Natural Fiber Reinforced Composites & Façade Applications

Thesis Defense

June 2022

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Delft University of Technology

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WHAT IS A FIBER REINFORCED COMPOSITE ?

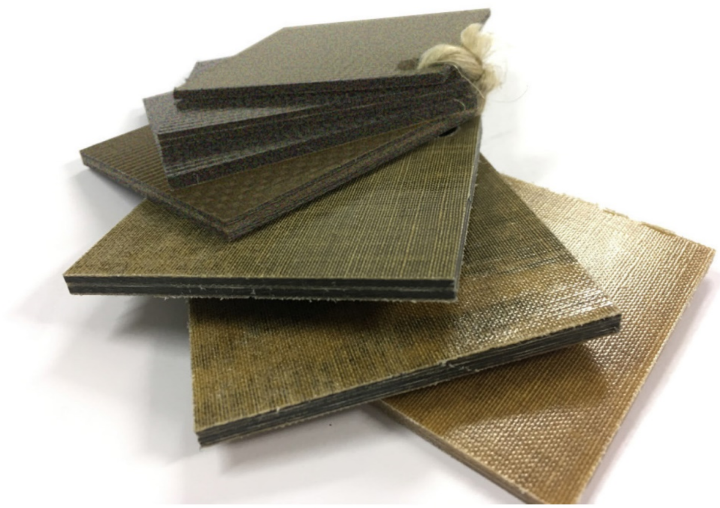
FIBER

Organic (natural)
Or
Inorganic (glass, carbon)

\+

POLYMER

Petro-based
Or
Bio-based



Material properties not available in nature

WHAT IS A FIBER REINFORCED COMPOSITE ?

ADVANTAGES OF COMPOSITES

Combines material properties in a way not available in nature

(Rajak, et al., 2019)

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Often Results in very lightweight materials, leading to easier and faster assembly

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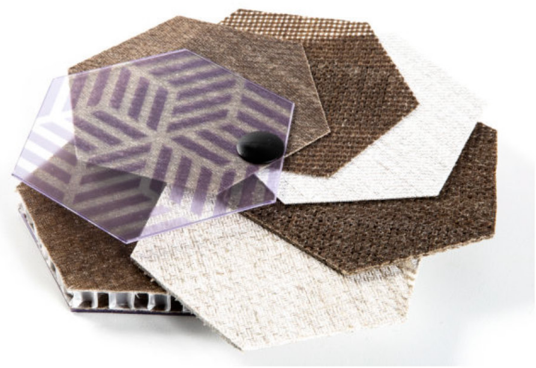
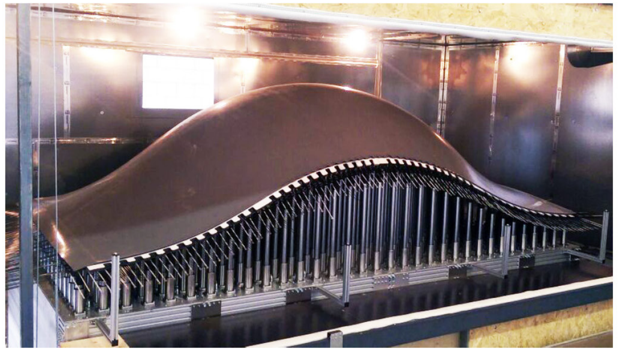


Often Results in very lightweight materials, leading to easier and faster assembly

(Rajak, et al., 2019)



Ability to be molded into complicated shapes

(ACMA, 2021)

WHAT IS A FIBER REINFORCED COMPOSITE ?

COMPOSITES IN THE BUILDING INDUSTRY

House of Dior - Seoul

WHAT IS A FIBER REINFORCED COMPOSITE ?

COMPOSITES IN THE BUILDING INDUSTRY

Steve Jobs Theater - California

WHAT IS A FIBER REINFORCED COMPOSITE ?

COMPOSITES IN THE BUILDING INDUSTRY

WHAT IS A FIBER REINFORCED COMPOSITE ?

COMPOSITES IN THE BUILDING INDUSTRY


Stedelijk Museum - Amsterdam

WHAT IS A FIBER REINFORCED COMPOSITE ?

COMPOSITES IN THE BUILDING INDUSTRY


Bio-Bridge - Eindhoven

WHY BIO-COMPOSITE ?

MOTIVE

Plant Fibers

Bio- Polymer

To fulfill **European Union's development strategies** for environmental challenges

↓

It is expected to **replace petro-based materials** with materials from **renewable sources**

↓

The production of materials from **bio-based feedstock is expected to grow up to 25%** in 2030

WHY BIO-COMPOSITE ?

ADVANATGES OF BIO-COMPOSITES

Comparable proporties to Inorganic composites (glass, carbon)

(Mohanty, 2005)

Plant Fiber are considerably sheaper than glass or carbon fibers

(Dittenber, et al., 2012)

The energy required to produce natural fibers is only 20% of the energy required for inorganic fibers

(Dittenber, et al., 2012)

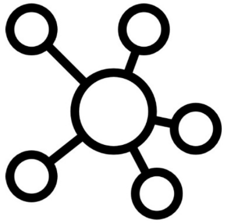
OBJCETIVE & WORK STRATEGY

Understand the mechanical performance of Bio-based Fiber Reinforced Composites when subjected to water, temperature, and UV radiation. Accordingly, explore its potential applications on the building envelope.

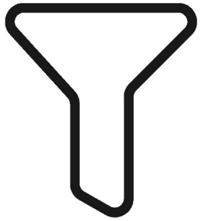
OBJCETIVE & WORK STRATEGY

Understand the mechanical performance of Bio-based Fiber Reinforced Composites when subjected to water temperature, and UV radiation. Accordingly, explore its potential applications on the building envelope.

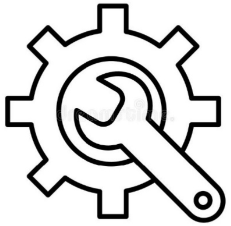
RESEARCH BY EXPERIMENTATION



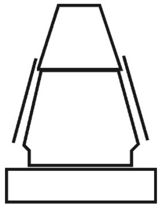
Mapping



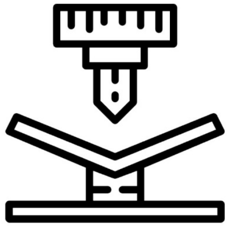
Filtering



Fabrication



Weathering Conditions



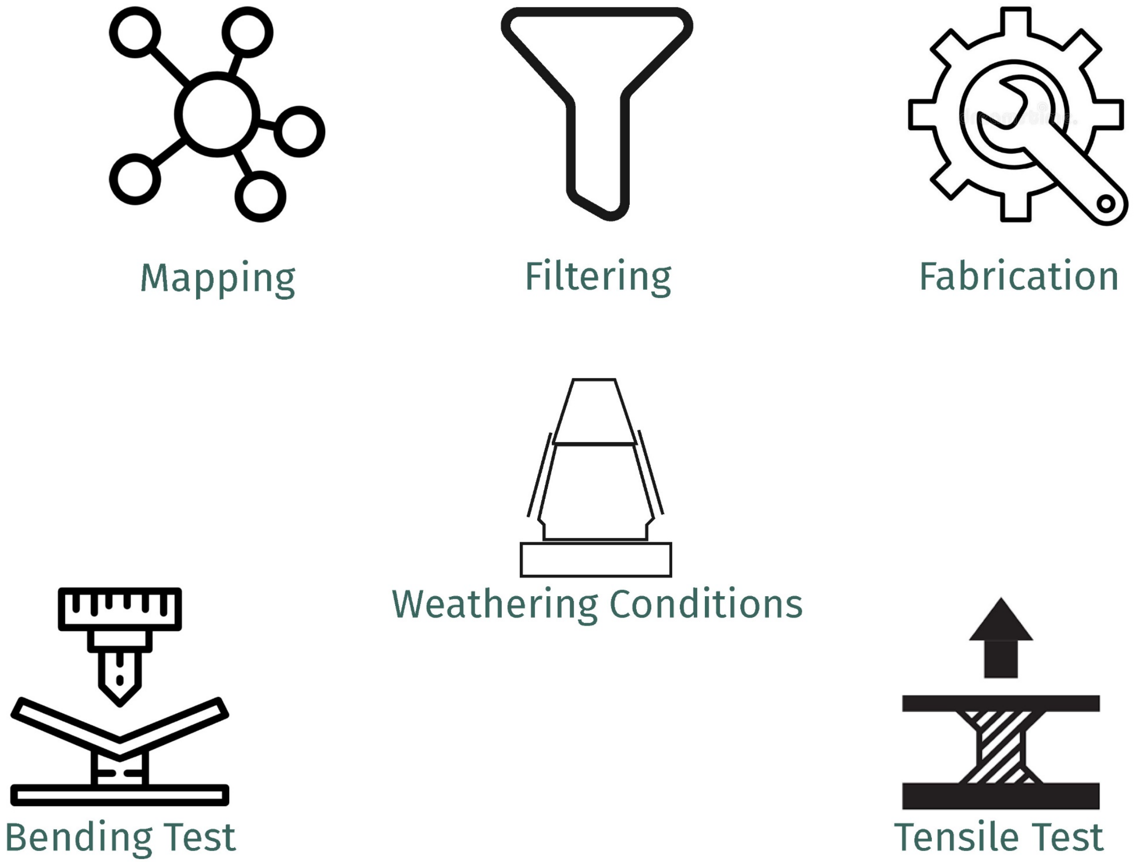
Bending Test

Tensile Test

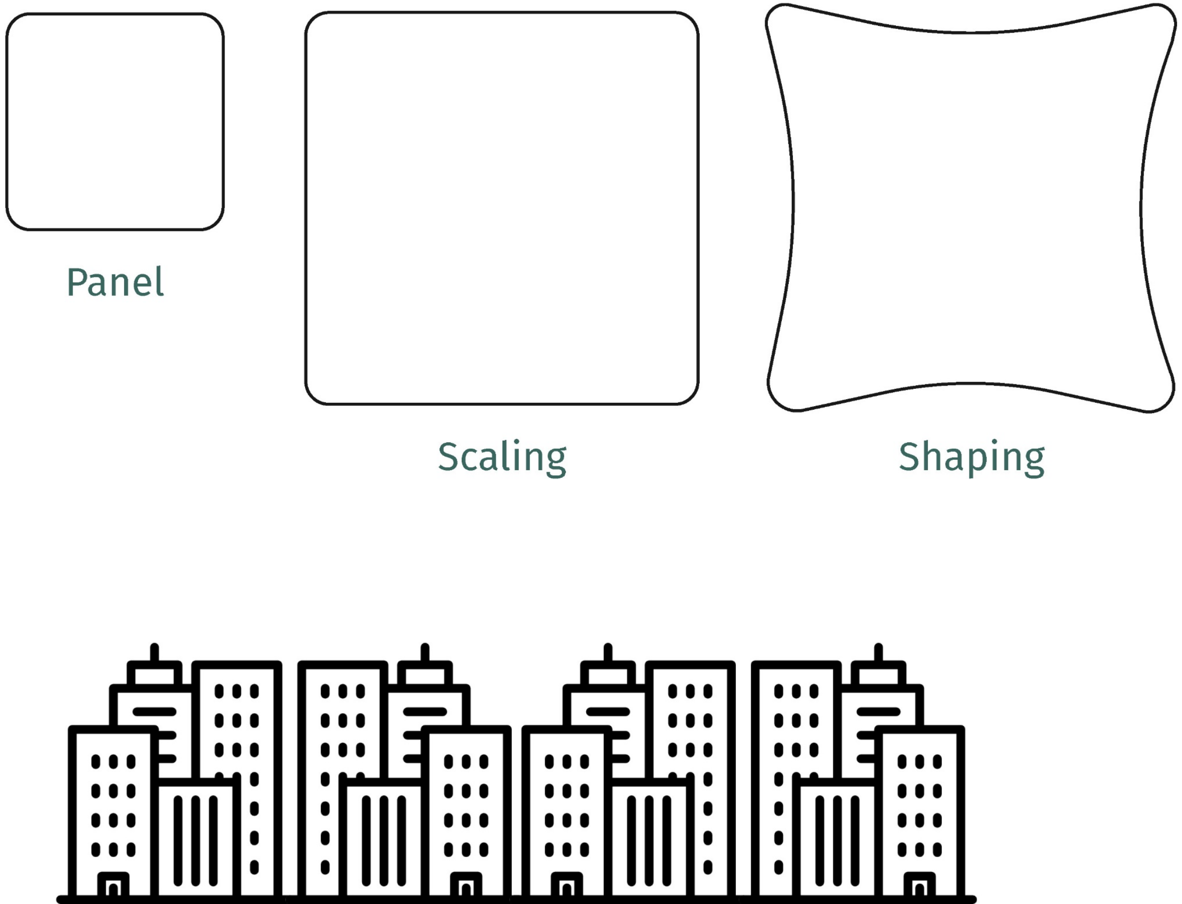
OBJCETIVE & WORK STRATEGY

Understand the mechanical performance of Bio-based Fiber Reinforced Composites when subjected to water, temperature, and UV radiation. Accordingly, explore its potential applications on the building envelope.

RESEARCH BY EXPERIMENTATION



RESEARCH BY DESIGN



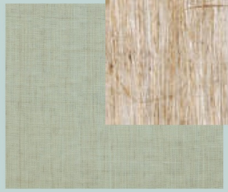
COMPOSITE FABRICATION

MAPPING & FILTERING OF PLANT FIBERS

Fibers	Density (g/cm^3)	stiffness (GPa)	moisture (%)	availability (Europe)	cost (EUR/m^2)
FLAX 	1.5	27	8	Yes	7
JUTE 	1.3	20	9	Yes	5
HEMP 	1.5	70	1.5	Rare	9.95

COMPOSITE FABRICATION

MAPPING & FILTERING OF PLANT FIBERS

Fibers	Density (g/cm³)	stiffness (GPa)	moisture (%)	availability (Europe)	cost (EUR/m²)
FLAX 	1.5	27	8	Yes	7
JUTE 	3	2	9	Y	5
HE 	5	7	5	Ra	95



COMPOSITE FABRICATION

MAPPING & FILTERING OF BIO-EPOXY

Bio-Epoxy	Bio Content (%)	Supplier (Name)	Country (Name)	Reference (Web)
Formulite 2500A	36.6	Cardolite	Belgium	www.vosschemiebenlux.com
Supersap INR	19	Entropoxy Res	Spain	www.pecepoxy.co.uk
Ampro BIO	40	Gurit	United Kingdom	www.gruit.com/AMPRO
1800 ECO	36	Resoltech	France	www.scabro.com
Greenpoxy 56	56	Sicomin	France	www.sicomin.fr
Infugreen 810	38	Sicomin	France	www.sicomin.fr

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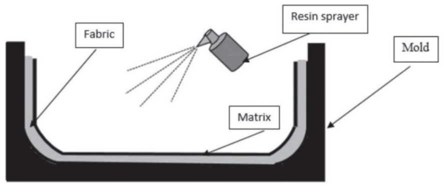
1800 ECO	36	Resoltech	France	www.scabro.com
Greenpoxy 56	56	Sicomin	France	www.sicomin.fr
Infugreen 810	38	Sicomin	France	www.sicomin.fr

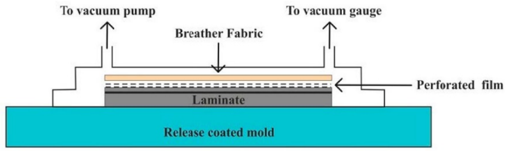
COMPOSITE FABRICATION

MANUFACTURING TECHNIQUES



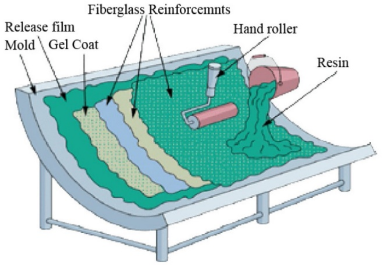
SPRAY-UP TECHNIQUE

- *Used for very big scale projects (Stedelijk Museum, Amsterdam)*



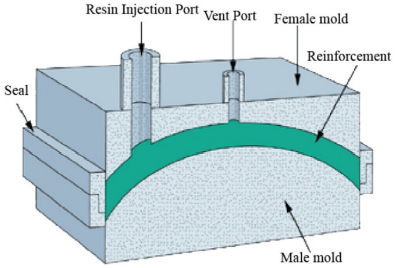
VACUUM BAGGING

- *Depends strongly on labor skills*



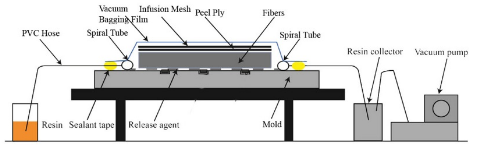
HAND LAY-UP TECHNIQUE

- *Depends strongly on labor skills*
- *Flaws in the surface due to uneven roller pressure*



COMPRESSION MOLDING

- *Expensive Tooling*
- *Usually used in composite manufacturing companies*

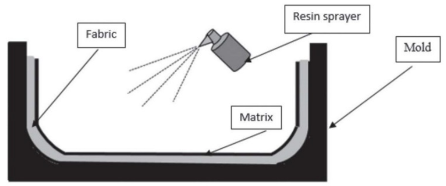


VACUUM INFUSION TECHNIQUE

- *Uniform distribution of epoxy and fibers*
- *Faster fabrication*
- *Consistent outcome*

COMPOSITE FABRICATION

MANUFACTURING TECHNIQUES



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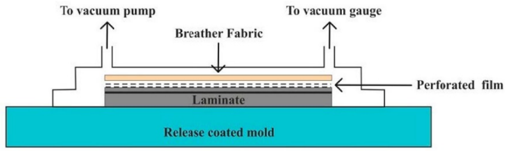

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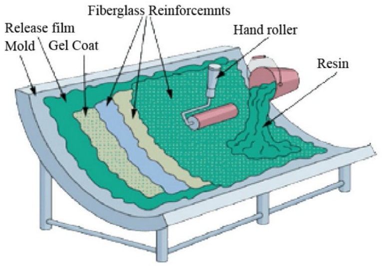

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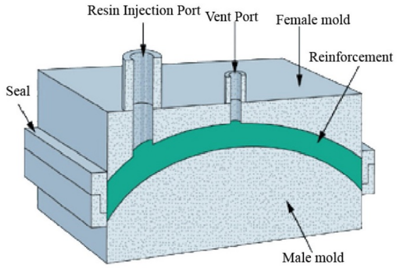

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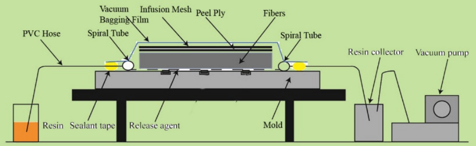

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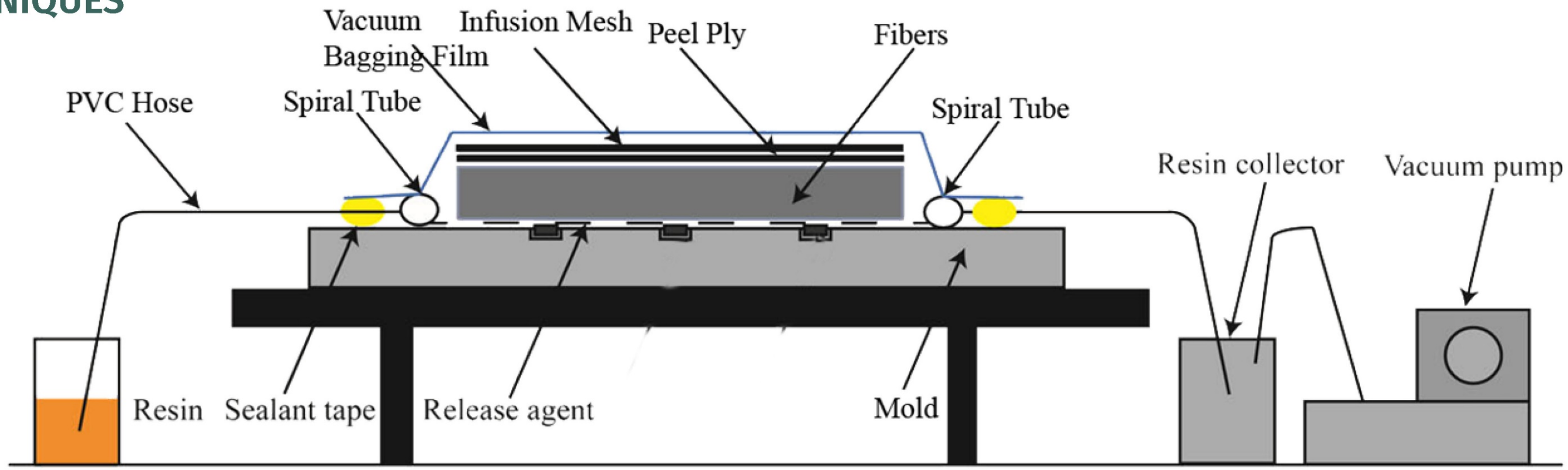
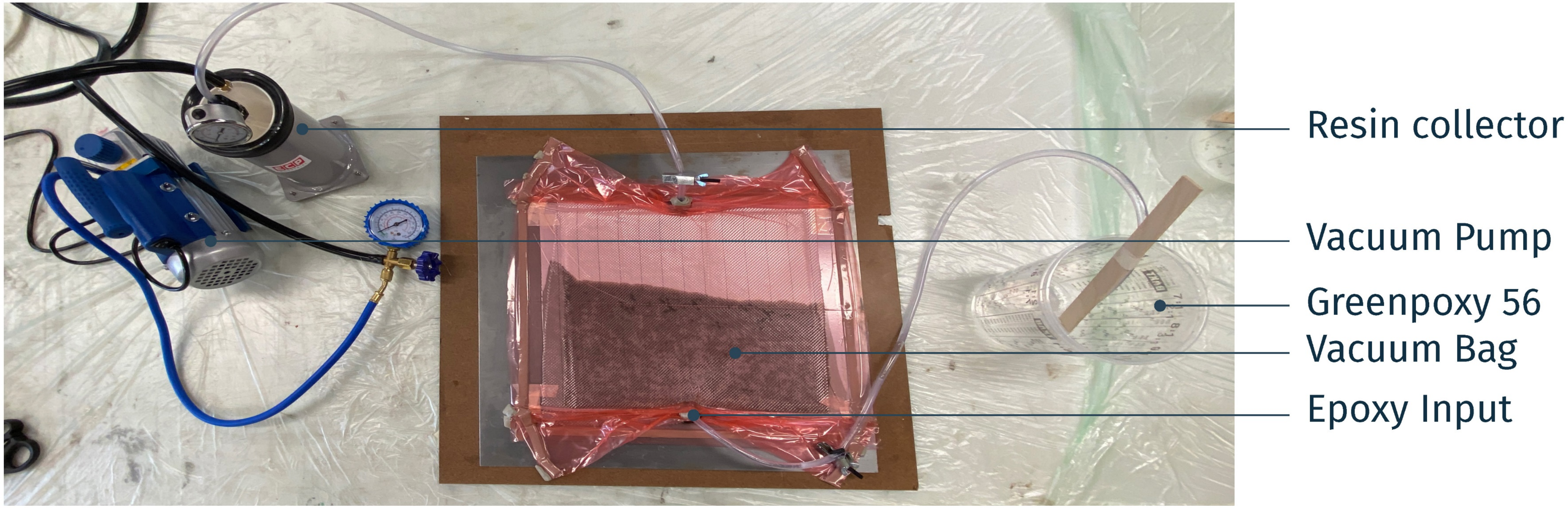


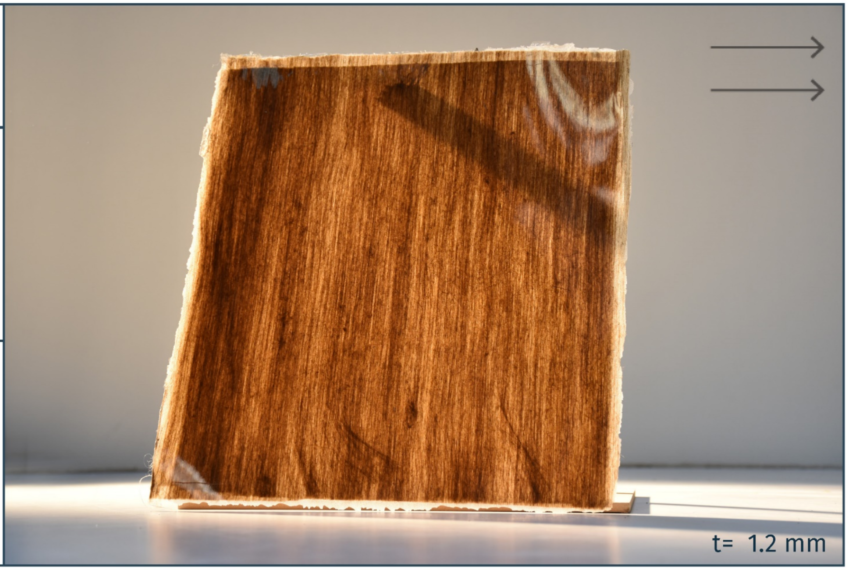


COMPOSITE FABRICATION

FABRICATION RESULTS

2 layers

F2: 220g Flax Unidirectional Tape



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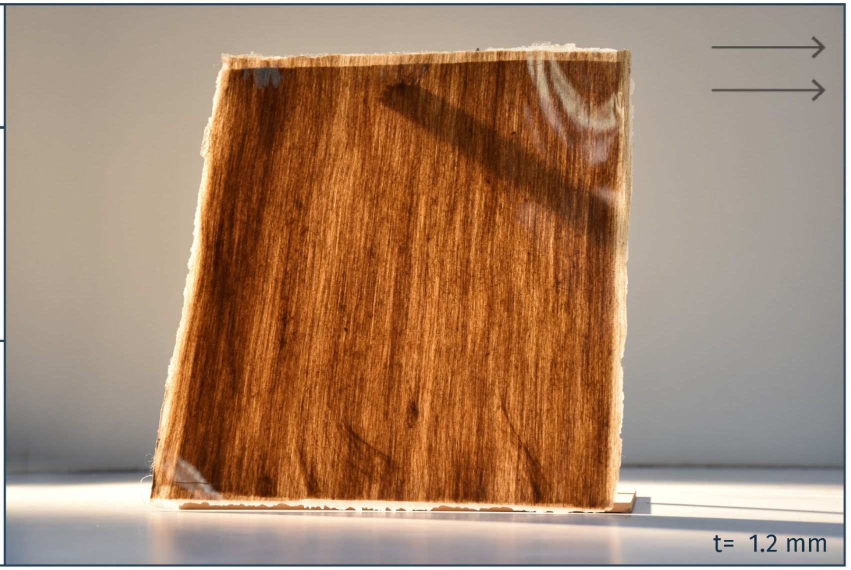


4 layers

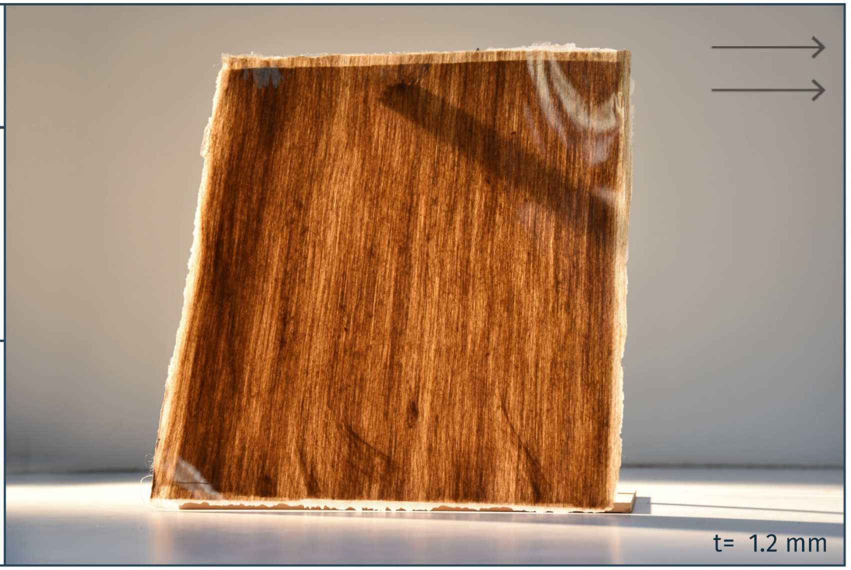
F4: 220g Flax Unidirectional Tape

COMPOSITE FABRICATION

FABRICATION RESULTS

2 layers

F2: 220g Flax Unidirectional Tape

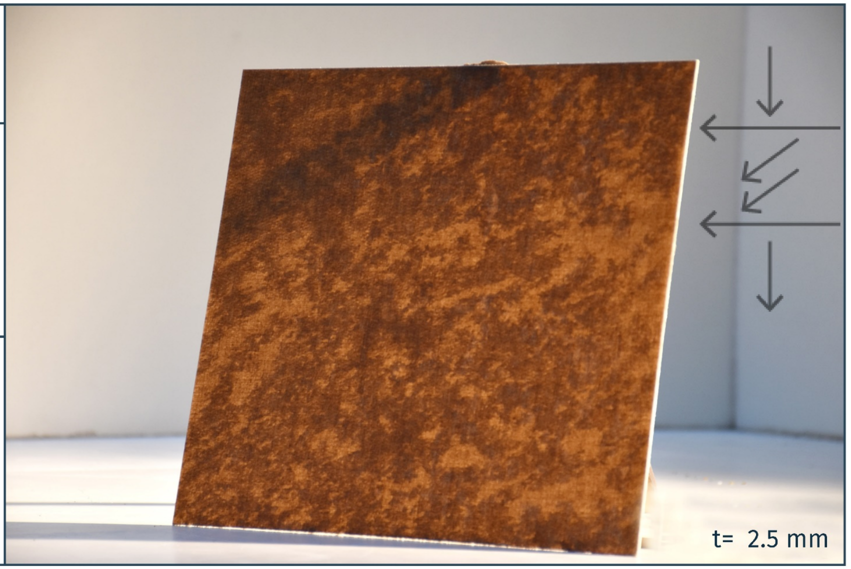


4 layers

F4: 220g Flax Unidirectional Tape

6 layers

F’6: 180g Flax Cross-Stitched Cloth



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FABRICATION RESULTS

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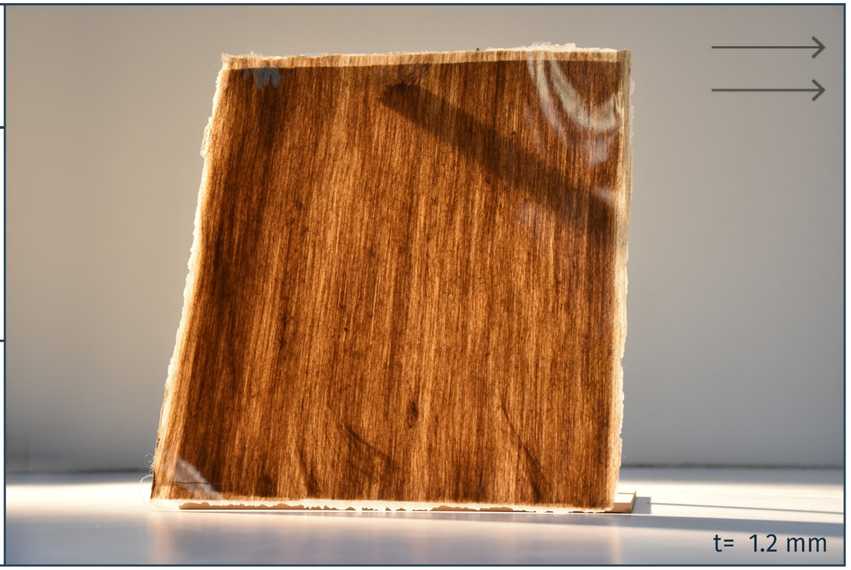
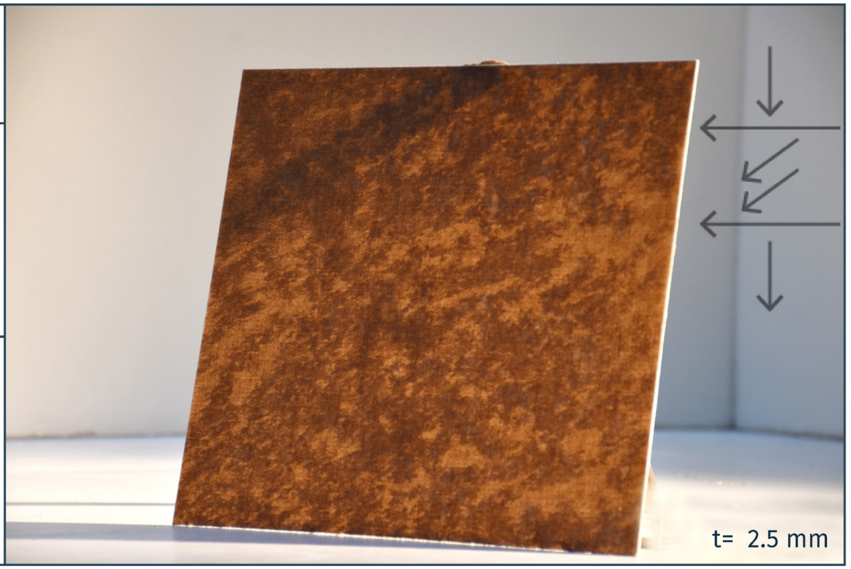


4 layers

F4: 220g Flax Unidirectional Tape

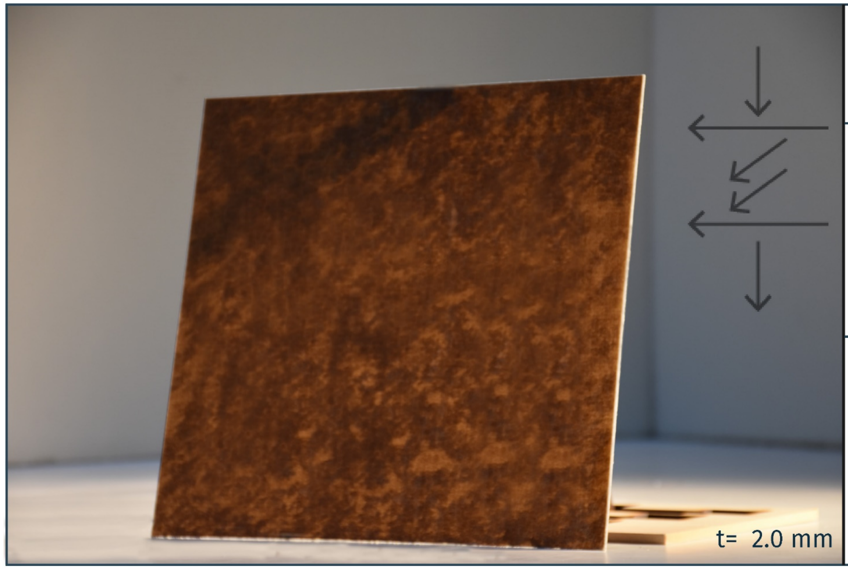
6 layers

F’6: 180g Flax Cross-Stitched Cloth



6 layers

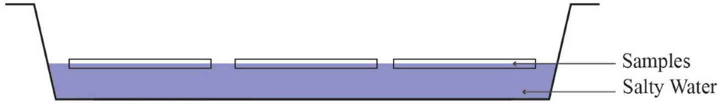
F”6: 180g Flax Cross-Stitched Cloth



MECHANICAL & PHYSICAL TESTING

ACCELERATED WEATHERING CONDITIONS

VISUAL INTERPRETATION - 65^{0} CYCLES (1 WEEK) - *Approx. 2 years*

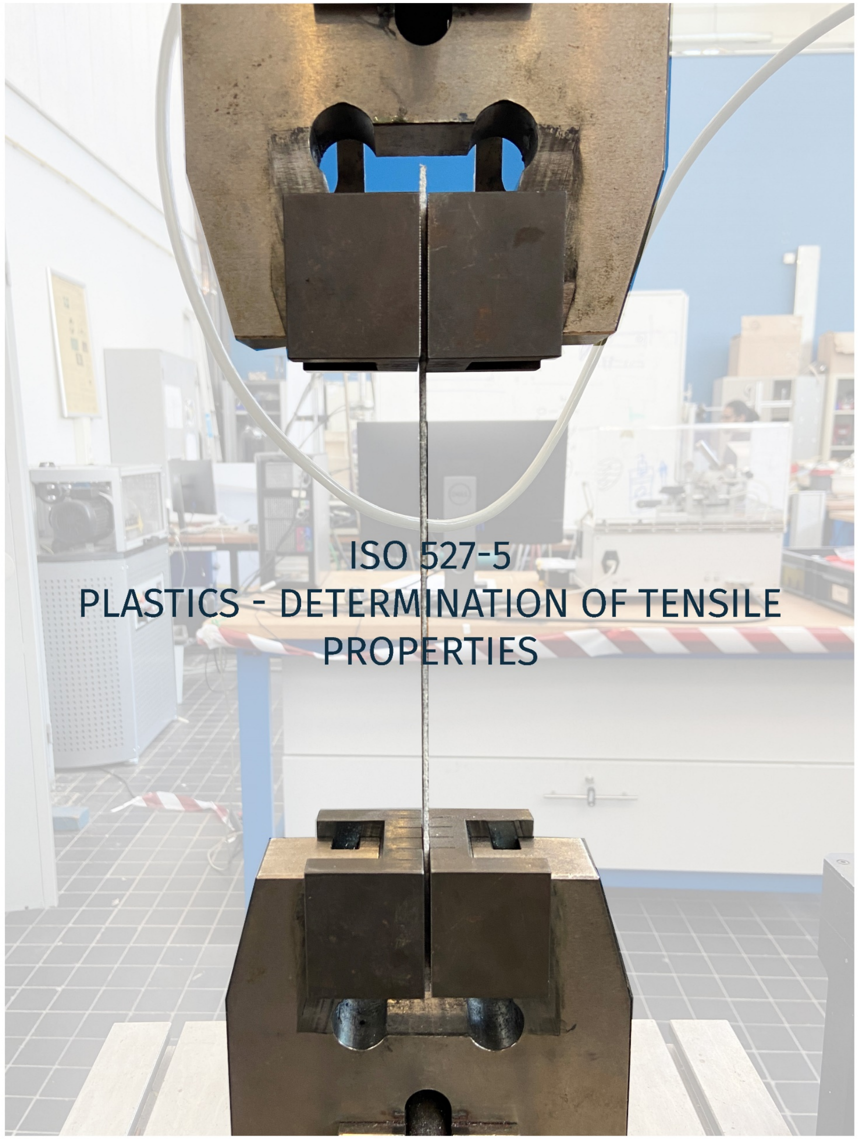


VISUAL INTERPRETATION - WATER IMMERSION (1 WEEK)

VISUAL INTERPRETATION - UV CYCLES (4 WEEKS) - *Approx. 4 years*

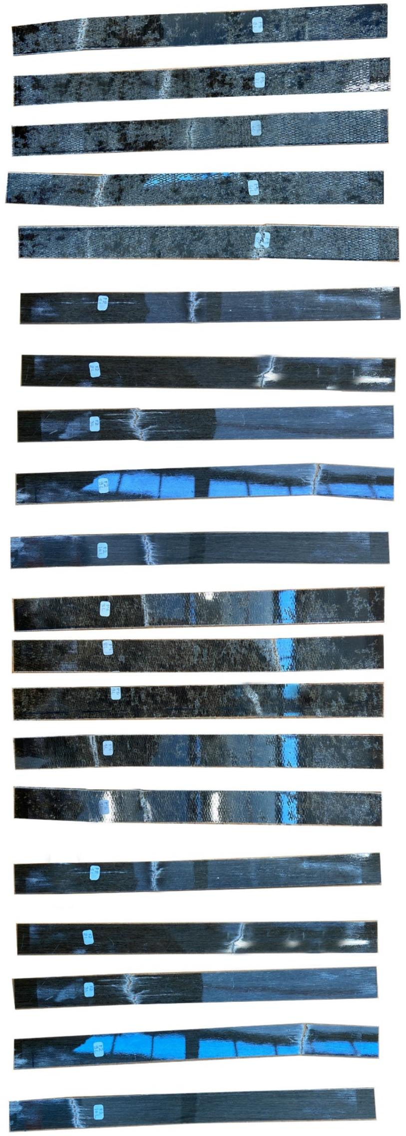
MECHANICAL & PHYSICAL TESTING

TENSILE & BENDING TESTING



ISO 527-5
PLASTICS - DETERMINATION OF TENSILE PROPERTIES

ISO 14125
FIBER-REINFORCED PLASTIC COMPOSITES - DETERMINATION OF FLEXURAL PROPERTIES



MECHANICAL & PHYSICAL TESTING

VISUAL INTERPRETATION

PANEL F2

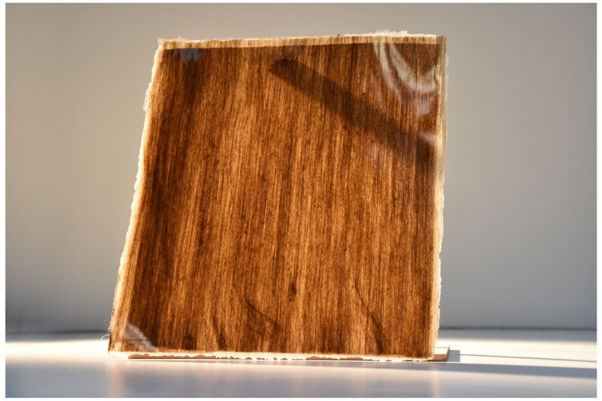
PANEL F4

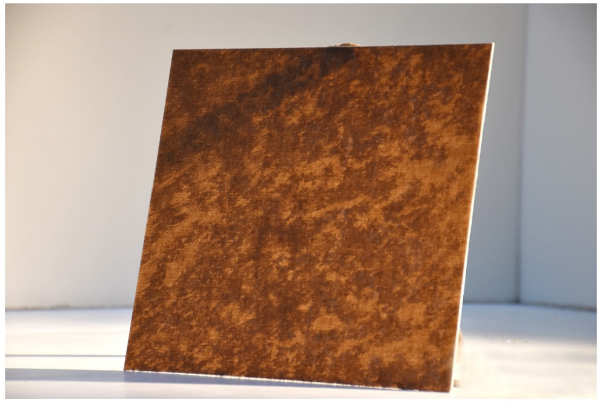
PANEL F’6 and F’’6

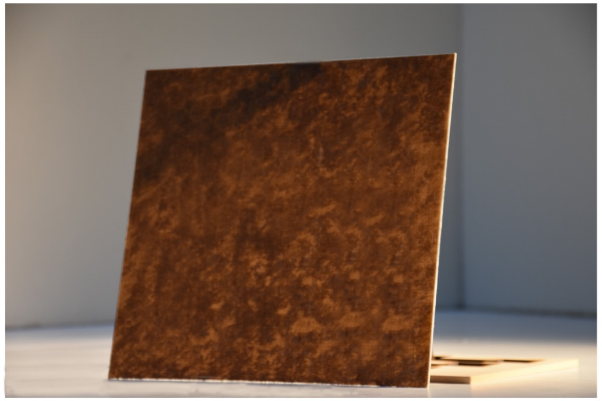
- REFLECTIVE
- SHINY
- TRANSLUCENT

MECHANICAL & PHYSICAL TESTING

VISUAL INTERPRETATION

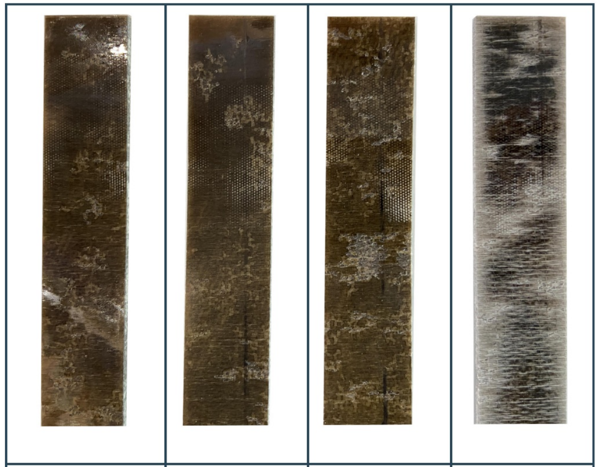






None	Temp	UV	Water

None	Temp	UV	Water



None	Temp	UV	Water

None	Temp	UV	Water

MECHANICAL & PHYSICAL TESTING

VISUAL INTERPRETATION - 650 CYCLES (1 WEEK) - APPROX. 2 YEARS

AFTER SUBJECTION TO TEMPERATURE

- NO VISUAL EFFECT

MECHANICAL & PHYSICAL TESTING

VISUAL INTERPRETATION - UV CYCLES (4 WEEKS) - APPROX. 4 YEARS

AFTER SUBJECTION TO UV CYCLES

- CHANGES TO ORIGINAL COLOR
- YELLOWISH FINISH

MECHANICAL & PHYSICAL TESTING

VISUAL INTERPRETATION - WATER IMMERSION (1 WEEK)

AFTER SUBJECTION TO WATER

- LOSS OF REFLECTIVITY
- LOSS OF EPOXY SURFACE
- FIBER EXPOSURE

MECHANICAL & PHYSICAL TESTING

PHYSICAL & MECHANICAL DATA CALCULATION

Panel Name	Fiber Type	Size (mmxmm)	Number of Layers	Orientation (o)	Infusion Time (min)	Epoxy Used	Hardner Used	Epoxy : Hardner Ratio (g)
F2	200g Unidirectional Flax Fiber	295 x 295	2	(0, 0)	7	Sicomin Greepoxy	SD 7561	100:36:00

Table 29: Panel F2 Fabrication Details

Panel	Thickness (mm)	Weight of Fibers (g)	Weight Matrix (g)	Density Fibers (g/cm^3)	Density Matrix (g/cm3)	Volume Fraction Fibers (-)			Volume Fraction Matrix (-)	Density Composite (g/cm^3)	Test Direction
						0^o	90^o	45^o			
F2	1.2	33	40.5	1.5	1.17	0.39	0	0	0.61	1.3	0

Table 30: Panel F2 Composition details

Panel	Ultimate tensile Strength (MPa)	Standard Deviation of UTS (MPa)	Young's Modulus (MPa)	Standard Deviation of YM's (MPa)	Elongation (%)
F2	197.5	29.7	5601.29	854	3.45
After Water Test	217	34	5204	432	4.15
After UV Test	165	31.5	5826	634	3.45
After Temp Test	234	21.5	6295	468	3.71

Table 31: Panel F2 Mechanical Properties (before & after weathering conditons)

Panel Name	Fiber Type	Size (mmxmm)	Number of Layers	Orientation (o)	Infusion Time (min)	Epoxy Used	Hardner Used	Epoxy : Hardner Ratio (g)
F4	200g Unidirectional Flax Fiber	295 x 295	4	(0, 90, 90, 0)	9	Sicomin Greepoxy	SD 7561	100:36:00

Table 32: Panel F4 Fabrication Details

Panel	Thickness (mm)	Weight of Fibers (g)	Weight Matrix (g)	Density Fibers (g/cm^3)	Density Matrix (g/cm3)	Volume Fraction Fibers (-)			Volume Fraction Matrix (-)	Density Composite (g/cm^3)	Test Direction
						0^o	90^o	45^o			
F4	3	66	81	1.5	1.17	0.195	0.195	0	0.61	1.31	0

Table 33: Panel F4 Composition details

Panel	Ultimate tensile Strength (MPa)	Standard Deviation of UTS (MPa)	Young's Modulus (MPa)	Standard Deviation of YM's (MPa)	Elongation (%)
F4	86.28	8.25	1718.27	121.4	3.61
After Water Test	74	11	1560	118	3.65
After UV Test	96	6	2641	151	3.6
After Temp Test	91	7.46	2324	146	3.9

Table 34: Panel F4 Mechanical Properties (before & after weathering conditons)

Panel Name	Fiber Type	Size (mmxmm)	Number of Layers	Orientation (o)	Infusion Time (min)	Epoxy Used	Hardner Used	Epoxy : Hardner Ratio (g)
F'6	180g Cross Stitched Flax Fiber	300 x 300	6	(0, 90, 45, 45, 90, 0)	13	Sicomin Greepoxy	SD 7561	100:36:00

Table 35: Panel F'6 Fabrication Details

Panel	Thickness (mm)	Weight of Fibers (g)	Weight Matrix (g)	Density Fibers (g/cm^3)	Density Matrix (g/cm3)	Volume Fraction Fibers (-)			Volume Fraction Matrix (-)	Density Composite (g/cm^3)	Test Direction
						0^o	90^o	45^o			
F'6	2.5	81	100	1.4	1.17	0.16	0.16	0.08	0.6	1.26	90

Table 36: Panel F'6 Composition details

Panel	Ultimate tensile Strength (MPa)	Standard Deviation of UTS (MPa)	Young's Modulus (MPa)	Standard Deviation of YM's (MPa)	Elongation (%)
F'6	86.158	2.72	2087.85	59	3.86
After Water Test	97	4.62	1878	68	5.16
After UV Test	88	4.56	2690	135	3.275
After Temp Test	92	3.56	2753	68	3.54

Table 37: Panel F'6 Mechanical Properties (before & after weathering conditons)

Panel Name	Fiber Type	Size (mmxmm)	Number of Layers	Orientation (o)	Infusion Time (min)	Epoxy Used	Hardner Used	Epoxy : Hardner Ratio (g)
F''6	180g Cross Stitched Flax Fiber	300 x 300	6	(0, 90, 45, 45, 90, 0)	13	Sicomin Greepoxy	SD 7561	100:36:00

Table 38: Panel F"6 Fabrication Details

Panel	Thickness (mm)	Weight of Fibers (g)	Weight Matrix (g)	Density Fibers (g/cm^3)	Density Matrix (g/cm3)	Volume Fraction Fibers (-)			Volume Fraction Matrix (-)	Density Composite (g/cm^3)	Test Direction
						0^o	90^o	45^o			
F''6	2	81	100	1.4	1.17	0.16	0.16	0.08	0.6	1.26	0

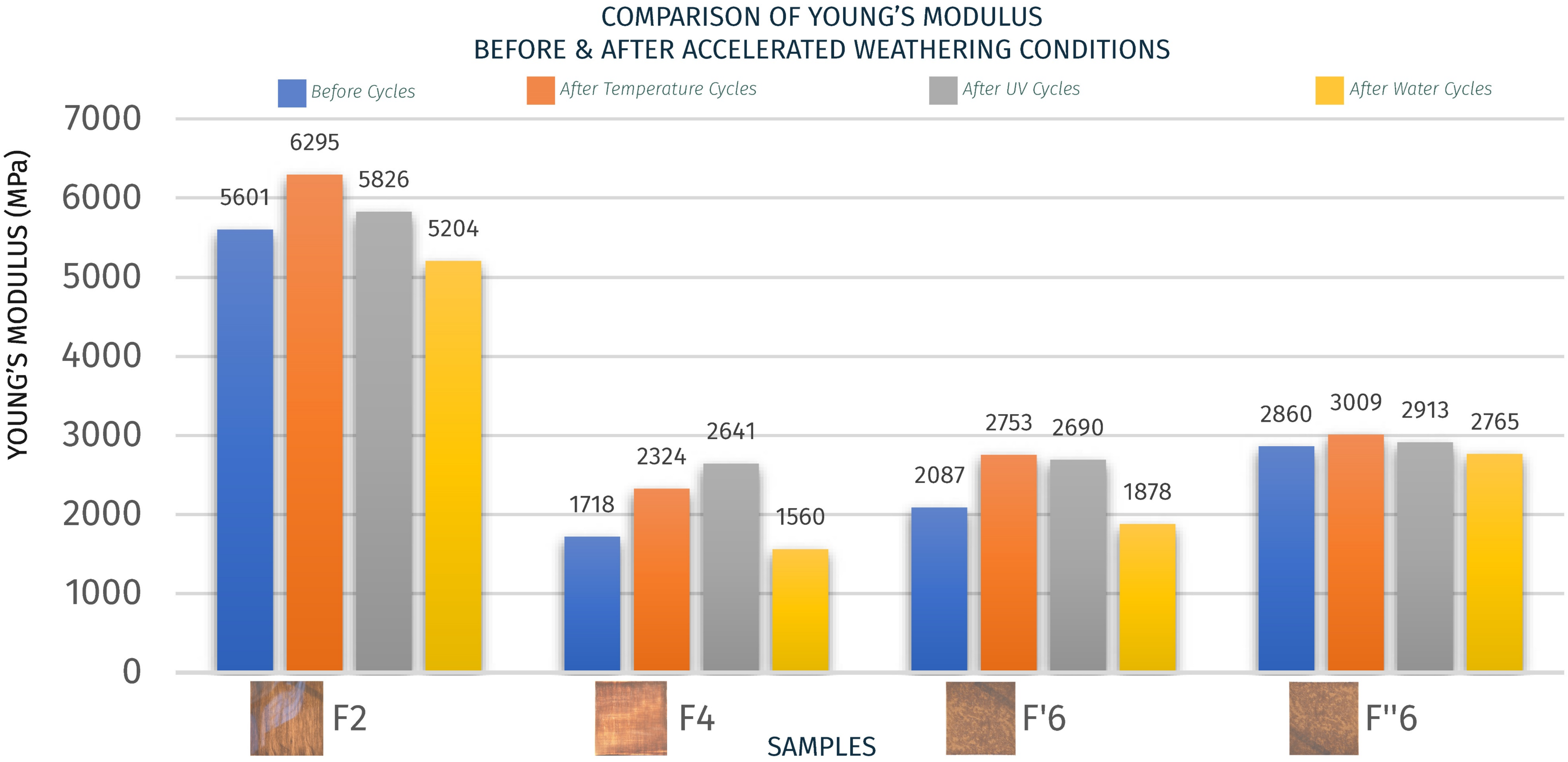
Table 39: Panel F"6 Composition details

Panel	Ultimate tensile Strength (MPa)	Standard Deviation of UTS (MPa)	Young's Modulus (MPa)	Standard Deviation of YM's (MPa)	Elongation (%)
F''6	104.55	7.72	2860.81	149.72	3.81
After Water Test	103.45	9.14	2765	95.5	3.765
After UV Test	96	11.56	2913	168	3.6
After Temp Test	108	12.5	3009	259	3.6

Table 40: Panel F"6 Mechanical Properties (before & after weathering conditons)

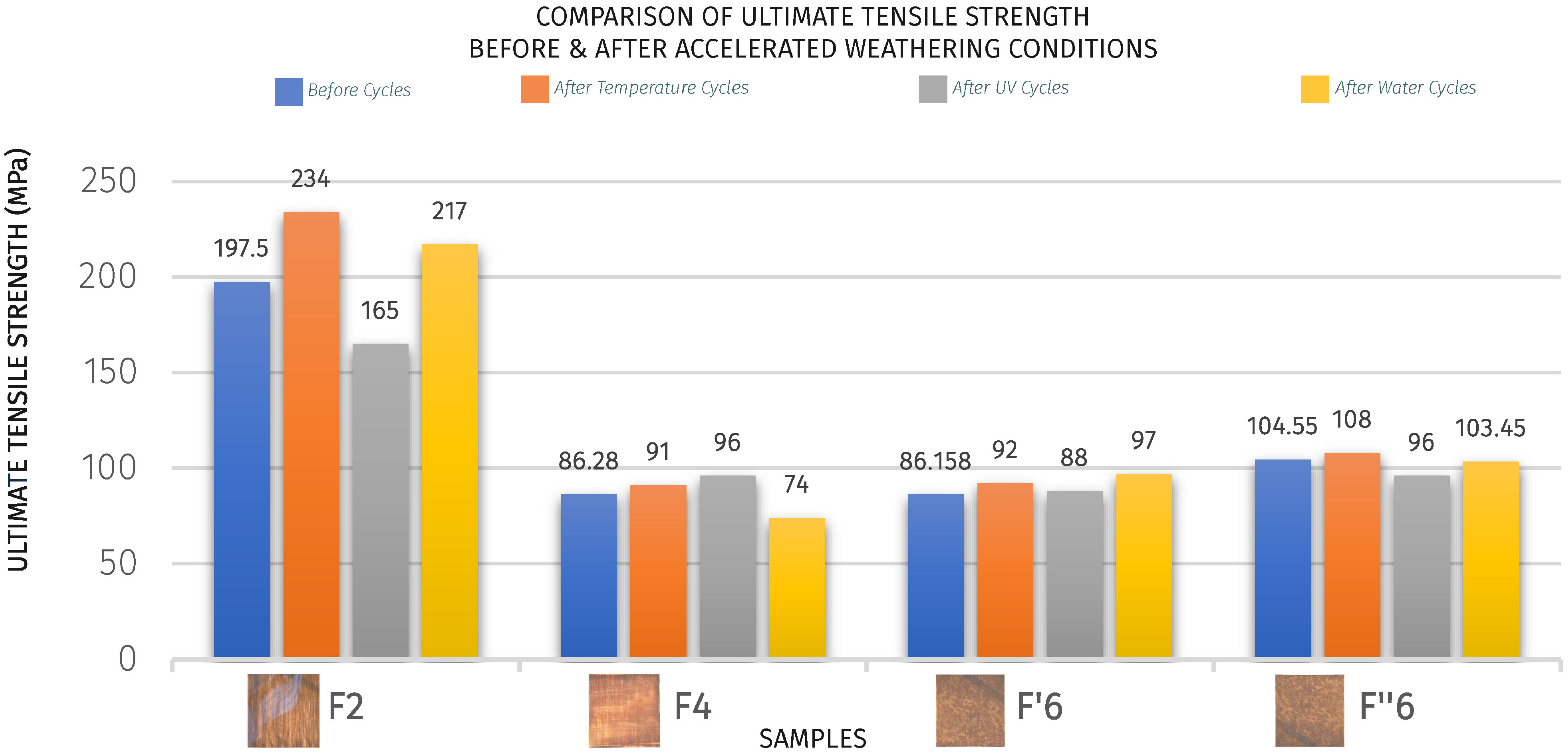
MECHANICAL & PHYSICAL TESTING

YOUNG'S MODULUS ANALYSIS



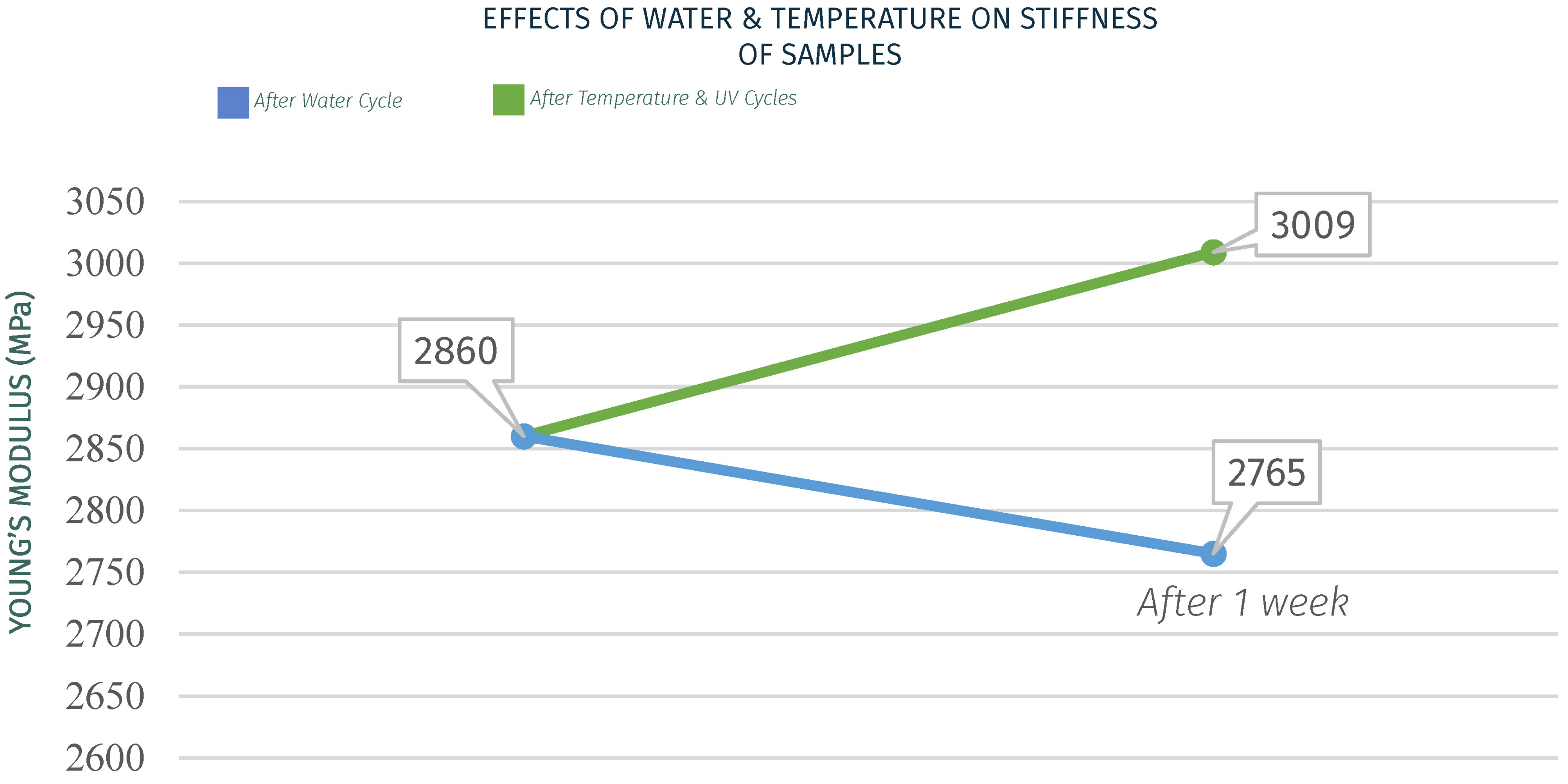
MECHANICAL & PHYSICAL TESTING

ULTIMATE TENSILE STRENGTH ANALYSIS



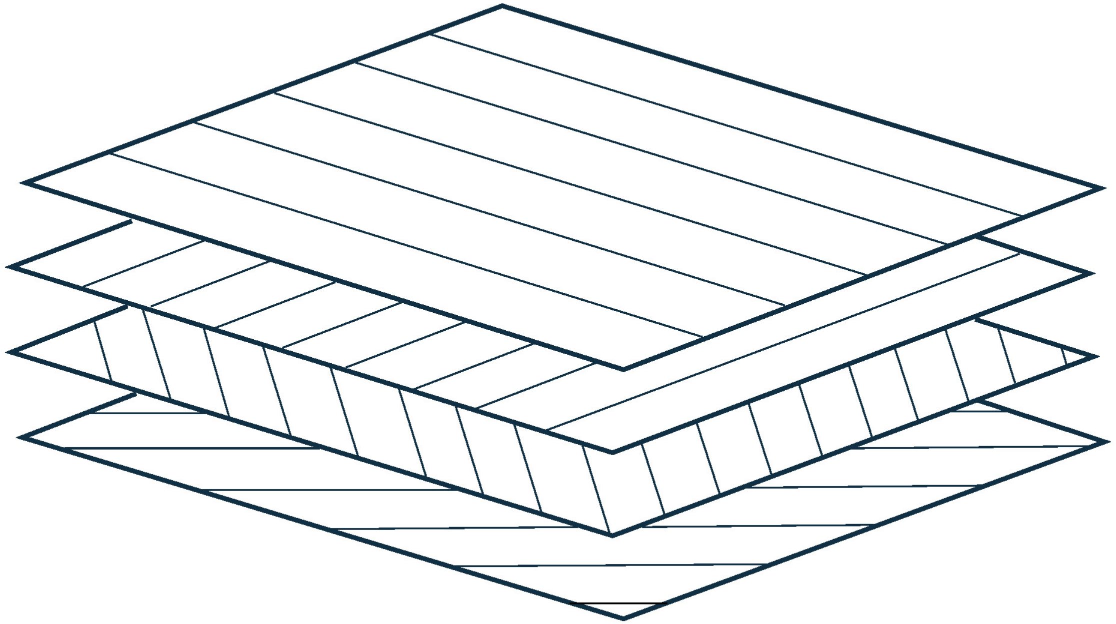
MECHANICAL & PHYSICAL TESTING

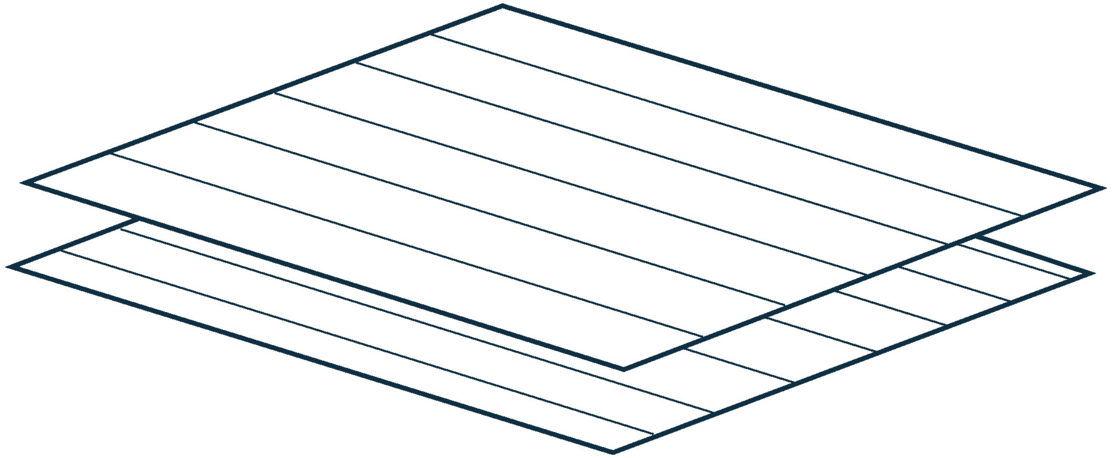
INTERPRETATION



MECHANICAL & PHYSICAL TESTING

INTERPRETATION - EFFECTS OF LAYERING DIRECTION ON TENSILE RESISTANCE





LESS BOND BETWEEN FIBERS

LESS RESISTANCE TO TENSILE LOADS

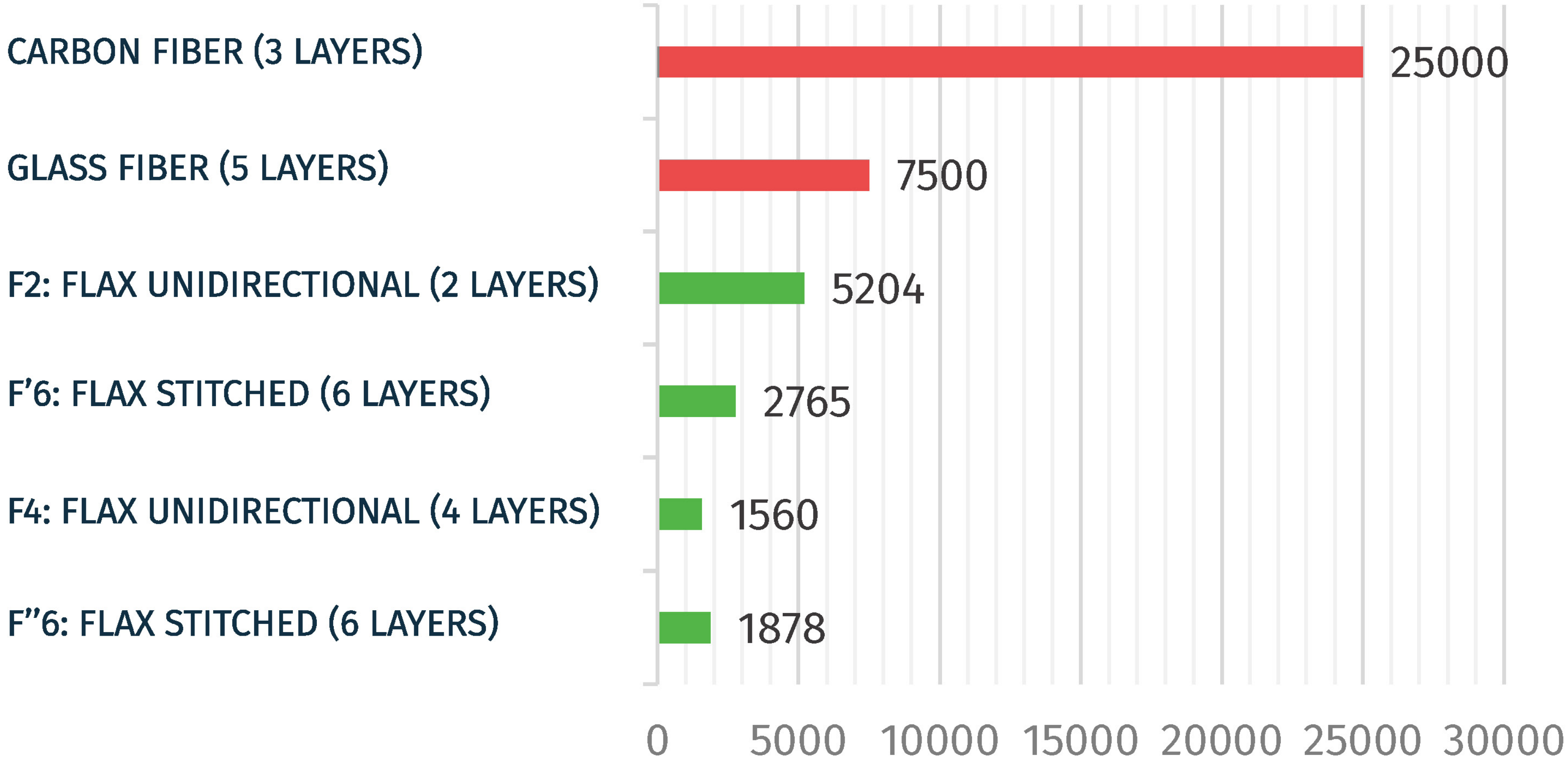
BETTER BOND BETWEEN FIBERS

MORE RESISTANCE TO TENSILE LOADS

MECHANICAL & PHYSICAL TESTING

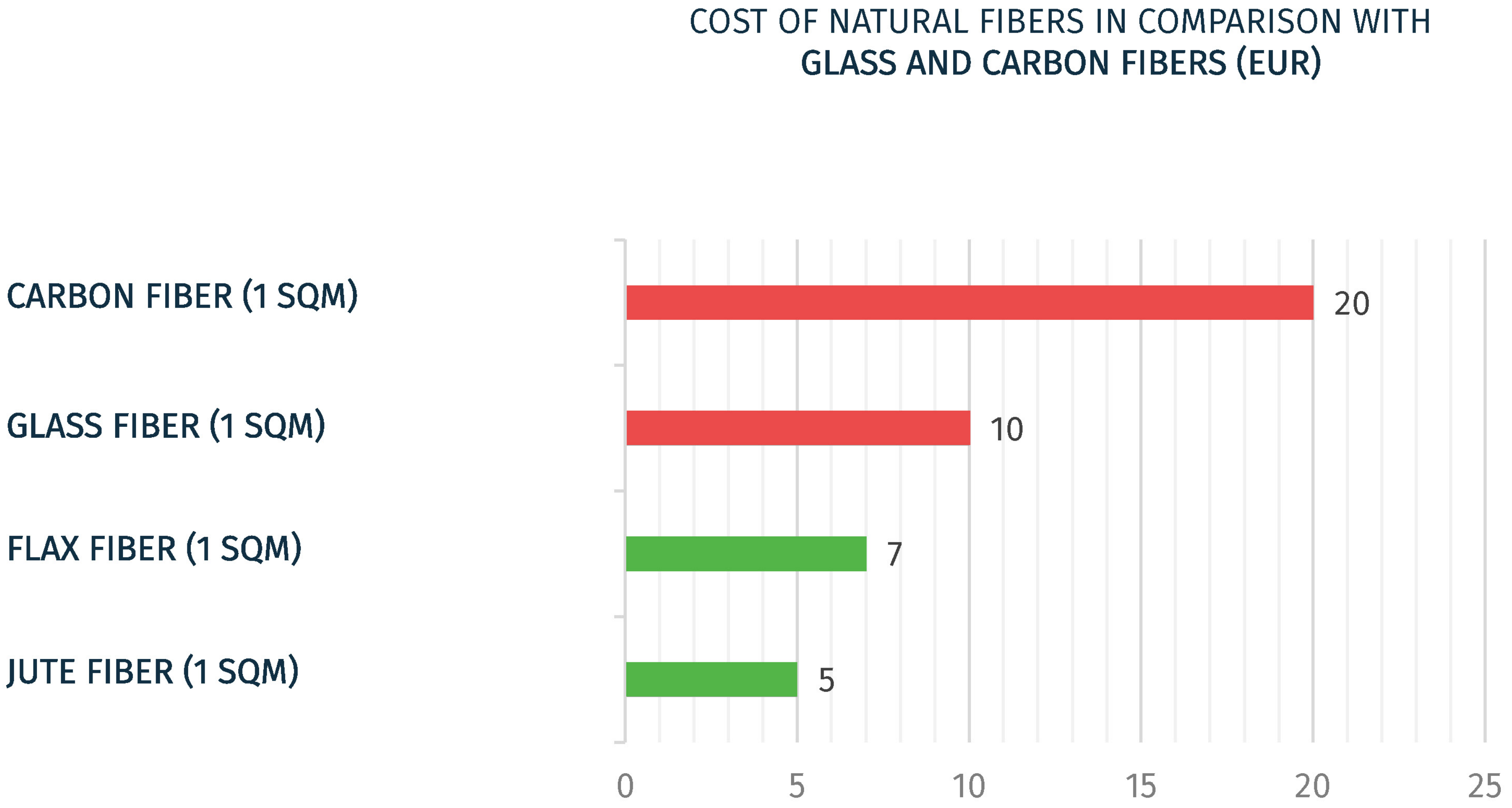
STIFFNESS COMPARISON WITH GLASS AND CARBON COMPOSITES

STIFFNESS OF BIO-BASED PANELS IN COMPARISON WITH GLASS AND CARBON FIBER COMPOSITES (MPA)



MECHANICAL & PHYSICAL TESTING

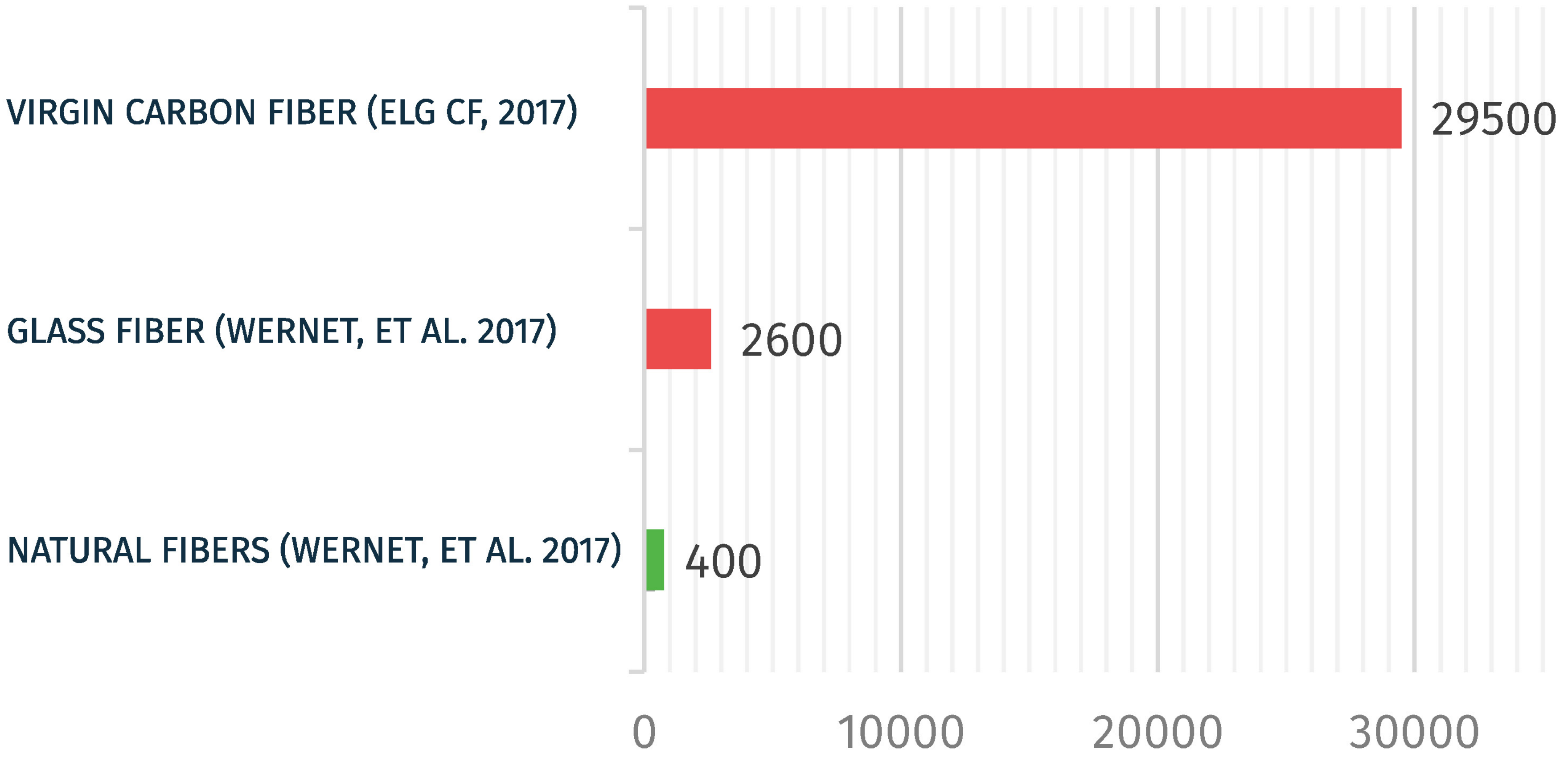
COST COMPARISON WITH GLASS AND CARBON COMPOSITES



MECHANICAL & PHYSICAL TESTING

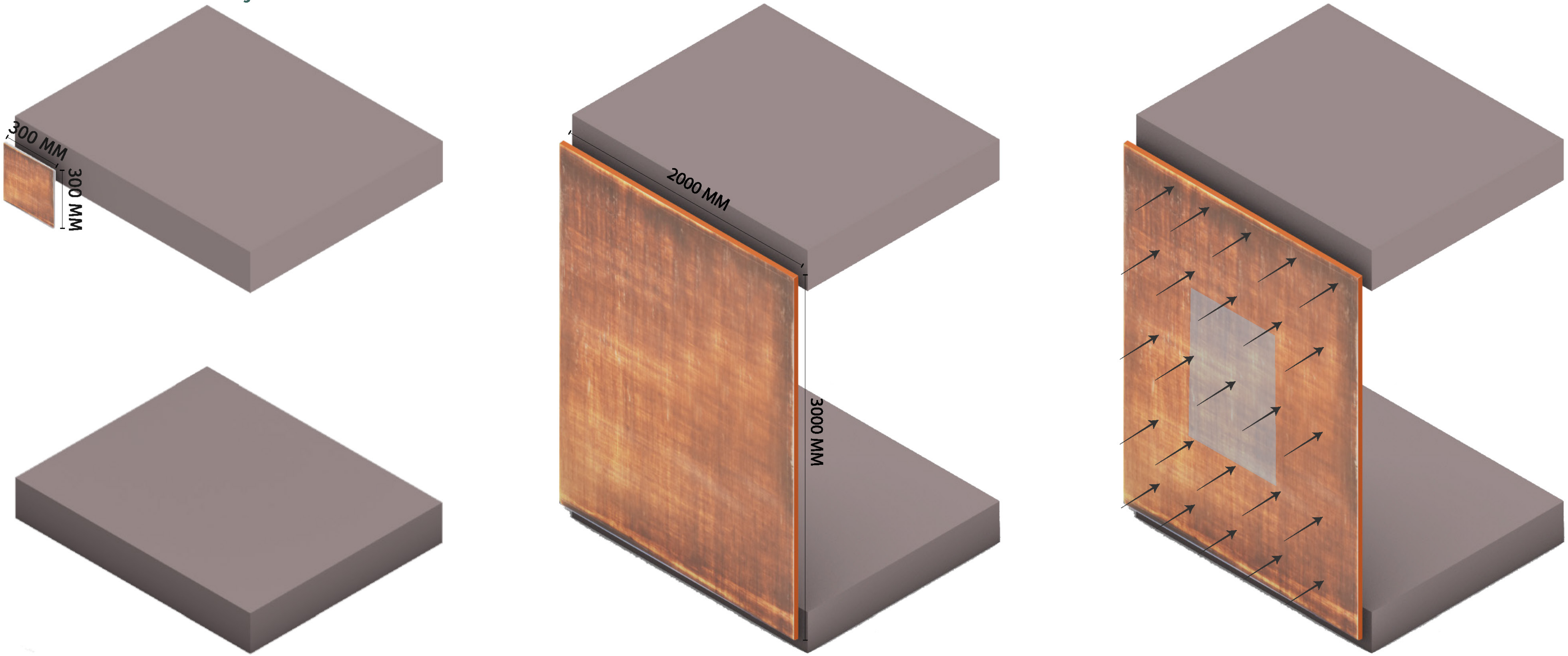
GREEN HOUSE GAS EMISSION COMPARISON WITH GLASS AND CARBON COMPOSITES

CARBON FOOTPRINT (GREEN HOUSE GAS EMISSION) OF NATURAL FIBERS IN COMPARISON WITH GLASS AND CARBON FIBER ($CO_{2\text{-}EQ}$/TONNE FIBER)



DESIGN WITH BIO-COMPOSITES

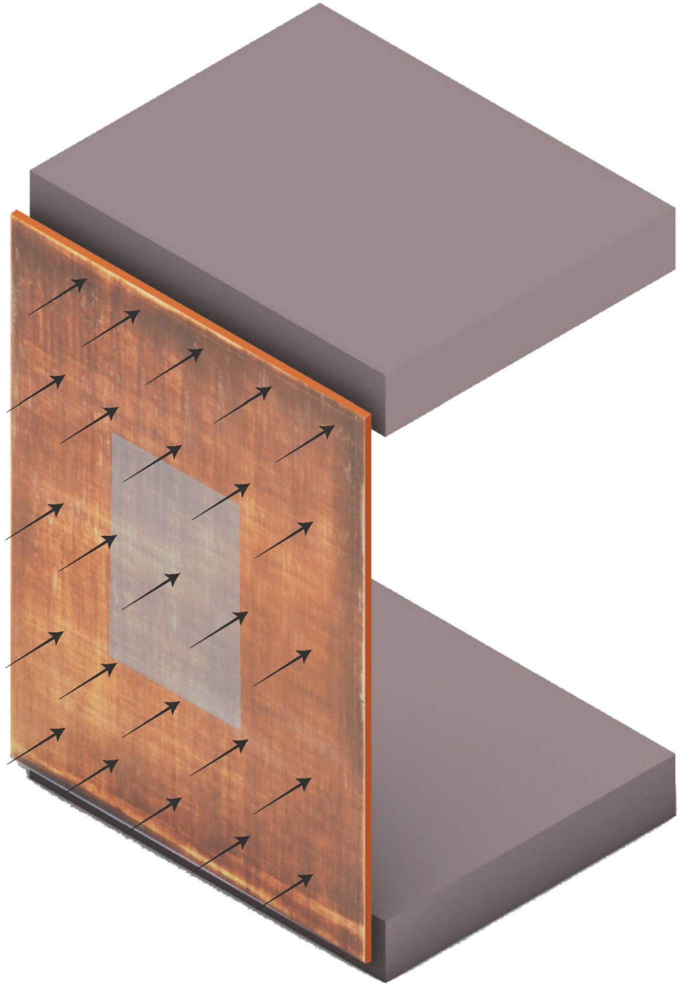
PANEL SCALING FOR FAÇADE APPLICATION



- WIND LOADS: 65 MPH
- WINDOW WEIGHT: 50 Kg

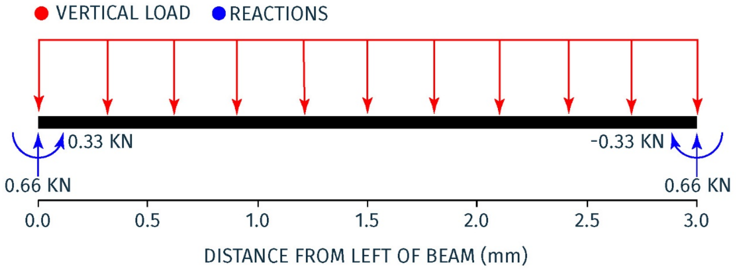
DESIGN WITH BIO-COMPOSITES

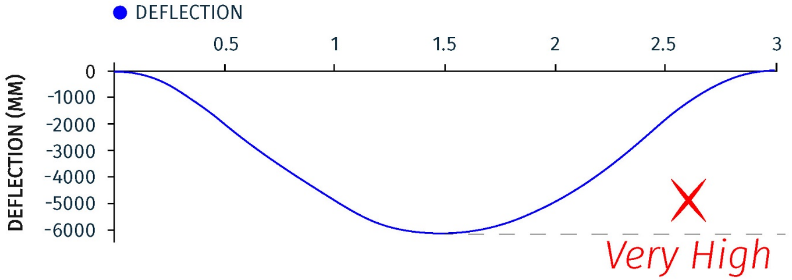
PANEL DEFLECTION ANALYSIS



PANEL F2

- THICKNESS (mm): 1.2
- YOUNG'S MODULUS (MPA): 5204
- MOMENT OF INERTIA (mm^4): 288
- SPAN (mm): 3000
- WIDTH (mm): 2000
- CROSS SECTION AREA (mm^2): 2400
- WIND LOADS: 65 MPH
- WINDOW WEIGHT: 50 Kg



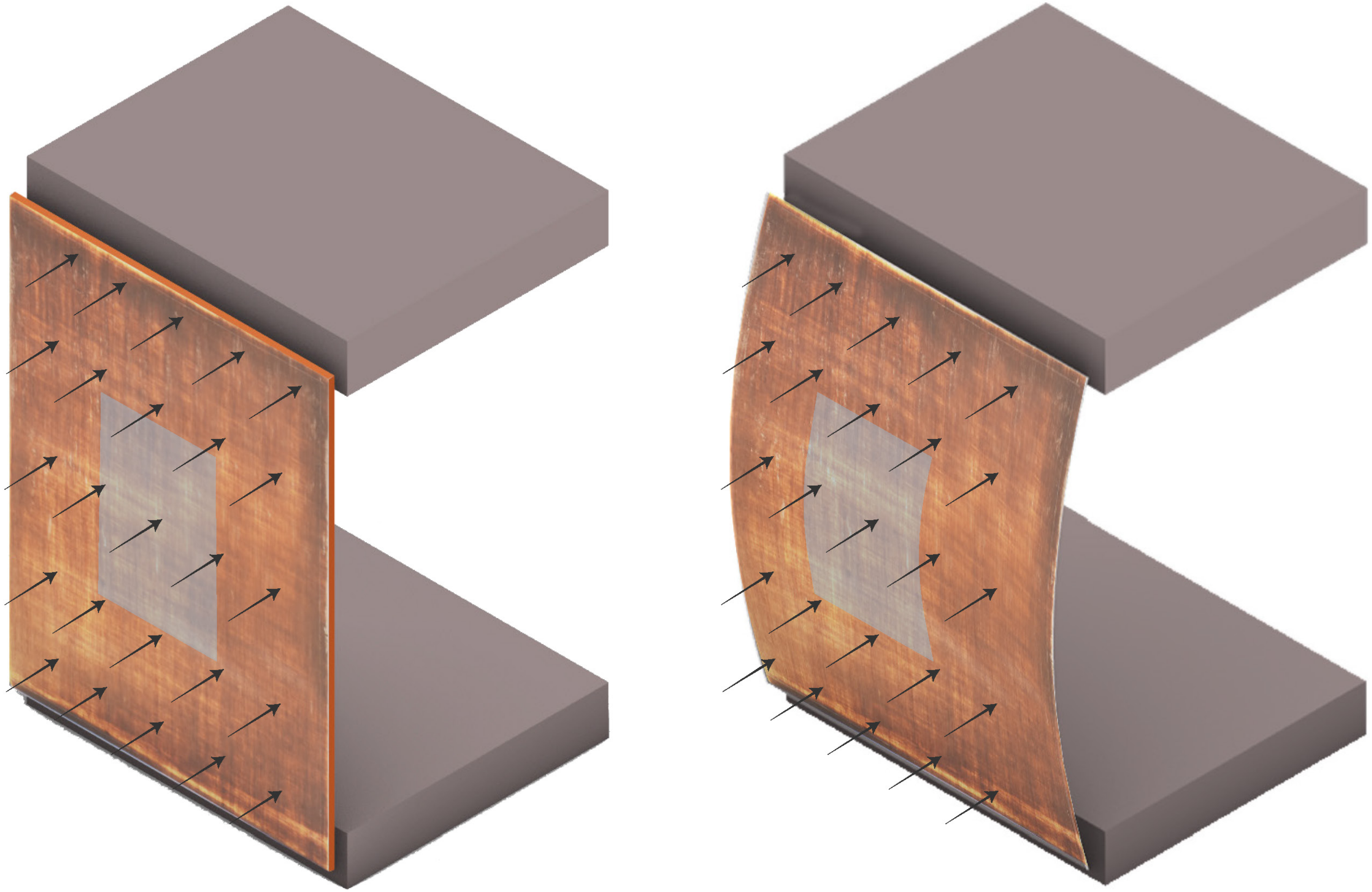


ALLOWABLE DEFLECTION:

$$\frac{Span}{100} = \frac{3000}{100} = 30\ mm$$

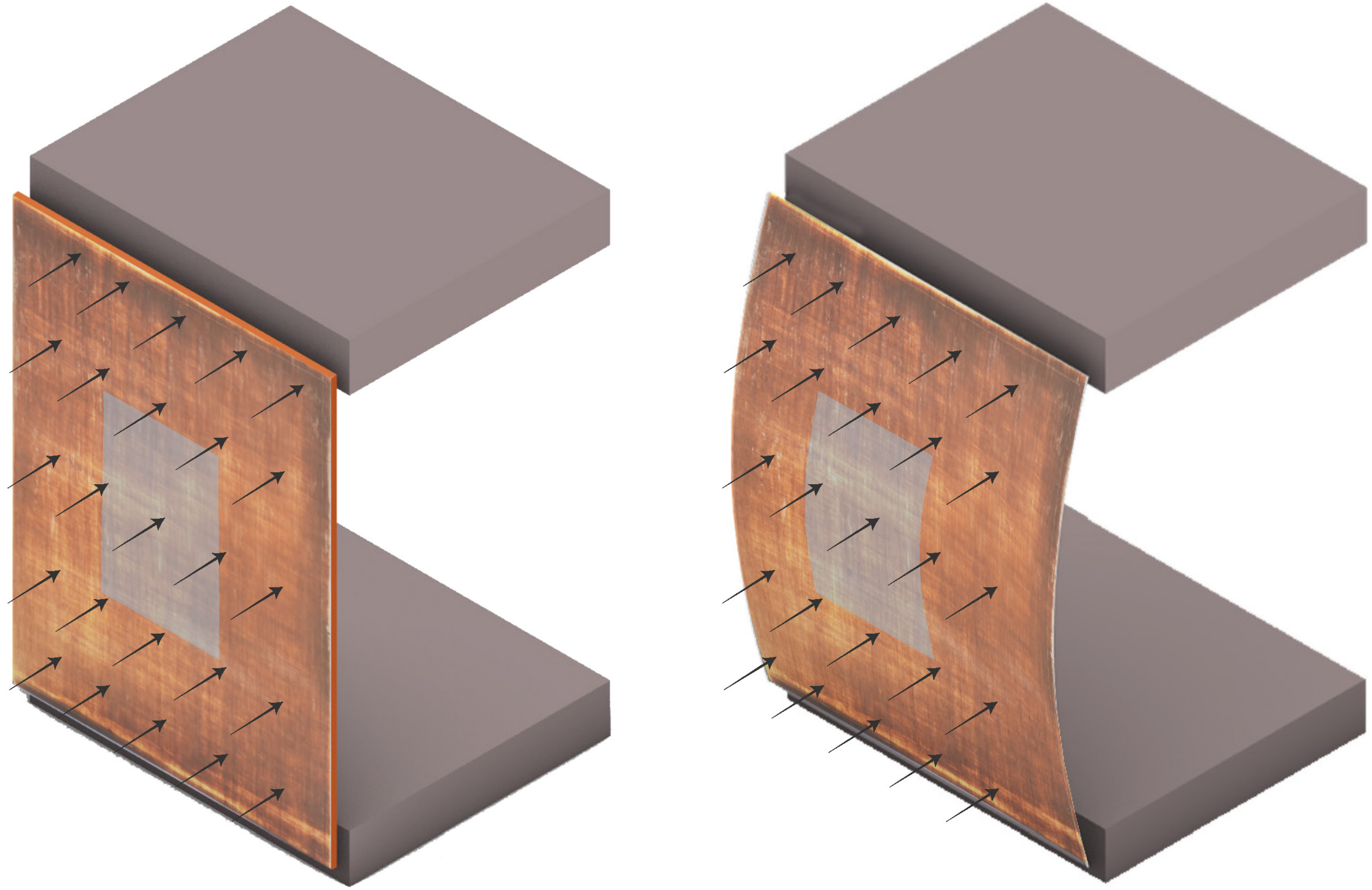
DESIGN WITH BIO-COMPOSITES

PANEL DEFLECTION ANALYSIS



DESIGN WITH BIO-COMPOSITES

PANEL DEFLECTION ANALYSIS



POSSIBLE SOLUTION

Fabricate similar panel with a curve in the span to increase resistance to wind loads

CHALLENGE

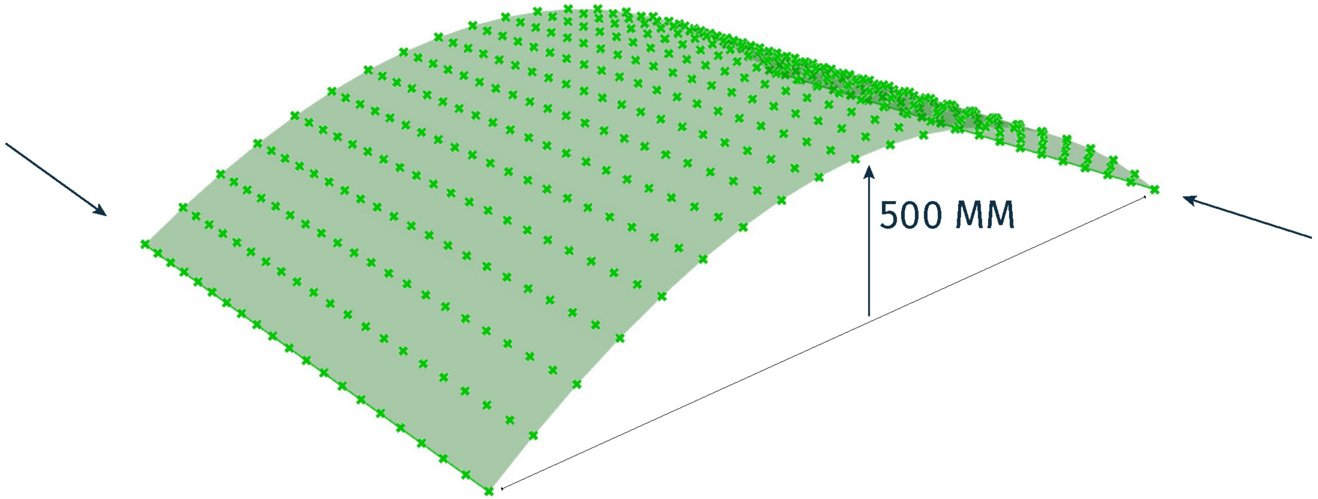
Determination of deflection using hand calculation became diffuclt

CHALLENGE SOLUTION

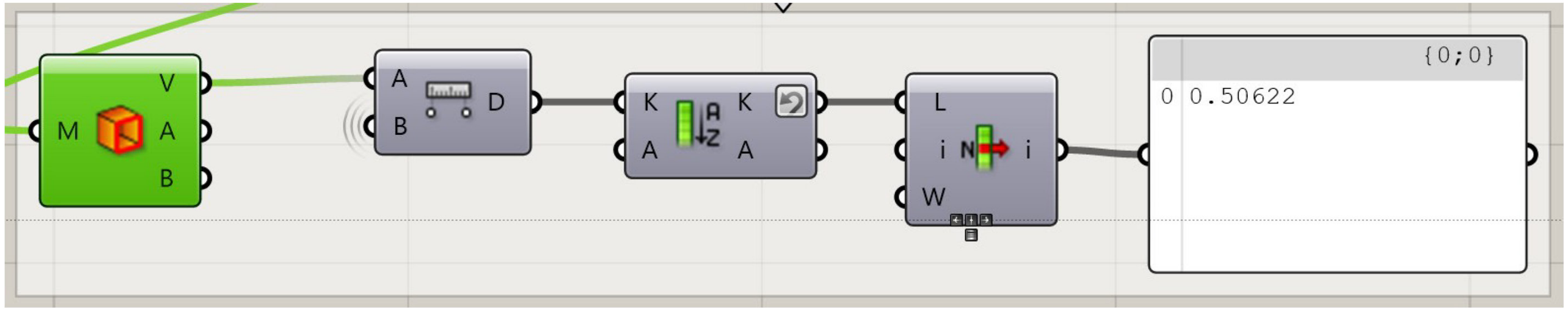
Use of Karamba and Kangaroo to run a structural analysis that show the deflections of the panel of Y axis *(due to wind loads)* & deflection on Z axis *(due to window weight and gravity)*

DESIGN WITH BIO-COMPOSITES

PANEL DEFLECTION ANALYSIS - SCRIPT DETAILS

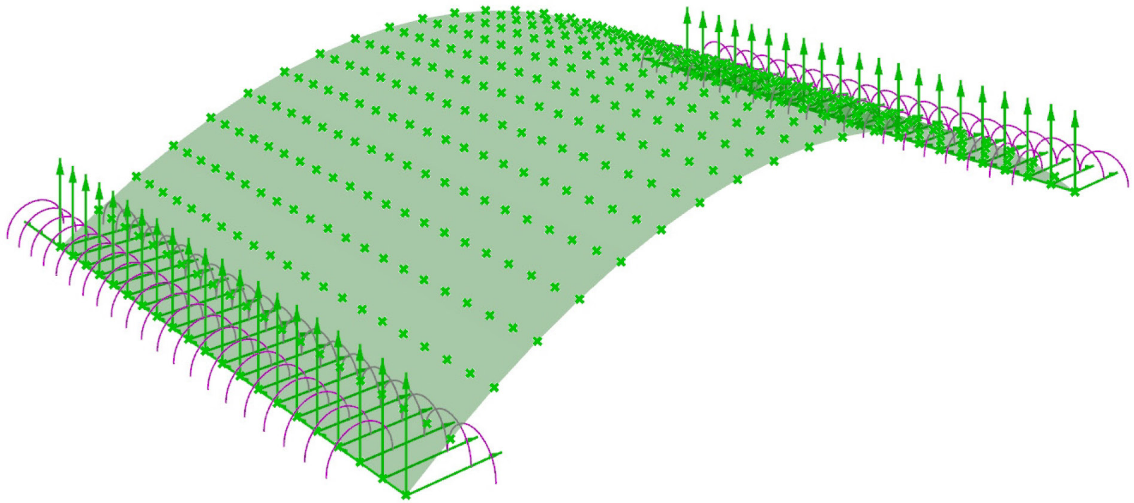


SHAPE DEFINITION

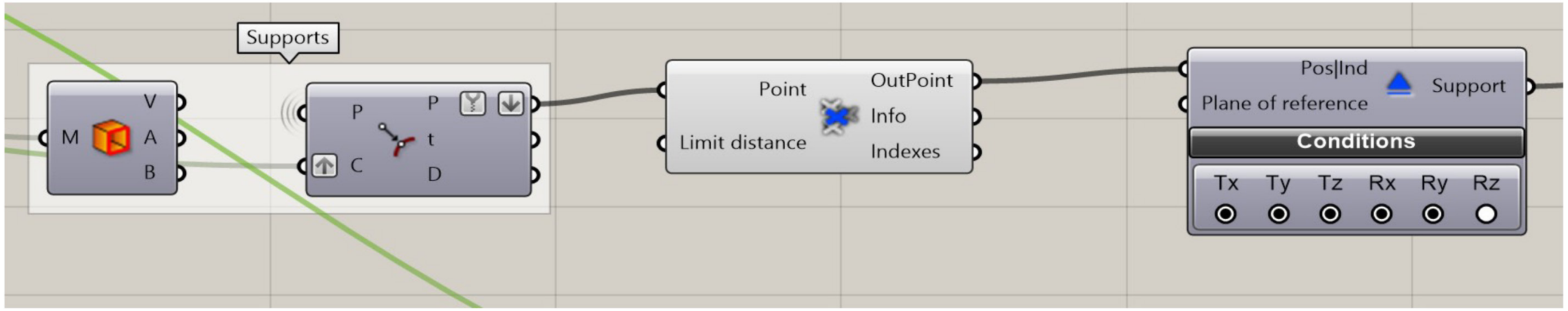


DESIGN WITH BIO-COMPOSITES

PANEL DEFLECTION ANALYSIS - SCRIPT DETAILS

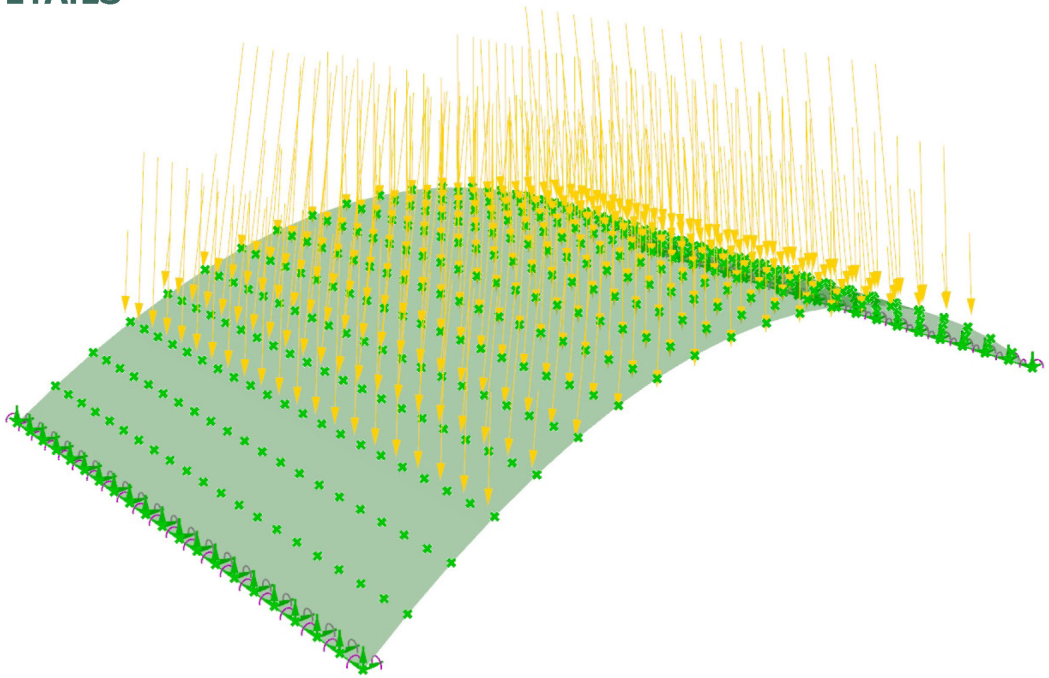


SUPPORT DEFINITION

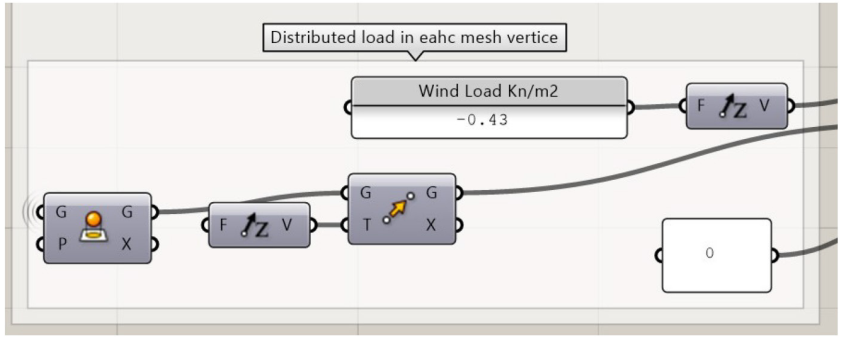


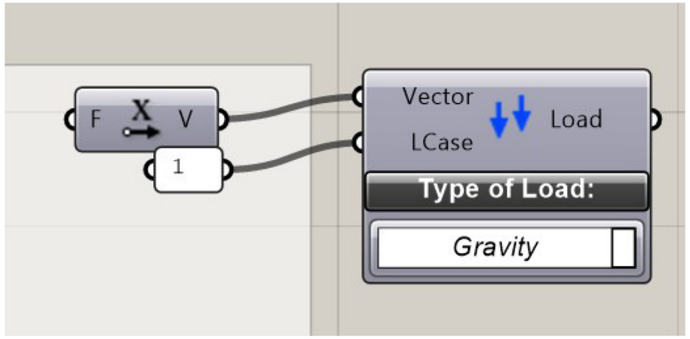
DESIGN WITH BIO-COMPOSITES

PANEL DEFLECTION ANALYSIS - SCRIPT DETAILS



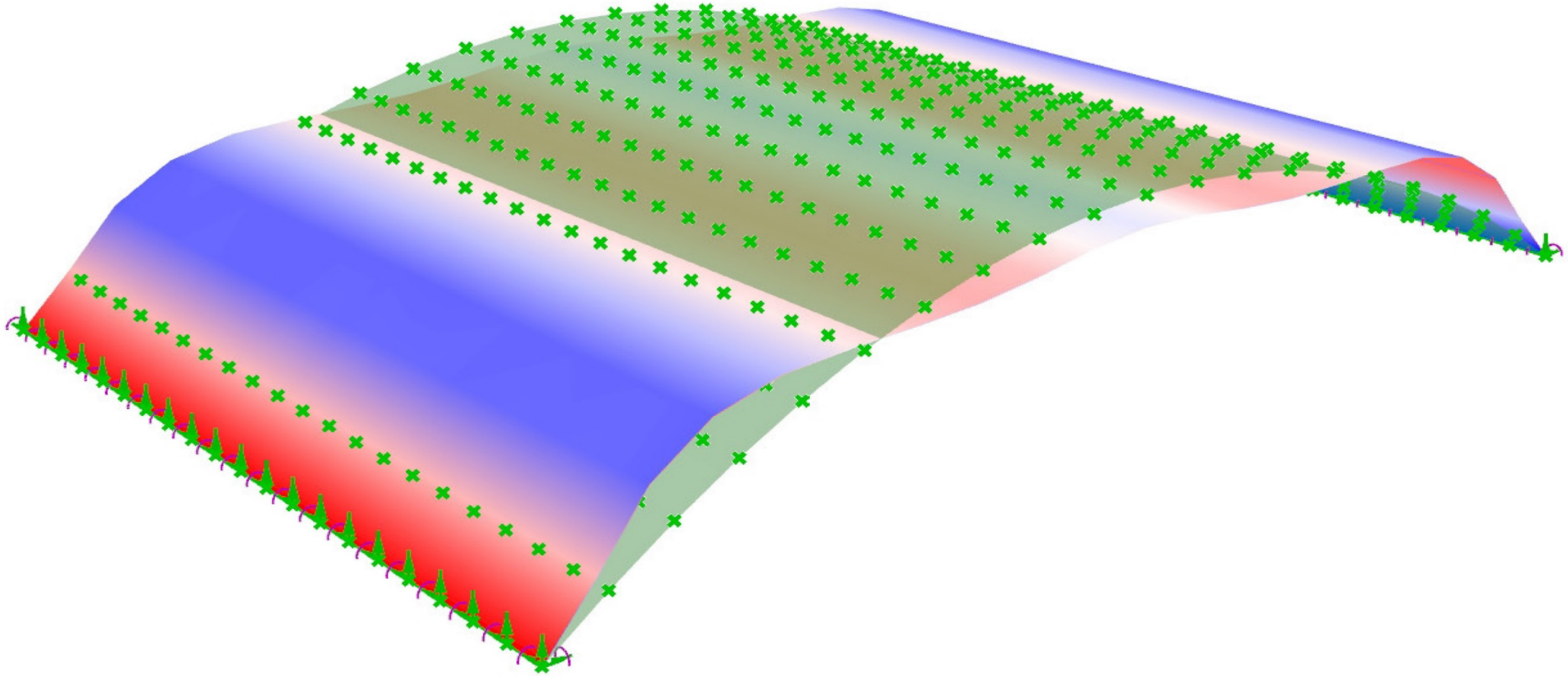
LOADS DEFINITION



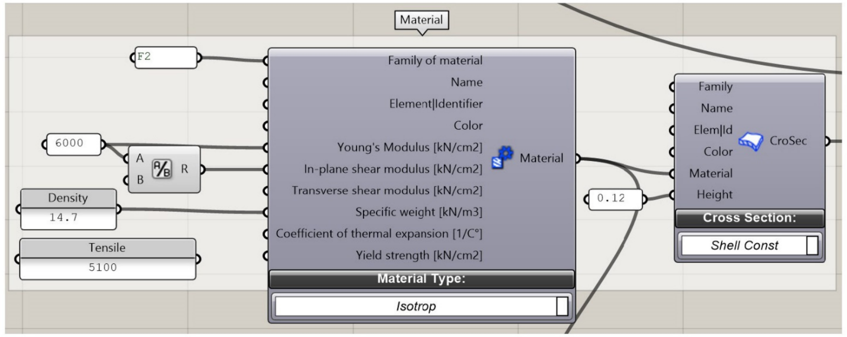


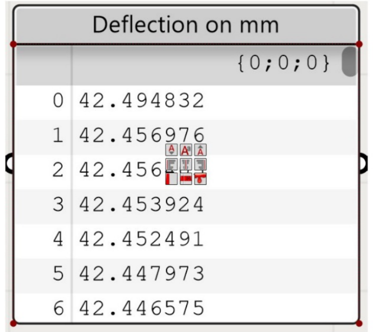
DESIGN WITH BIO-COMPOSITES

PANEL DEFLECTION ANALYSIS - SCRIPT DETAILS



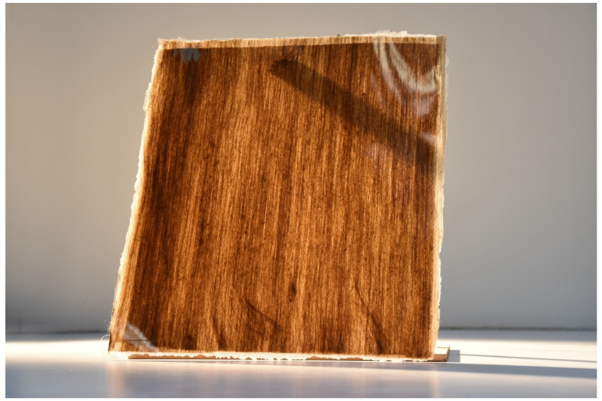
MATERIAL PROPERTIES & VISUALIZATION





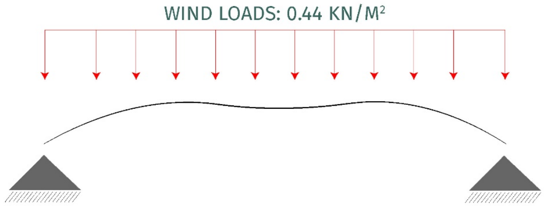
DESIGN WITH BIO-COMPOSITES

PANEL DEFLECTION ANALYSIS



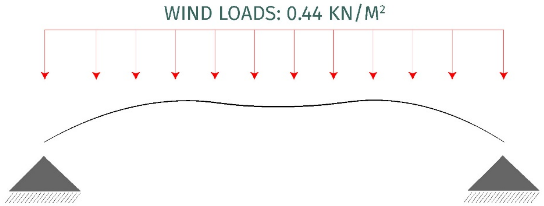
ALLOWABLE DEFLECTION Y AXIS	DEFLECTION Y AXIS	DEFLECTION Z AXIS
30 MM	48.99 MM	45.7 MM

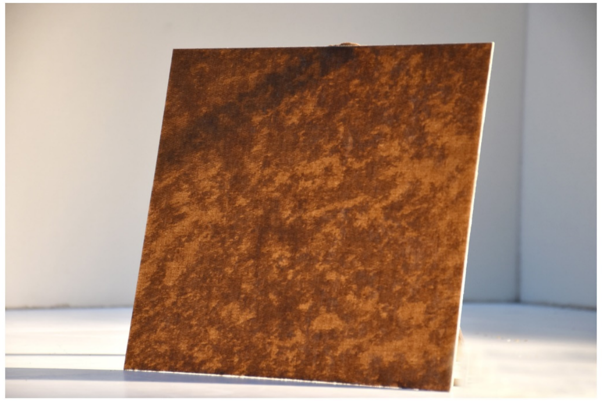
SERVICEABILITY LIMIT STATE ✗



ALLOWABLE DEFLECTION Y AXIS	DEFLECTION Y AXIS	DEFLECTION Z AXIS
30 MM	10.46 MM	24.36 MM

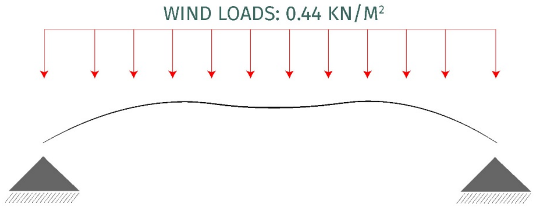
SERVICEABILITY LIMIT STATE ✓

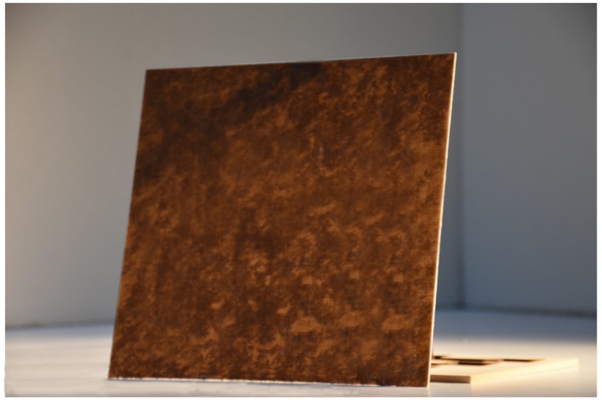




ALLOWABLE DEFLECTION Y AXIS	DEFLECTION Y AXIS	DEFLECTION Z AXIS
30 MM	15.04 mm	20.1 MM

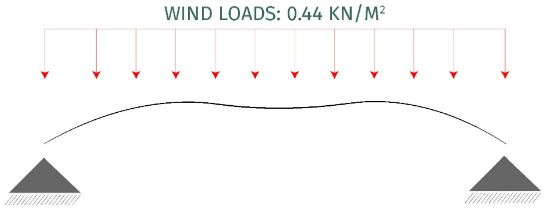
SERVICEABILITY LIMIT STATE ✓





ALLOWABLE DEFLECTION Y AXIS	DEFLECTION Y AXIS	DEFLECTION Z AXIS
30 MM	19.90 MM	29 MM

SERVICEABILITY LIMIT STATE ✓



DESIGN WITH BIO-COMPOSITES

SERVICEABILITY LIMIT STATE & ULTIMATE LIMIT STATE

1 SERVICEABILITY LIMIT STATE

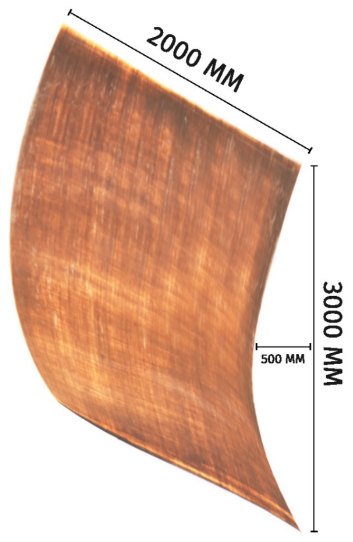
Deflection on Y axis < Allowable Deflection

2 ULTIMATE LIMIT STATE

Check if δmax < Ultimate Limit State

$$\text{With } \delta max = \frac{M_{max}}{z}$$

$$ULS = \frac{UTS - (1.64 * SD)}{2.2}$$



						Serviceability Limit State			*Ultimate Limit State*		
Panel	**Thickness (mm)**	**Ultimate Tensile Strength (MPa)**	**Standard Deviation (Mpa)**	**Young's Modulus (Mpa)**	**Loads**	**Allowable Deflection (mm)**	**Deflection Y (mm)**	**Satisfied**	**ULS (Mpa)**	**δ_{max} (Mpa)**	**Satisfied**
F2	1.2	165	31.5	5204	Wind + Weight	30	48.9	NO	51.52	2.5	YES
F4	3	74	11	1564	Wind + Weight	30	10.46	YES	25.44	1.1	YES
F'6	2.5	88	4.56	1878	Wind + Weight	30	15.04	YES	36.6	9.6	YES
F''6	2	96	11.56	2765	Wind + Weight	30	19.9	YES	35.02	1.5	YES

DESIGN WITH BIO-COMPOSITES

SERVICEABILITY LIMIT STATE & ULTIMATE LIMIT STATE

1 SERVICEABILITY LIMIT STATE

Deflection on Y axis < Allowable Deflection

2 ULTIMATE LIMIT STATE

Check if δmax < Ultimate Limit State

$$\text{With } \delta max = \frac{M_{max}}{z}$$

$$ULS = \frac{UTS - (1.64 * SD)}{2.2}$$

(Partial Safety Factor)

Panel	Thickness (mm)	Ultimate Tensile Strength (MPa)	Standard Deviation (Mpa)	Young's Modulus (Mpa)	Loads	*Serviceability Limit State*			*Ultimate Limit State*		
						Allowable Deflection (mm)	Deflection Y (mm)	Satisfied	ULS (Mpa)	δ_{max} (Mpa)	Satisfied
F2	1.2	165	31.5	5204	Wind + Weight	30	48.9	NO	51.52	2.5	YES
F4	3	74	11	1564	Wind + Weight	30	10.46	YES	25.44	1.1	YES
F'6	2.5	88	4.56	1878	Wind + Weight	30	15.04	YES	36.6	9.6	YES
F''6	2	96	11.56	2765	Wind + Weight	30	19.9	YES	35.02	1.5	YES

DESIGN WITH BIO-COMPOSITES

SERVICEABILITY LIMIT STATE & ULTIMATE LIMIT STATE

1 SERVICEABILITY LIMIT STATE

Deflection on Y axis < Allowable Deflection

2 ULTIMATE LIMIT STATE

Check if δmax < Ultimate Limit State

$$\text{With } \delta max = \frac{M_{max}}{z}$$

$$ULS = \frac{UTS - (1.64 * SD)}{2.2}$$

Panel	Thickness (mm)	Ultimate Tensile Strength (MPa)	Standard Deviation (Mpa)	Young's Modulus (Mpa)	Loads	*Serviceability Limit State*			*Ultimate Limit State*		
						Allowable Deflection (mm)	Deflection Y (mm)	Satisfied	ULS (Mpa)	δmax (Mpa)	Satisfied
F2	1.2	165	31.5	5204	Wind + Weight	30	48.9	NO	51.52	2.5	YES
F4	3	74	11	1564	Wind + Weight	30	10.46	YES	25.44	1.1	YES
F'6	2.5	88	4.56	1878	Wind + Weight	30	15.04	YES	36.6	9.6	YES
F''6	2	96	11.56	2765	Wind + Weight	30	19.9	YES	35.02	1.5	YES

DESIGN WITH BIO-COMPOSITES

SERVICEABILITY LIMIT STATE & ULTIMATE LIMIT STATE

1 SERVICEABILITY LIMIT STATE

Deflection on Y axis < Allowable Deflection

2 ULTIMATE LIMIT STATE

Check if δmax < Ultimate Limit State

$$\text{With } \delta max = \frac{M_{max}}{z}$$

$$ULS = \frac{UTS - (1.64 * SD)}{2.2}$$

Panel	Thickness (mm)	Ultimate Tensile Strength (MPa)	Standard Deviation (Mpa)	Young's Modulus (Mpa)	Loads	*Serviceability Limit State*			*Ultimate Limit State*		
						Allowable Deflection (mm)	Deflection Y (mm)	Satisfied	ULS (Mpa)	δmax (Mpa)	Satisfied
F2	1.2	165	31.5	5204	Wind + Weight	30	48.9	NO	51.52	2.5	YES
F4	3	74	11	1564	Wind + Weight	30	10.46	YES	25.44	1.1	YES
F'6	2.5	88	4.56	1878	Wind + Weight	30	15.04	YES	36.6	9.6	YES
F''6	2	96	11.56	2765	Wind + Weight	30	19.9	YES	35.02	1.5	YES

DESIGN WITH BIO-COMPOSITES

SERVICEABILITY LIMIT STATE & ULTIMATE LIMIT STATE

1 SERVICEABILITY LIMIT STATE

Deflection on Y axis < Allowable Deflection

2 ULTIMATE LIMIT STATE

Check if δmax < Ultimate Limit State

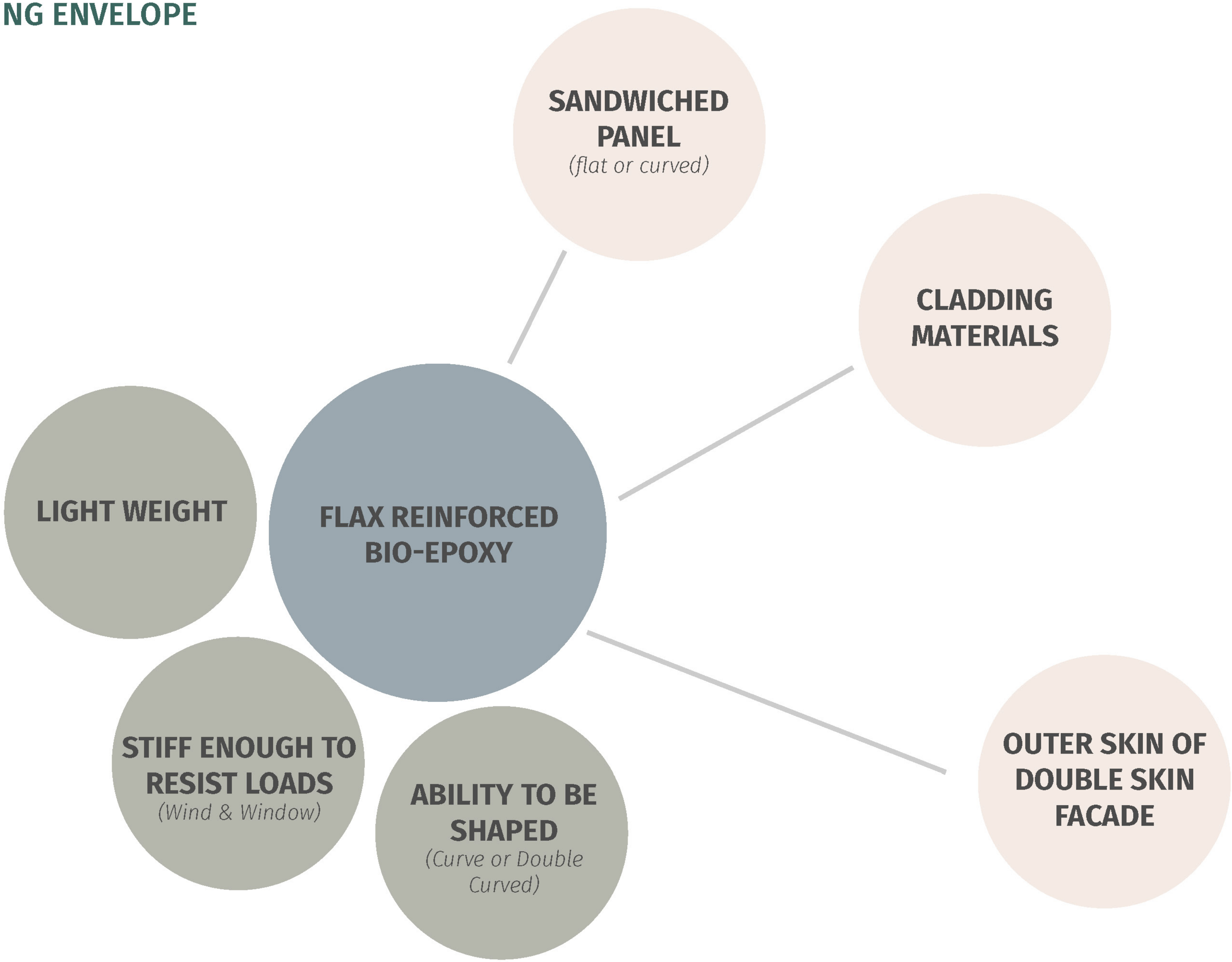
$$\text{With } \delta max = \frac{M_{max}}{z}$$

$$ULS = \frac{UTS - (1.64 * SD)}{2.2}$$

Panel	Thickness (mm)	Ultimate Tensile Strength (MPa)	Standard Deviation (Mpa)	Young's Modulus (Mpa)	Loads	*Serviceability Limit State*			*Ultimate Limit State*		
						Allowable Deflection (mm)	Deflection Y (mm)	Satisfied	ULS (Mpa)	δmax (Mpa)	Satisfied
F2	1.2	165	31.5	5204	Wind + Weight	30	48.9	NO	51.52	2.5	YES
F4	3	74	11	1564	Wind + Weight	30	10.46	YES	25.44	1.1	YES
F'6	2.5	88	4.56	1878	Wind + Weight	30	15.04	YES	36.6	9.6	YES
F''6	2	96	11.56	2765	Wind + Weight	30	19.9	YES	35.02	1.5	YES

DESIGN WITH BIO-COMPOSITES

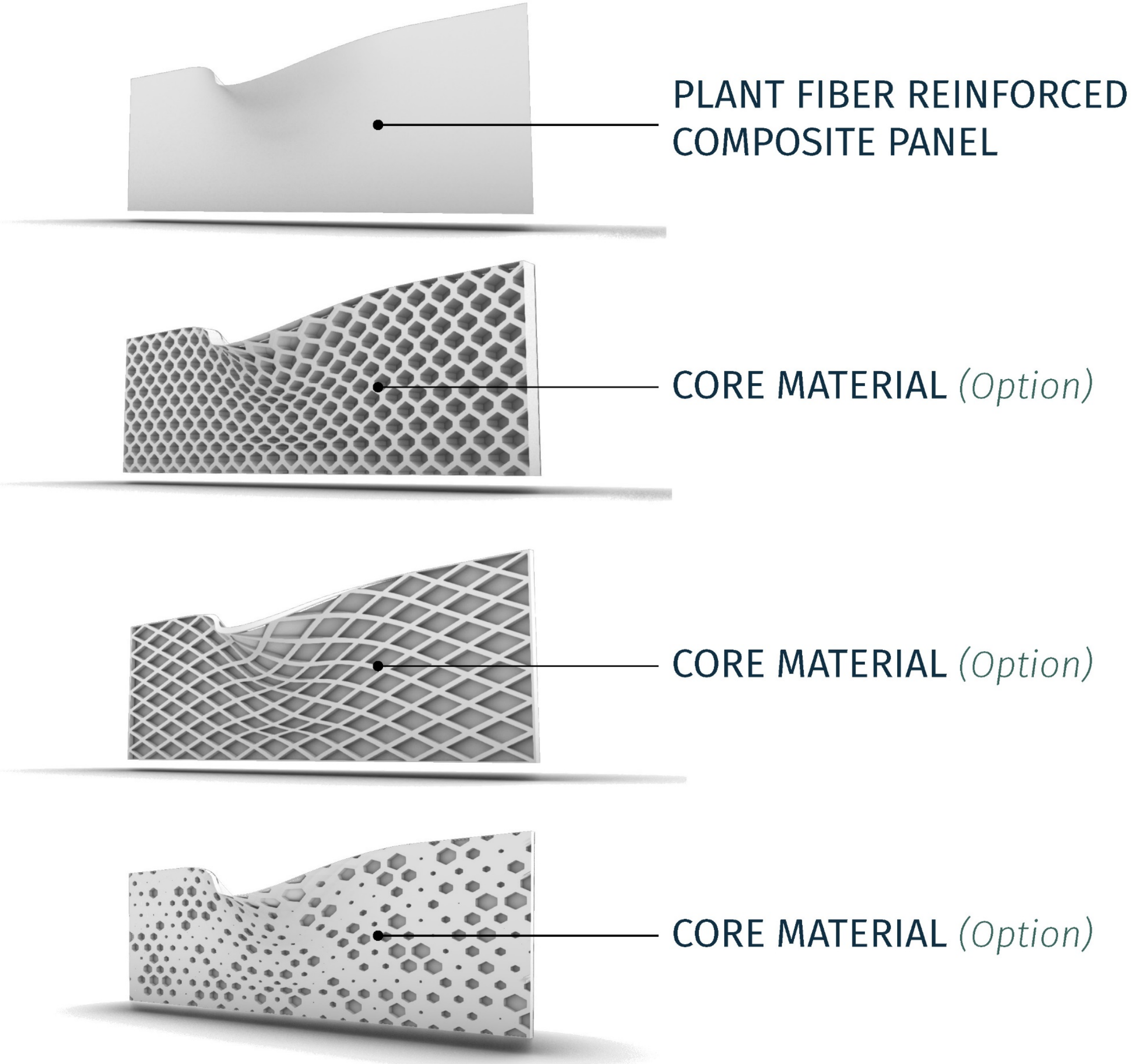
APPLICATIONS ON THE BUILDING ENVELOPE

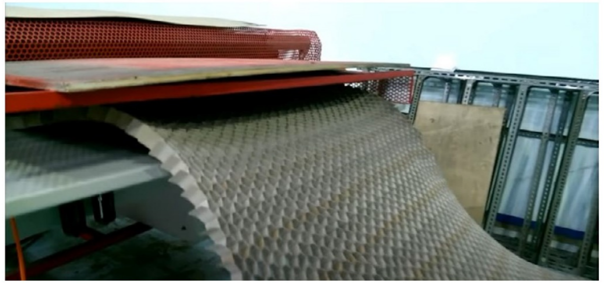


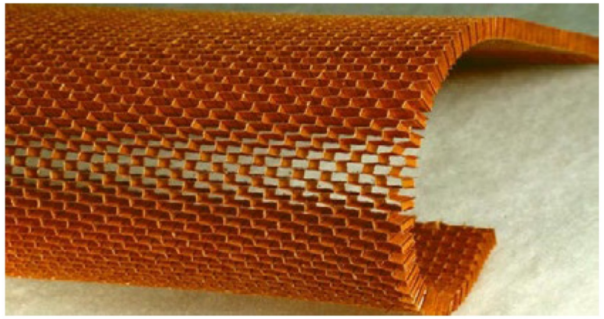
DESIGN WITH BIO-COMPOSITES

SANDWICHED PANEL

Project: CIPEA No. 4 House - *Architect:* AZL Architects - *Year:* 2008 - *Location:* China



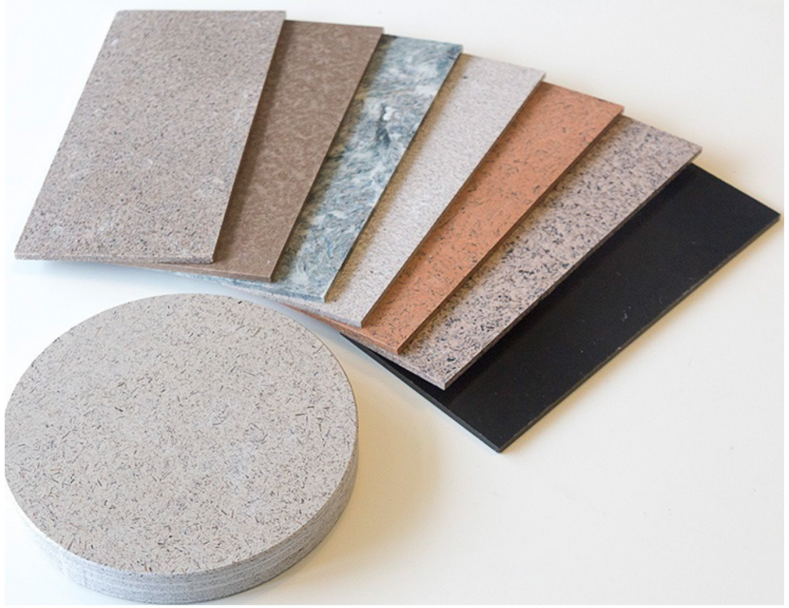




DESIGN WITH BIO-COMPOSITES

CLADDING MATERIAL

Company: NPSP B.V - *Product:* Nabasco - *Material:* Paper Waste - *Location:* The Netherlands

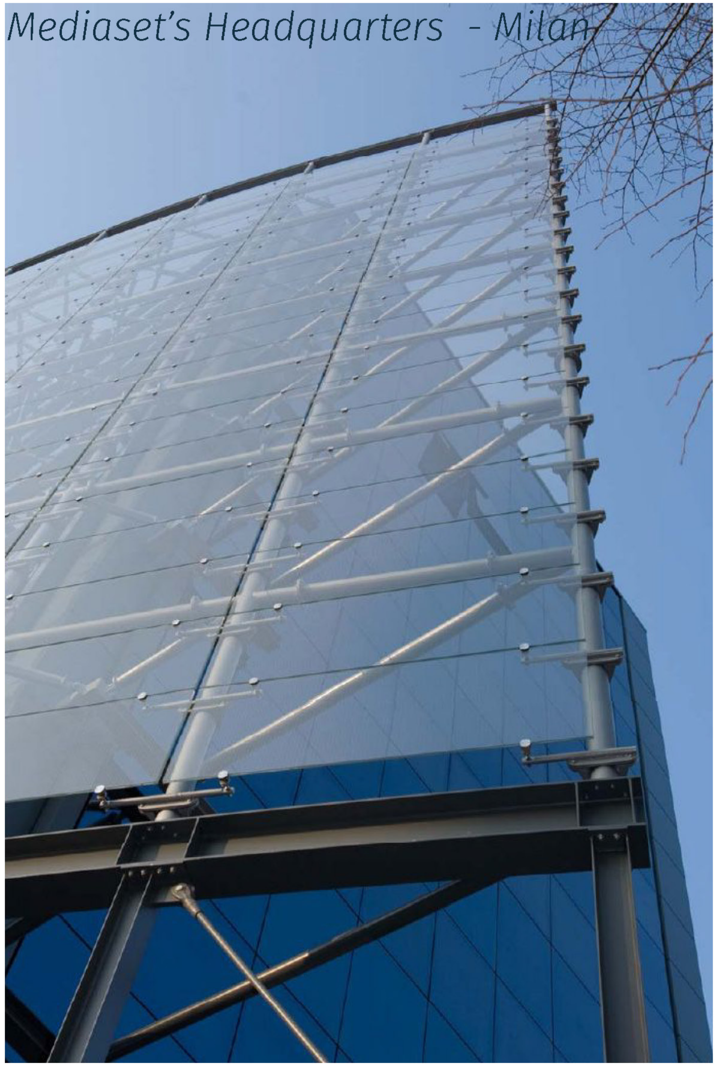


DESIGN WITH BIO-COMPOSITES

EXTERNAL SKIN OF A DOUBLE SKIN SYSTEM

Haver & Boeker - US

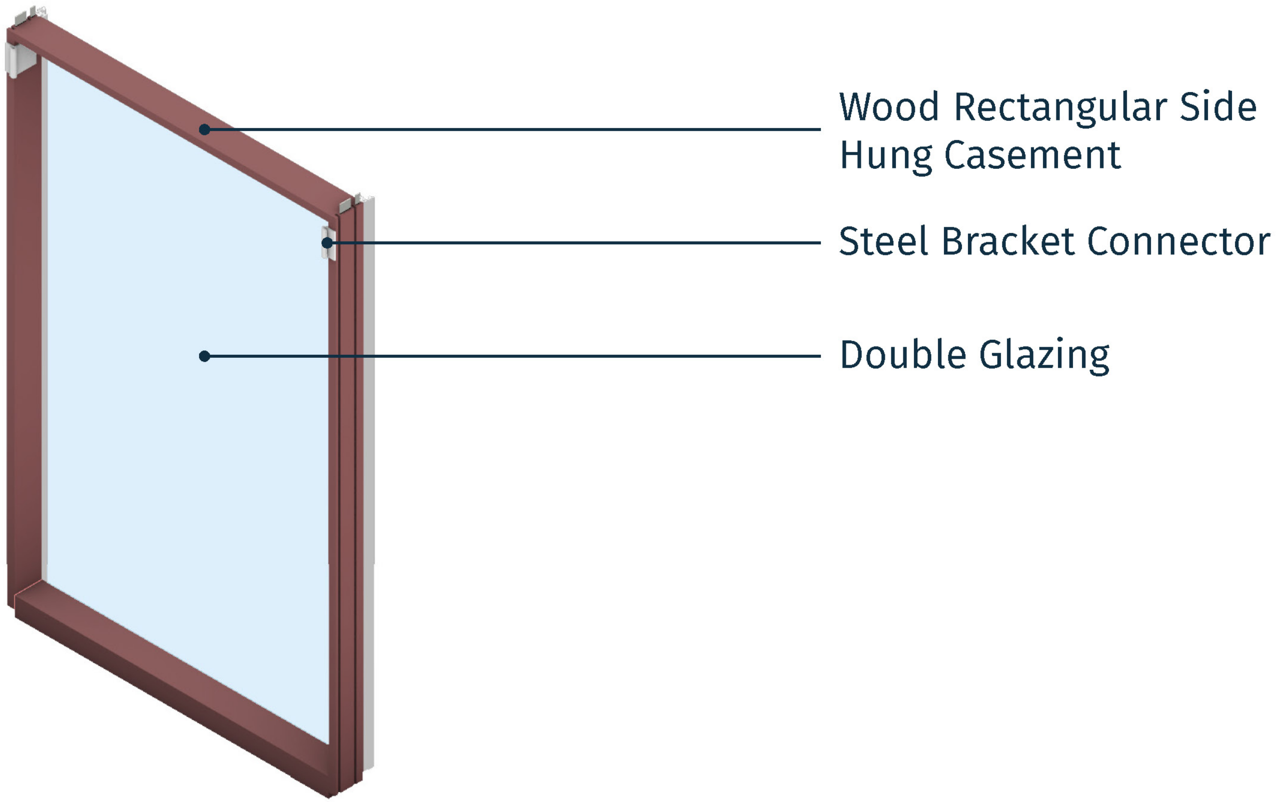
Mediaset's Headquarters - Milan



PolitieKantoor - Brugge

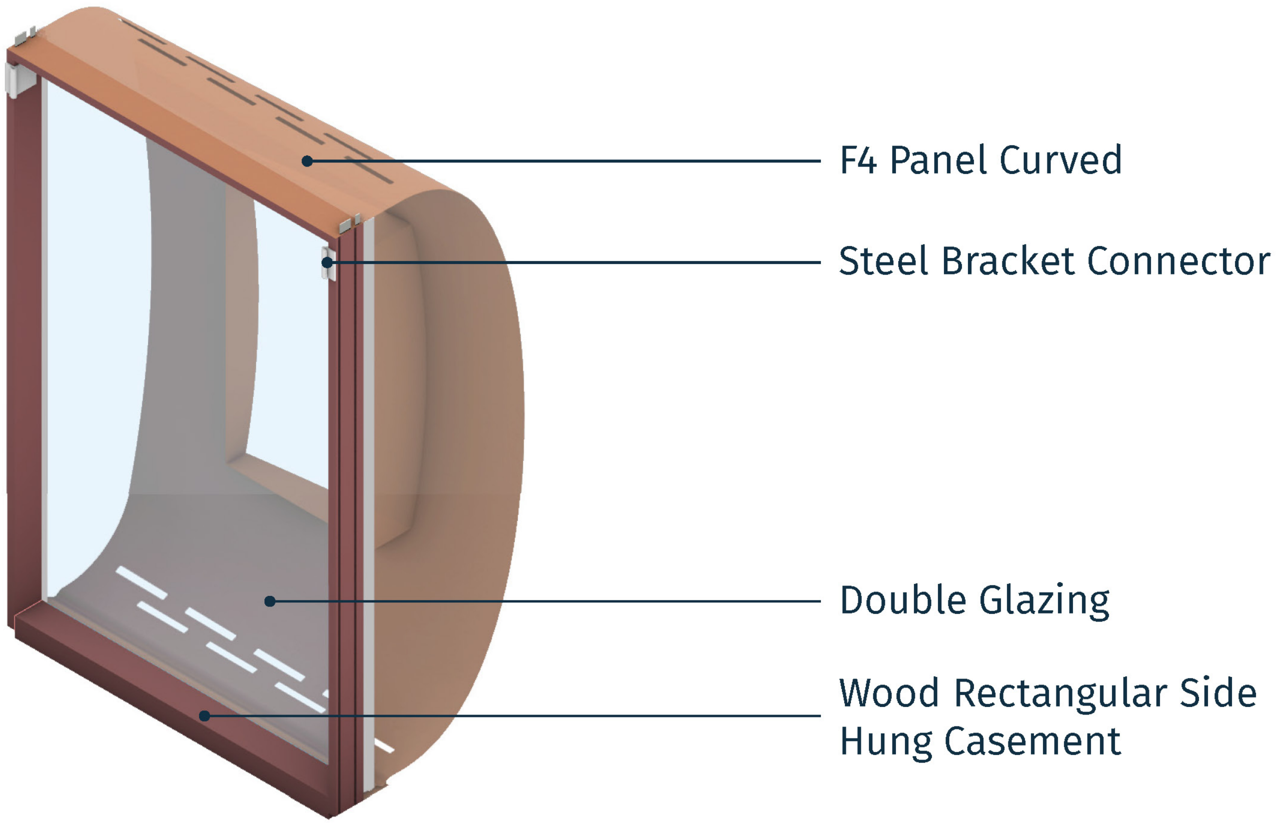
DESIGN WITH BIO-COMPOSITES

DESIGN SUGGESTION - UNITIZED DOUBLE SKIN SYSTEM



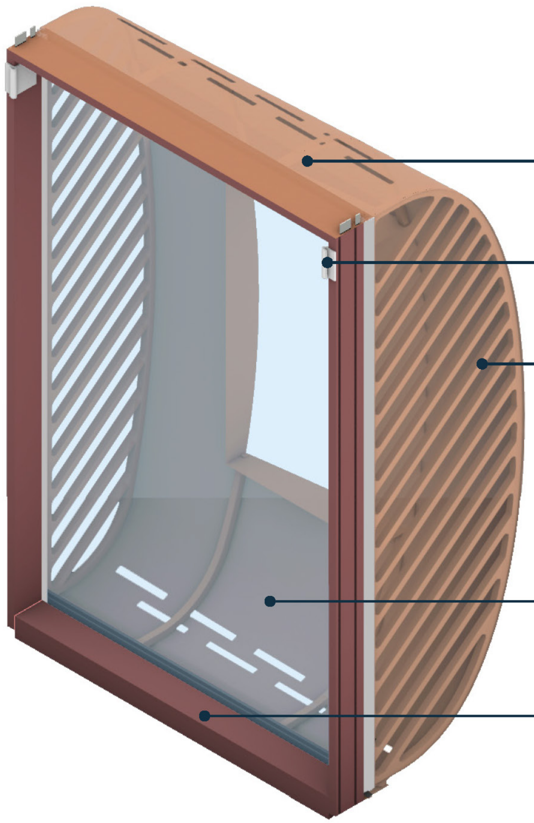
DESIGN WITH BIO-COMPOSITES

DESIGN SUGGESTION - UNITIZED DOUBLE SKIN SYSTEM



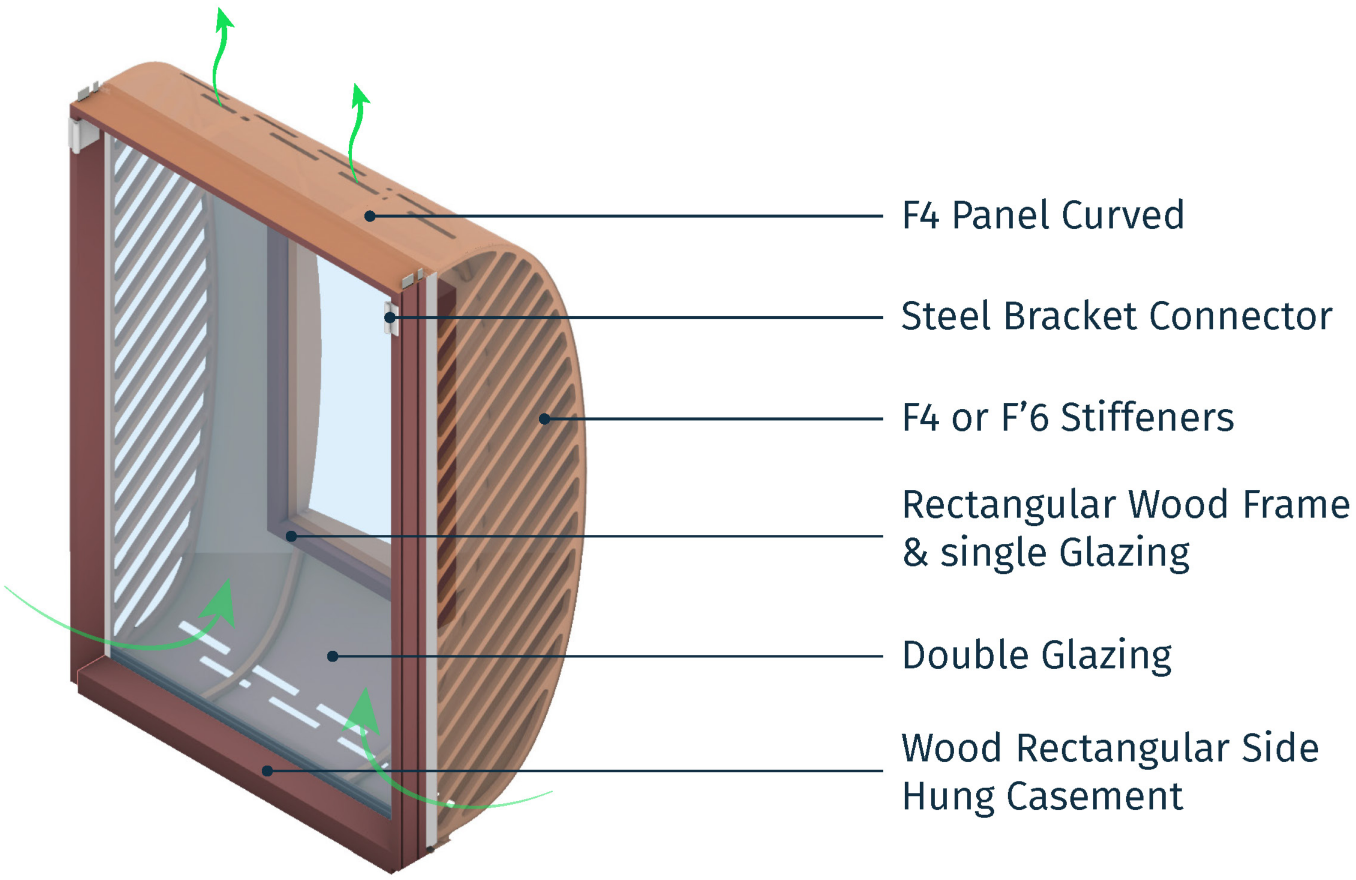
DESIGN WITH BIO-COMPOSITES

DESIGN SUGGESTION - UNITIZED DOUBLE SKIN SYSTEM



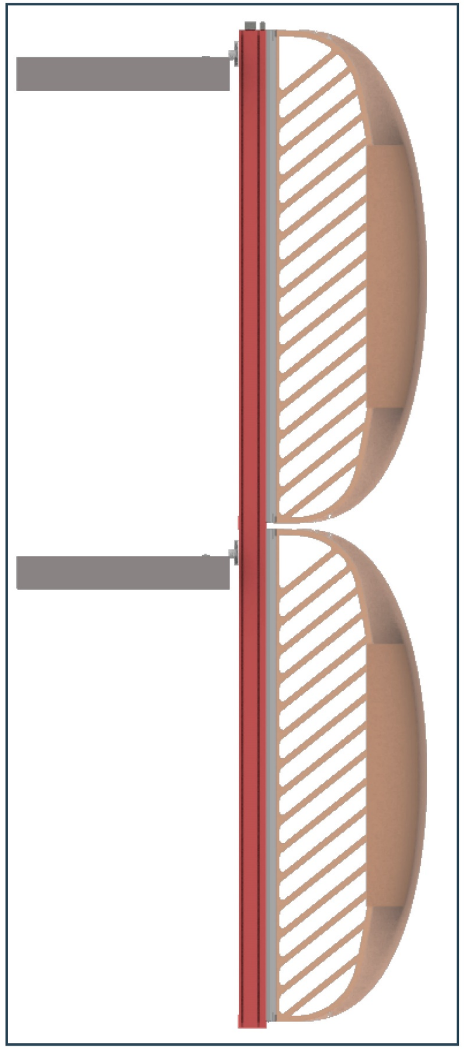
DESIGN WITH BIO-COMPOSITES

DESIGN SUGGESTION - UNITIZED DOUBLE SKIN SYSTEM

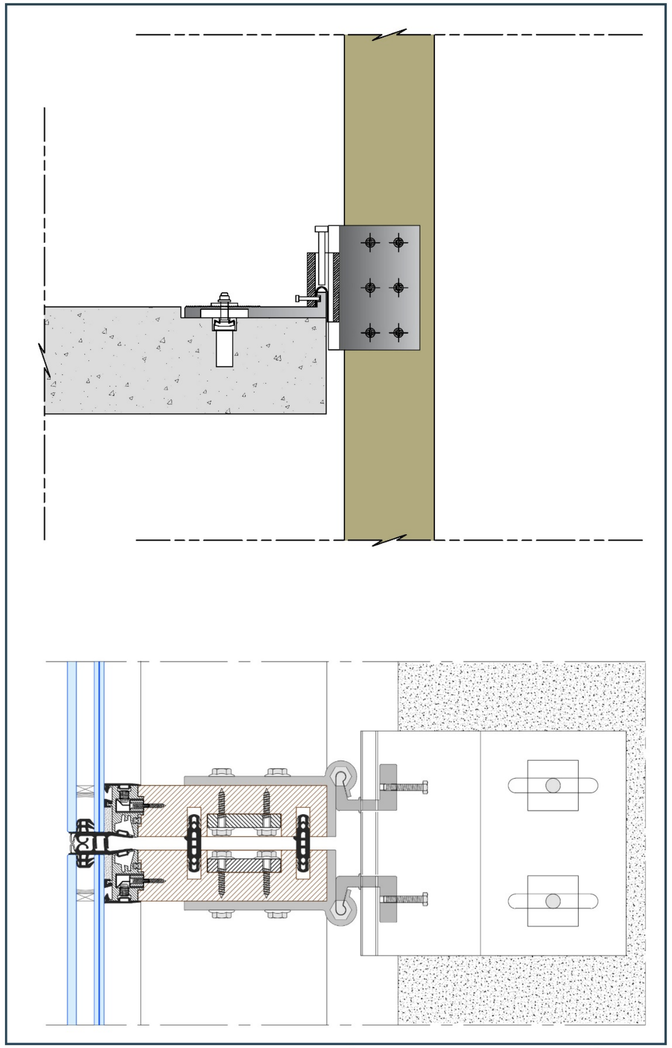


DESIGN WITH BIO-COMPOSITES

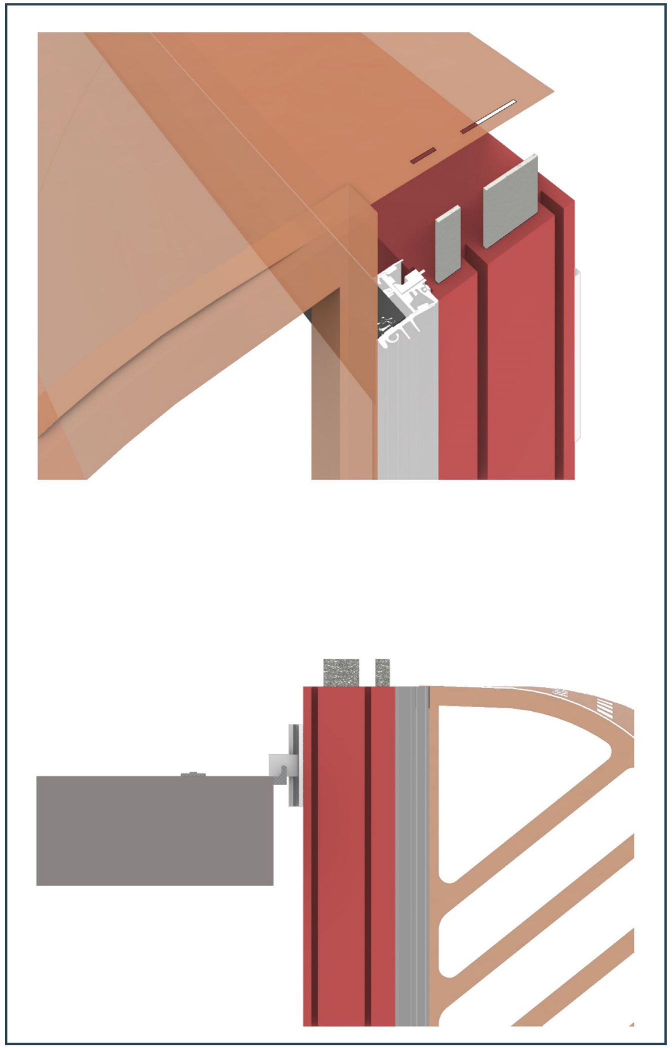
DESIGN SUGGESTION - UNITIZED DOUBLE SKIN SYSTEM



FACADE SIDE ELEVATION



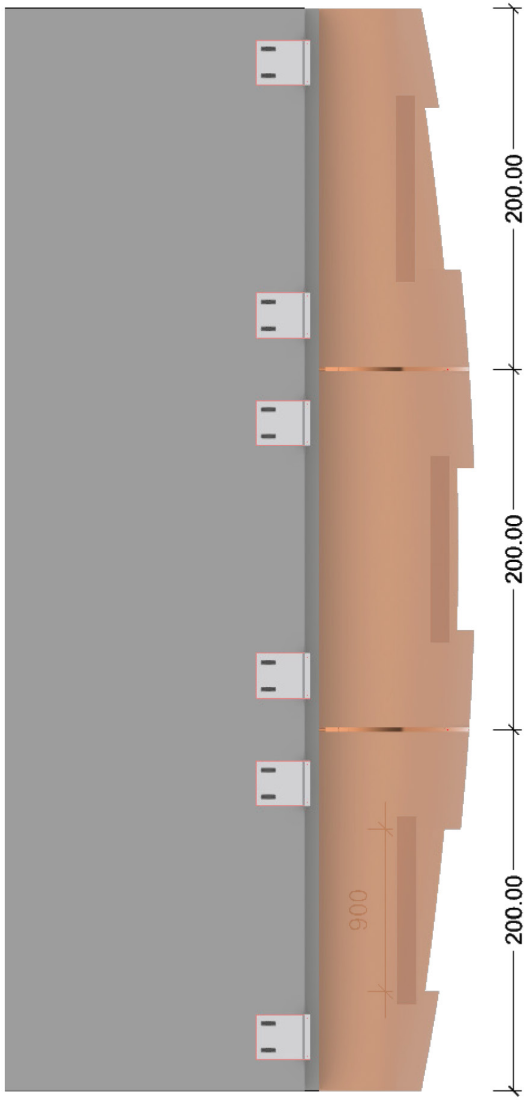
BRACKET DETAIL *(Section & Plan)*



F4 PANEL CONNECTION TO MULLION

DESIGN WITH BIO-COMPOSITES

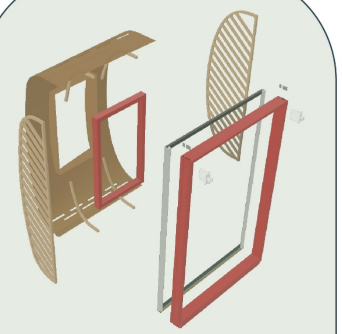
DESIGN SUGGESTION - UNITIZED DOUBLE SKIN SYSTEM



- PREFABRICATED UNITIZED SYSTEM
- INNER SKIN VENTILATION
- FREE FORM DESIGN

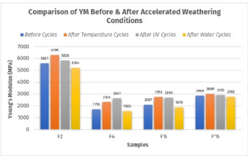
CONCLUSIONS & RECOMMENDATIONS

BIO-BASED FIBER REINFORCED COMPOSITES



Potential facade applications explored

Satisfying “SLS” & “ULS” for a panel size of 2 x 3 meters



Safe Mechanical Properties after subjection to Weathering Conditions

Proving the ability to fabricate complicated shapes

Aesthetical Value & control over aspects (reflectivity, translucensy)

Sheaper than convential composites

Extremely lower Carbon Footprint

Light Weight Material

CONCLUSIONS & RECOMMENDATIONS

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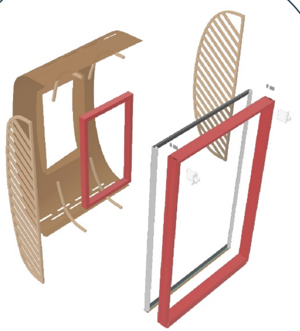

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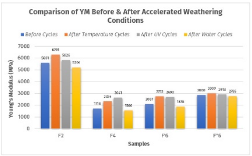

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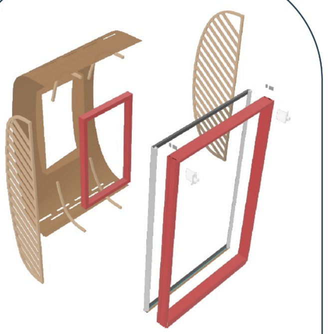

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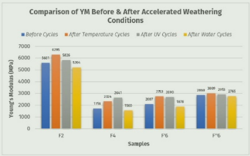

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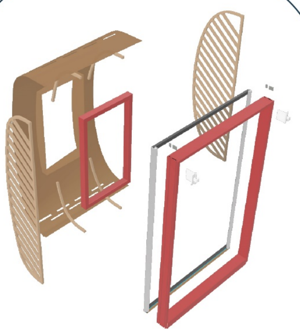

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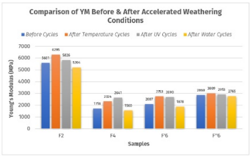

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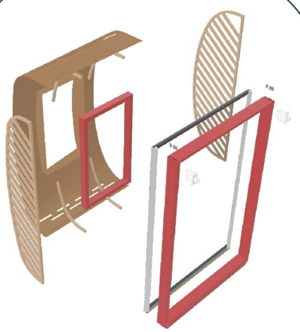

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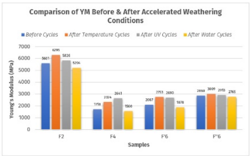

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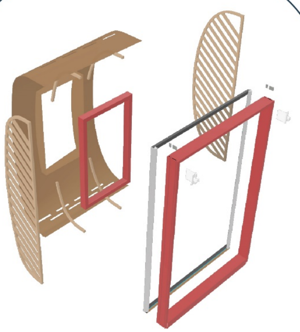

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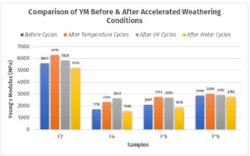

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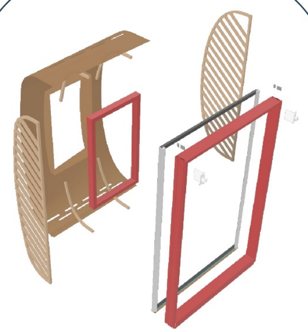

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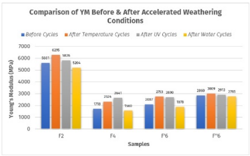

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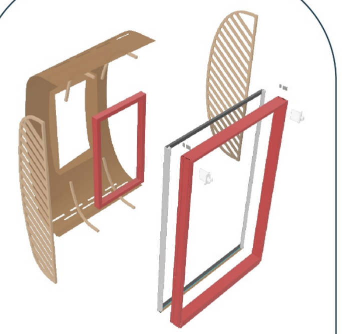

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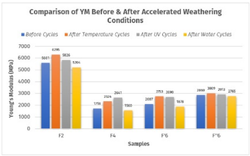

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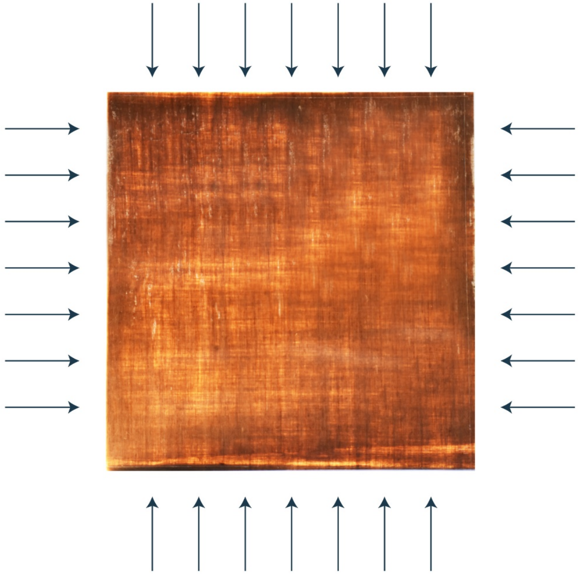
RECOMMENDATIONS FOR FUTURE RESEARCH

Bio-Based Coating Against Water

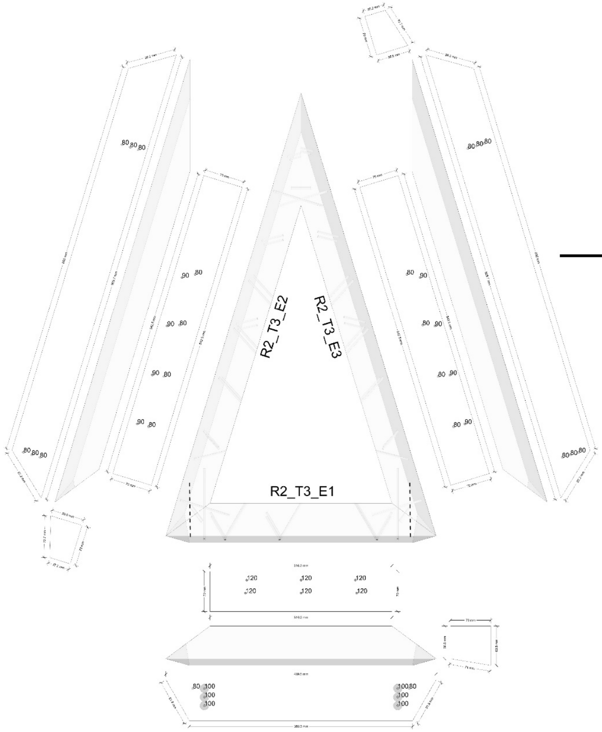


Develop Frame System to Protect Edges & Back-side from Water

Fire Safety Check

ABT COLLABORATION

ING. GERTJAN PETERS - ABT B.V.
EMAIL: G.PETERS@ABT.EU



THANK YOU FOR YOUR TIME

Student: **Nader Merhi**

First Mentor: **Prof.dr.ir. Mauro Overend** (AE+T - Structural Design)

Second Mentor: **Ir. Arie Bergsma** (AE+T - Façade Design)

External Collaboration: **Ing. Gertjan Peters** (ABT B.V.)

Delft University of Technology