Moss
Artwork by
M. Bilow

bio-host glass

An upcycling foam glass, optimized for bioreceptive applications in the urban environment.

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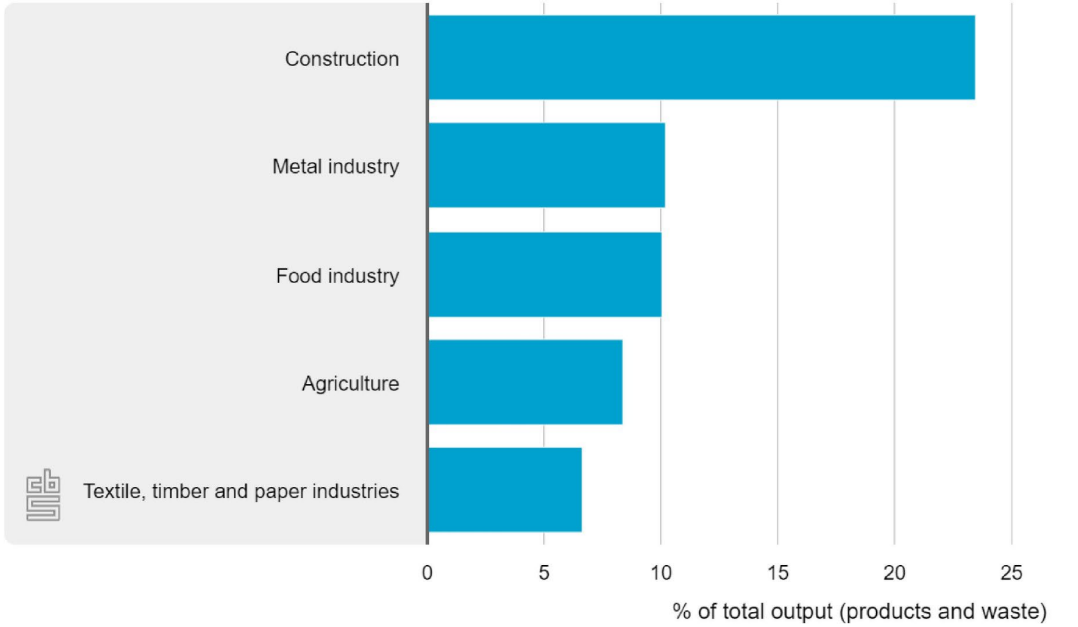
Bristogianni T. (1st mentor)
Bilow M. (2nd mentor)
Oikonomopoulou F. (3rd mentor)

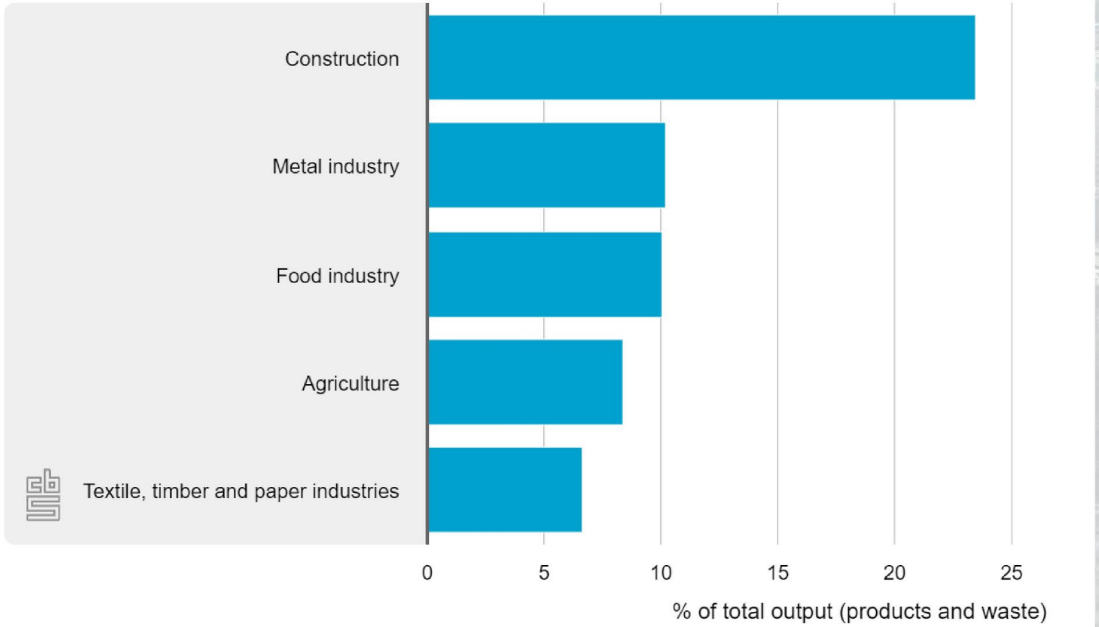
rotterdamclimateinitiative.nl, 2013



1)Excluding the petroleum industry, mining and quarrying, services, electricity industry, repair and installation, and water and waste management.

cbs.nl, 2019

rotterdamclimateinitiative.nl, 2013



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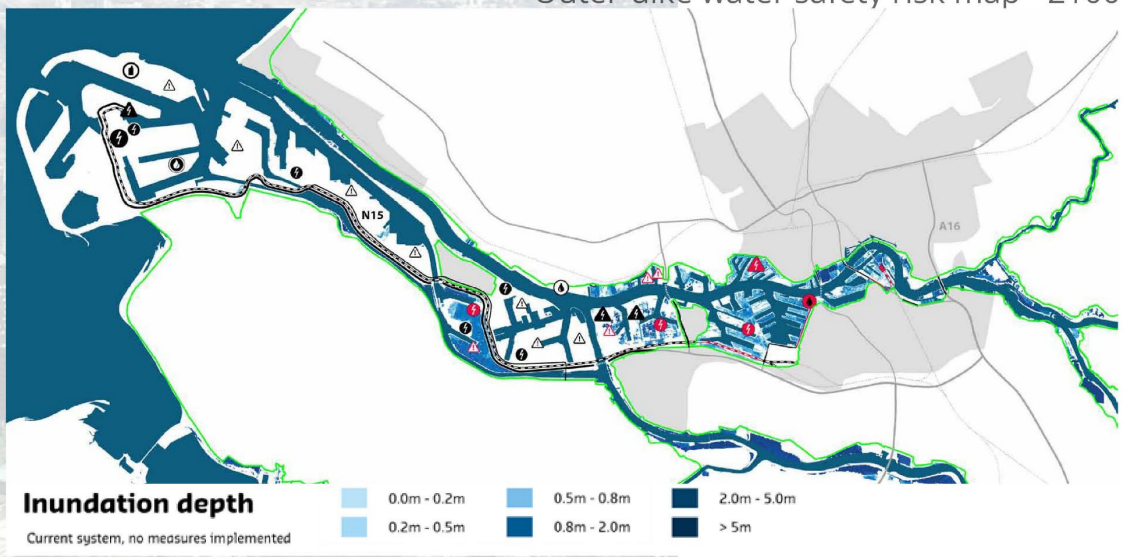
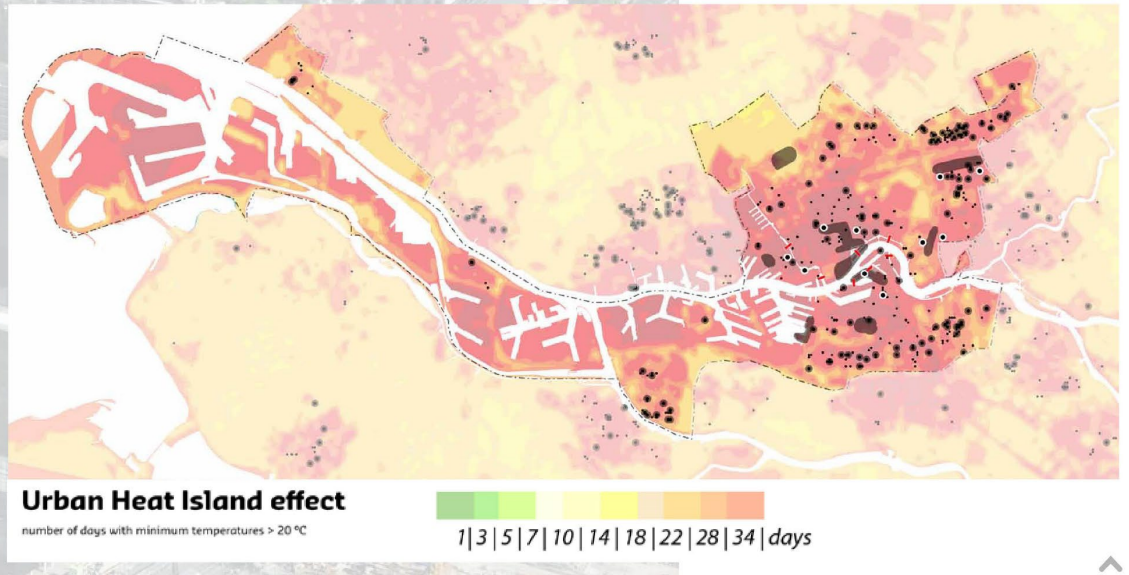
cbs.nl, 2019

Outer-dike water safety risk map - 2100

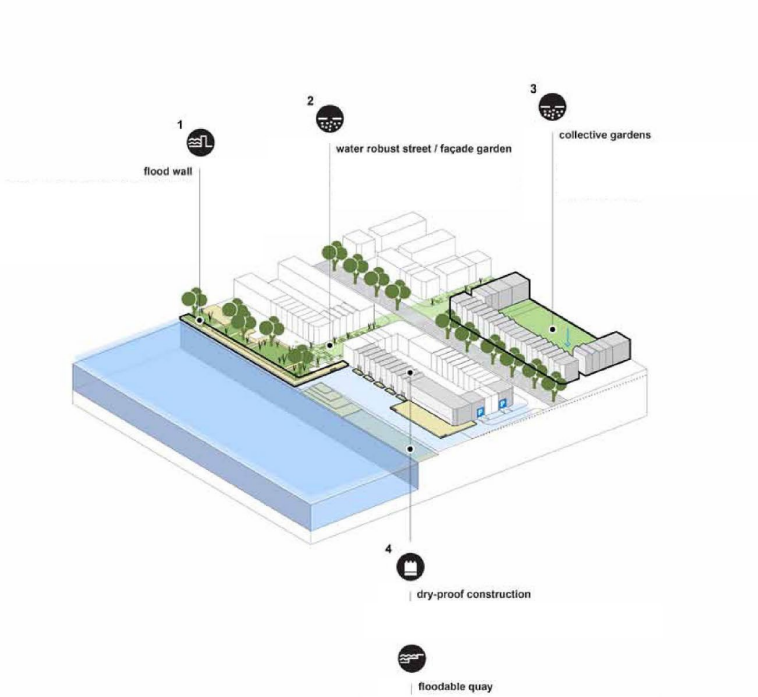


2050

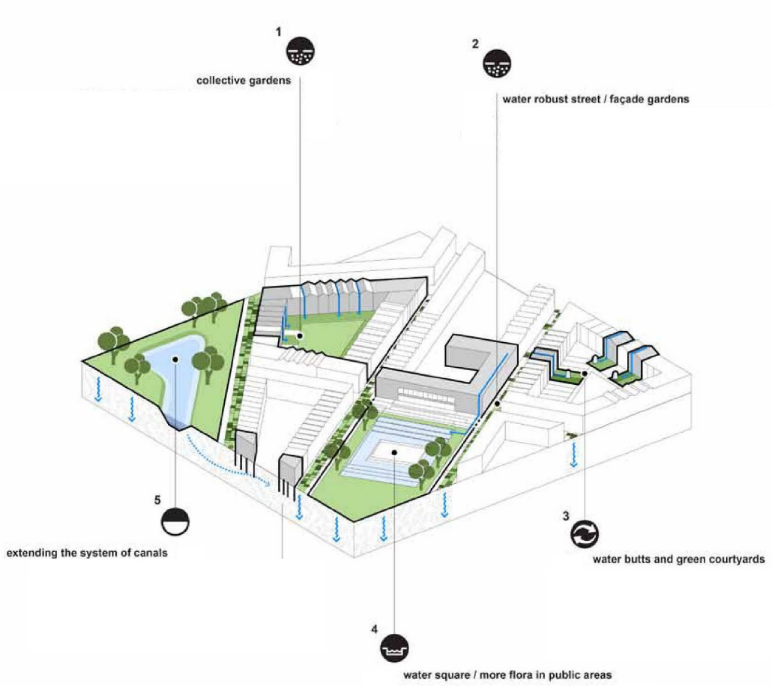


rotterdamclimateinitiative.nl, 2013

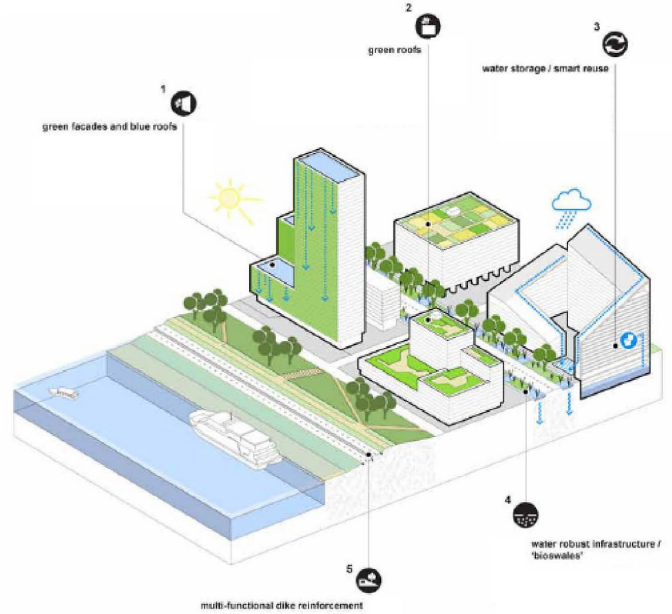
Green & blue network expansion



Outer-dike urban districts



Inner-dike urban districts



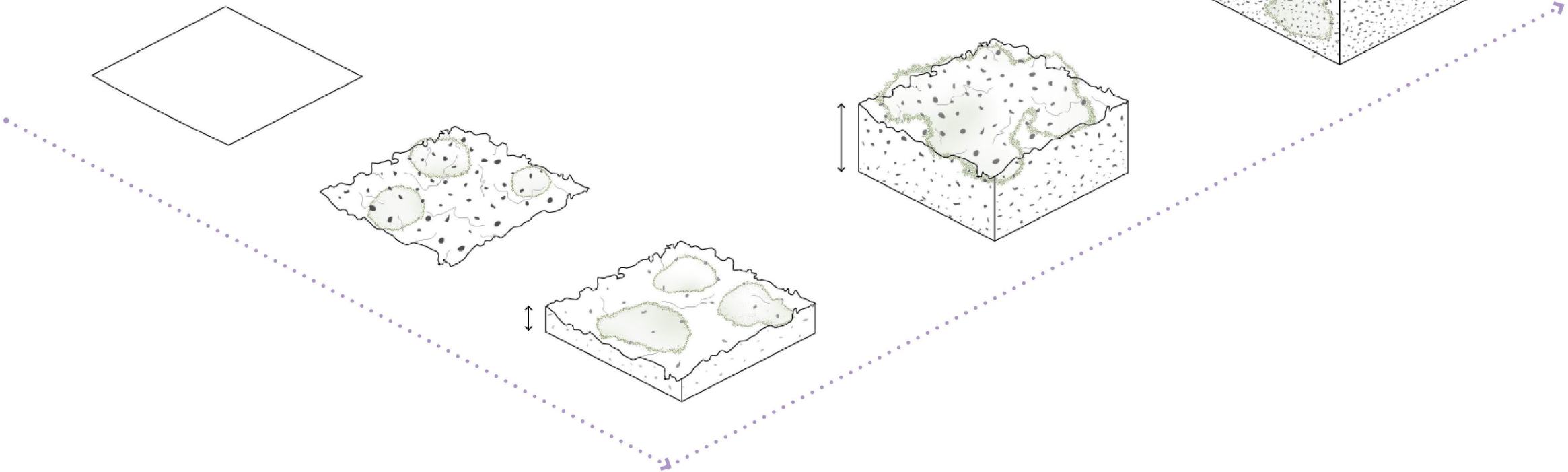
Compact city

Vision

00. Reflective Surface

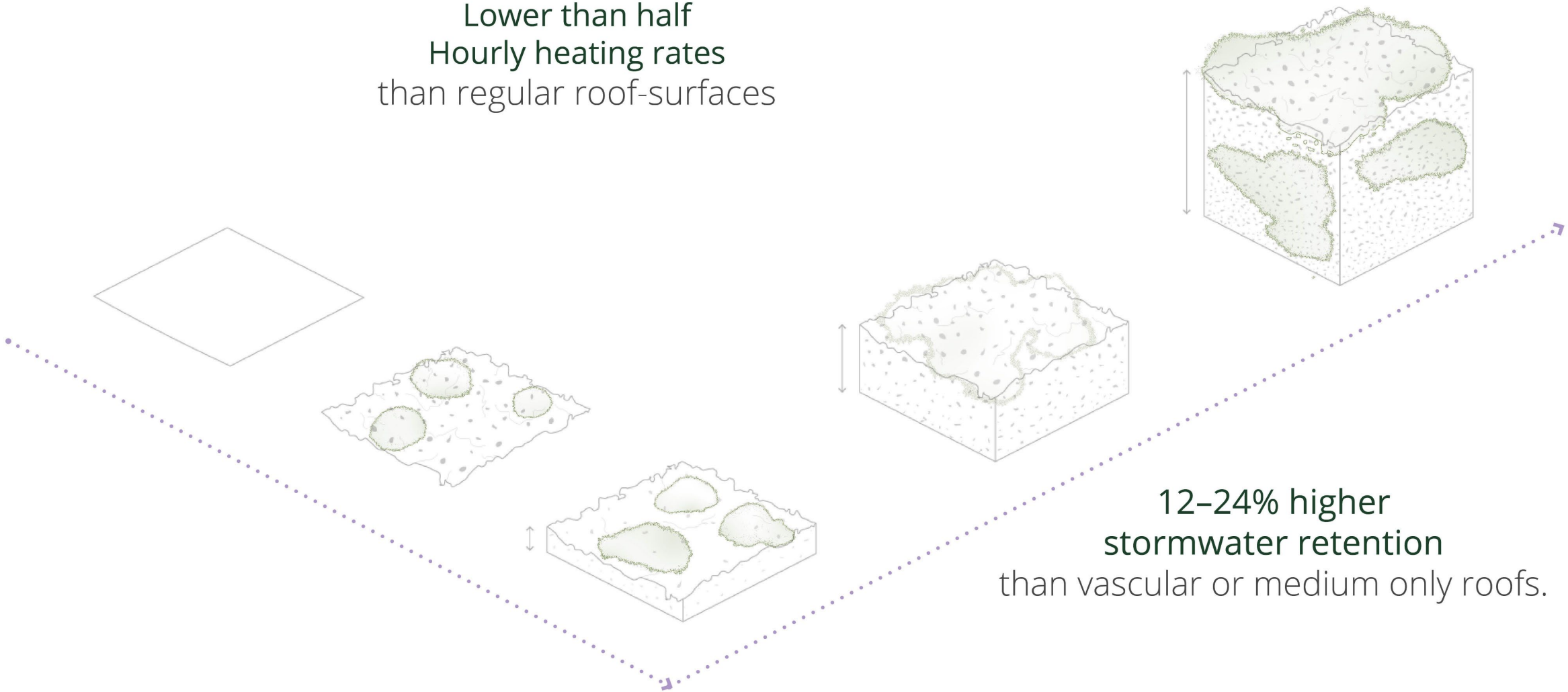
01. Porous Surface

02. Porosity gradient
+
thickness



Gains

Lower than half
Hourly heating rates
than regular roof-surfaces

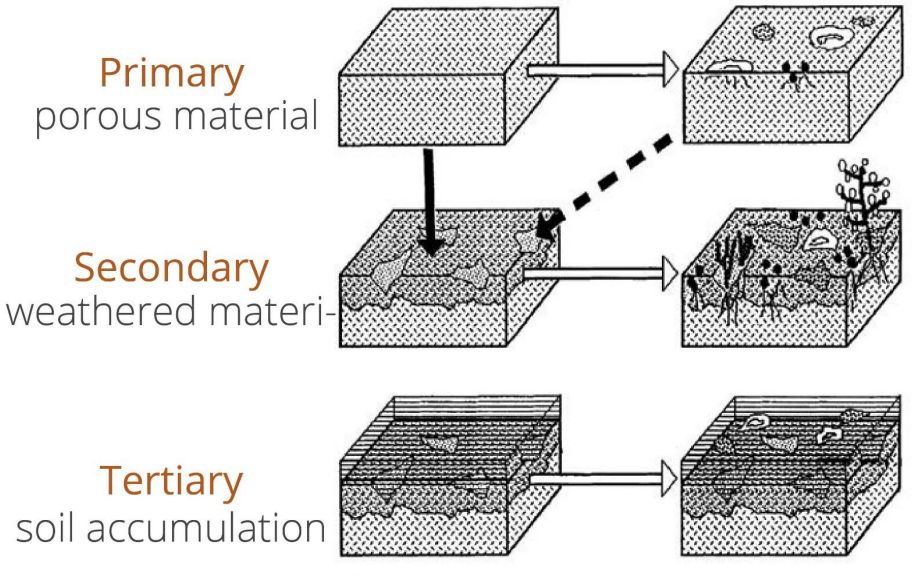


12–24% higher
stormwater retention
than vascular or medium only roofs.

Definition of bioreceptivity

‘ability of the material to be colonized by microorganisms’.
(Guillitte, 1995)

Lichens and mosses forming a diverse biofilm on stone.



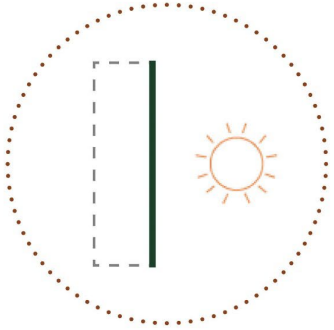
Guillitte, O. (1995).

Sanmartín, P. et al. (2021).

Conditions for bioreceptivity

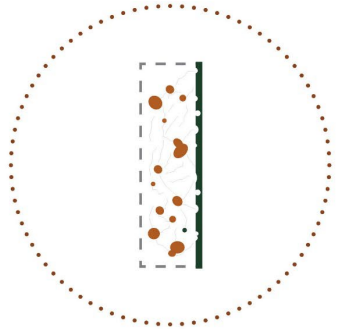
Rainfall or/and
Irrigation RH 70% ±

Nutrients transferred

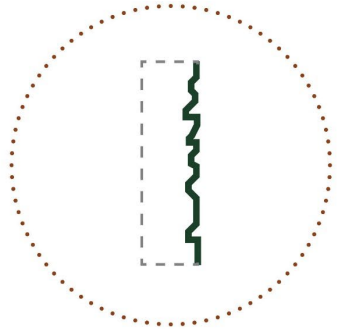


Solar exposure
depending on the
microorganism

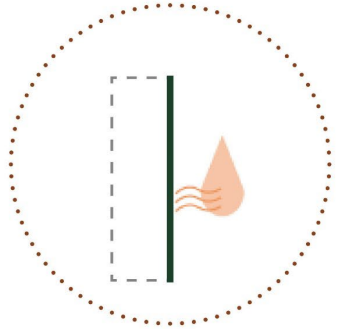
Proximity to sea
or greenery



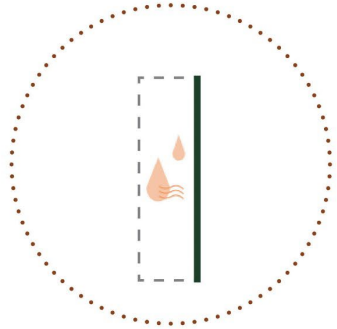
Capillary Porosity



Surface Roughness/
Surface Grooves



Water absorption

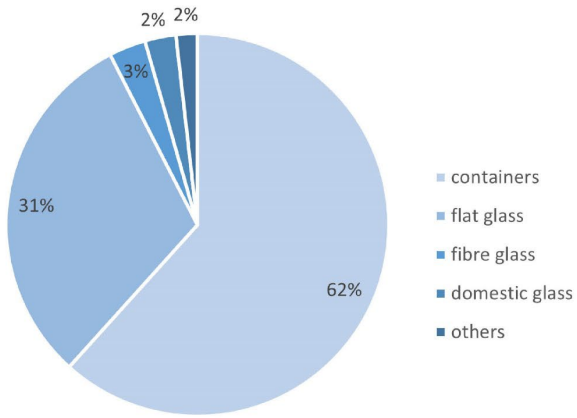


Water retention

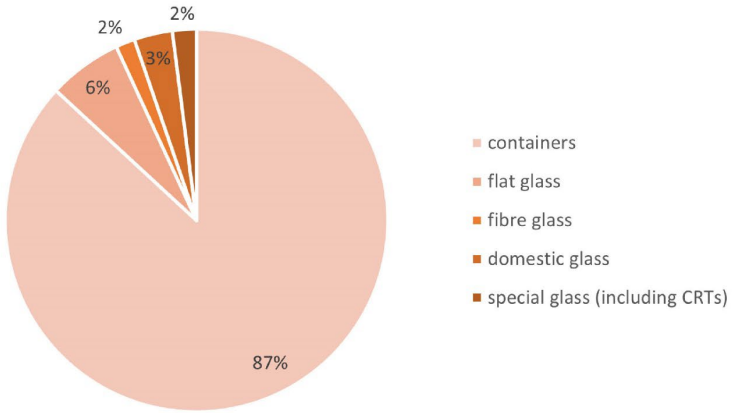
Neutral pH

Enviromental ‹ › Material-focused

Glass waste as raw material



Glass Production per sector, Glass Alliance, 2021



Glass Waste per sector, Glass Alliance, 2021

ARUP, 2018.

Glass waste as raw material

Bristogianni T. , 2019.

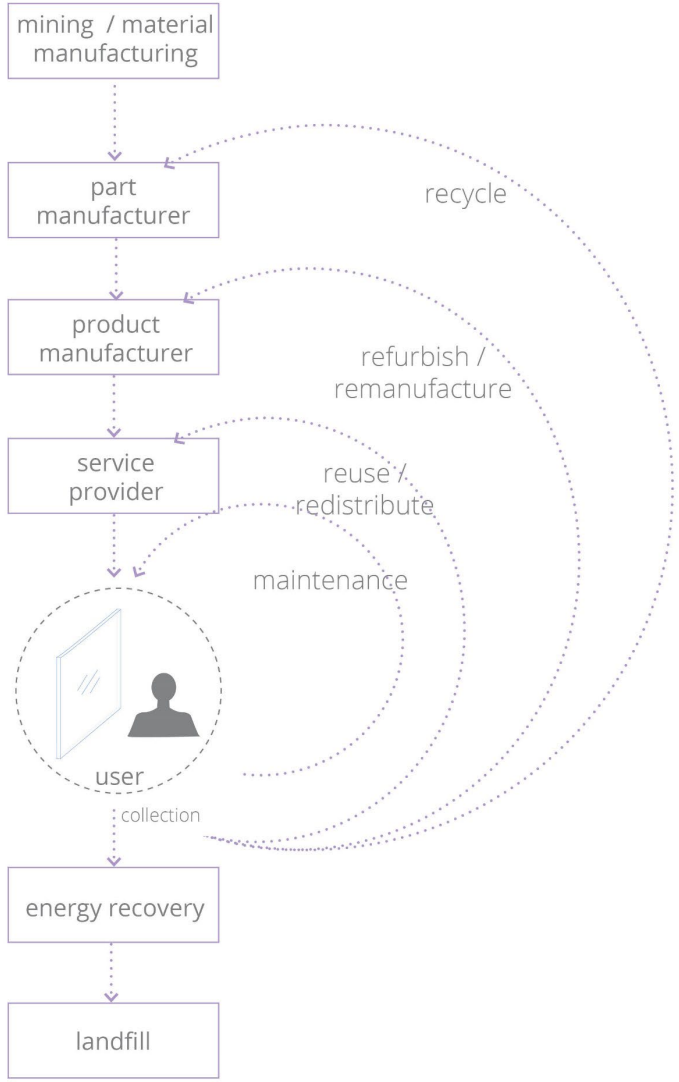


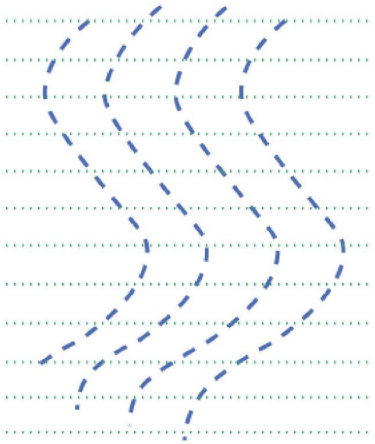
Diagram inspired by Linear and Circular process of float glass, 2020, originally from DeBrincat & Babic.

Research Question

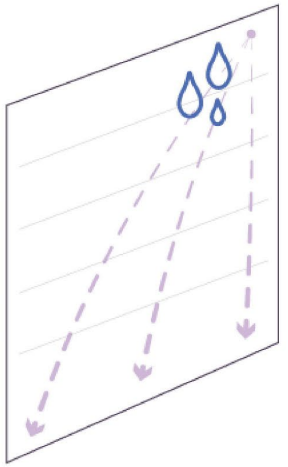
How can porous glass be manufactured out of glass waste to obtain bioreceptivity and which are the possible applications for this new material ?

Research scales

micro



meso

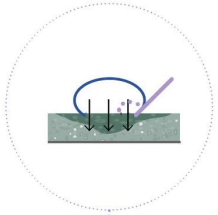


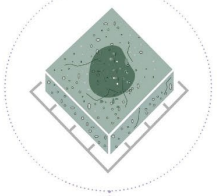
macro

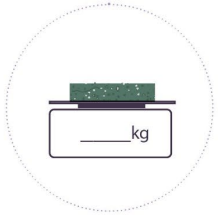
Testing & experimenting process

1st batch
(TC01, TC04-TS10)

Testing

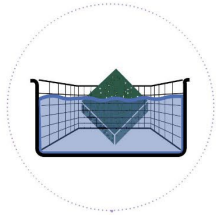


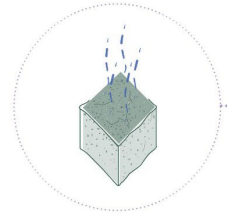


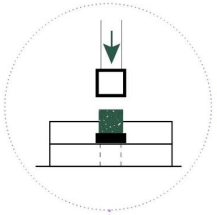


2nd batch
(TC11- TBS18)

Testing

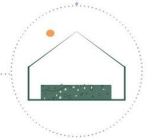


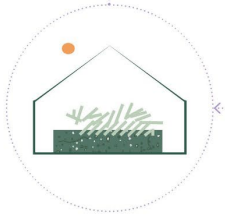




3rd batch
(TBS19- TBS24)

Testing

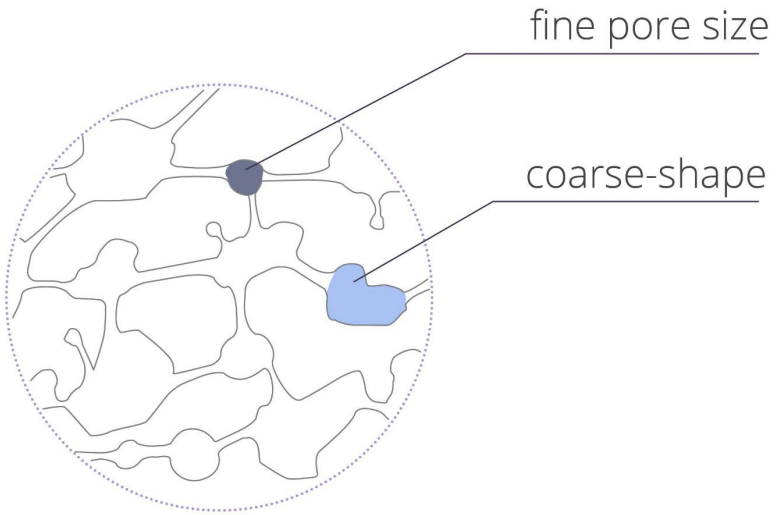




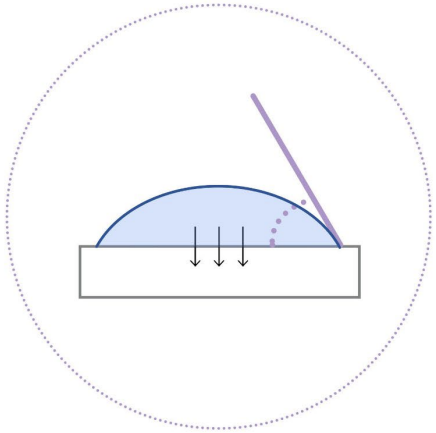
Design

Material potential
for applications

Microstructure goal



Connected Porosity

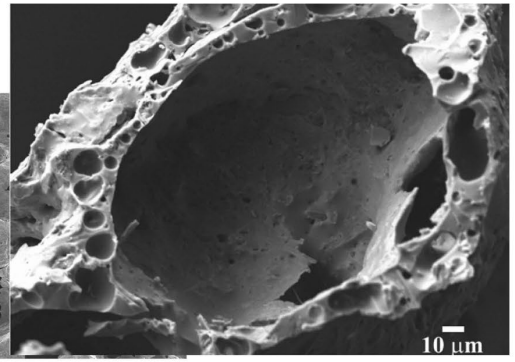


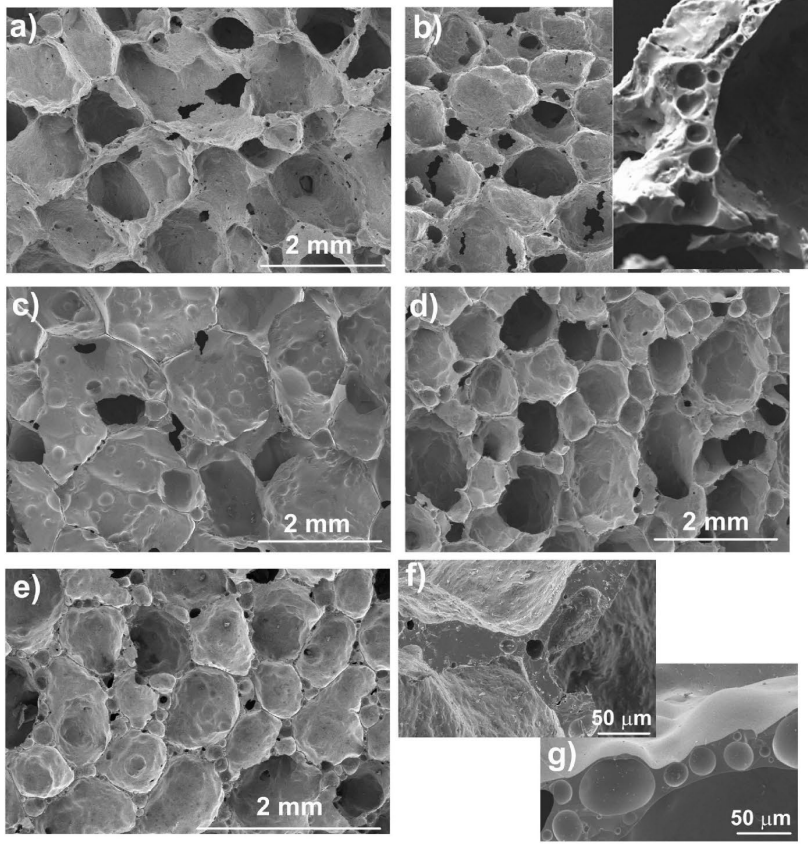
Low contact angle

Literature evidence

Open-porous glass-foams

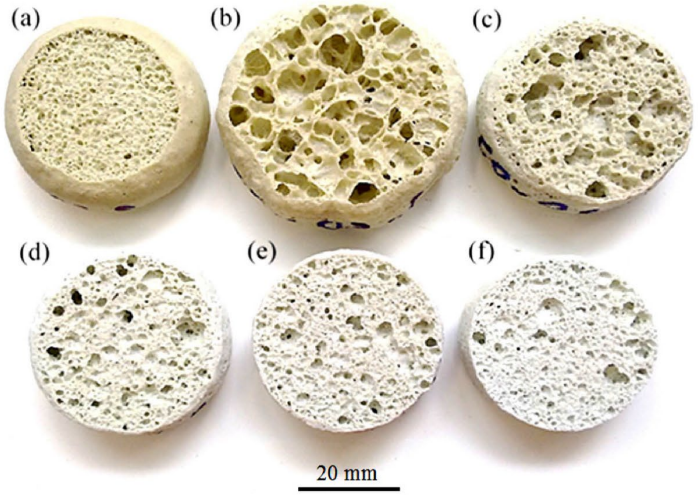
micrometre pores in the pore walls of open-porous foam glass from waste flatglass.
König J. et al., 2019.





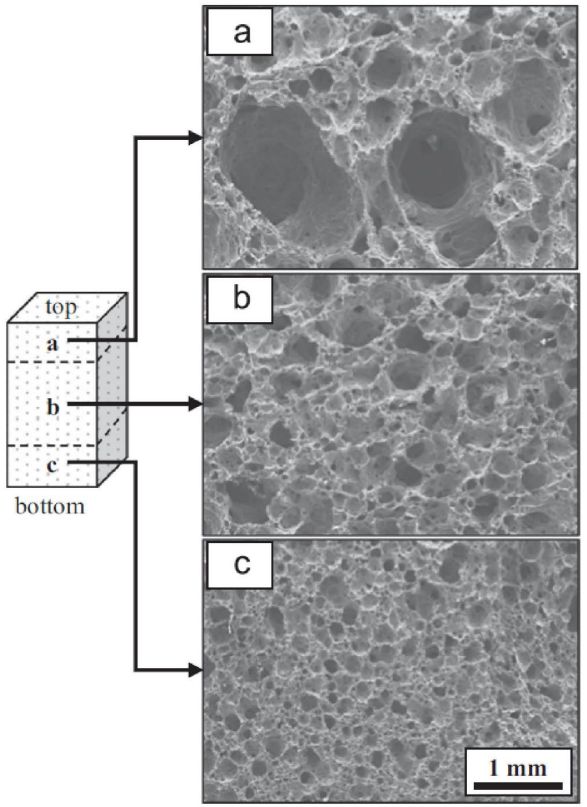
SEM images of open-porous samples from SLS glass and closed-porous from panel glass.
König J. et al., 2020.

Eggshells as foaming agent



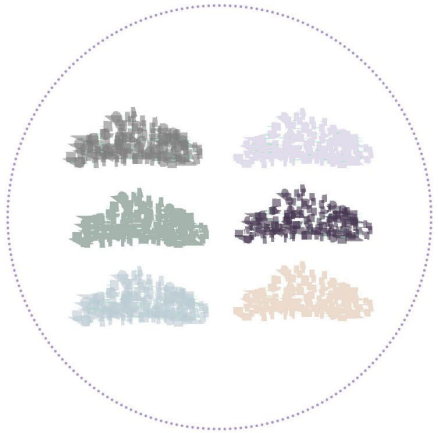
Different content of eggshells in the mixture,
Souza et al., 2017.

Porosity gradient

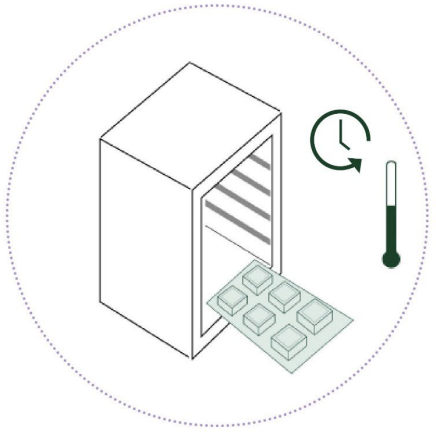


SEM micrograph of glass foam out of panel CRT with calcite.
Fernandes et al., 2014.

Tested Parameters

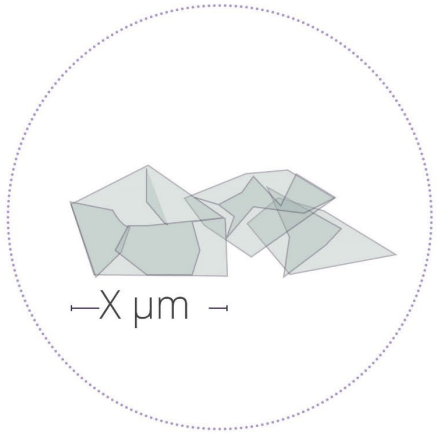


Glass waste & foaming additives



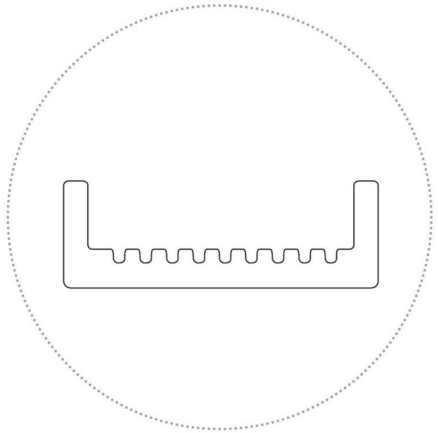
Heating schedule

- Top Temperature
- Dwell time at Top temp.
- Cooling rate



Cullet / powder

- Granule size
- Weight percentages



Mould shape capabilities

Recipe & Production variables tested

1. Recipe Test

Main Ingredient	Foaming Agent	Other additives
soda-lime glass	calcite ($CaCO_3$)	$CaHPO_4$ (for crystallization)
Borosilicate (B_2O_3)	dolomite ($CaMg(CO_3)_2$)	vitrified bone ash
CRT glass	carbon black	fly ash
Cyclon mix*	eggshells**	concrete
special black glass		vermiculite

optimization for max usage of waste

2. Process

Top Temp.	Dwell time to top temp.	Fast Cooling to annealing point
790 °C	2 hrs	1 hr
840 °C	5 hrs	2 hrs
900 °C	10 hrs	4 hrs
960 °C		

optimization of pore structure & energy

* Cyclon mix: by-product of recycling glass bottles, mainly containing SLS glass but heavily contaminated
** egg-shells contain 95% of CaO, making them worthy of research for glass-foams

Samples

TC01

TT02

TT03

Tiles

TC04

TC05

TC06

TS07

TBS08

TC09

TS10

TC11

TC12

TC13

TC14

Moss Growth

TBS15

TS16

TBS17

Moss Growth

TBS18

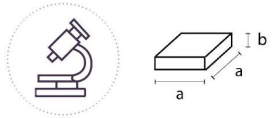
TBS (19-21)

Compressive strength

TBS22

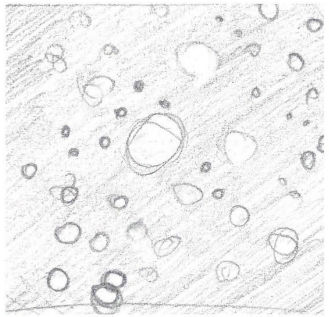
Mould-design

Microstructure Types

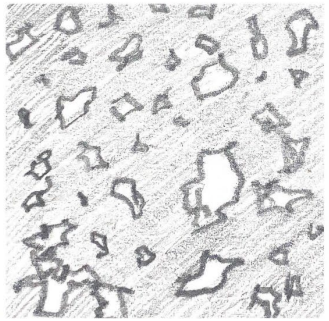


Type 01

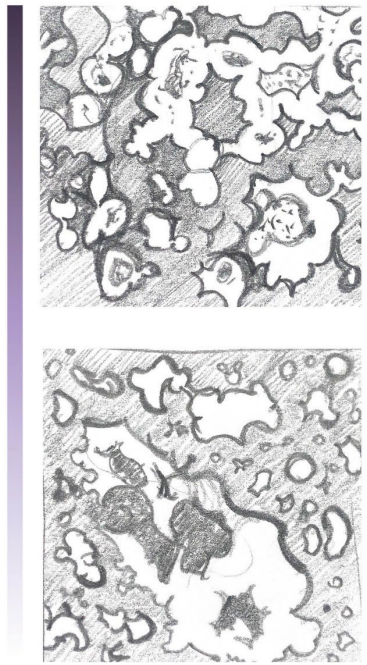
a_



b_

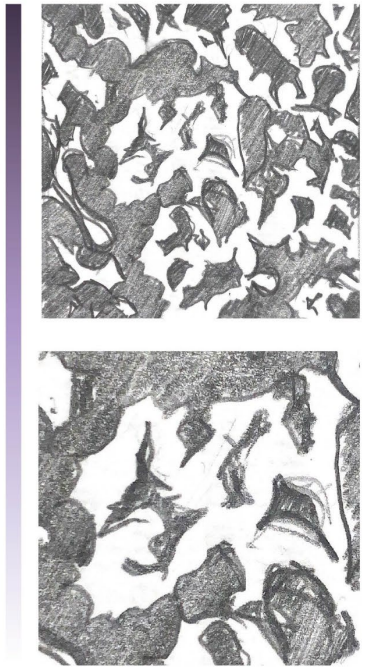


Type 02

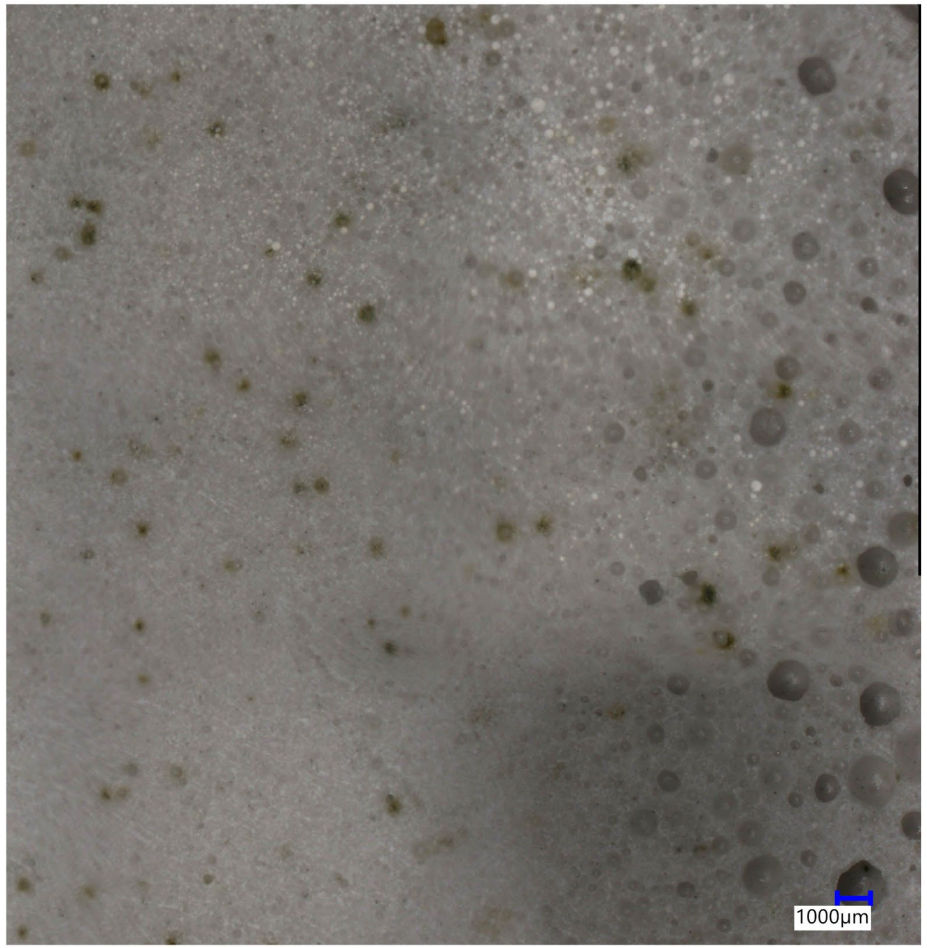


Type 03

Type 04

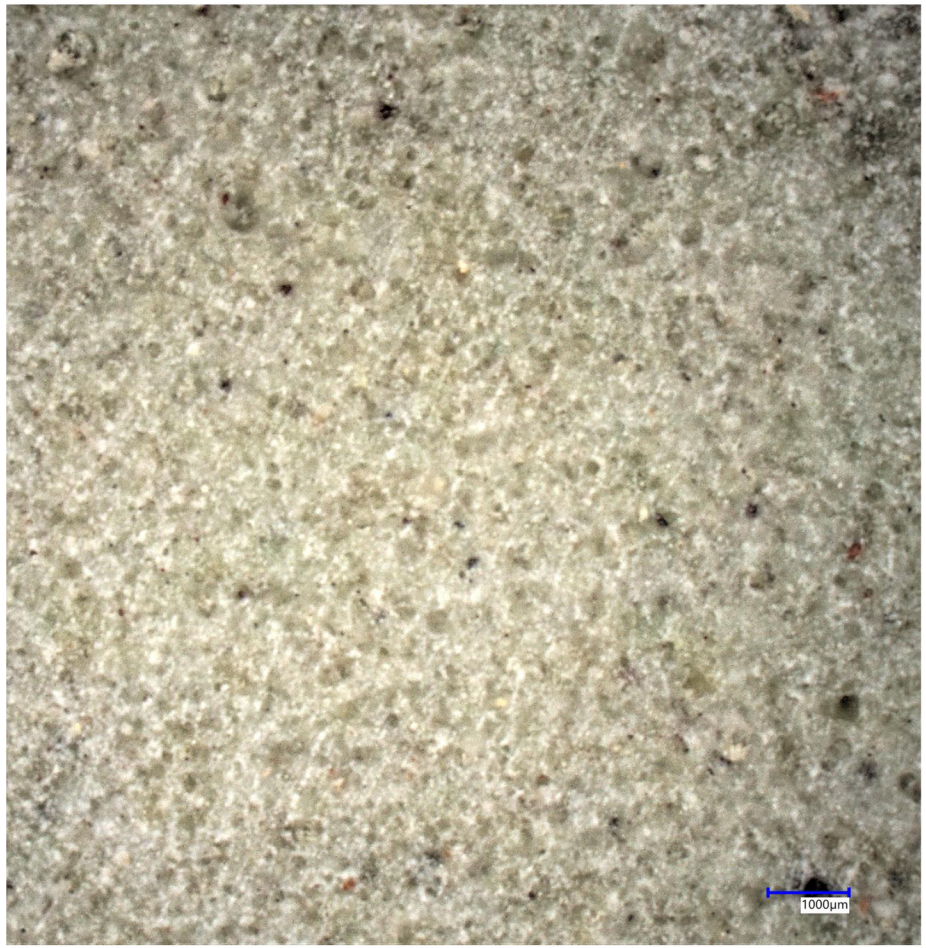


Porosity features | Type 01

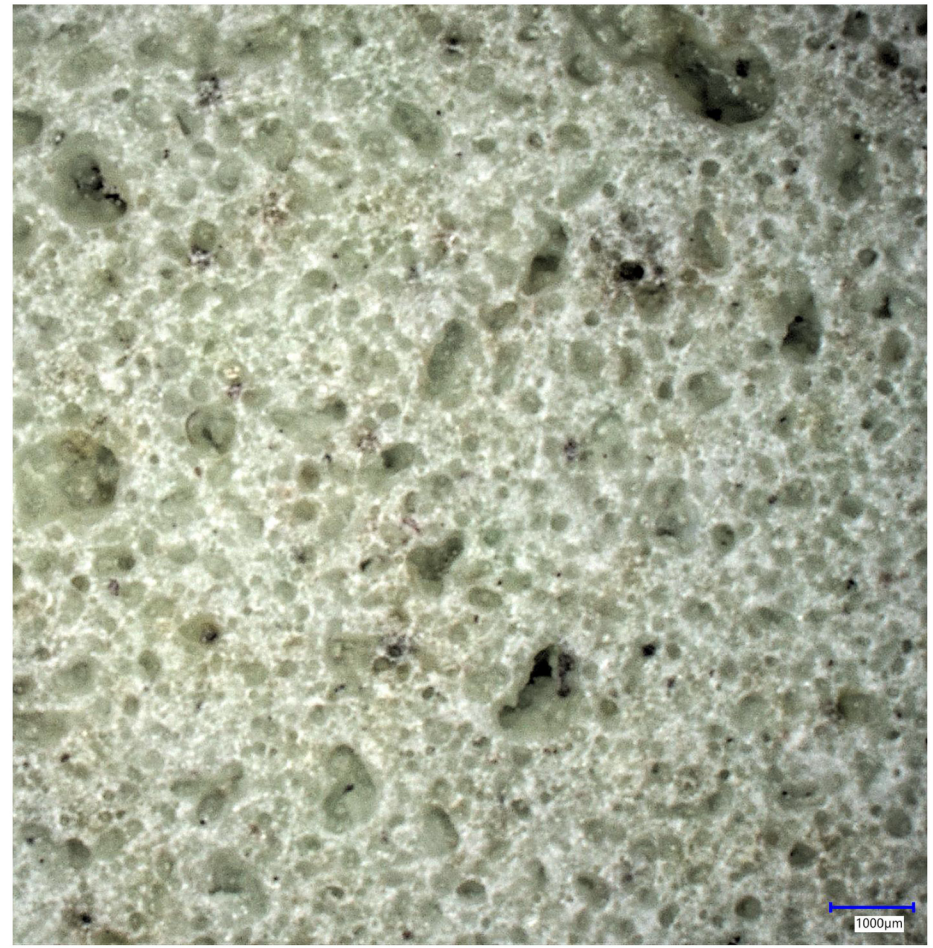


TS07	TS10
Soda-lime glass powder (50-250µm)	
Carbon black (0.33wt%) $CaHPO_4$ (1.66wt%)	
960 °C	790 °C
2 hrs	
slow	fast

Porosity features | Type 02

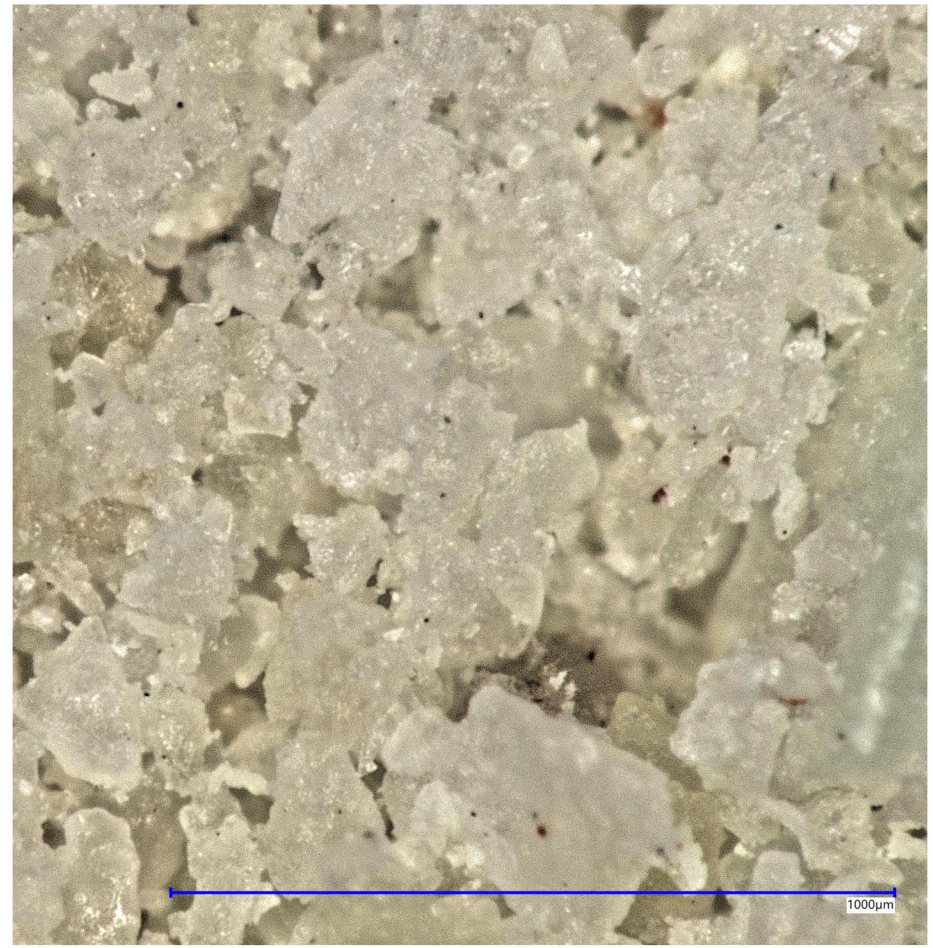


TC05	TC06
Cyclon mix*	
Carbon black (0.33wt%) $CaHPO_4$ (1.66wt%)	
840 °C	960 °C
max	2 hrs
/	slow

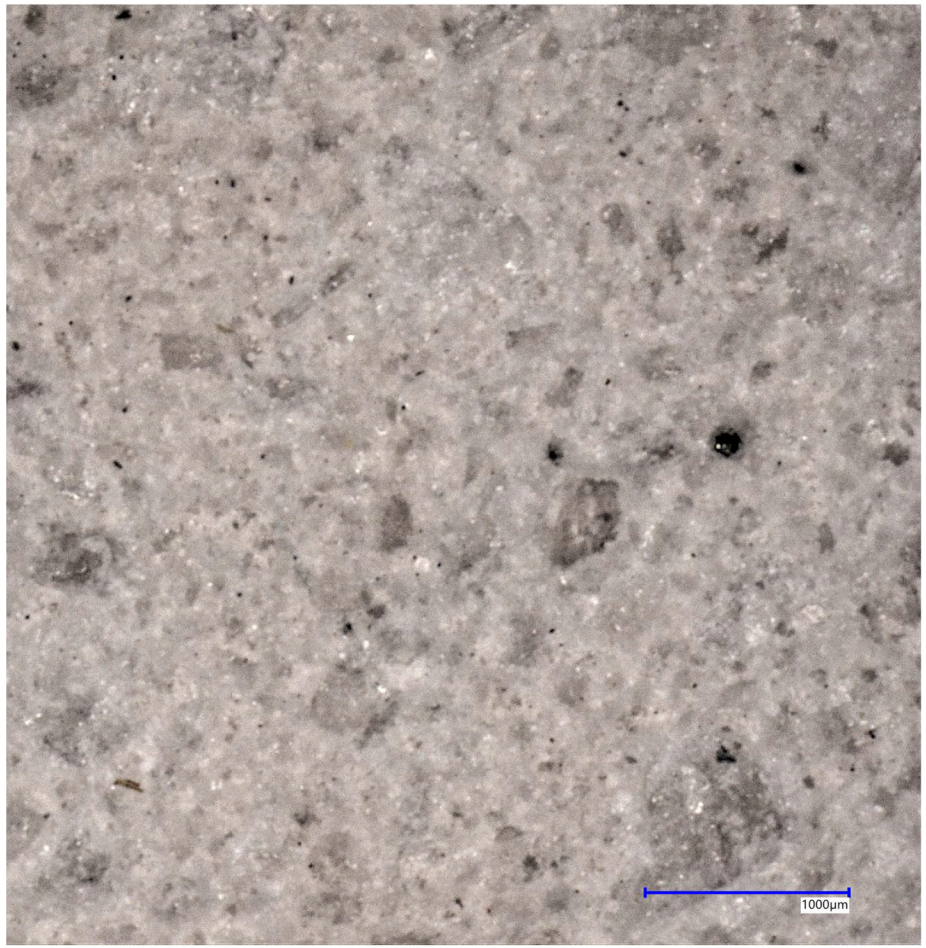


Porosity features | Type 03

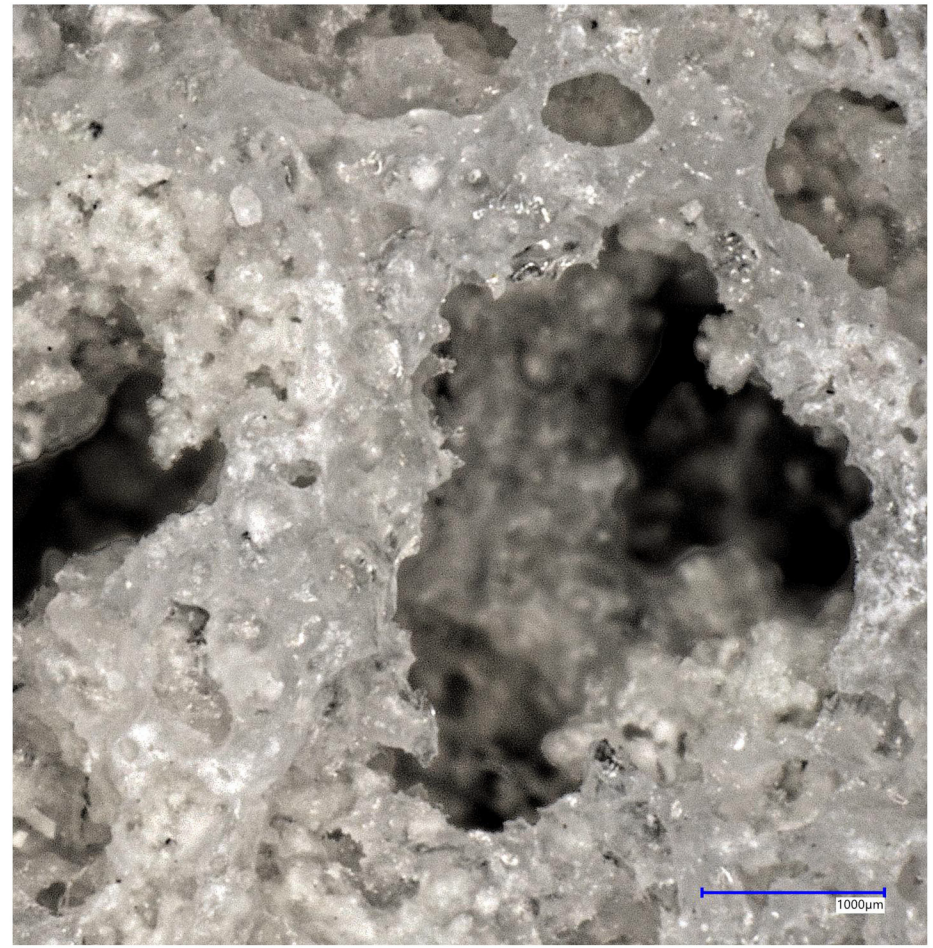
TC04	TC11
Cyclon mix*	
$CaCO_3$ (10%wt) +	$CaCO_3$ (3%wt)
840 °C	
max	2 hrs
slow	fast



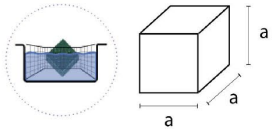
Porosity features | Type 04

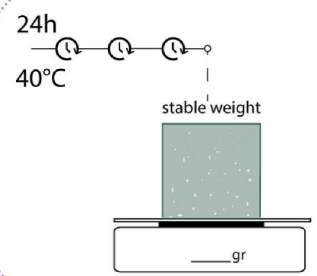


TBS08	TS16
Borosilicate cullet (50%) Soda-lime powder (50%)	Soda-lime cullet (50%) Soda-lime powder (50%)
Carbon black (0.33%wt) $CaHPO_4$ (1.66%wt)	$CaCO_3$ (5%wt)
790 °C	840 °C
max	2 hrs
– /	fast

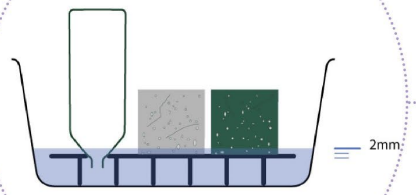


Process of testing Hydraulic Properties

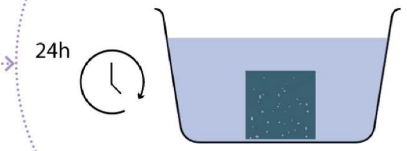


1. 

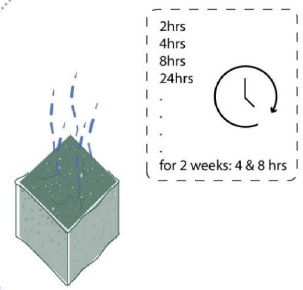
Dried weight measurement (W_d)

2. 

Water Absorption rate

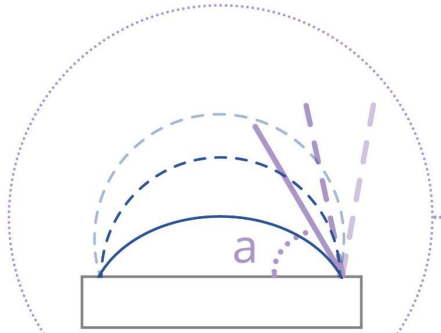
3. 

Saturation weight measurement (W_s)

4. 

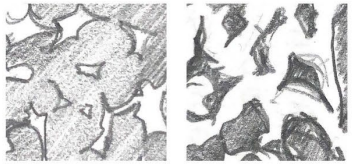
Evaporation rate

Quick-testing of Contact Angle



Hydrophilic /
Hydrophobic solid

→ a = 0 °



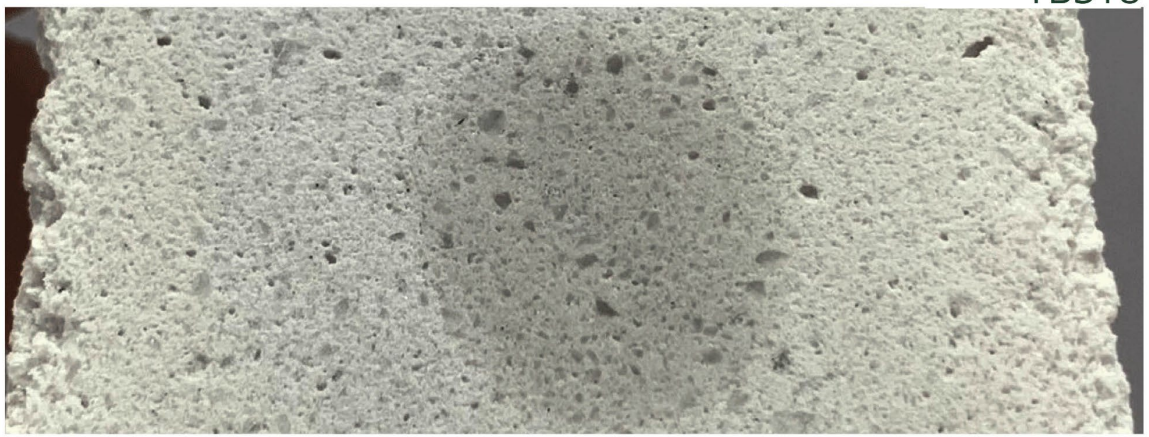
Type 03 Type 04

→ a < 90 °

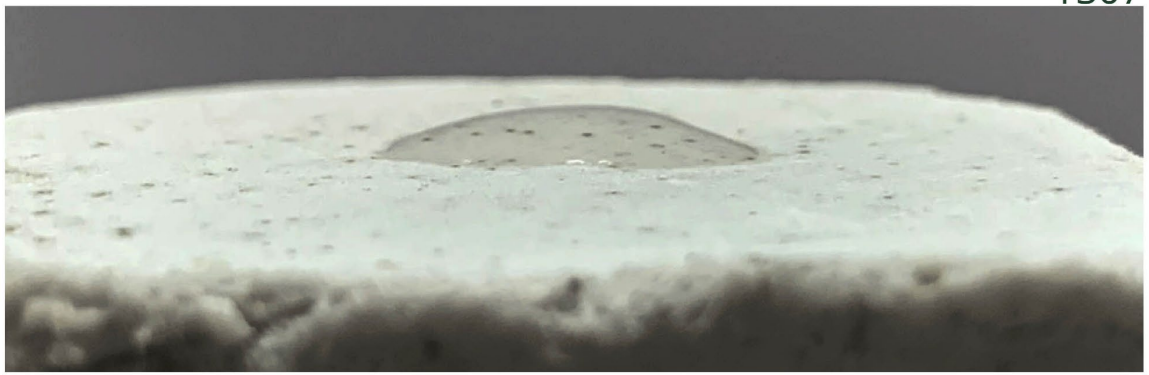
→ ≈ a > 90 °

indication of hydrophobic surface

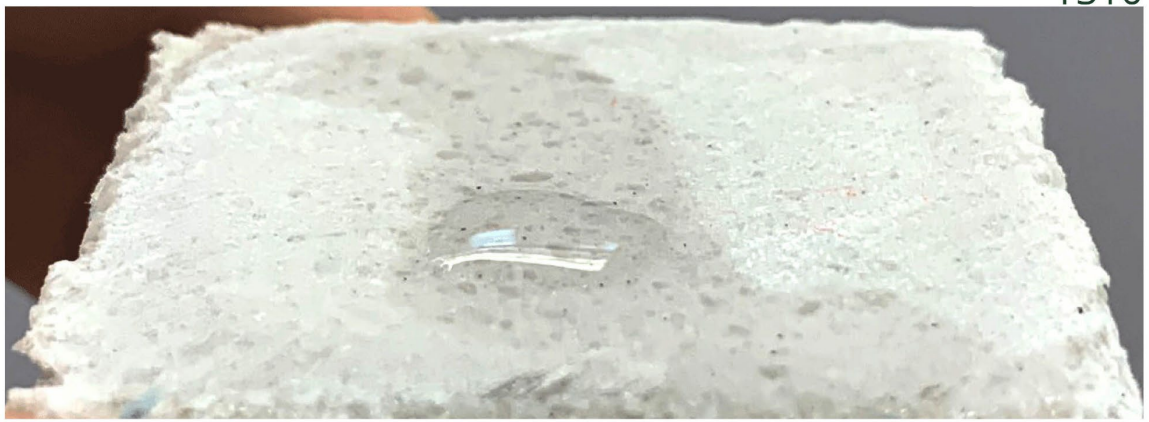
TBS18



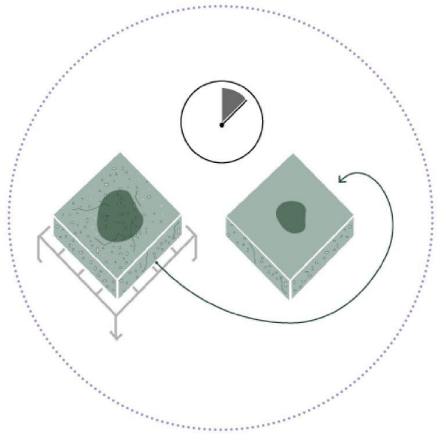
TS07



TS10

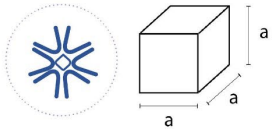


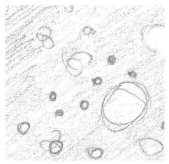
Quick-testing for Permeability



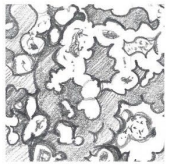
Water permeability

Frosting Resistance



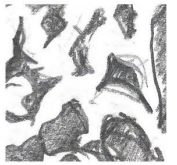


Type 01



Type 02

Type 03



Type 04

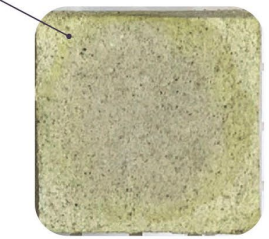
Rating of Specimens

higher water aborption

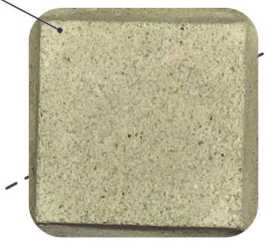
slow-pace evaporation

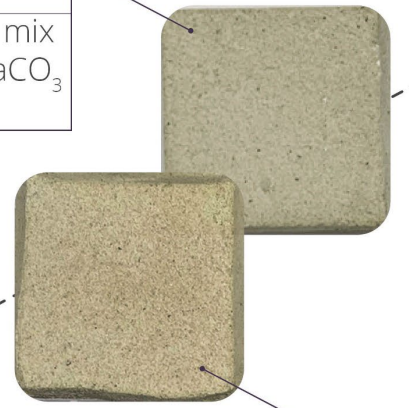
TC04
Cyclon* mix
(10%) $CaCO_3$
840°C

TC11
Cyclon mix*
(3%) $CaCO_3$
840°C



TC12
Cyclon mix*
(5%) $CaCO_3$
840°C





TC13
Cyclon mix*
(10%) $CaCO_3$
840°C

TS16
SLS float
2 sizes
(5%) $CaCO_3$
840°C

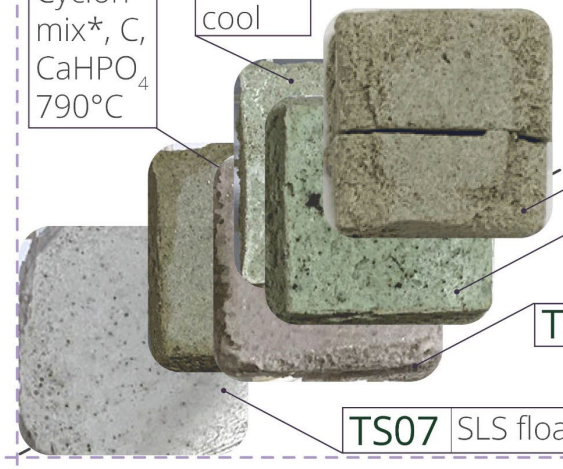
TBS18
SLS float
powder,
Borosilicate
cullet,
(5%) $CaCO_3$
790°C

TBS08 SLS float powder, Borosilicate cullet, C, $CaHPO_4$, 790°C

TBS15 SLS float powder, Borosilicate cullet, (5%) $CaCO_3$, 840°C

TC01
Cyclon
mix*,
840°C
slow
cool

TC09
Cyclon
mix*, C,
$CaHPO_4$
790°C



TC05 Cyclon mix*, C, $CaHPO_4$, 840°C, slow cool

TC06 Cyclon mix*, C, $CaHPO_4$, 960°C, slow cool

TS10 SLS float powder, C, $CaHPO_4$, 790°C

TS07 SLS float powder, C, $CaHPO_4$, 960°C, slow cool

Rating of Specimens

higher water aborp-tion

TC04

TC11 x

TC12 x

TC13

brittle

brittle

TS16

unpredictable expansion

TBS08

TC01

TBS15

TC09

low-performance

TC05

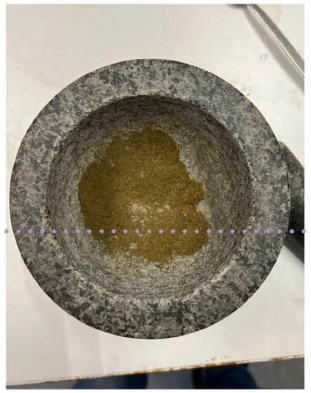
TC06

TS10

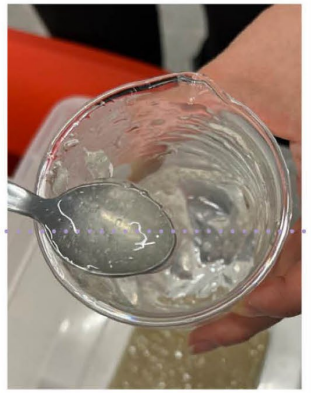
TS07

slow-pace evaporation

Moss growth on most promising reci-

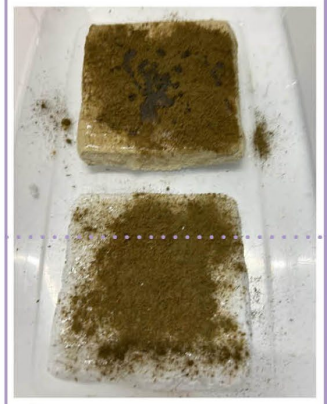


01. turn moss to powder

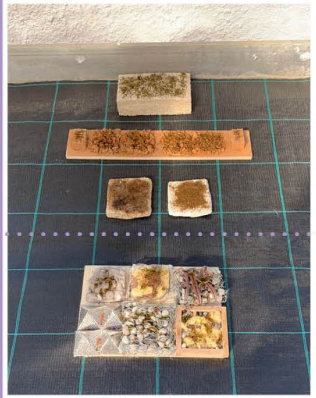


02. natural glue

03. apply

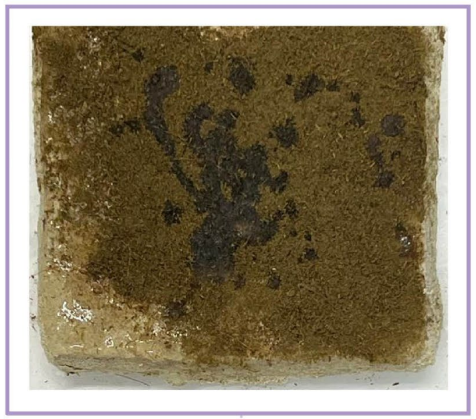
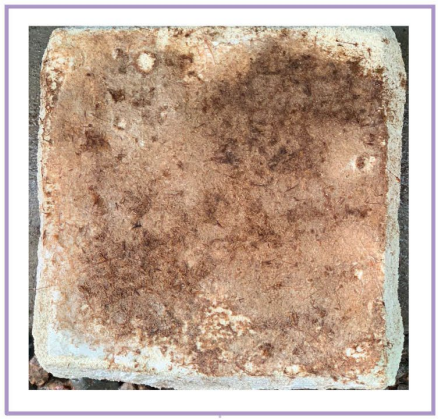
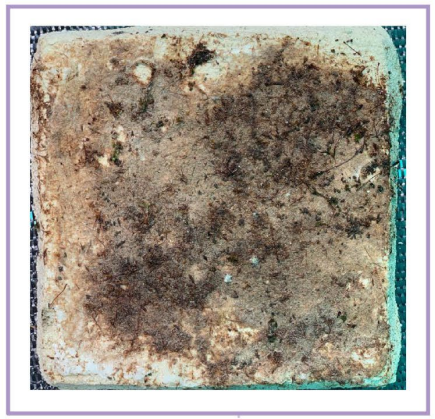
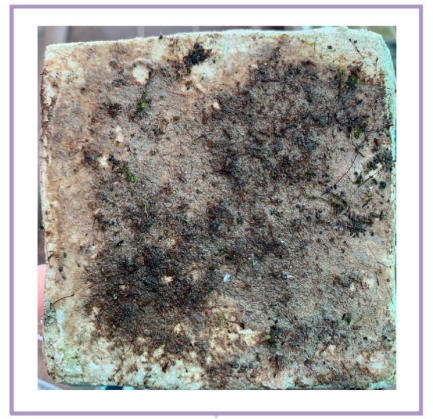
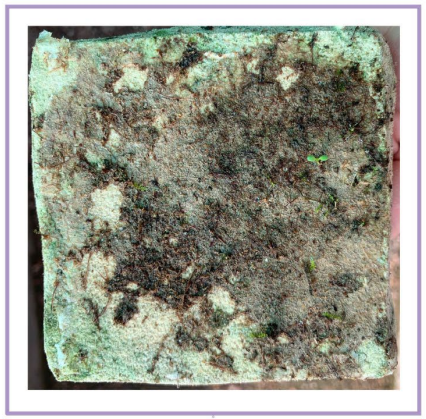


04. moss on samples



05. keep in controlled moist conditions & monitor

Moss growth on most promising reci-

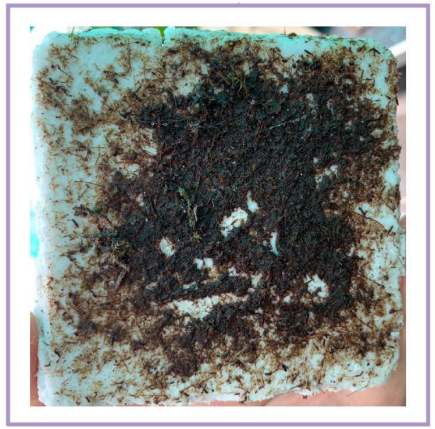
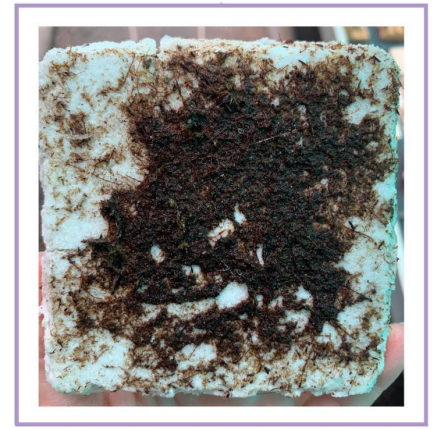
1st week

3rd week

4th week

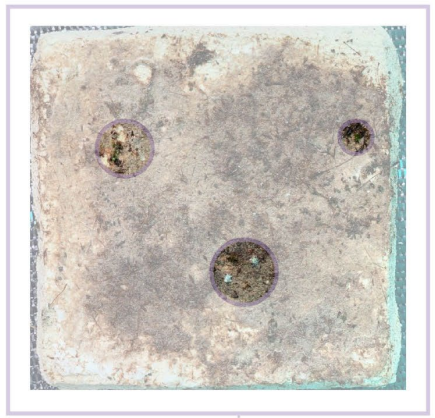
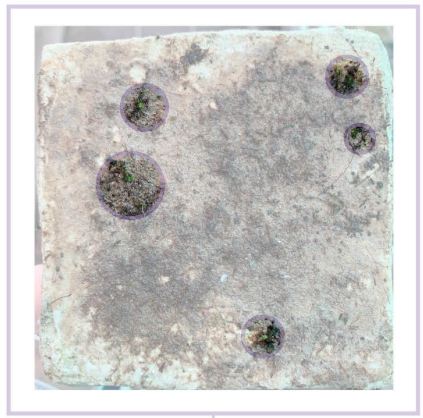
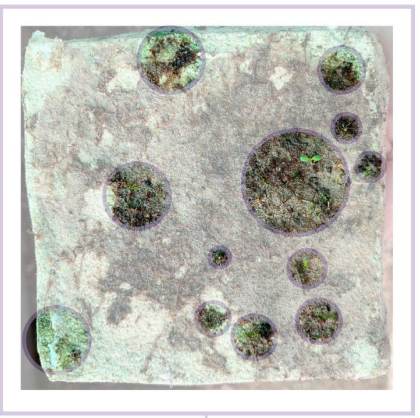
6th week



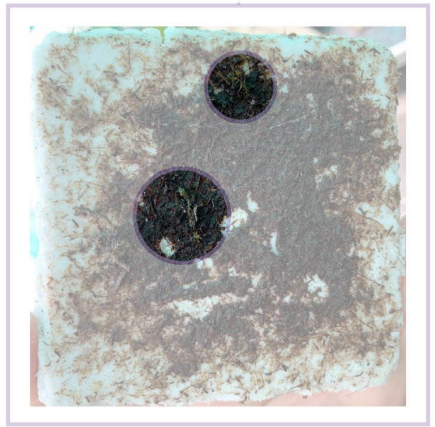
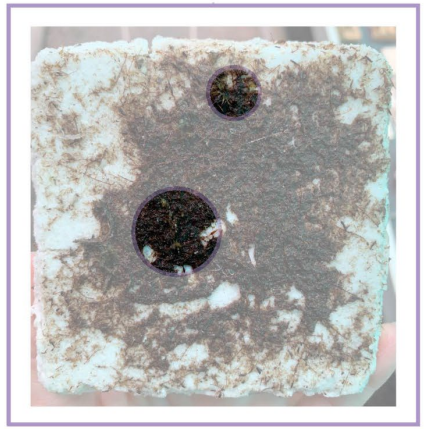




Moss growth on most promising recipes

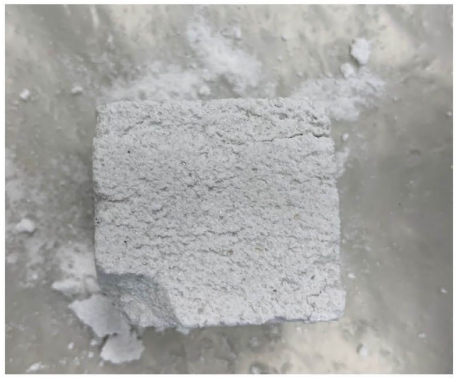


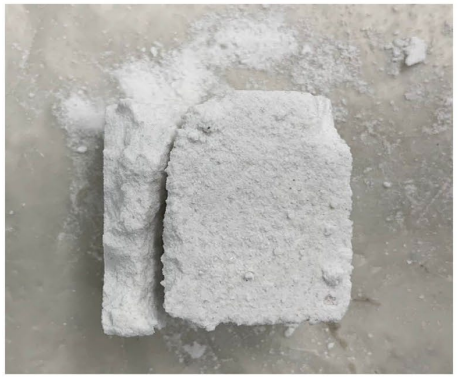
1st week

3rd week

4th week

6th week



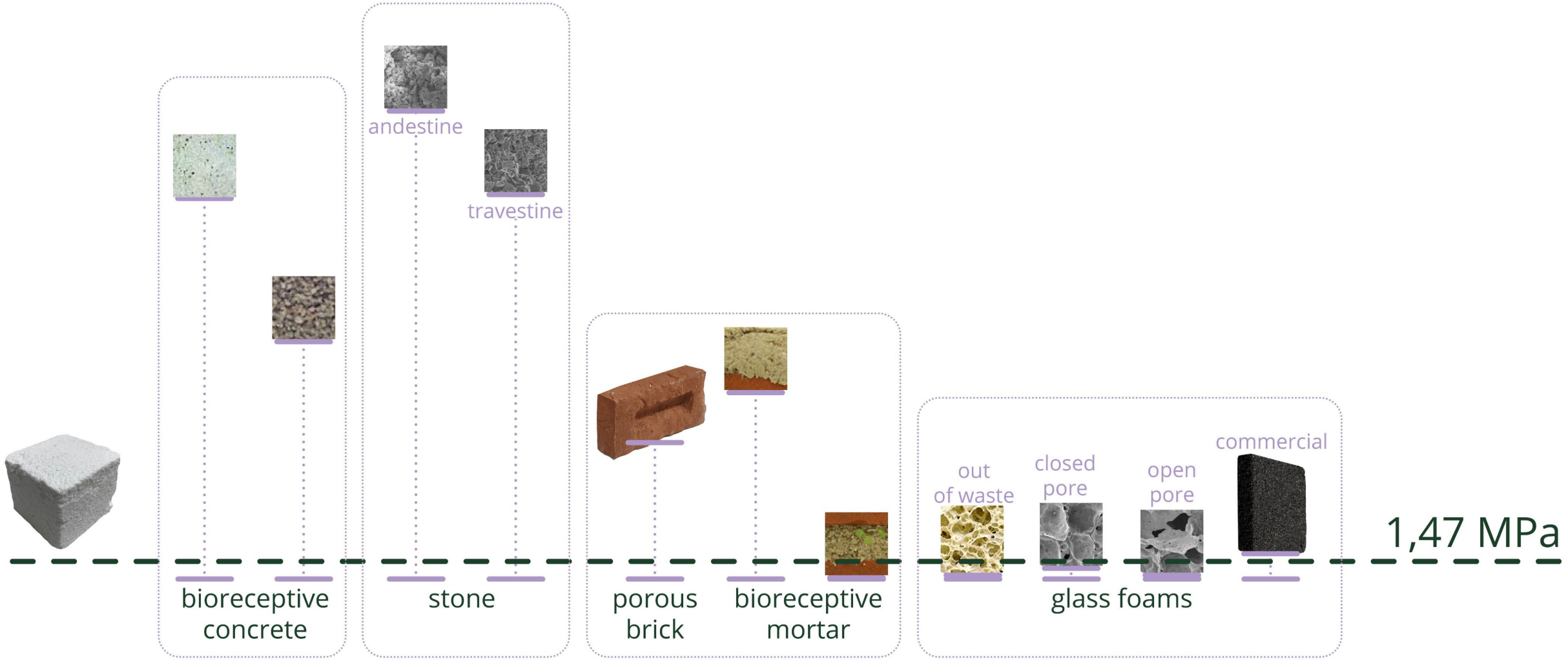

Compressive strength test to assess its suitability



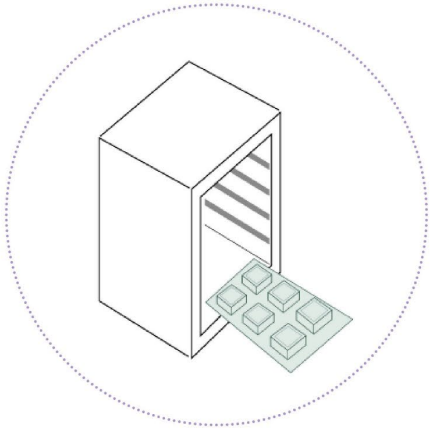


Compressive strength test to assess its suitability

Compressive comparison



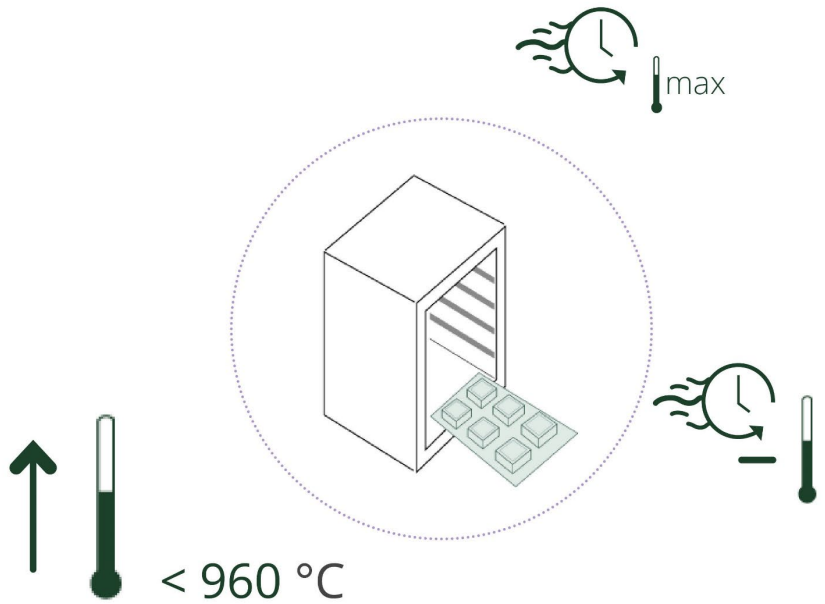
Material Findings



< 960 °C

01. Higher
top temperatures

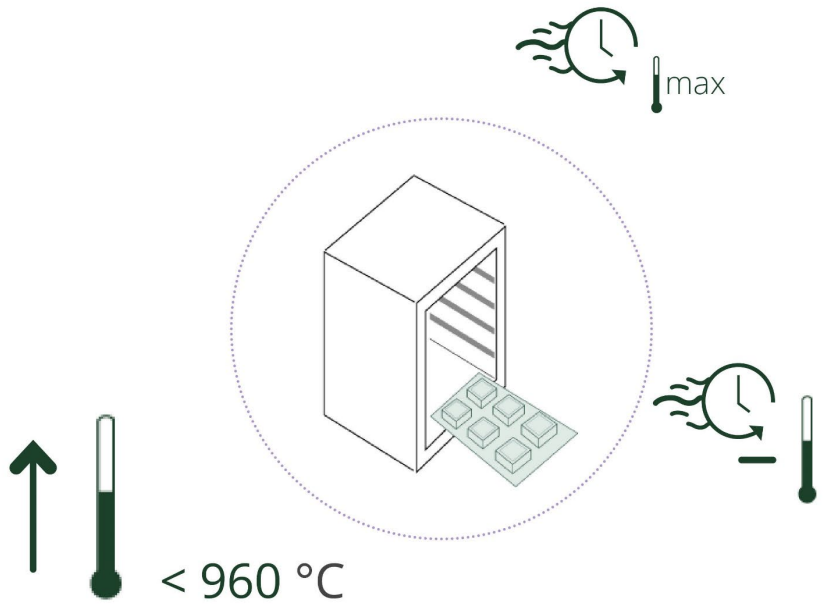
Material Findings

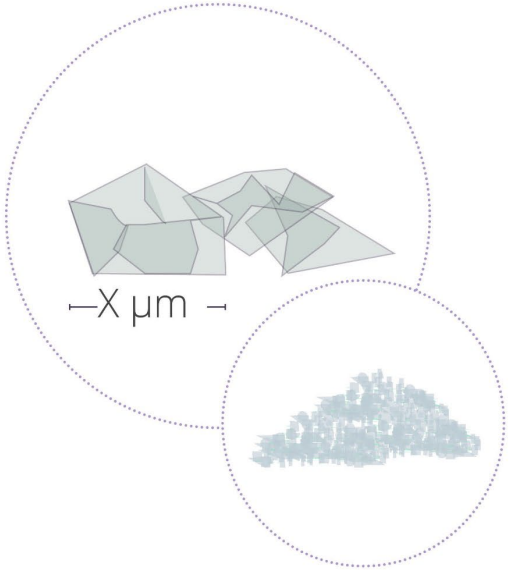


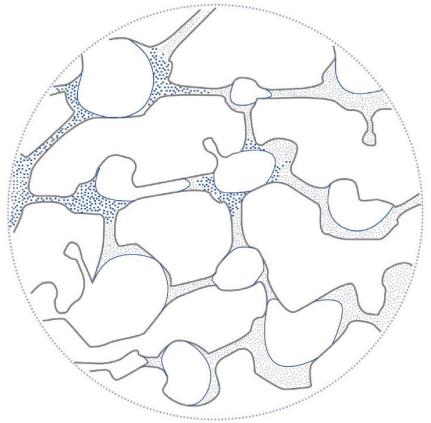
01. Higher
top temperatures

02. Fast cooling &
dwell time
at top temperature

Material Findings







01. Higher top temperatures

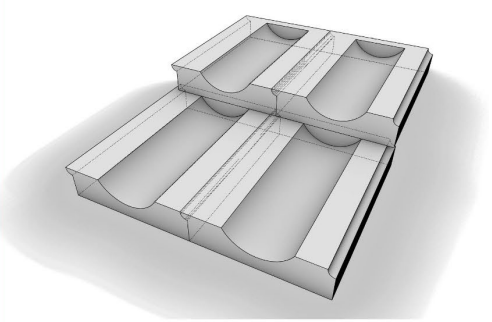
02. Fast cooling & dwell time at top temperature

03. Combination of different particle sizes

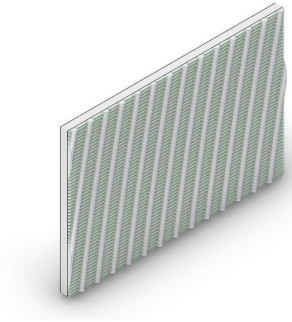
according to glass sources

Increased Porosity network

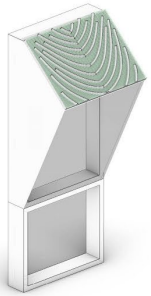
bio-host glass catalogue



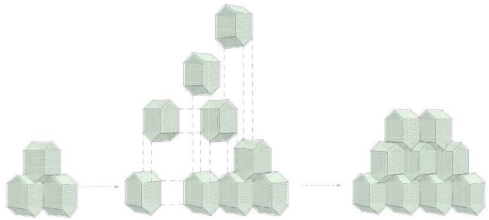
Roof tile



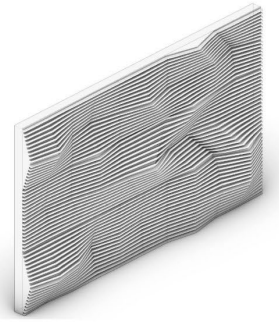
Facade panel



Sunshading panel



Facade block



Acoustical panel

Meso-scale design & Mould experimentaion

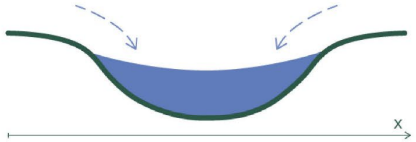
raw material

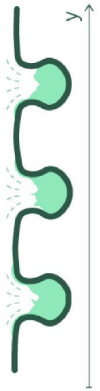
tile's back surface (after foaming)

mould shape

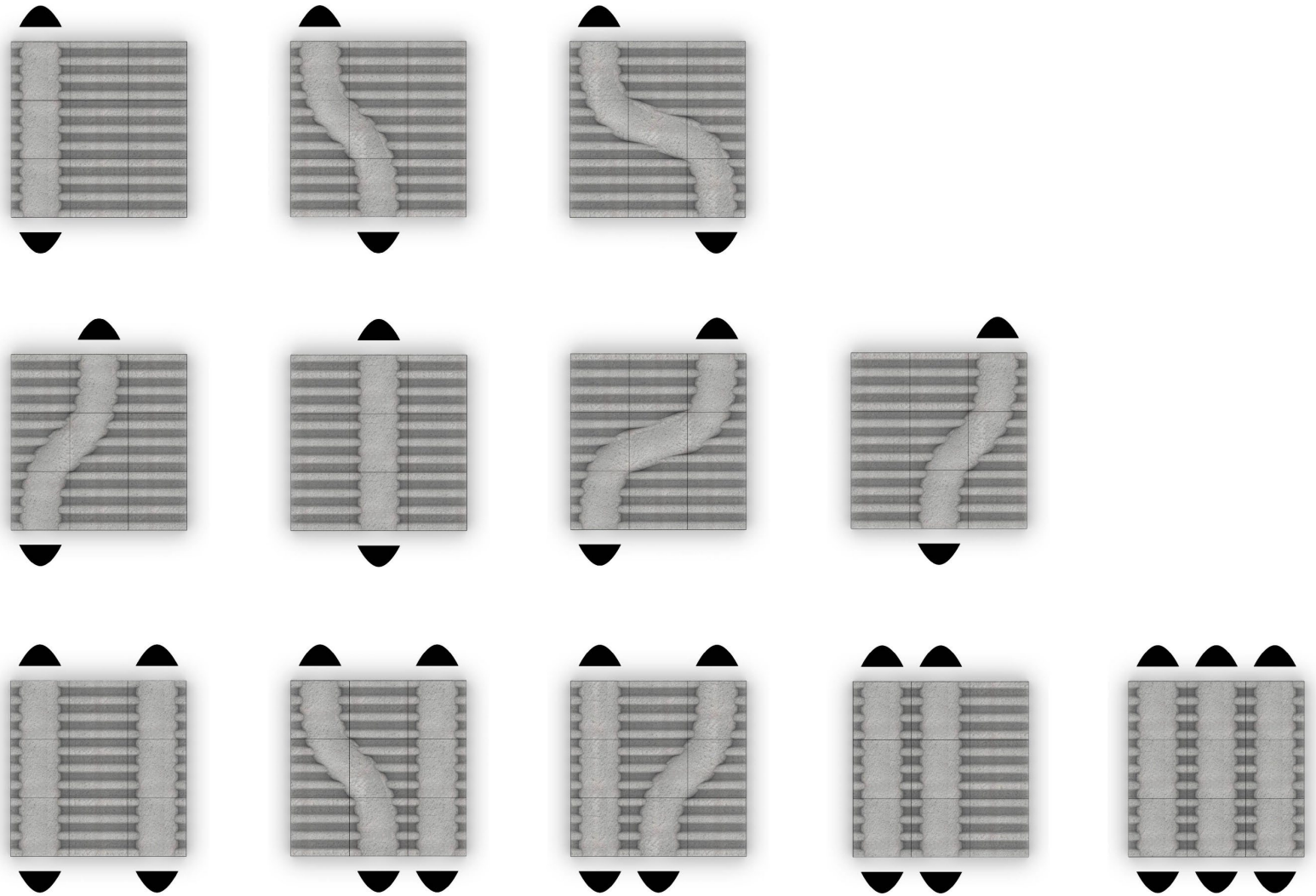
3d-printed pattern designed by A. Niarchou.

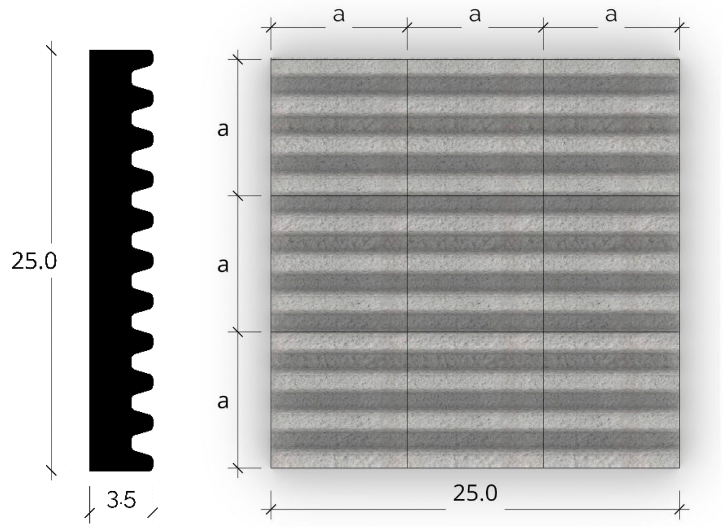
mixture (before foaming)



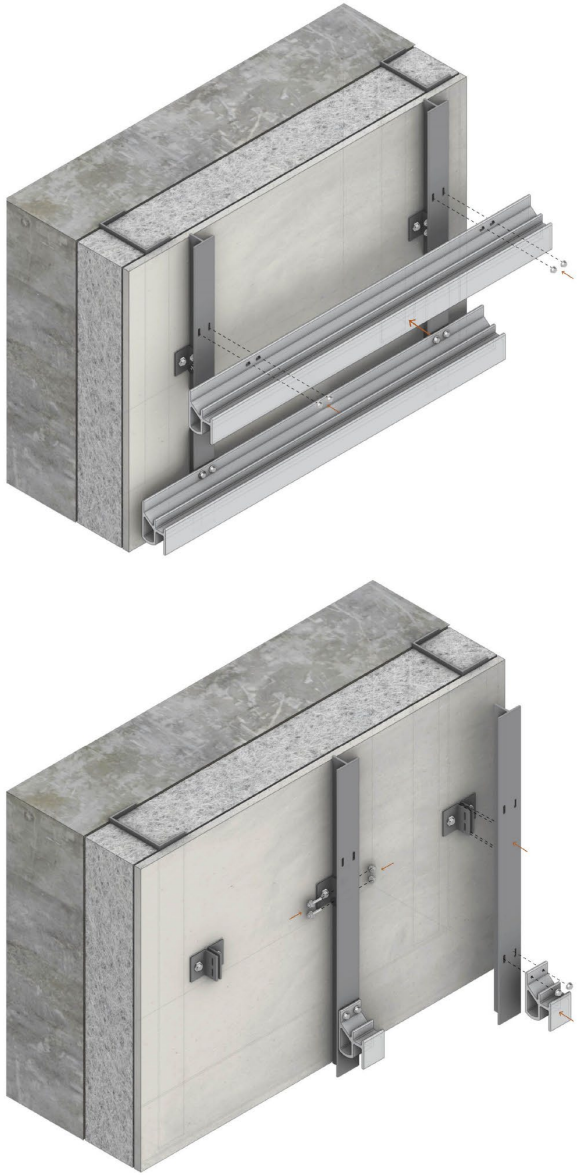


Facade tile mould-standardization

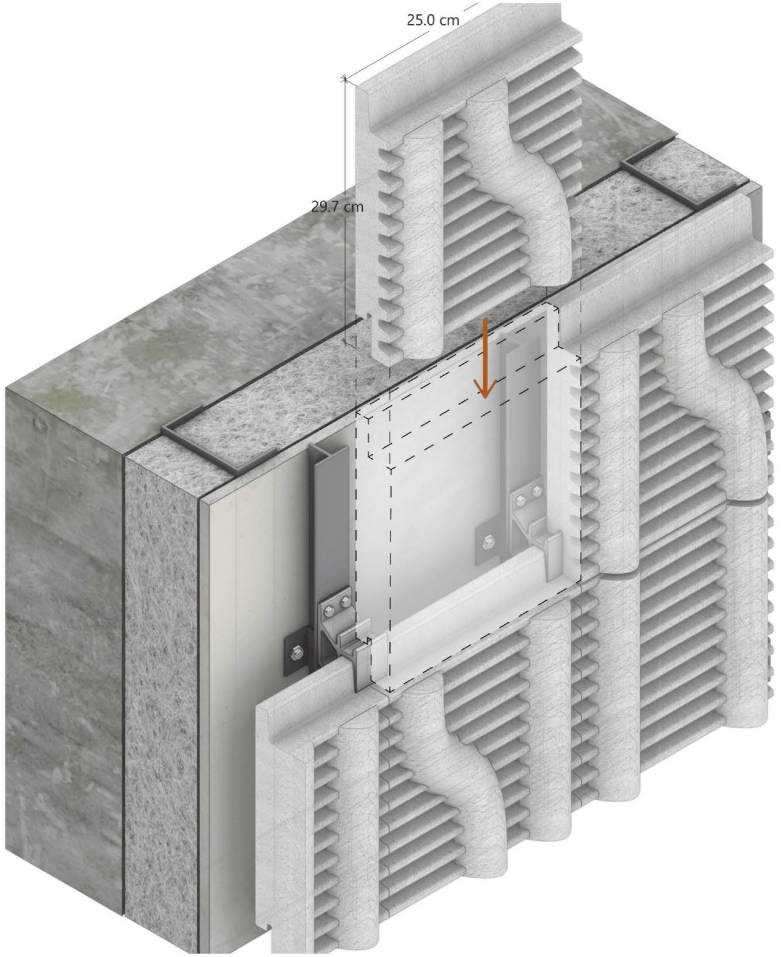




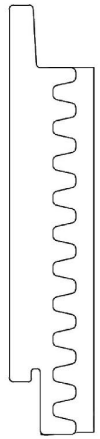
Assembly Process | Standard cladding system connections



01. Supporting framework



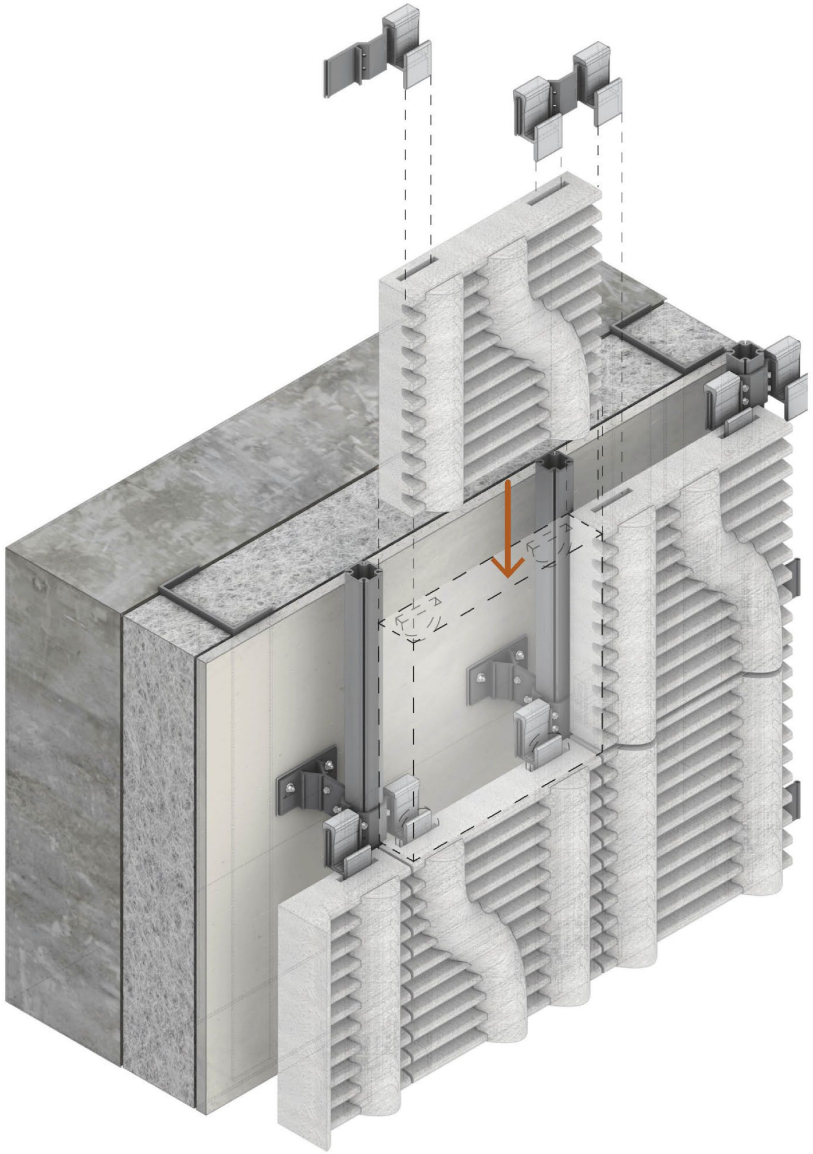
02. Tile positioning



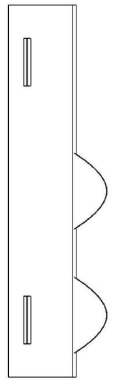
tile side-view
for interlocking shape
with the system

Assembly Process | Lego-like connections by BILDA

01. Supporting framework



02. Tile positioning



tile top-view
for the precicion
slots

Assembly Criteria

No direct screwing on the material

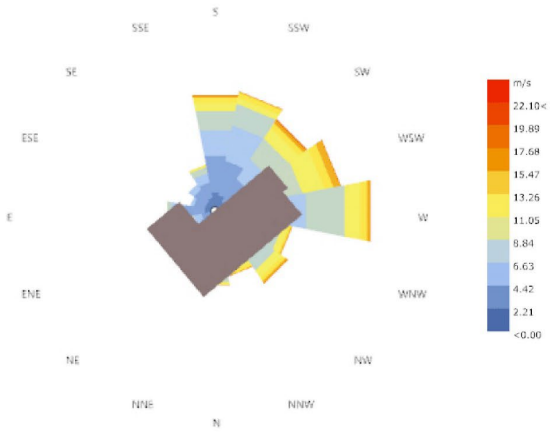
Reversible system

Re-used & recycled parts

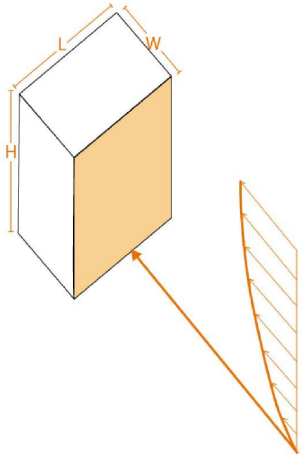
Minimum material usage

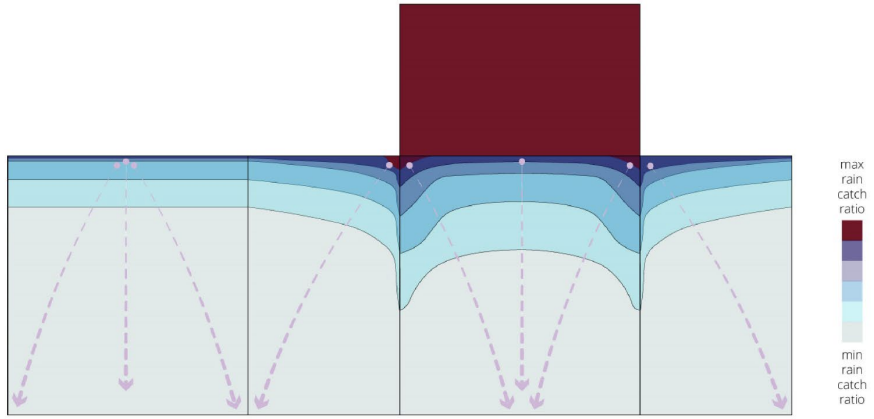
Surface suitability

Data-driven design strategy for the macro-scale

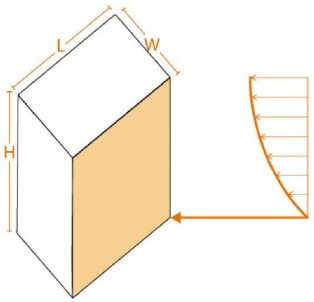


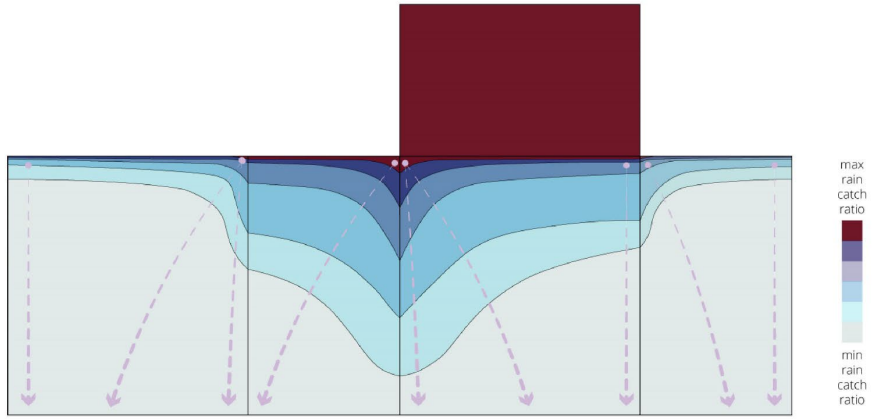
01. Principal wind orientation
+ Cfd analysis



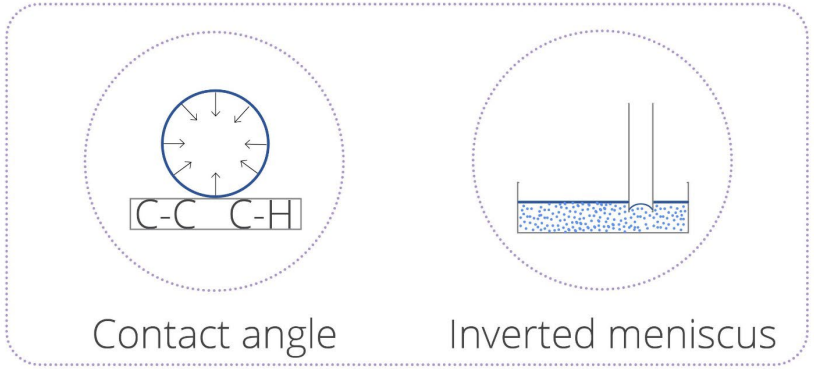


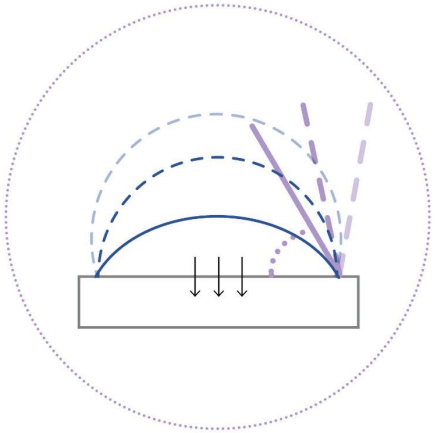
02. Wind-driven rain impingement patterns & direction of water-flow curves





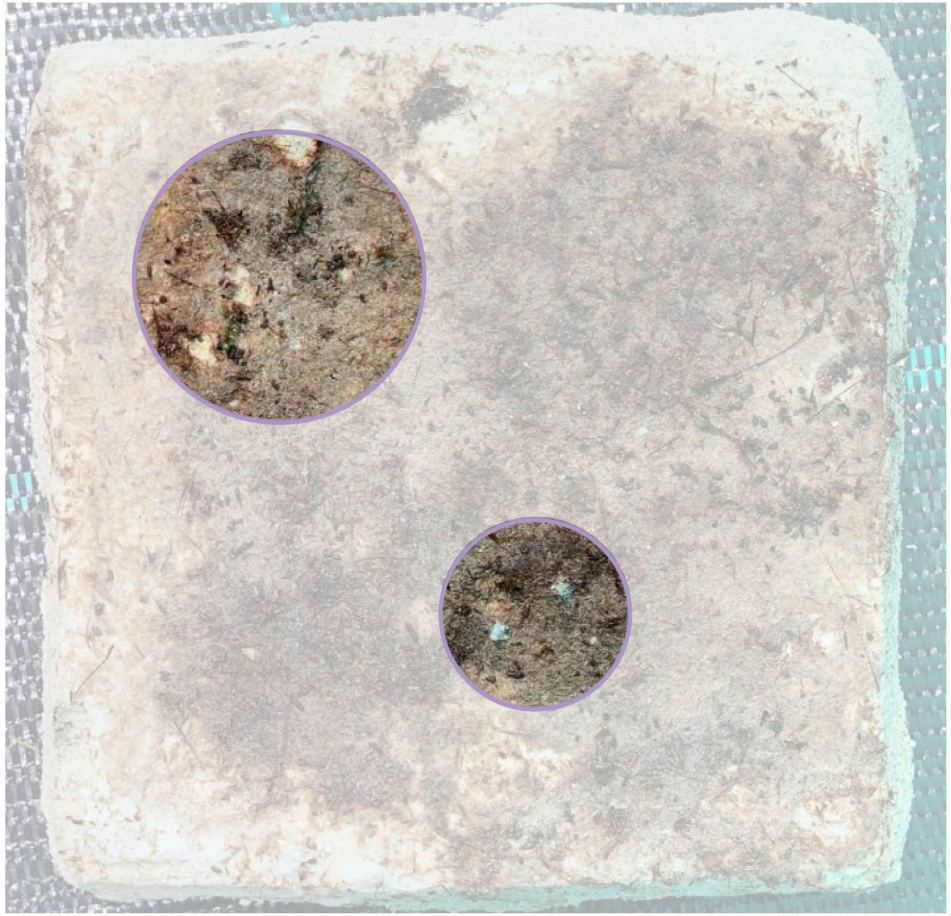
Thank you!

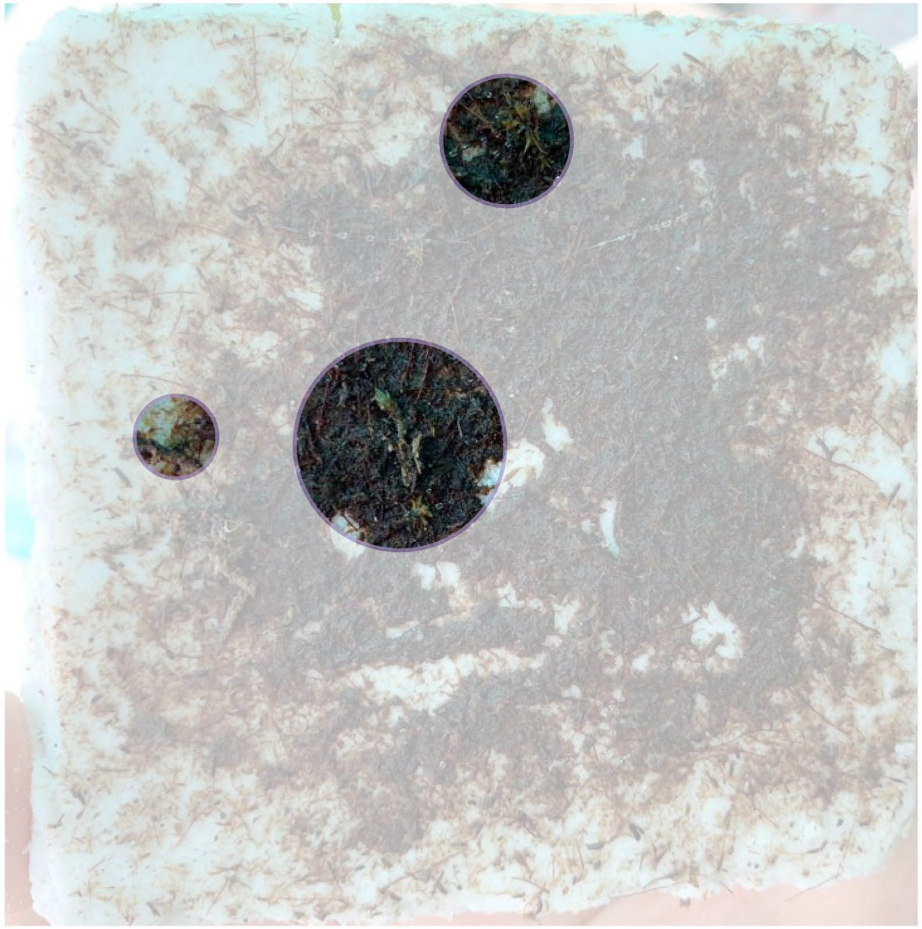

C-C
C-H
Contact angle
Inverted meniscus



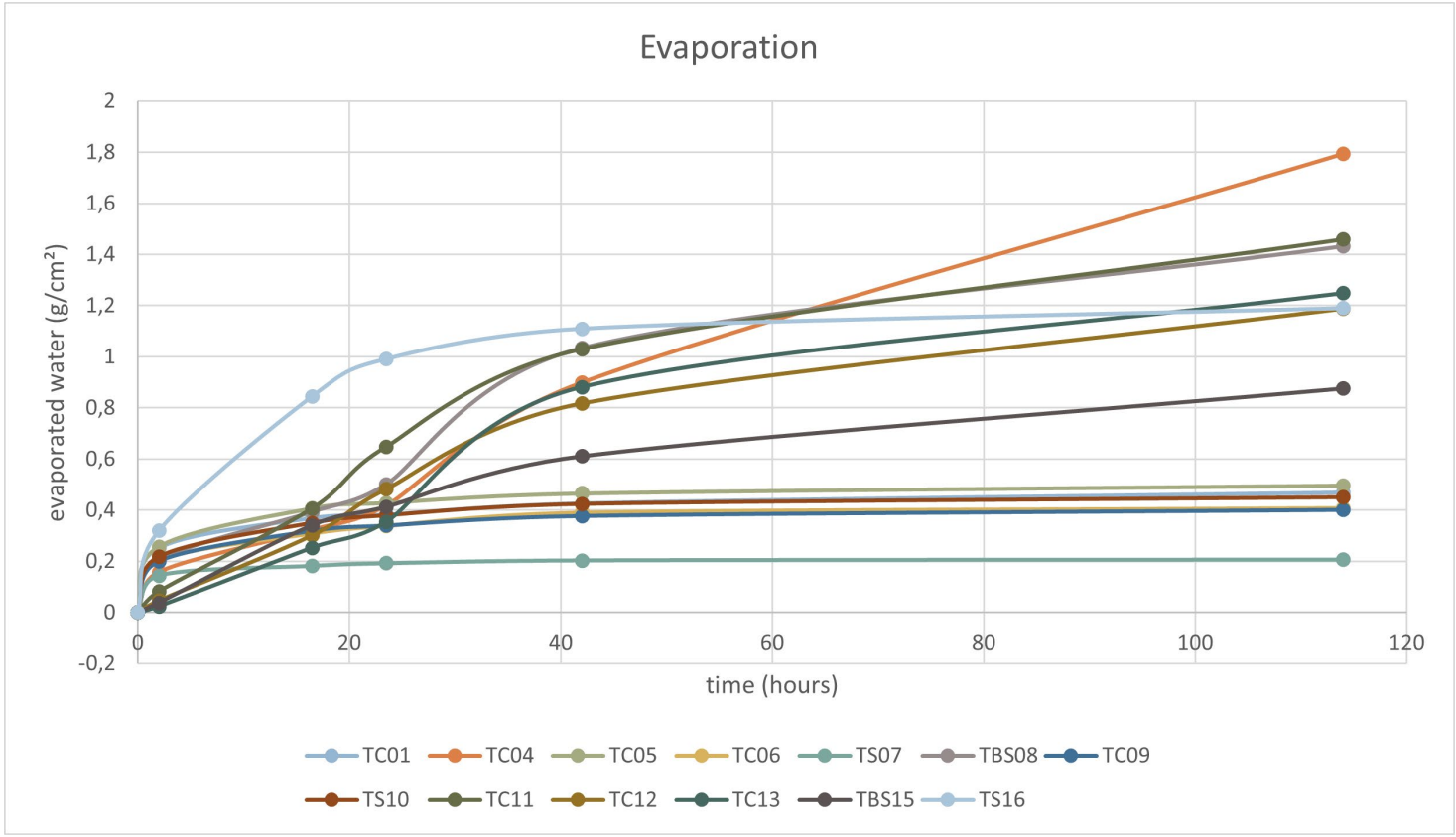
Appendix - Moss growth results

3rd week

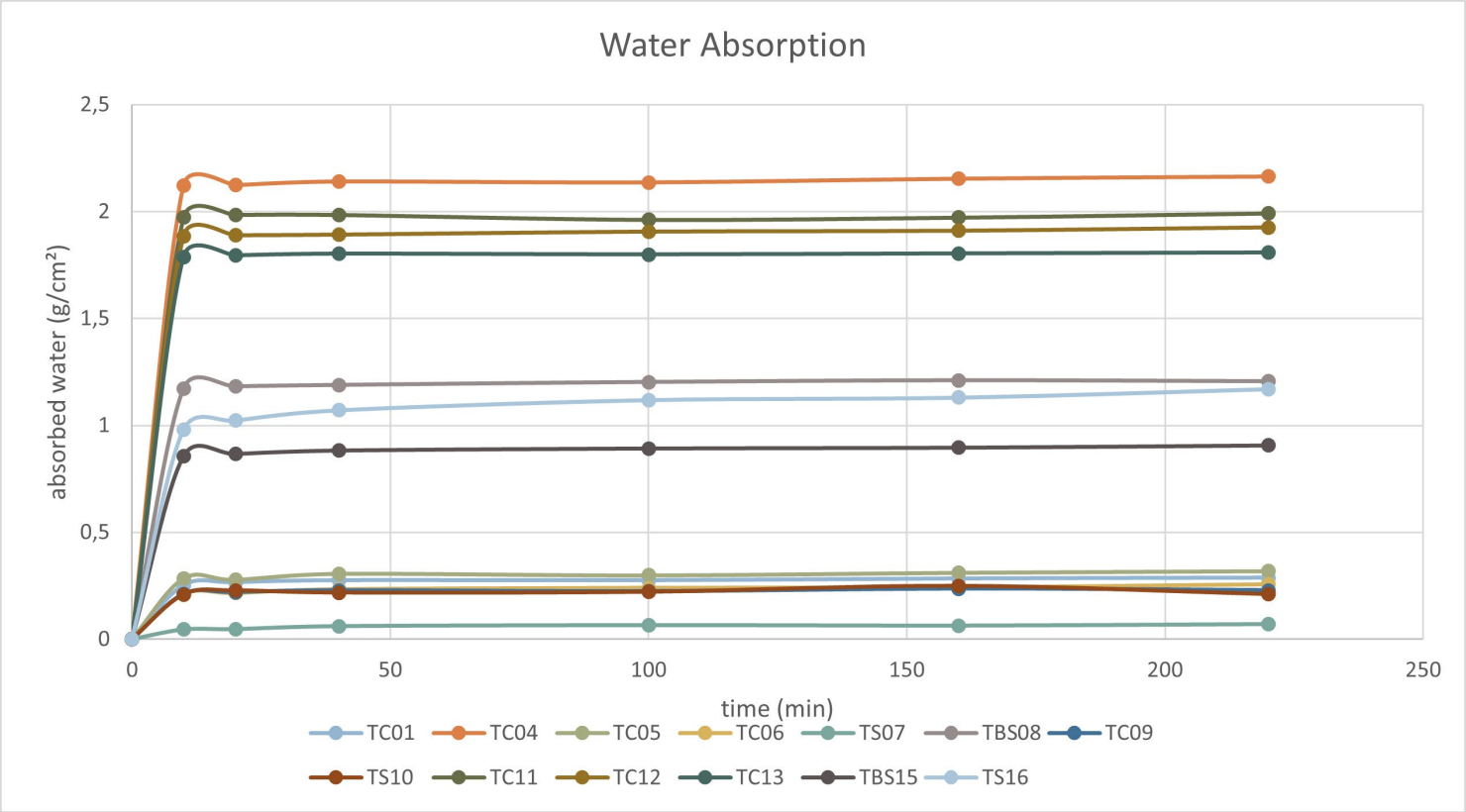




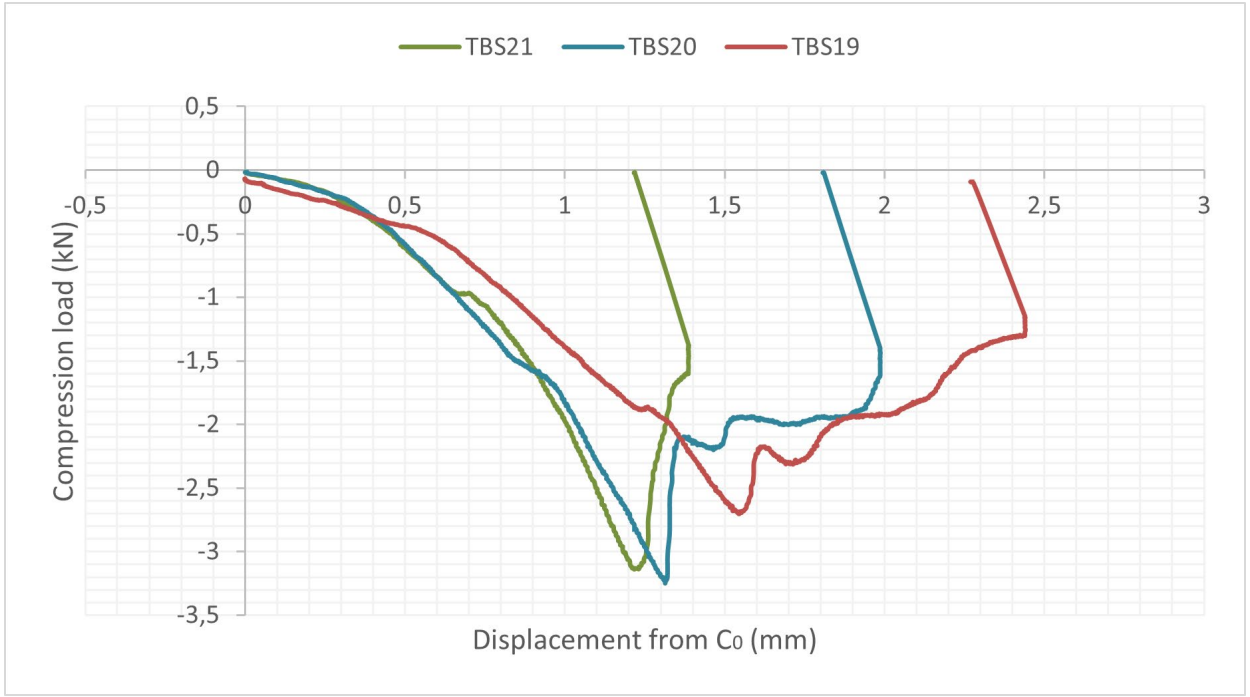
Rating of Specimens

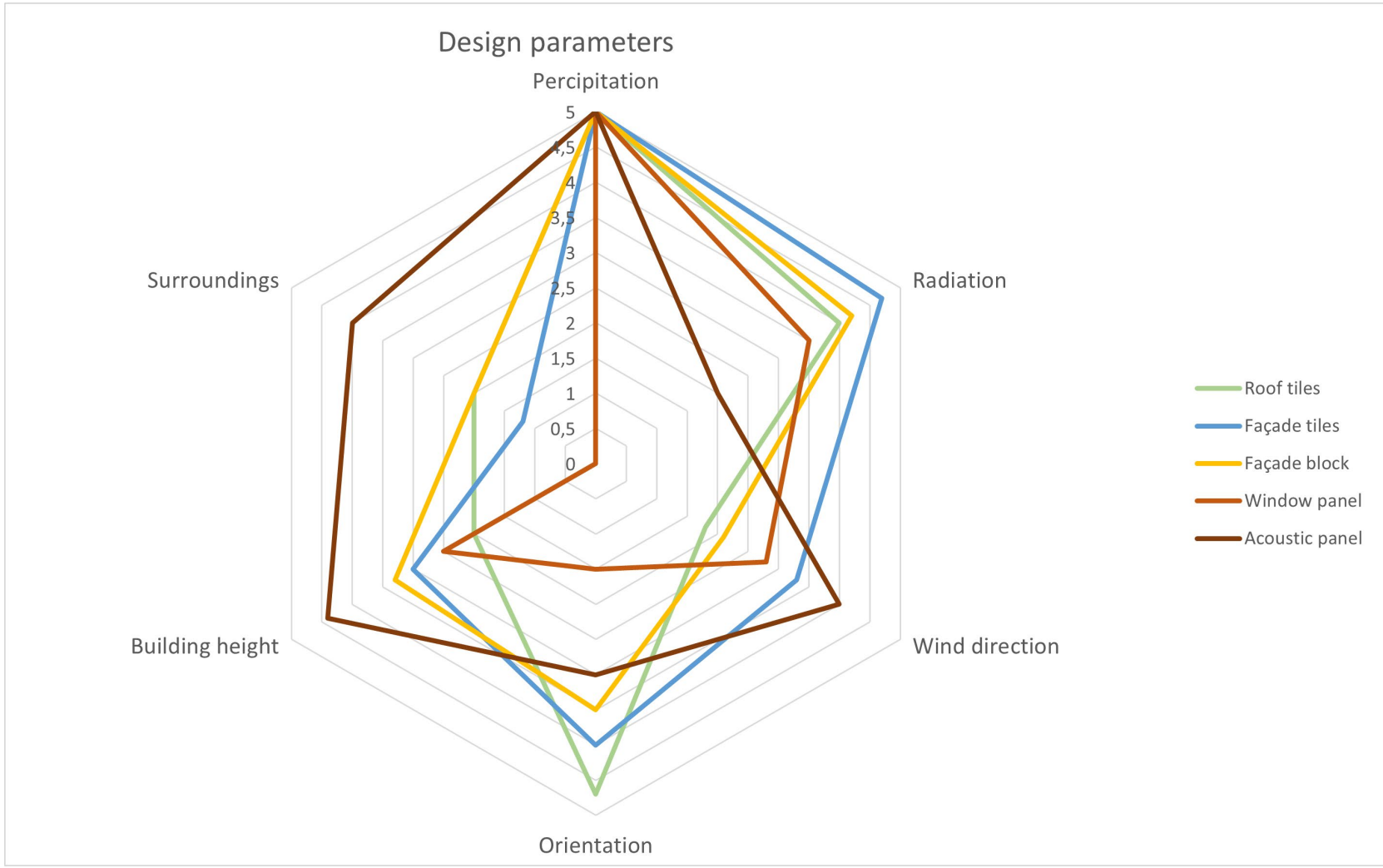


Rating of Specimens



Rating of Specimens




Design parameters
Percipitation
Radiation
Wind direction
Orientation
Building height
Surroundings
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
Roof tiles
Façade tiles
Façade block
Window panel
Acoustic panel