BONDLESS INNOVATION

EVALUATING DIRECT ADHESION IN A CONCRETE-GLASS INTERFACE FOR FREE FORM TRANSPARENCY.

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TU Delft

“I am exploring ways to improve the **bond strength** of a **glass-concrete interface** to evaluate the **production process** for creating a new type of **hybrid facade panel**”

1. INTRODUCTION
2. PROBLEM STATEMENT
3. PART I: EXPERIMENT
4. PART I: DESIGN
5. IMPLEMENTATION
6. CONCLUSION

Todays skyline all-glass buildings

Climate crisis

Experts call for ban on glass skyscrapers to save energy in climate crisis

Commentary

Commentary: Buildings with fully glazed façades heat up too fast, are an environmental "failure"

Modern building façades are allowing more heat in and out of buildings, requiring a higher usage of artificial cooling and heating, says an architecture researcher.

Sustainability for All.

News • Treehugger Voices

Can an All-Glass Office Building Really Be Considered Green?

By Lloyd Alter
Updated May 27, 2020

Glass skyscrapers: a great environmental folly that could have been avoided

Published: May 14, 2019 2.46pm CEST

The New York Times

Climate Change › | Climate F.A.Q. | Rising Home Insurance

How Can Buildings Beat the Heat in a Desert City? Blend Ancient and Modern.

More architects in the United Arab Emirates, the host of this year's U.N. climate summit, are moving past glass skyscrapers and focusing on sustainability.

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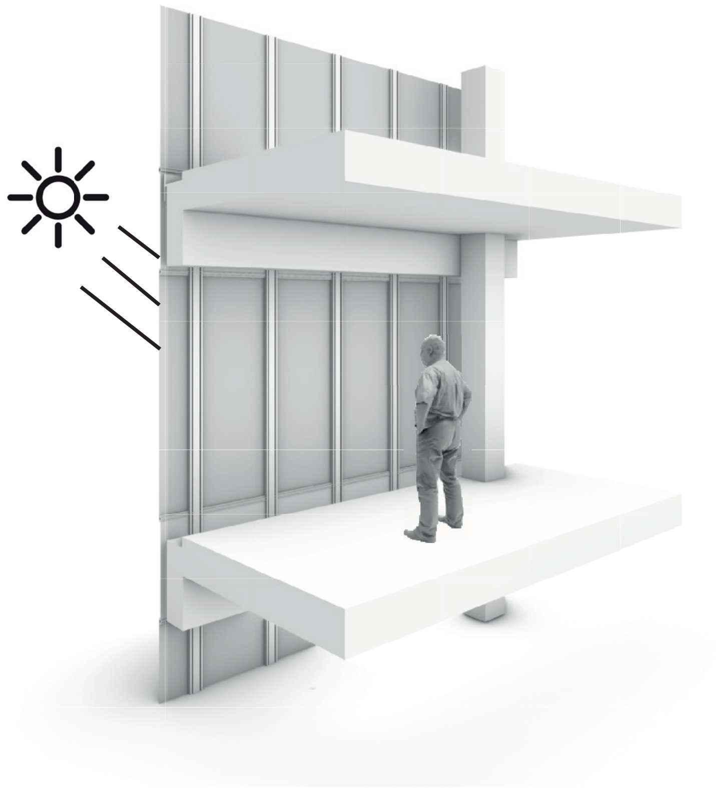
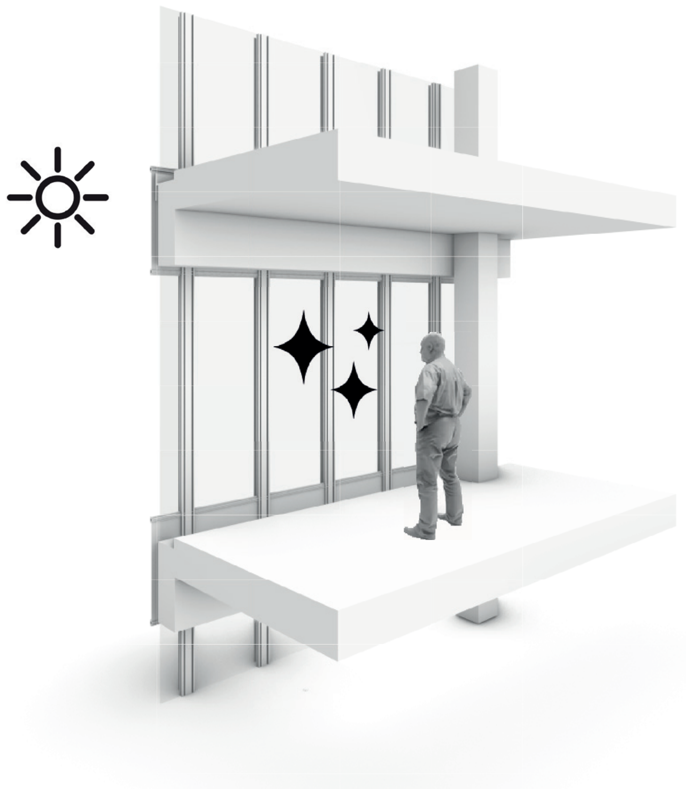
FULL GLAZED FACADE
Limitations

HEAT GAIN



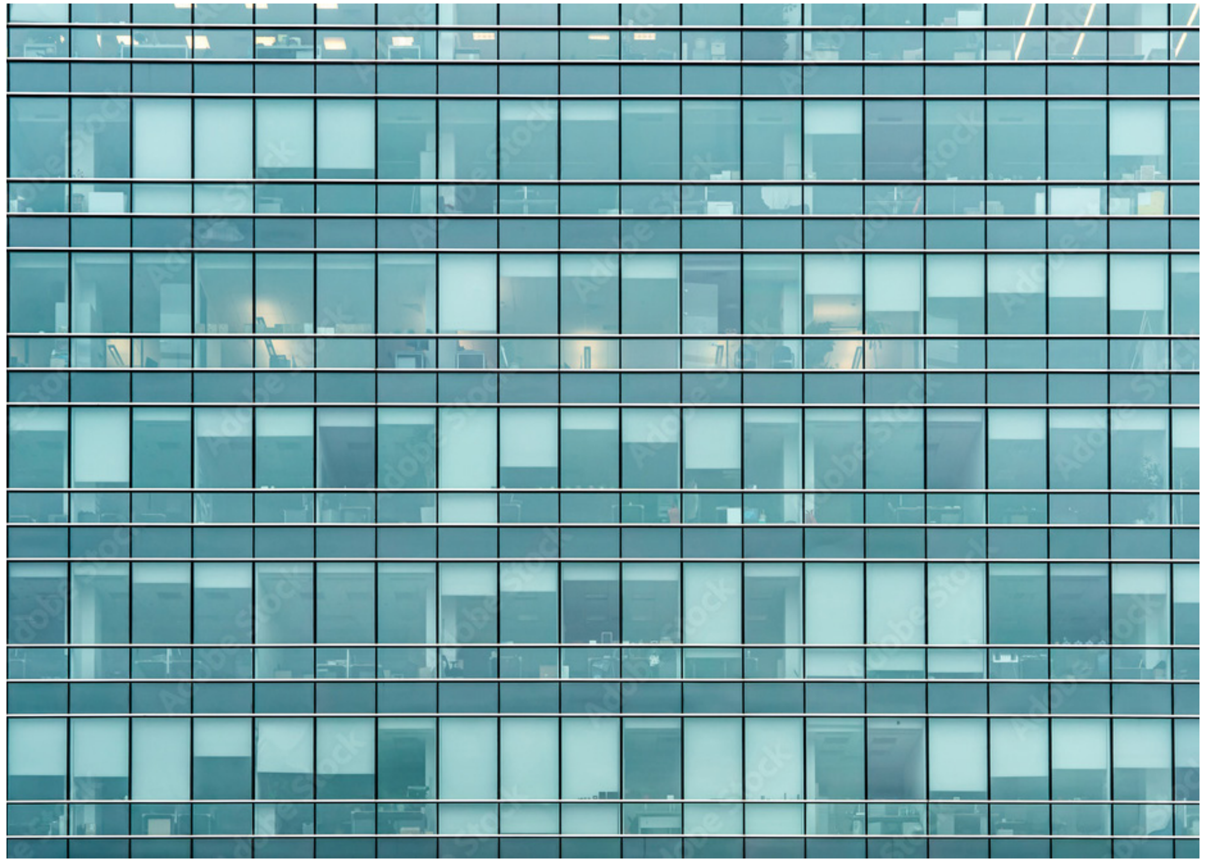
VIEW BLOCKAGE



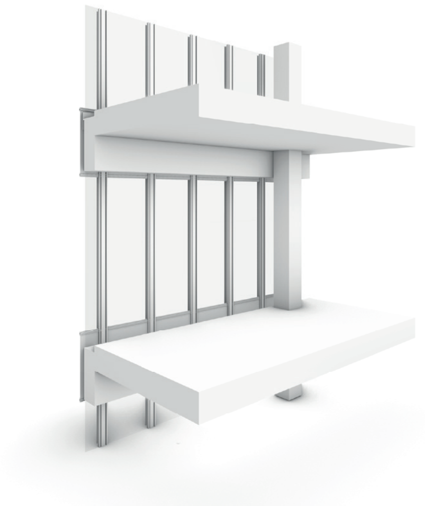
GLARE

NO DESIGN FREEDOM

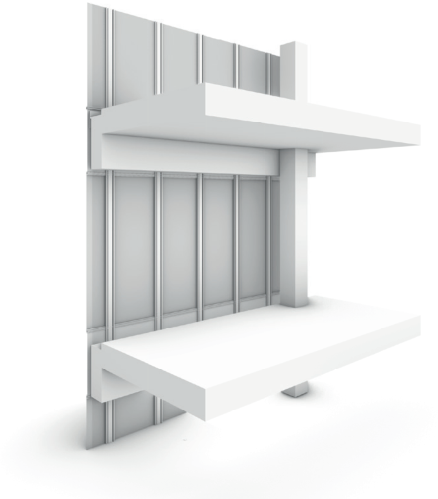
monotomy full glazed facades



DESIGN IDEOLOGY
Hybrid facade panel



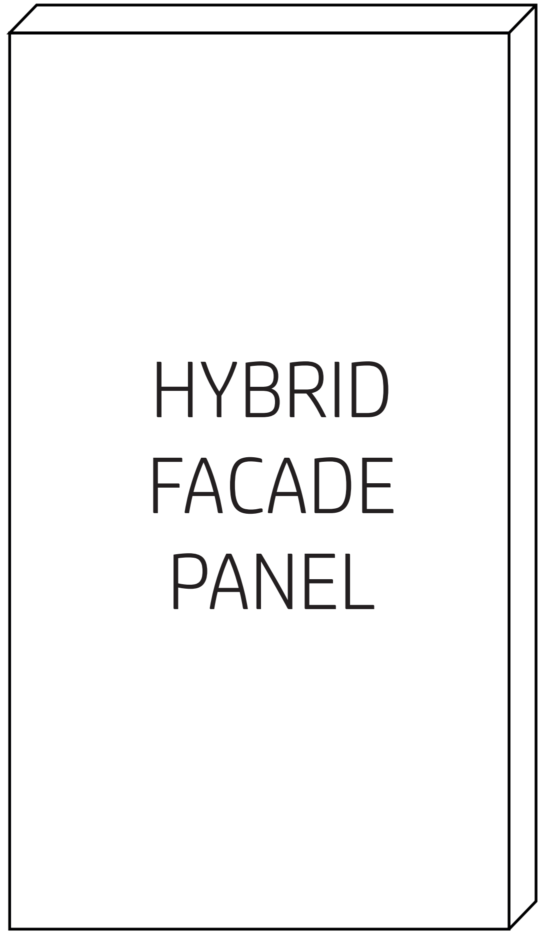
Transparency



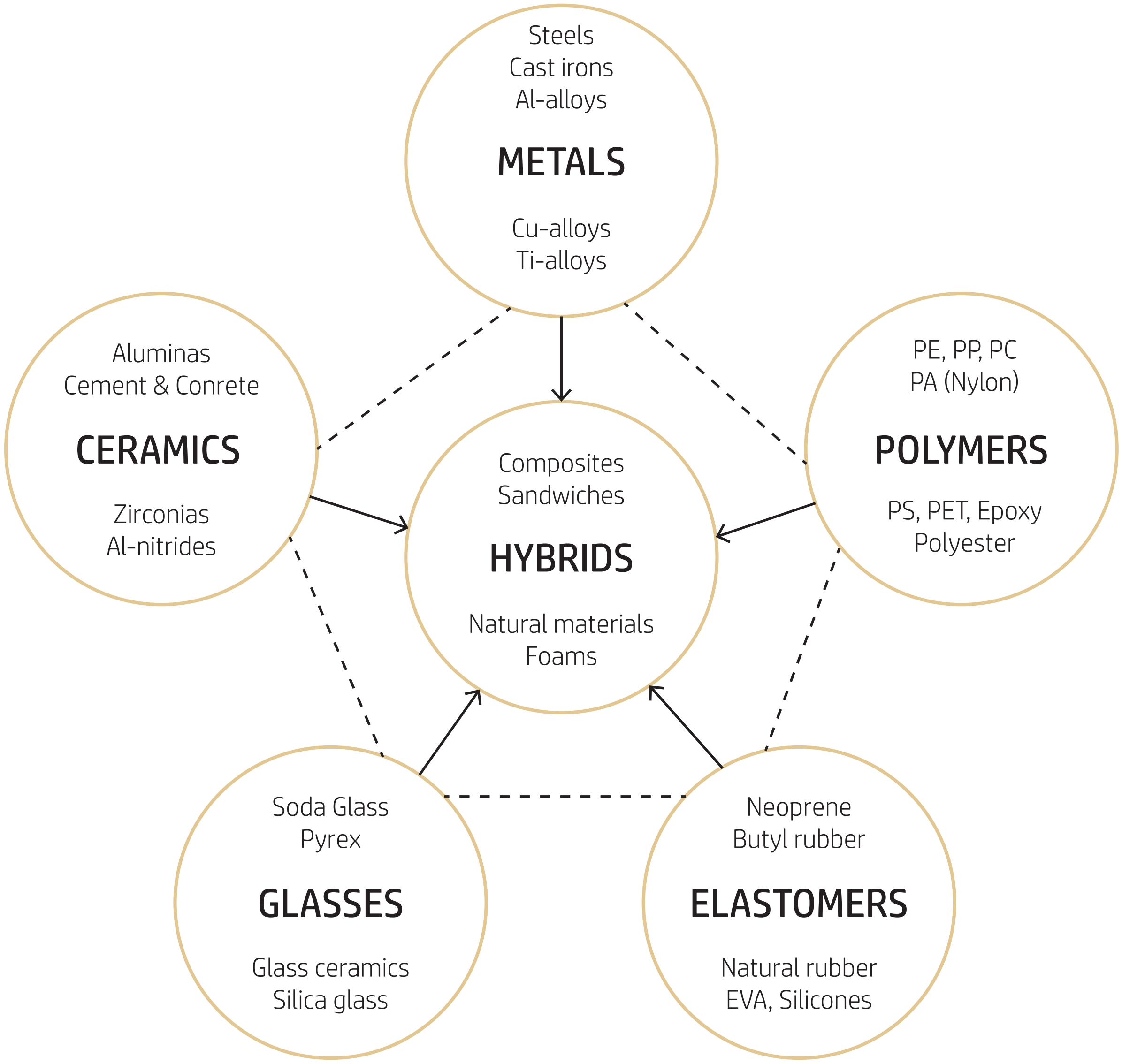
Opaqueness

Free-form design

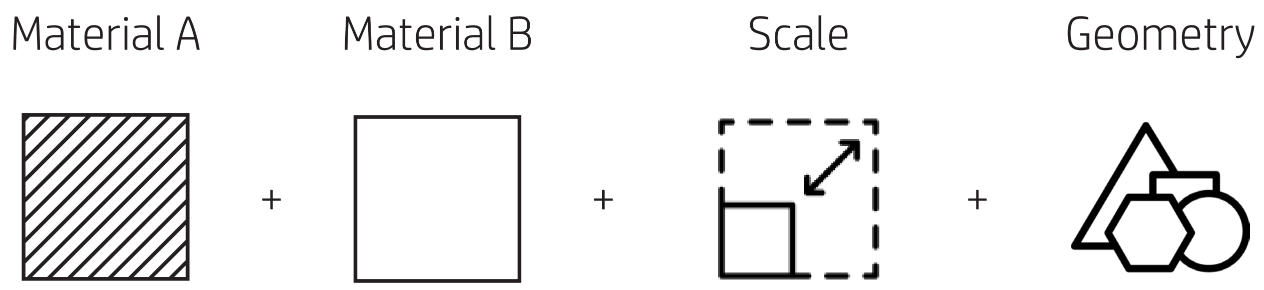
New Design Language

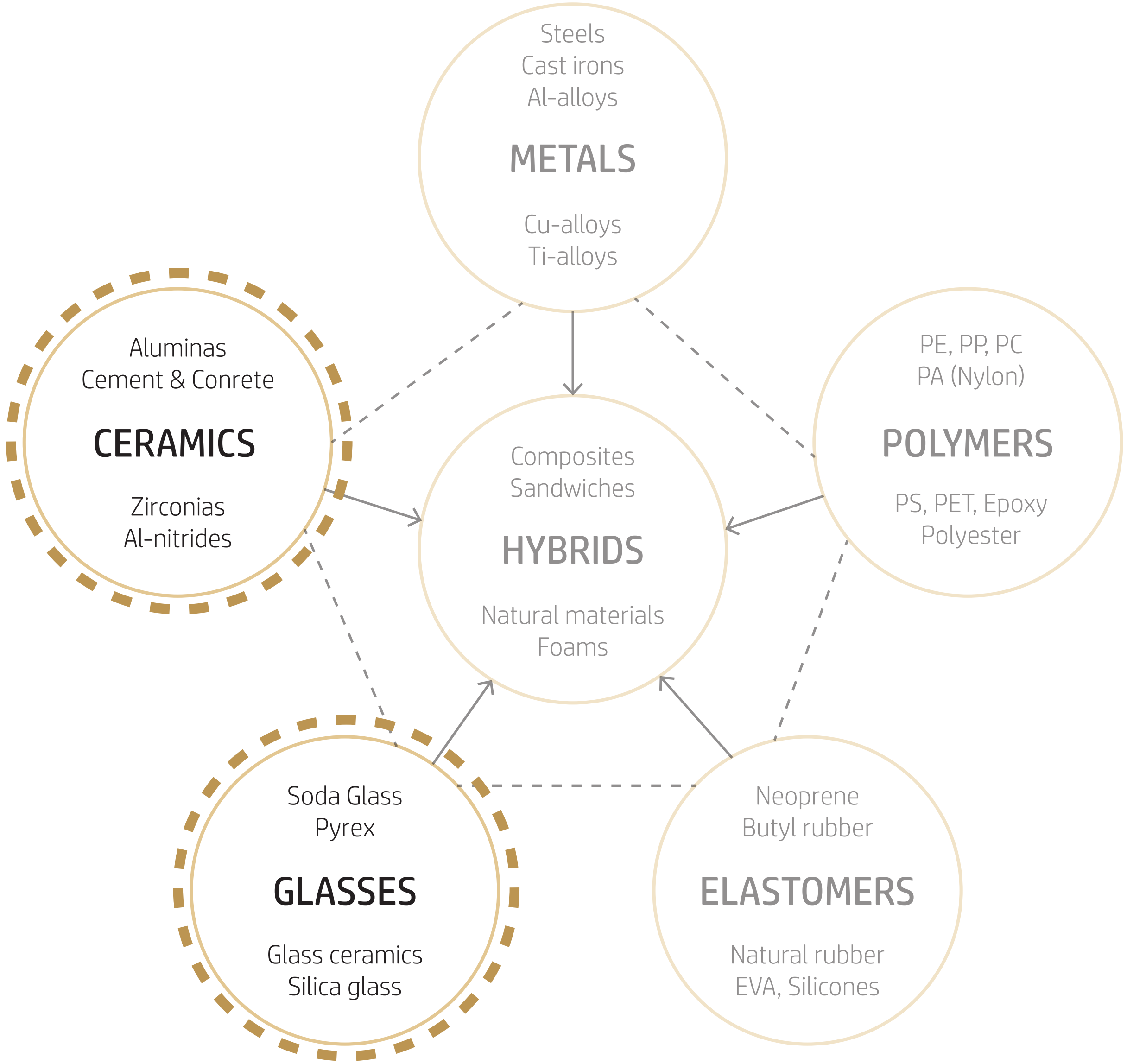


HYBRID MATERIAL
Selection

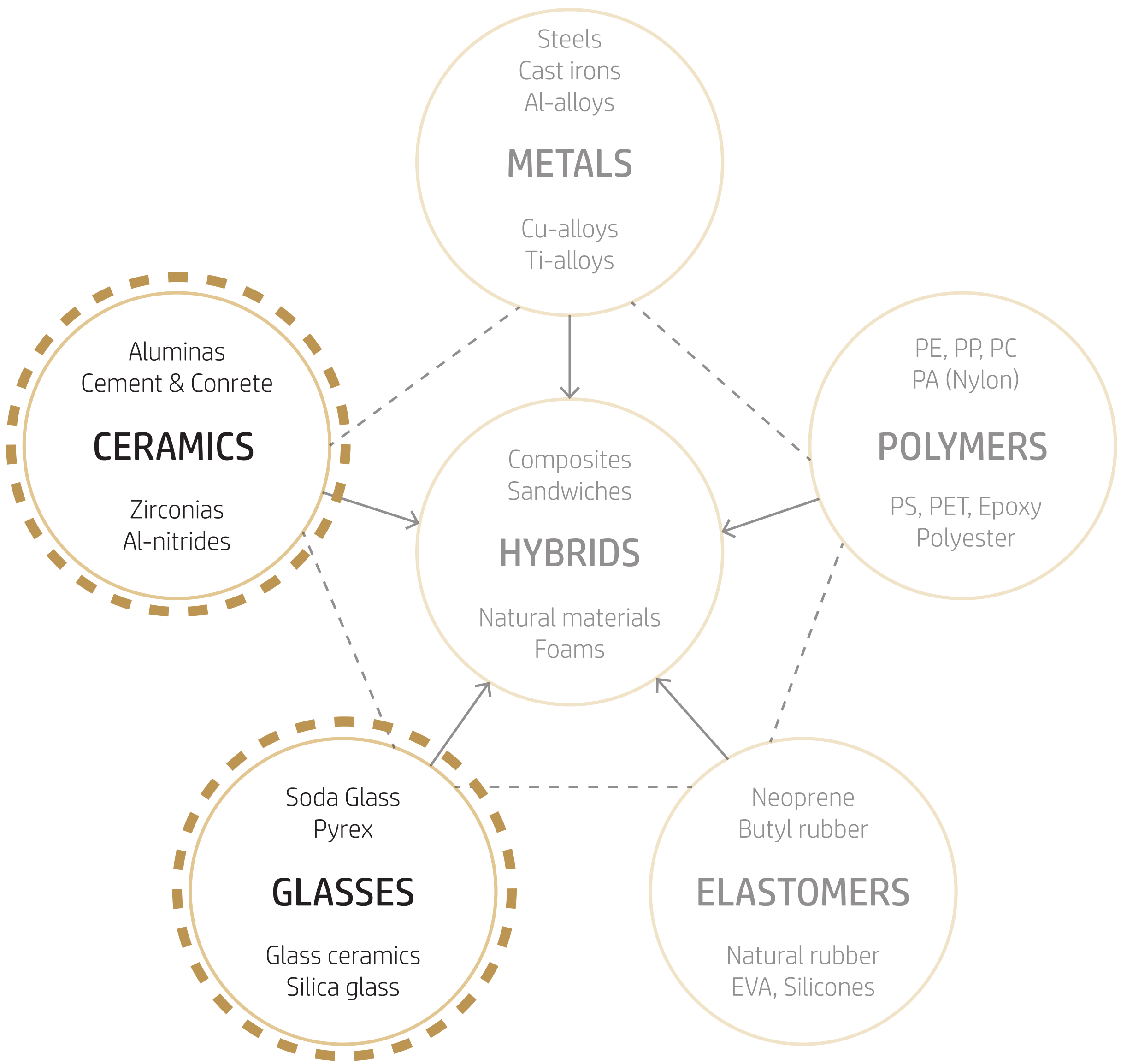


HYBRID :





CONCRETE + GLASS



CONCRETE

Shapeability

Durable

Low costs

Most used building material

Structurability

GLASS

Optical transparency

Durable

Recyclable

Structurability

Aesthetic

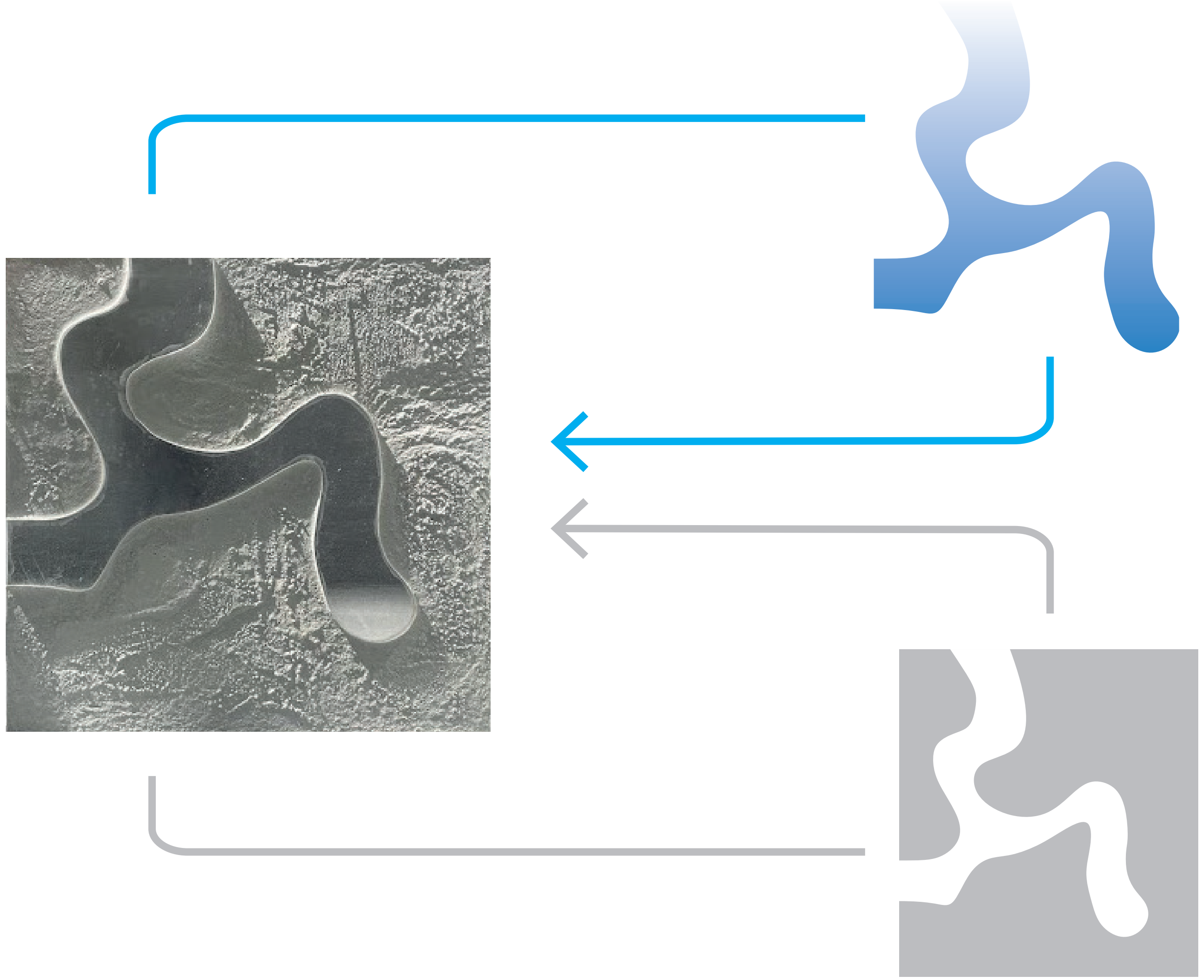
Closely alligned thermal expansion

Concrete and glass ≠ sustainable

Concrete and glass = more sustainable

DESIGN FOR DISASSEMBLY

Transforming the weak interface between concrete and glass into something useful can enhance the panel’s disassembly potential.

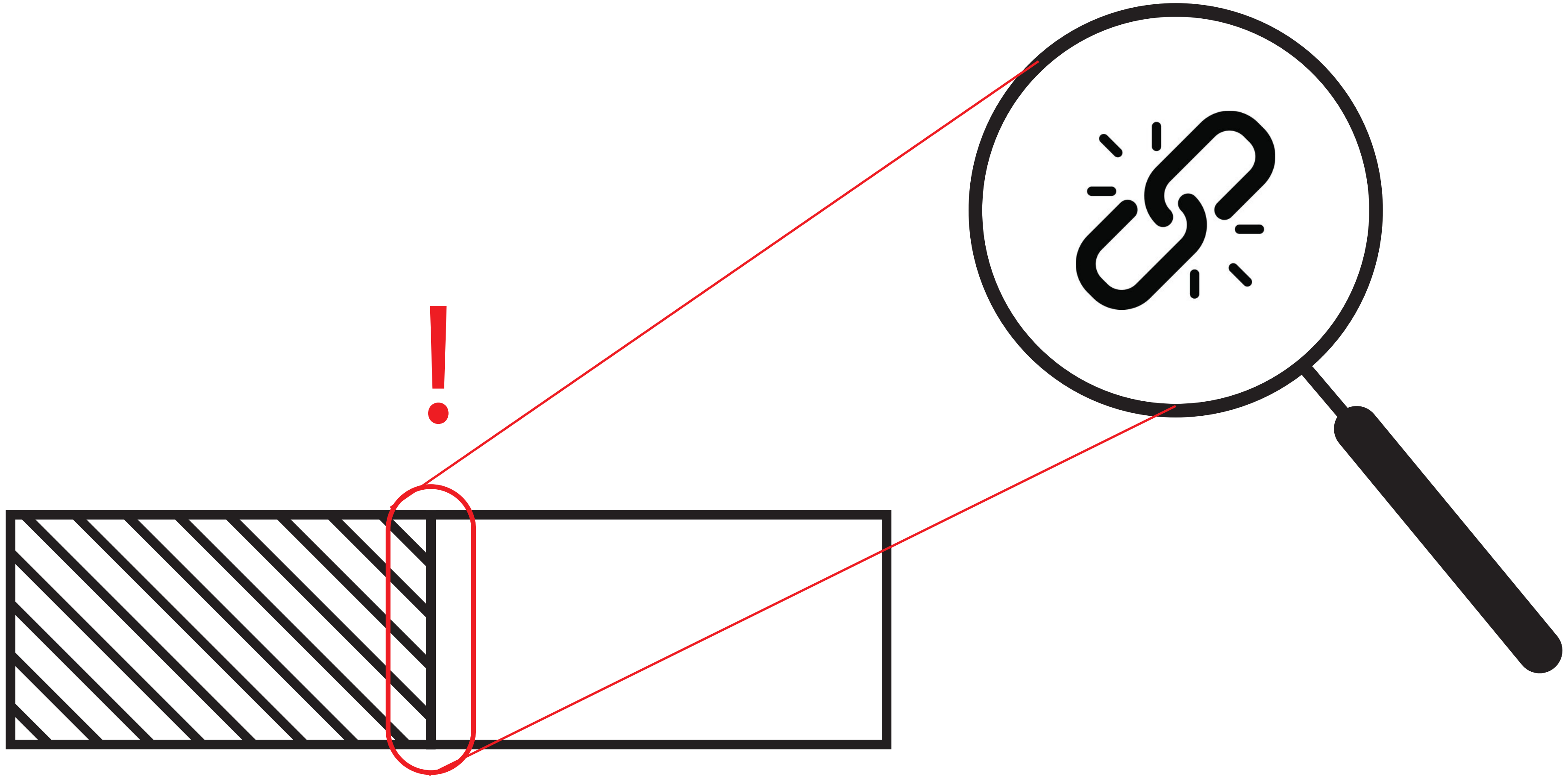


MAIN RESEARCH QUESTION

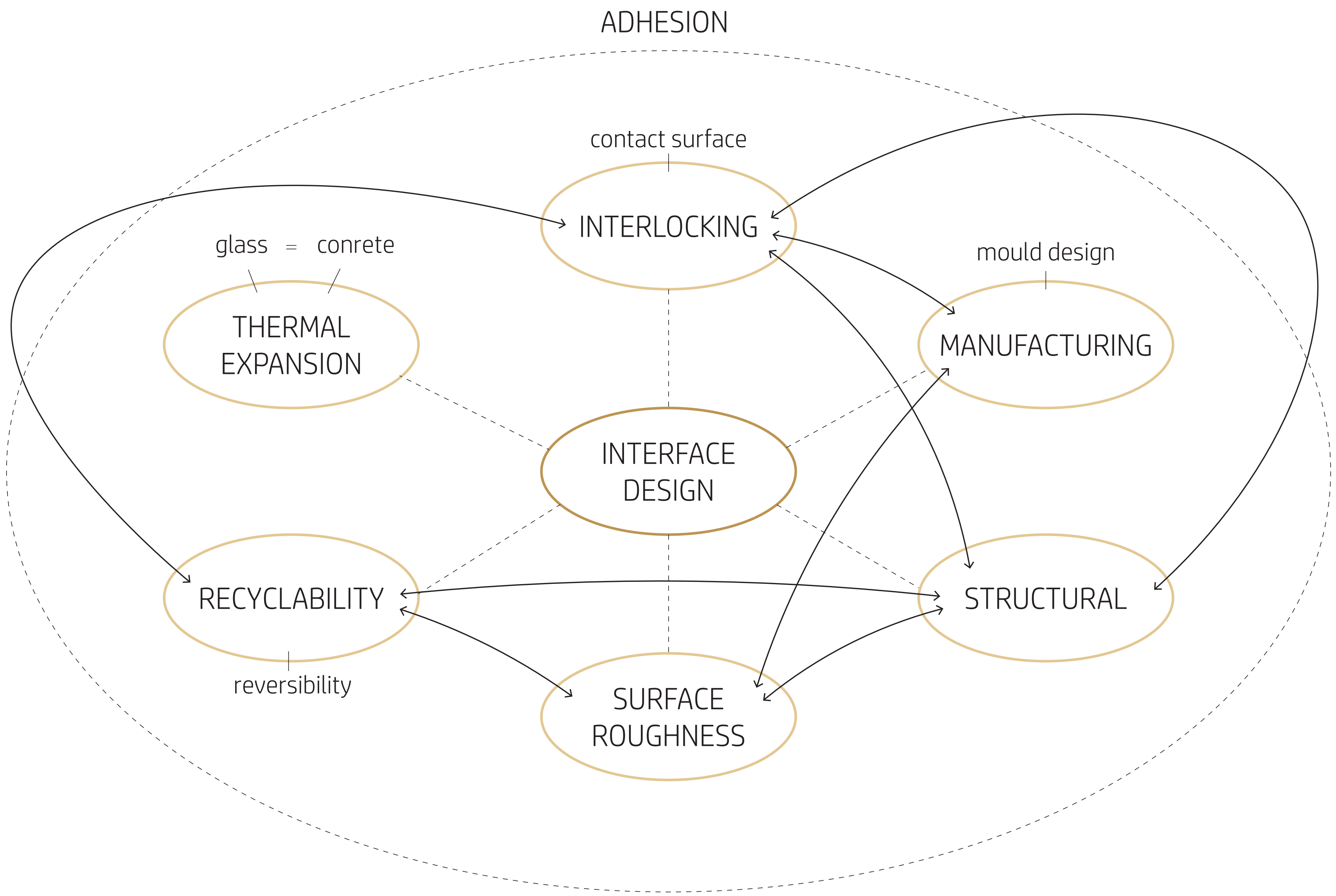
To what extend can **design considerations** ensure the structural integrity of a **hybrid interface** incorporating direct adhesion between **concrete** and **glass** for creating a hybrid facade panel?

PART I:

EXPERIMENTAL PART



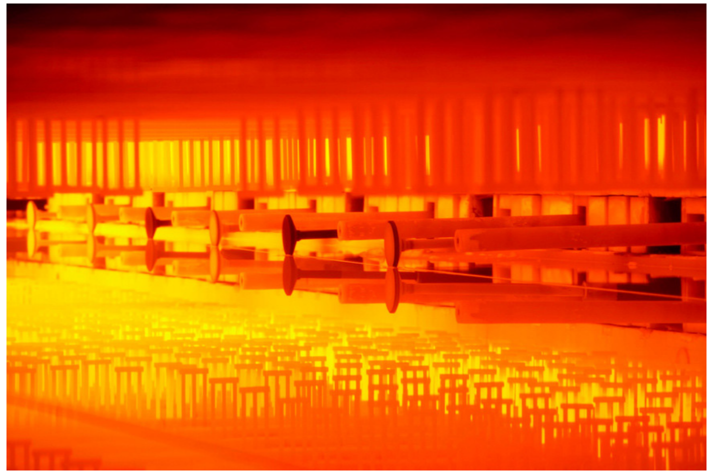
DESIGN CRITERIA
Interface design



MANUFACTURING

GLASS FABRICATION METHODS

FLOAT GLASS



- Precise manufacturing
- high quality
- cost-effective

+ Limited design freedom
+ Waste generation
+ lamination (hard to recycle)

CAST GLASS

- Labor intensive
- Time consuming
- Post-processing mould making

+ Fully recyclable
+ Design freedom
+ Few manufacturing waste

3D PRINTED GLASS

- Layered transparency
- Laboratory scale
- Size limitations

+ No mould & postprocessing
+ Design freedom
+ Zero waste & recyclable

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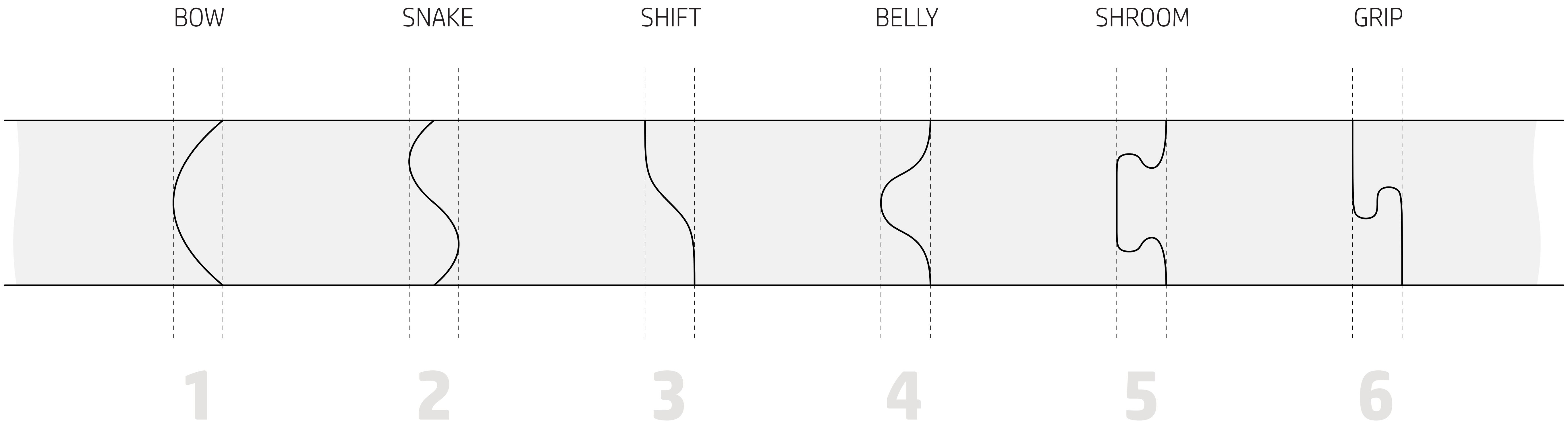
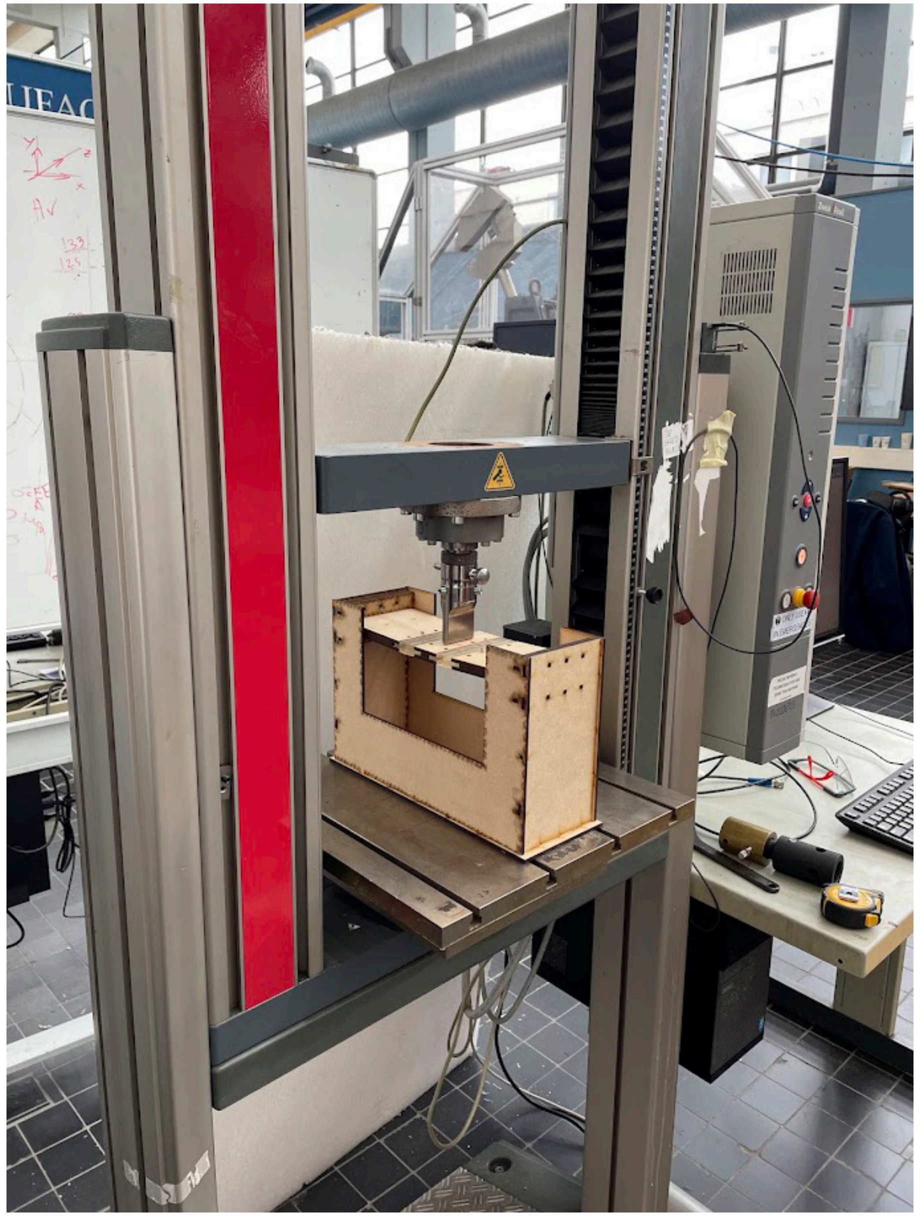
INTERLOCKING FORM

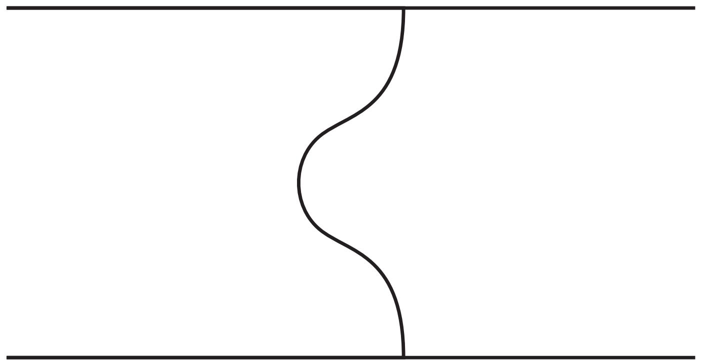
DESIGN OPTIONS
Interlocking form



EXPERIMENTAL SET-UP
Interlocking form

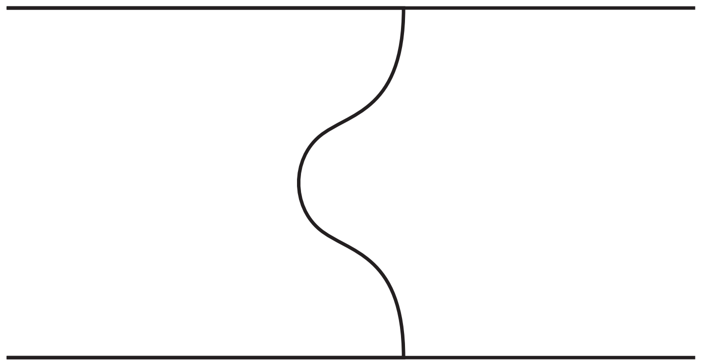


BELLY SHAPE



- Symmetry in the design
- Interlocking constrainment
- Structural integrity
- Contact surface
- Glass manufacturing limitations

BELLY SHAPE



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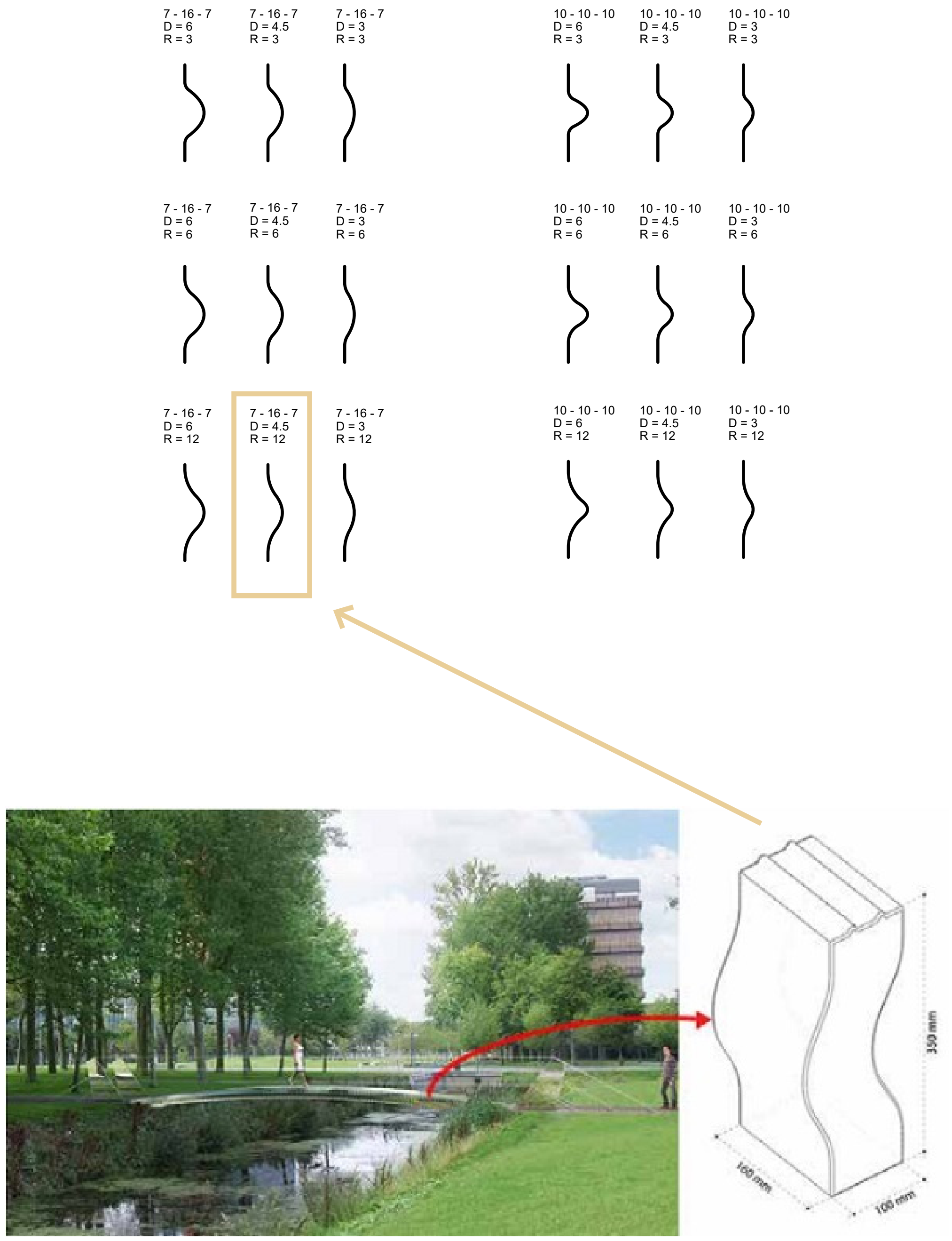
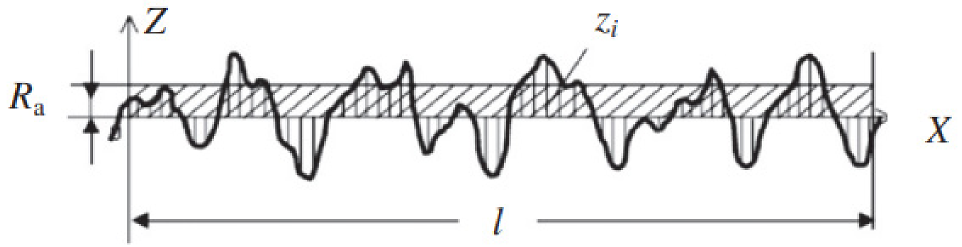
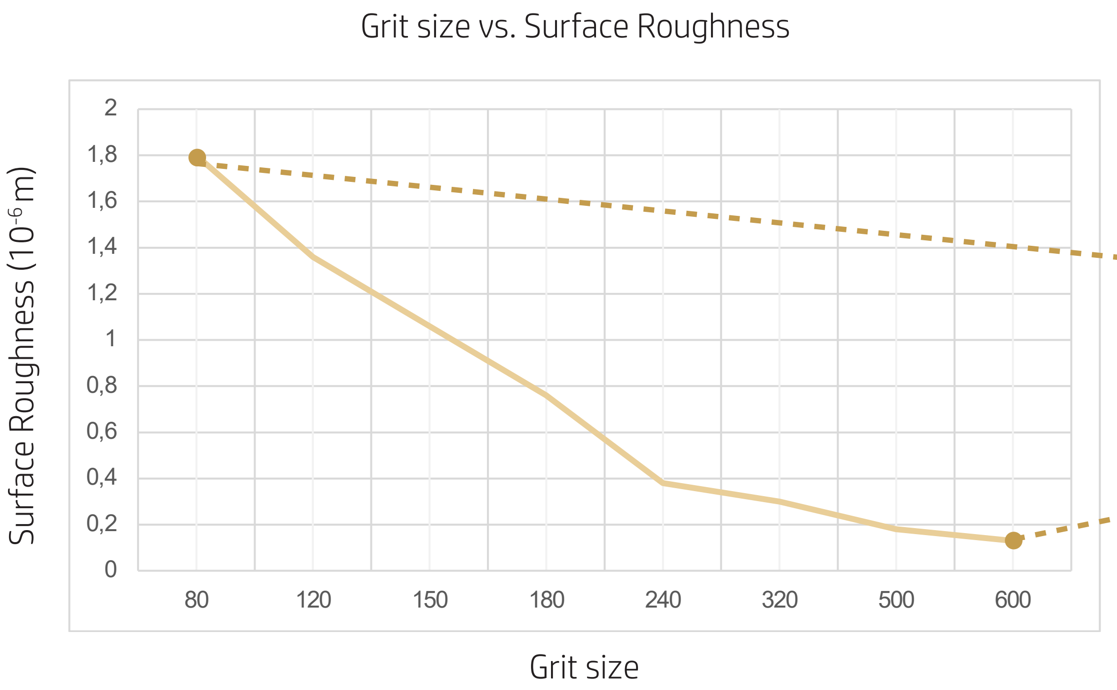
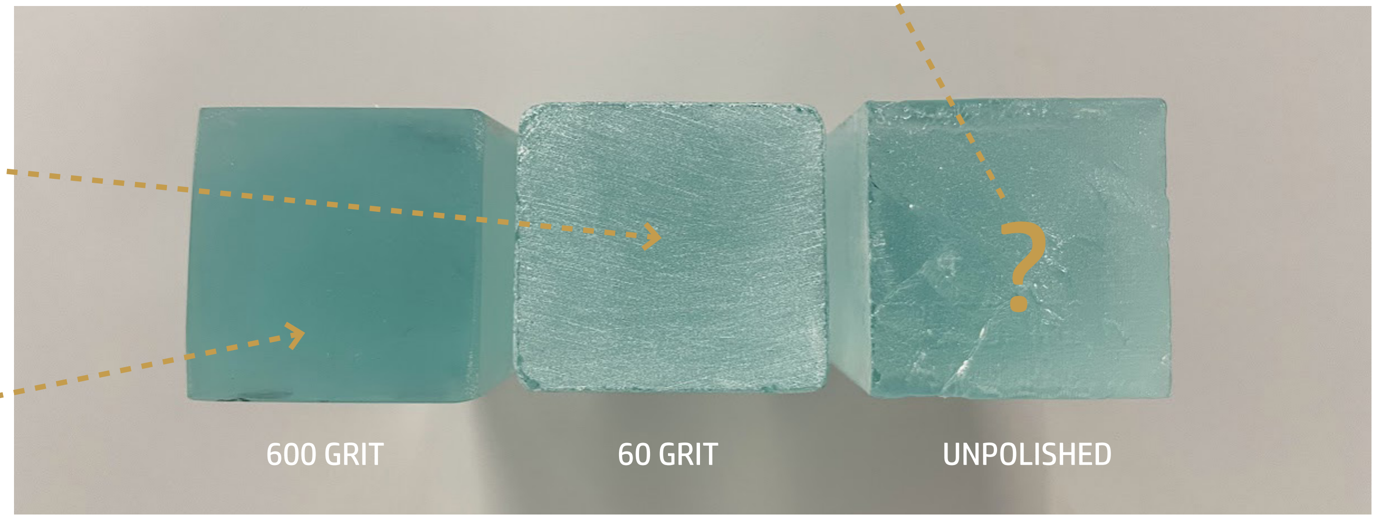


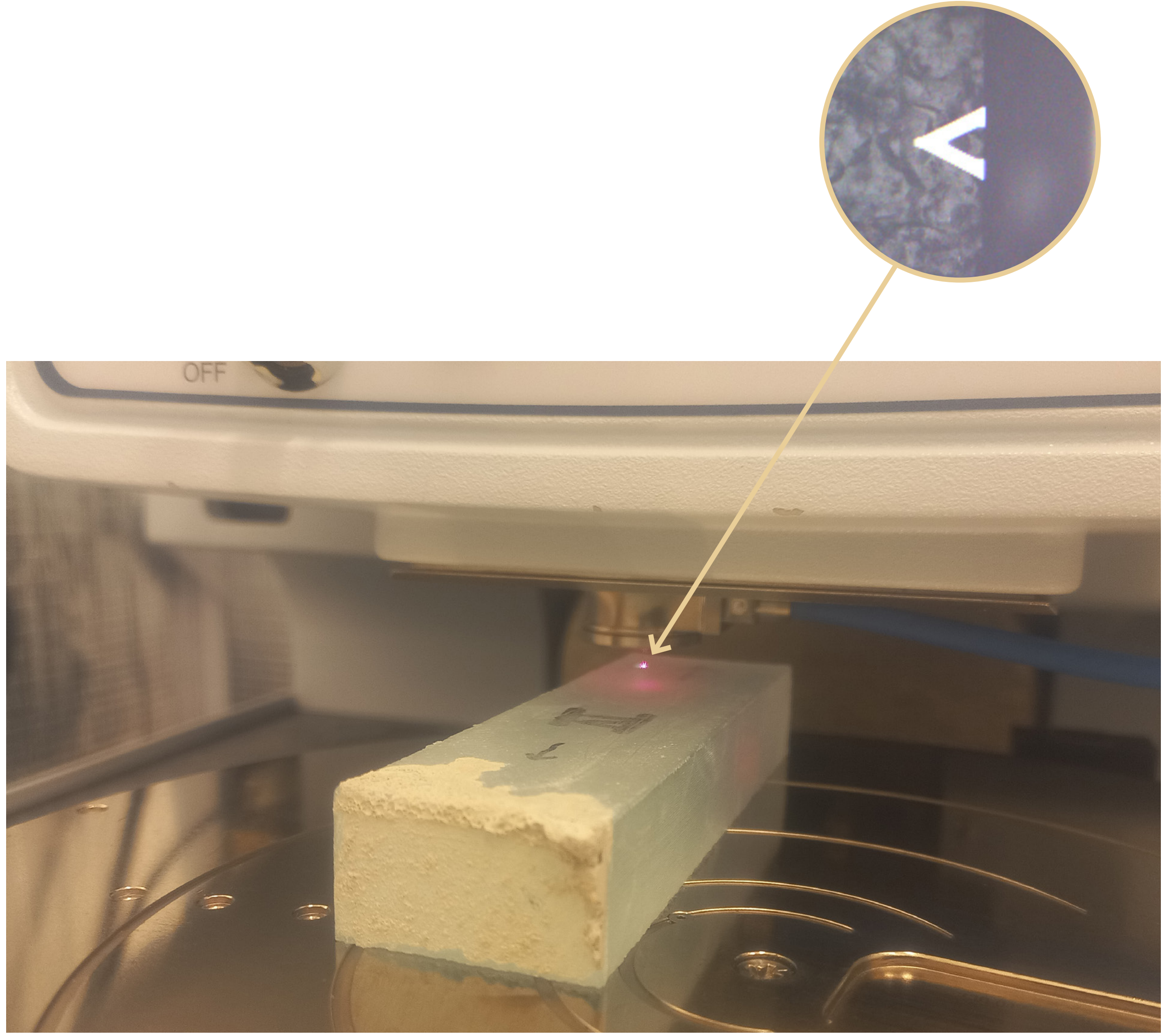
SURFACE ROUGHNESS

Does the **unpolished** surface and impurity from **mould particles** of a cast glass element increase the **adhesion** strength of a hybrid interface?







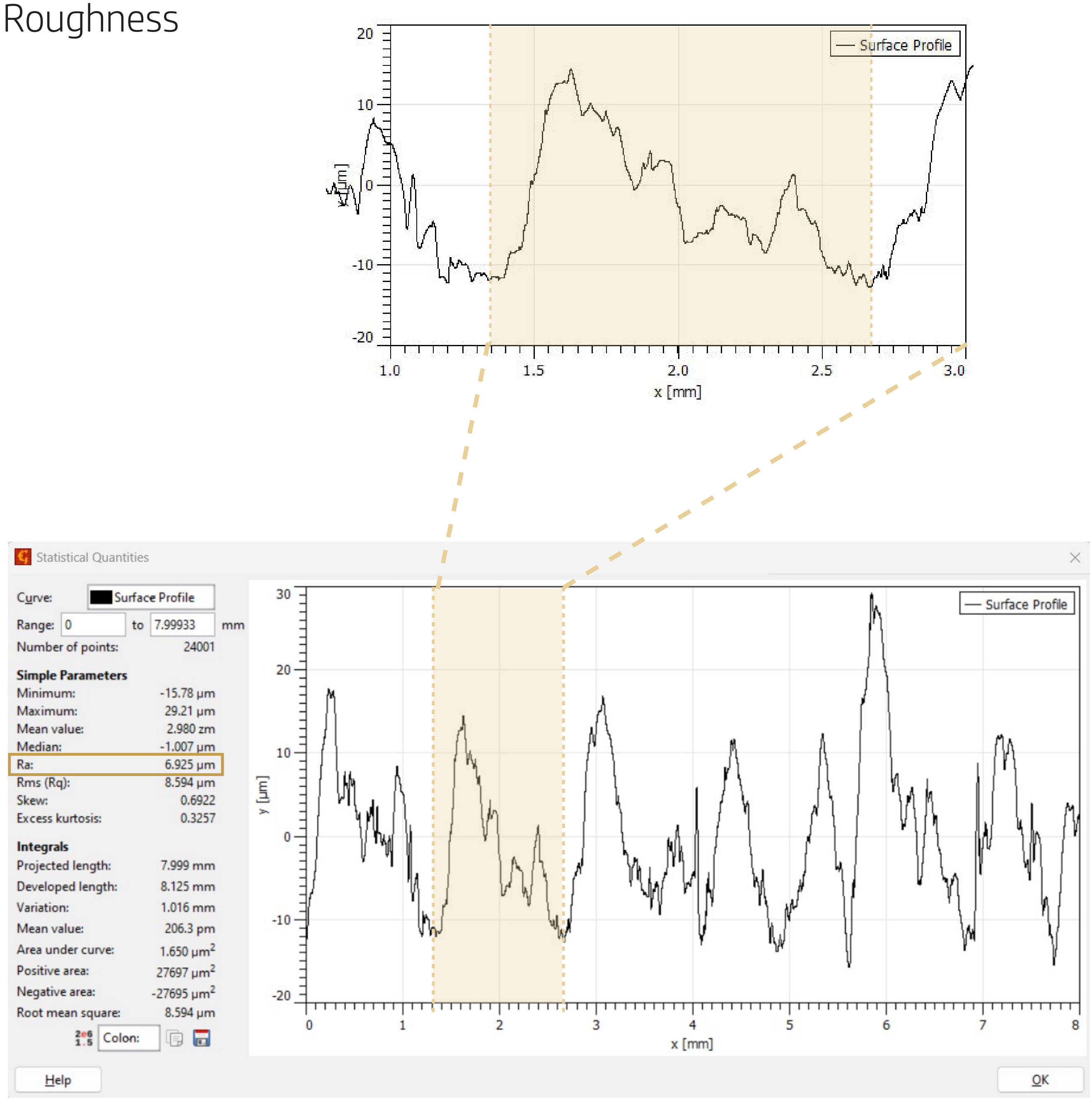


Atomic Force Microscop (AFM)

Surface unpolished cast glass.

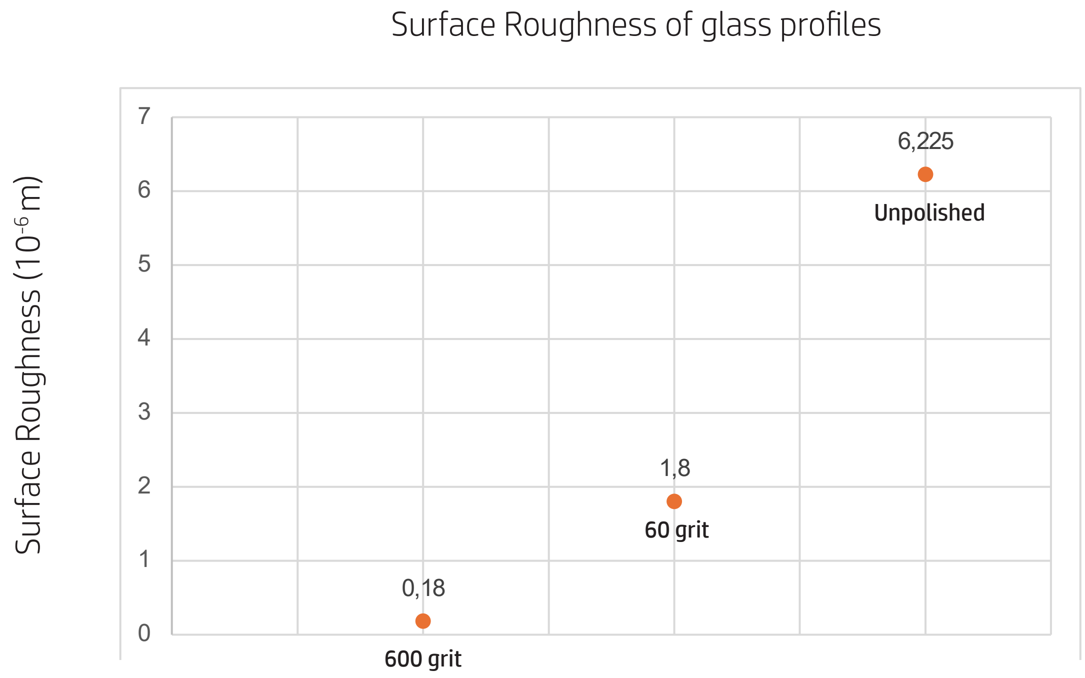
PROFILOMETER
Surface Roughness

Peak average R_a = 5.656 μm

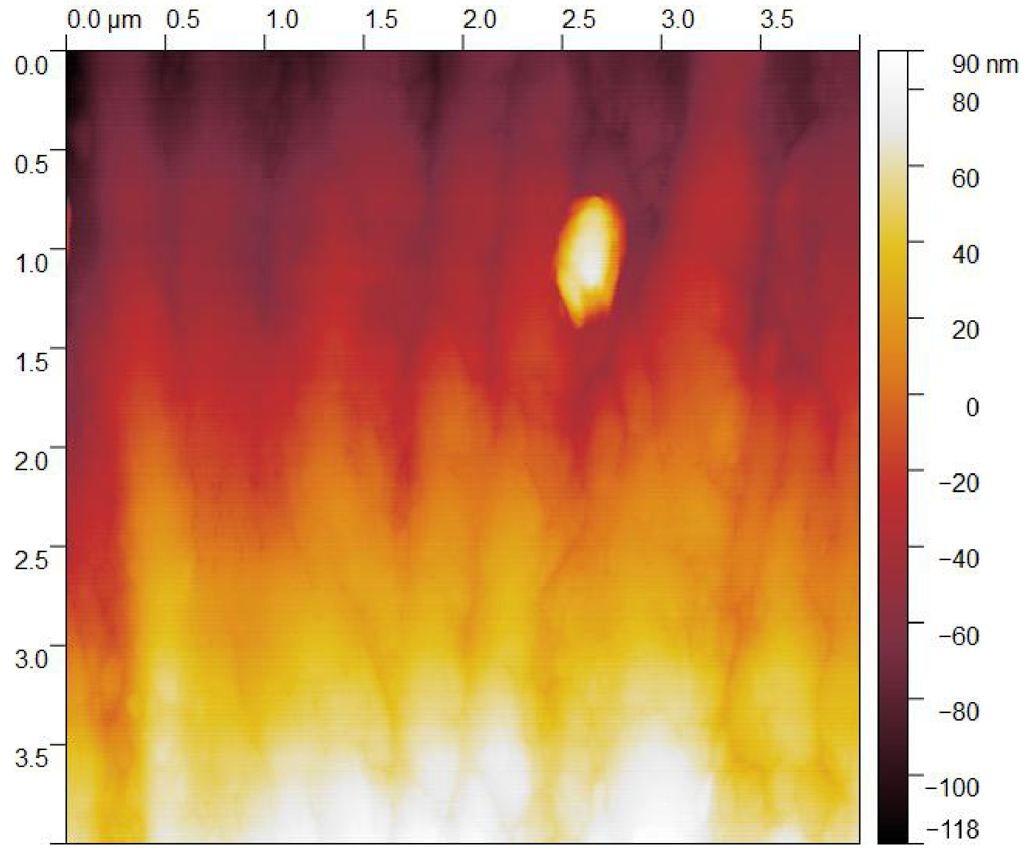


Average surface roughness

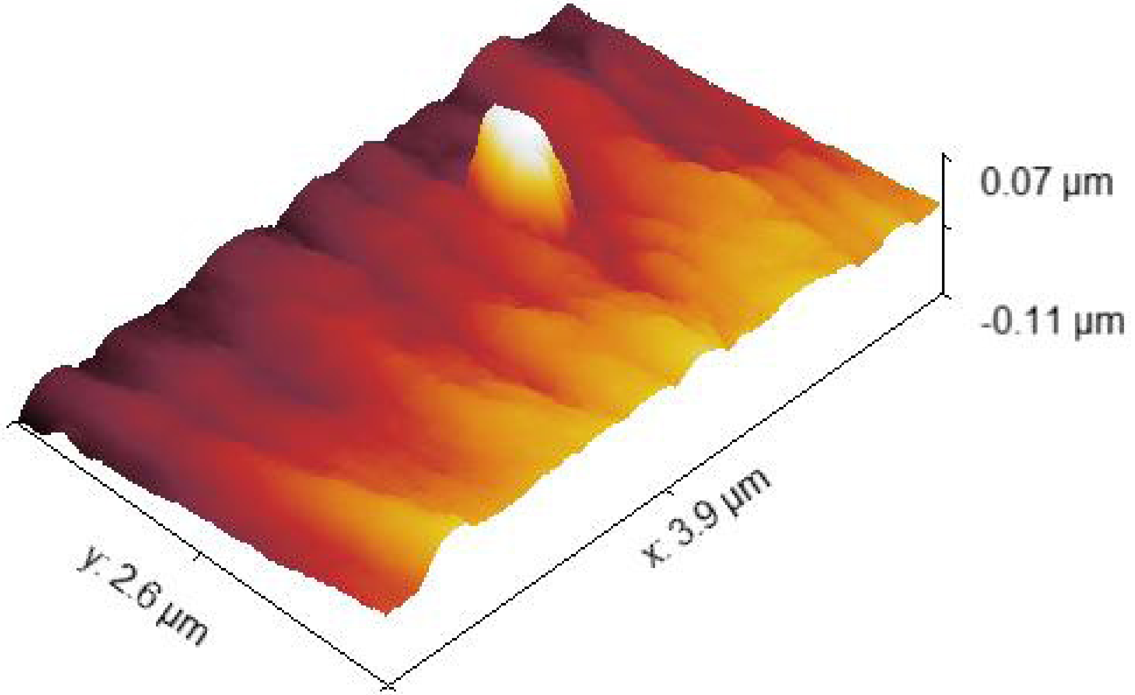
R_a = 6.225 μm



Mould particles have a size of an **0,2 x 0,1 µm**



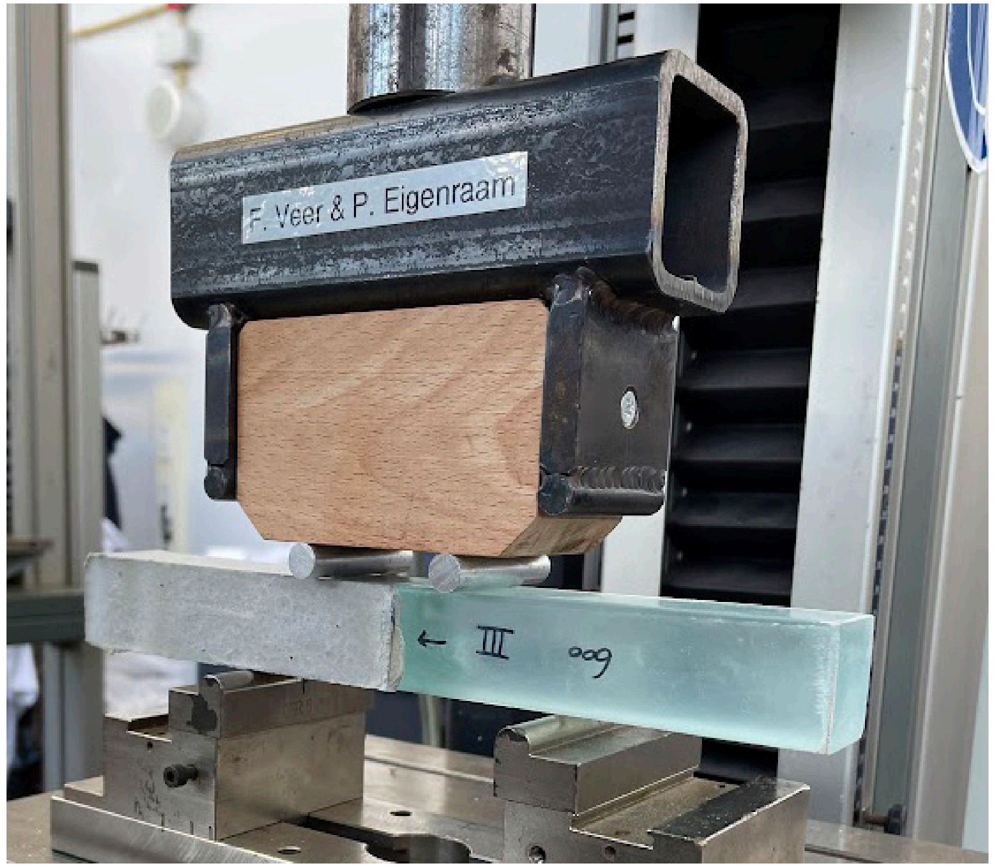
Roughness profile measured on 3.5 x3.5 µm surface



3D visualisation of the measured surface profile with a mould particle.

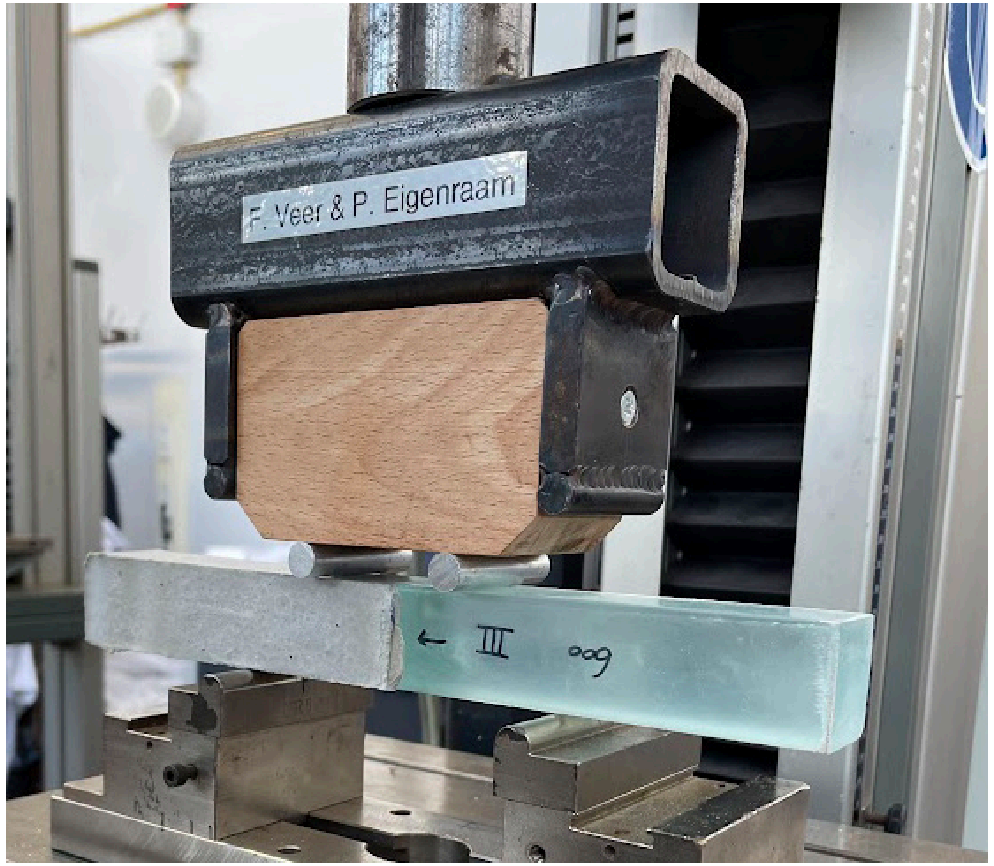
TIME FOR TESTING

4-POINT BENDING



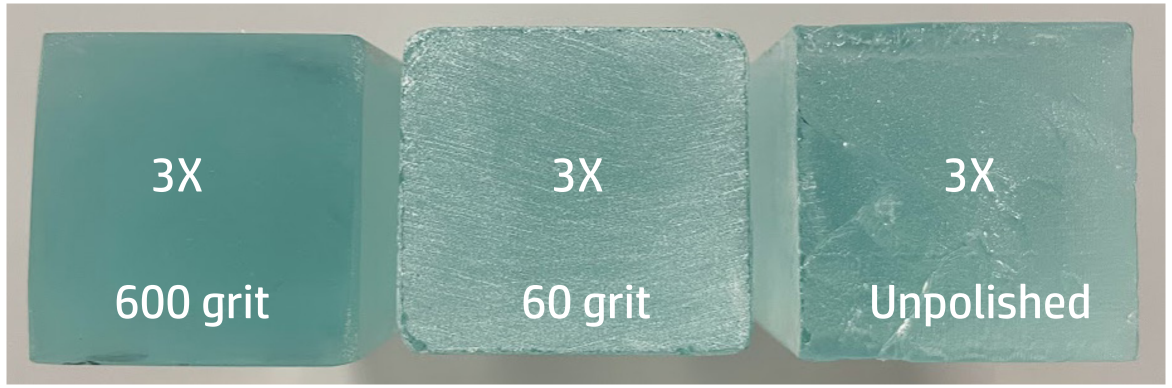
DIRECT SHEAR TEST

4-POINT BENDING TEST 1



SPECIMEN 240 x 30 x 30 mm

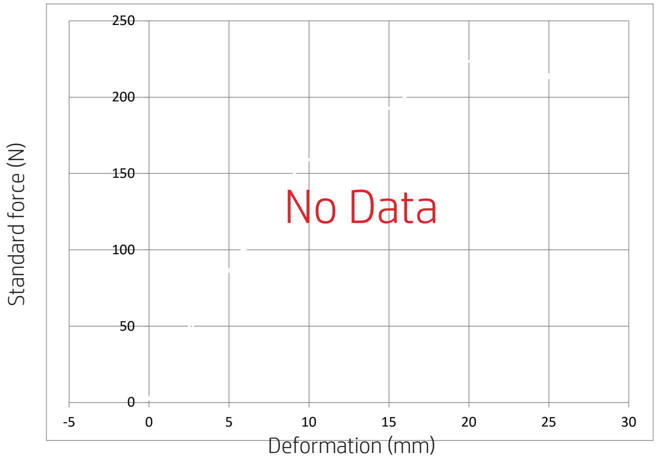
DIFFERENT SURFACE ROUGHNESSES



POUR RESULTS
Failure

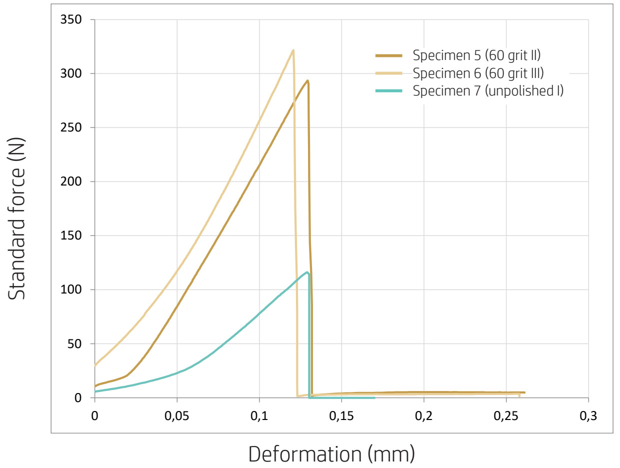
Pouring #1

4-point bending results (Pour 1)



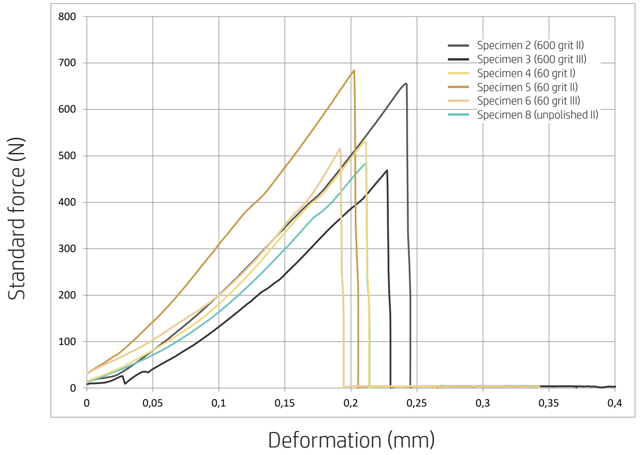
Pouring #2

4-point bending results (Pour 2)

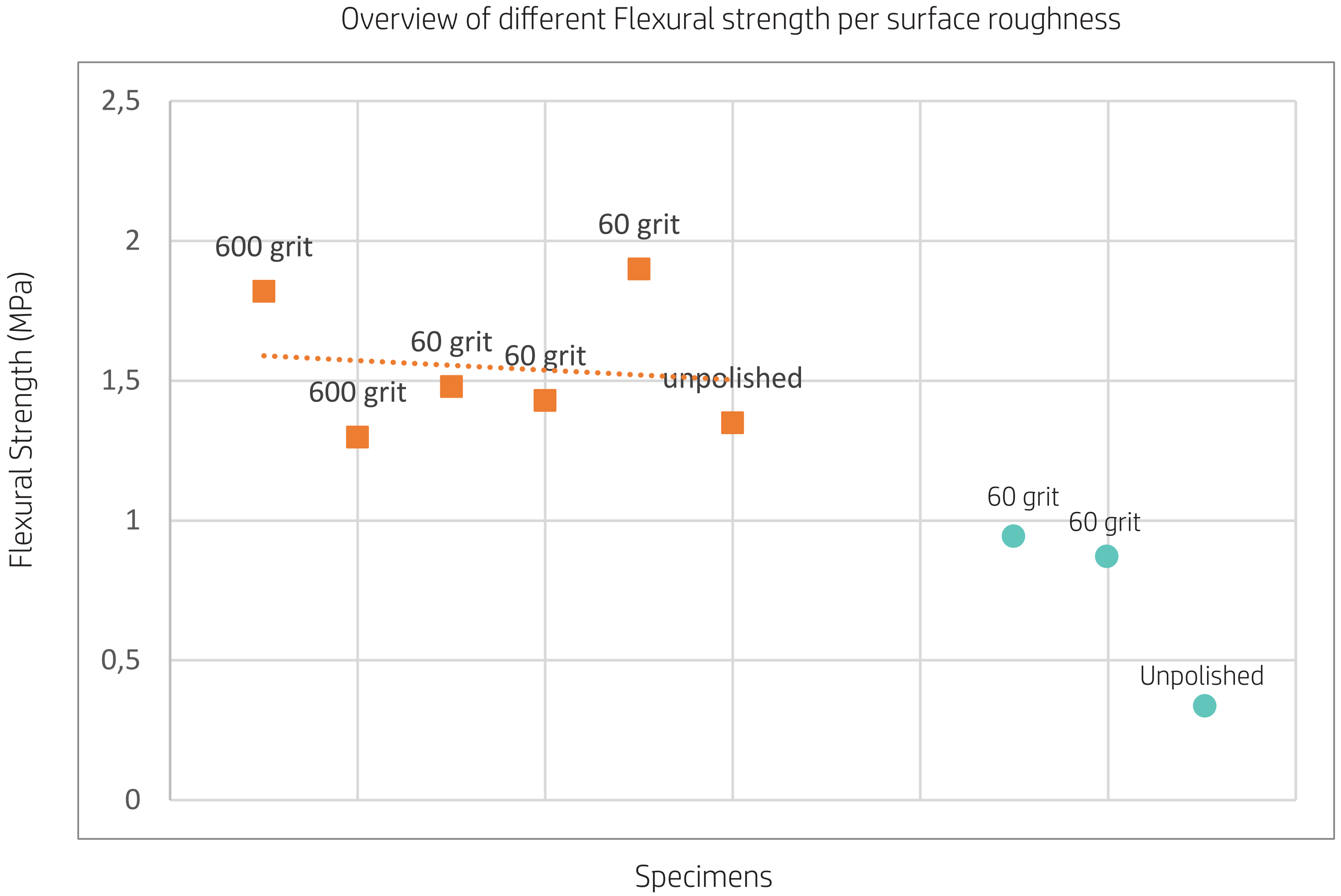


Pouring #3

4-point bending results (Pour 3)



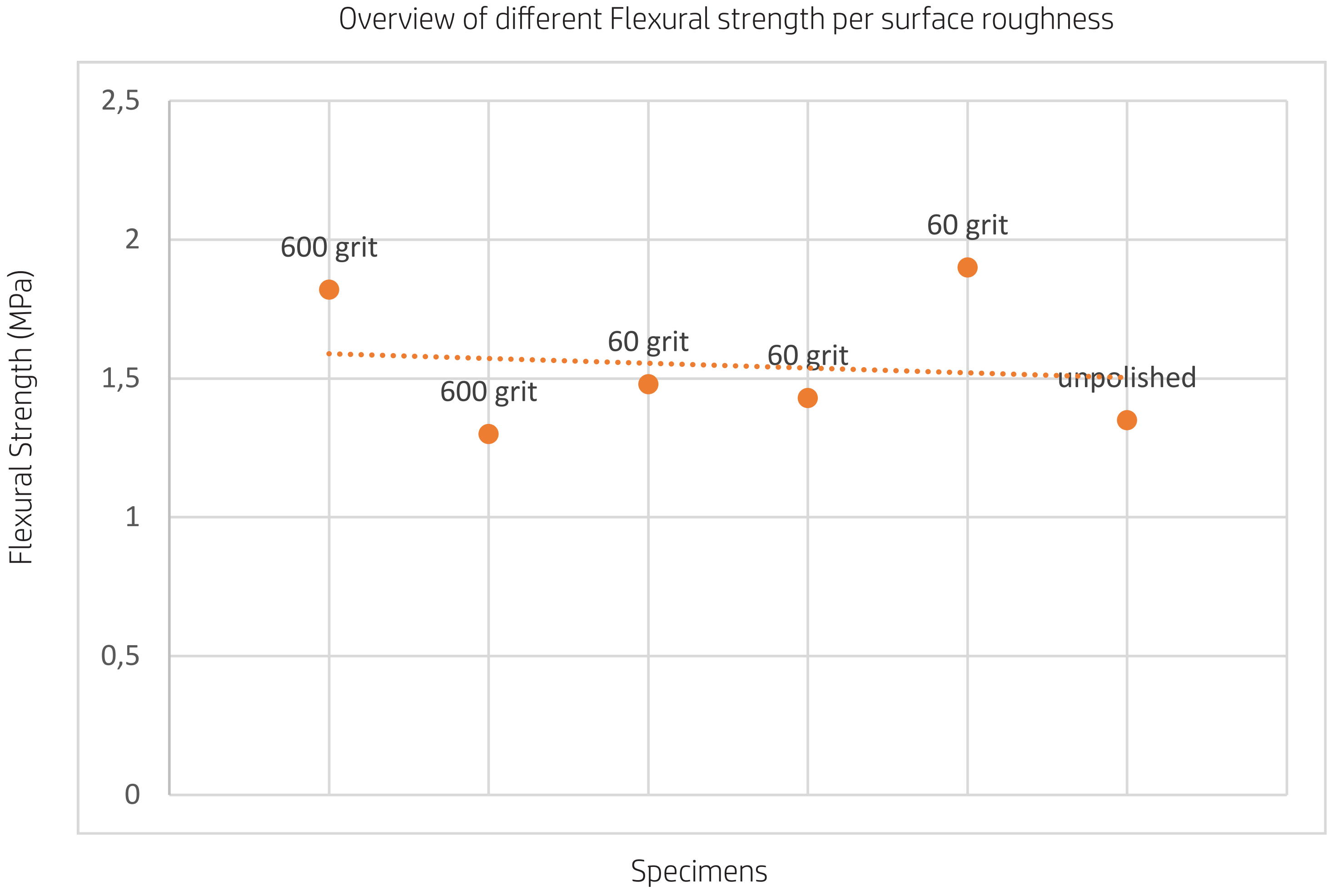
OVERVIEW TEST 1
Bending



CONCLUSION

- A **well mixed concrete** mixture signifcantly improves the bond adhesion and strength

OVERVIEW TEST 1
Bending

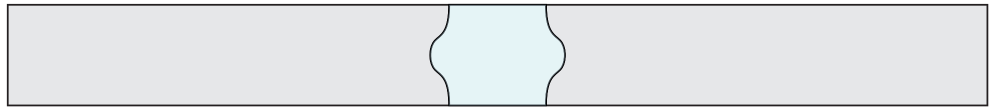


CONCLUSION

- A **well mixed concrete** mixture signifcantly improves the bond adhesion and strength
- **Constant flexural strength** despite the different surface roughness
- All specimens had a clear break: **Brittle behaviour**
- Surface roughness influenced the **interface adhesion**
- Unpolished surface does **not improve** the interface adhesion and strength

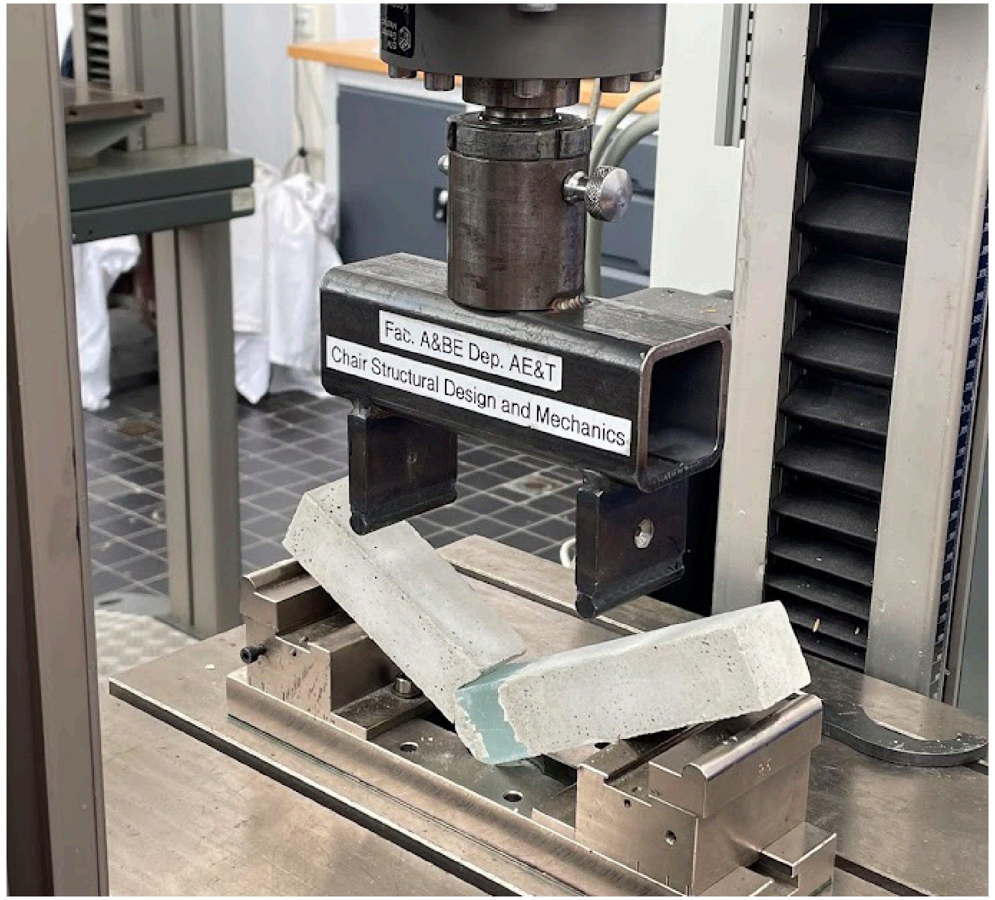
4-POINT BENDING TEST 2

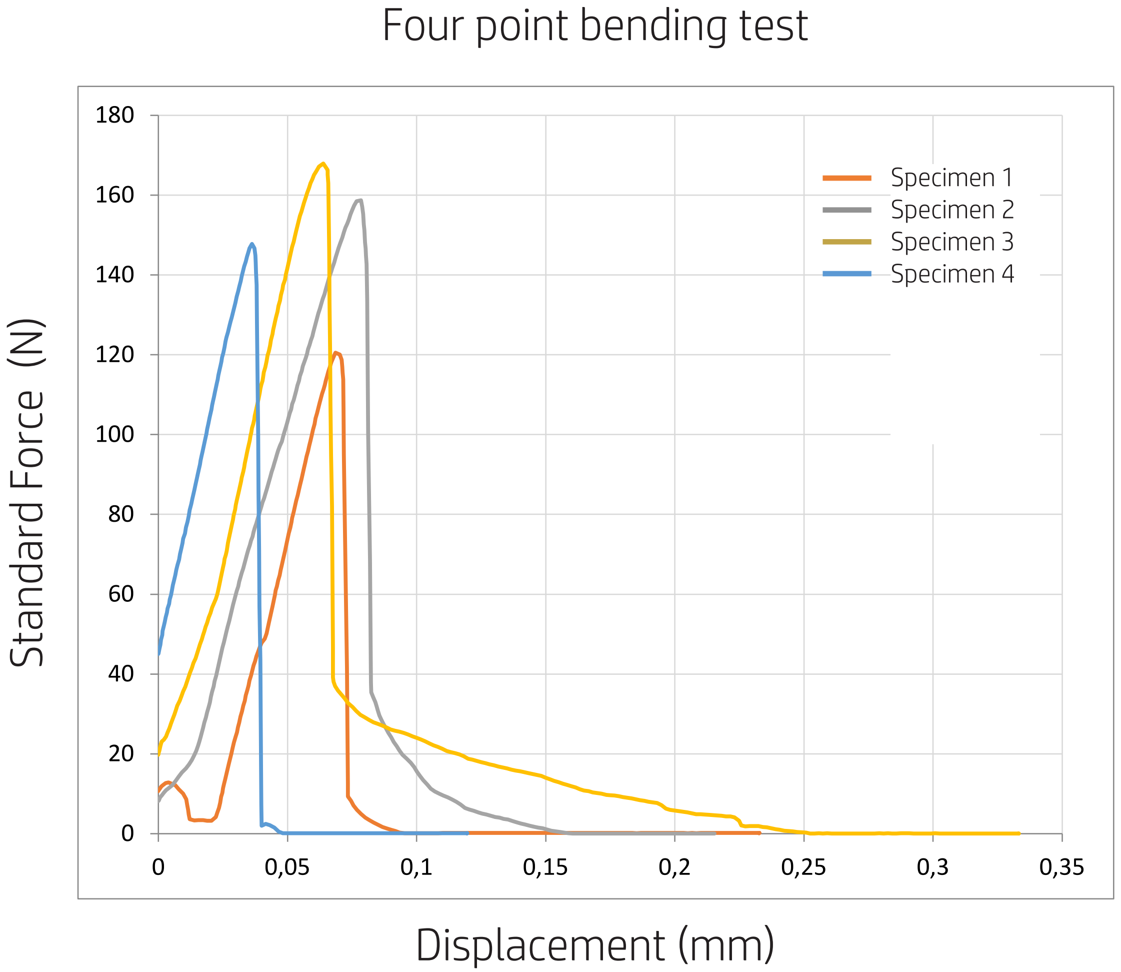
SPECIMEN 240 x 30 x 30 mm

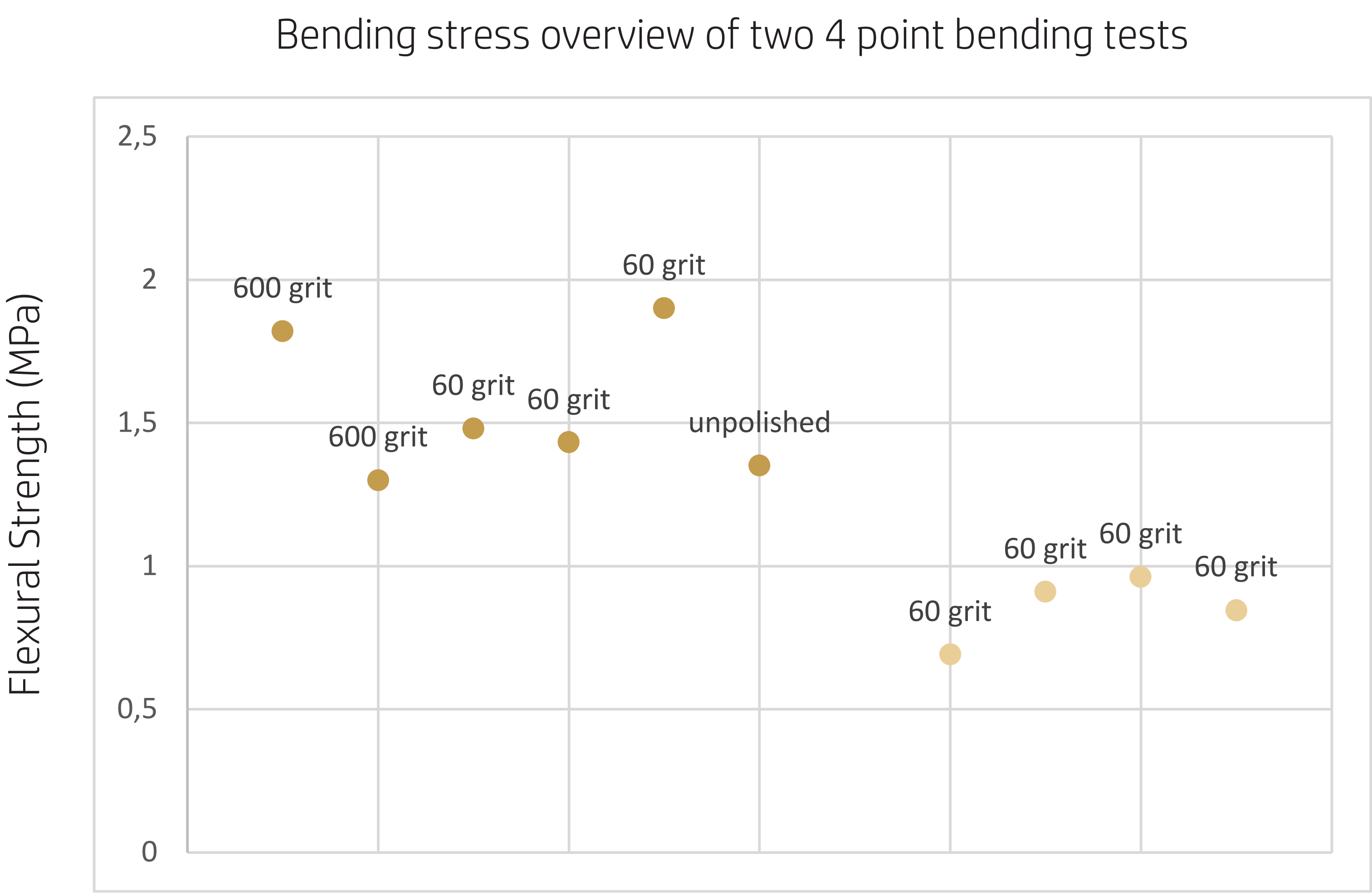


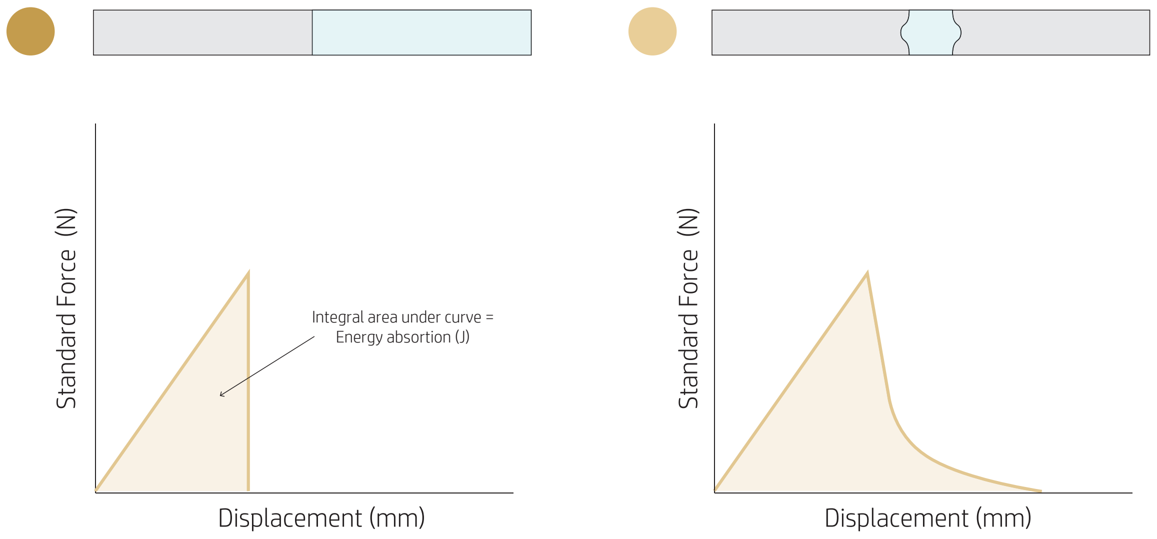
INTERLOCKING FORM

4-POINT BENDING TEST 2







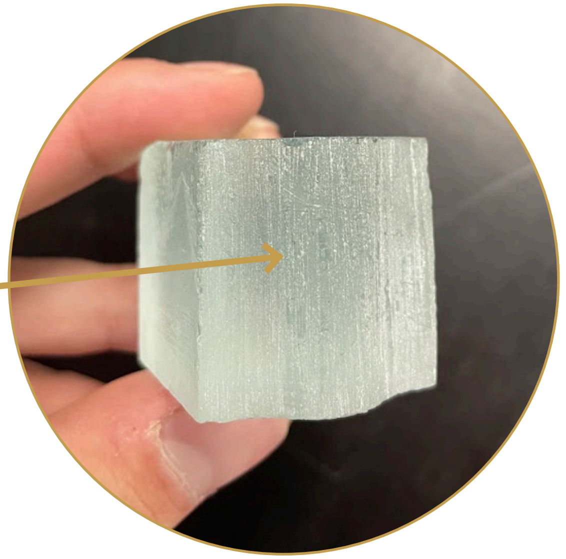


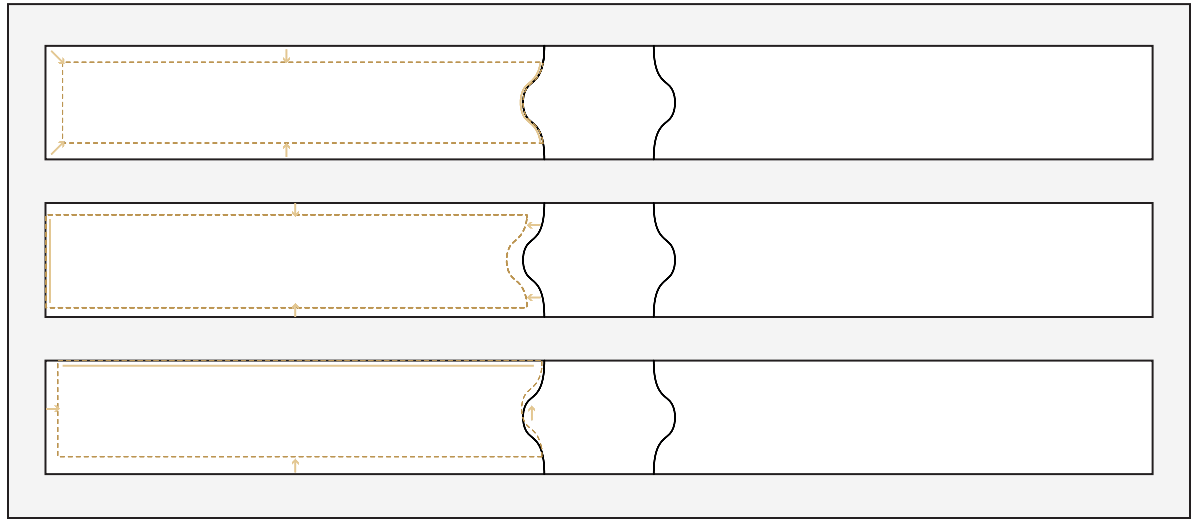
CONCLUSION:

- Test 2 showed a lower bending stress capacity primarily due to the presence of **two interfaces**.
- The bending stress capacity remains **insufficient** for implementing a full-scale facade panel
- all specimens exhibited non-brittle failure, indicating that the interlocking form contributed **energy absorption in the interface**

#2 DIRECT SHEAR TEST

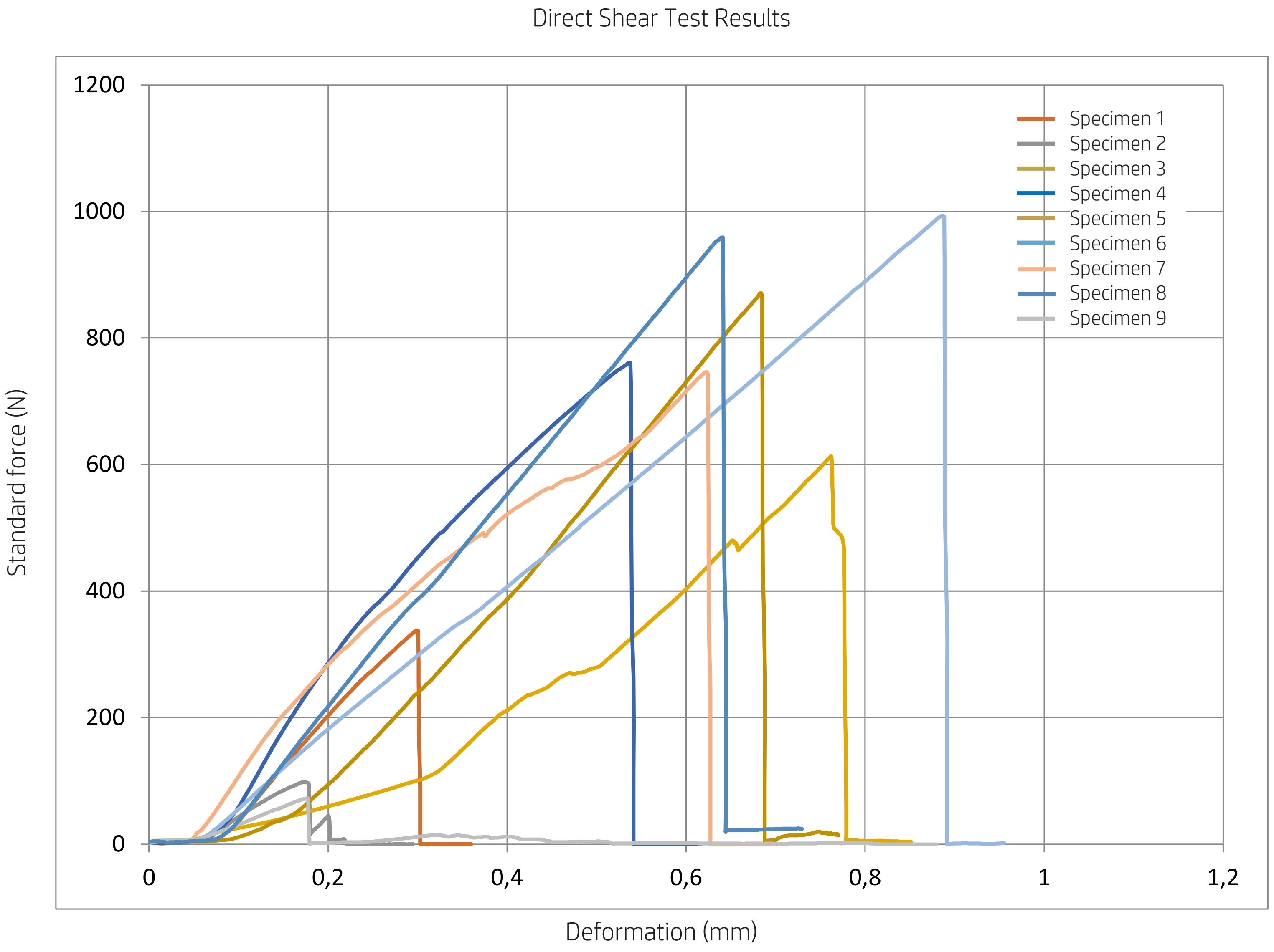
SHRINKAGE STRESS
Concrete curing



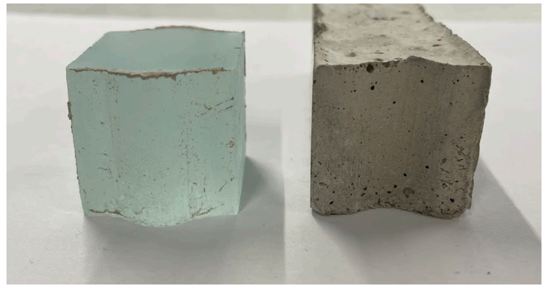


$$\sigma_{shrinkage}\ (MPa) > \sigma_{adhesion}\ (MPa)$$

FAILURE MODE
Shear



(1)

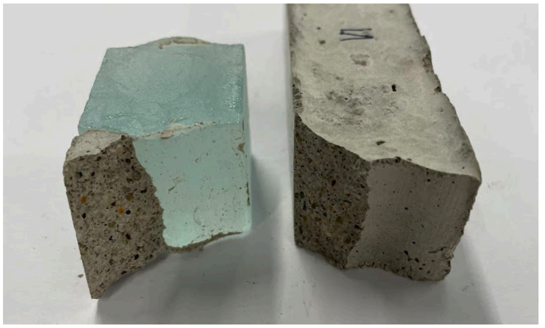


Interfacial failure

(2)

Interfacial failure + Concrete failure

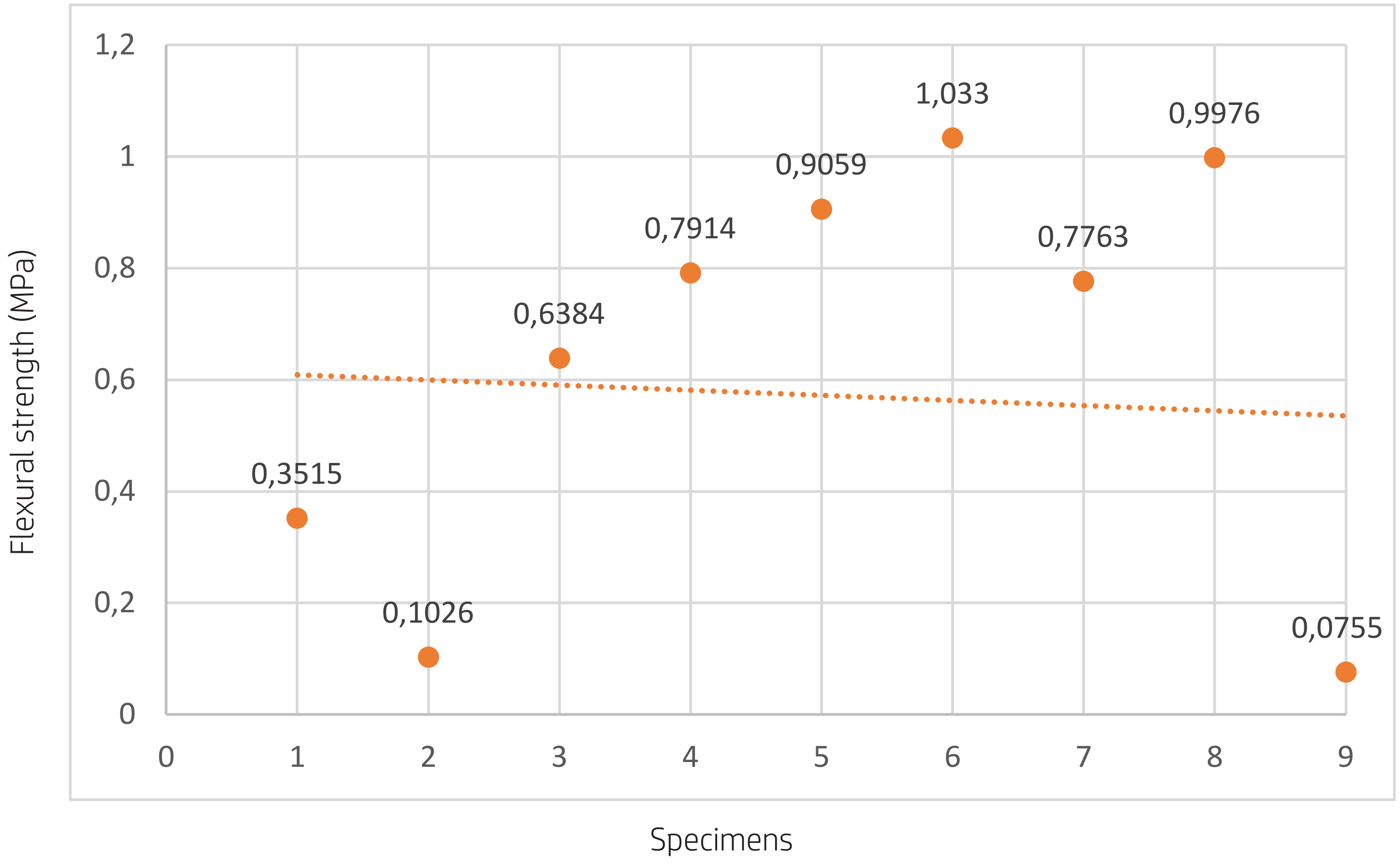
(3)



Serrated interfacial failure

CONCLUSION TEST 1
Shear

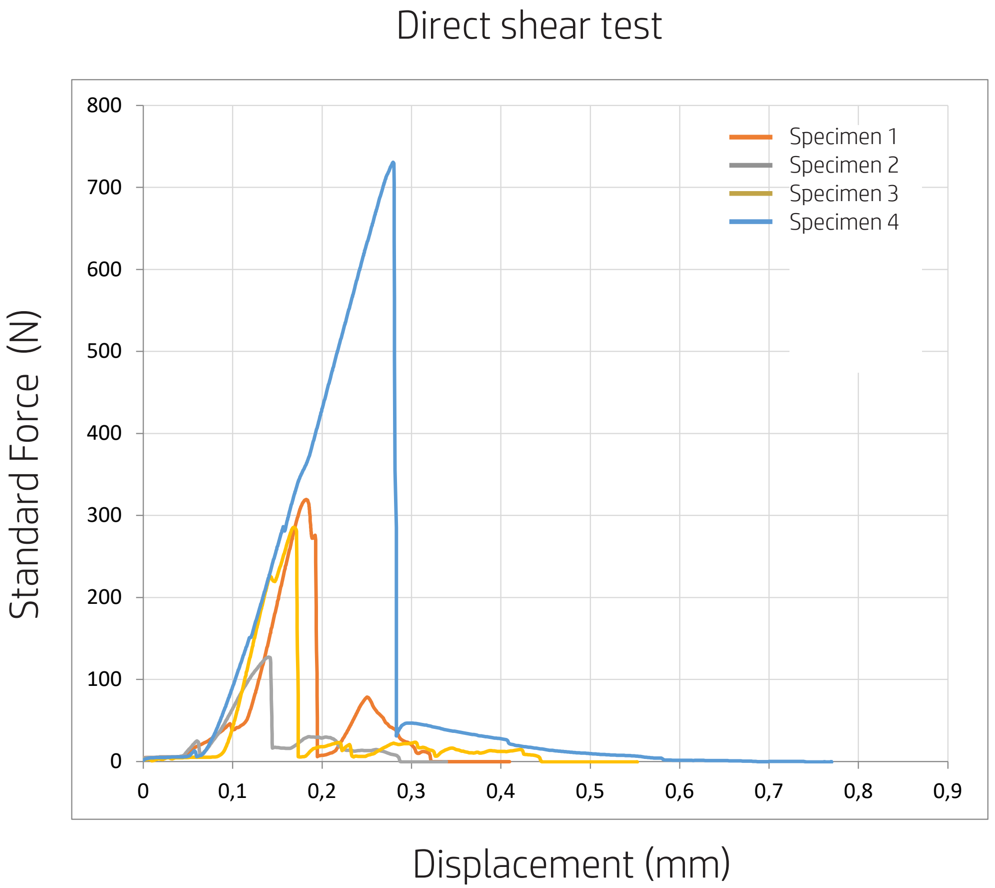
Overview Shear stress capacity of th the direct shear test results

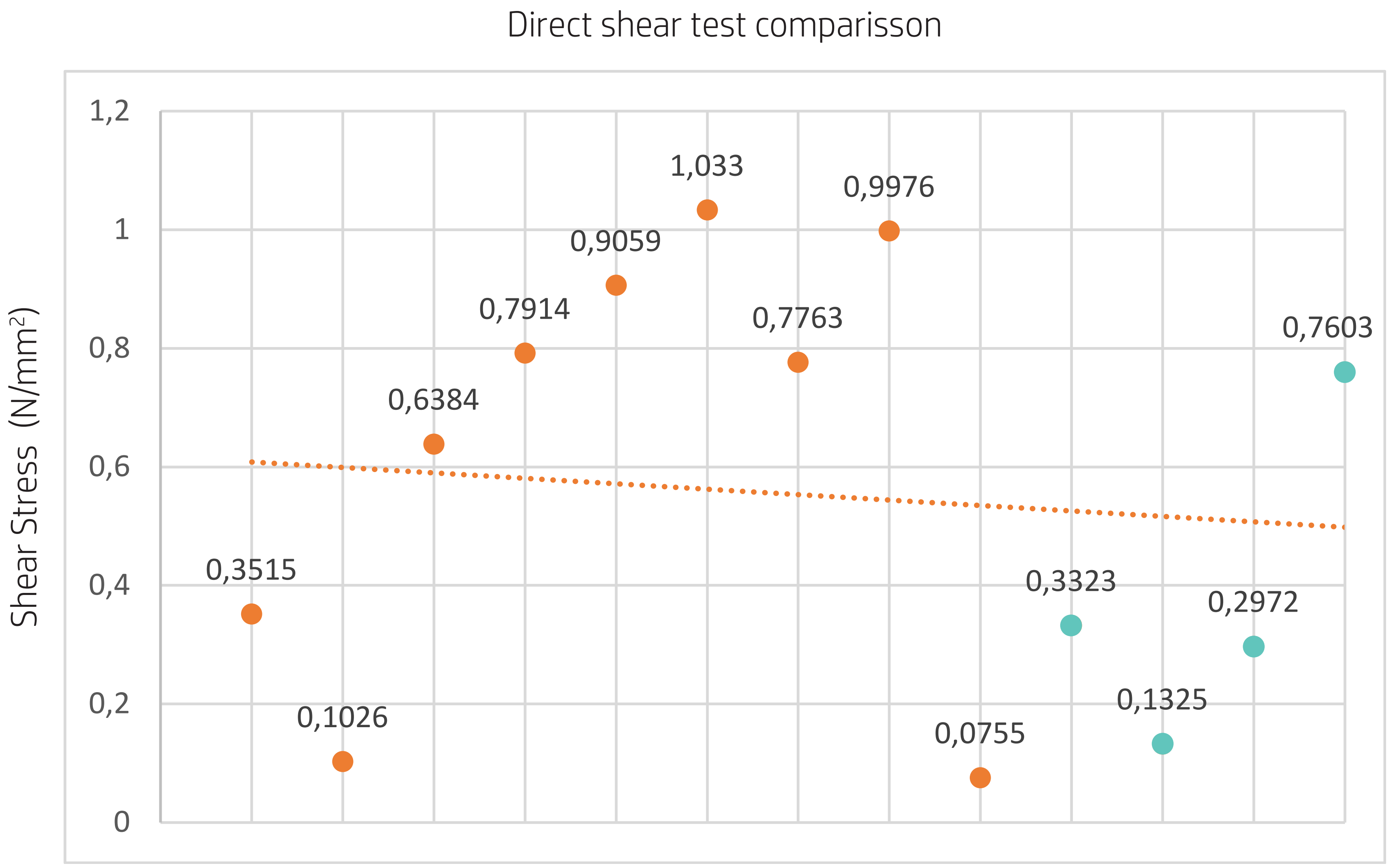


CONCLUSIONS

- Concrete **shrinkage** causes stresses and adhesion failure that pull the glass on one side.
- The occurrence of a serrated failure suggests a significant degree of interaction between the concrete and glass
- formation of physical anchorages at the interface due the interlockiong form.
- serrated failure mode of the interface indicates a failure in the concrete

DIRECT SHEAR TEST #2

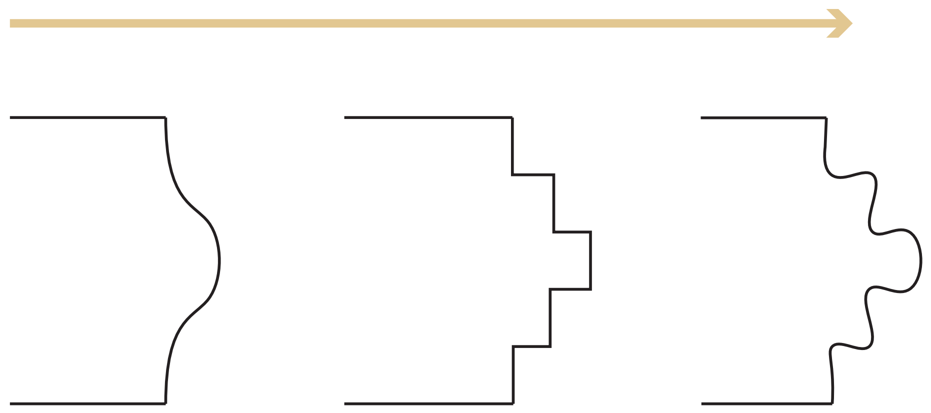




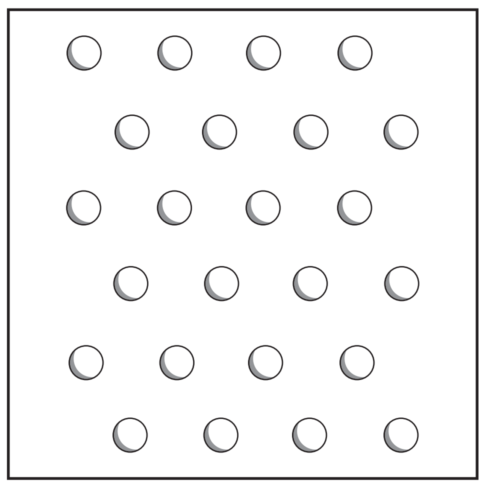
60 grit polished in one direction

Diagonal cut with a dremmel

- MORE EXTREME INTERLOCKING FORMS
- SURFACE ROUGHNESS INCORPRATED IN MOULD DESIGN
- NOT MICRO-SCALE BUT MACRO-SCALE ROUGHNESS
- IMPROVED CONCRETE MIXTURE (GRC OR UHPC)
- DIFFERENT SODA_LIME GLASS COM-POISTIONS (ART GLASS)

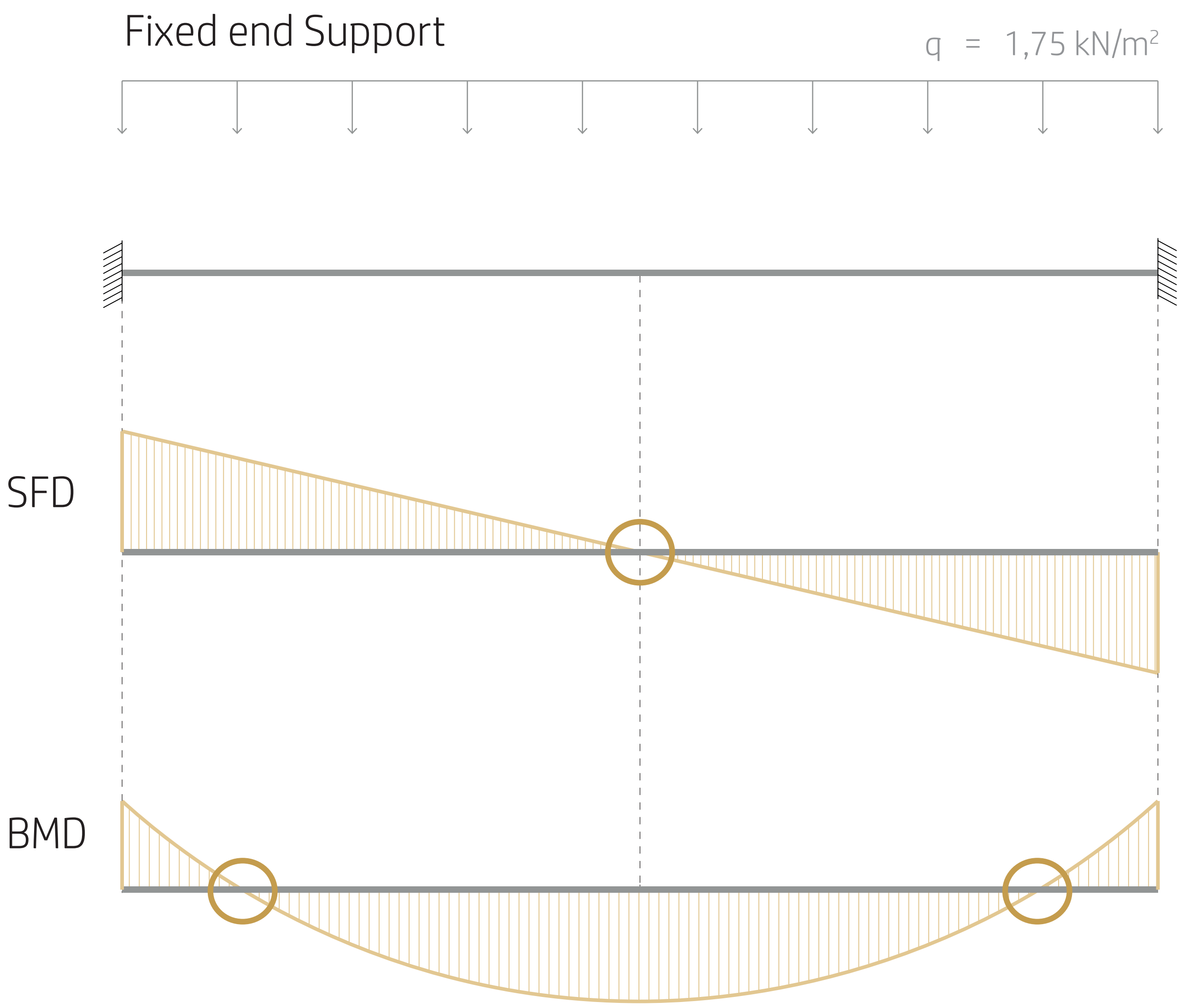


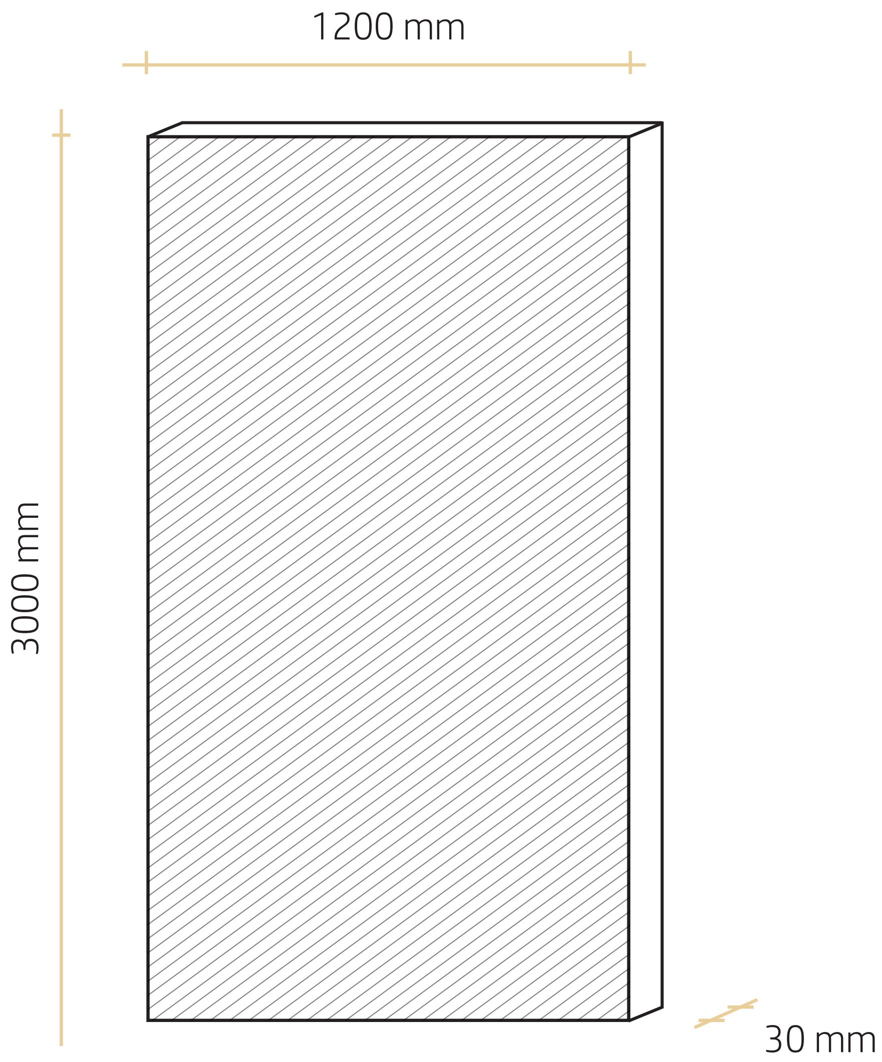
More interlocking form



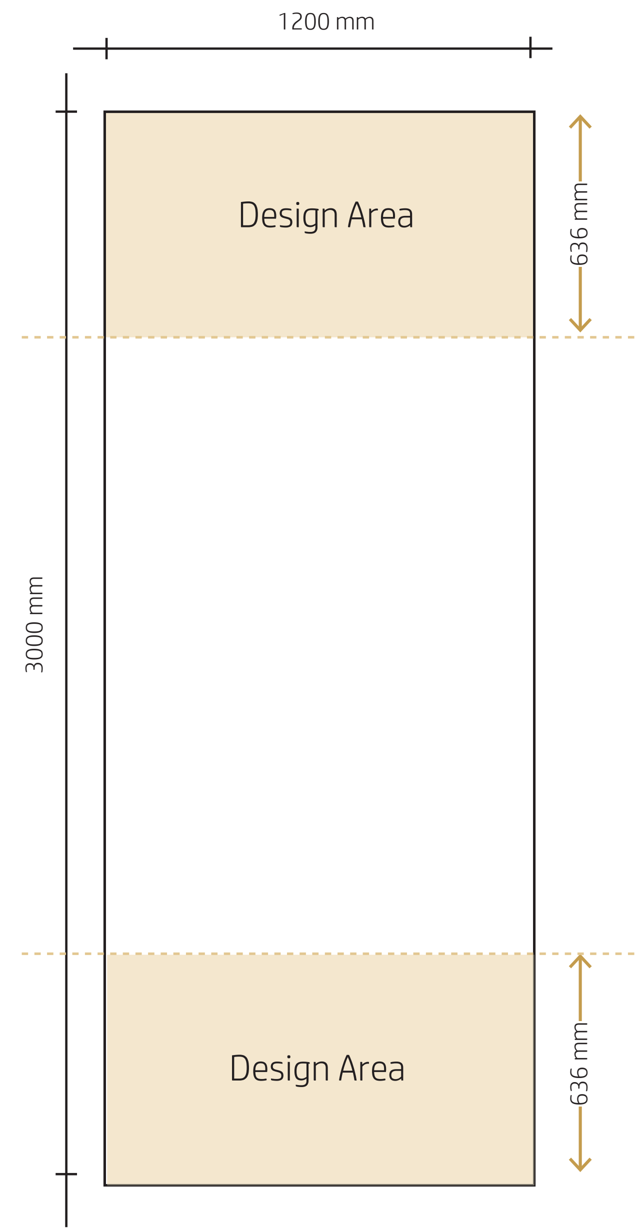
Dimpled surface as macro-roughness

What if put a hybrid interface in a facade panel?


Fixed end Support
q = 1,75 kN/m²
SFD
BMD


1200 mm
3000 mm
30 mm

BENDING



Limited Design Freedom

FORMULA FINDING DESIGN BENDING AREA:

$$M_x = \frac{w}{12}(6Lx - L^2 - 6x^2)$$

Where 'M_x' is calculated with

$$\sigma = \frac{M*y}{I}$$

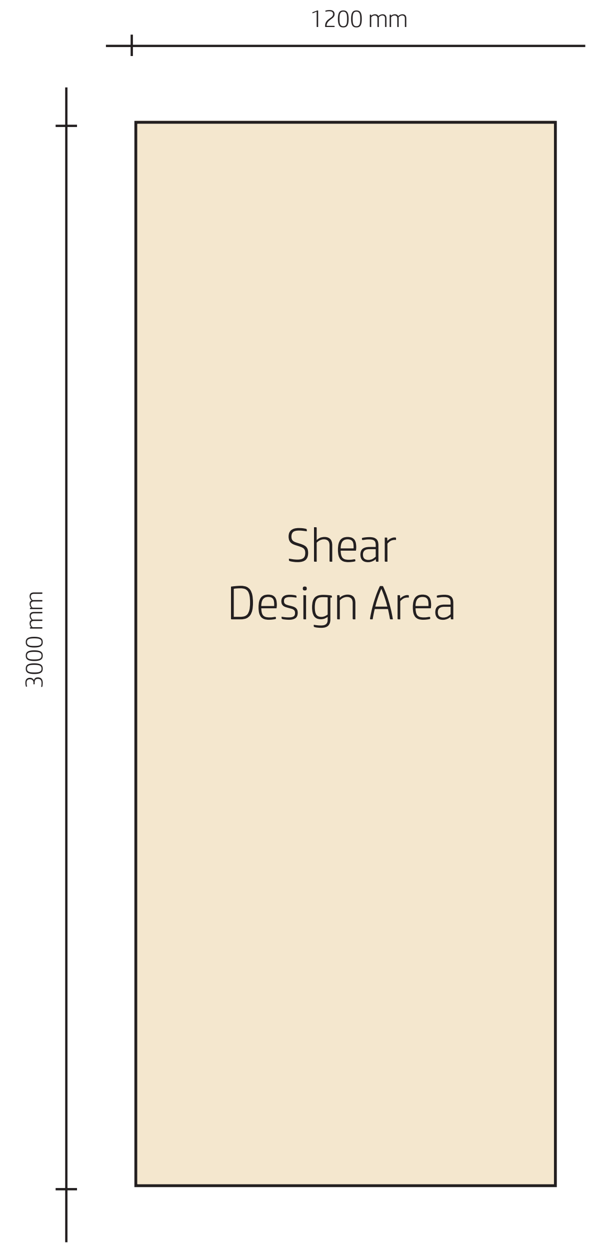
σ = 1,603 N/mm²
y = 15 mm
I = 2700000 mm⁴

$$288540 = \frac{1750}{12}(6*3000x - 3000^2 - 6x^2)$$

We find 'x' as design area limit

x = 635,95 mm and
x = 2364.05 mm

SHEAR



Full Design Freedom

FORMULA FINDING DESIGN SHEAR STRESS CAPACITY:

$$\tau = \frac{V}{A}$$

V = maximum load
A = shear load area

$$\tau = \frac{2625\ N}{38448{,}12\ mm2}$$

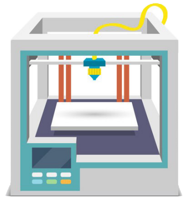
$$= 0.0683 N/mm2$$

$$T_{interface} = 0{,}567\ N/mm^2 \quad > \quad T_{panel} = 0{,}0683\ N/mm^2$$

PART II:

DESIGN PART

MANUFACTURING CONSIST OF 3 PARTS:



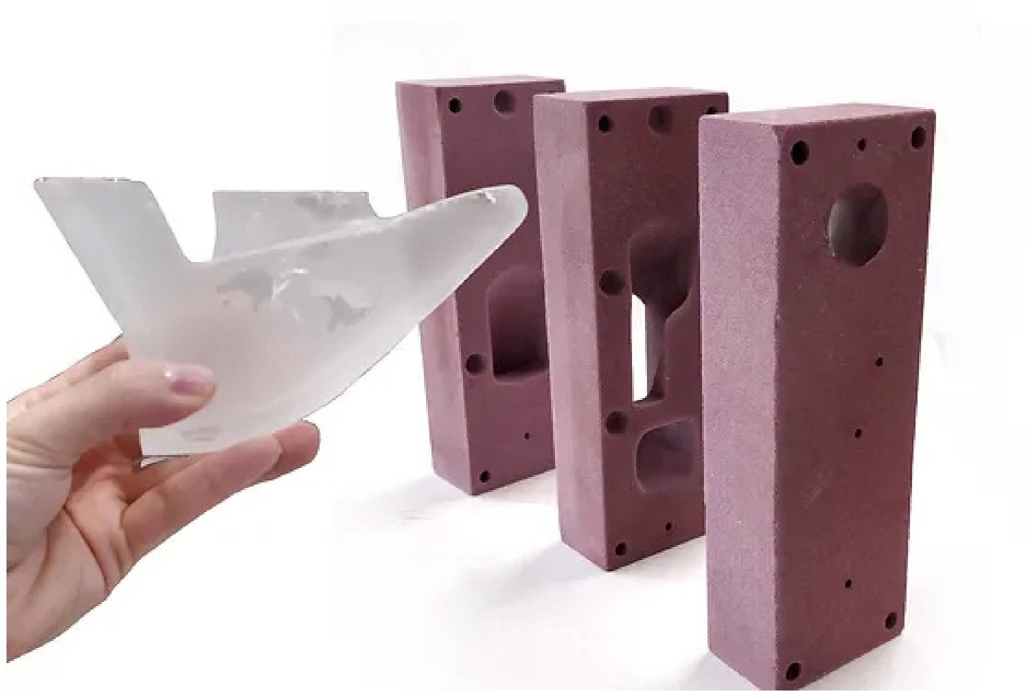
I Mould manufacturing

II Glass manufacturing

III Concrete manufacturing

MANUFACTURING
Mould

Kiln Casting
- **Disposable mould**
  - single use kiln-casting
  - **3D printed sand**
  - Silica plaster
- Permanent mould
  - Stainless Steel
  - Graphite
  - multiple use melt-quenching



- Biggest printable scale
- Industrialiased process
- Recyclable potential

First cast glass -> secondly pour concrete

Glass (Soda-lime)	Temperature	Concrete
	1400 °C	Concrete melts down
Melting point	1300 °C	
	1200 °C	Concrete melting starts
	1100 °C	
	1000 °C	
	900 °C	
	800 °C	Total loss of water of hydration
Softening point	700 °C	
	600 °C	
Annealing point	500 °C	
Strain point	400 °C	Dissociation of calcium hydroxide
	300 °C	Start of silicious concrete strength loss
	200 °C	water to vapour
	100 °C	
Glass (Soda-lime)	27 °C	**Concrete**

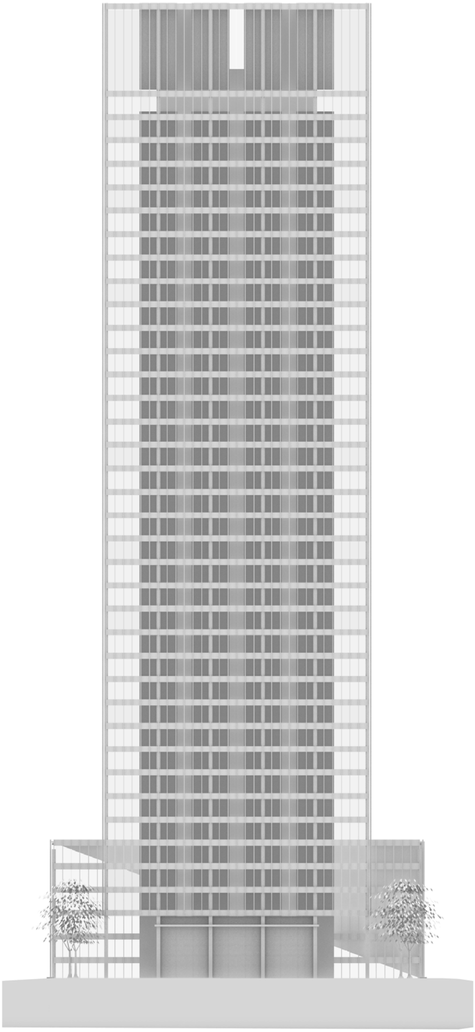
concrete structurally not usefull

DESIGNED FOR DISASSEMBLY

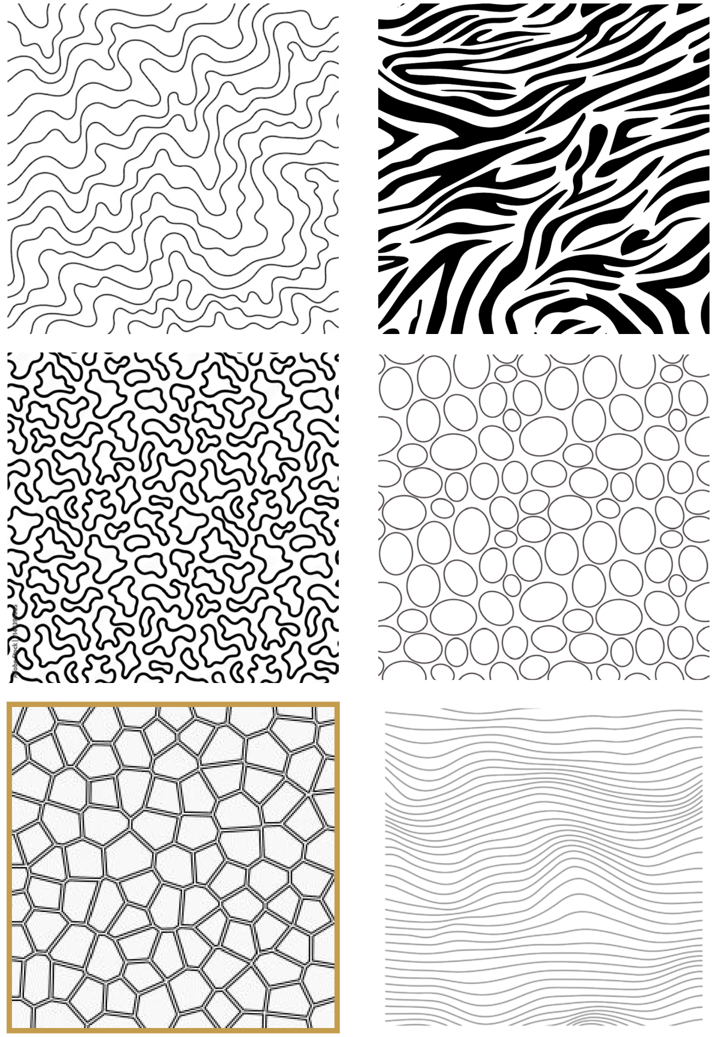
SEAGRAM OFFICE BUILDING - NEW YORK

- Single glazed
- Shading only open or closed
- Overheating in summer
- Monotone Facade

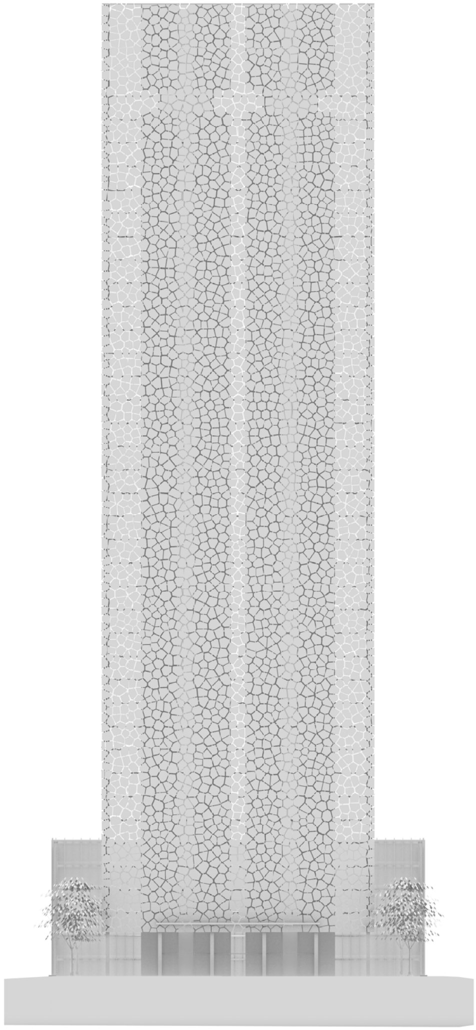
FREE-FORM DESIGN
Facade



Current situation

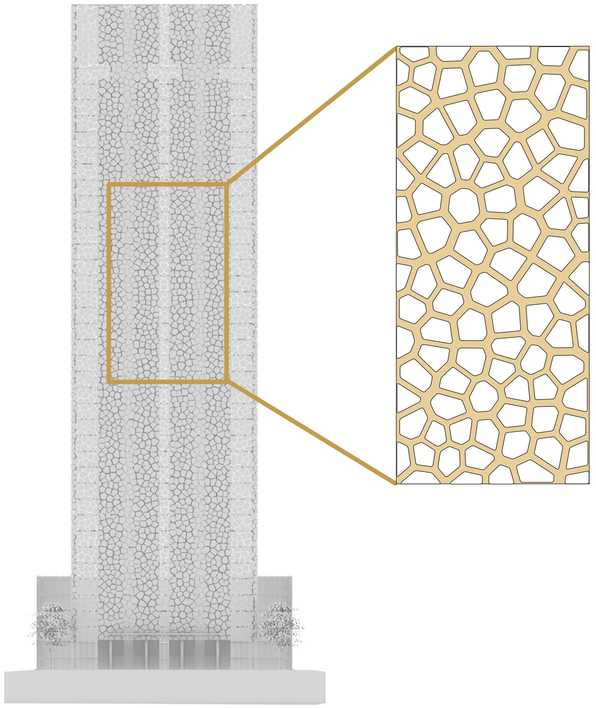


Make free-form design



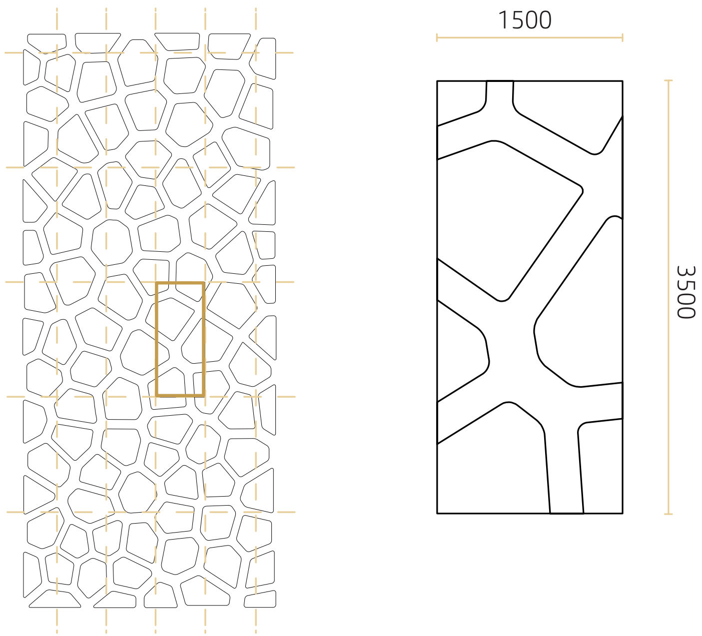
Design option

PRODUCTION STEPS
Panel



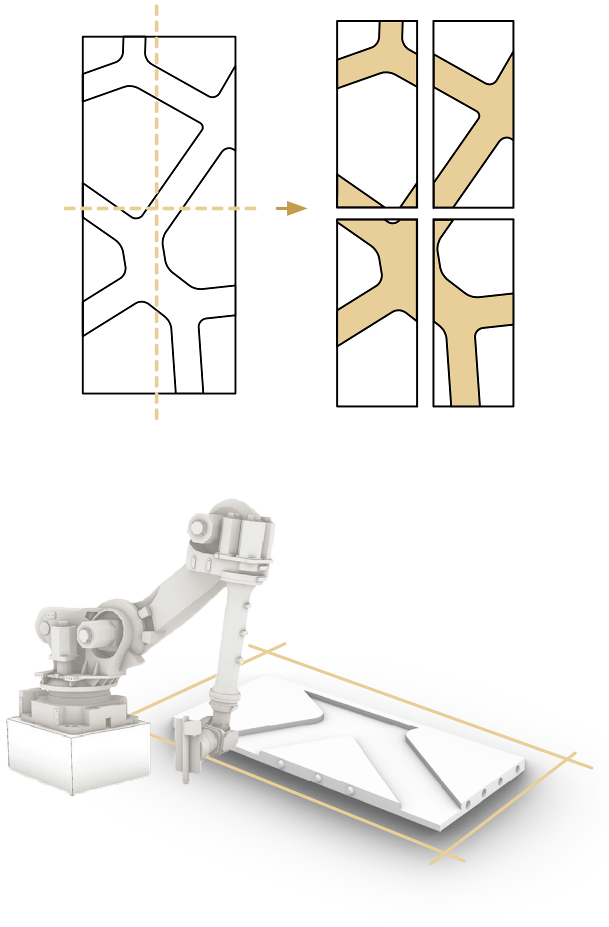
DESIGN

STEP 1



RASTERISATION

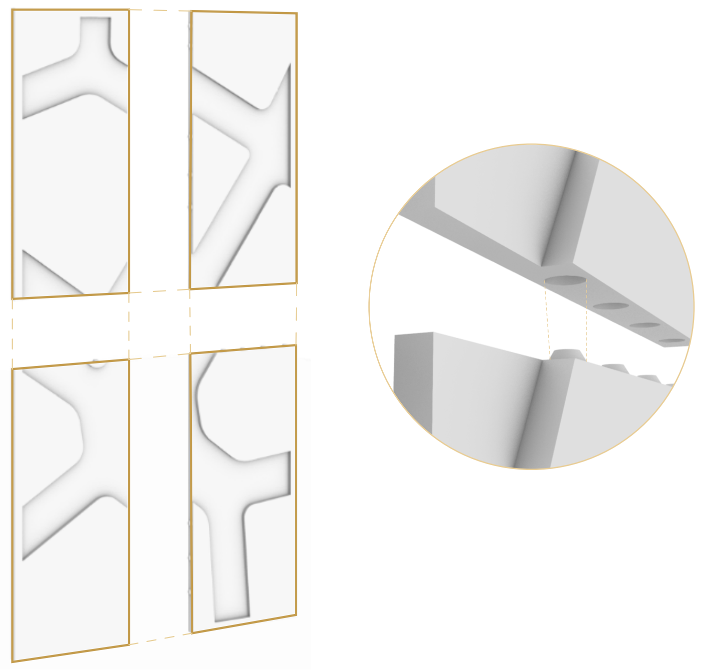
STEP 2



SAND MOULD MAKING

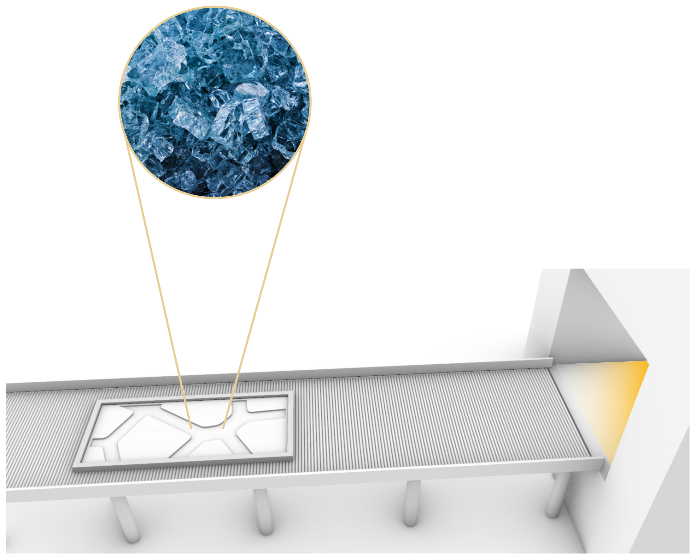
STEP 3

PRODUCTION STEPS
Panel



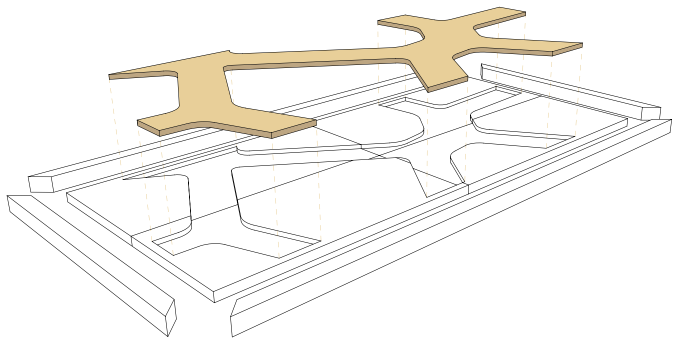
ASSEMBLY SAND MOULD

STEP 4



CULLET PLACING + FIRING

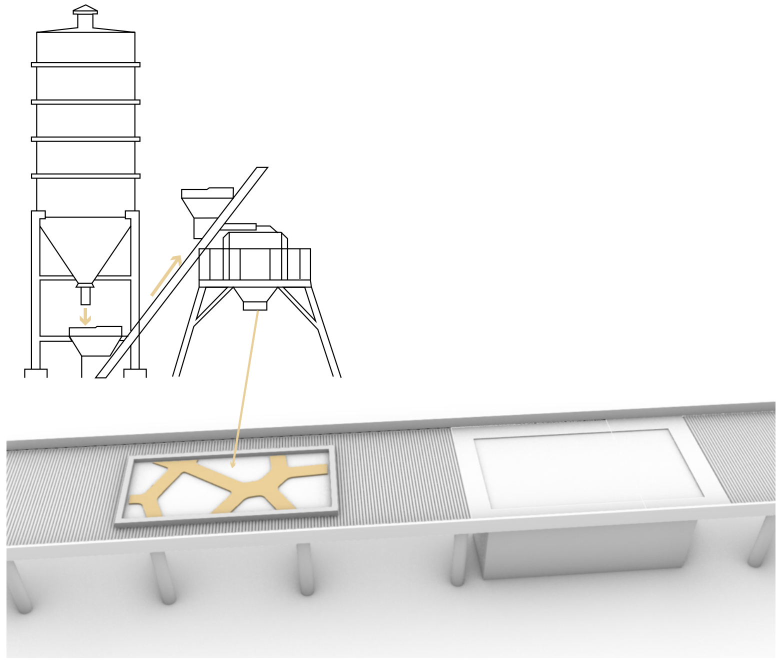
STEP 5

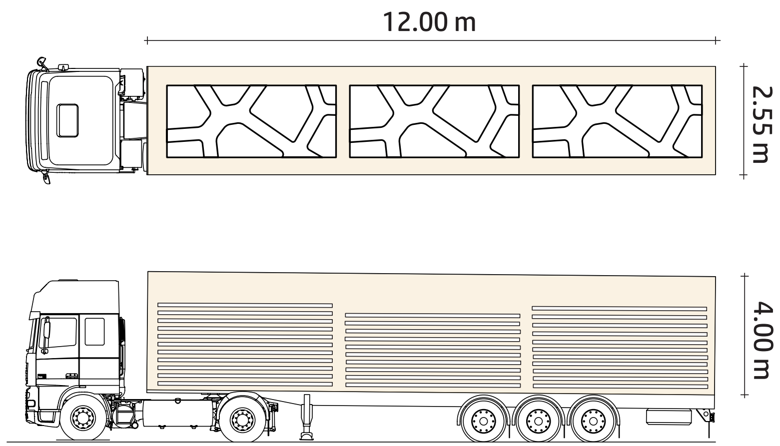


ANNEALING + COOLING DOWN

STEP 6

PRODUCTION STEPS





POURING CONCRETE + COMPACTING

STEP 7

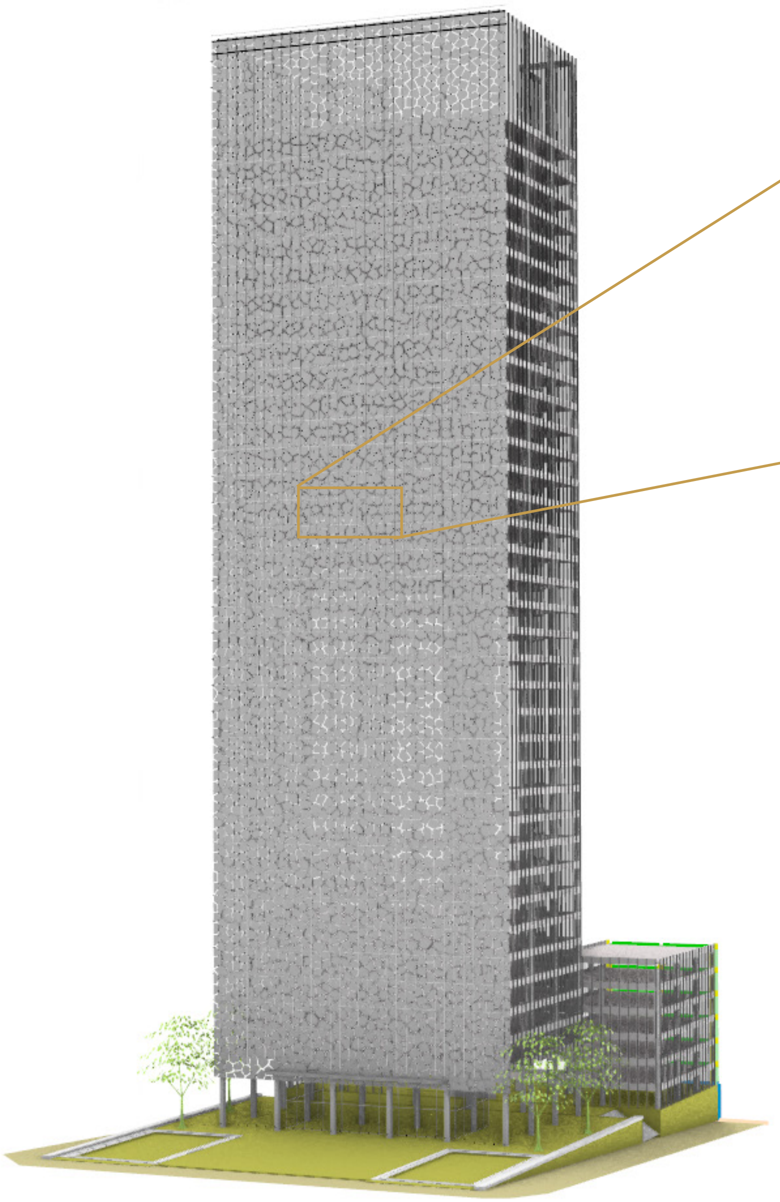
FINISHING

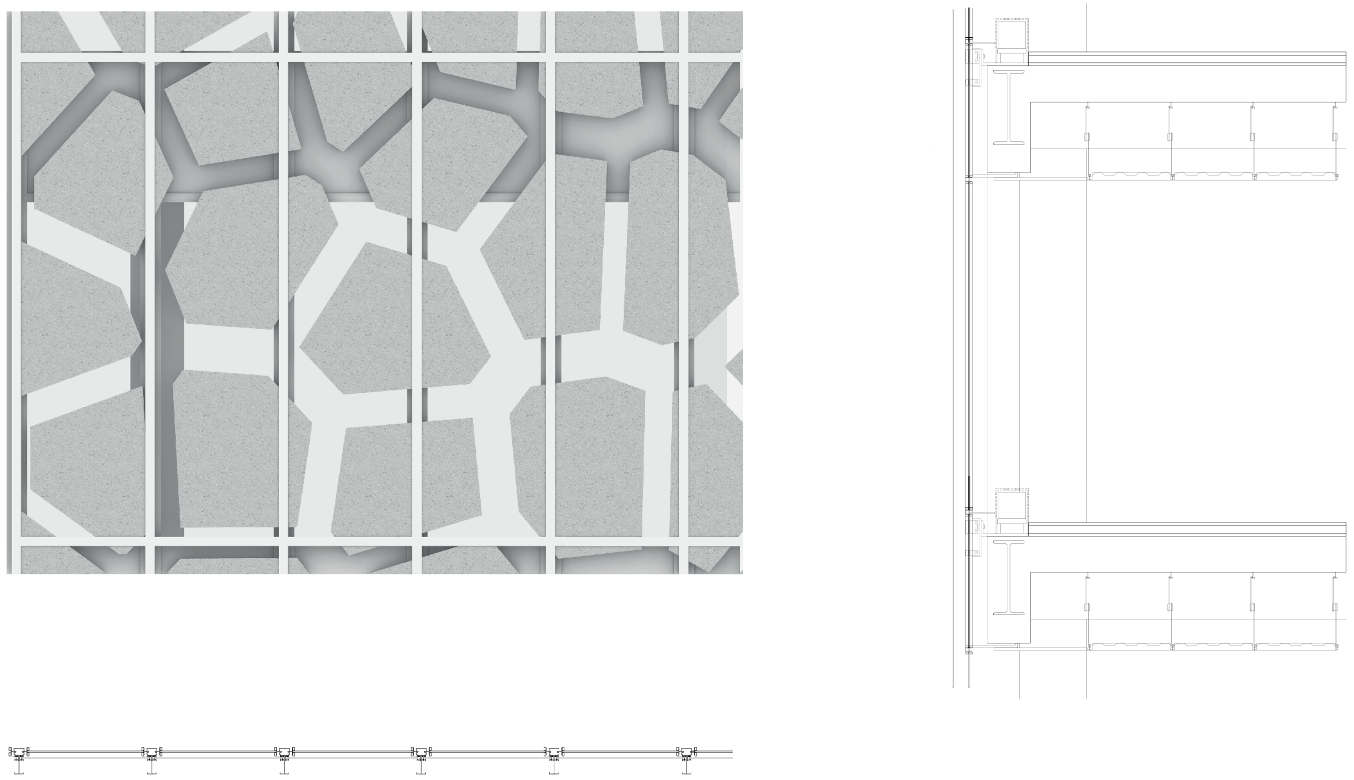
STEP 8

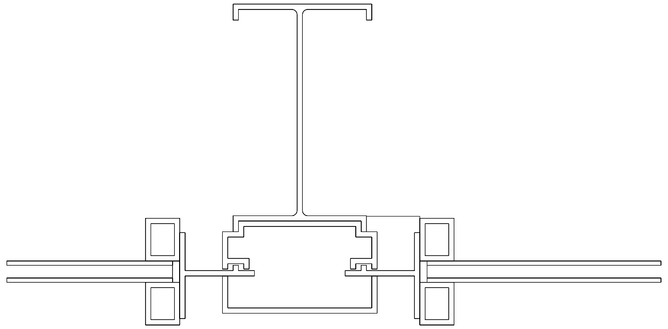
TRANSPORTATION

STEP 9

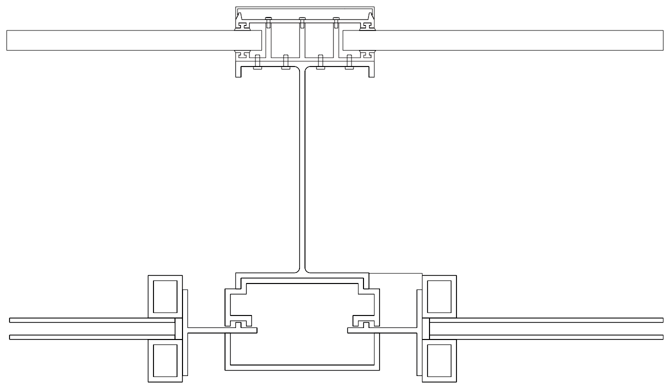
FACADE DETAIL
Old vs New





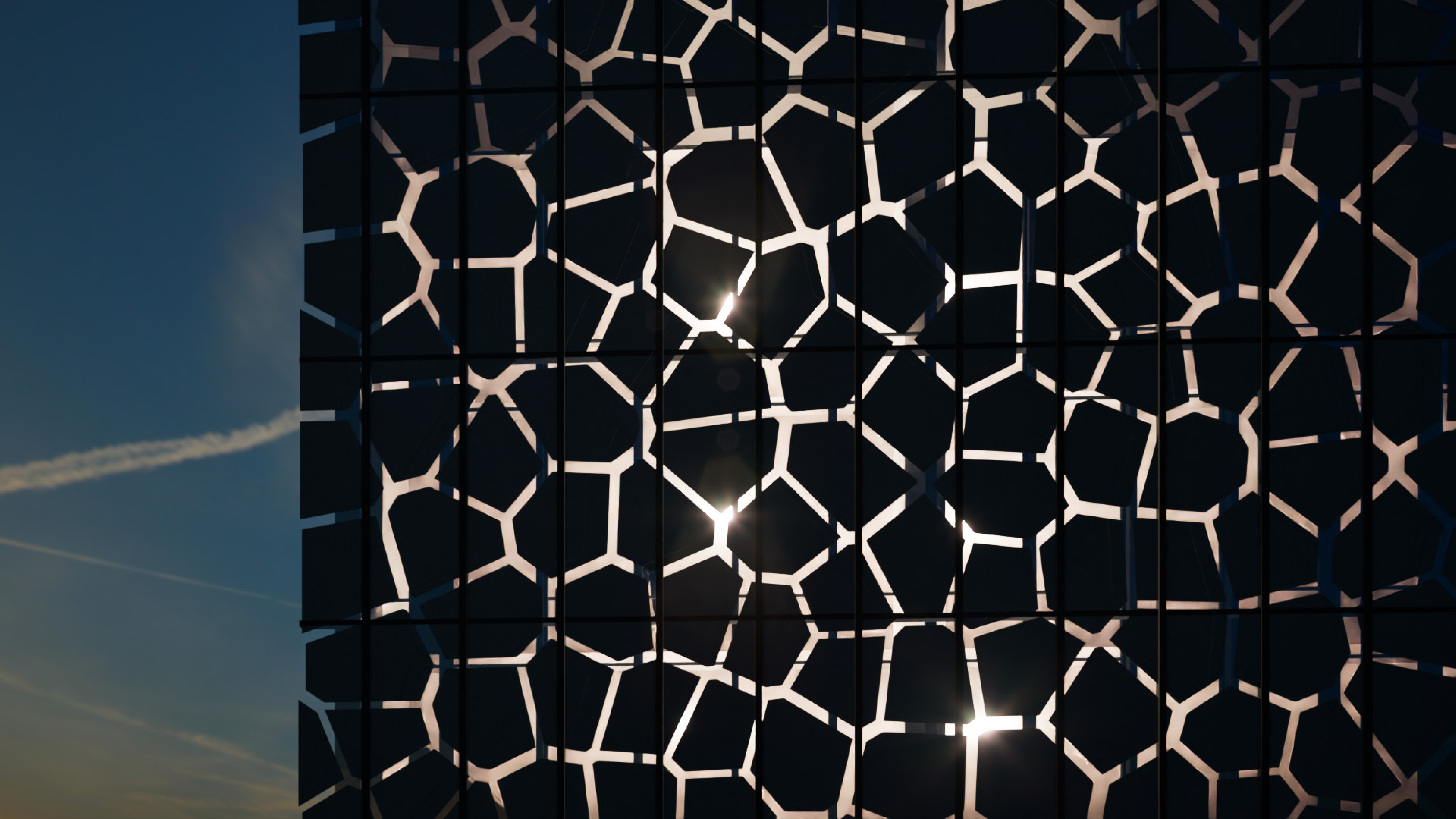


Current facade design



Facade design including a hybrid panel.


HORIZON



CONCLUSIONS **INTERFACE**:

- Shear stress capacity is feasible
- Bending stress capacity is insufficient.
- Adhesion percentage is inadequate.
- Concrete quality requires enhancement.
- Interlocking form ensures structural integrity.
- Surface roughness should be applied at the macro scale

CONCLUSIONS **MANUFACTURING**:

- High potential for industrialization.
- Using two materials and design for disassembly enhances recyclability potential.
- Offers a new design language
- Architectural flexibility

THANK YOU!

APPENDIX

Societal Value

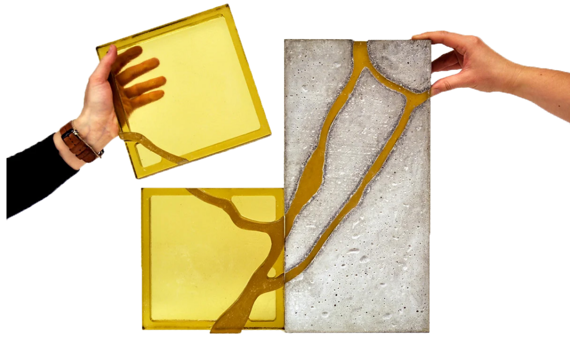
- Innovative Construction Materials
- Architectural flexibility

Scientific Value

- Material Science Advancements
- Interdisciplinary Knowledge

Sustainable Value

- Resource Efficiency
- Recyclability



(1)

Concrete mixture (per L):

CEM I 52.5 R	450 gr
Norman Sand	1350 gr
Water	225 gr

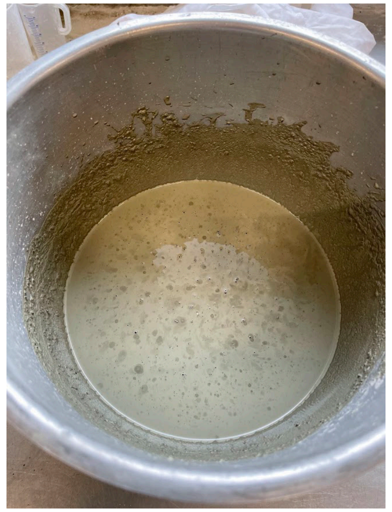
(3)

Concrete mixture (per L):

CEM III/A 52.5 N	450 gr
Norman Sand	1350 gr
Water	225 gr

Concrete mixture (per L):

CEM III 52.5 R	450 gr
Norman Sand	1350 gr
Water	225 gr
Glenuim 51 (Plasticizer)	1 gr



(2)

(4)

Concrete mixture (per L):

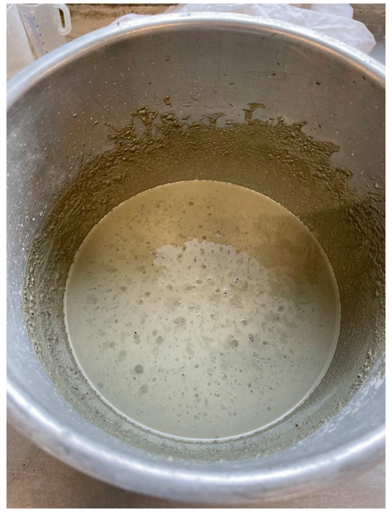
CEM III/A 52.5 N	450 gr
Norman Sand	1350 gr
Water	225 gr
Glenuim 51 (Plasticizer)	1 gr

CONRETE MIXTURE
Result

(1)

(3)

(2)

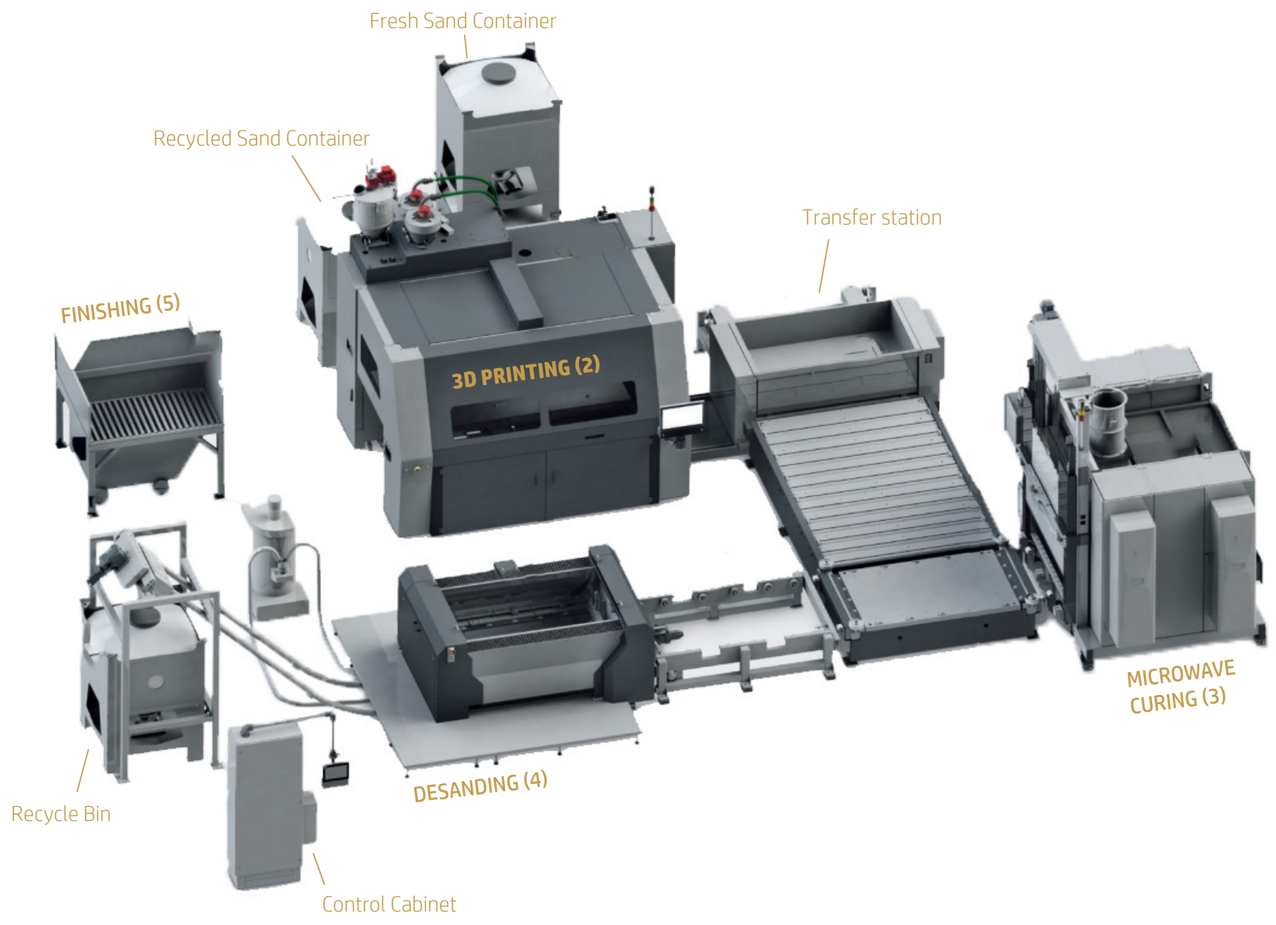


(4)

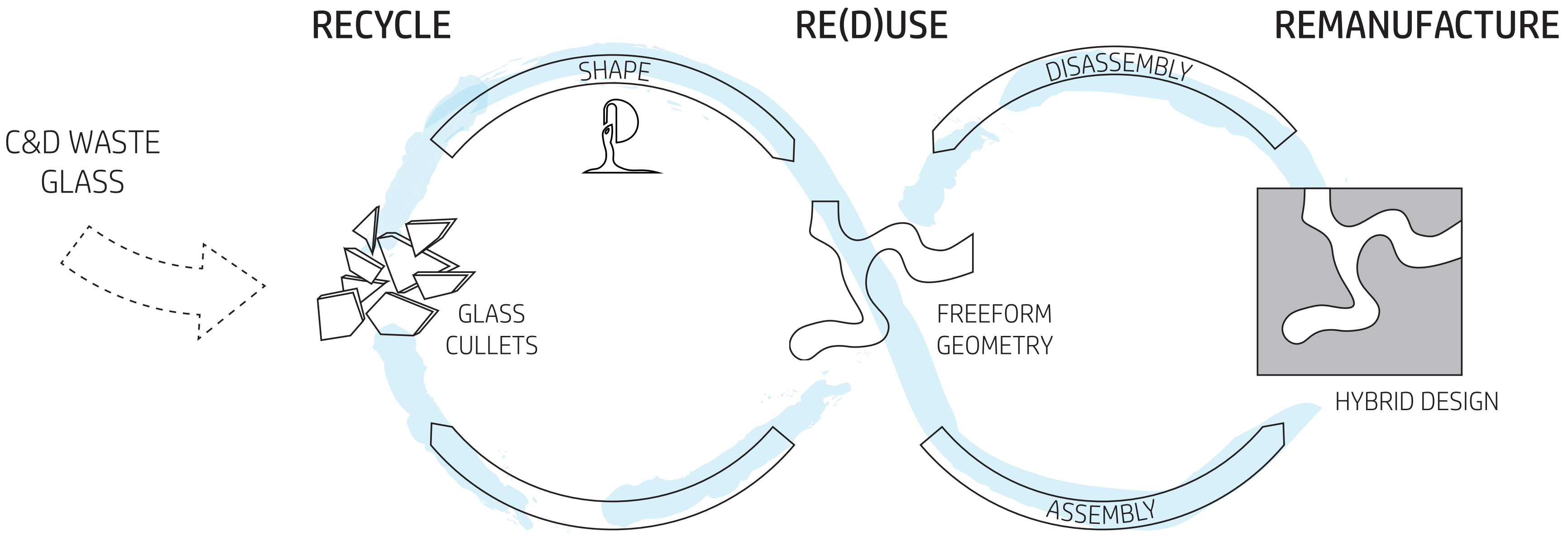
1 2 3 4

CEM III + Plasticizer

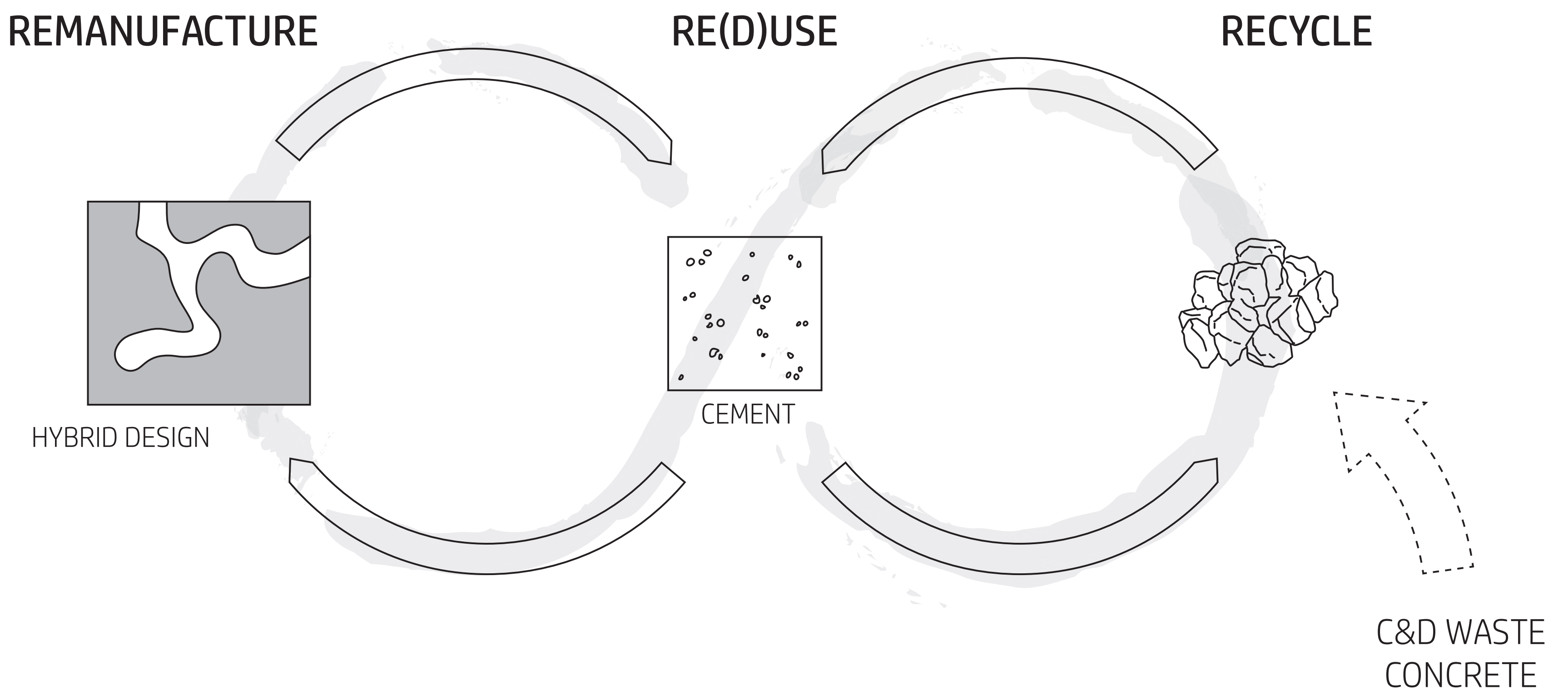
- Use an outer **frame** to constrain the interlocking sand mould pieces
- Application of **coatings** for high surface quality (Arkopal B 5).
- A minimum thickness of **3 to 4 mm** in any section of the mould, with an added thickness of 15 mm around the periphery of the geometry
- Maximum print size is **2200 x 1200 mm**
- **Recycle** sand when desanding and afte firing.



- The interface is always the weakest point; therefore, less strong glass can be used.
- There is **sustainability potential** by using recycled glass cullets.
- By avoiding additives, the glass retains its purity, making it **100% recyclable**.
- The largest kiln glass oven can accommodate a maximum size of **3500 x 1500 mm** with a thickness range of 15-40 mm.
- Use **soda-lime glass** compositions due to their favorable thermal expansion matching

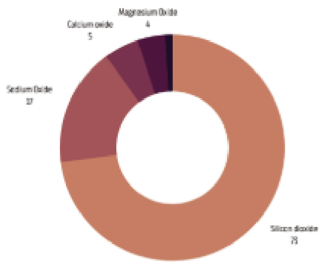
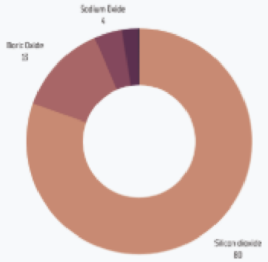
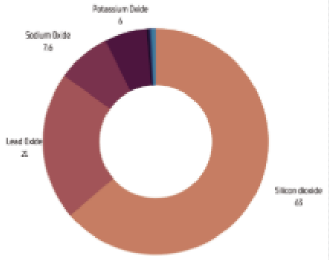
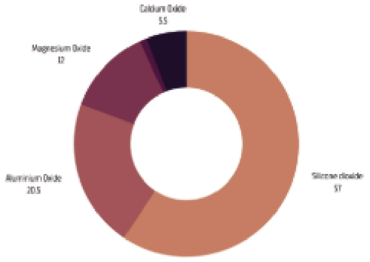
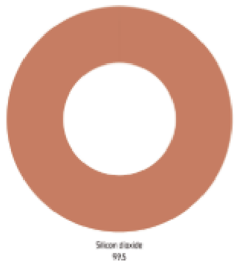
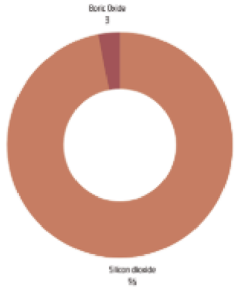


- hybrid mixture of Glass Fiber Reinforced Concrete (**GRC**) and Ultra-High Performance Concrete (**UHPC**).
- Add supplementary cementitious materials (SCMs) to mitigate the risk of Alkali-Silica Reaction (**ASR**).
- Prefab concrete panel are already one of the most industrialised facade panels.
- concrete component can be **filtered, crushed, and recycled** to supply cement for new concrete mixtures.
- Homogeneous composition in terms of **no contaminants** in Recycled Concrete Aggregate (RCA).



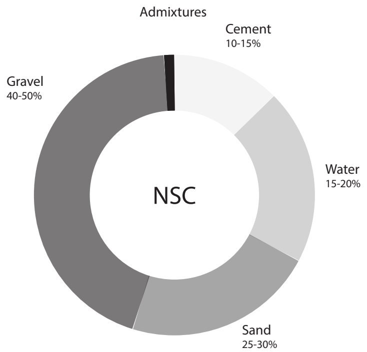
			Structural			Physical			Chemical			Sustainable				Efficiency		
importancy factor	1	2	1	2	1	4	1	2	1	1	3	3	3	4	4	4	1	4
criteria	Density	tensile	yield	Compressive	thermal (U)	expansion	Heat capacity	Combustibilty	Weather resistar	UV-resistance	Embodied energy	Recyclable	Durability	Manufacturing waste	Costs	Shapebility	Accesible	Aesthetics*
value	kg/m3	N/mm2	N/mm2	N/mm2	W/mC	Ustrain / C	J/kg.C				MJ/kg	potential		(I - V)	EUR/kg			
Minerals & Stone (stone)	2300	2 - 25	2 - 25	55 - 255	5,4 - 6	3,7 - 6,3	840 -920	excellent	excellent	excellent	0,952 - 11,6	no	excellent	V	0,323 - 5,3	fair	good	-
Fired Clays (brick)	2000	6,9 - 14	6,9 - 14	69 - 140	0,4 - 0,8	8 - 11	750 - 850	excellent	excellent	excellent	3 - 3,3	no	excellent	II	0,53 - 1,41	poor	good	-
Cement & Concrete (concrete)	2400	1,1 - 1,3	1 - 1,2	13 - 30	1,65 - 2,6	8 - 12	835 - 1050	excellent	excellent	excellent	0,776 - 0,856	yes / no	excellent	I	0,03 - 0,05	excellent	fair	-
Polymer Composite (FRP)	1850	207 - 304	207 - 304	207 - 257	0,42 - 0,51	8,64 - 33	1020 - 1120	good	excellent	fair	95,7 - 106	no	fair	II	28,8 - 31,6	excellent	excellent	-
Thermoplastics (tpPVC)	1360	38 - 46	37,6 - 45,5	37 - 44,3	0,147 - 0,209	65 - 81	1000 - 1100	poor	excellent	fair	60,9 - 67,2	yes	good	II	1,5 - 1,64	excellent	excellent	-
Natural Materials (wood)	550	2,27 - 6,13	1,26 - 3,58		0,218 - 0,382	2 - 11	1660 - 1710	fair	fair	good	11 - 115	no	fair	IV	1,47 - 2,28	fair	fair	-
Alloys (non-ferrous) (aluminium)	2700	288 - 571	241 - 520	245 - 521	135 - 185	22,7 - 24,6	879 - 999	excellent	excellent	excellent	187 - 206	yes	excellent	III	3,03 - 3,2	fair	excellent	-
Metals (ferrous) (stainless steel)	7700	515 - 1300	257 - 1140	252 - 1200	14 - 24,9	10,8 - 16,5	450 -510	excellent	excellent	excellent	69,1 - 76,2	yes	excellent	III	2,4 - 2,57	fair	good	-

			Structural			Physical			Chemical			Sustainable				Efficiency		
importancy factor	1	2	1	2	1	4	1	2	1	1	3	3	3	4	4	4	1	4
criteria	Density	tensile	yield	Compressive	thermal (U)	expansion	Heat capacity	Combustibilty	Weather resistar	UV-resistance	Embodied energy	Recyclable	Durability	Manufacturing waste	Costs	Shapebility	Accesible	Aesthetics*
value	kg/m3	N/mm2	N/mm2	N/mm2	W/mC	Ustrain / C	J/kg.C				MJ/kg	potential		(I - V)	EUR/kg			
Glass	2450	40	N/A	310 -342	0,7 - 1,3	9,2 - 9,5	850 - 950	good	excellent	excellent	8,24 - 9,11	yes	excellent	good	1,2 - 1,41	good	good	excellent
Polycarbonate	1200	62 -72	59 -69	69 - 86	0,19 - 0,22	120 - 125	1150 - 1250	fair	good	fair	101 -111	yes	excellent	good	3,8 - 4,30	good	excellent	fair
Acrylic	1170 - 1200	54 - 72	54 - 72	72 - 124	0,167 - 0,251	90 - 162	1400 - 1520	fair	good	excellent	107 - 118	no	good	good	1,59 - 2,22	excellent	good	excellent
ETFE	1700	42 -47	34 - 37	46,6 - 51,4	0,137	106	1200 - 1250	good	excellent	good	250	yes	excellent	excellent	17 - 23	good	excellent	fair
Epoxy	1100 - 1400	45 - 89,6	36 - 71,7	103 -172	0,181 - 0,196	81 - 117	1180 - 1240	poor	good	fair	115 - 127	no	excellent	good	2,7 - 4,76	excellent	fair	excellent

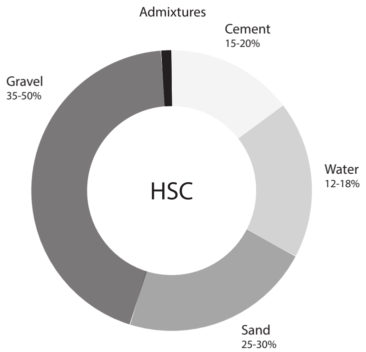
	SODA LIME GLASS	BOROSILICATE GLASS	LEAD SILICATE GLASS	ALUMINOSILICATE GLASS	FUSED-SILICA GLASS	96% SILICA GLASS
GLASS TYPE	 73% SiO_2, 17% Na_2O, 5% CaO, 4% MgO, 1% Al_2O_3	 80% SiO_2, 13% B_2O_3, 4% Na_2O, 2.3% Al_2O_3, 0.1% K_2O	 63% SiO_2, 21% PbO, 7.6% Na_2O, 6% K_2O, 0.3% CaO, 0.2% MgO, 0.2%, B_2O_3, 0.6% Al_2O_3	 57% SiO_2, 20.5% Al_2O_3, 12% MgO 1% Na_2O, 5.5% CaO	 99.5% SiO_2	 96% SiO_2, 3% B_2O_3
OBSERVATIONS	Durable. Least expensive type of glass. Poor thermal resistance. Poor resistance to strong alkalis (e.g. wet cement)	Good thermal shock and chemical resistance. More expensive than sodalime and lead glass.	Second least expensive type of glass. Softer glass compared to other types. Easy to cold-work. Poor thermal properties. Good electrical insulating properties.	Very good thermal shock and chemical resistance. High manufacturing cost.	Highest thermal shock and chemical resistance. Comparatively high melting point. Difficult to work with. High production cost.	Very good thermal shock and chemical resistance. Meticulous manufacturing process and high production cost.
APPLICATIONS	• Window panes • Bottles • Façade glass	• Laboratory glassware • Household ovenware • Lightbulbs • Telescope mirrors	• Artistic ware • Neon-sign tubes • TV screens (CRT) • Absorption of X-rays (when PbO % is high)	• Mobile phone screens • Fiber glass • High temperature thermometers • Combustion tubes	• Outer windows on space vehicles • Telescope mirrors	• Furnace sight glasses • Outer windows on space vehicles
M.P	1350-1400 [°C]	1450-1550 [°C]	1200-1300 [°C]	1500-1600 [°C]	>>2000 [°C]	>>2000 [°C]
S.P	730 [°C]	780 [°C]	626 [°C]	915 [°C]	1667 [°C]	1500 [°C]
A.P	548 [°C]	525 [°C]	435 [°C]	715 [°C]	1140 [°C]	910 [°C]
ST. P	505 [°C]	480 [°C]	395 [°C]	670 [°C]	1070 [°C]	820 [°C]
DE.	2460 [kg/m3]	2230 [kg/m3]	2850 [kg/m3]	2530 [kg/m3]	2200 [kg/m3]	2180 [kg/m3]
C.E	8.5 [10^-6/°C]	3.4 [10^-6/°C]	9.1 [10^-6/°C]	4.2 [10^-6/°C]	0.55 [10^-6/°C]	0.8 [10^-6/°C]
Y.M	69 [GPa]	63 [GPa]	62 [GPa]	87 [GPa]	69 [GPa]	67 [GPa]

MIXTURES

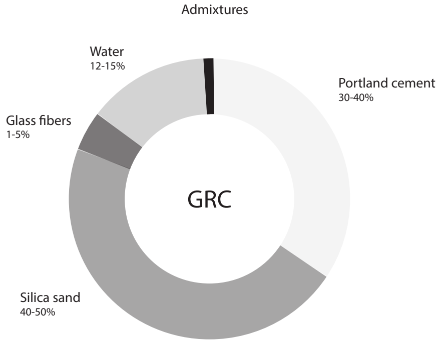
NORMAL STRENGTH CONCRETE



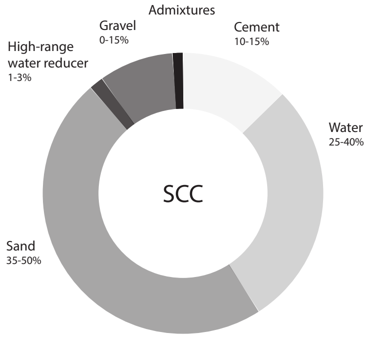
HIGH STRENGTH CONCRETE



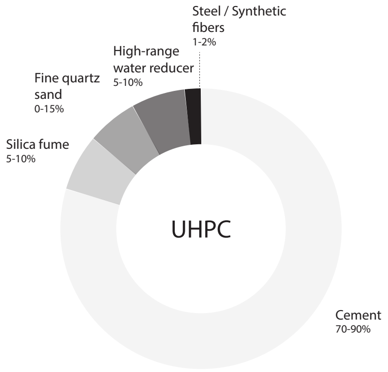
GLASSFIBRE REINFORCED CONCRETE



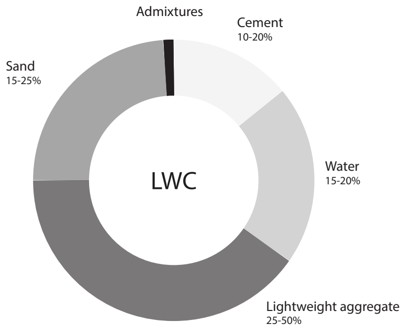
SELF-CONSOLIDATING CONCRETE



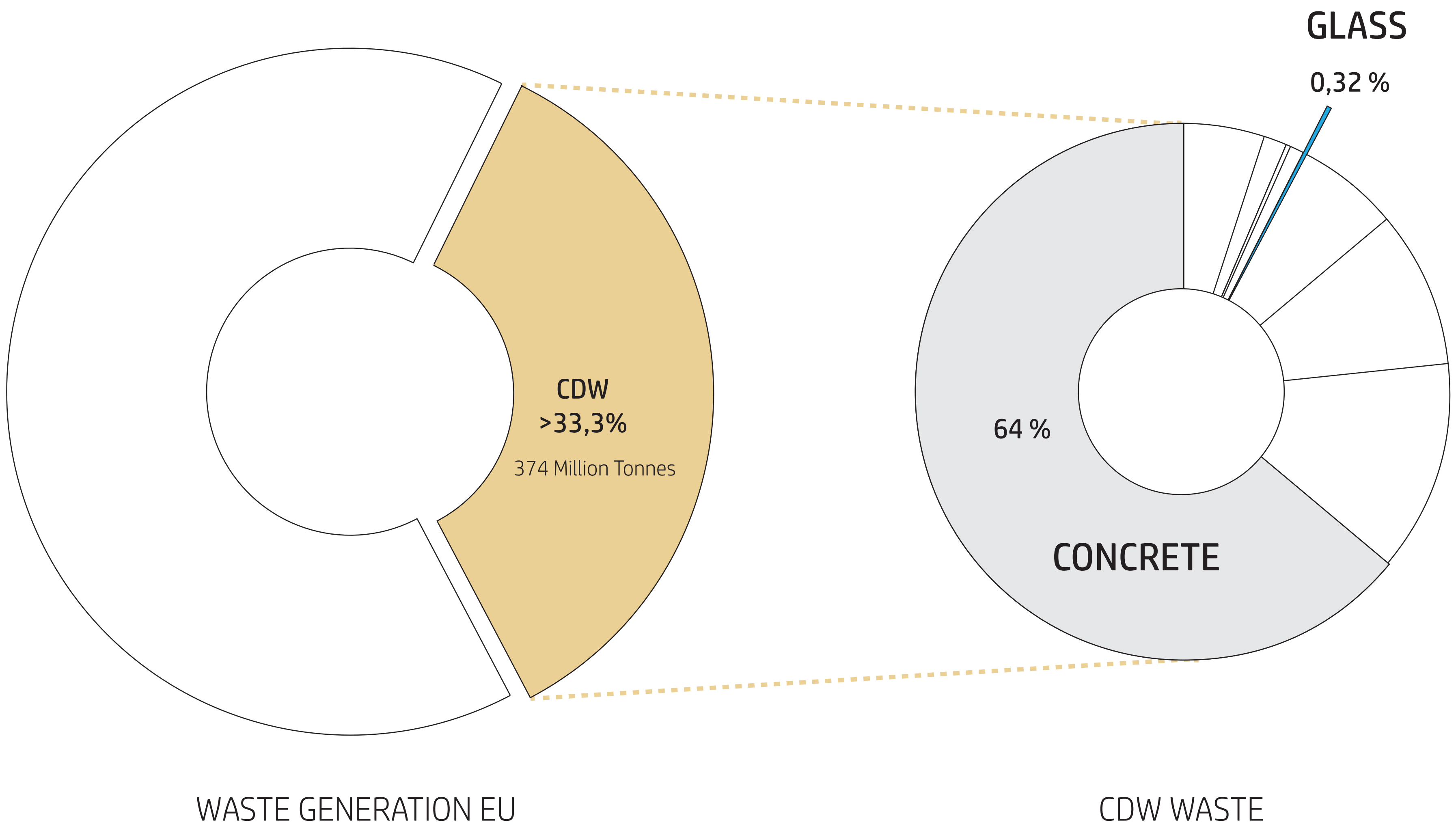
ULTRA-HIGH PERFORMANCE CONCRETE

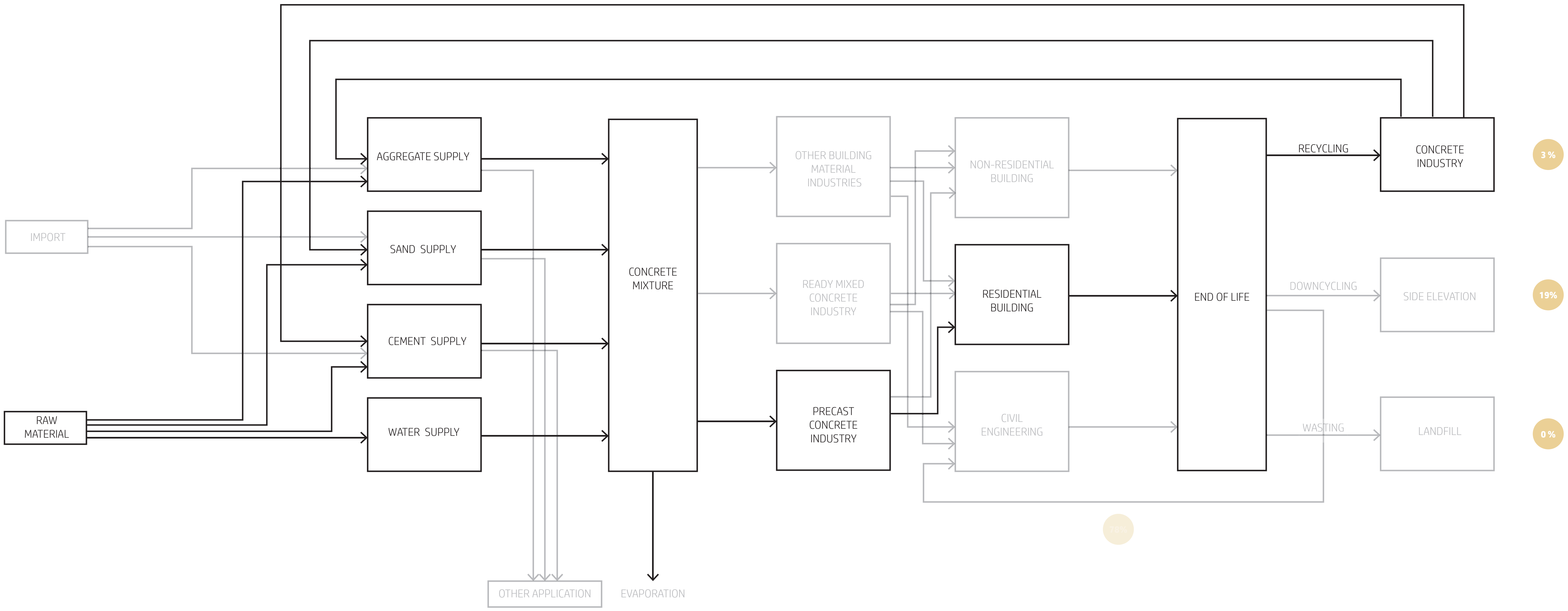


LIGHTWEIGHT CONCRETE

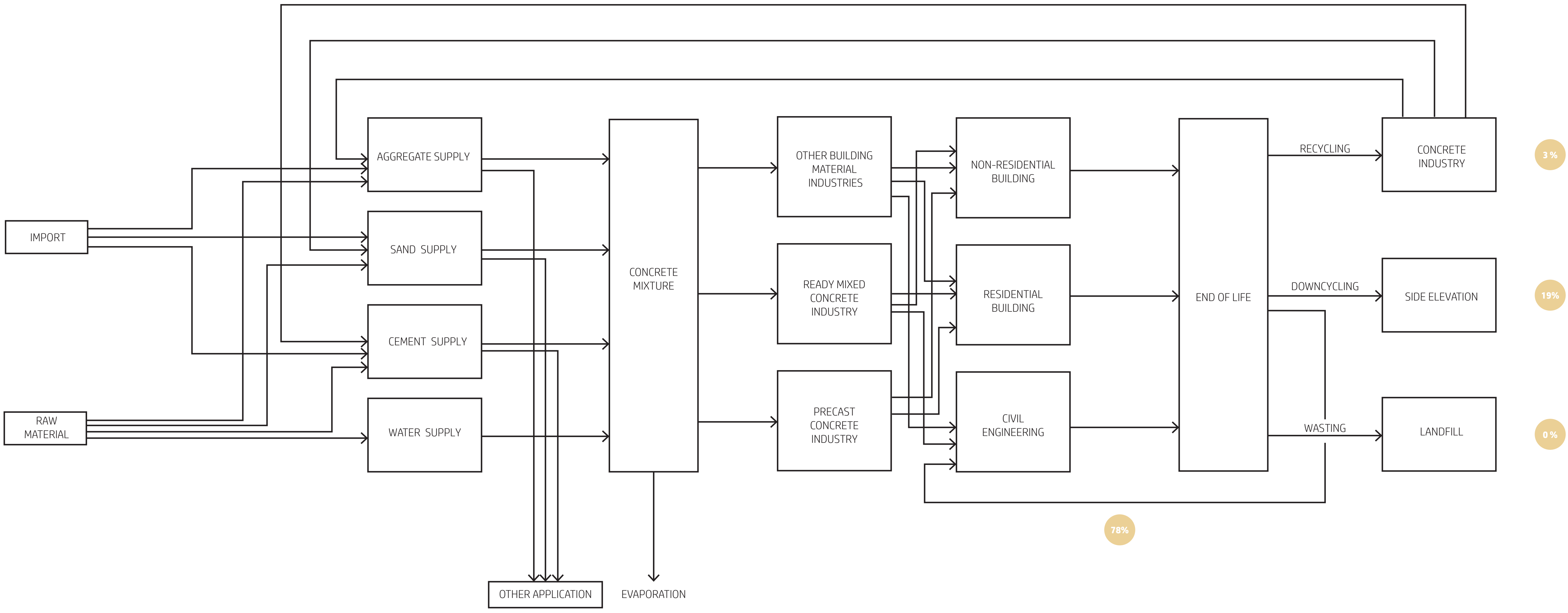


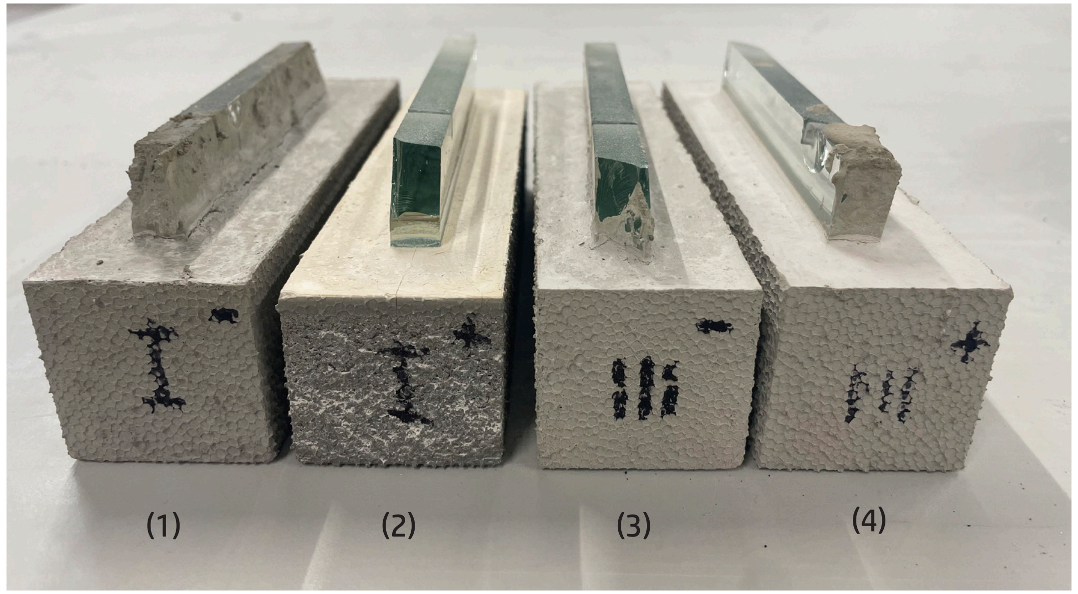
	NORMAL STRENGTH CONCRETE	HIGH STRENGTH CONCRETE	GLASSFIBRE REINFORCED CONCRETE	SELF-CONSOLIDATING CONCRETE	ULTRA-HIGH PERFORMANCE CONCRETE	LIGHTWEIGHT CONCRETE
PROPERTIES	Cost effective. Easy production. Raw materials widely avaiable. Versality in use. Lower strength. Limited durability. Cracking potential.	Increased compressive strength, but lower ductility. Better durability but more brittle than NSC. Costs economically viable.	High strength-to-weight ratio. Good durability and resistance to environmental factors. Enhanced tensile strength. Brittle. Color, texture and shape versatility. Cost-effective.	High fluidity concrete without vibration. Resistannce to segregation. Easy filling, Easy passage. High deformation ability. Significant shrinkage deformation.	High flowing ability. High early and final strength. Superior durability. Expensive.	Low weight. Improved thermal properties. Lower strength properties than normal weight concrete. Less stiff. More possibilities for creep and shrinkage.
C.	+	++	+++	+++	+++++	+++
DE.	2400 [kg/m3]	>3000 [kg/m3]	1800-2000 [kg/m3]	2400 [kg/m3]	2520 [kg/m3]	<2200 [kg/m3]
C.S	20-40 [MPa]	>60 [MPa]	>40 [MPa]	34 [MPa]	>150 [MPa]	17 [MPa]
T.S	2-5 [MPa]	4-7 [MPa]	11 [MPa]	4 [MPa]	>20 [MPa]	2 [MPa]
F.S	3-5 [MPa]	5-10 [MPa]	15 [MPa]	15 [MPa]	45 [MPa]	2 [MPa]
C.E	5.5 - 8.5 [10^-6/C]	5.5 - 8.5 [10^-6/C]	5-8 [10^-6/C]	5.5 - 8.5 [10^-6/C]	4 - 7 [10^-6/C]	5 - 8 [10^-6/C]

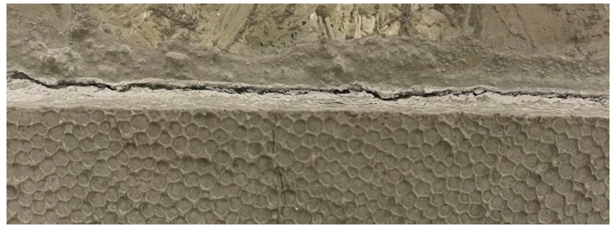

CDW
>33,3%
374 Million Tonnes
GLASS
0,32 %
64 %
CONCRETE
WASTE GENERATION EU
CDW WASTE



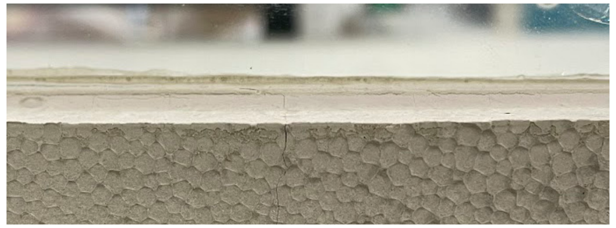
IMPORT
RAW MATERIAL
AGGREGATE SUPPLY
SAND SUPPLY
CEMENT SUPPLY
WATER SUPPLY
CONCRETE MIXTURE
OTHER APPLICATION
EVAPORATION
OTHER BUILDING MATERIAL INDUSTRIES
READY MIXED CONCRETE INDUSTRY
PRECAST CONCRETE INDUSTRY
NON-RESIDENTIAL BUILDING
RESIDENTIAL BUILDING
CIVIL ENGINEERING
END OF LIFE
RECYCLING
DOWNCYCLING
WASTING
CONCRETE INDUSTRY
SIDE ELEVATION
LANDFILL
3 %
19%
0 %


IMPORT
RAW MATERIAL
AGGREGATE SUPPLY
SAND SUPPLY
CEMENT SUPPLY
WATER SUPPLY
CONCRETE MIXTURE
OTHER APPLICATION
EVAPORATION
OTHER BUILDING MATERIAL INDUSTRIES
READY MIXED CONCRETE INDUSTRY
PRECAST CONCRETE INDUSTRY
NON-RESIDENTIAL BUILDING
RESIDENTIAL BUILDING
CIVIL ENGINEERING
END OF LIFE
RECYCLING
DOWNCYCLING
WASTING
CONCRETE INDUSTRY
SIDE ELEVATION
LANDFILL
3 %
19%
0 %
78%





(1)



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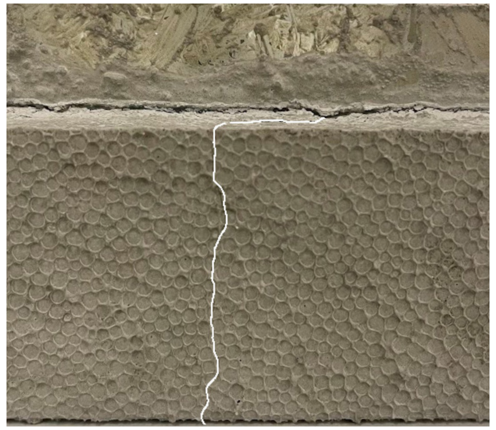
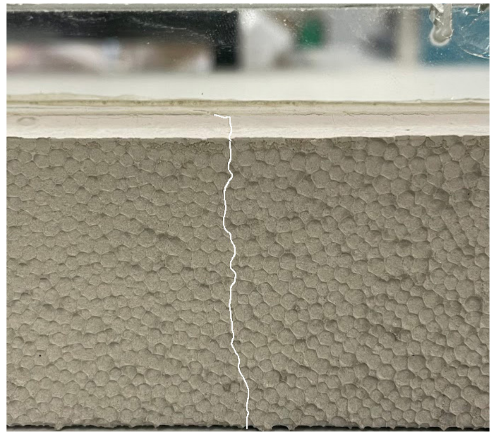


(1)



(4)

ONLY TWO MATERIALS

- No Screws
- No Bolts
- No Drilling