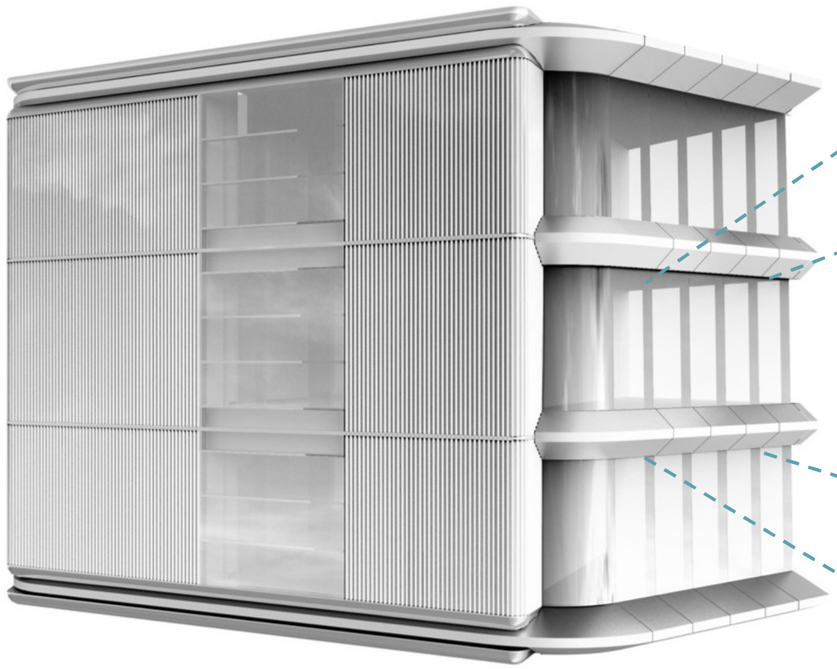
1 Tensile Specimen Each

1 Flexural Specimen Each

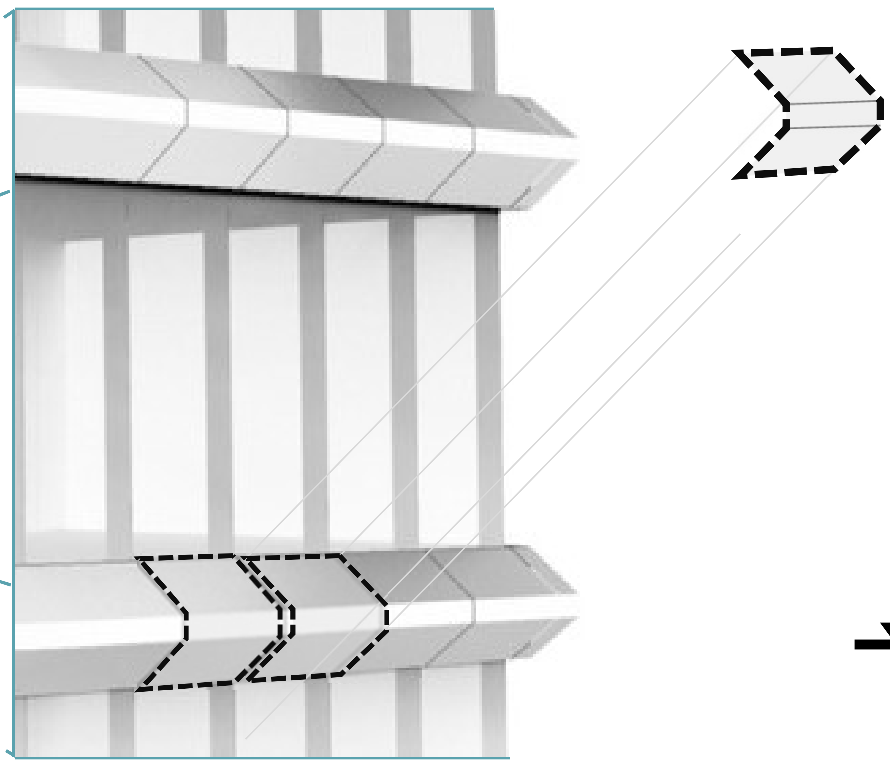
Demonstrate Reshaping


Elevation - South
0
25m

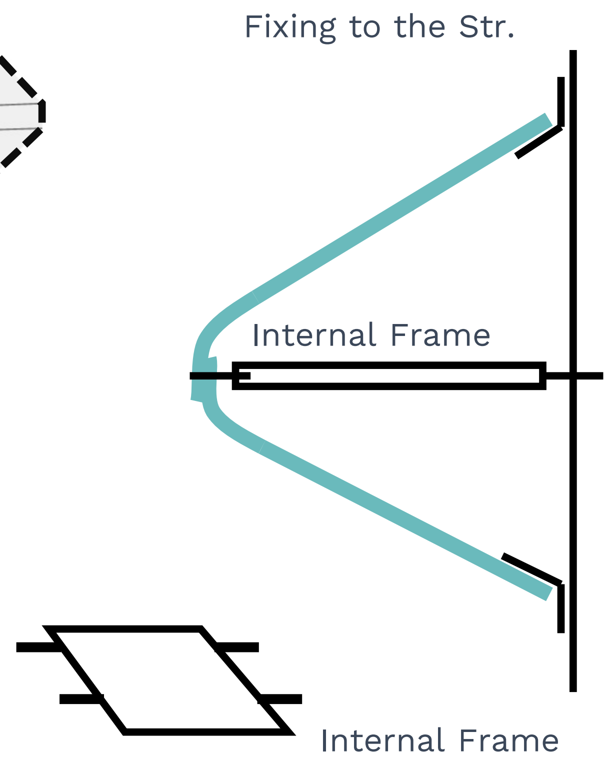
Case Geometry



MOL Campus Cladding Mock-up
From Case Study Details - Scheldebouw



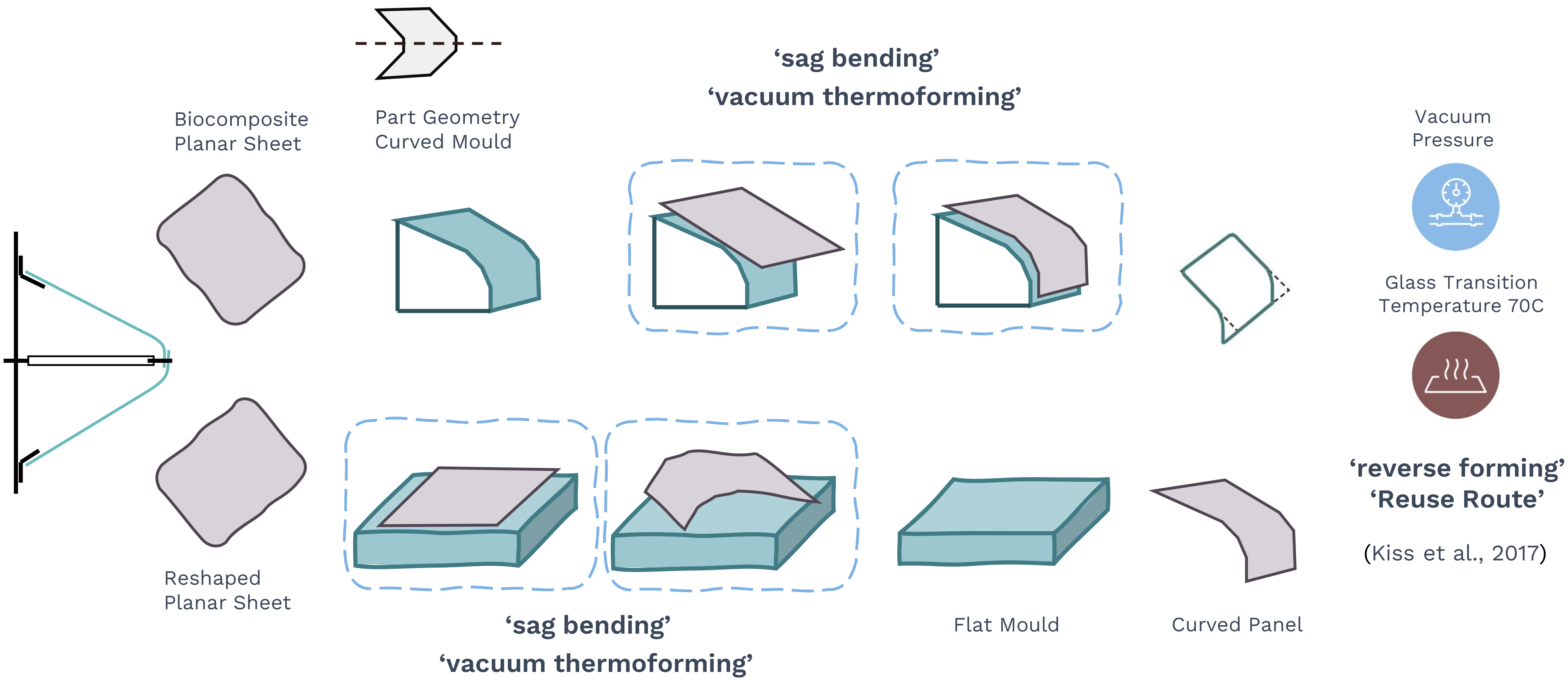
Part Geometry
'emulating'



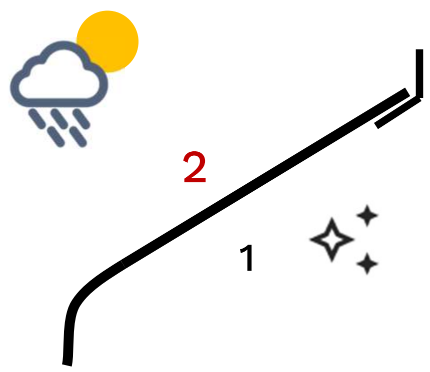
'rethinking'
With Flax-PLA Composite

current production lab limits
60x60cm press, panel in parts

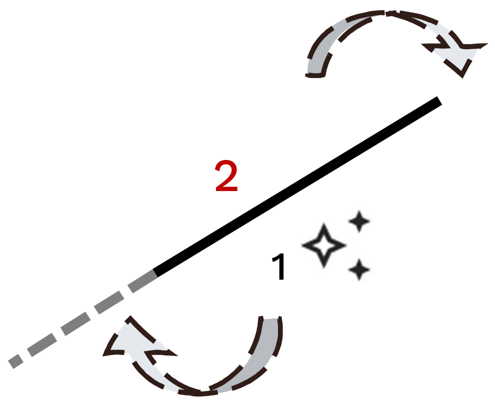
The Reverse Forming Strategy



Reverse Forming in Practice

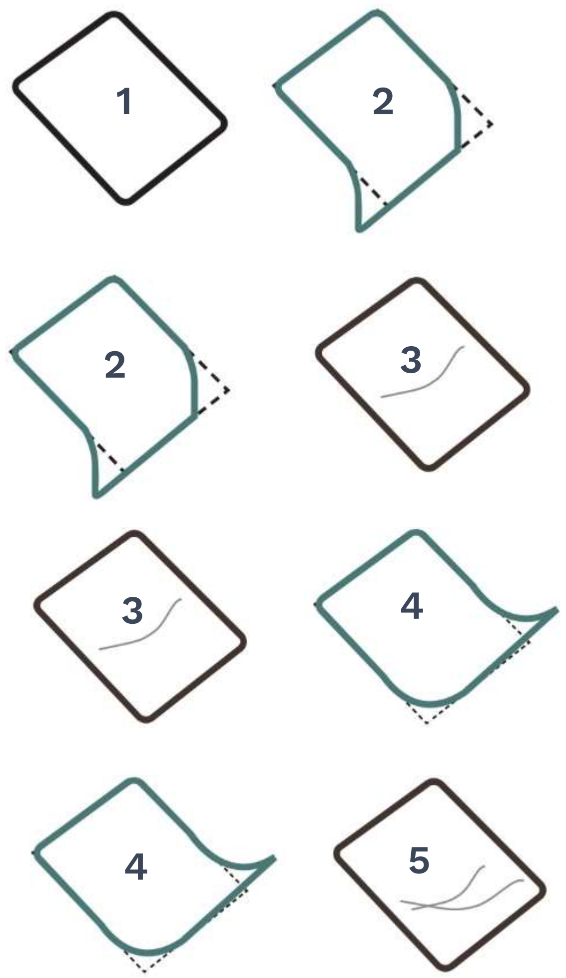


A) Original Flat Sheet is **Shaped as Profile**



B) **Profile** demounted; formed **back to Flat**

C) Protected **Interior Facia** has **potential**, so **Panel reverse & curved** for **Reuse**.



Manufacture Curve & Install

Post Service Life, Demount & Flatten

Reverse – Curve

Install Again

Post Lifespan

Flatten for ... ()

reserve strength of **unexposed interior** surface

can be leveraged

to **extend the design life** of the cladding panel.

Strategy Rank

Is it feasible to prove developability /reshaping in biocomposites?

'Smarter Product Use & Manufacture'

(Potting et al. 2017)

'Extend Life Span of Product & it's Parts'

DOMAINS
(major)

Refuse RAW MATERIAL USE	**Rethink** INTENSIFYING PRODUCT USE	**Reduce** CONSUMING LESSER RESOURCES
Re-Use FULFILS ORIGINAL FUNCTION	Repair REPAIR & MAINTAIN FOR REUSE	Refurbish RESTORE OLD PRODUCT
Biological Origins MATERIAL	Sheet Forming for Cyclic Shaping MANUFACTURING	Repurpose - Remould MANAGEMENT

Vacuum Thermoforming

Feasibility check of the Reshaping

Specimens

473 | 673 | 464 | 664

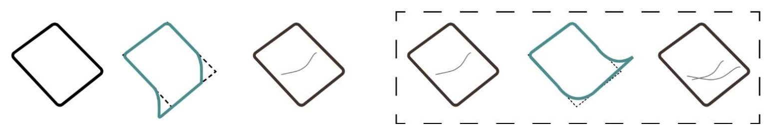
Tensile Specimen

Flexural Specimen

8 specimens

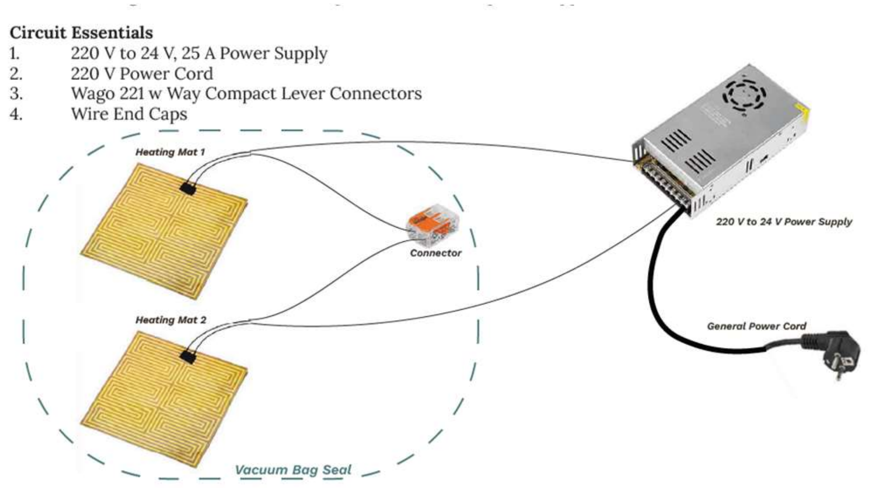
Reshaping Cycles applied to all **8** specimens

4 Tensile Specimens – 2 Shaping Cycles
4 Flexural Specimens – 2 Shaping Cycles



setup

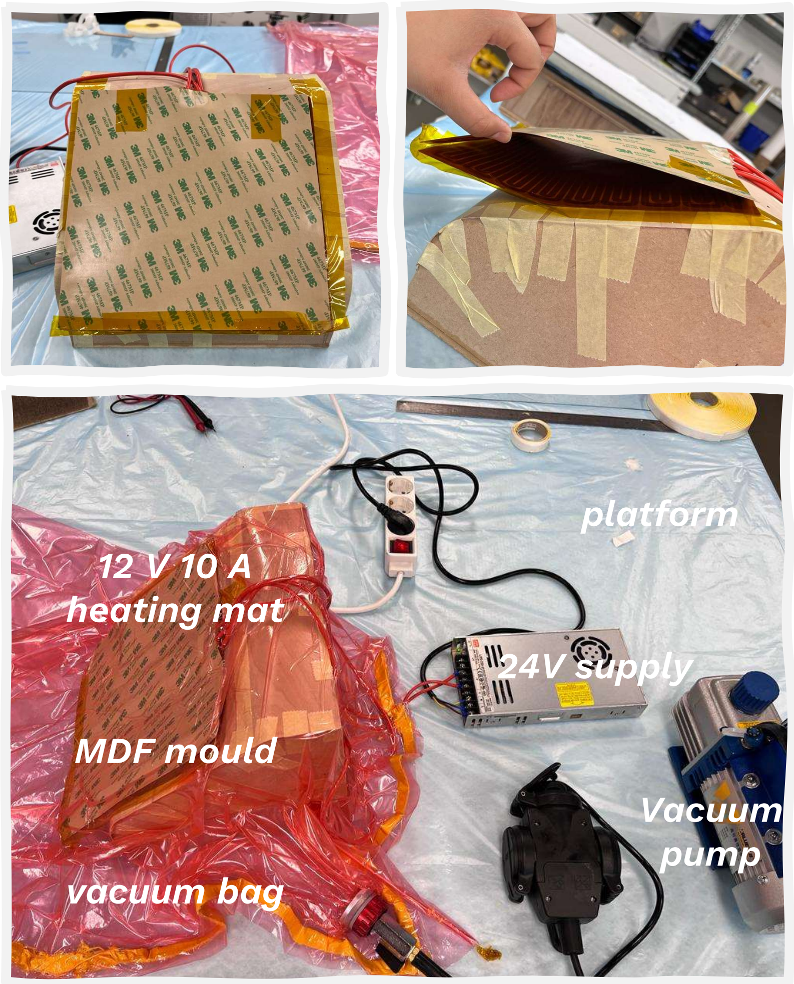
kit of parts



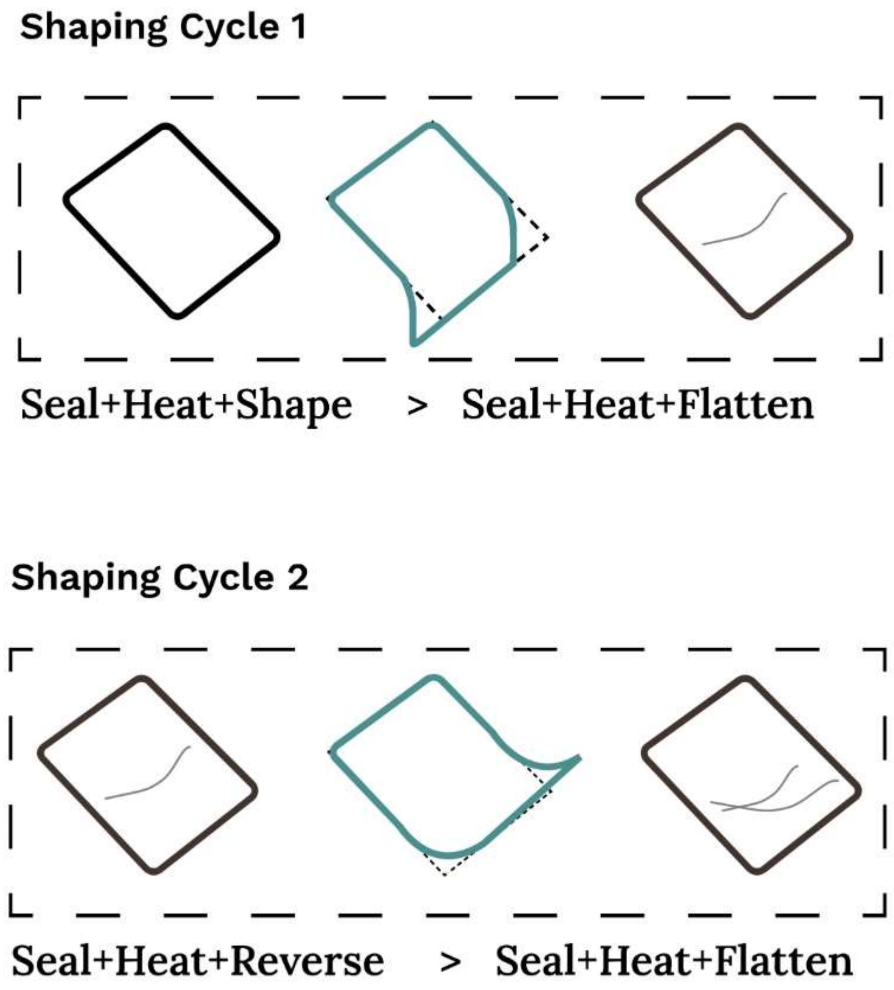
circuit & seal assembly

Reshaping Results

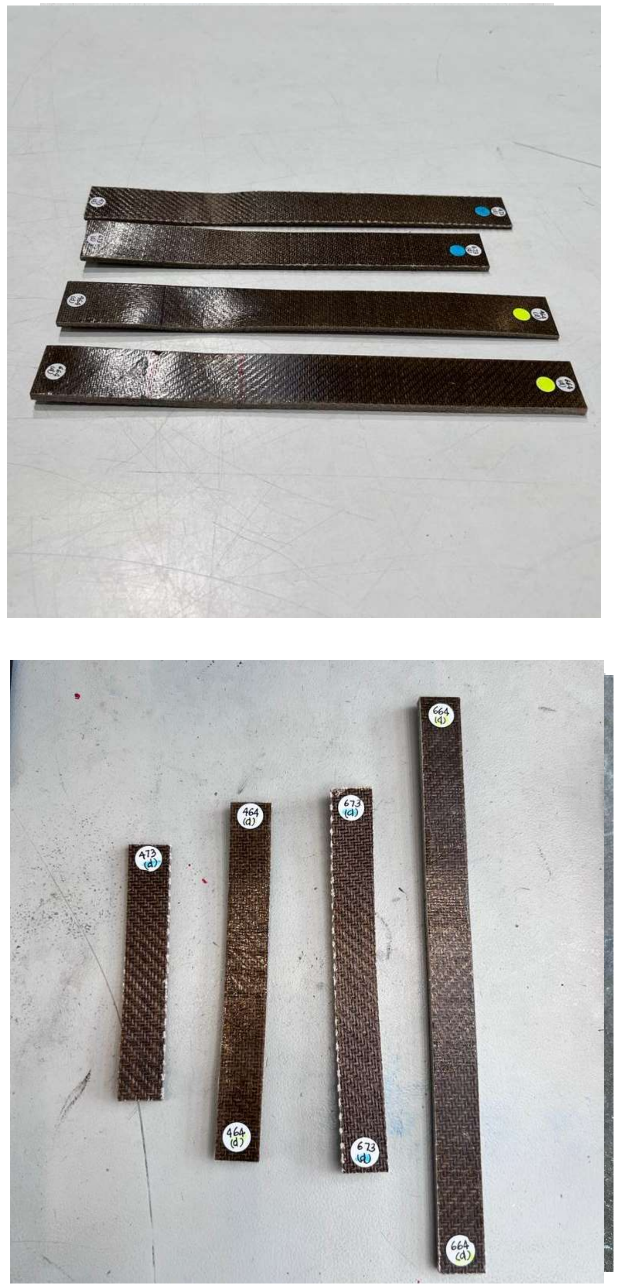
Mould Conformity = **High**
Time Required = 1-3 mins to reach Tg
Power Supply = 2A Vacuum, 20 A Mat



vacuum thermoforming



shaping cycles

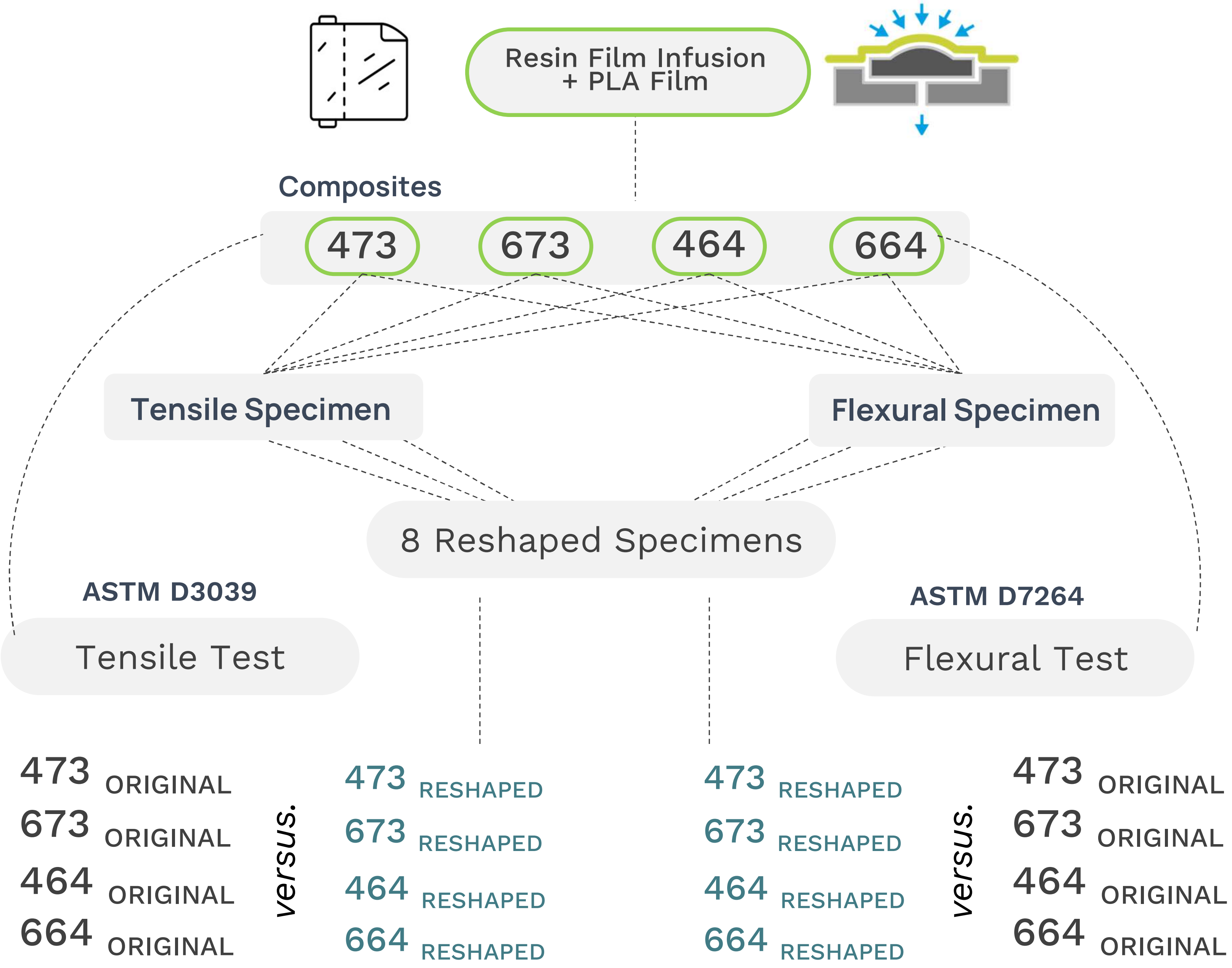


outcomes

Yes, vacuum thermoforming using heat-pads can reshape the FLAX PLA composite.

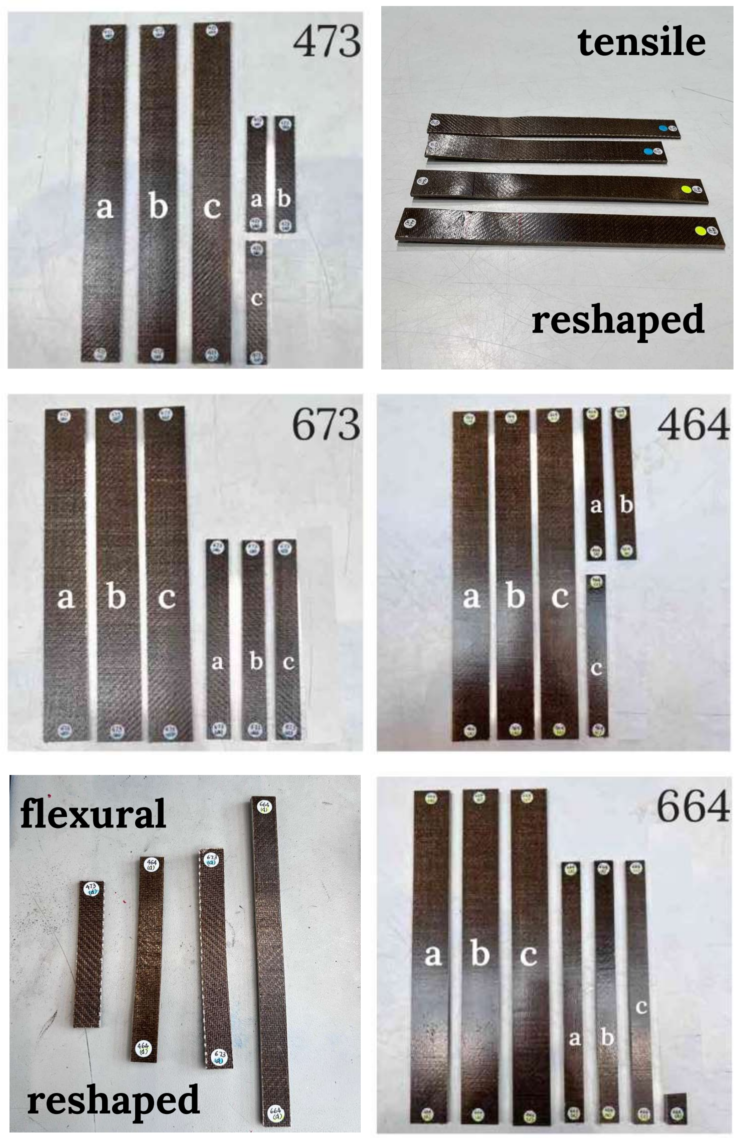
Testing Program

Is there a difference in mechanical properties of the biocomposite before & after reshaping?



Strength Testing

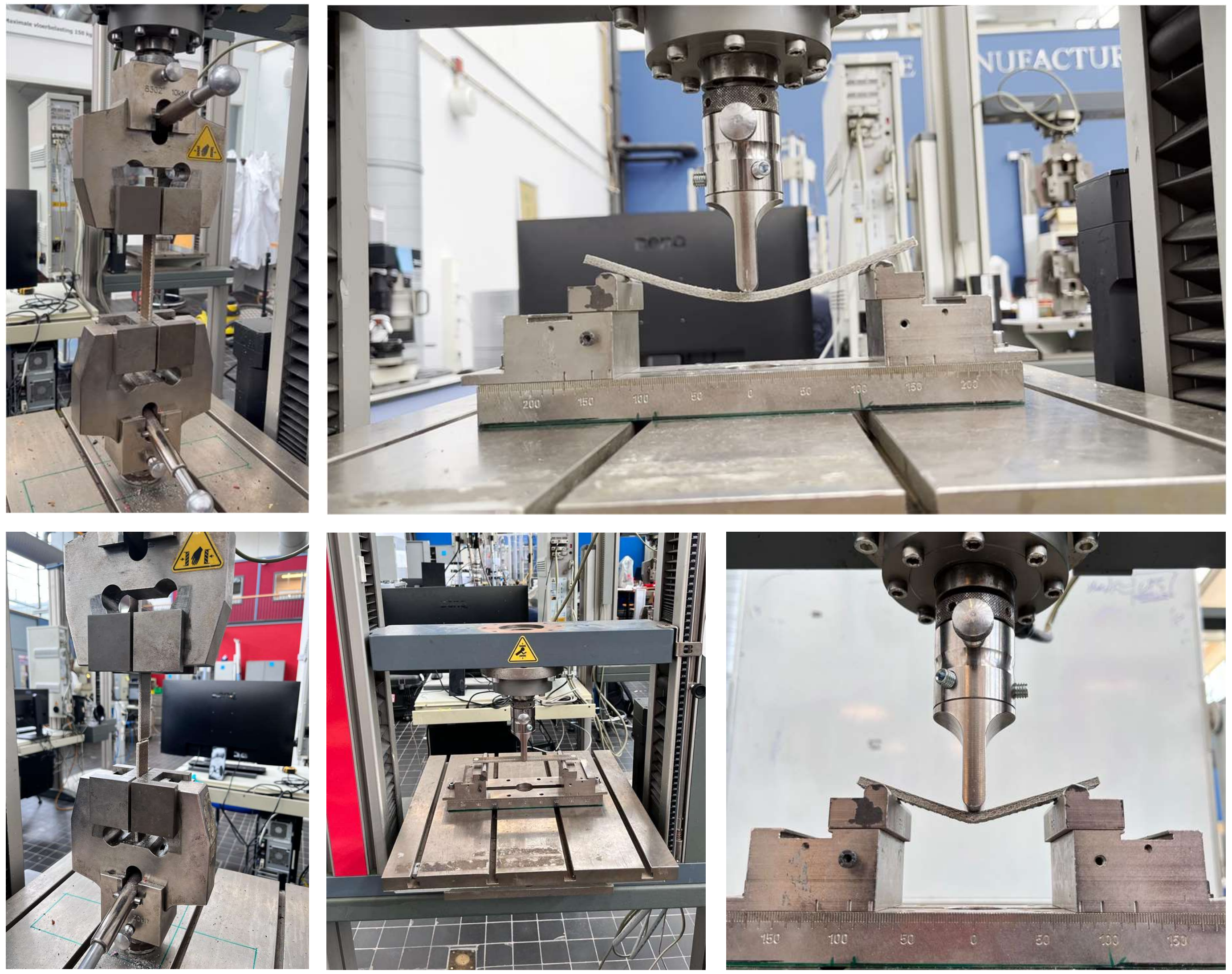
Original Specimens : Tensile & Flexural Test Batch



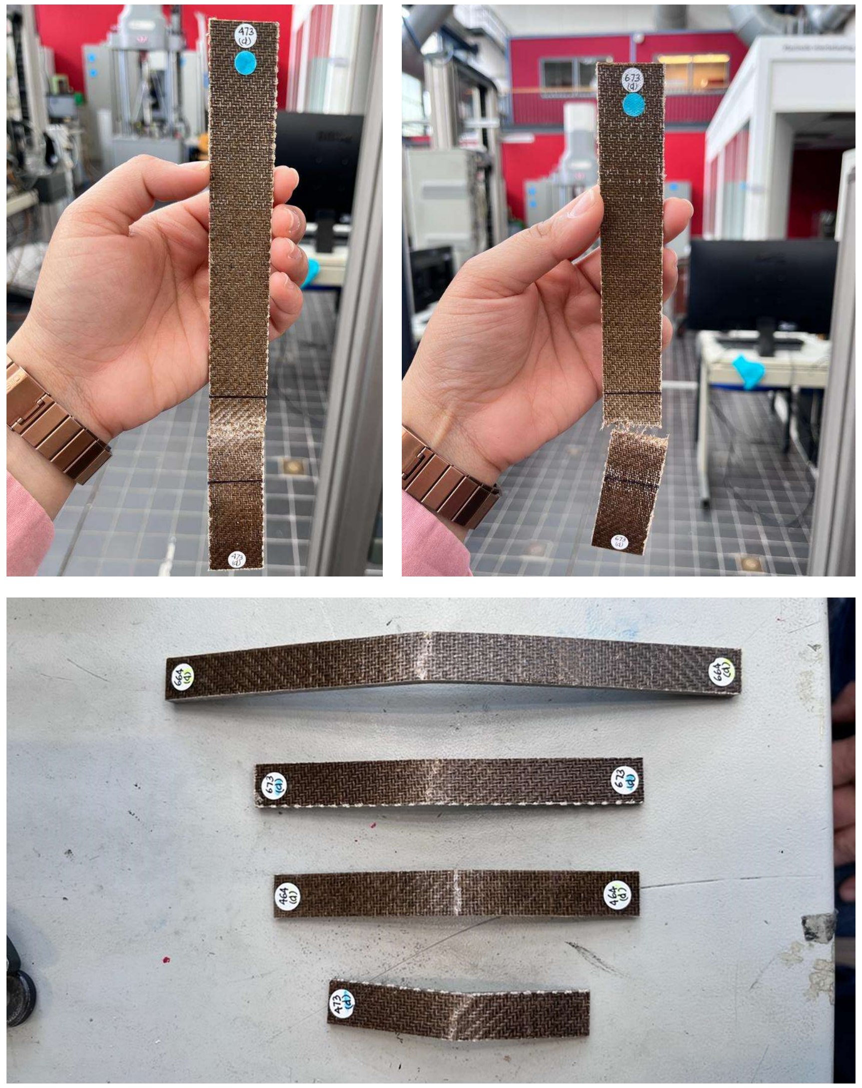
Testing Program

Responses Deflection between Original Specimens vs. Reshaped Specimens

'test protocol'

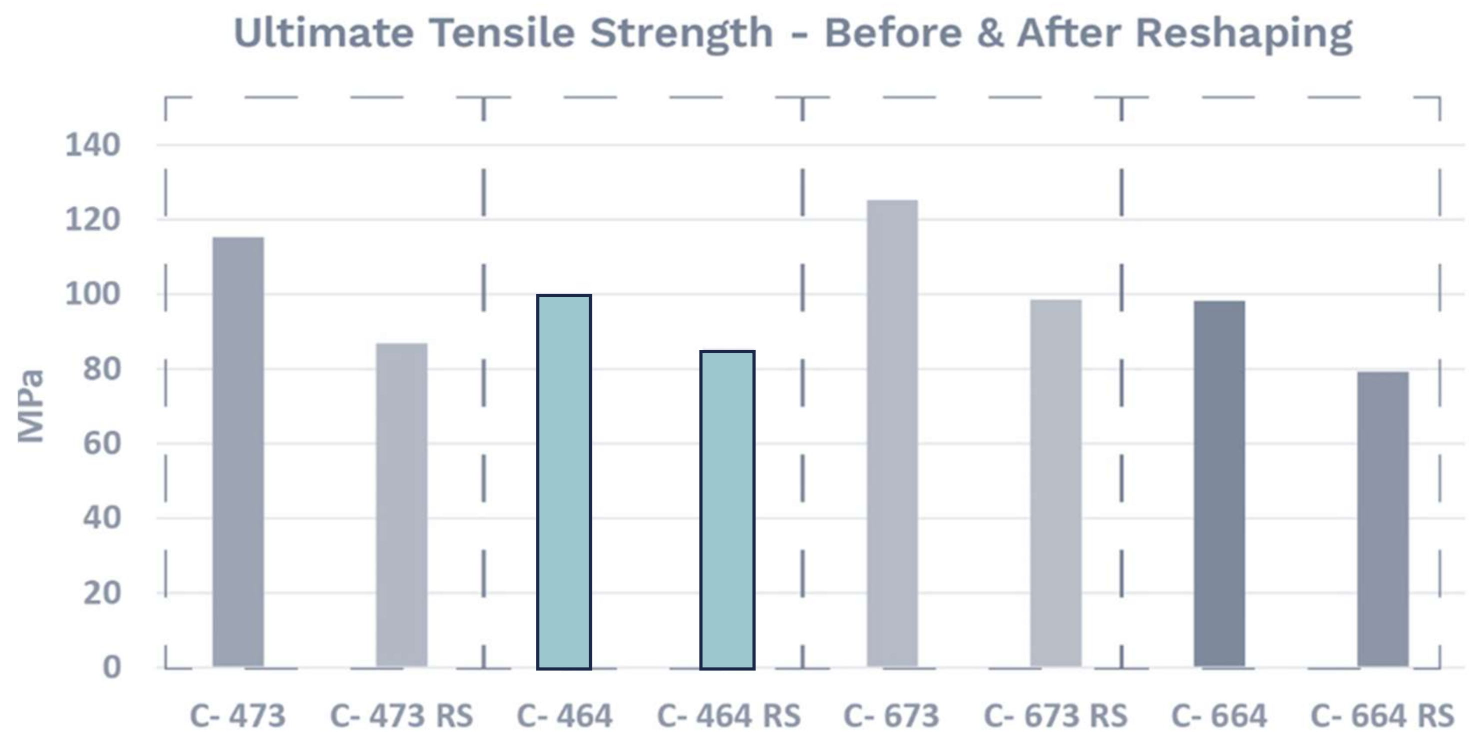


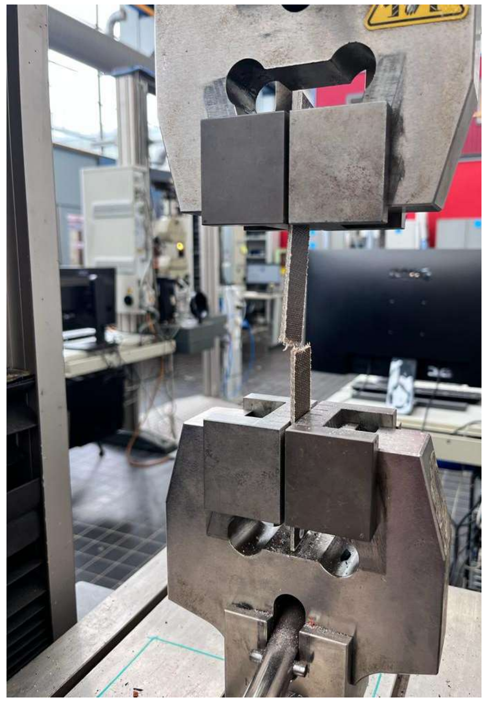
tensile & flexural testing

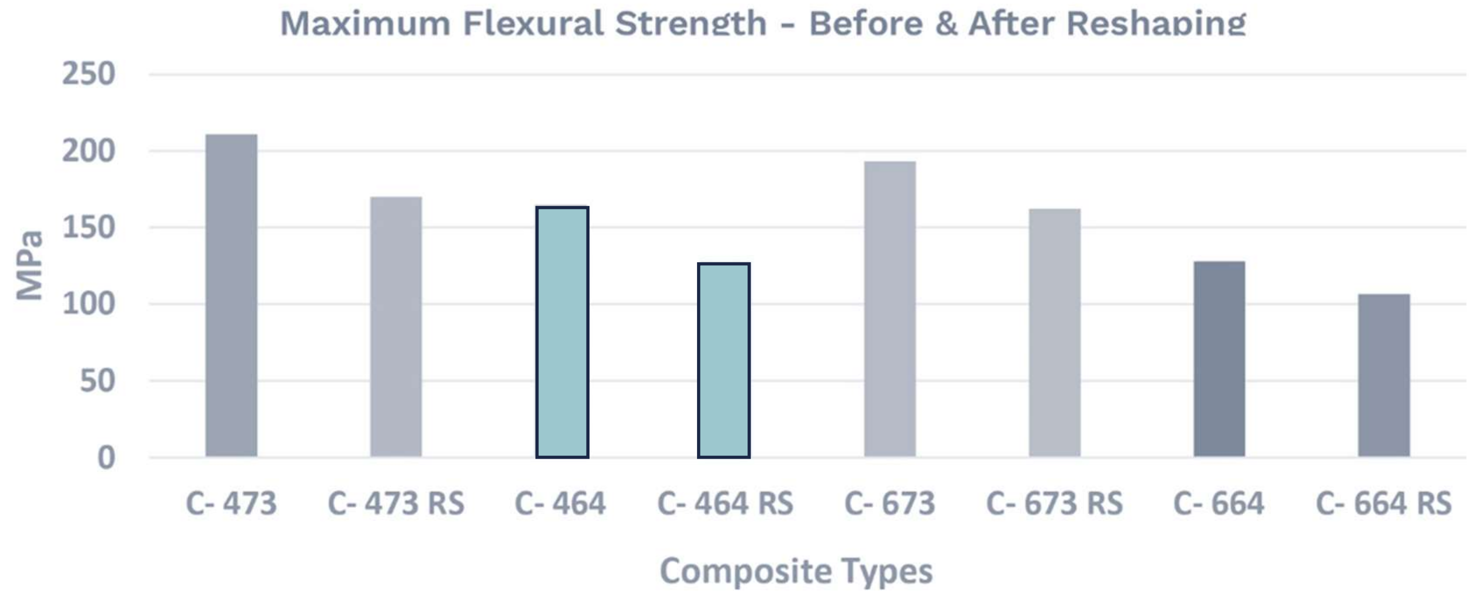


outcomes

Result Trends







Ult. Tensile Strength
15% to 25%
due to Reshaping

Reduction in % **Less** when

High PLA
Ratio
60:40

Low Flax
Lamina
4 Layers

Max Flexural Strain

Increase is higher in 6 layer
Lowest strain in 4 layers

C-464

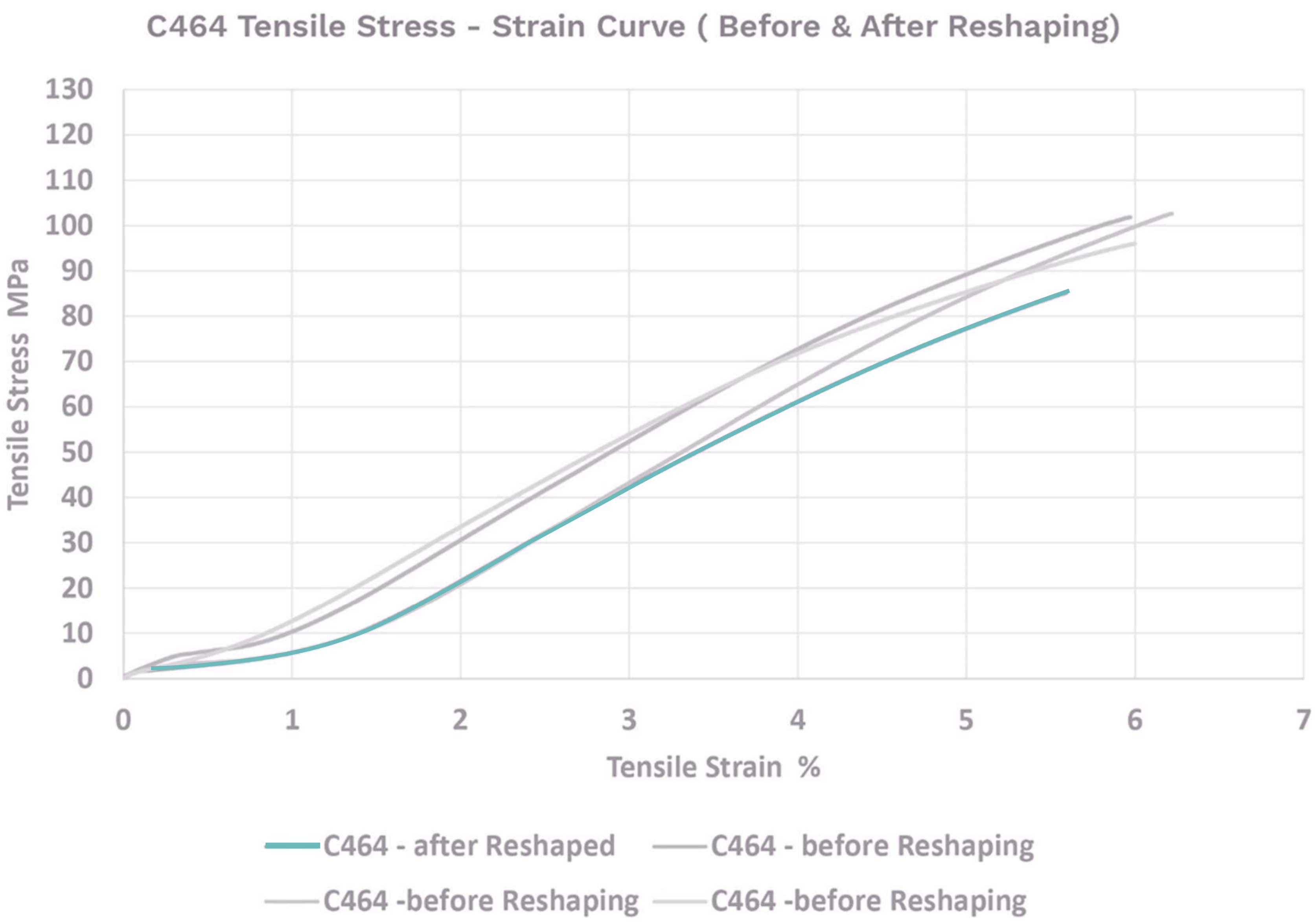


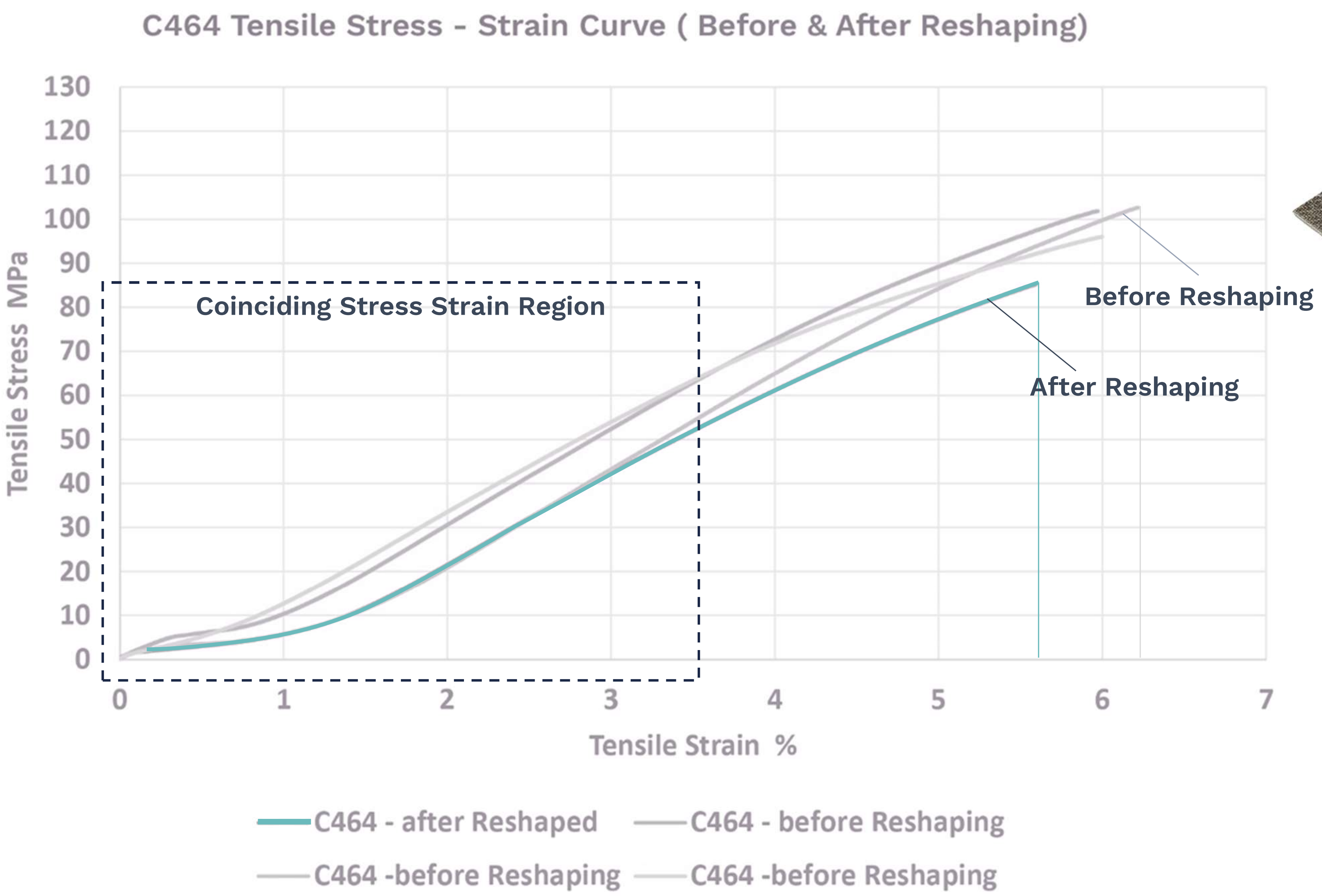
Table - C 464 - Ultimate Tensile Properties Before & After Reshaping

Description	Value	Unit
F^{tu} Ultimate Tensile Strength	100.071	MPa
E^{chord}-Chord Modulus of Elasticity	1.195	GPa
ε - Ultimate Tensile Strain	6.050	%
F^{tu} Ultimate Tensile Strength - Reshaped	85.250	MPa
E^{chord}-Chord Modulus of Elasticity - Reshaped	1.254	GPa
ε - Ultimate Tensile Strain - Reshaped	5.593	%

Table - C 464 - Flexural Properties Before & After Reshaping

Description	Value	Unit
σ Max Flexural Strength	165.027	MPa
E_f^{chord}-Chord Modulus of Elasticity	1.769	GPa
ε - Max Flexural Strain	2.539	%
σ Max Flexural Strength - Reshaped	127.976	MPa
E^{chord}-Chord Modulus of Elasticity - Reshaped	1.200	GPa
ε - Max Flexural Strain - Reshaped	2.843	%

C-464



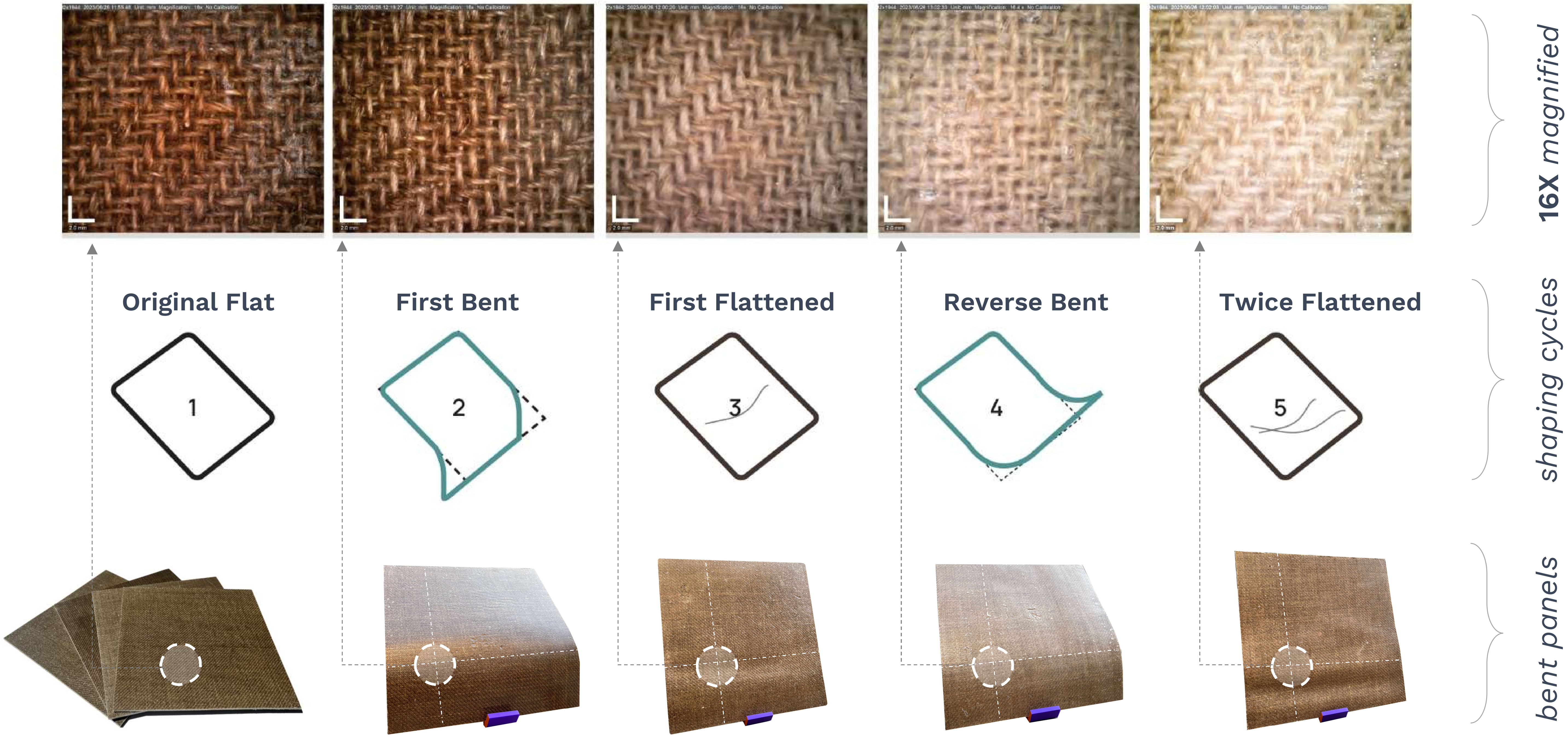
Lowest Reduction
Tensile Strength
– 15%

Lowest Increase
Max Flexural
Strain

Wind Load
Deflection
(External)

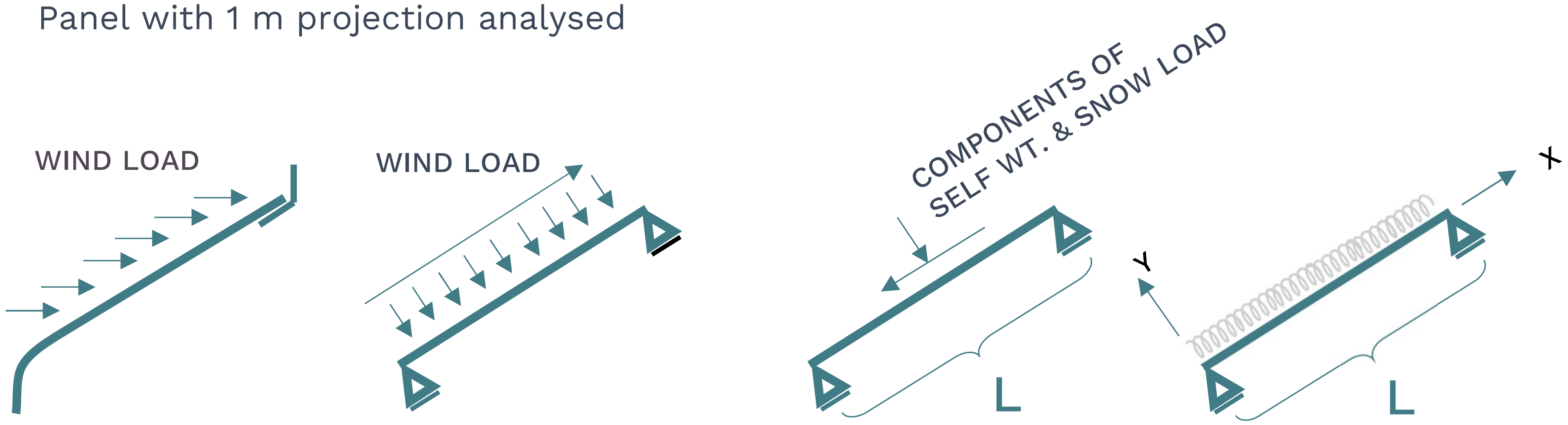
Micrographs of C-464

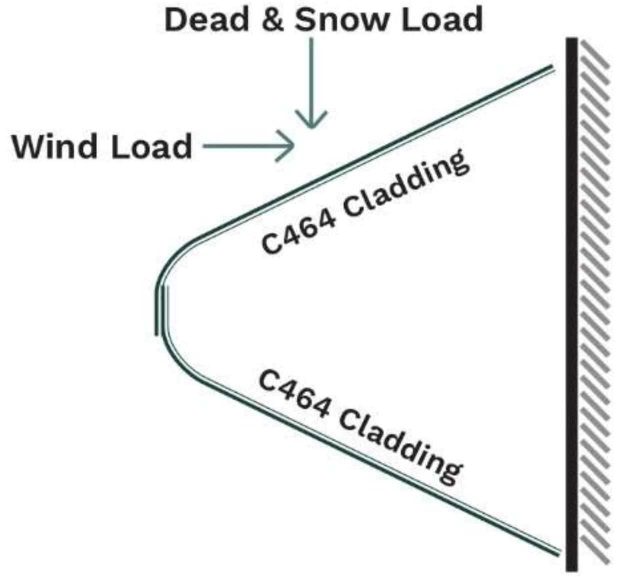
Texture **Unchanged for 60:40 ; Fade seen in 70:30**



Reduced Strength Analysis

Panel with 1 m projection analysed



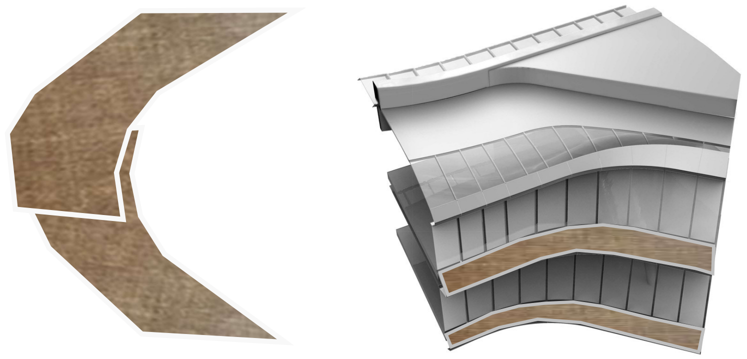


Case Study:

across all load combinations

C464: Post **Reshaping**

With 1.5 Safety Factor



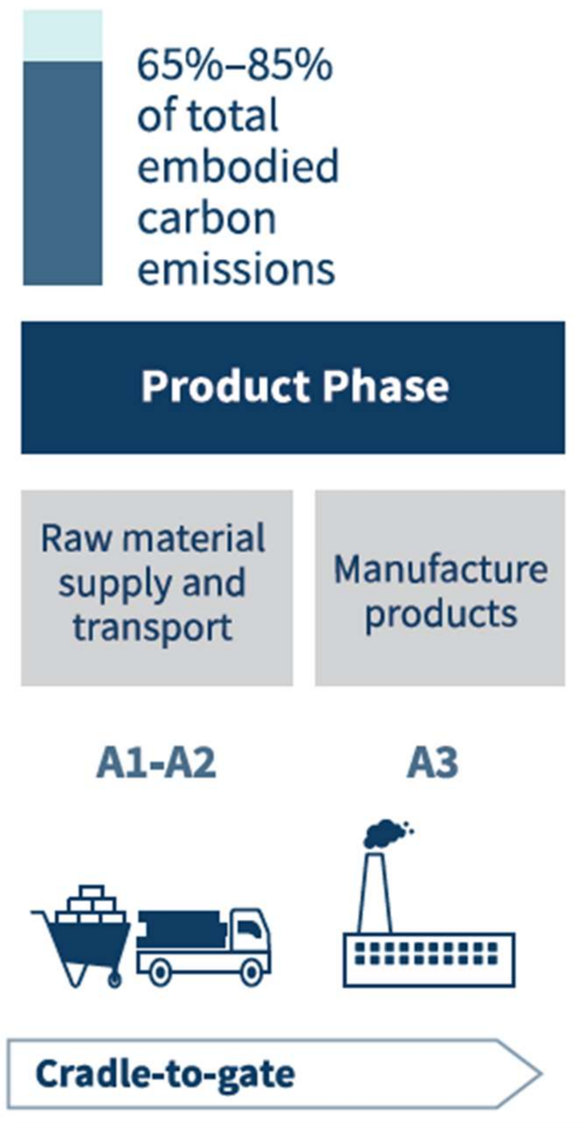
Maximum Flexural Stress
68.97 MPa

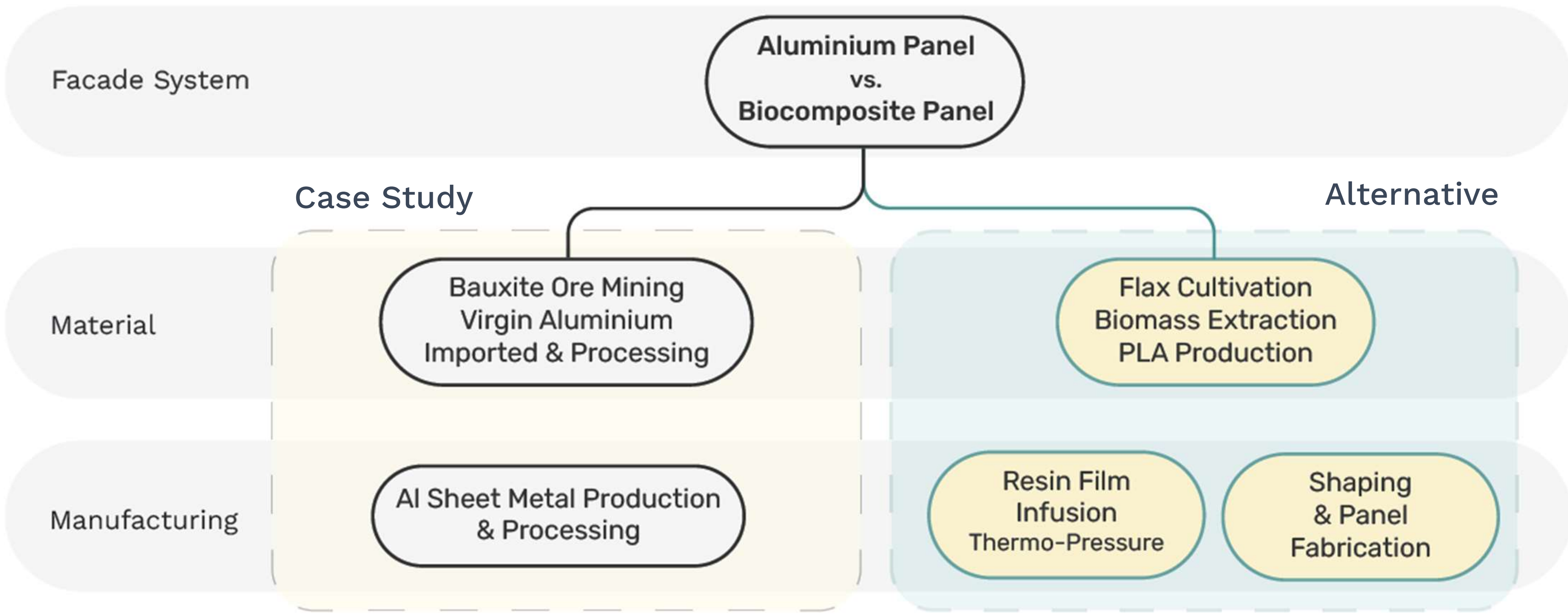
<

Allowable Flexural Strength
85.32 MPa

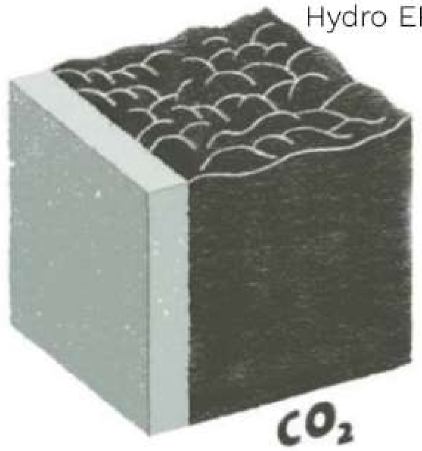
C464 maintains structural integrity within permissible limits & safety standards

Cradle-to-Gate Embodied Carbon



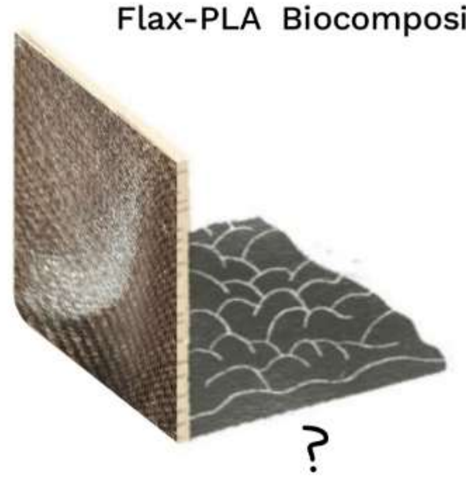


3 mm Anodized Aluminium
Hydro EPD



79 kg of CO_2e/m^2

Flax-PLA Biocomposite



XX kg of CO_2e/m^2 of Facade Surface Area

Source: Rocky Mountain Institute

Inventory Flows Data + System Boundary

Flax Crop Cultivation

Weaving Flax Textiles

Corn Crop Processing

PLA Products Film

Carbon Sequestration figure for GWP

Technical Flax Fabric	**- 1.2** kg CO_2 eq/kg textile
Polylactic Acid Film	**- 0.3** kg CO_2 eq /kg PLA

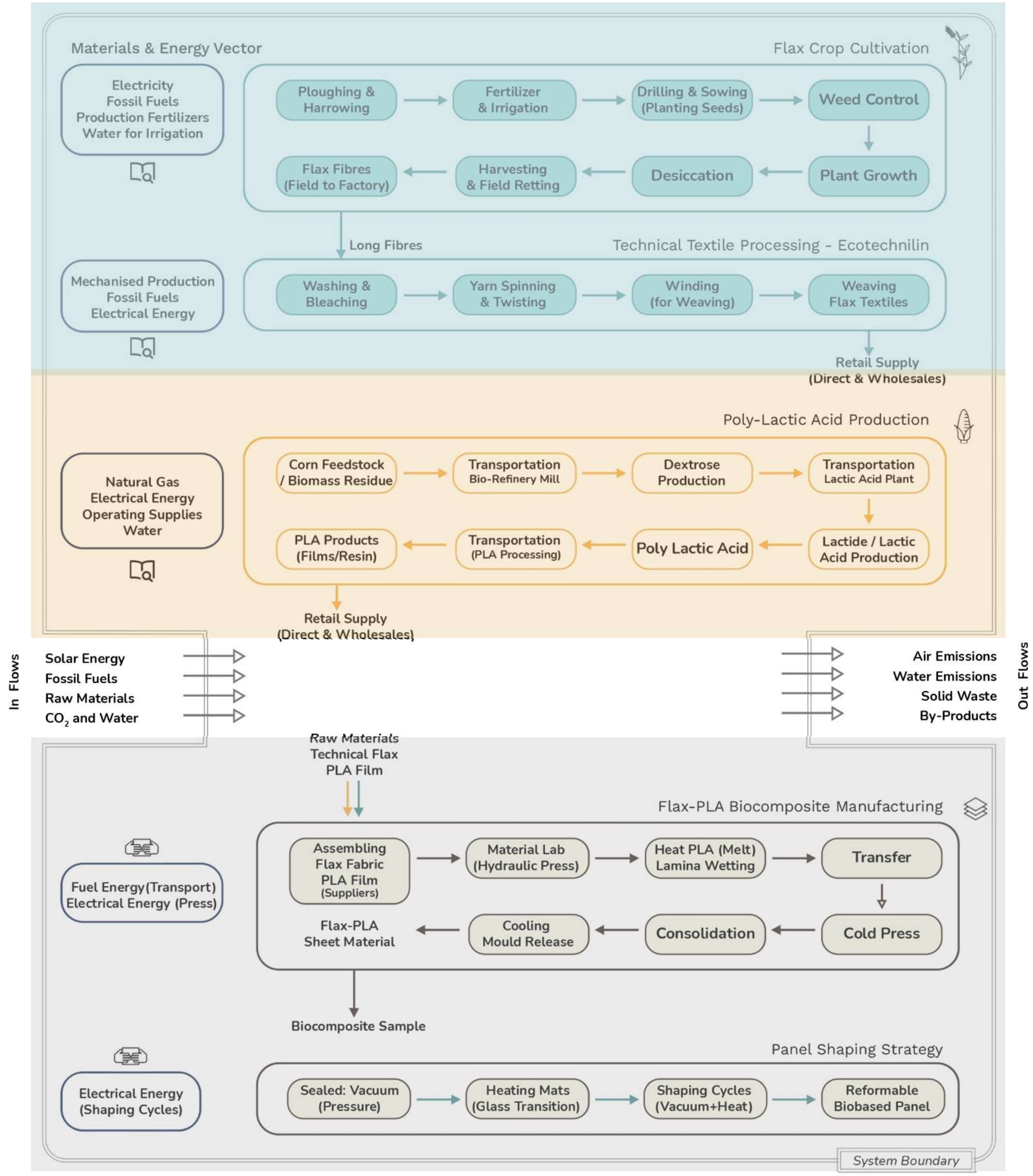
Assembling Flax Fabric PLA Film

Consolidation Resin Film Infusion

Shaping Cycles

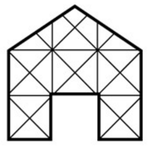
Vacuum Pressure Heating Mat

Obtained from own processes



(ANSYS, Gonsalez-Garcia et al., 2010; Le Duigou et al., 2011; E.T.H. Vink et al., 2003; Le Duigou et al., 2012)

Cradle-to-Gate Embodied Carbon



Functional Unit = 1 m² of Façade Surface Area

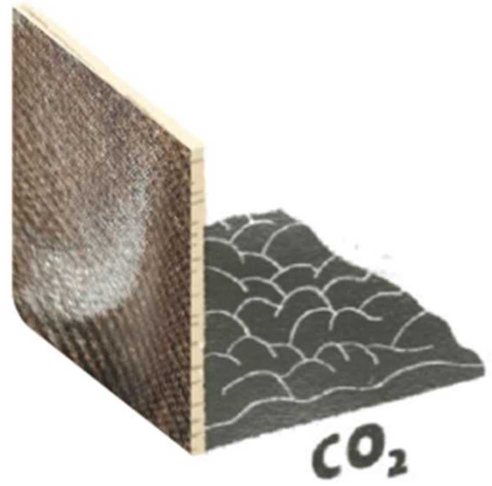
Calculating Embodied Impact for a Panel of 1 m² C464 density = 2.74 kg/m³

Flax (- 0.98) + Resin Film Infusion + Shaping Cycles

PLA (- 5.7768) (+ 2.28) (+ 1.58) (+ 0.106)

Raw Material Processing → Biocomposite Production → T → Panel Manufacturing

Transport

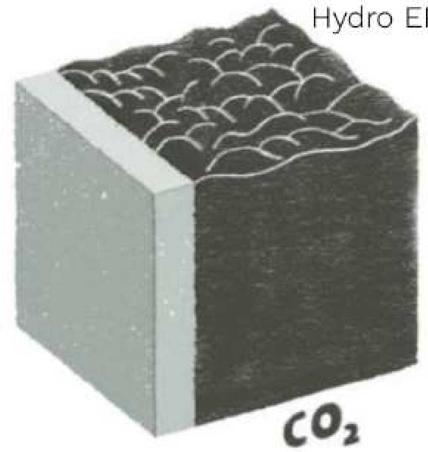


-2.7908 kg CO_2e/ 1 m² of BioComposite

Calculating Embodied Impact for a Panel of 1 m² C464 density = 2712 kg/m³

3 mm Anodised Aluminium Sheet Metal (ISO 14025, EN 15804, Hydro EPD)

3 mm Anodized Aluminium
Hydro EPD



+ 79,0 kg CO_2 e/ 1 m² of Al. Sheet

Gap Addressed

‘100% biobased
& carbon sequestering’

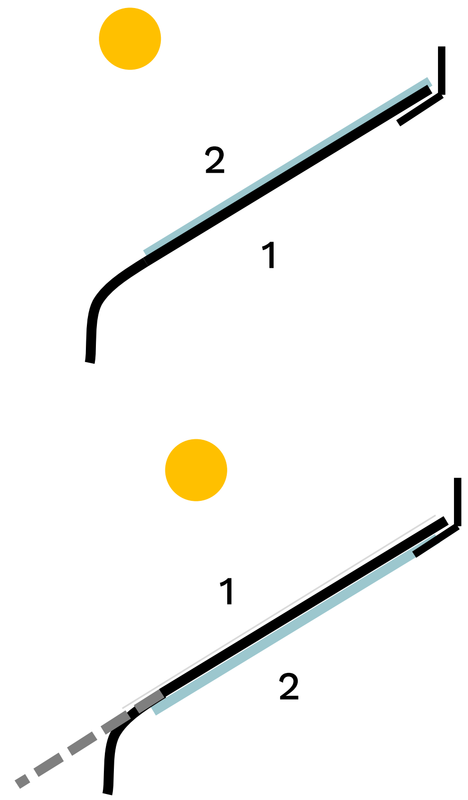
Consolidated Flax & PLA Film

Carbon Sequestering
Fully Biosourced, Biodegradable

*‘**proved** developability’*

Implemented Developable Surfaces
In Fibrous BIO-Composites

(Chanda & Bhattacharyya, 2022)



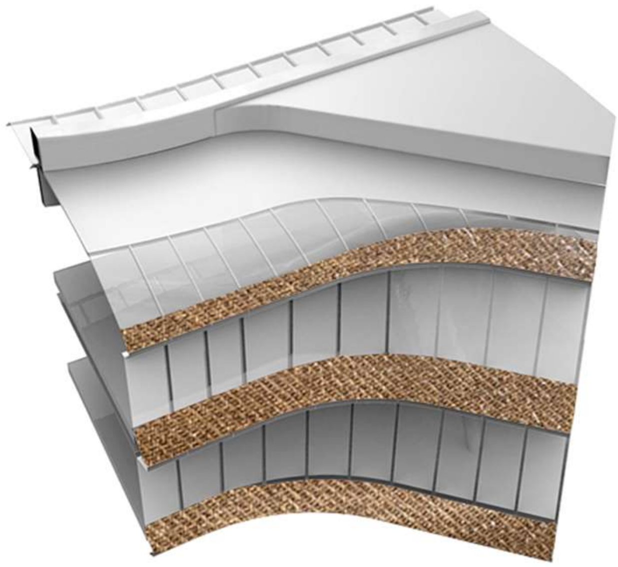
*‘**extended** design life’*

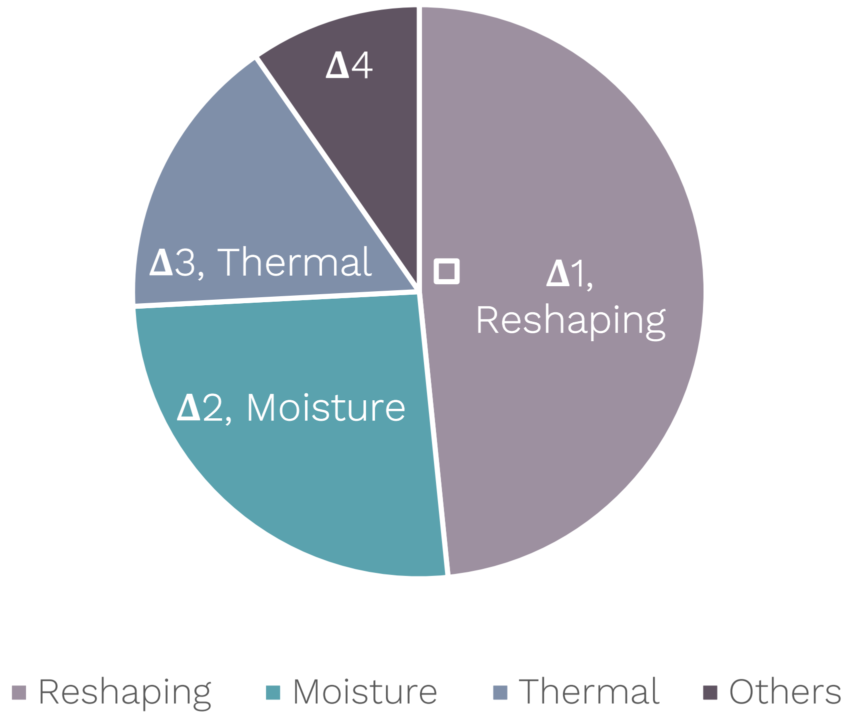
(Reshaping in Practice)

Reshaping Strategy
leveraging reserve strength

Façade Ready?

Preliminary tests to assess viability as an outdoor material





RETHINK

INTENSIFYING PRODUCT USE

SHAPING IT OVER X 2

LIMITATION TO FAÇADE USE

Factors Loss in Strength Δ1 to Δ4

TESTS FOR FAÇADE USE

TO DETERMINE DURABILITY

1 **Water Absorption Test?**

ASTM

2 **Outdoor Weathering Test?**

ASTM

POTENTIAL LIFECYCLE

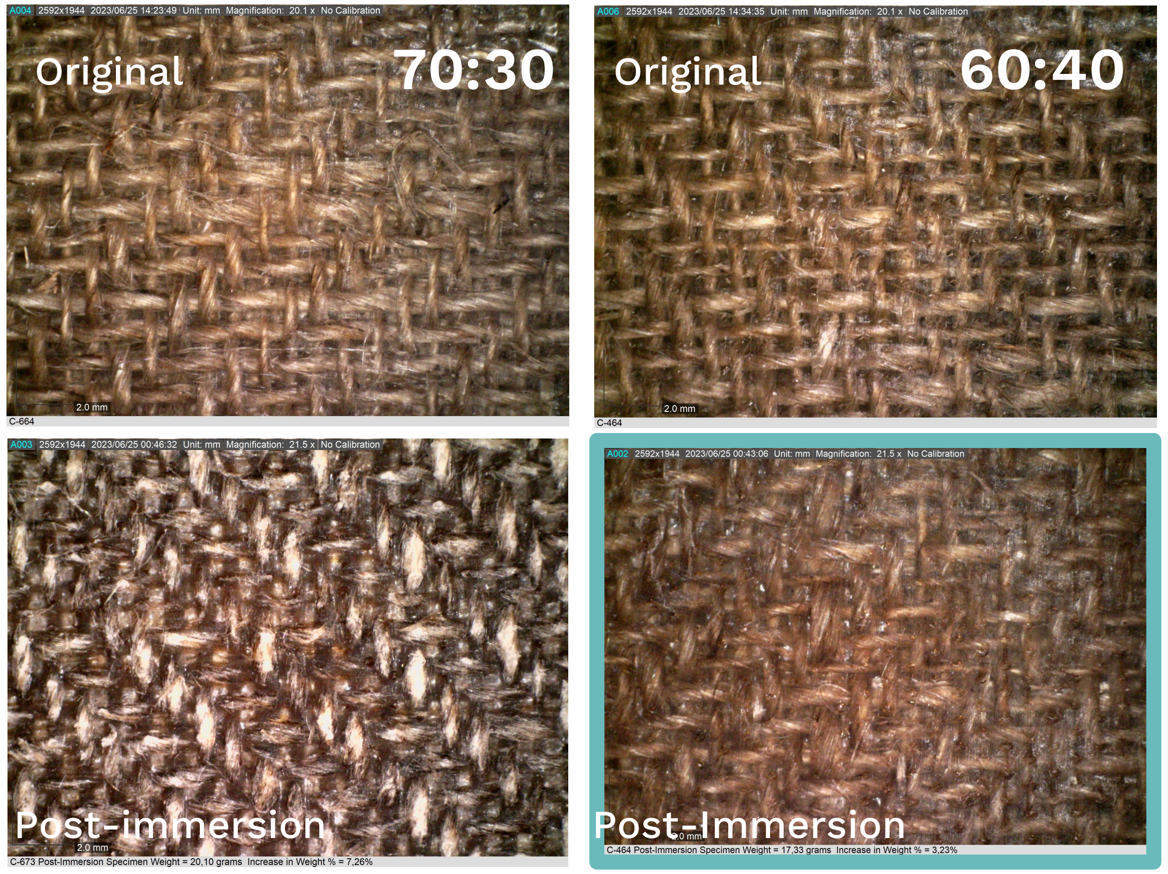
(operational carbon excluded *)

Water Absorption Tests + Results

Preliminary tests to assess viability as an outdoor material

Surface Frayed, +9.31%

Surface Intact, +3.23%



C-473

C-464

protocol

Edges Conditioned with Water Sealant Adhesive

Weighed after Edge Conditioning

ASTM D5229

testing response

Test at Think Lab, TU Delft

72 hours

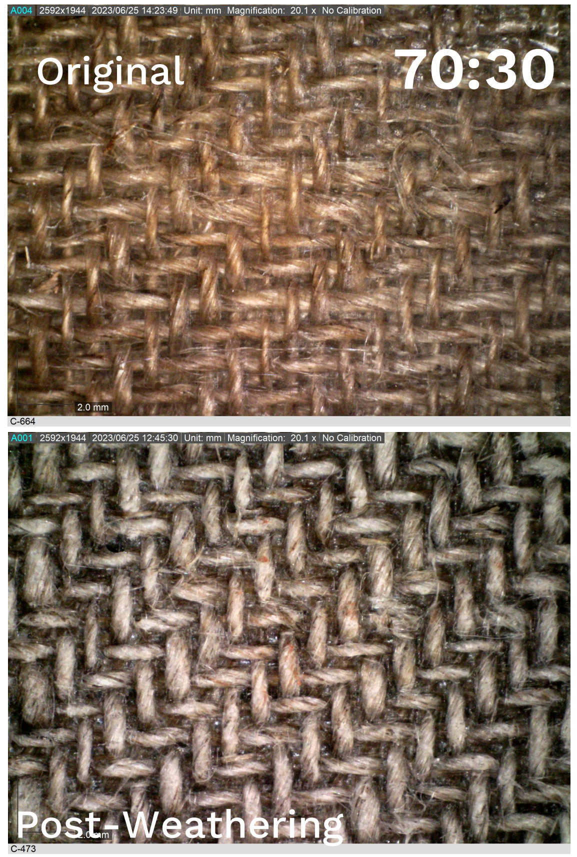
post-immersion analysis

C-464 - protected facia lowest weight gain (+3.23%)

Outdoor Weathering Tests + Results

Preliminary tests to assess viability as an outdoor material

Surface Frayed, +1.12%



C-473

Surface Intact, +0.35%

C-464

protocol

Placed in an Outdoor rack

ASTM D1435

testing – 4 weeks

Placed at +2,0 m south-east facing sill

Faculty of Architecture, TU Delft

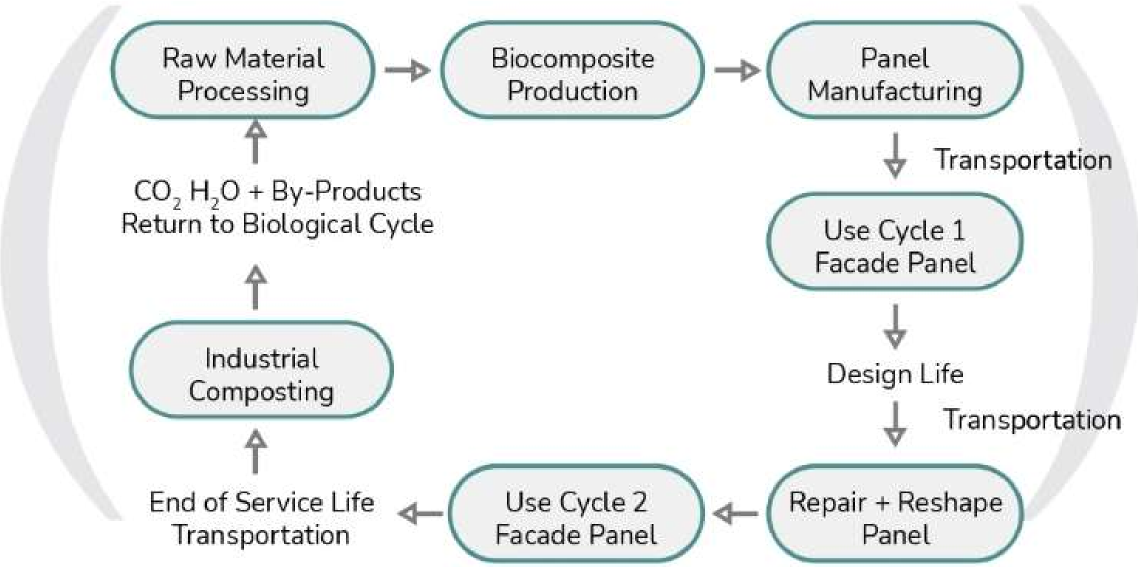
post-immersion analysis

C-464 - protected facia lowest weight gain (+0.35%)

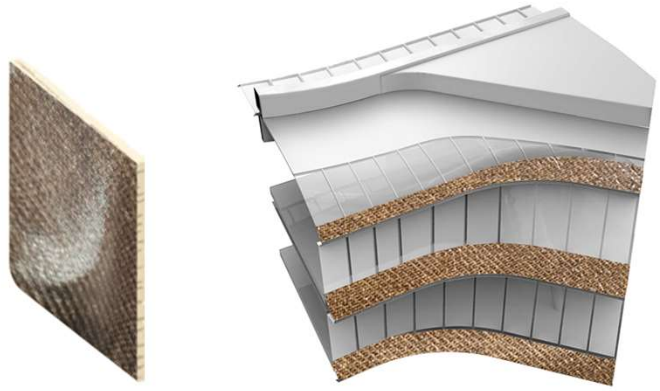
Higher PLA Ratio Performed Better

Lifecycle Estimate

(Stages A1-C4 Omitting Operational Energy B6-B7 Stages)



Conservative LCA Estimate = 5 Years / whole lifecycle



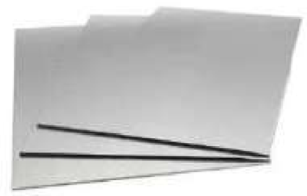
-2.7908 kg CO_2e/ 1 m^2 of BioComposite

Façade Life ≈ + 9.1792 kg CO_2e/m^2 x **5** ≈ **+ 45.896** kg CO_2e/m^2

5 cycles

CO2

1 cycle



GWP Impacts of **2** ±1 **complete lifecycles** of Flax - PLA Composite

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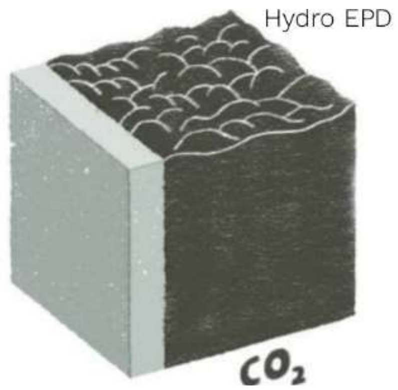
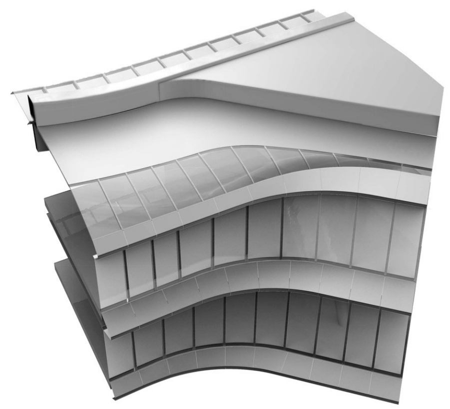
GWP Impact of **Aluminium Production** from a Single Lifecycle





+ 79,0 kg CO_2 e/ 1 m^2 of Al. Sheet

= embodied + transport x **1** ≈ **+ 80.6** kg CO_2e/m^2

Lifespan Expectancy – Future Work

≈ + 9.1792 x 5

≈ + 45.896 kg CO_2e/m^2

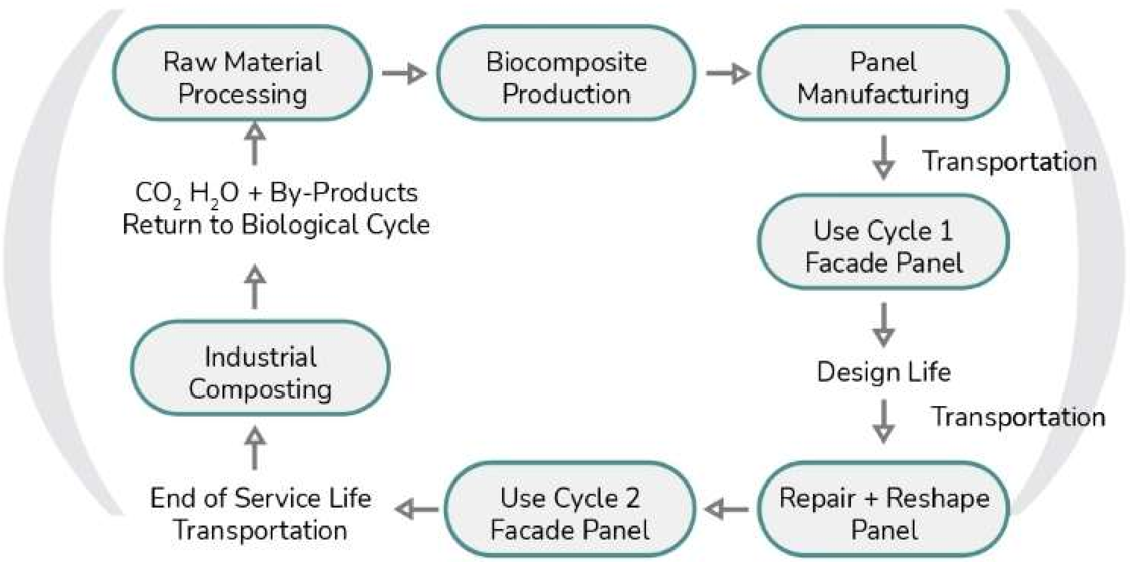
≈ + 12.2 x 3

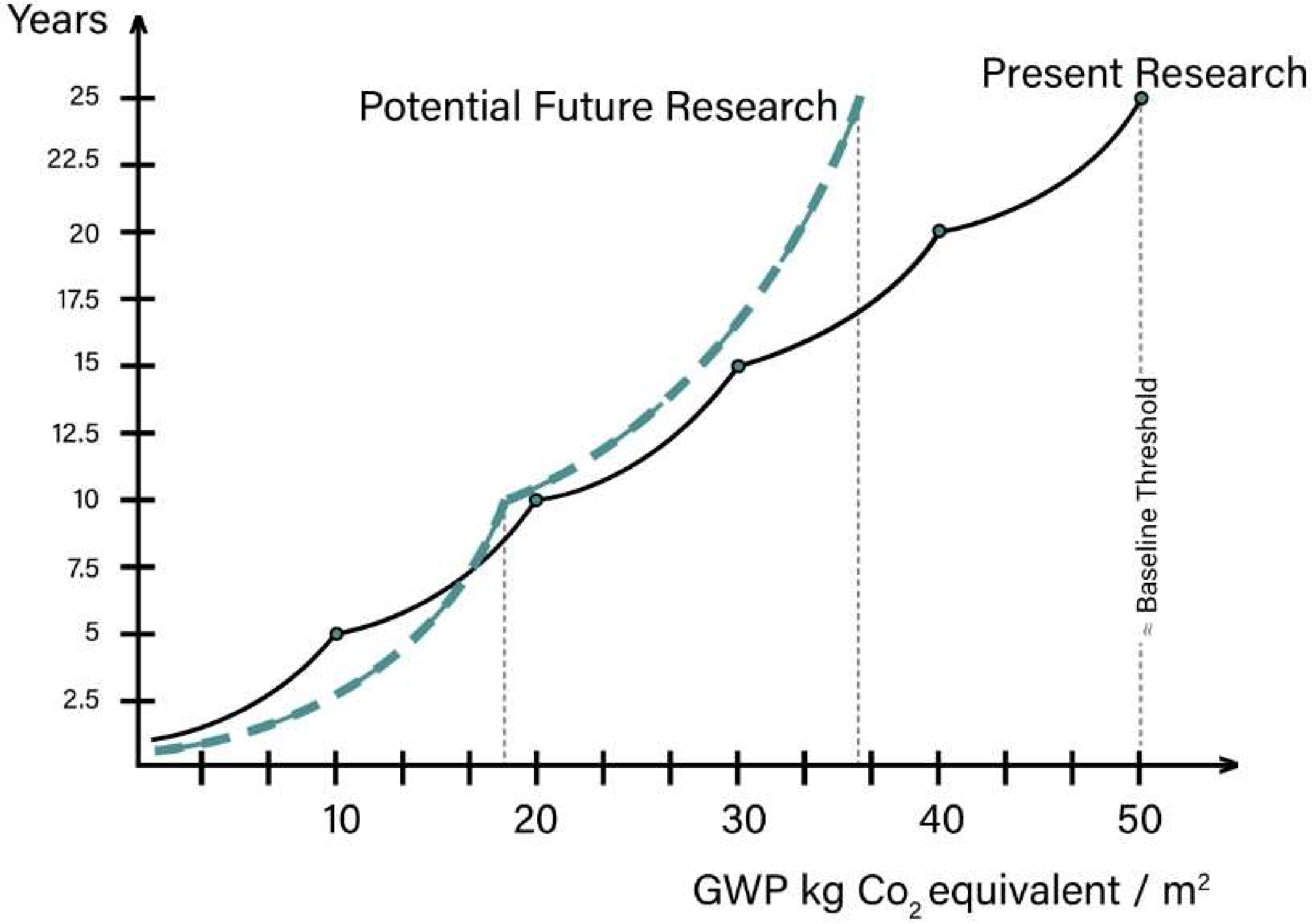
≈ + 36.66 kg CO_2e/m^2

≈ + 15.1 x 2

≈ + 30.2 kg CO_2e/m^2

5 10 15





*any logical future **technological enhancement** carbon load should not exceed the conservative estimate (lowest use-span considered)*

Pilot Studies !

Laboratory Research

Pavilions – Research Sites
Live Environmental Behaviour

Fire Performance
Flame Propagation & Smoke Production
Combustibility & Material Reaction

Weather Tightness
Air & Water Infiltration
Air & Water Exfiltration
Light Transmittance & Reflectance

Design Details
Application Exploration
Facade Archetypes

Durability & Lifetime Expectancy
Accelerated Ageing
Durability of Material
Repair & Replacement of Material

Implementation
Production Methodology & Tolerances
Installation Methodology (Assembly)

Major Research Themes
Minor Research Themes

Material Performance
Thermal Line, Thermal Behavior
Impact Test
Fixing Test

Safety & Security
Burglary Resistance Integration
Blast & Ballistic Resistance

Movement & Tolerances
Installation Tolerances
Building Movement Tolerances

Acoustical Behaviour
External Noise Transfer
Internal Noise Reduction (Flanking)

People's Pavilion visualised with the Flax-PLA Biocomposite

Real-Time Data

'Extend Life Span of Product & it's Parts'

(Potting et al. 2017)

To Assess Re-Use

FULFILS

ORIGINAL FUNCTION

To Assess Repairability

REPAIR & MAINTAIN FOR REUSE

ORIGINAL FUNCTION

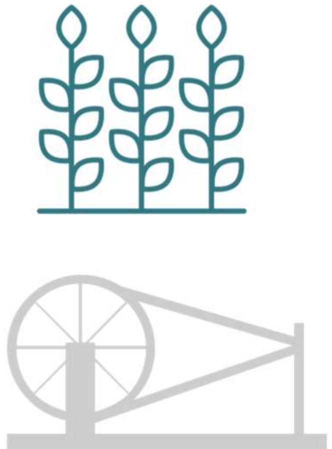
Growing Pavilion visualised with the Flax-PLA Biocomposite

Scientific + Societal Reflections

'extend life'
PHAs, PA11,
High Temp PLA
88 C

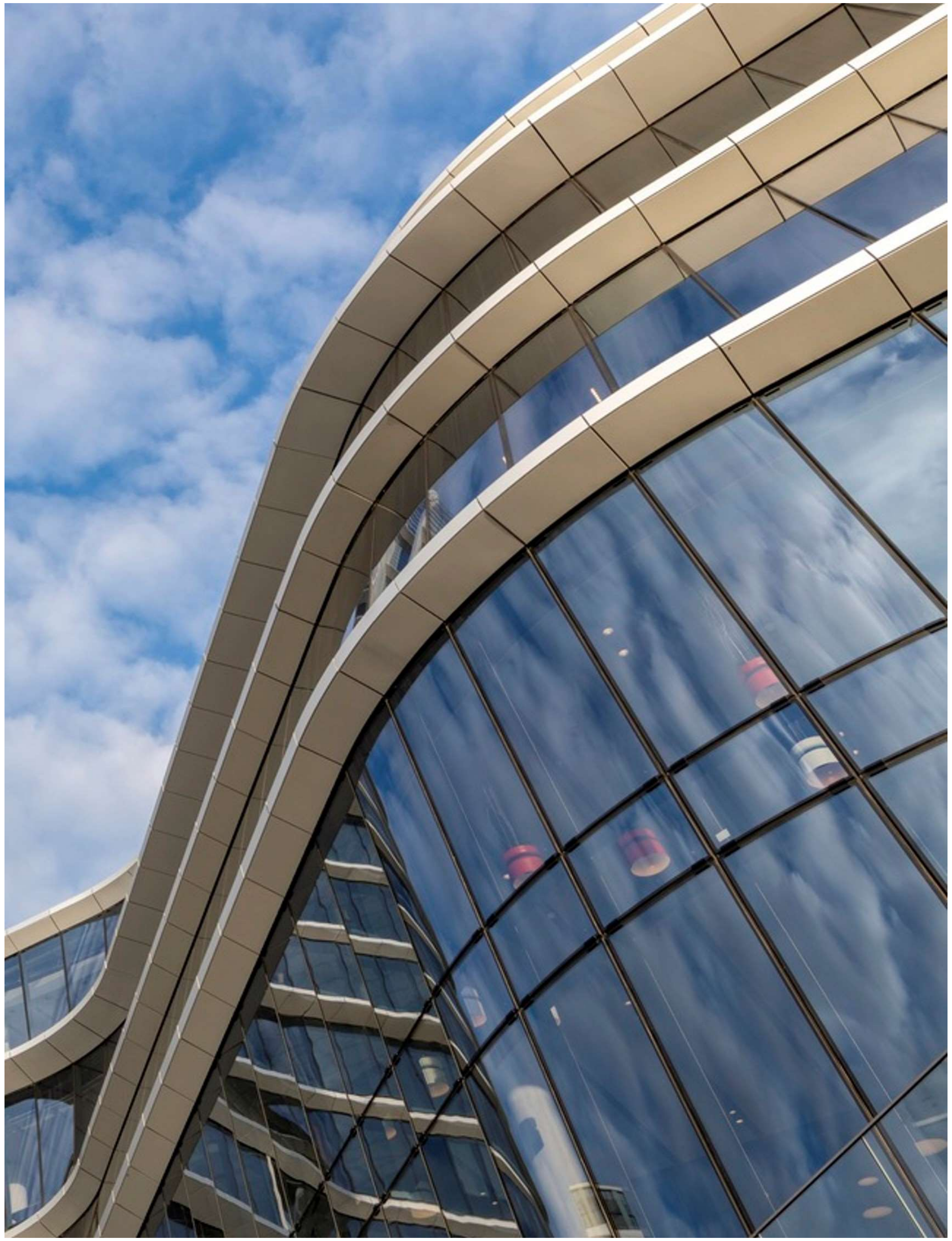
reorder testing
simulate real
conditions

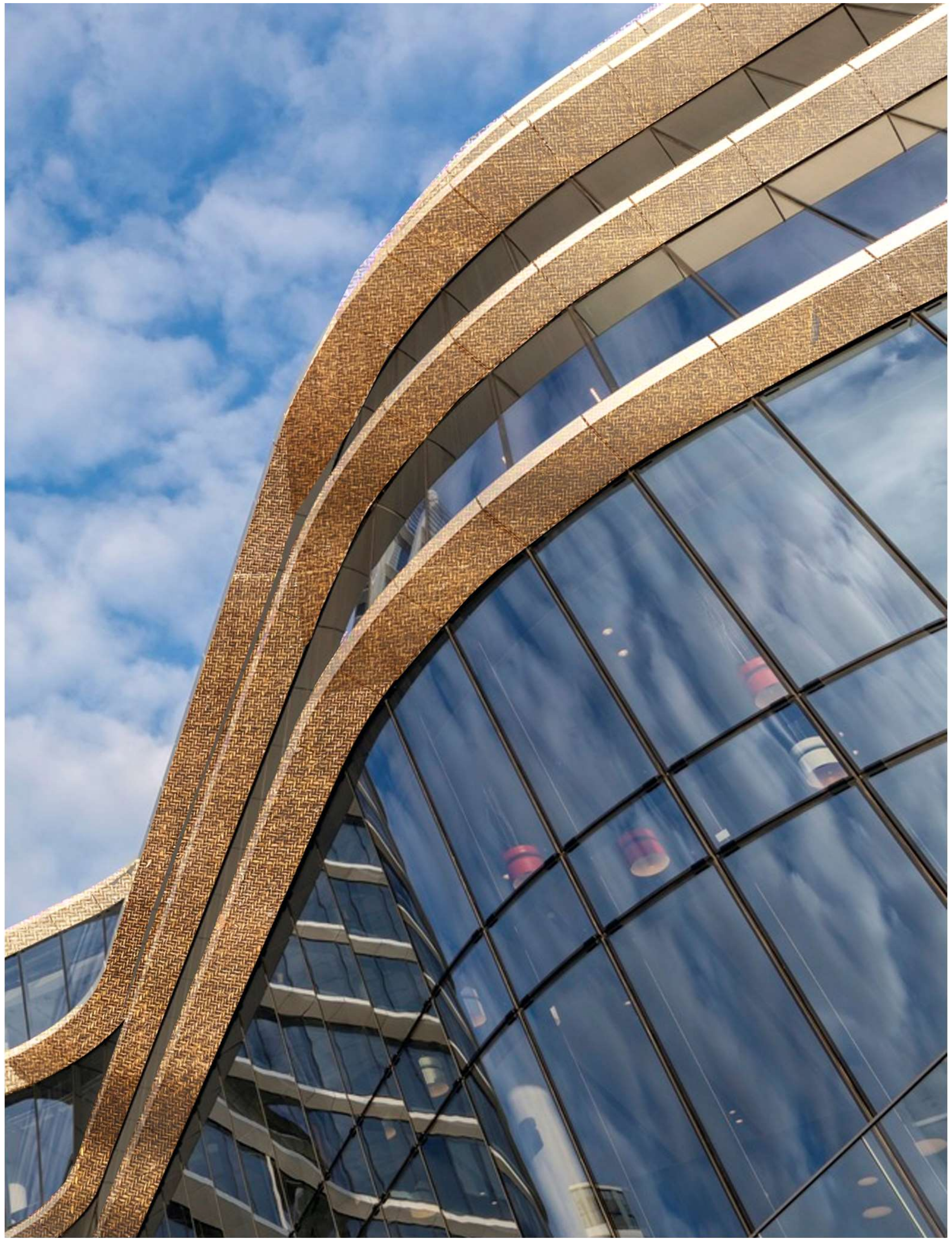
Adaptability
geographic
economic
technological



'bast fibres'
Jute, Kenaf,
Hemp

versatile
aesthetics
scalable





Facilitated by: *Willem Bottger*
Mark Lepelaar

Special Thanks to: *Janneke Verkerk - Evers*
Hans Jansen

Delegate : *Ing. Peter De Jong*

Guided by:

Dr Olga Ioannou
Building Product Innovation

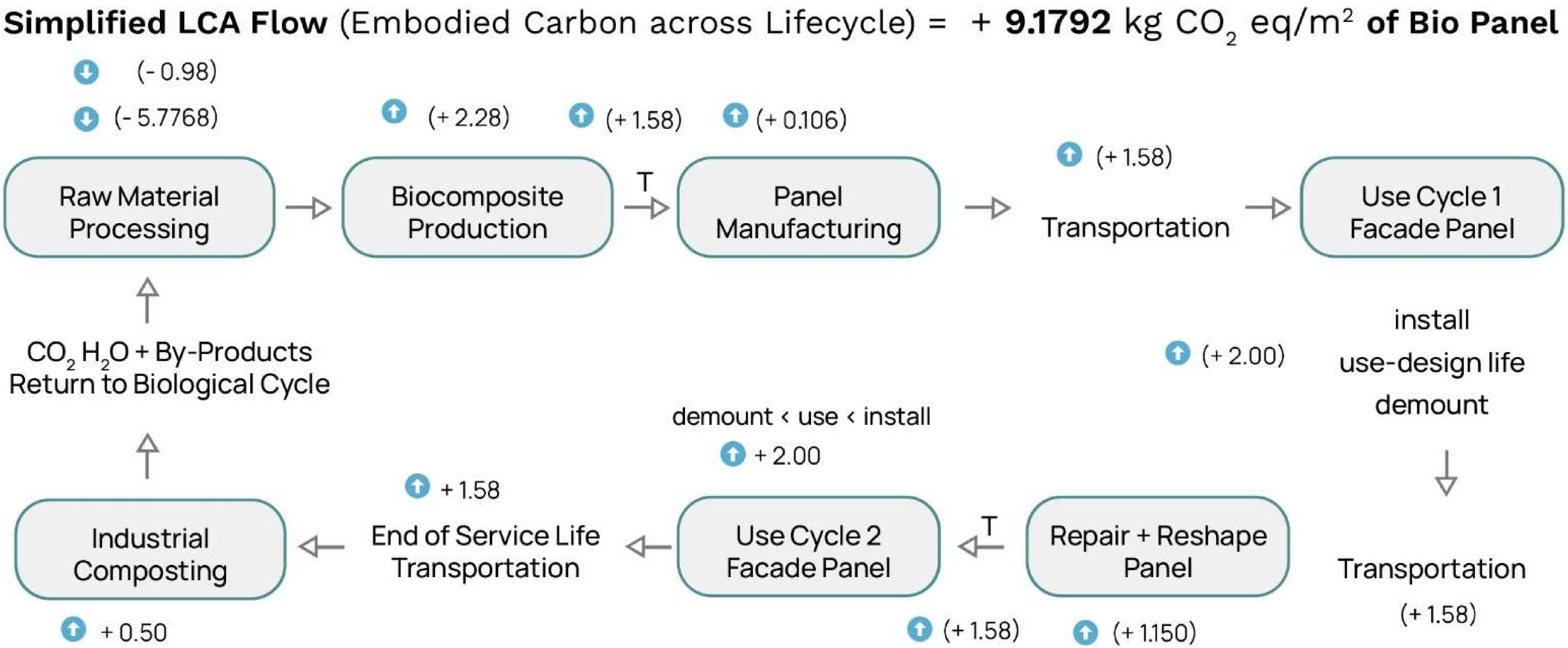
&

Dr Mauro Overend
Structural Design & Mechanics

*“ engineering a **biobased & circular** alternative for **facade cladding** systems featuring **complex geometries** ”*

SCHELDEBOUW npsp TUDelft BK Bouwkunde

Annex


Simplified LCA Flow (Embodied Carbon across Lifecycle) = + 9.1792 kg CO_2 eq/m² of Bio Panel
(- 0.98)
(- 5.7768)
(+ 2.28)
(+ 1.58)
(+ 0.106)
(+ 1.58)
Raw Material Processing
Biocomposite Production
T
Panel Manufacturing
Transportation
Use Cycle 1 Facade Panel
install
use-design life
demount
(+ 2.00)
CO_2 H_2O + By-Products Return to Biological Cycle
demount ‹ use ‹ install
+ 2.00
+ 1.58
Industrial Composting
End of Service Life Transportation
Use Cycle 2 Facade Panel
T
Repair + Reshape Panel
Transportation
(+ 1.58)
+ 0.50
(+ 1.58)
(+ 1.150)