

# A CIRCULAR BIOBASED COMPOSITE FACADE

Research on a high performance and circular application of biobased composite on a facade

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Introduction

Biobased composite

Circularity

Durability

Shadowcosts

Design parameters

Case studies

Conclusions

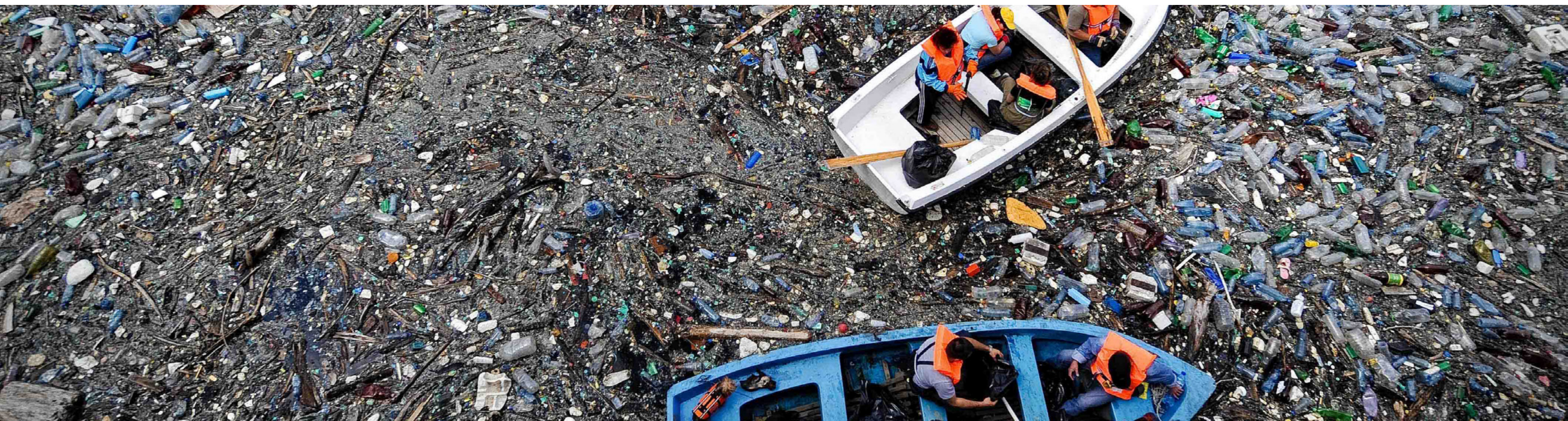
Recommendations

# INTRODUCTION

# INTRODUCTION | Problem statement

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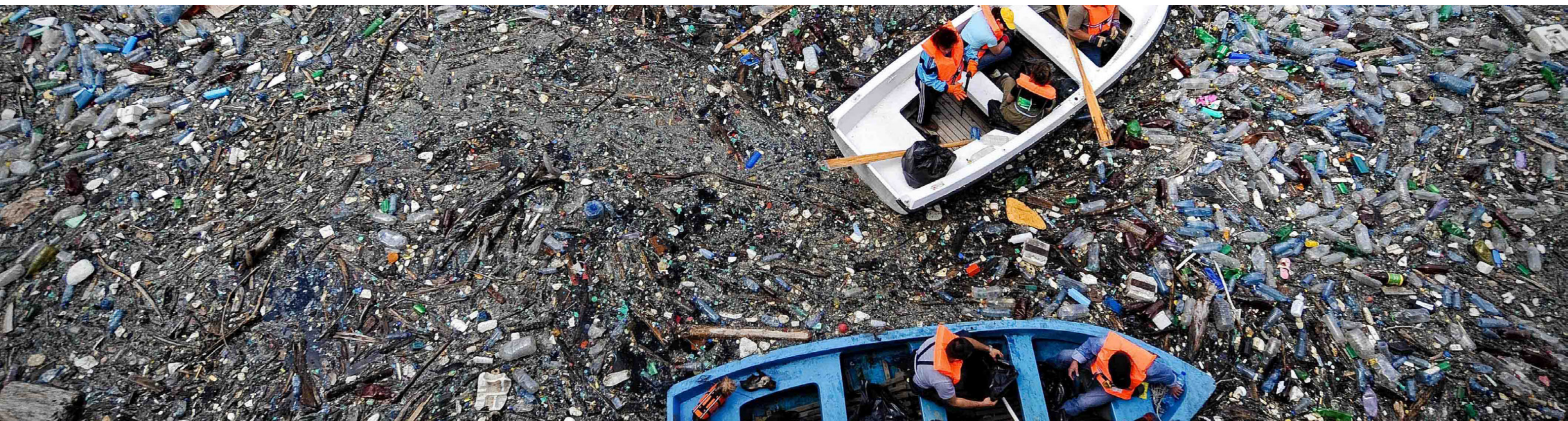
“The building industry produces annually **twice as much waste** as all the Dutch households together”



# INTRODUCTION | Problem statement

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“Most construction waste goes into landfills, increasing the burden of **landfill loading** and operation”



# INTRODUCTION | Problem statement

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## Material scarcity

Copper

Lead

Zinc

Aluminum

38 years

8 years

34 years

510 years



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# INTRODUCTION | Research goal

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Explore whether a **more environmental friendly** composite material could be offered to designers while retaining **the same design options** current materials offer



# INTRODUCTION | Approach

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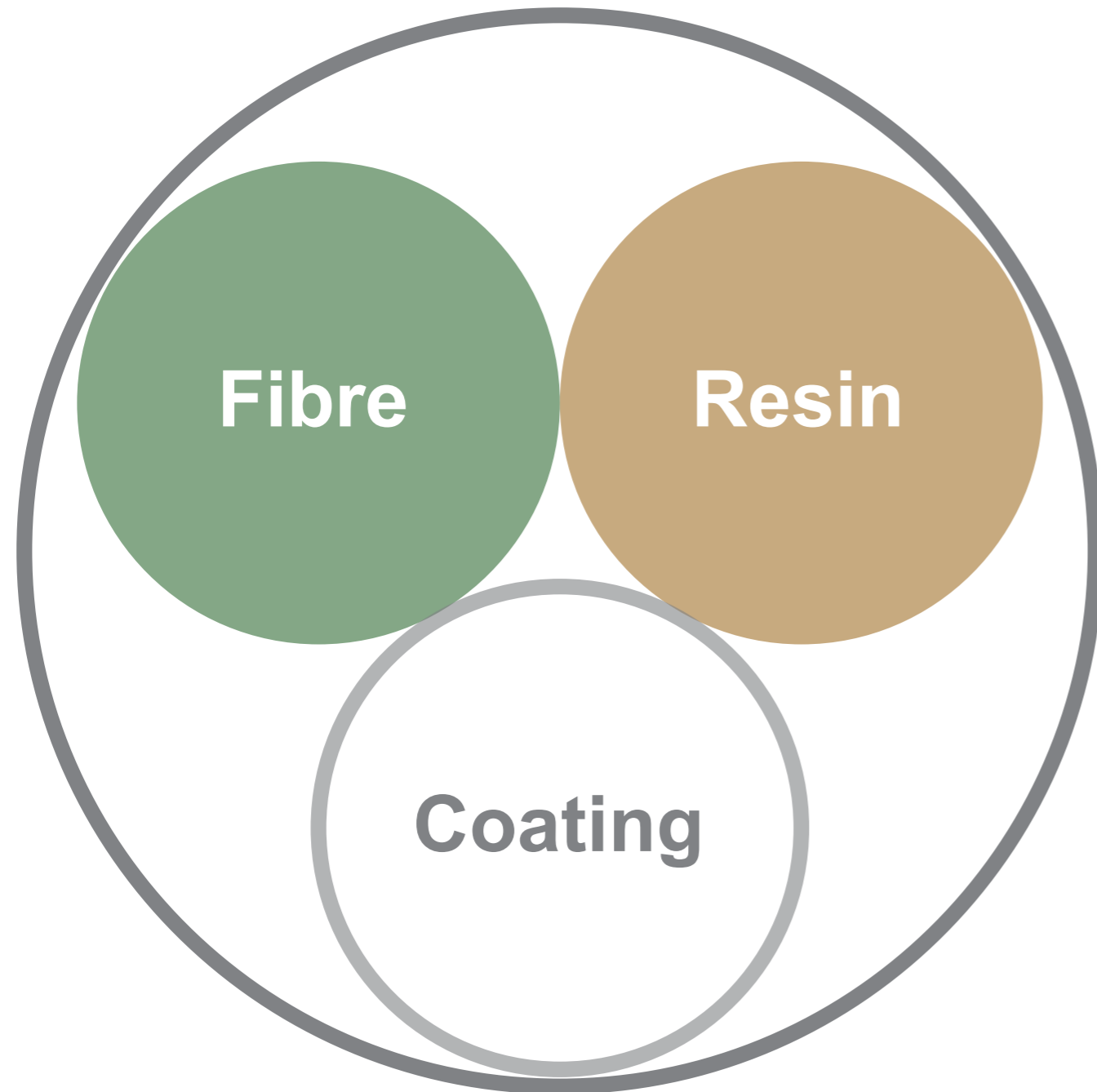
“What is possible with **biobased composite** when used for a **circular facade design**?”



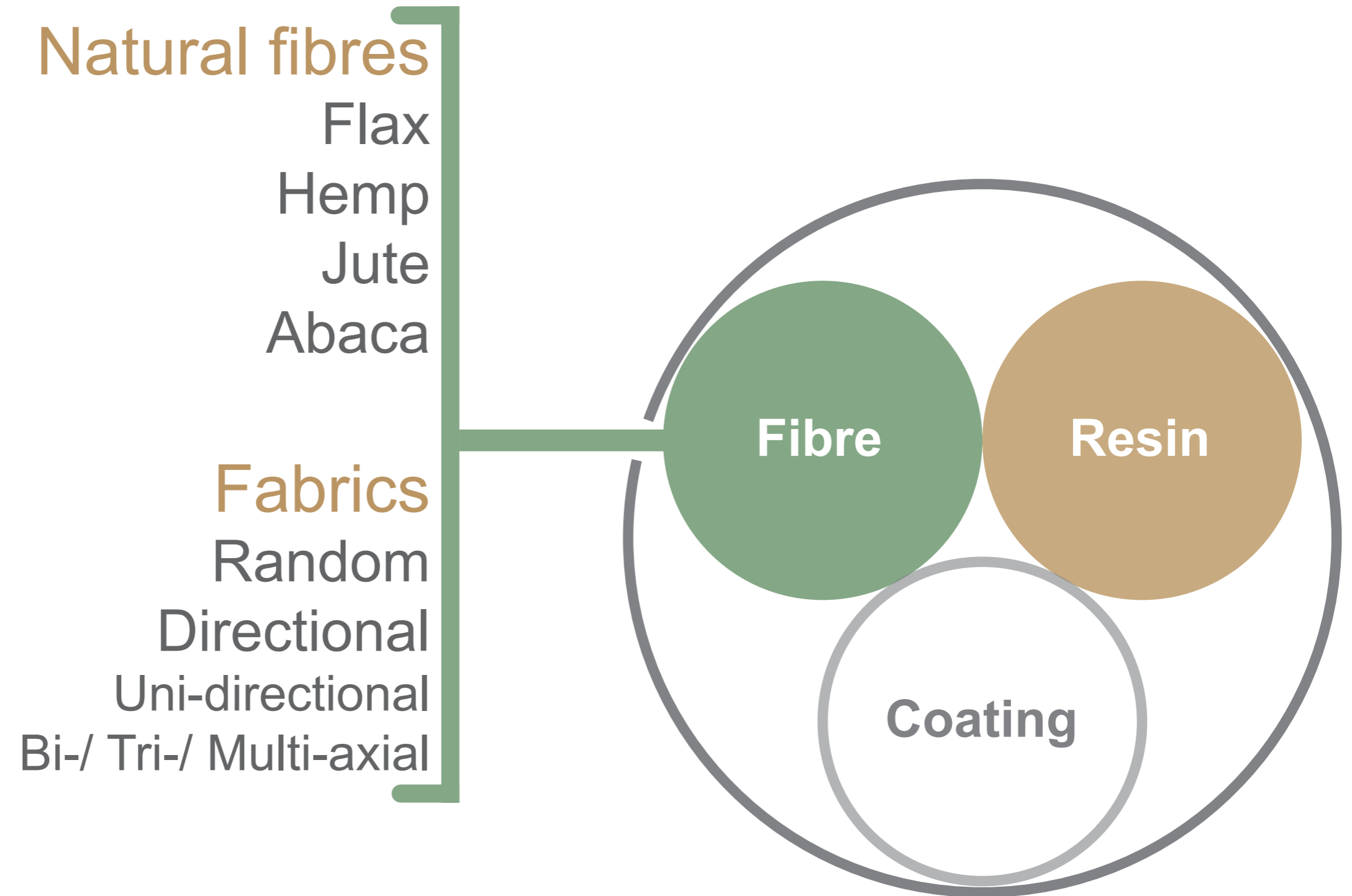
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# BIOBASED COMPOSITE

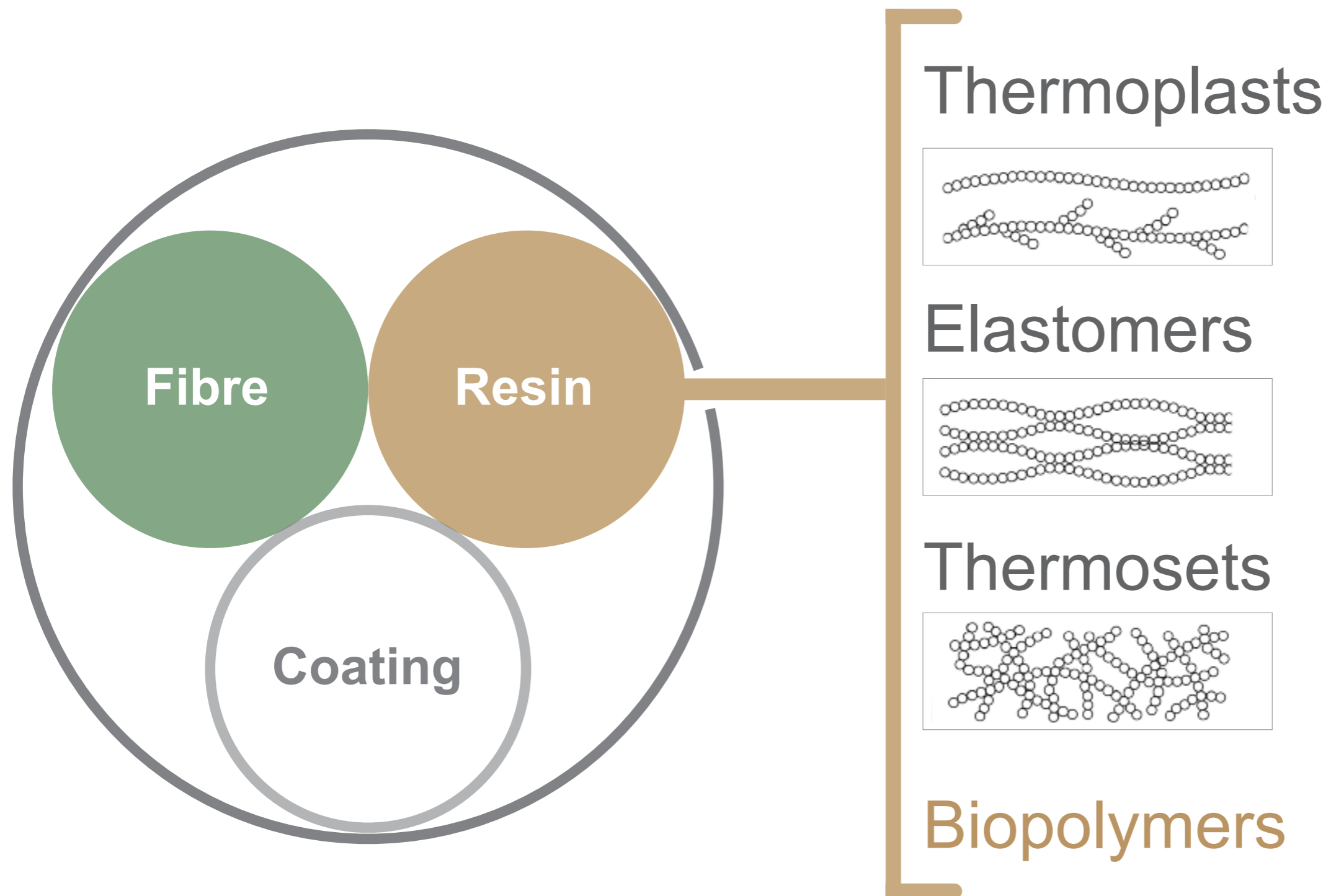
# INTRODUCTION | Biobased Composite



# INTRODUCTION | Biobased Composite



# INTRODUCTION | Biobased Composite



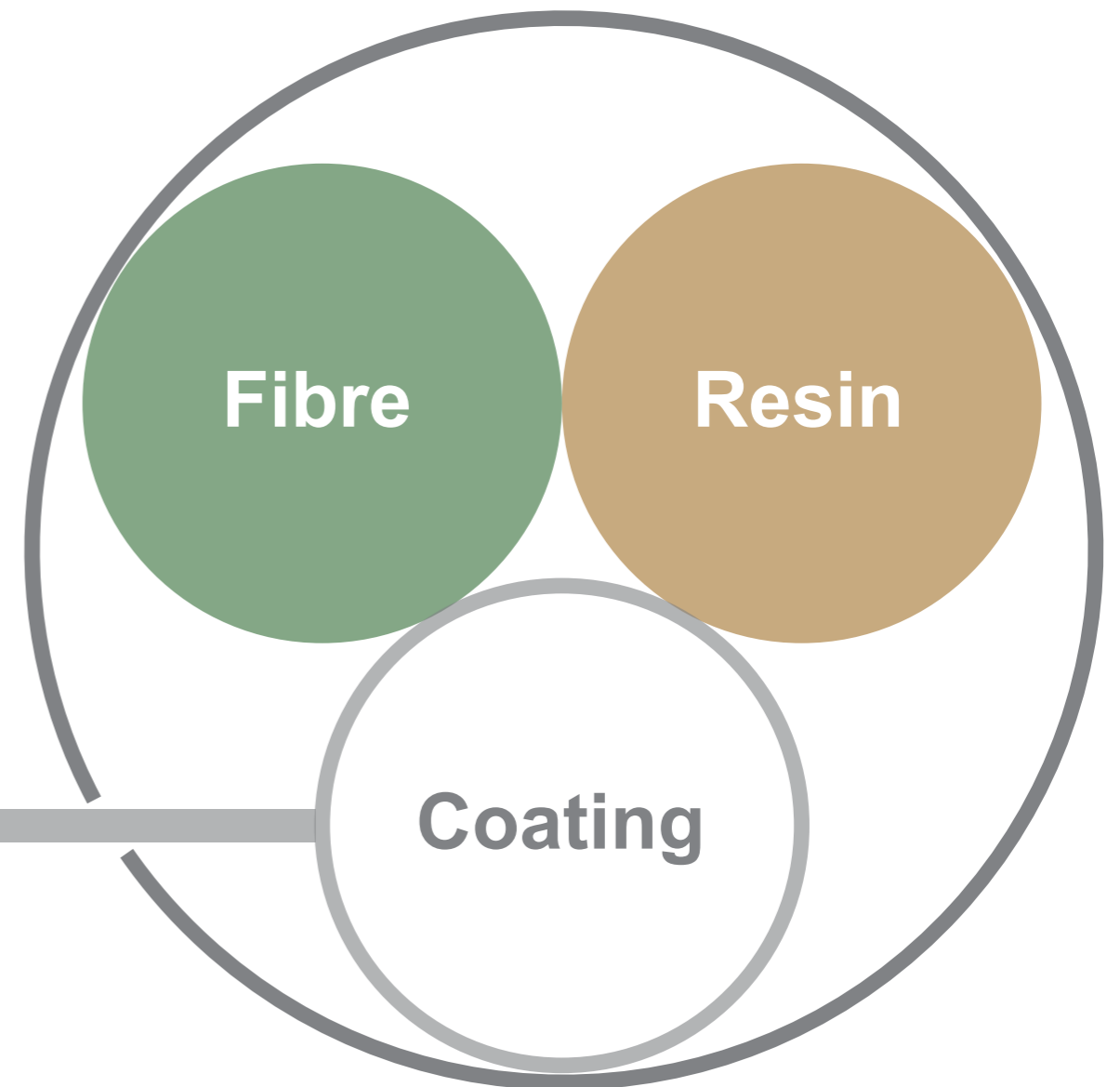
# INTRODUCTION | Biobased Composite

Pigment, solvent, binder

Organic

Protective  
UV-radiation  
Water  
Fire

Decorative  
Paint  
Laquer



# FORMER PROJECTS | WORLDS FIRST BIOBASED COMPOSITE FACADE



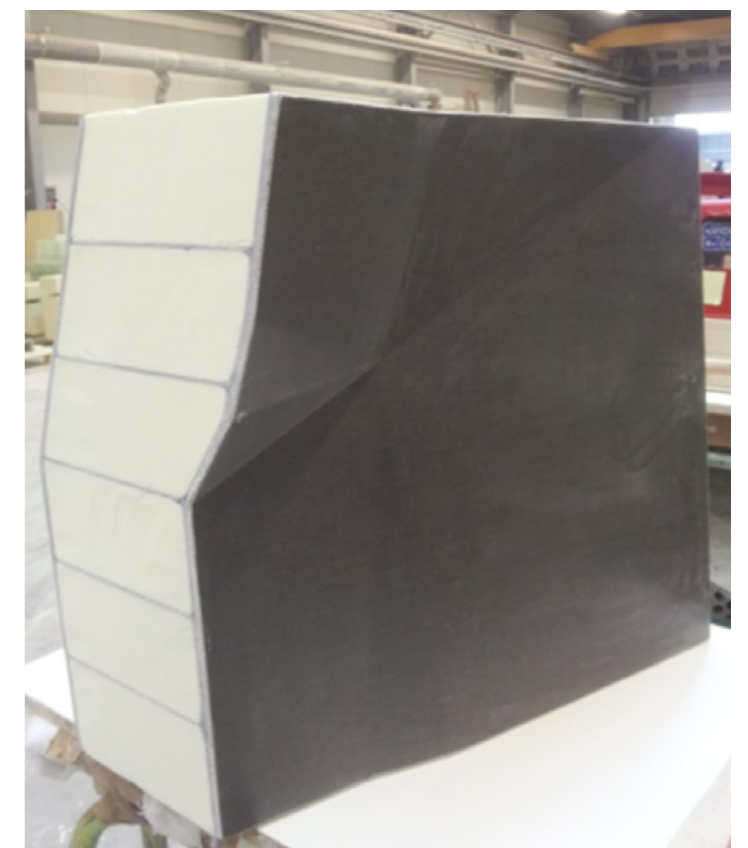
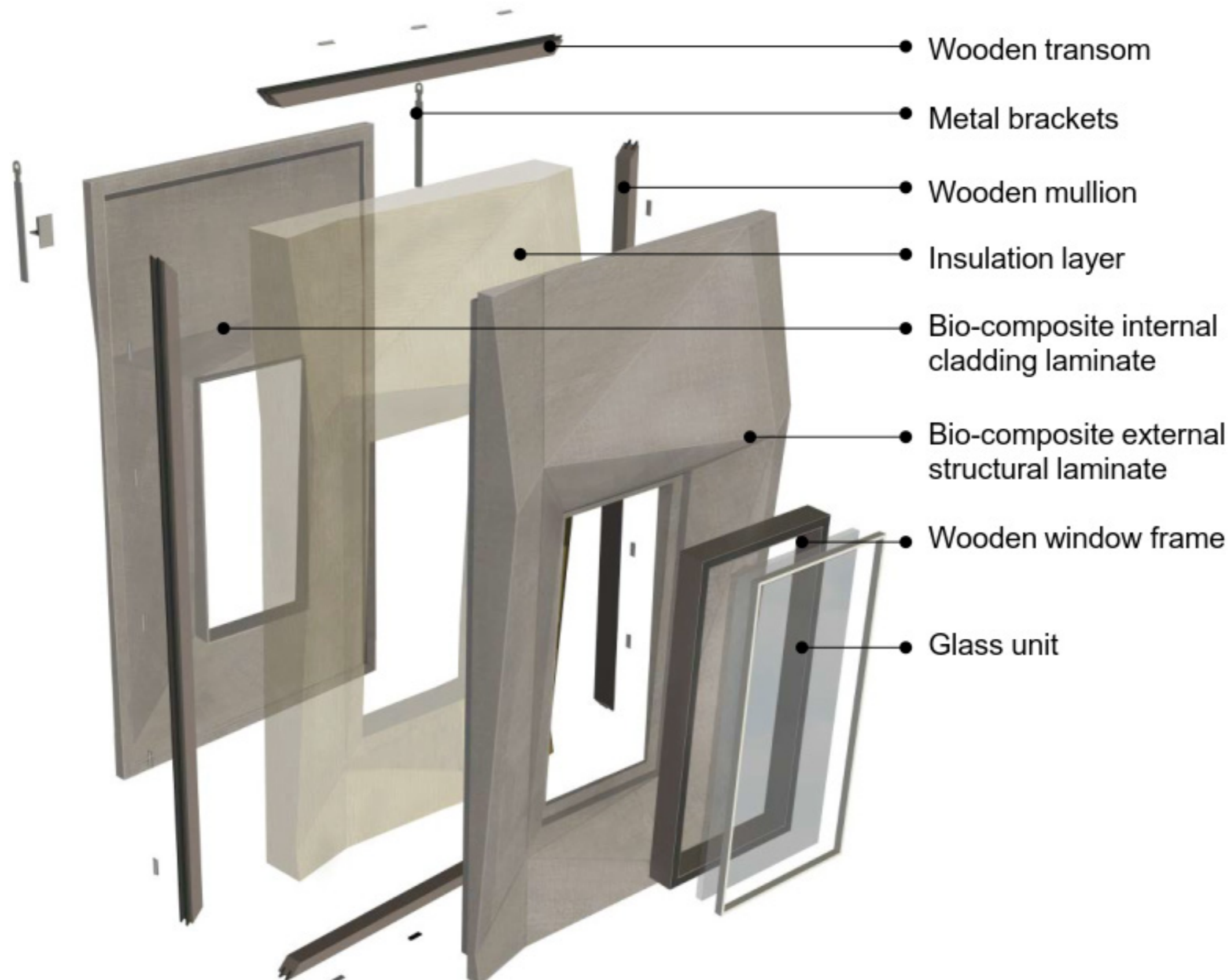
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## FORMER PROJECTS | EXTERNAL WALL PANEL - THE BIOBUILD PROJECT



a circular biobased composite facade

# FORMER PROJECTS | EXTERNAL WALL PANEL - THE BIOBUILD PROJECT



a circular biobased composite facade

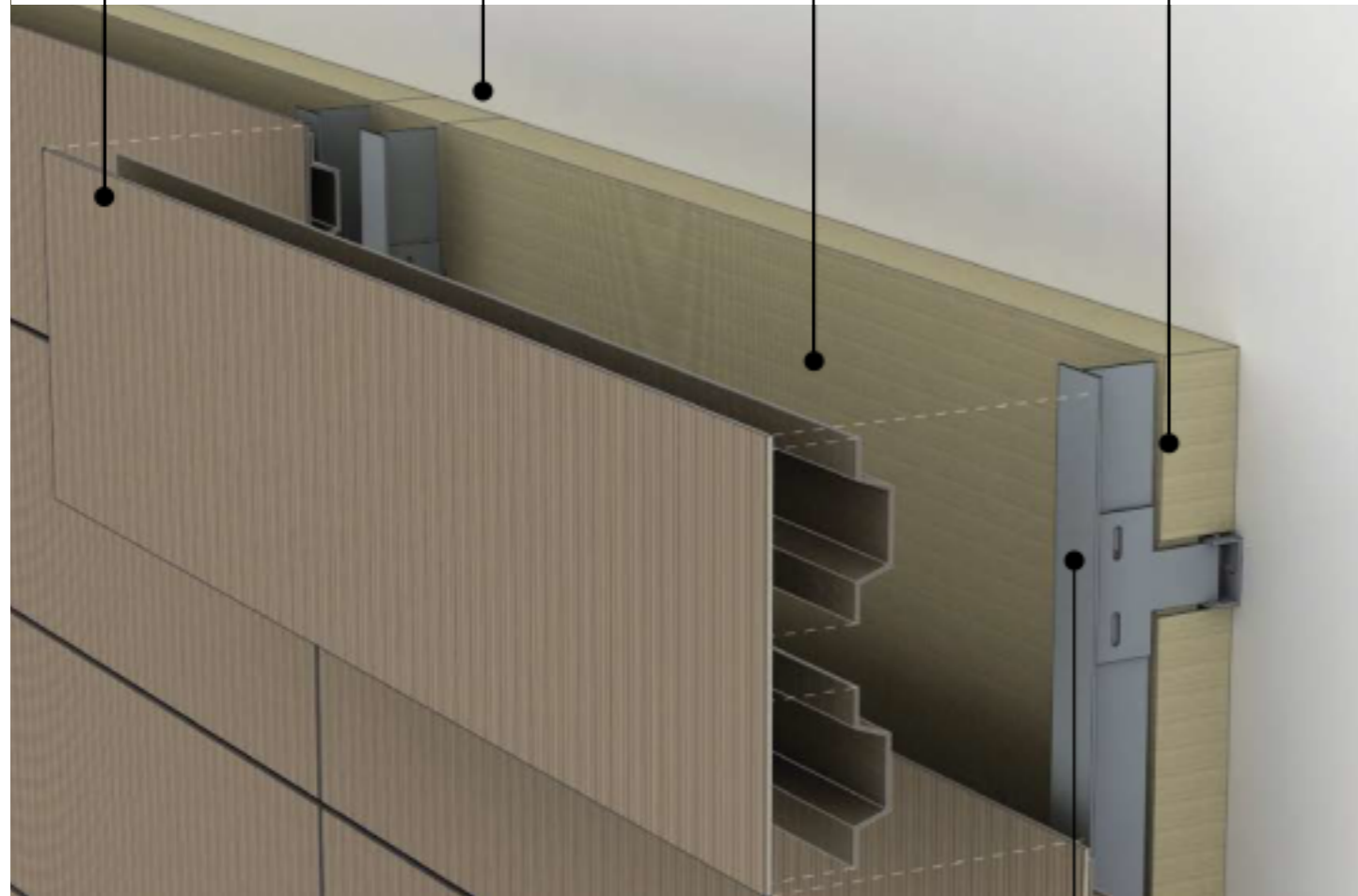
# FORMER PROJECTS | EXTERNAL CLADDING KIT - THE BIOBUILD PROJECT

Flat biobased  
composite panel

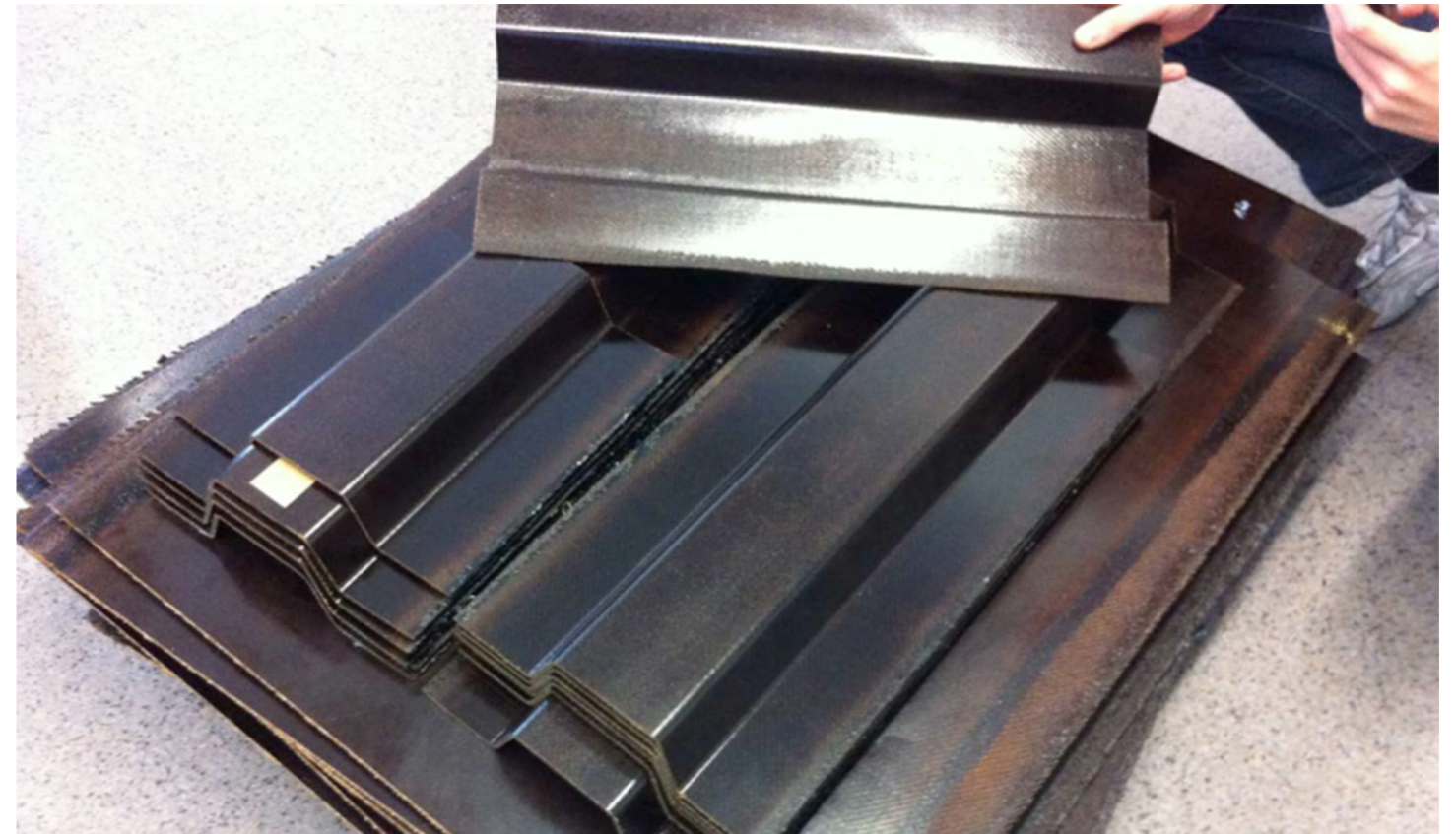
Natural insulation

Stiffening profiles

Metal brackets

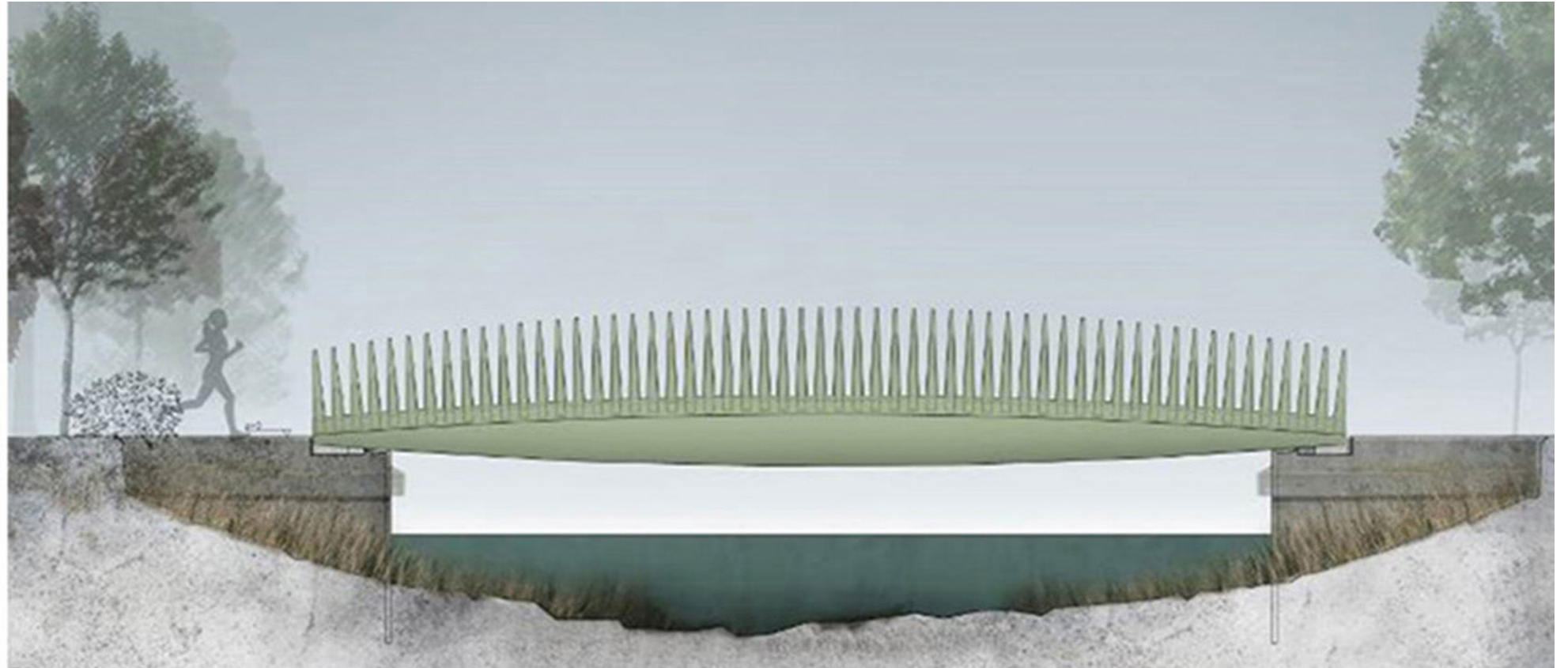


Metal sub-structure



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# FORMER PROJECTS | BIOBASED COMPOSITE PEDESTRIAN BRIDGE



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CIRCULARITY

# CIRCULARITY | Introduction

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“At this moment, in the Netherlands 50% of the national raw material consumption is caused by the construction industry and 40% of this amount refers to demolition waste”



# CIRCULARITY | Introduction

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1. **Reduce** resources
2. **Reuse** resources
3. **Circular solutions**

# CIRCULARITY | Approach

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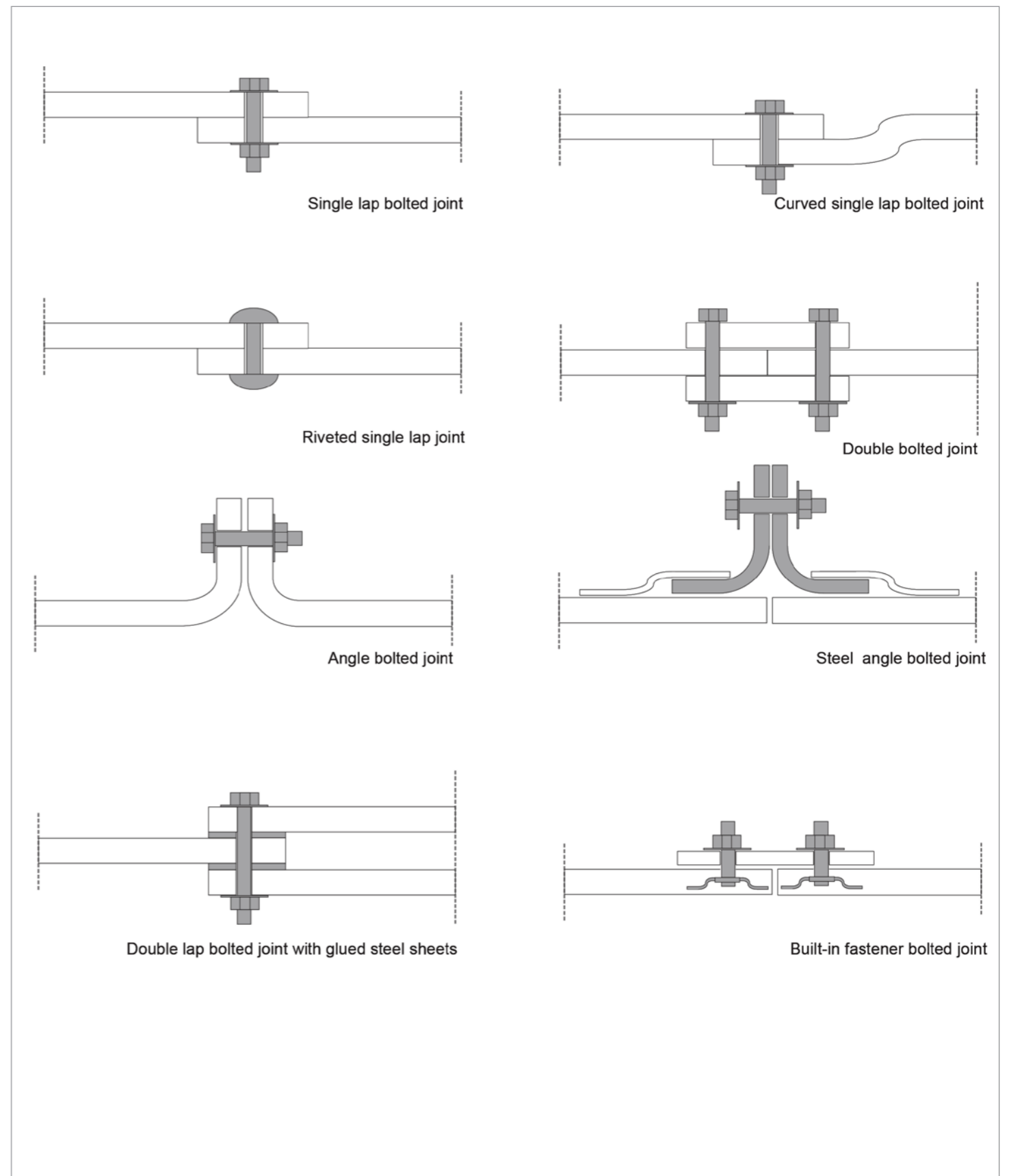
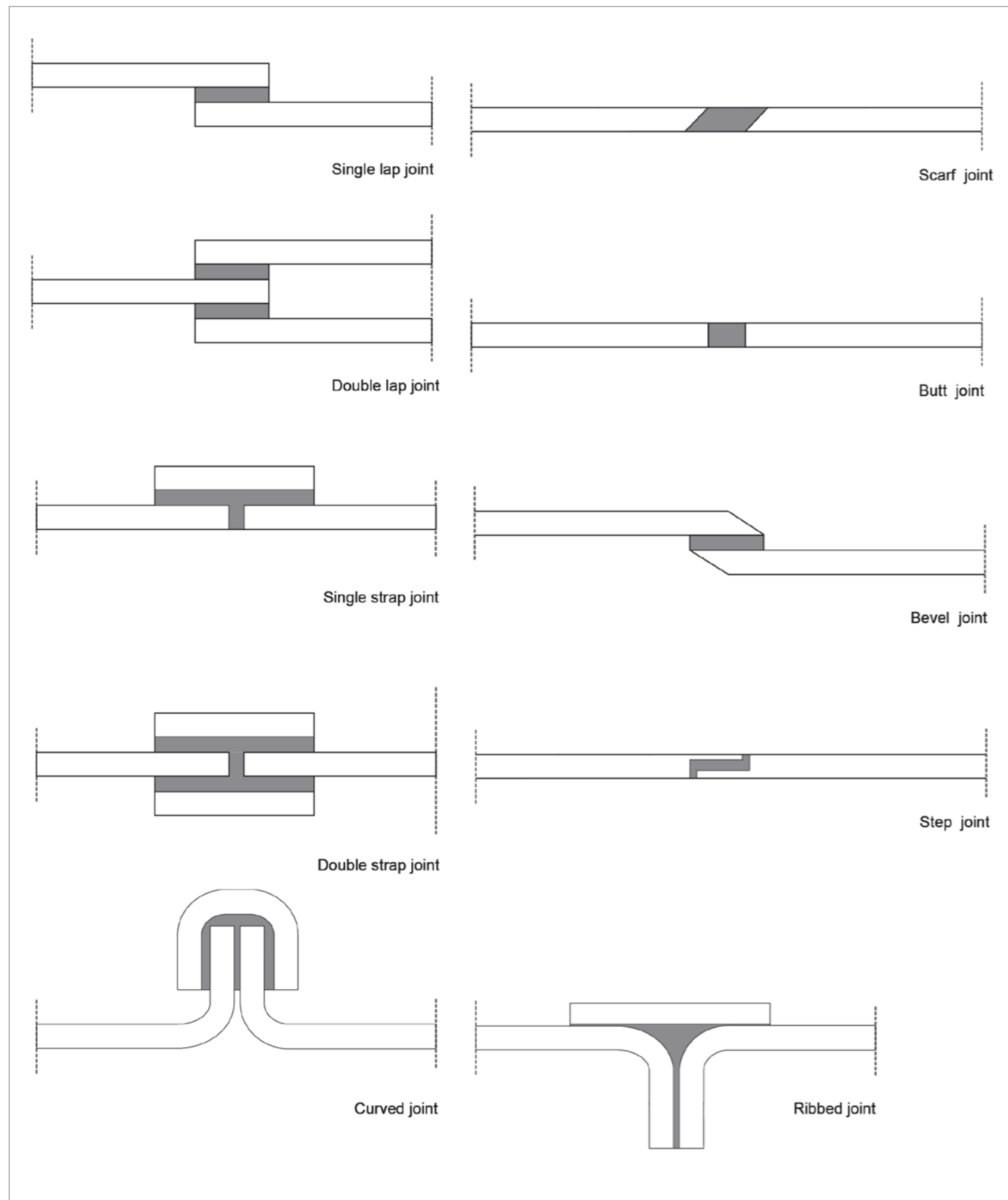
“Keep materials performing as long as possible”

“Avoid waste”

“Regard waste as resource”



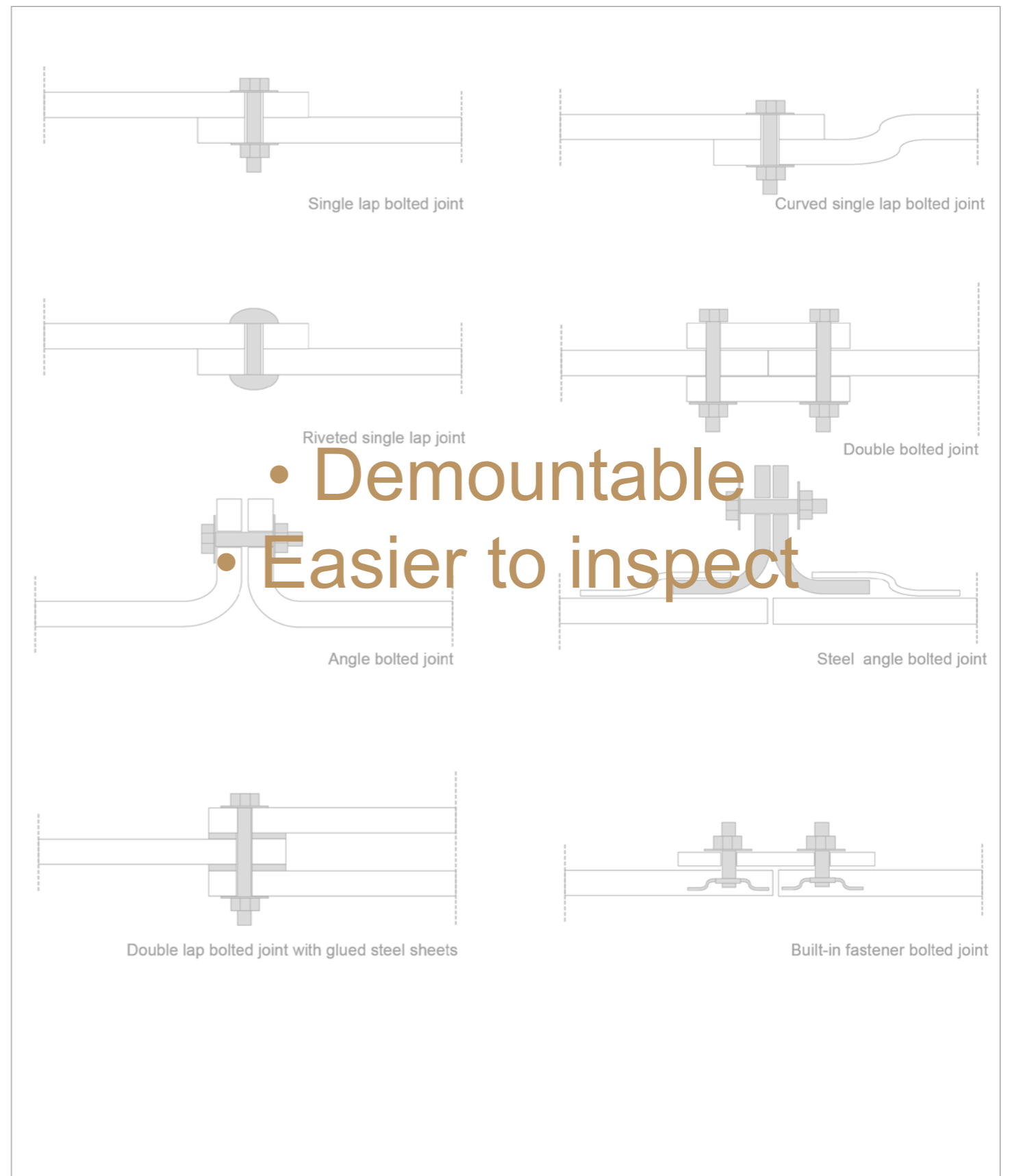
# CIRCULARITY | Connections



# CIRCULARITY | Connections

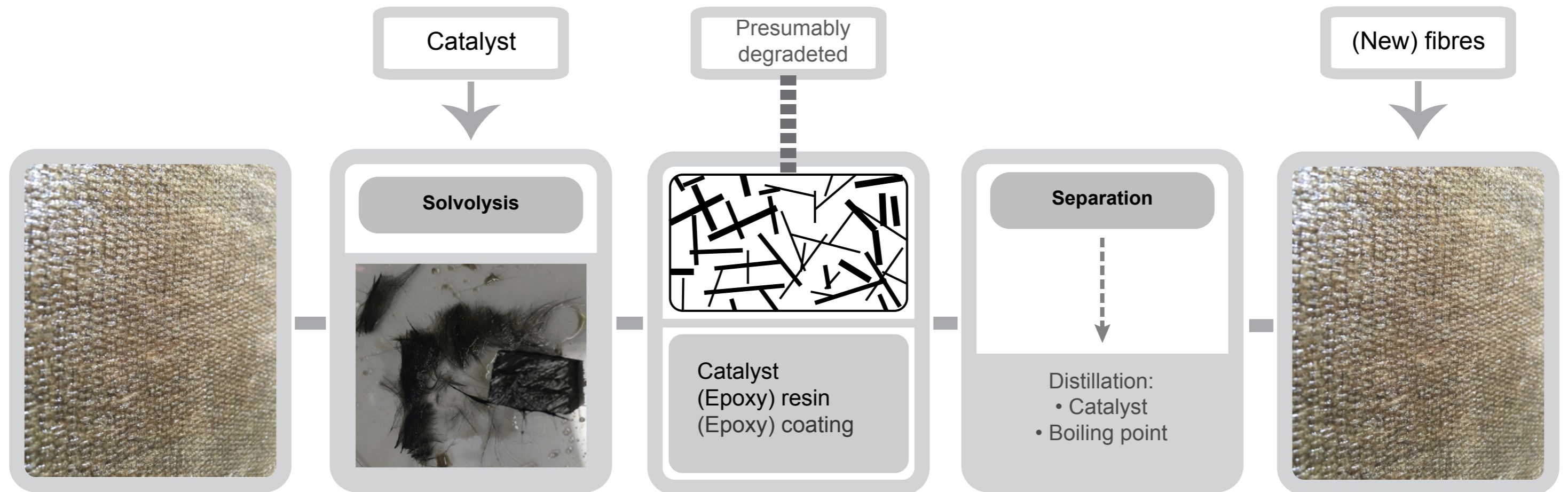


- No stress concentration
- Quick to apply



- Demountable
- Easier to inspect

# CIRCULARITY | Recycling



DURABILITY

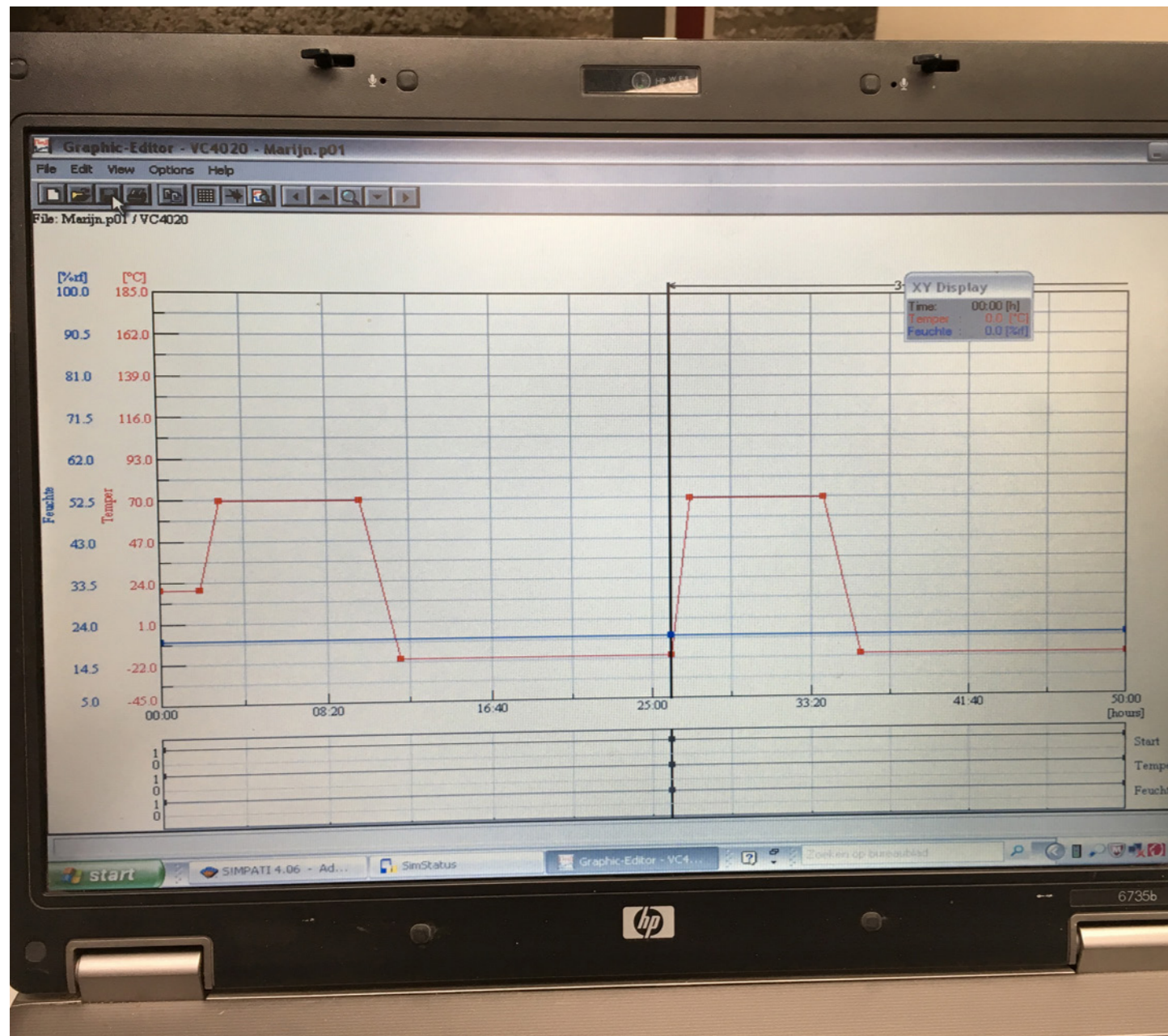
# DURABILITY | Tests

- Establish the **durability** of biobased composite
- Estimate the **lifetime**



# DURABILITY | Tests

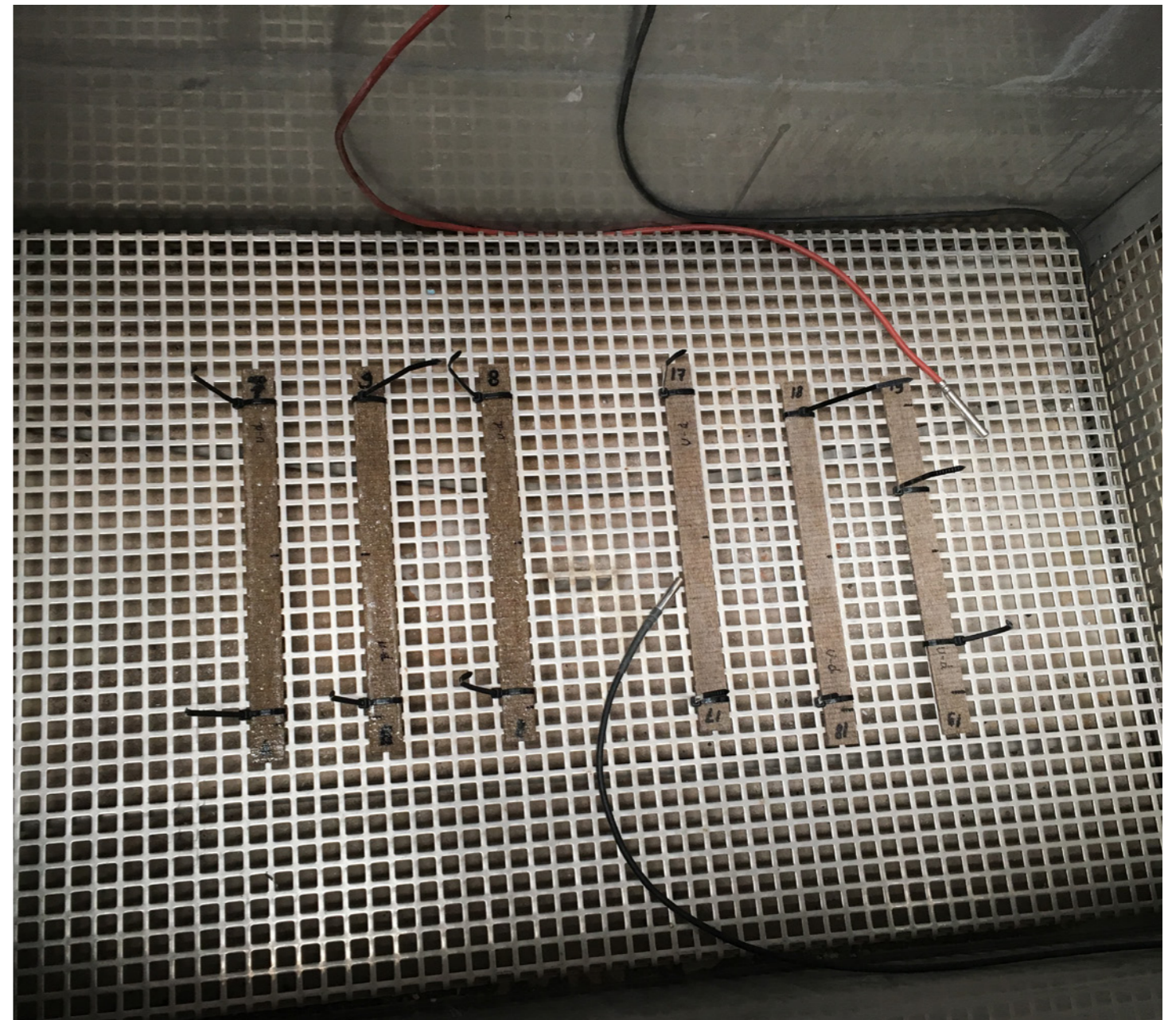
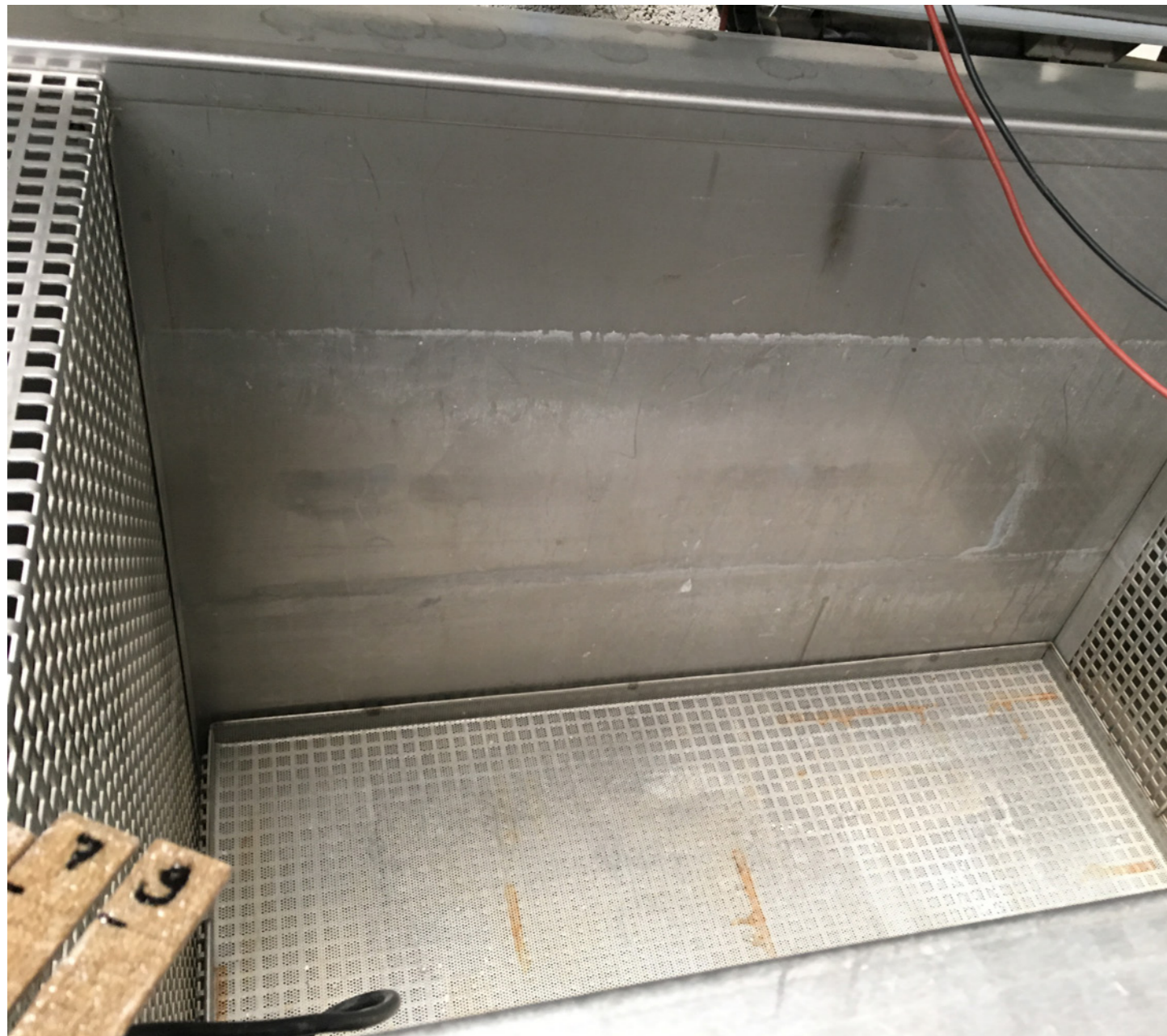
Warmth-Cold cycles  
5 days: -20°C to 70°C



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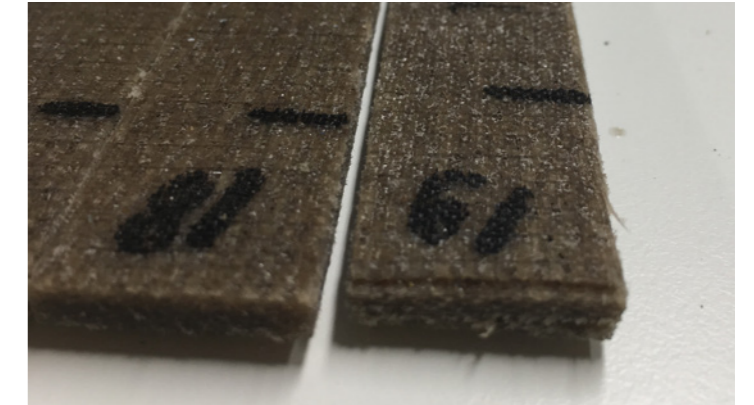
# DURABILITY | Tests

Freeze-thaw cycles  
One month: Water/ -20°C



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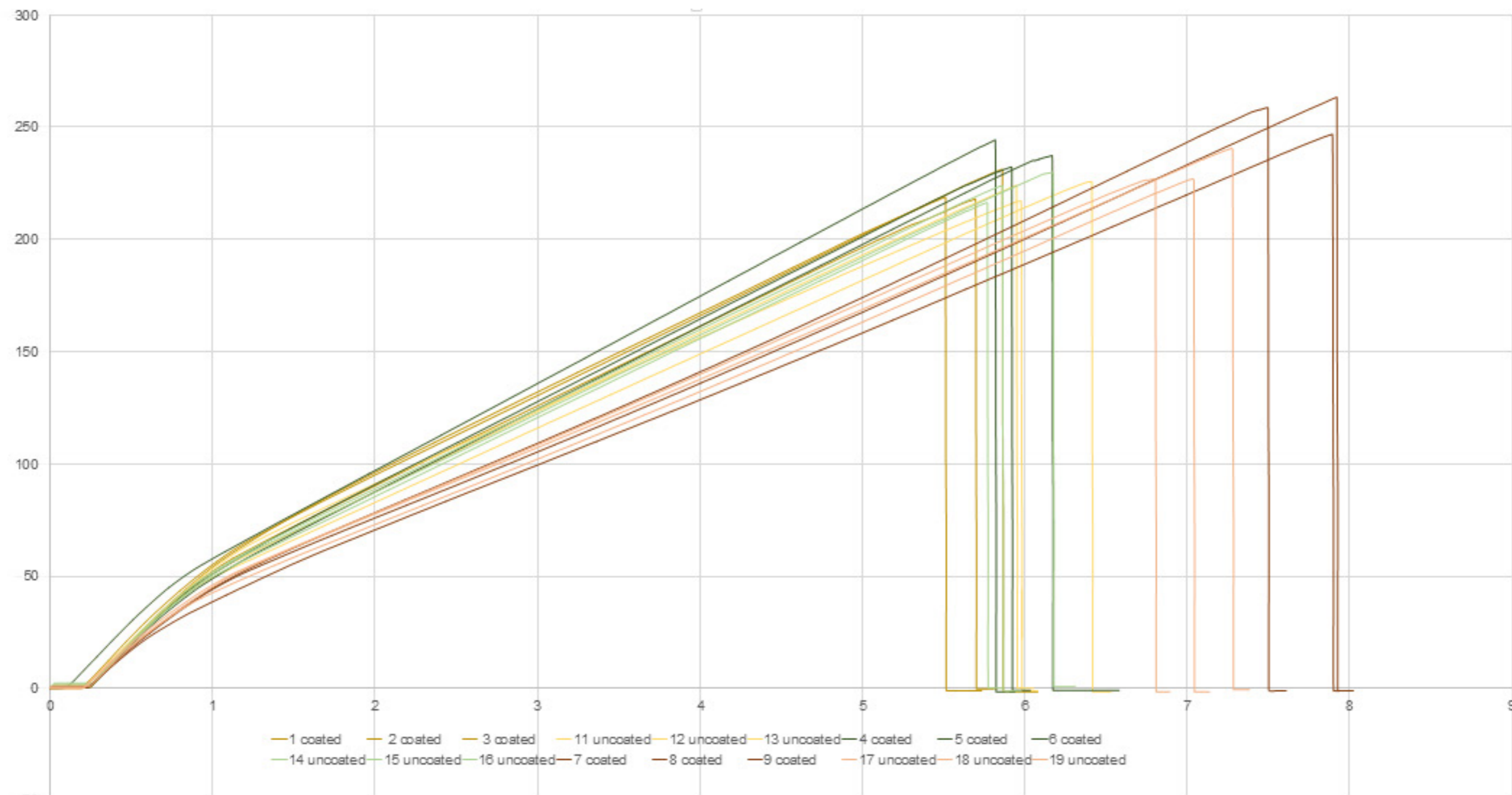
# DURABILITY | Tests results - Visual



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# DURABILITY | Tests results - Tensile strength

Warmth-cold: Coated +7%      Uncoated +0.7%  
Freeze-thaw: Coated +15%      Uncoated +4.4%



## DURABILITY | Tests results - Youngs modulus

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Warmth-cold: Coated -3%	Uncoated -1%
Freeze-thaw: Coated -13%	Uncoated -13%



# DURABILITY | Tests results - Breaking pattern

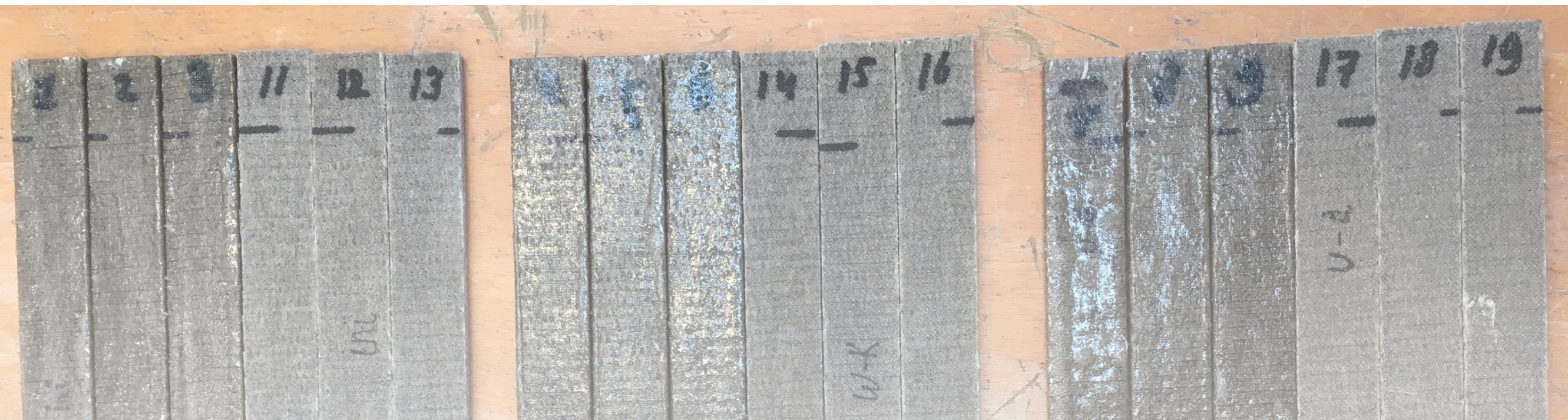


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## DURABILITY | Conclusions

When the material is coated and the bending stiffness is designed including a safety margin, the lifetime is estimated to be similar to other common facade materials

Breaking pattern changes after freeze-thaw cycles





SHADOWCOSTS

# SHADOWCOSTS | Introduction

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“Shadowcosts are the cost for the preventive measures which must be taken to reduce the emissions to a sustainable level”



# SHADOWCOSTS | Different materials

Material	S-c (€)	per
<u>Steel</u>		
Cladding	€ 0,17	kg
Light construction steel	€ 0,17	kg
Stainless steel	€ 2,12	kg
<u>Coatings</u>		
Powdercoating	€ 1,54	kg
Wetpainting	€ 0,97	kg
Galvanising (zinc)	€ 1,09	kg
<u>Aluminum</u>		
Aluminum (47% secondary)	€ 2,65	kg
<u>Coatings</u>		
Anodising	€ 0,58	m2
powder coating	€ 1,52	m2
<u>Wood</u>		
Hard, sustainably managed	€ 0,02	kg
Hard, not-sustainably managed	€ 0,02	kg
Soft, sustainable managed	€ 0,04	kg
Soft, not-sustainably managed	€ 0,07	kg
Soft, laminated	€ 0,07	kg

<u>Coatings</u>		
Paint, nature based/ water based	€ 0,15	kg
Paint, acrylate	€ 0,34	kg
Paint, alkyd	€ 0,57	kg
Paint, stony ground	€ 0,57	kg
<u>Composite</u>		
Glass fibre reinforced polyester	€ 0,76	kg
Biobased composite	€ 0,23	kg
<u>Coatings</u>		
Spray paint	€ 1,20	kg
<u>Insulation</u>		
Rockwool	€ 0,10	kg
PUR foam	€ 0,38	kg
PLA	€ 0,80	kg
Flax fibre	€ 0,23	kg
<u>Additional</u>		
Gypsum board	€ 0,03	kg
Granite	€ 0,01	kg

# SHADOWCOSTS | Shadowcosts per m<sub>2</sub>

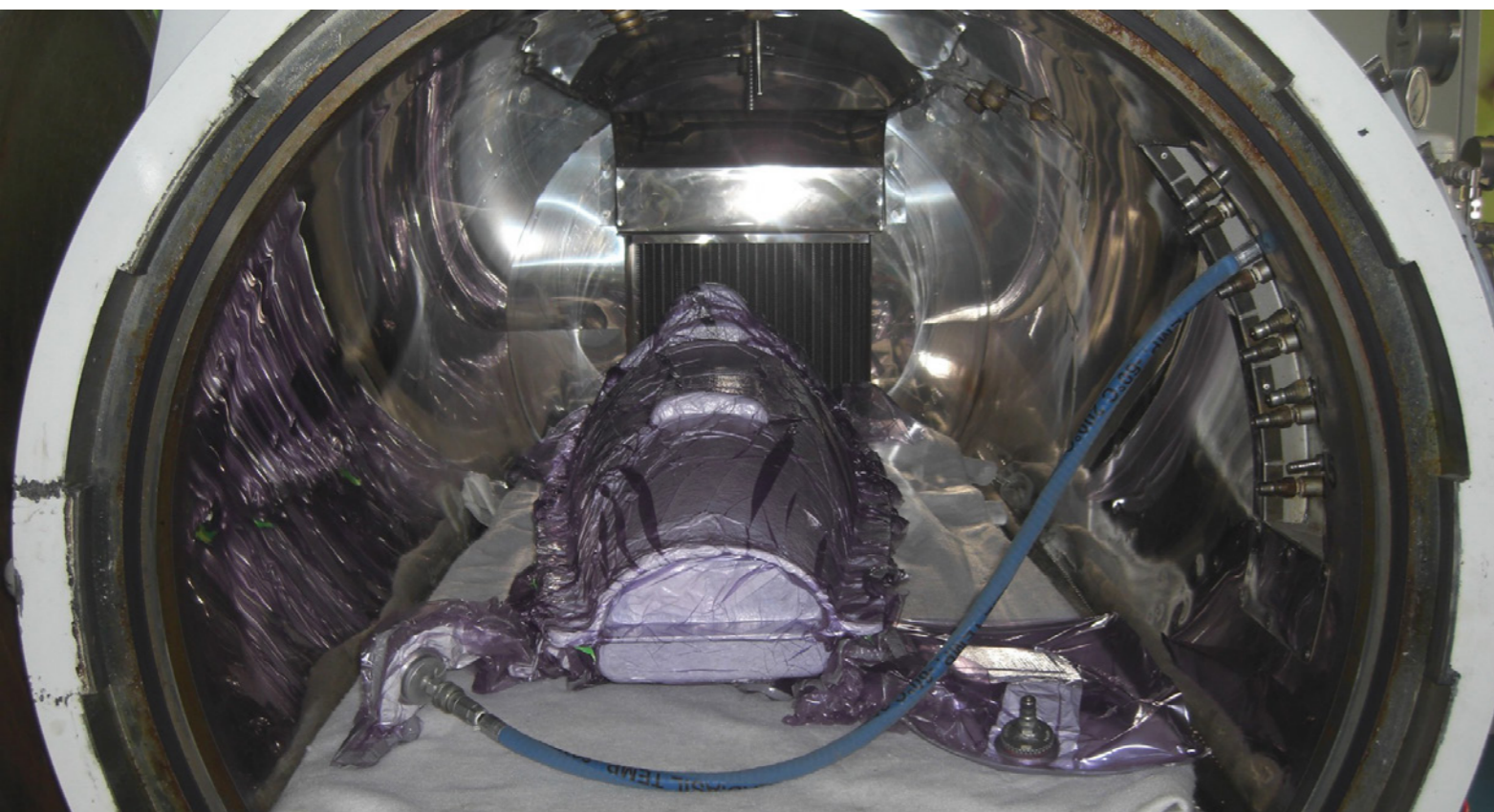
Material	Density (kg/m3)	Shadowcosts (€)	Youngs modulus	Shadowcosts/m2
Wood	530	€ 0,02	13	0.17
Steel	7870	€ 0,17	210	1.33
Aluminum	2700	€ 2,65	69	21.47
Glassfibre-reinforced composite	2000	€ 0,76	69	4.56
Biobased composite	1115	€ 0,23	11,4	4.61

# DESIGN PARAMETERS

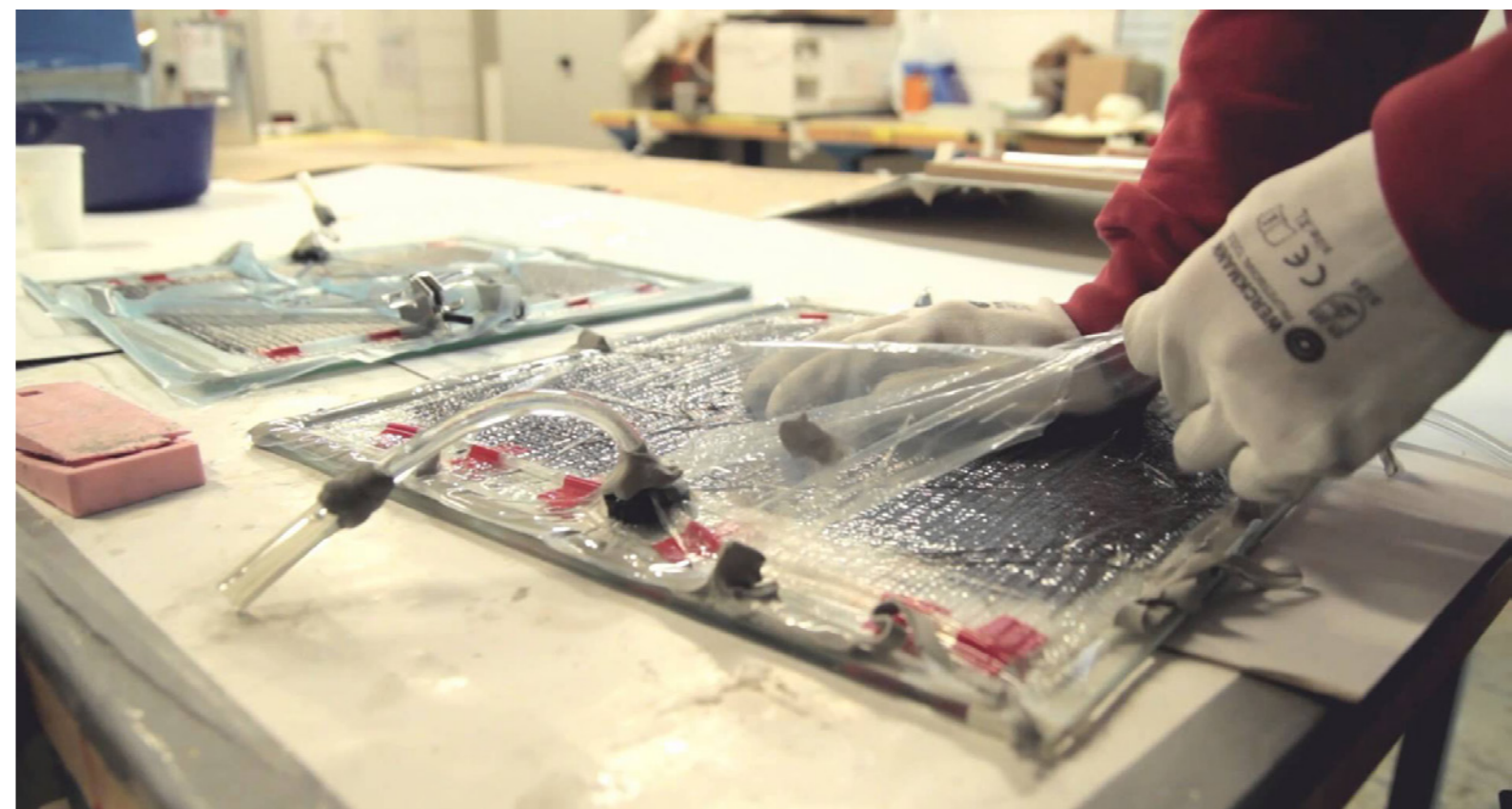
# DESIGN PARAMETERS | Production techniques

Avoid:

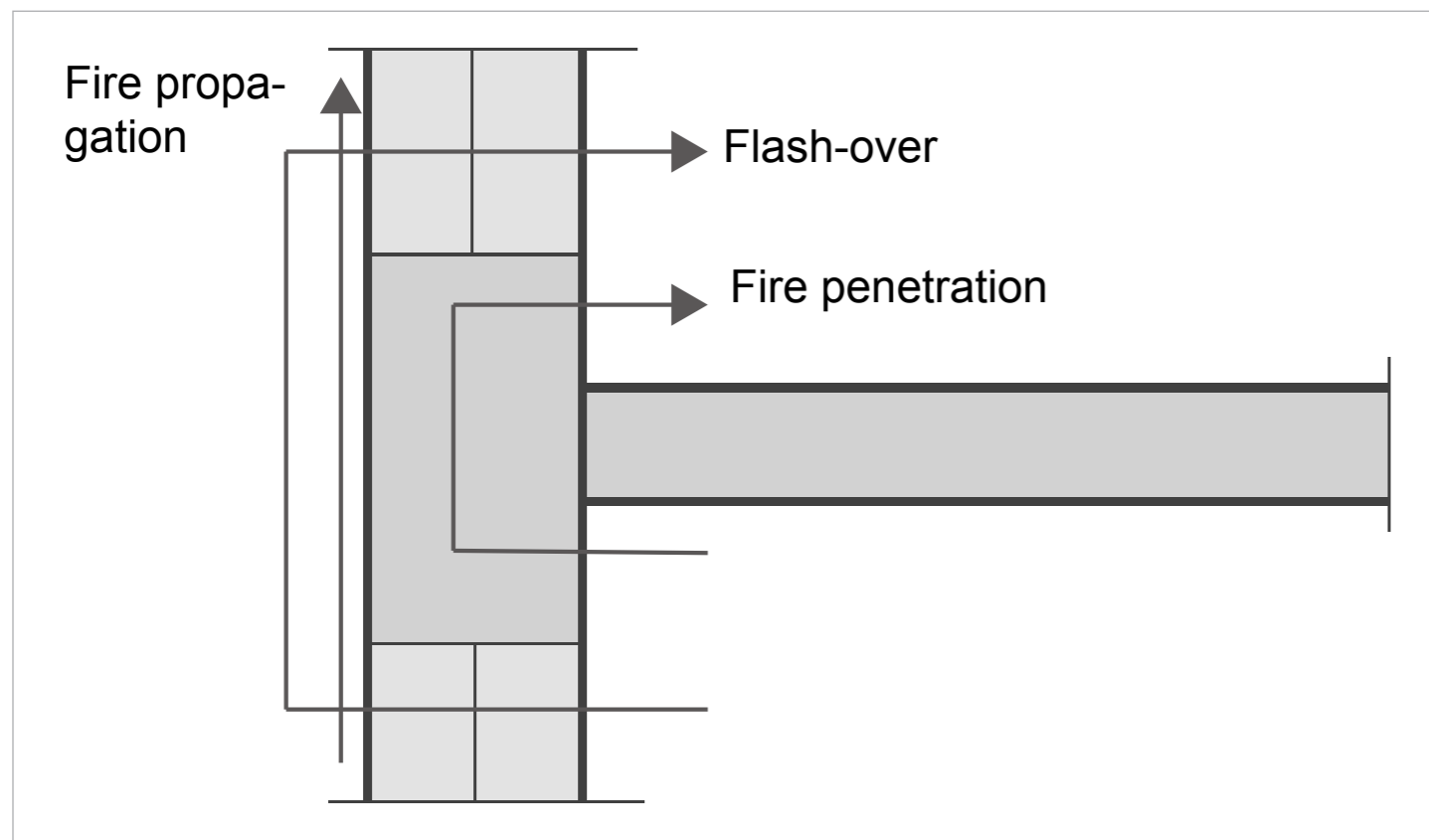
- An autoclave
- Additional material like molds, vacuum bags, etc
- Emissions evaporating during the process



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# DESIGN PARAMETERS | Safety requirements - Fire-safety



- ☐ Apply a fire-retardant **coating**
- ☐ Use a fire retardant **resin**
- ☐ Apply the material only to **low-rise buildings**

# DESIGN PARAMETERS | Thermal transmittance

Wood: 0.16 W/m<sup>2</sup>K

Biobased composite: 0.056 W/m<sup>2</sup>K

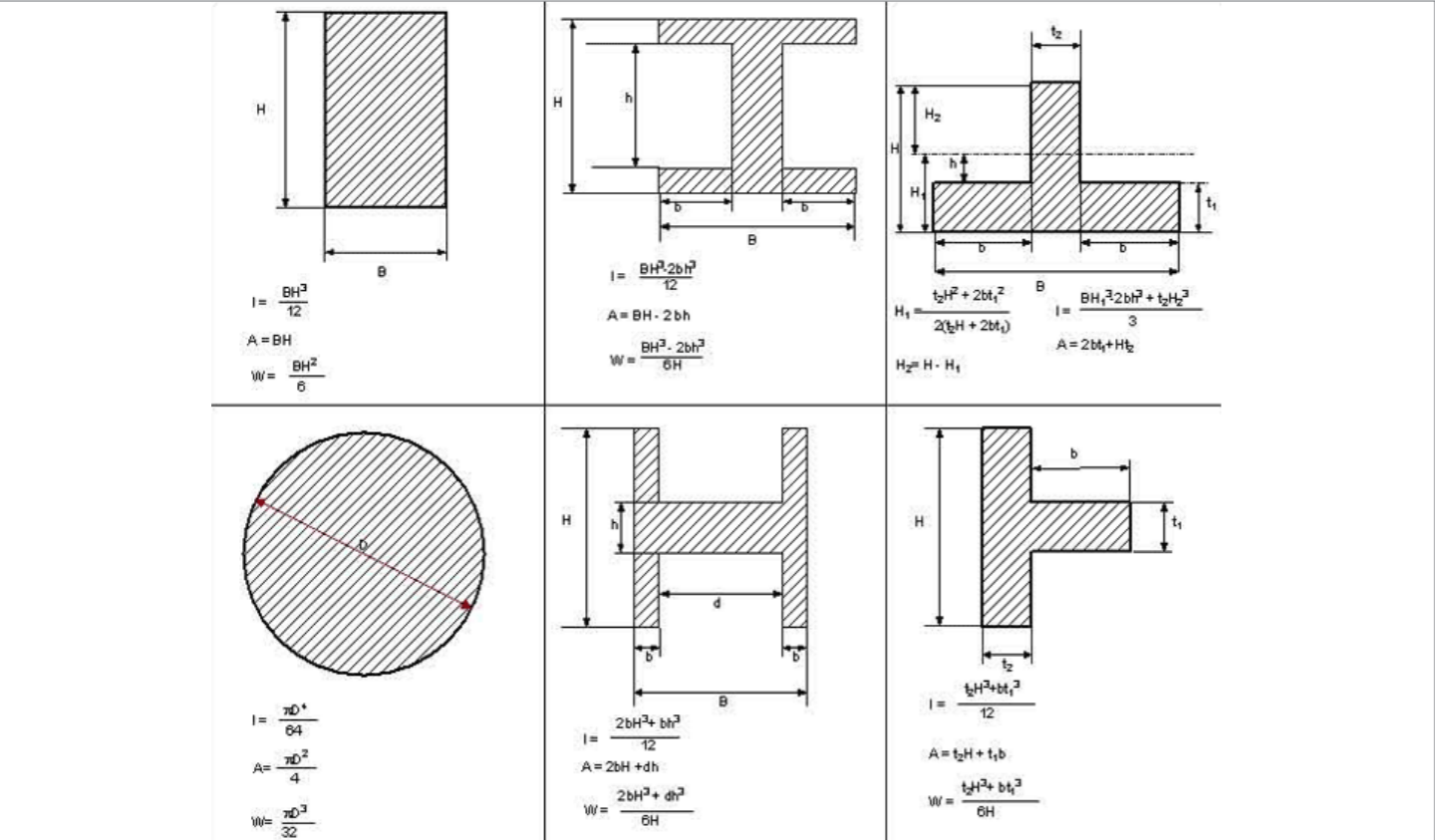
Material	$\lambda$ (W/m*K)	d (mm)	Rd (m)	Density (kg/m3)	Weight (kg/m2)
Gypsum board 0,95 cm	0,16	9,5	0,0059375	7,62 (kg/m2)	7,62 (kg/m2)
Gypsum board 1,25 cm	0,16	12,5	0,0078125	10,2 (kg/m2)	10,2 (kg/m2)
Steel reinforced concrete per dm	1,7	100	0,06	2400	240
Steel per mm	50	1	0,00002	7870	7,87
Aluminum per mm	200	1	0,000005	2700	2,7
Wood (Fir) per cm	0,18	10	0,06	530	5,3
Balsae wood per cm	0,048	10	0,21	1600	16
Biobased composite (flax-supersap)per cm	0,056	10	0,18	1115	11,15
Biobased composite (hemp-supersap)per cm	0,056	10	0,18	1148	11,48
Fibreglass-polyester composite per cm	0,015	10	0,67	1522,4	15,22
Aircavity (stationary, 15°) per cm	0,026	10	0,38	1,225	0,01
Glass	1,05	4	0,0038095	2500	10
Ceramic	0,8	40	0,05	2200	110

# DESIGN PARAMETERS | Geometry - Bending stiffness

Bending stiffness = Moment of Inertia \* Youngs modulus

Moment of inertia

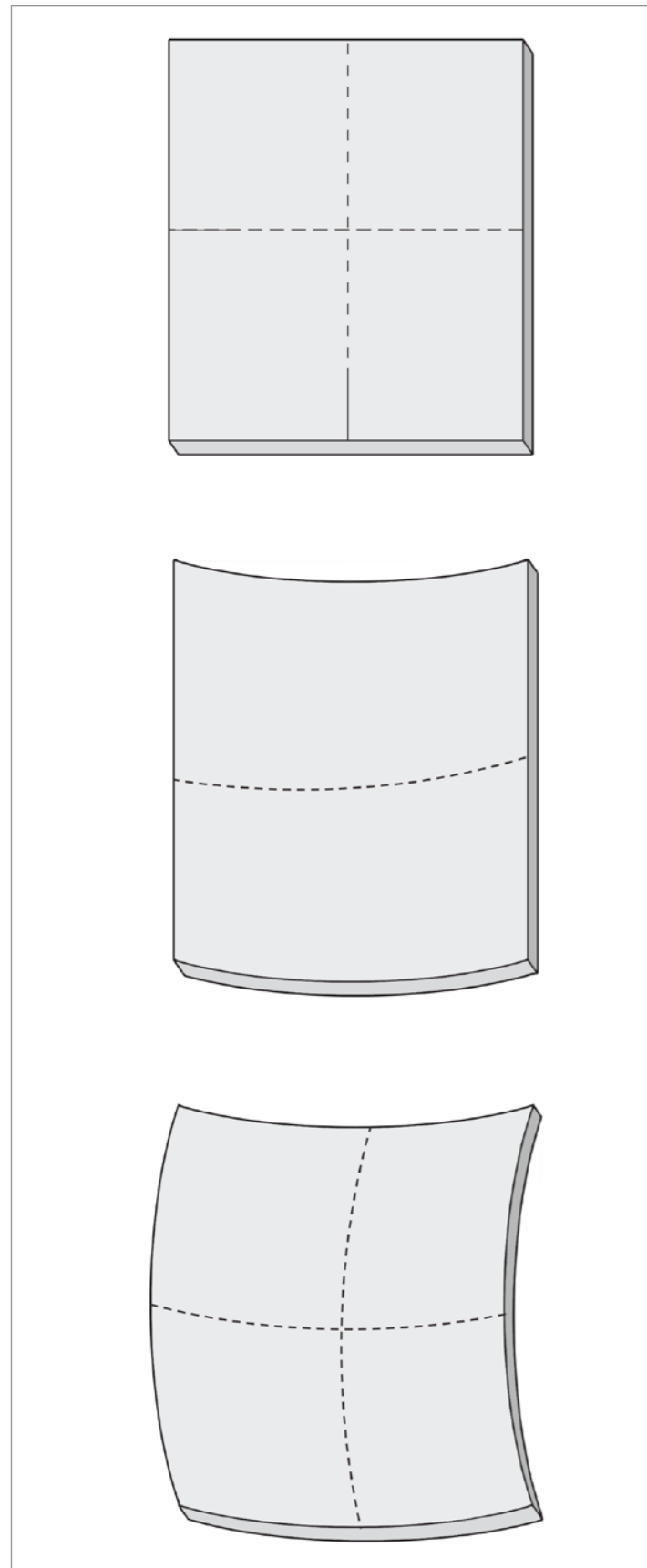
Youngs modulus



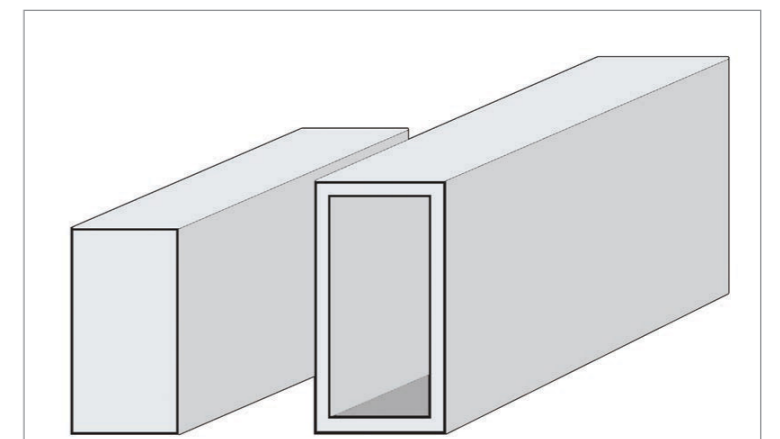
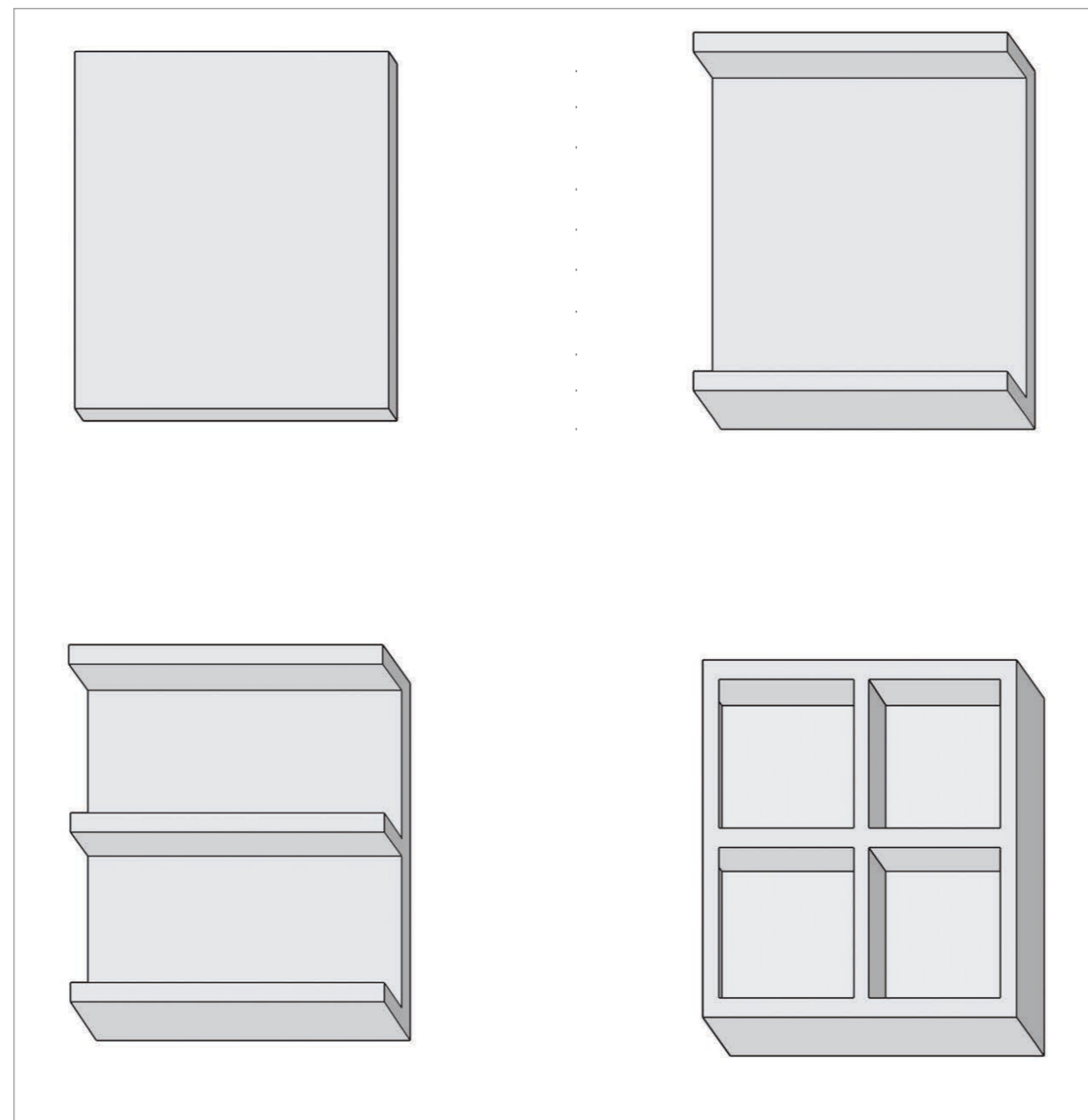
	Y-M (Gpa)	Density (kg/m3)
Steel	210	7870
Aluminum	69	2700
Biobased composite	11,4	1115

a circular biobased composite facade

# DESIGN PARAMETERS | Geometry - Bending stiffness



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# CASE STUDIES

# CASE STUDIES | Facades

What is **possible** with biobased composite, when used for a facade design?



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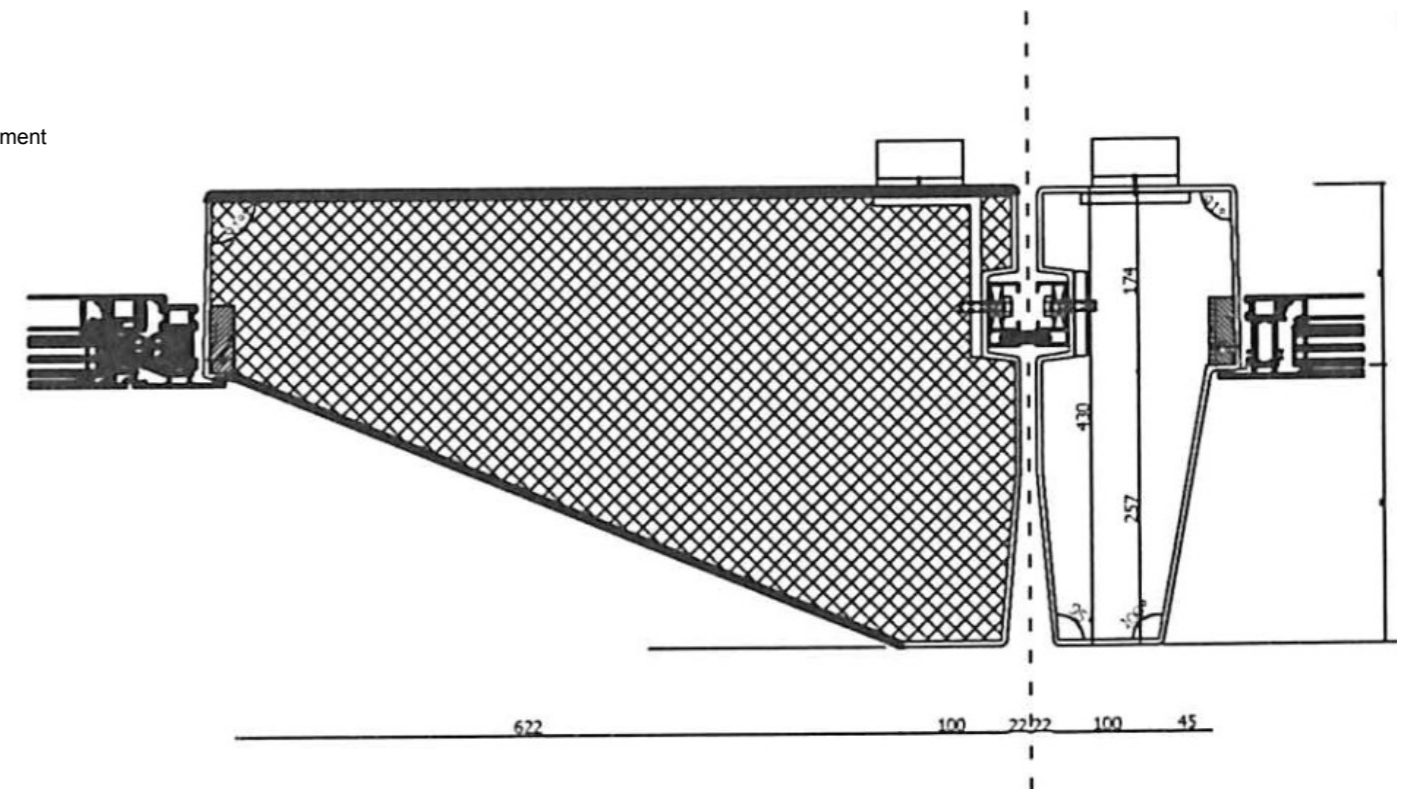
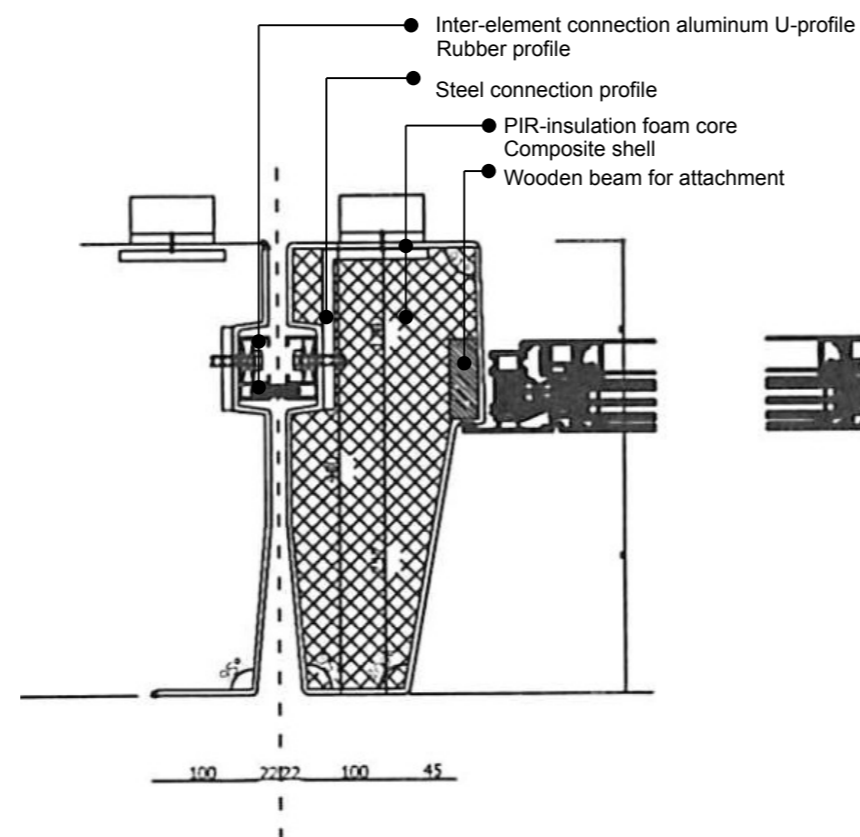
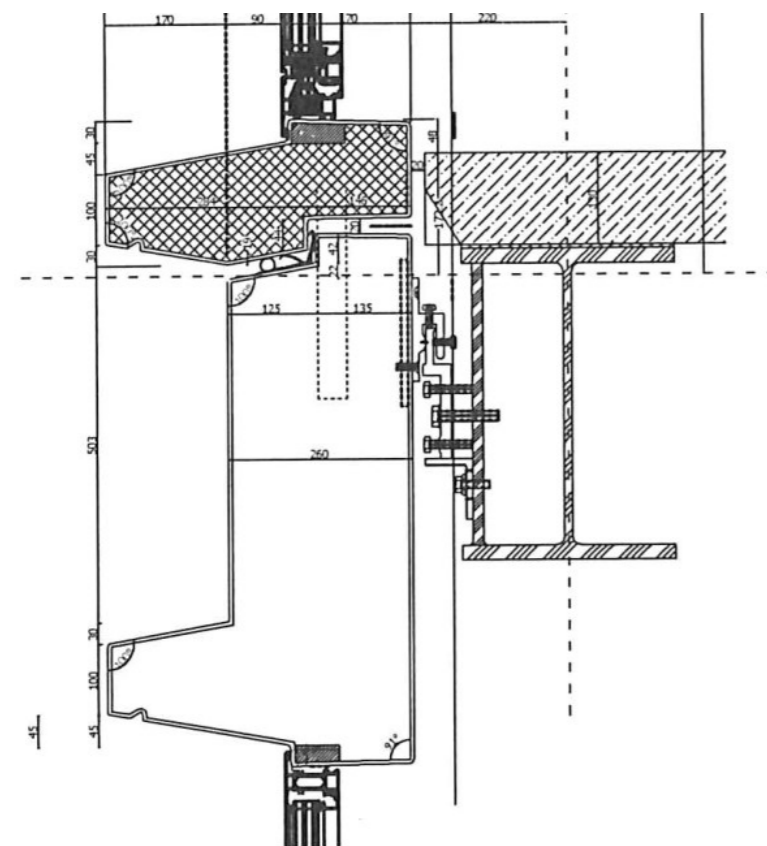
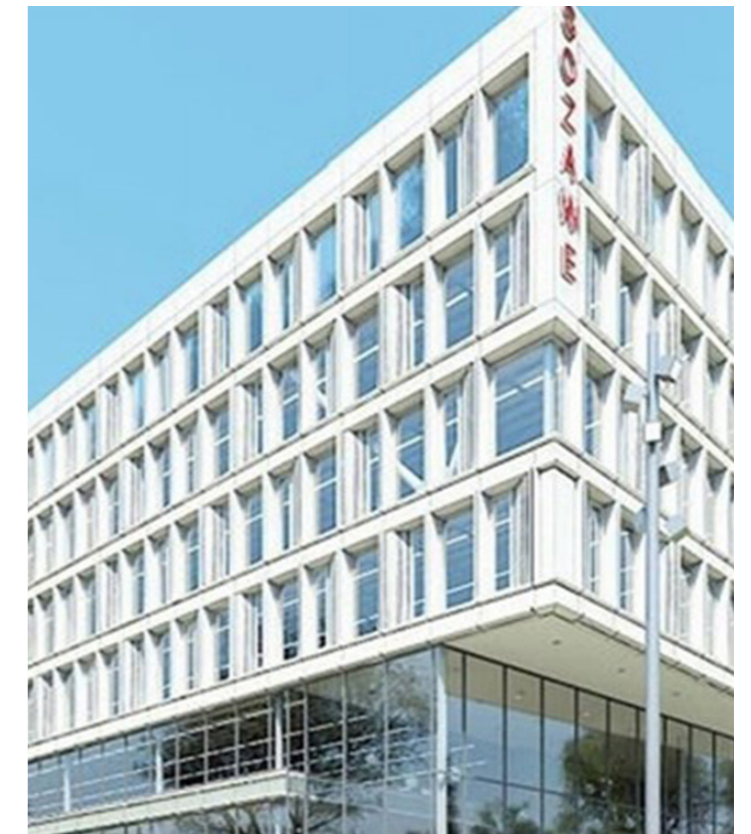
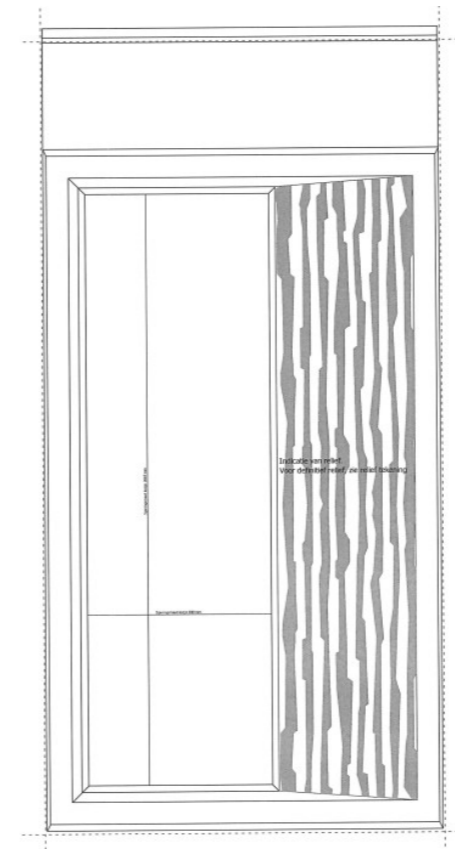
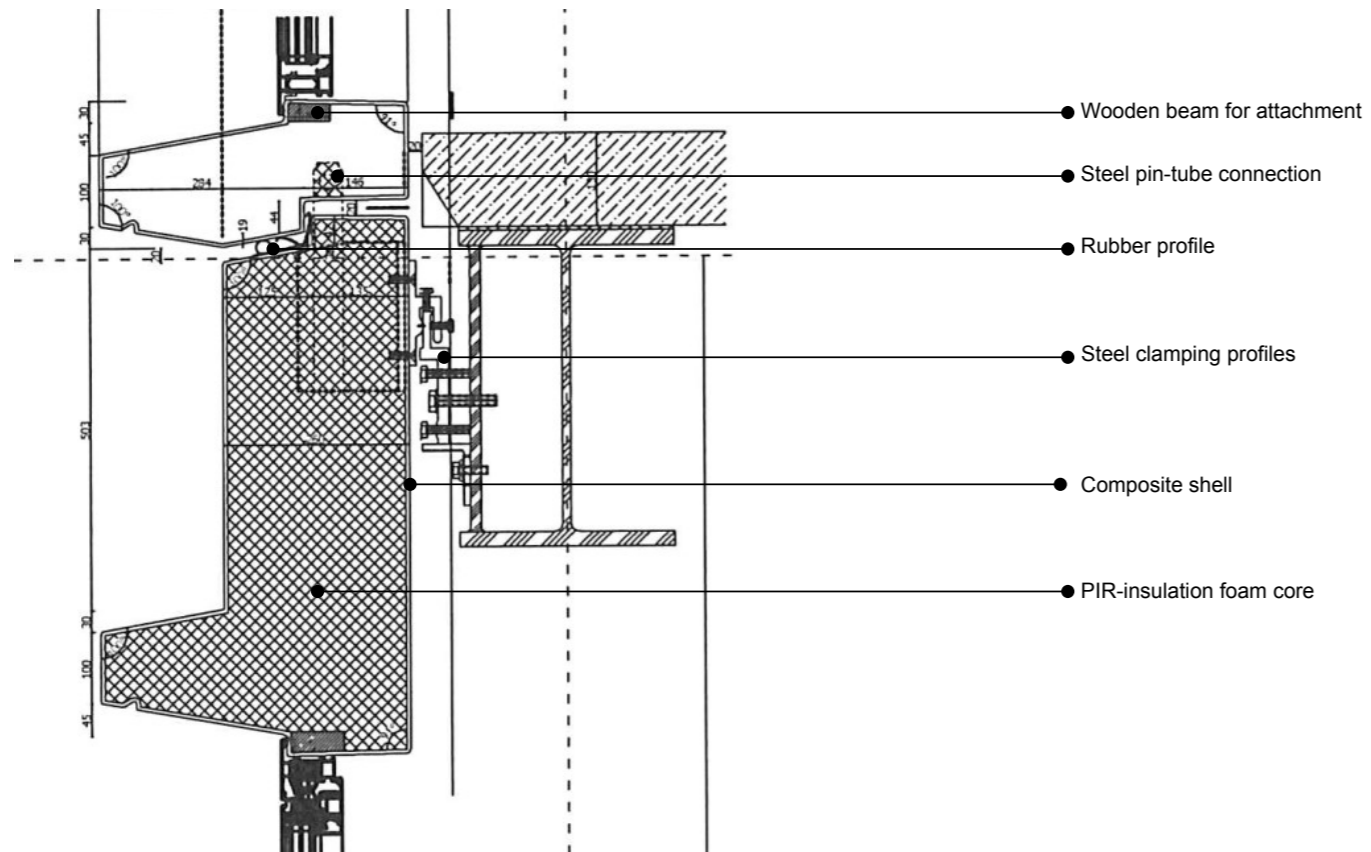


# CASE STUDIES | Products - Approach

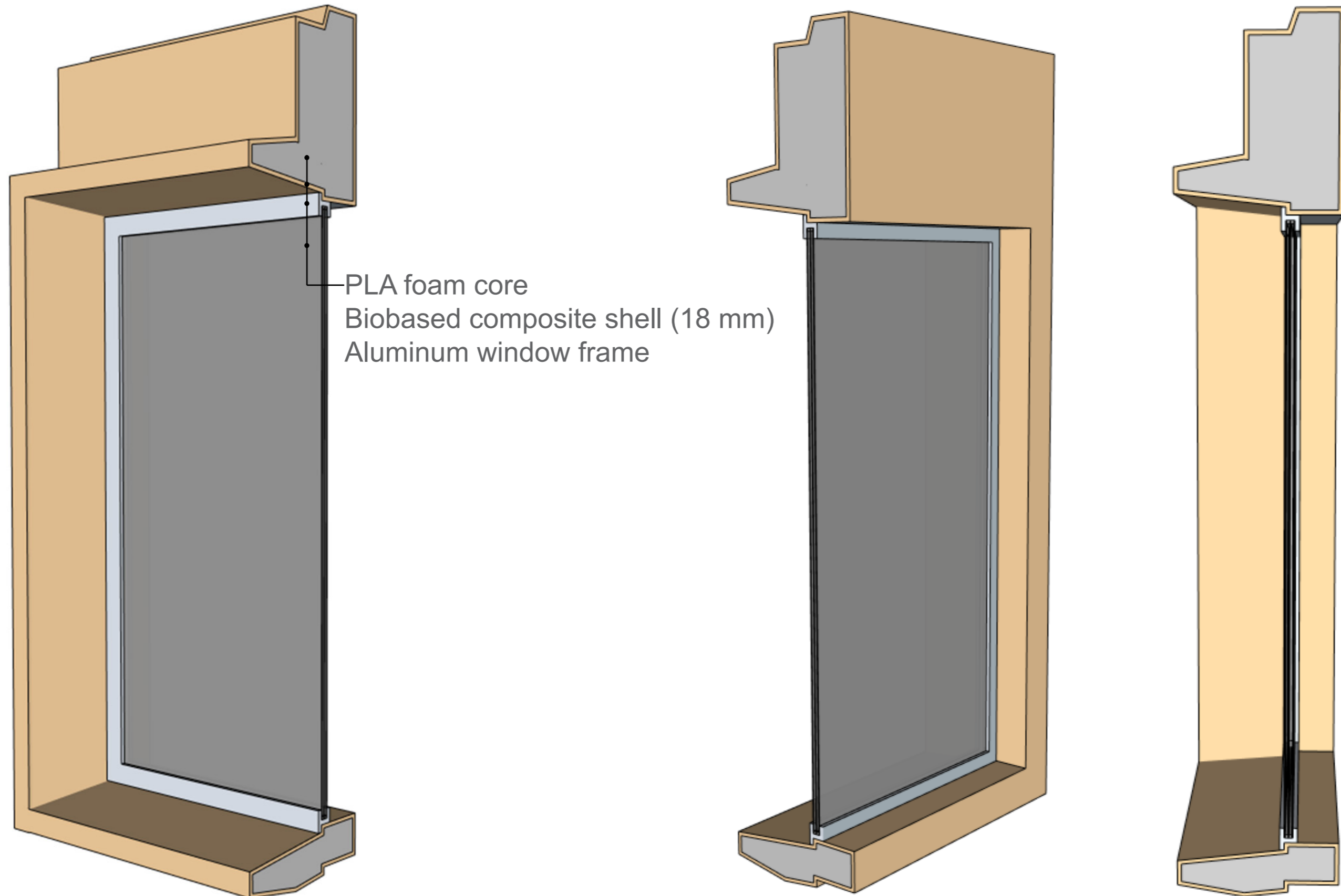
Weight	kg/m <sup>2</sup>	12.15		
Rc-value	m <sup>2</sup> *K/W	4.53		
Schadowcosts	€/m <sup>2</sup>	3.52		
Circular scenario	Re-use	Adapt	Recycle	10

Weight	kg/m <sup>2</sup>	25.24		
Rc-value	m <sup>2</sup> *K/W	4.5		
Schadowcosts	€/m <sup>2</sup>	10.12		
Circular scenario	Re-use	Adapt	Recycle	10

# CASE STUDIES | Element Facade

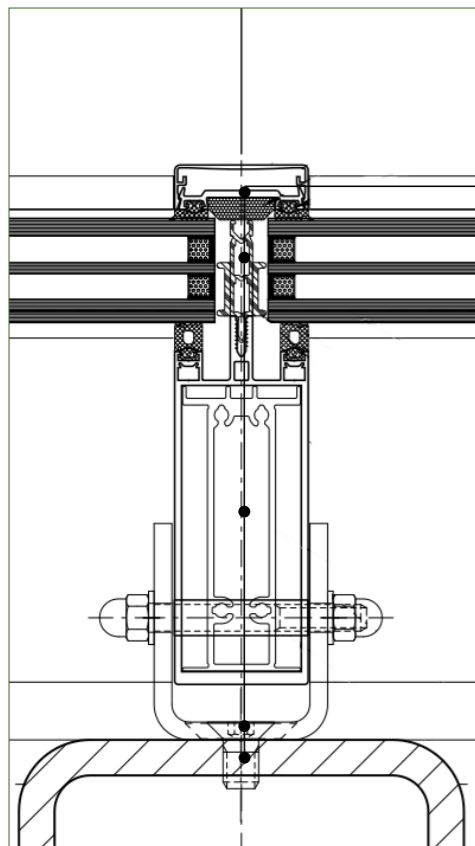


# CASE STUDIES | Element Facade

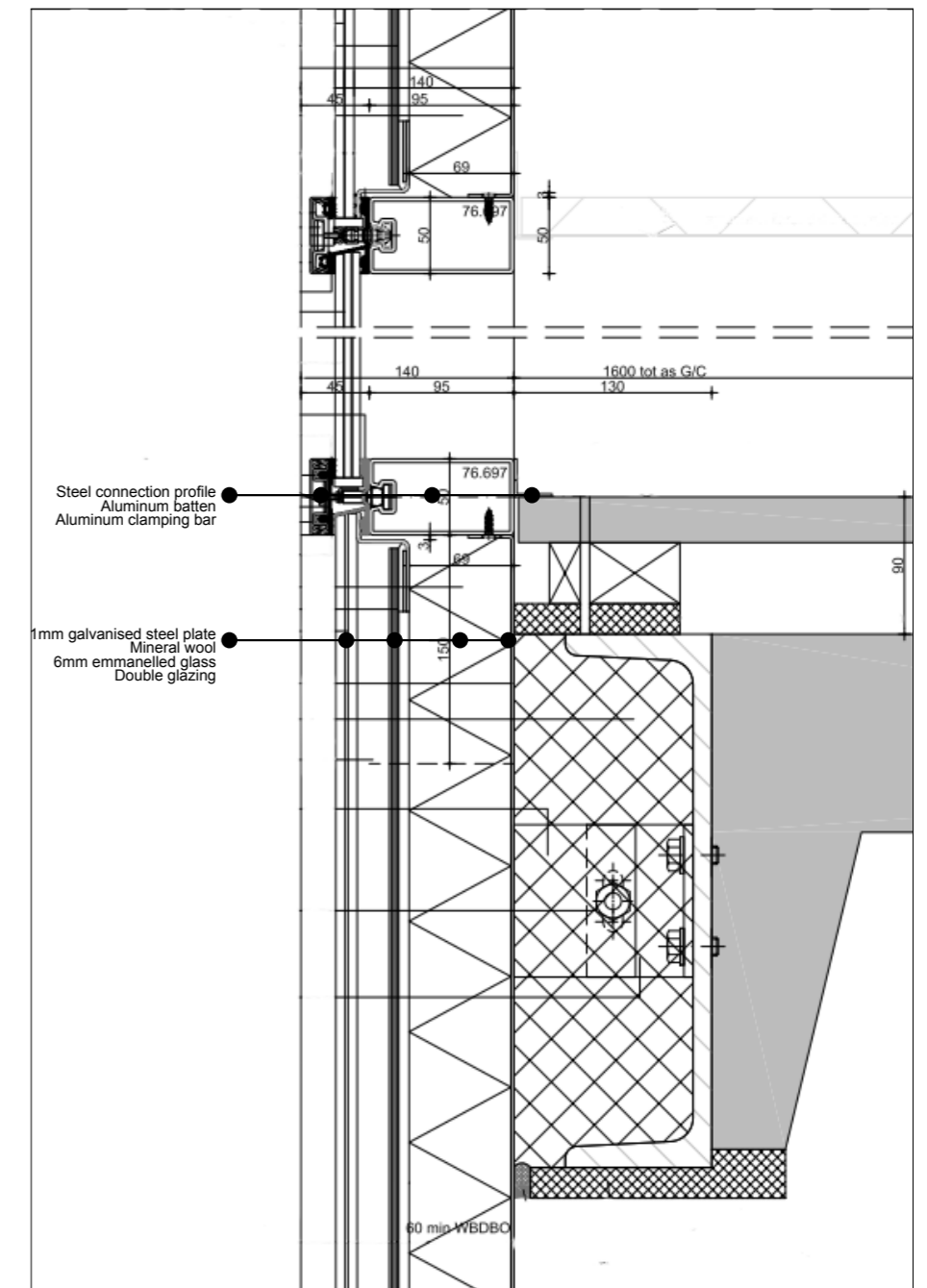
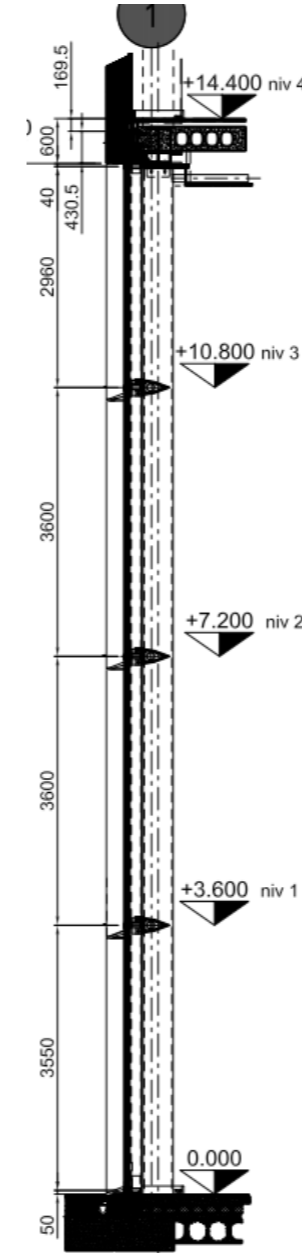
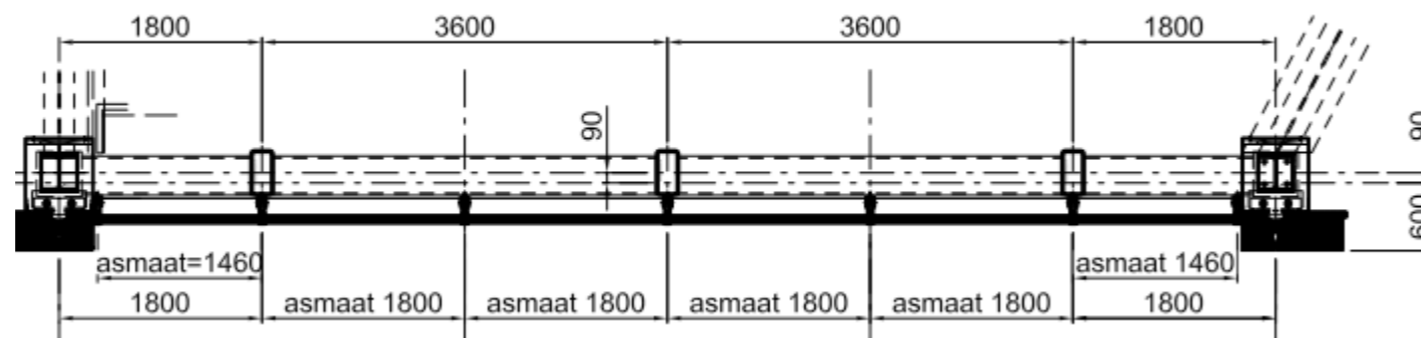


a circular biobased composite facade

# CASE STUDIES | Curtain wall

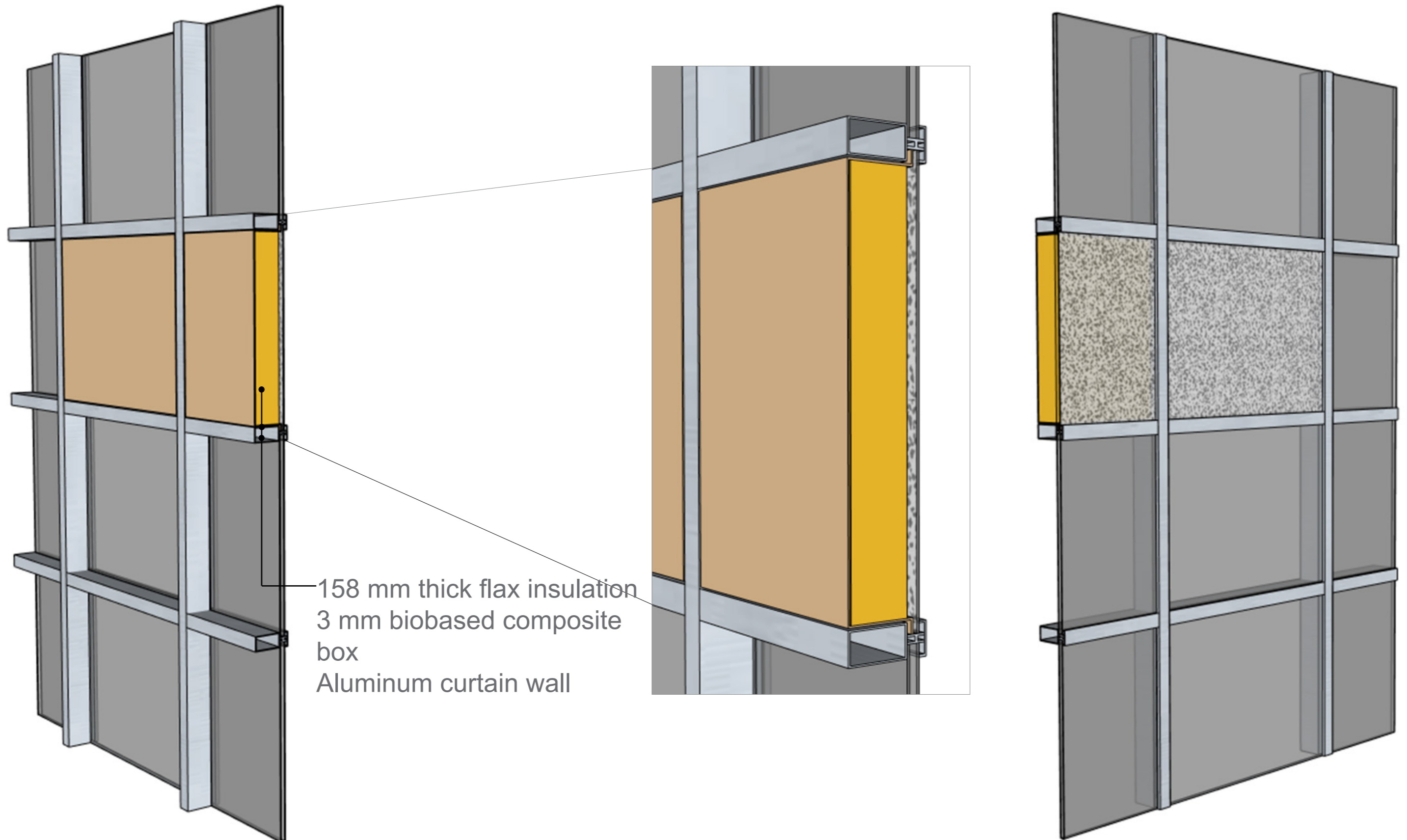


Steel column  
Steel U-profile  
Aluminium truss  
Plastic spacers  
Aluminum clamping bar



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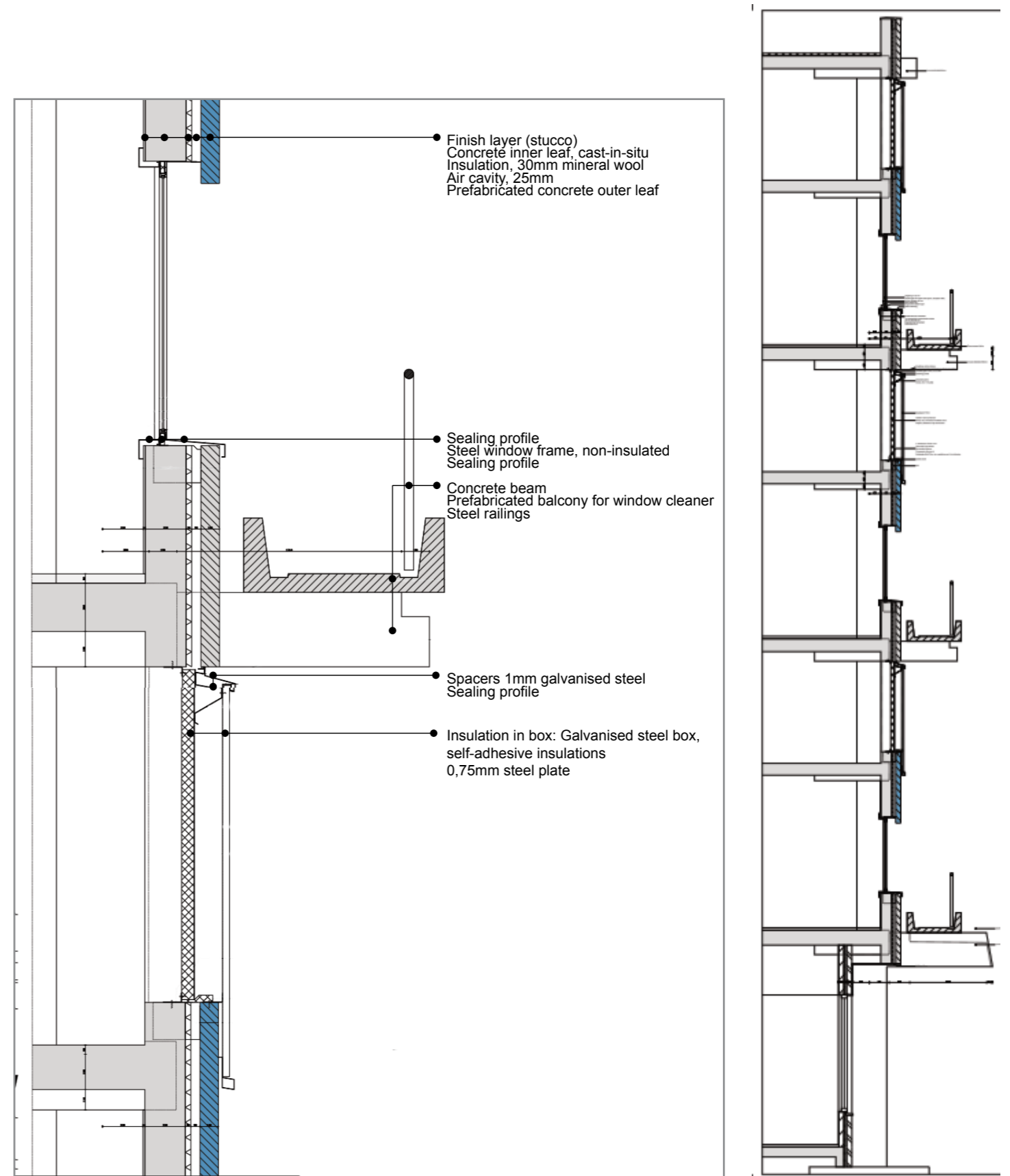
# CASE STUDIES | Curtain wall



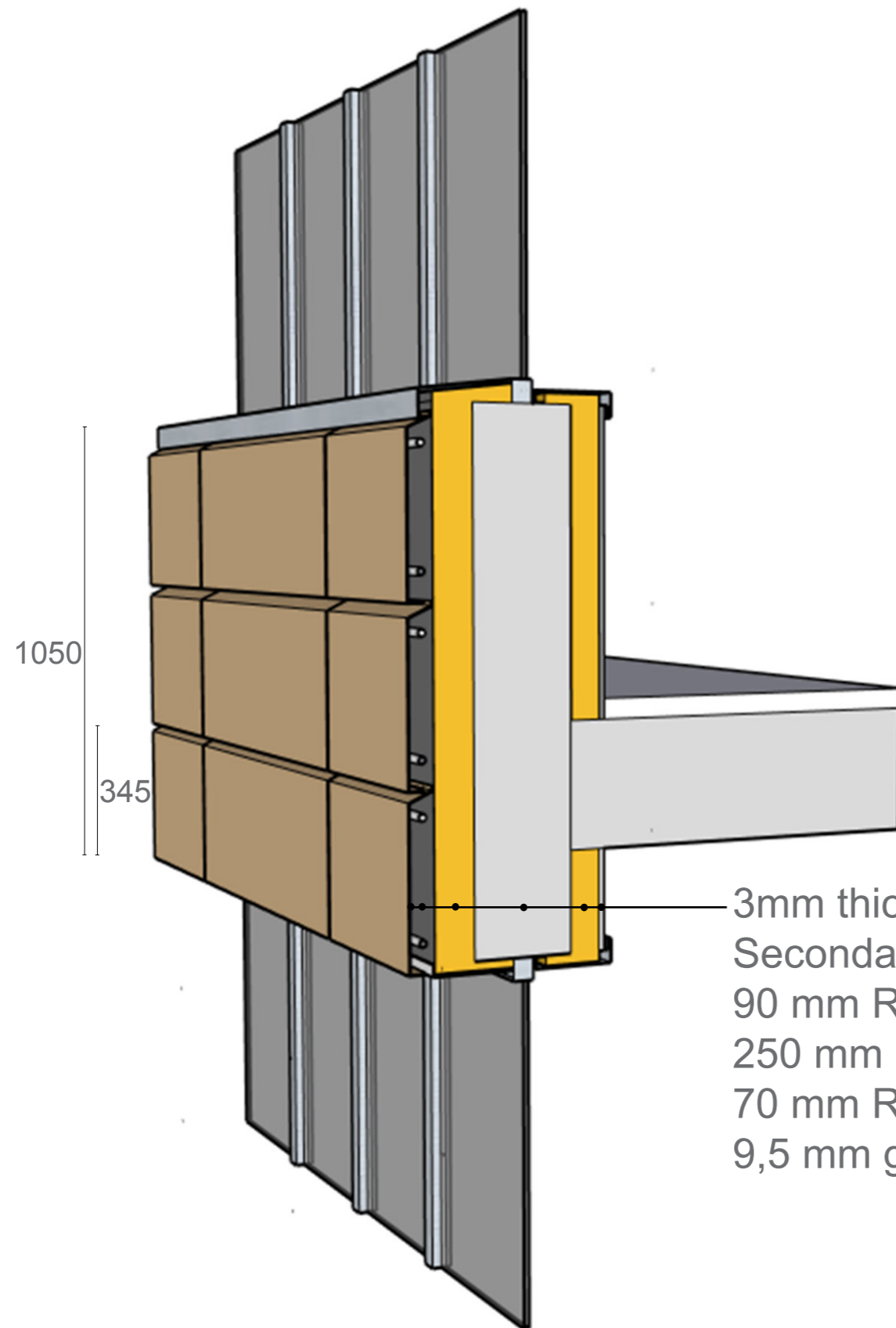
# CASE STUDIES | Parapet facade



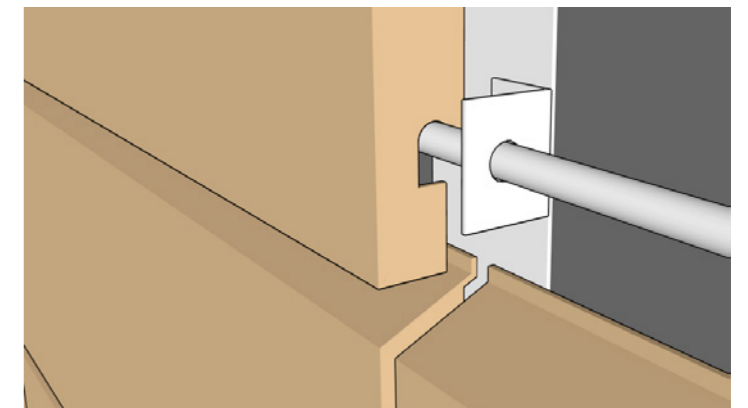
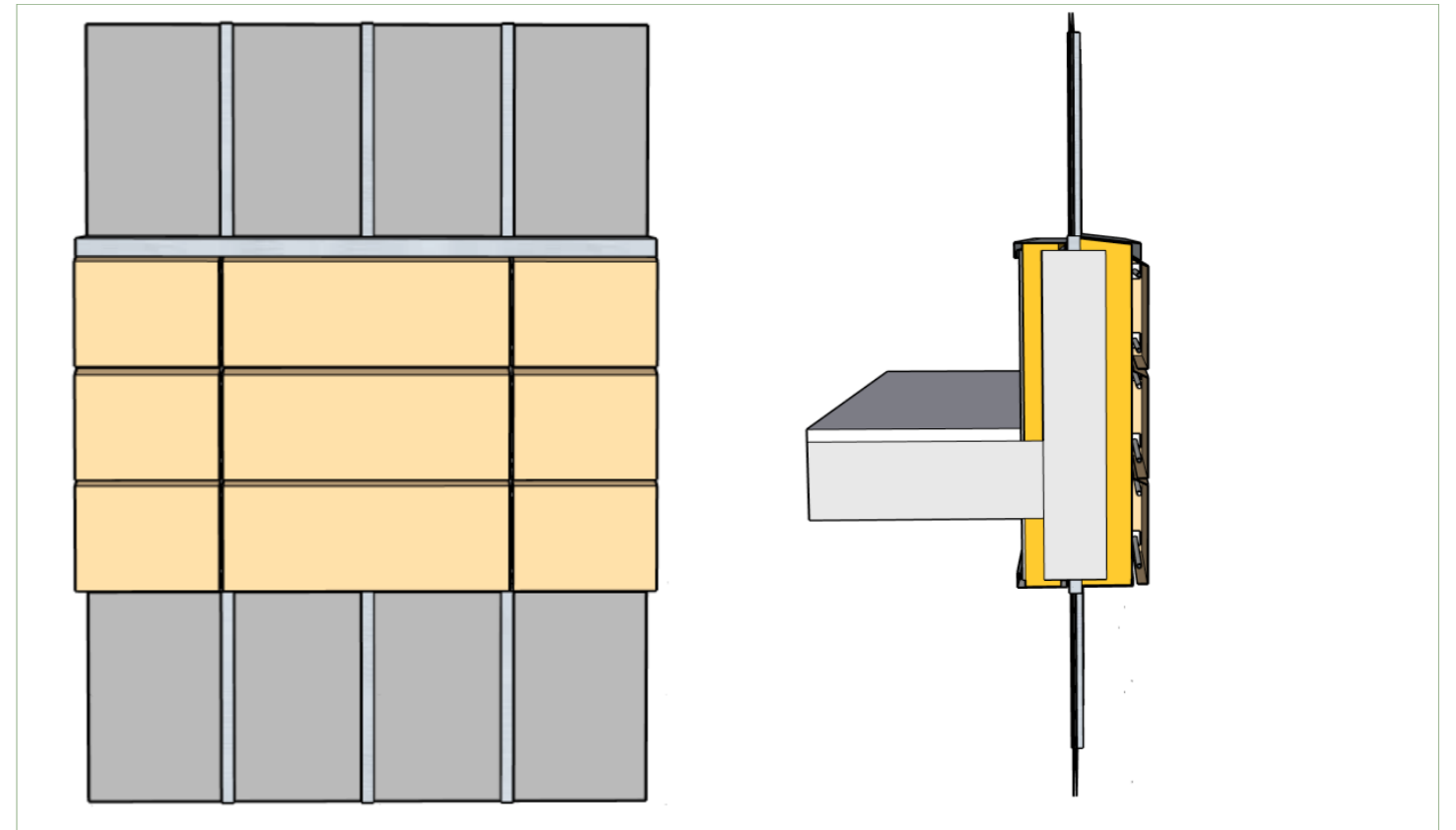
a circular biobased composite facade



# CASE STUDIES | Parapet facade

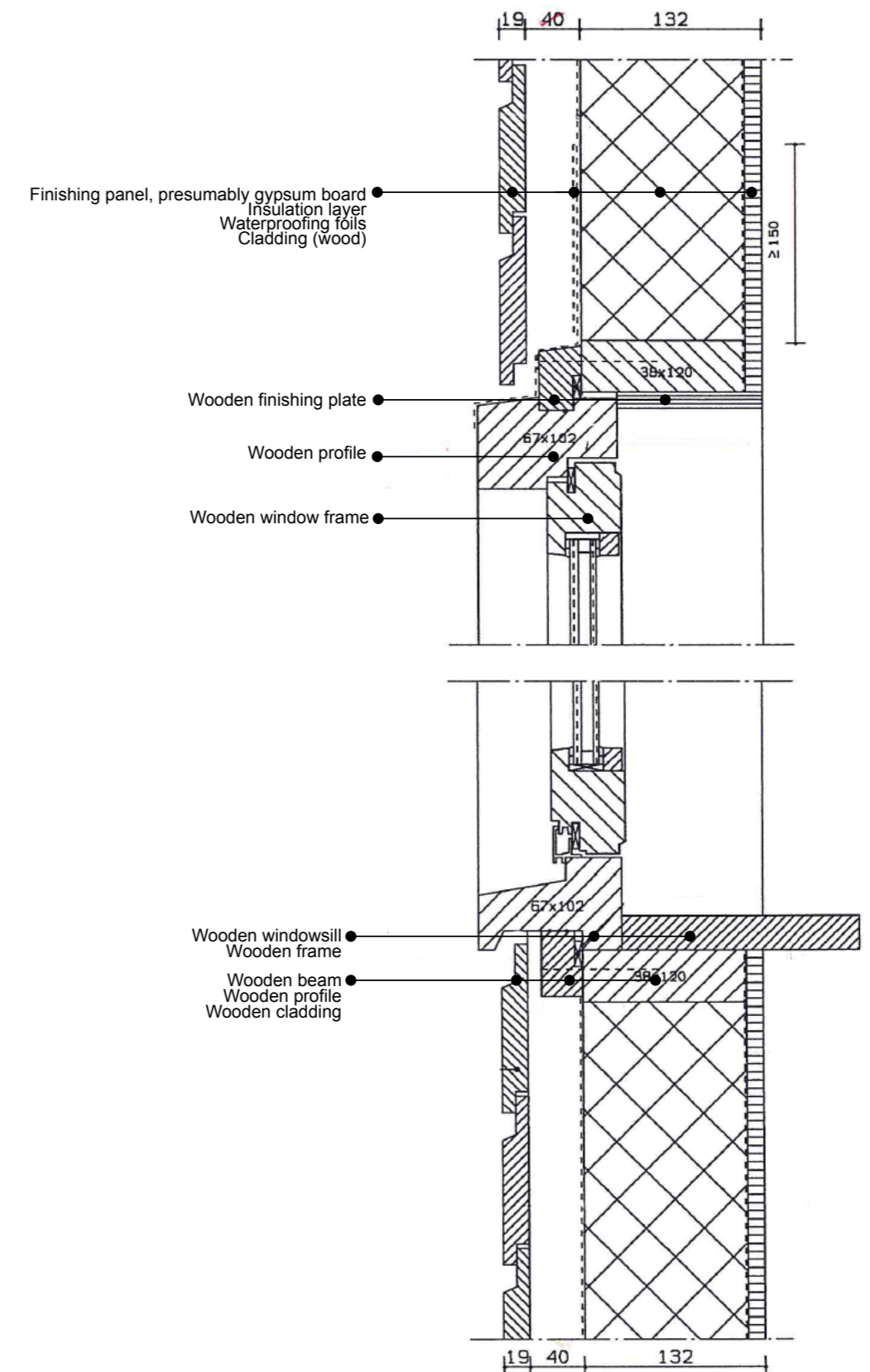
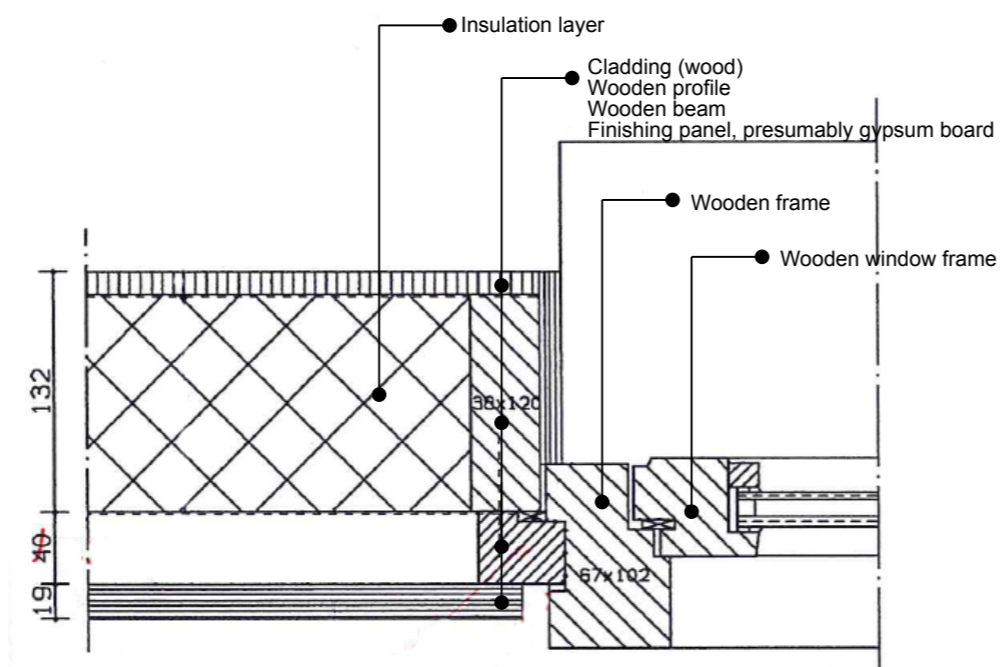


3mm thick biobased composite cassettes  
Secondary structure  
90 mm Rockwool insulation  
250 mm Concrete (existing)  
70 mm Rockwool  
9,5 mm gypsum board



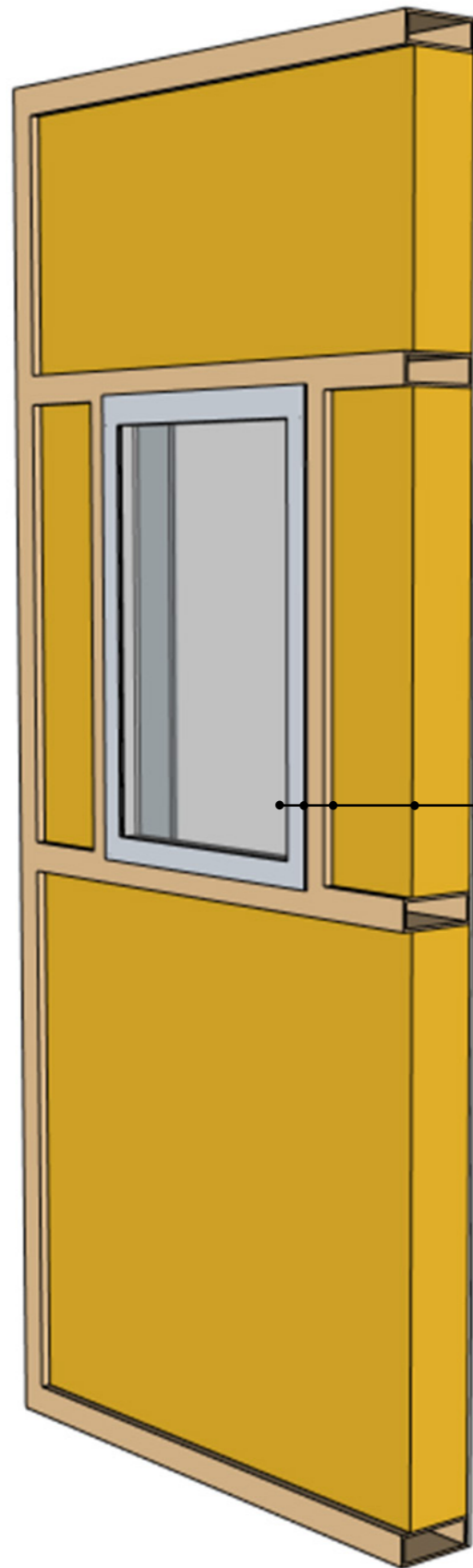
a circular biobased composite facade

# CASE STUDIES | Timber frame

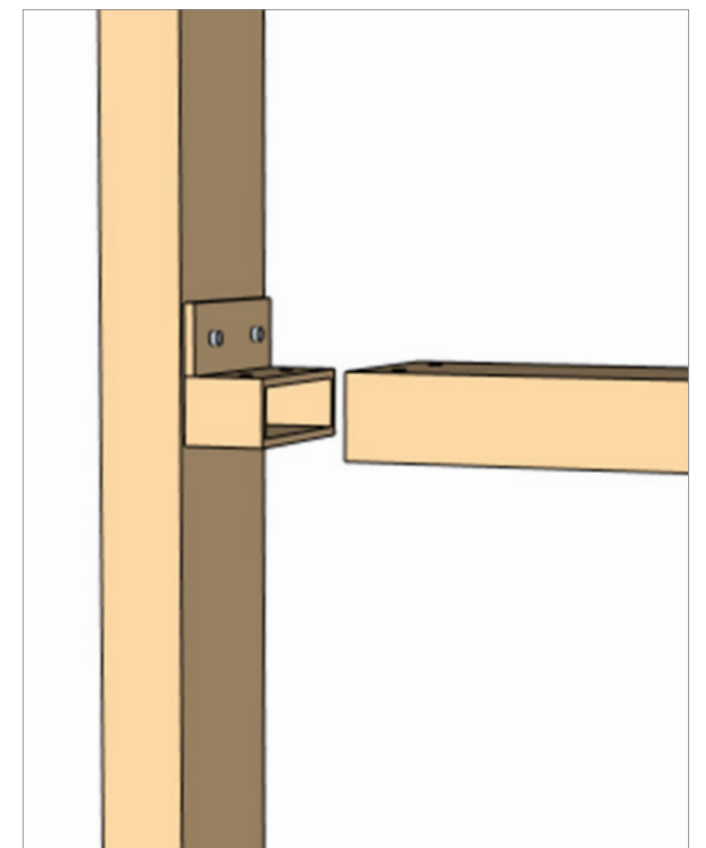
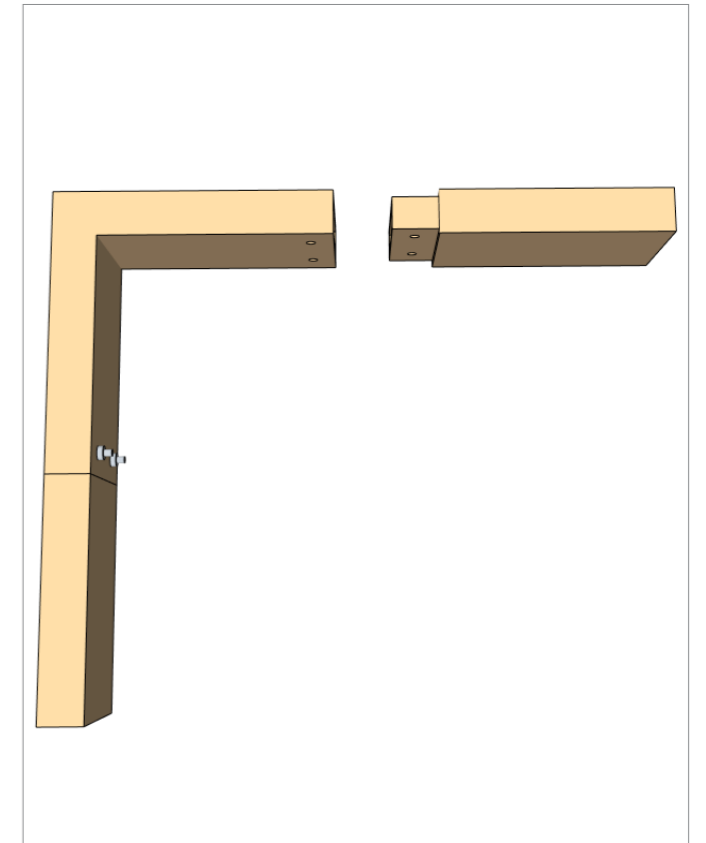
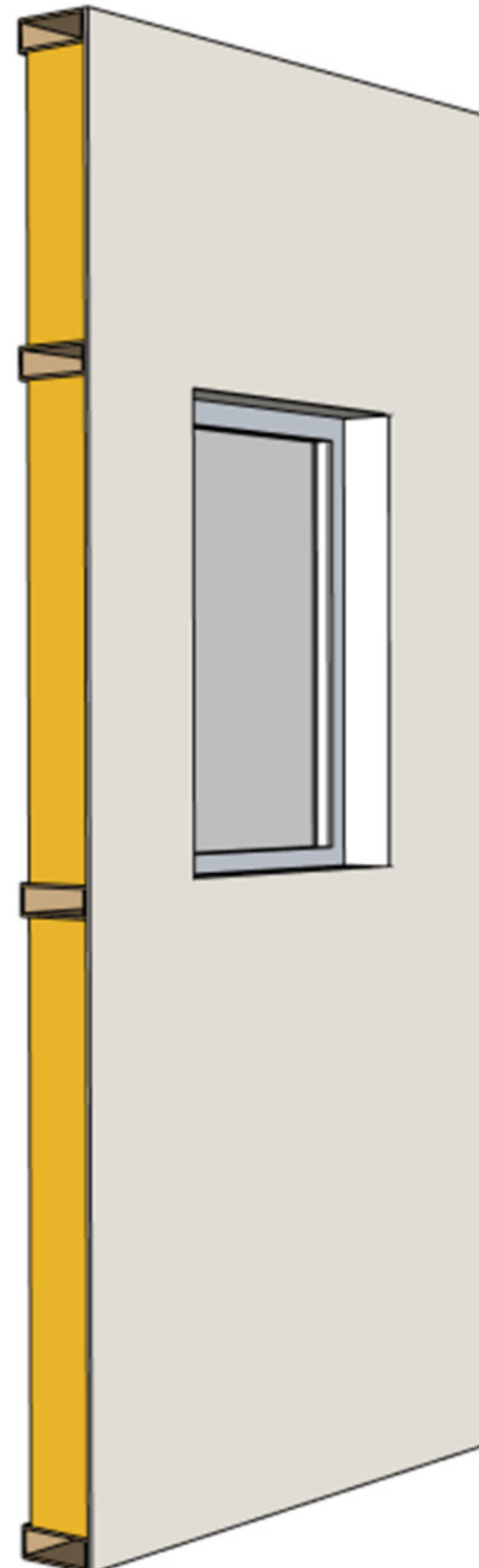


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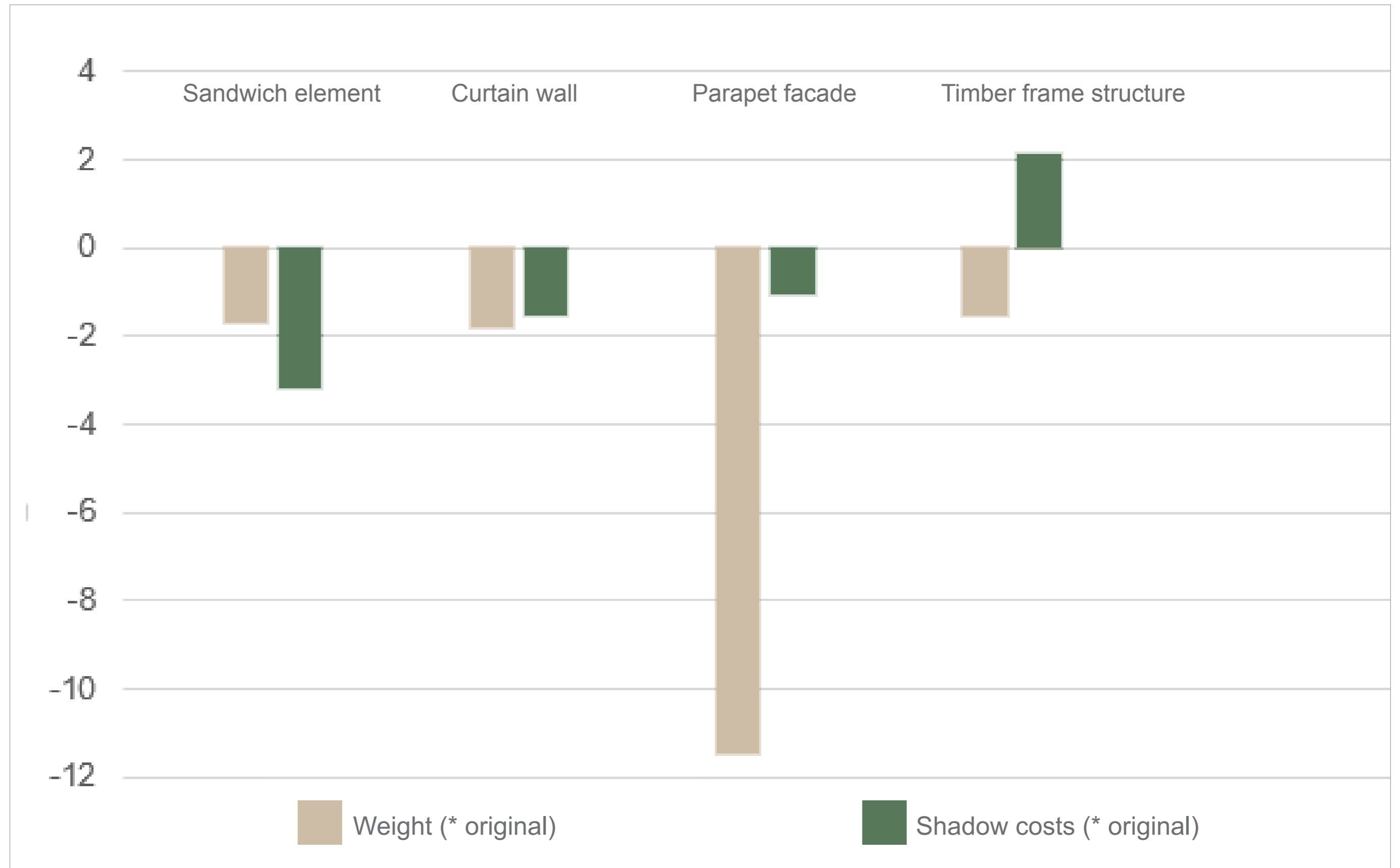
# CASE STUDIES | Timber frame



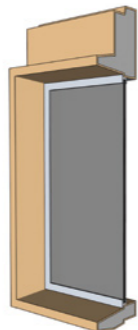
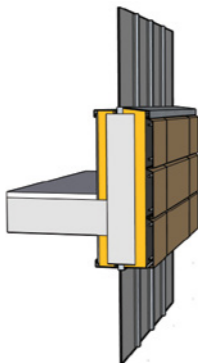
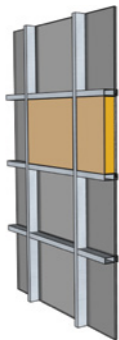
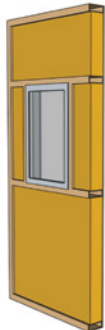
Double glazing  
Wooden window frame  
Biobased composite  
extruded hollow profile  
(60\*160) 6mm thick  
Flax fibre panel insulation  
(158 mm)  
Gypsum board (9,5mm)



# CASE STUDIES | Results



# CASE STUDIES | Results

Concept	Weight (kg)	Shadowcosts (€)	Circular scenario
	<div><div>46.63</div><div>113.58</div><div>65.37</div></div>	<div><div>26.17</div><div>41.99</div><div>35.83</div></div>	<div></div>
	<div><div>213.22</div><div>18.65</div></div>	<div><div>2.87</div><div>2.73</div></div>	<div></div>
	<div><div>29.09</div><div>11.32</div></div>	<div><div>4.01</div><div>2.60</div></div>	<div></div>
	<div><div>42.11</div><div>27.41</div><div>20.72</div></div>	<div><div>2.20</div><div>4.75</div><div>3.16</div></div>	<div></div>

# CONCLUSIONS

# CONCLUSIONS | Shadowcosts

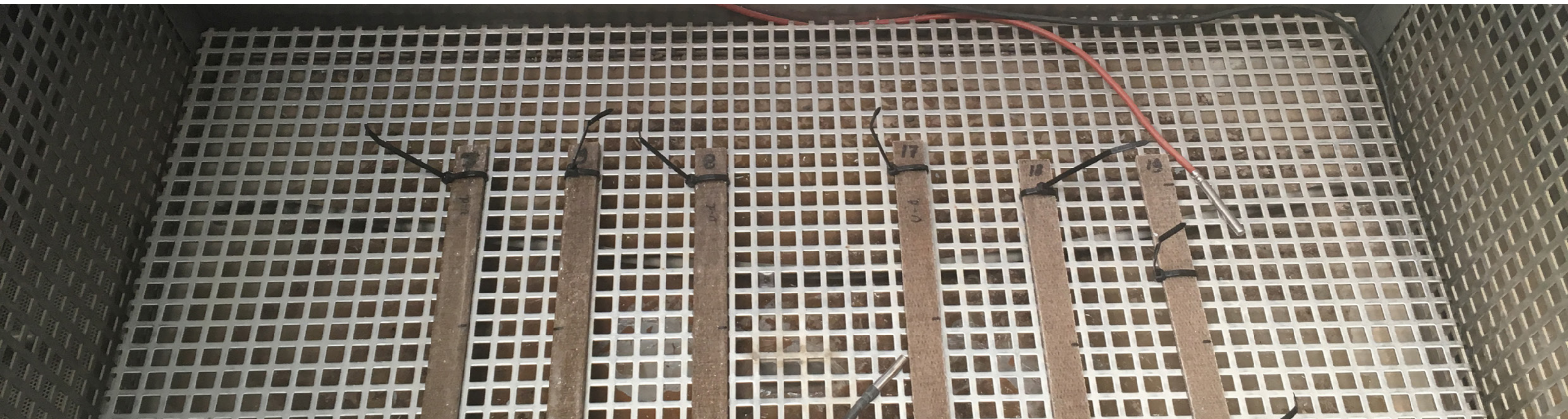
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Material	Youngs modulus	Bending stiffness	“Needed” shadowcosts
Steel	3.5	1.3	0.17
Wood	27	22.5	0.01
GRP	1.01	-2	X
Aluminum	-4.7	X	X

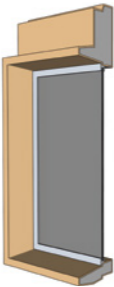

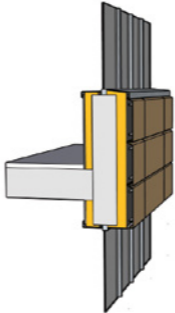

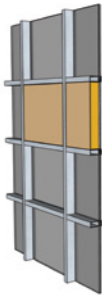



## CONCLUSIONS | Durability

---

The expectation is that **when the material is coated and the bending stiffness is designed including a safety margin, the lifetime will be similar to other common facade materials**



# CONCLUSIONS | Circularity

Concept	Circular scenario	Concept	Circular scenario
			
			

## CONCLUSIONS | Material scarcity

---

Environmental impact still quite high

- Opportunity in replacing scarce materials



## CONCLUSIONS | “Best concept”

---

“The aim is to explore whether a more environmental friendly composite material could be offered to designers while retaining the same design options current materials offer”



## CONCLUSIONS | “Best concept”

---

Is biobased composite an **environmental friendly alternative**?

Does biobased composite **offer the same design options** current materials do?



## CONCLUSIONS | “Best concept”

---

“What is the **best concept** for a design with biobased composite ?”



# RECOMMENDATIONS

# RECOMMENDATIONS | Material development

---

## 1. Share information



a circular biobased composite facade

# RECOMMENDATIONS | Material development

## 2. Shadowcosts & Coating

Material	Youngs modulus	Bending stiffness	"Needed" shadowcosts
Steel	3.5	1.3	0.17
Wood	27	22.5	0.01
GRP	1.01	-2	X
Aluminum	-4.7	X	X



# RECOMMENDATIONS | Material development

---

## 3. Testing Durability



a circular biobased composite facade

# RECOMMENDATIONS | Material development

---

## 3. Testing Recycling

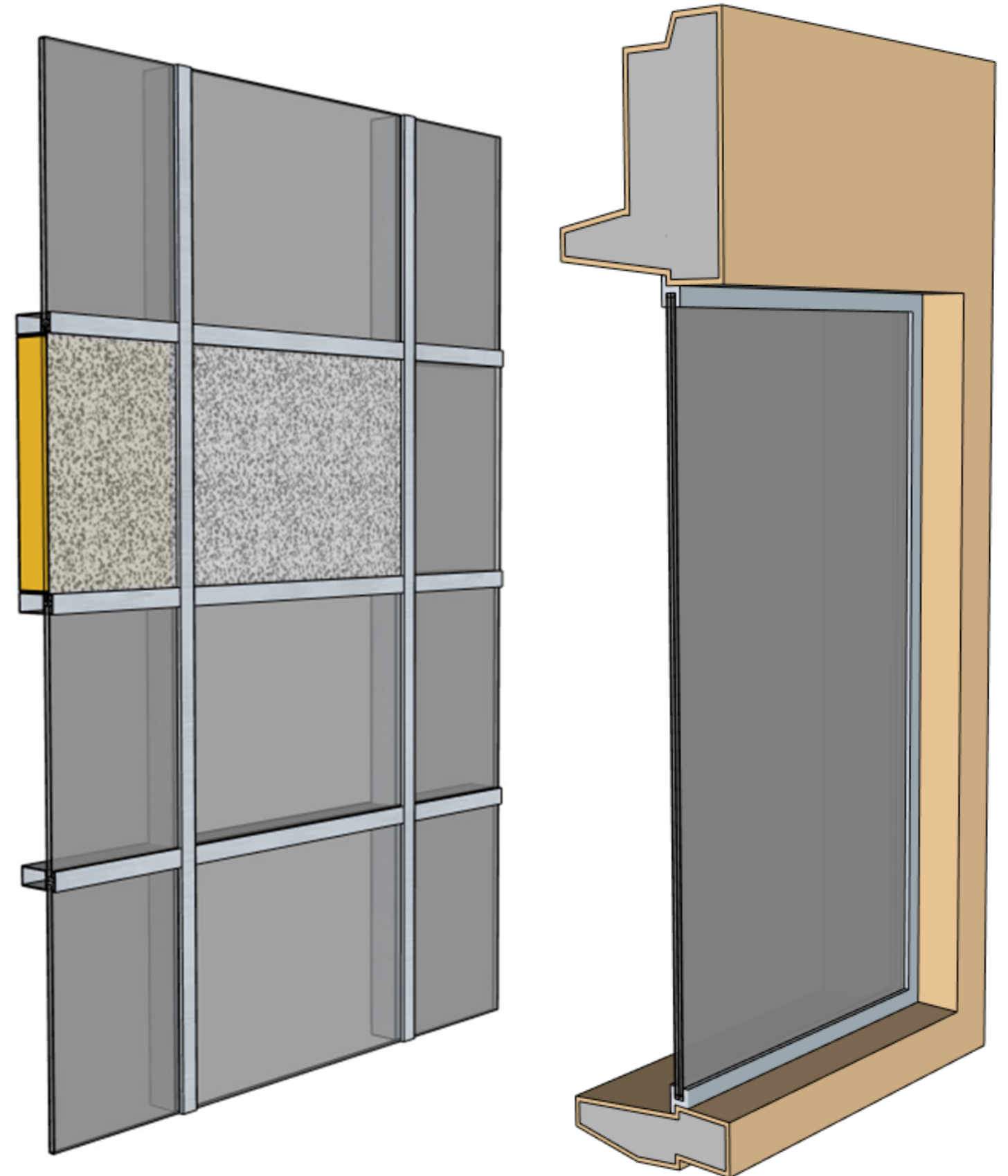


a circular biobased composite facade

# RECOMMENDATIONS | Concepts

## 6. Further design/elaboration of the concepts

- Improve circular scenario



# RECOMMENDATIONS | Certification

7. Define a **European/ Worldwide test method** for new, innovative materials



# RECOMMENDATIONS | Further research

---

## (Bio) Chemical:

- Possibility of recycling (on large scale)
  - Resin improvement
  - Coating improvement

# RECOMMENDATIONS | Further research

---

## Facade technical:

- Structural calculations
- Circular building concepts

**□ How can the circular scenario of the concept facades be improved?**

# FIRE-SAFETY



There are three types of fire loads:

- Fire penetration
- Flash-over
- Fire propagation

**Fire penetration**

Fire penetration through the facade can only be avoided when the material is not consumed by fire, for which openings in the facade appear. This can be provided by any layer in the facade construction, for example a fire-proof retention wall can be placed.

☐ Fire proof retention wall

**Flash-over**

Fire spread from one floor to the floor above through the facade can also be avoided by one continuous layer of fire-proof material in the facade. This doesn't necessarily need to be the cladding material. Another option is a fire-proof parapet of sufficient dimensions.

- ☐ Continuous fire-proof layer
- ☐ Fire-proof parapet

**Fire propagation**

Most important and most problematic for this research is fire propagation along the facade. This means that a material ignites too quickly, for which the fire quickly spread upwards. Especially for high-rise buildings this causes a high risk since evacuation times are higher. Since the propagation time of the material is not known, different indicative solutions are:

- ☐ Use a fire-retardant coating
- ☐ Use a fire-retardant resin
- ☐ Apply the material only to low-rise buildings

### Requirements

For office buildings there are no requirements related to the acoustical insulation of the facade.

It is recommended to apply the former requirement which said that **the sound insulation should be such that the sound insulation level will not exceed 40 dB(A)**.

A cavity wall with sound insulation would be a good option. It is recommended to use as little as possible single point supports, and a resilient core material which absorbs sound.

The interm sound insulation regarding the facade is important too.

### Mass

Since the mass of a facade influences the amount of noise entering a building, a high mass would be preferable regarding sound insulation.

### Sandwich construction

Since biobased composite offers good opportunity to be used in **lightweight constructions**, a sandwich construction is possible too. For a sandwich element the most important parameters are the **thickness of the construction and the type of core material**. This thickness defines which sounds enter a building, since the width allows certain sound waves to continue while others are blocked.

The interm sound insulation in a sandwich element is important. The material should be resilient and sound absorbing.

### Supports

In general, **single point supports** between inner and outer parts of a facade **should be avoided** because they can cause noise "leakage".

- ❑ Mass
- ❑ Sandwich construction
- ❑ No single point connections

# SOUND INSULATION

[illegible]

# WEATHER TIGHTNESS & APPEARANCE

Moisture proof outer layer  
Deterioration can be a problem.

## Coating

Regarding the coating, the focus should be on **water tightness**. Therefore the most interesting test (by its test results) would be a water penetration test. Also deterioration could be a problem.

To be able to test the water tightness accurately, a water penetration test should be carried out. Since this was not possible, the assumption was made that the material needs to be coated for outside applications, but for interior use it can be applied without a coating. This was also decided regarding the UV-radiation blocking properties of most coatings. NPSP advises to always coat an element for exterior application, both for water tightness and UV-radiation.

☐ Coat elements when applied outside

## Color

Of course, when a different color than brown is desired, a color coating should be applied anyway. However the composition of this coating can possibly be different from coatings for water tightness and UV-blocking purposes which might decrease the environmental impact.

## Deterioration

For deterioration, it is expected that when the material is produced in high quality and an appropriate coating is applied, deterioration won't take place.

Coatings can provide:

- Water tightness
- UV-radiation blocking
- Fire-safety
- Aesthetic properties such as color



**Bending stiffness**

The young modulus of biobased composite is much lower than that of steel and aluminum. Therefore the material *deforms more* under the same load. For the calculations the thickness of biobased composite is multiplied by the difference in youngs modul.

Options to reduce the necessary material thickness and to increase the bending stiffness are:

- ☐ add ribs
- ☐ curve the material
- ☐ produce a sandwich element.

**Weather influences**

The main loads on a facade, other than its own load, are caused by weather influences. Important loads are caused by wind and the weight of accumulating water or snow.

**Thickness**

To establish the thickness necessary to transfer all loads, the *structural properties of biobased composite were compared* to those of steel and aluminum.

Roughly can be assumed that the necessary thickness of biobased composite is **6 times** the thicker than that of **aluminum** and **15 times** the thickness of **steel**, taking the ratios of their youngs modul.

This does not regard the tensile strength which is far more in proportion to steel and aluminum.

**Weight**

The graph underneath shows the weight according to the needed thickness to achieve the same strength as one millimeter steel, according to the ratio of youngs modul.

How the bending stiffness can be improved, other than by increasing the thickness is explained in the section about "shape".

**Weight per square meter**

	Unit	Steel	Aluminum	Biobased composite
Tensile strength	[N/cm²]	400	360	172 (unreinforced)
Youngs modulus	[GPa]	210	69	11.4
Density	kg/m³	7850	2702	1186
Weighted	kg/m²	7.9	9.1	20.07

**WEIGHT**

### Table shadowcosts

Material	\$/kg (€)	per
Concrete	6.11	kg
Light insulation (sand)	0.11	kg
Gravel	5.12	kg
Concrete coating	€ 1.54	kg
Gravel coating	€ 1.17	kg
Graveling (perc)	€ 1.09	kg

Material	Young modulus	Bending stiffness	Thermal expansion
Steel	210	1.3	1.17
Aluminum	70	22.5	0.01
Reinforced concrete	110	0.92	11.4

### Shadowcosts

The shadowcosts of a material show the **cost** for the **preventive measures** which must be taken to reduce the emissions to a sustainable level.

Material	Young modulus	Bending stiffness	Thermal expansion
Steel	3.5	1.3	0.17
Aluminum	4.7	X	X

This table shows how many times the shadowcosts should increase/decrease to compete with the materials, regarding the young modulus or bending stiffness. Shadowcosts are calculated **per kg weight**. Future methods to improve the shadowcosts are:

- Explore the recycling methods**  
 Recycling methods decrease the shadowcosts because the materials performs longer.
- Decrease the weight**  
 This mainly applies to the **rein** which causes most of the weight.
- Improve the resin**  
 When **toxic solvents** are removed from the resin and the **biosourced** content increases, the shadowcosts decrease.

# SHADOWCOSTS

**Circular building principle**  
The circular building principles enhances "closed loop thinking", adaptive design and upgrading. The aim is to keep materials and products **performing** as long as possible, avoiding discarding them while in the same time products or materials are used as **"material banks"**.

There are **four demands** to a circular material.

1. Of high quality
2. Of sustainable origin
3. Non-toxic
4. Consistent with the biological cycle and cascade, or one or more technical cycles

Besides these intrinsic properties, a material or product should relate to the design and use of buildings.

- Dimensions (dynamic capacity demands)
- Connections (dry and logical)
- Performance time (defining the life span)

**New stepped strategy**  
The **NSS (new stepped strategy)** introduced to specify the link between the material and product cycles and the building design is based on **three steps**:

1. Reduce resource.
2. Reuse resource
3. Apply regenerative (circular) solutions

In the research, a division was made between three aspect of the circular scenario of an element:

- **Re-use** focusses mainly on the possibility to **dismount** the elements and the estimated **quality** the part has after being used, which is connected with its lifespan.
- **Adaptability** concerns whether the part can be **changed** or **upgraded**, or parts can be replaced.
- **Recyclability**. This research does not concern the recyclability of other materials than biobased composite. To be able to measure the recycling possibilities, a division is made regarding the **ability** to separate the used materials.

Reuse was rated highest since this strategy requires the least additional energy and/or material, then Adaptability and last recyclability.

**CIRCULARITY**

A green sports car is shown on an assembly line. A robotic arm is positioned above the car, and a worker is visible in the background. The car is green and has a sleek design. The background shows a factory setting with a blue sky and some trees. The text 'MODULARITY & EFFICIENCY' is overlaid on the right side of the image.

## Efficiency

For (cost) efficiency there are 9 design rules:

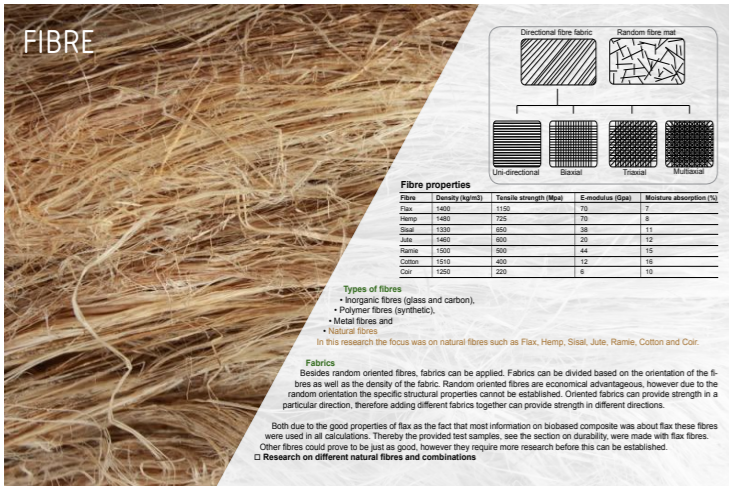
1. Minimize part counts
2. Eliminate threaded fasteners
3. Minimize variation
4. Easy serviceability and Maintainability
5. Minimize assembly directions
6. Consider ease of handling
7. Design for multifunctionality
8. Design for ease of production
9. Prefer modular design

Not all design rules are applicable to a circular composite design, therefore compromises might need to be made. The most important aspects are explained more detailed, for the explanation of the other rules see paragraph 4.1.



- ❑ **Minimize part counts**  
Composite materials offer a good potential for **part integration**, which minimizes the need for assembly.
- ❑ **Easy serviceability and Maintainability**  
Products should be designed in such a way that parts are **easy accessible for assembly, disassembly and inspection**.
- ❑ **Minimize assembly directions**  
While designing a product, it is important to think about the operations needed to attach different parts.
- ❑ **Consider ease of handling**  
For smooth assembly and ease of handling, parts should **not be heavy and not have too many curves**.
- ❑ **Design for ease of production**  
A design should profit from the strengths of the production technique. A design should be **simplified as much as possible** to ease manufacturing and assembly, and be easier understandable for workers.
- ❑ **Prefer modular design**  
If a product contains **standardized modules**, each module can independently be designed and improved without affecting the others. Besides this, replacement and assembly will be easy.

# MODULARITY & EFFICIENCY





# FIBRE



**Directional fibre fabric**      **Random fibre mat**

**Unidirectional**      **Biaxial**      **Quasi-isotropic**      **Multi-axial**

**Fibre properties**

Fibre	Density (kg/m <sup>3</sup> )	Tensile strength (Nsp)	E-modulus (GPa)	Moisture absorption (%)
Flax	1480	110	70	7
Hemp	1480	725	70	8
Stear	1330	650	38	11
Jute	1480	900	20	12
Ramie	1500	800	44	15
Cotton	1510	400	12	16
Coir	1510	220	8	10

**Types of fibres**

- Organic fibres (glass and carbon).
- Polymer fibres (synthetic).
- Metal fibres and
- Natural fibres

In this research the focus was on natural fibres such as Flax, Hemp, Sisal, Jute, Ramie, Cotton and Coir

**Fabrics**

Besides random oriented fibres, fabrics can be applied. Fabrics can be divided based on the orientation of the fibres as well as the density of the fabric. Random oriented fibres are economical advantageous, however due to the random orientation the specific structural properties cannot be established. Oriented fabrics can provide strength in a particular direction, therefore adding different fabrics together can provide strength in different directions.

Both due to the good properties of flax as the fact that most information on bio-based composite was about flax fibres were used in all calculations. Thereby the provided test samples, see the section on durability, were made with flax fibres.

Other fibres could prove to be just as good, however they require more research before this can be established.

□ **Research on different natural fibres and combinations**

# RESIN

**Types of polymers**

- Thermoplastics (thermosetting plastics)
- Elastomers (elastic thermoplastics)
- Thermosets (or thermosetting plastics)

The polymers are classified based on how their molecules bond. Thermoplastics can be molded again while heated, while thermosets cannot be melted after curing. Elastomers are a group of Thermoplastics, however they are much more elastic.


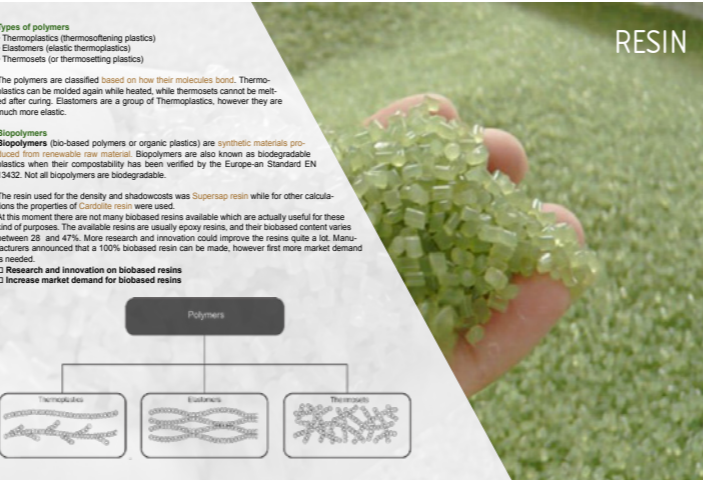
**Biopolymers**

**Biopolymers** (bio-based polymers or organic plastics) are synthetic materials produced from renewable raw material. Biopolymers are also known as biodegradable plastics when their compostability has been verified by the European Standard EN 13432. Not all biopolymers are biodegradable.

The resin used for the density and shadowcoasts was Supersap resin while for other calculations the properties of Lucidite resin were used.

At this moment there are not many bio-based resins available which are actually useful for these kind of purposes. The available resins are usually epoxy resins, and their bio-based content varies between 28 and 47%. More research and innovation could improve the resins quite a bit. Manufacturers announced that a 100% bio-based resin can be made, however first more market demand is needed.

- ❑ Research and innovation on bio-based resins
- ❑ Increase market demand for bio-based resins



```
graph TD; Polymers --> Thermoplastics; Polymers --> Elastomers; Polymers --> Thermosets;
```

# CORE MATERIALS

**Sandwich constructions**  
Sandwich constructions are materials consisting out of two **outer layers** and one **inner core material**. These three layers are usually **glued together**.

**Core materials**  
For core materials, both synthetic as biobased materials are available. Materials based on non-renewable fossil fuels are usually not very environmental friendly.  
Cork, and second best balsa wood have the lowest embodied energy.

```
graph TD; CM[Core material] --- IL[Intermediate adhesive layer]; CM --- OL[Outer layer]; OL --- IL; IL --- OL
```

```
graph TD; CM[Core materials] --> FPF[Plastics, papers and fibres]; CM --> F[Foams]; CM --> HC[Honeycombs]; CM --> BW[Balsa wood]; F --> GCF[Glass & ceramic foams]; F --> PF[Polymer foams]; F --> MF[Metal foams]; PF --> F1[flexible]; PF --> T1[tough]; PF --> B1[brittle]
```

# SHAPE

**Youngs moduli**

Unit	Steel	Aluminium	Fibreglass composite
[GPa]	210	69	1-4

The thickness of the youngs modulus of fibreglass composite is much lower than that of steel and aluminium.

For the calculations the **thickness of fibreglass composite is multiplied by the difference in youngs moduli**.

**Increase bending stiffness**  
Options to reduce the necessary material thickness and to increase the bending stiffness are to:

- ☐ add ribs
- ☐ curve the material
- ☒ produce a sandwich element
- ☒ increase the dimensions of a hollow profile

The table below shows the calculated bending stiffnesses of the concept facades. This table shows that the thicknesses based on the youngs modulus are (highly) over dimensioned. For the specific calculations see chapter 7 of the thesis.

Element	B [cm <sup>4</sup> ]	E [GPa]	E [MPa/cm <sup>2</sup> ]	Weight [kg]	Dia.	Sandwich height [cm]	Software [Sd]	Sandwich width [cm]	B/E [mm/cm <sup>4</sup> ]
Standard facade	2,00E+09	4.0	1.96E+07	4.8	1,00E+00	100	1,00E+00	4.4	4.4E+06
Standard hollow composite PLK	2,00E+09	11.4	2.30E+07	35.24	1,00E+00	115	1,27E+04	6.54	2.65E+06
Sandwich System	4.10E+08	69	1.58E+10	44.65	5.00E+00	126	1,00E+00	4.36	1.00E+06
Standard System	1,00E+09	11.4	2.30E+07	62.3	1.25E+00	115	1,27E+04	6.54	2.22E+06
Woolen fibre facade frame	6.45E+06	0.3	7.75E+05	16.21	6.60E+00	69	6.66E+03	19.37	1.02E+06
Br filler core sandwich	1.90E+08	10.4	4.58E+07	12.77	3.00E+00	115	1,20E+04	6.4	1.00E+06
Ceramic layer sandwich	1.75E+08	10.4	4.58E+07	2.4	1.40E+00	115	1,20E+04	6.4	1.15E+06

[illegible]

**Accelerated weathering tests**

To establish the **durability** of biocased composite and to get an idea of the **estimated lifetime** of the material, **accelerated weathering tests** were carried out.

For new materials there are **no test plans defined**. Together with specialists of **SKG-kob** two test were defined for biocased composite.

The two test performed are:

- Warmth-cold cycle test, which performs 5 cycles of 24 hours for temperatures are between -20 °C and 70 °C.
- The second test is a freeze-thaw test which performs 30 cycles of 24 hours. The machine first soaks the samples in water and then freezes them up until -20 °C.
- Thereby a initial group of control group was used, which was not exposed to any accelerated weathering influences.

For each test three coated and three uncoated samples are used.

Sample	Young modulus (GPa)	Tensile strength (N/mm²)	Compressive strength (N/mm²)
Control	18,9	121,9	1.168
Uncoated	18,9	121,9	1.168
Coated	18,9	121,9	1.168
Average	18,9	121,9	1.168

Sample	Young modulus (GPa)	Tensile strength (N/mm²)	Compressive strength (N/mm²)
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Control	18,9	121,9	1.168
Uncoated	18,9	121,9	1.168
Coated	18,9	121,9	1.168
Average	18,9	121,9	1.168

**Results**

Tensile tests were performed to establish how much the samples degraded under the accelerated weathering tests. The results of this test are shown in the table on top.

Visually there were **almost no differences** between the samples before and after the tests. The edges of the uncoated samples tested for the freeze-thaw cycles were a little more rough, some fibres were sticking out.

These tests must be interpreted as an **indication**.

- The warmth-cold cycles tested group shows a **small increase in tensile strength** and a **small decrease in young modulus**.
- The freeze-thaw cycles tested samples showed a **large increase in tensile strength** and a **large decrease in young modulus**.

□ The expectation is that when the material is coated and the bending stiffness is designed including a safety margin, the lifetime would be similar to other common facade materials.

**DURABILITY**

**CONCEPTS**

A study was performed exploring four common used facades in office buildings in the Netherlands.

This study first focused on different facade products, see the graph on top. Following four facade designs were transformed into biobased designs, using biobased composite and natural based insulation. The original designs and concepts were compared on their

- weight
- insulation value
- shadowcoasts
- circular scenario

**Weight vs Shadowcoasts**

**Flat plate**

Element	Weight	Shadowcoasts
Sandwich element	Low	Low
Timber frame structure	Low	Low
Glazed spandrel	Low	Low
Transposed panel	Low	Low
Caseworks	Low	Low

**Weight vs Shadowcoasts**

**Parquet facade**

Element	Weight	Shadowcoasts
Sandwich element	Low	Low
Adjusted sandwich element	Low	Low
Curtain wall	Low	Low
Timber frame structure	Low	Low
Adjusted timber frame structure	Low	Low

**Conclusion**

The graphs above show how many times the weight and shadowcoasts increased or decreased compared to the original element. It shows that improvement in terms of weight and shadowcoasts can be made replacing common used building materials by biobased composite, however not for all designs and materials. To improve the environmental impact the shadowcoasts themselves should be improved too.

The circular scenarios turned out to be equal to those of the original elements.

**Research project**

This poster was made based on the content of the graduation research "A circular bio-based facade. Research on a high performance and circular application of bio-based composite on a facade" as part of my graduation for the track Building Technology at the Technical University of Delft. The research is performed in cooperation with DGMIR.

*"The building industry produces annually twice as much waste as all the Dutch households together, and is therefore responsible for 40% of the total amount of waste"*

*"Most construction waste goes into landfills, increasing the burden of landfill loading and operation"*

Both quotes together define the problem definition.

The aim was to explore whether a more environmental friendly composite material could be offered to designers while retaining the same design options current materials offer. To do so, the circular possibilities of a facade design mainly constructed out of bio-based composite have been explored.

For more information and the references, see the thesis  
**"A circular bio-based composite facade"**  
Verinde, M. F. (2017).

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**A CIRCULAR BIOBASED  
COMPOSITE FACADE**



THANK YOU FOR YOUR ATTENTION