

Bioreceptive Façade Design

Improving our harsh urban climates

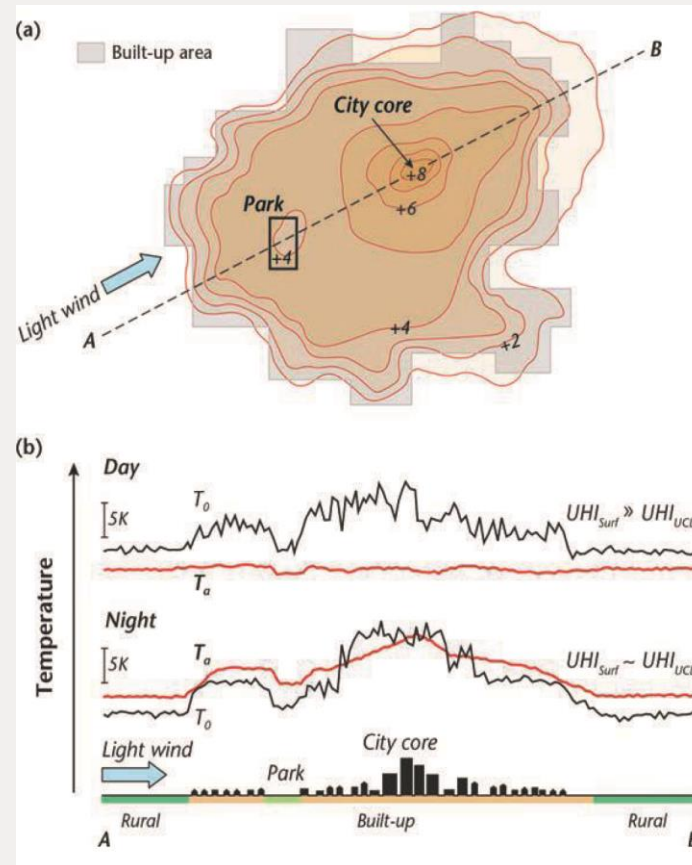
Bioreceptivity

“the aptitude of a material to be colonised by one or several groups of living organisms without necessarily undergoing any biodeterioration”

(Gillite, 1995)

Why bioreceptivity?

City climate



Temperature in cities, reproduced from Oke, Mills, Christen, & Voogt, 2017

Why bioreceptivity?

Facade greening

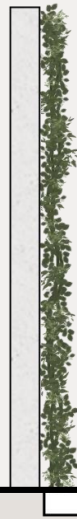


(DeMilked, 2015)

Why bioreceptivity?

Facade greening

Green facade



Living wall



Bioreceptive facade



Research



(Manso & Aguado, 2016)

- Material properties concrete
- Laboratory tests under 'optimum' conditions

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(Manso & Aguado, 2016)



(Aničić et al., 2009)

Research

- Material properties concrete
- Laboratory tests under 'optimum' conditions



(Manso & Aguado, 2016)



(Aničić et al., 2009)

How is bioreceptivity affected by the urban climate and how does it contribute to improve it?

Focus

Are bioreceptive façade panels an effective measure to improve city climates in The Netherlands?

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Are bioreceptive façade panels an **effective** measure to improve city climates in The Netherlands?

- Temperature reduction
- Air quality
- Water retainment
- Aesthetical benefits

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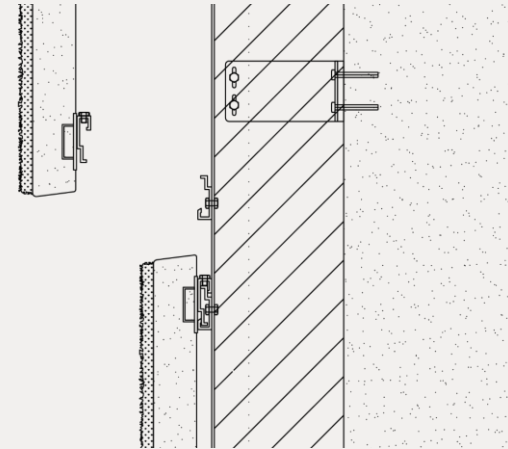
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- Water retainment
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Restrictions

Precast concrete façade panels

Bioreceptivity: Bryophytes (moss)

Case study area: Rotterdam



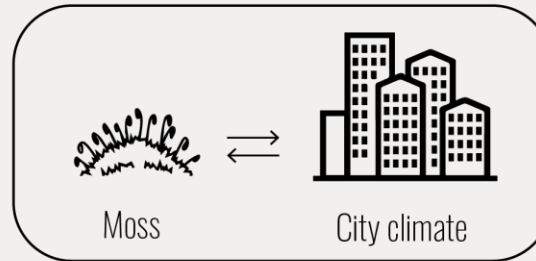
Façade detail

Structure

Are bioreceptive façade panels an effective measure to improve city climates in The Netherlands?

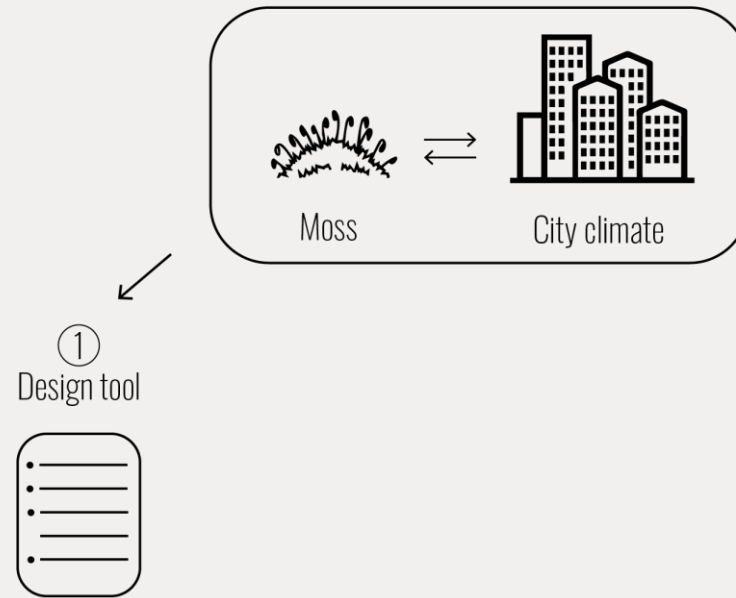
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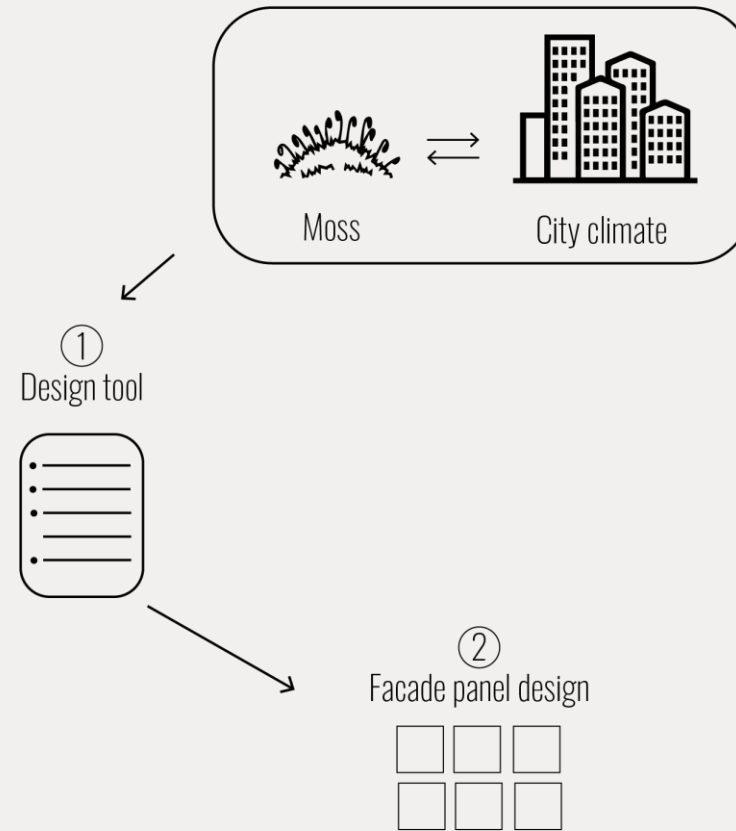
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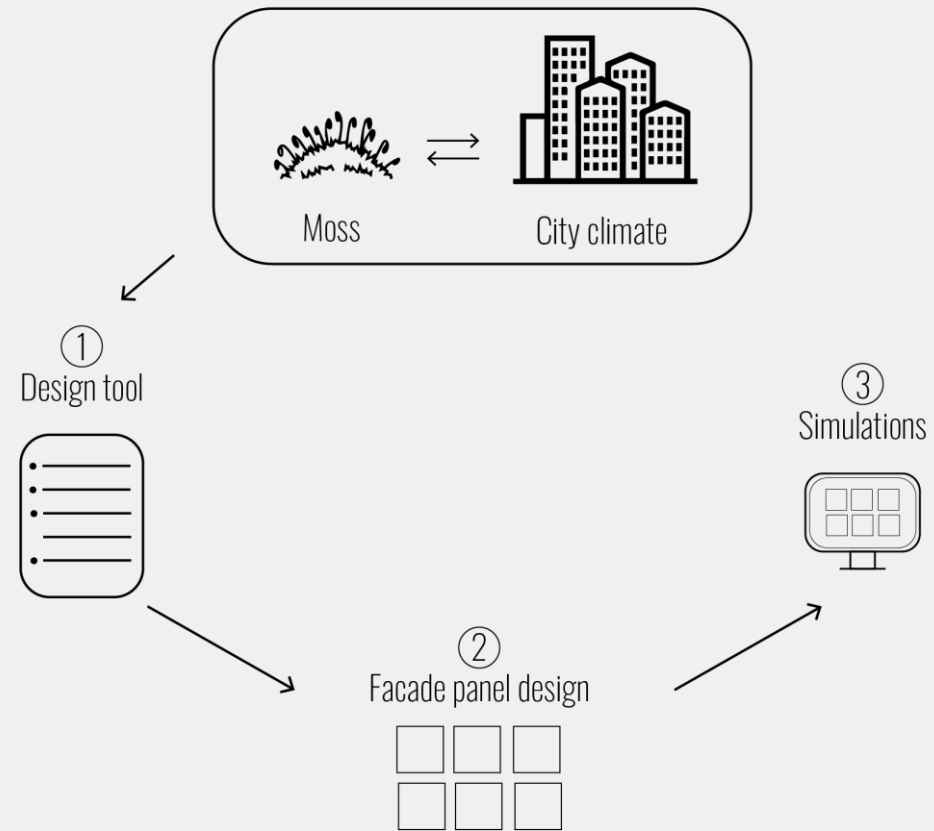
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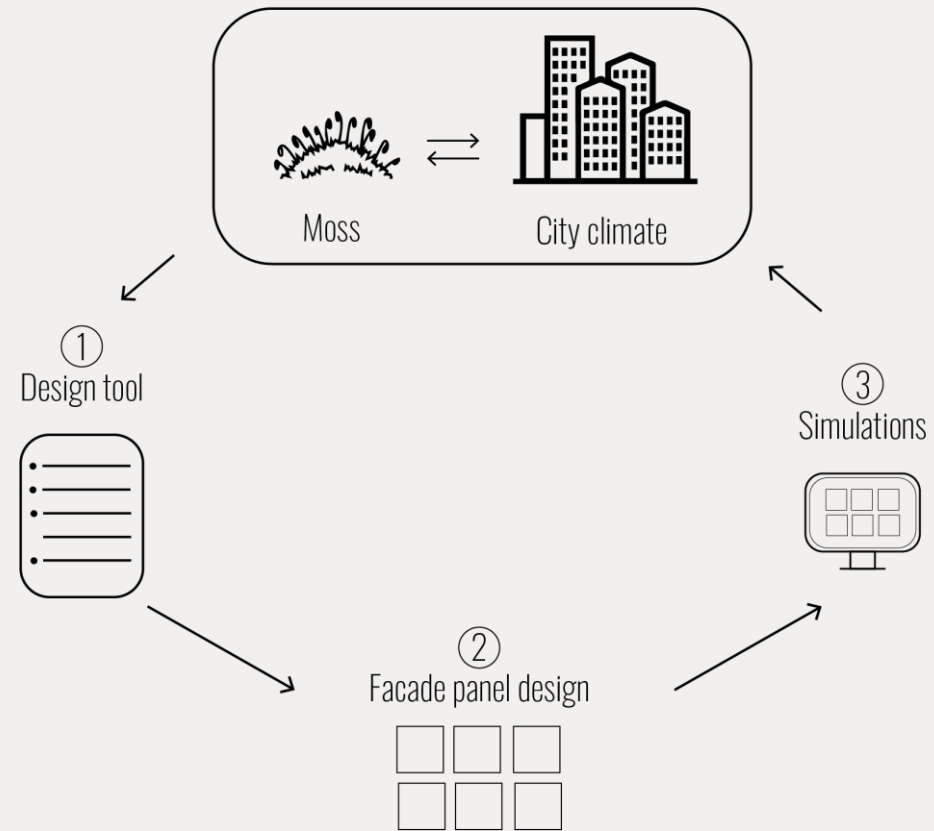
Structure

Are bioreceptive façade panels an effective measure to improve city climates in The Netherlands?



Structure

Are bioreceptive façade panels an effective measure to improve city climates in The Netherlands?



①

Design tool



How to develop a design tool for bioreceptive facade panels to account for the bryophytes' habitat conditions in The Netherlands?

Natural habitat

Conditions

Temperature

15 - 25 °C

Nutrients

Low requirement

Water

Moist climates

Solar radiation

Low light conditions

Humidity

High levels >50%

Wind

Intermediate

Natural habitat

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Intermediate

Limits

- **Moisture** important factor in their habitat; Bryophytes are poikilohydric, this means their hydration state is controlled by the environment. (87% - 305%)

Natural habitat

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- Moisture important factor in their habitat; Bryophytes are poikilohydric, this means their hydration state is controlled by the environment.
- Bryophytes are in a dehydrated, metabolically inactive state (dormant)

Natural habitat

Conditions

Temperature	15 - 25 °C
Nutrients	Low requirement
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- Moisture important factor in their habitat; Bryophytes are poikilohydric, this means their hydration state is controlled by the environment.
- Bryophytes are in a dehydrated, metabolically inactive state (dormant)
- Too much sunlight damages bryophytes (better resistant when moist)

Façade implementation; city climate

Conditions

Temperature	15 - 25°C	Increased
Nutrients	Low requirement	Decreased
Water	Moist climates	Slight increase
Solar radiation	Low light conditions	Decreased
Humidity	High levels >50%	Decreased
Wind	Intermediate	Decreased

Façade implementation; city climate

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Limits

- Water availability not a limiting factor on façade application due to irrigation.

Façade implementation; city climate

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Limits

- The Netherlands 21 days >25°C
- +/- 30 days <50% relative humidity in summer

City climate to city structure

Challenging and potential urban scenario's in Rotterdam



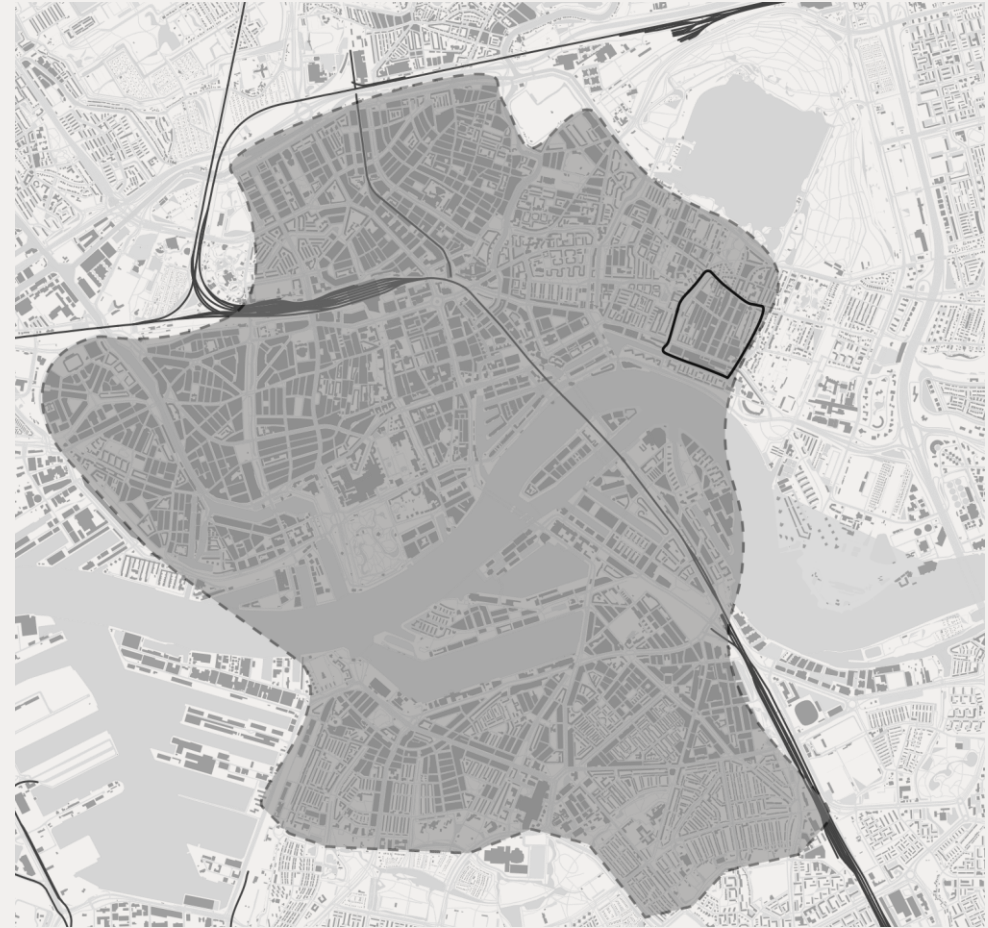
(Van der Hoeven & Wandl, 2015)

City climate to city structure

Challenging and potential urban scenario's in Rotterdam



Building envelope [m²]



Sky view factor

Rotterdam

Challenging and potential urban scenario's in Rotterdam

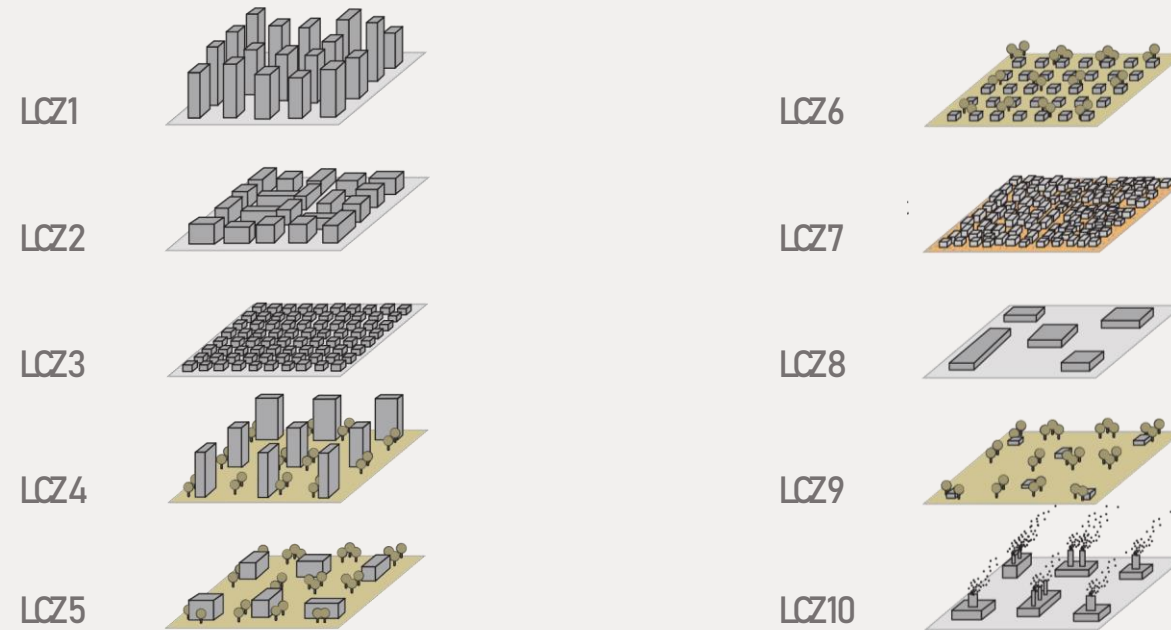


Cool district



Kralingen

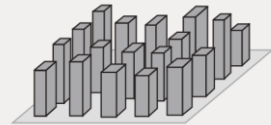
City climate to city structure



LCZs, reproduced from Oke, Mills,
Christen, & Voogt, 2017

Rotterdam

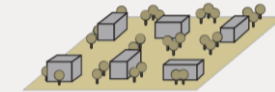
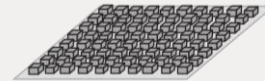
Challenging and potential urban scenario's in Rotterdam



Cool district

LCZ1 – Compact Hghrise

Hgh building enveloperatio



Kralingen

LCZ3 – Compact lowrise

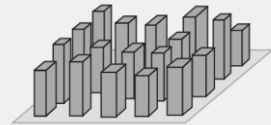
LCZ5 – Open midrise

Hgh sky viewfactor

Representative neighborhood
typology in The Netherlands

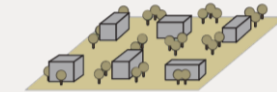
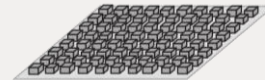
Rotterdam

Challenging and potential urban scenario's in Rotterdam



Cool district

LCZ1 – Compact Hghrise
High building envelope ratio

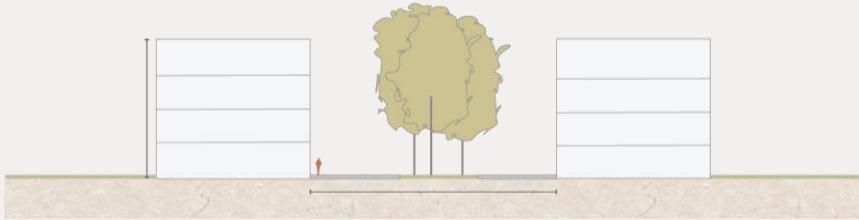


Kralingen

LCZ3 – Compact lowrise
LCZ5 – Open midrise
High sky view factor

Representative neighborhood
typology in The Netherlands

Kralingen



LCZ5 – Open midrise

Building plan fraction
37%

Canyon aspect
0.5

Building height
+/- 13m



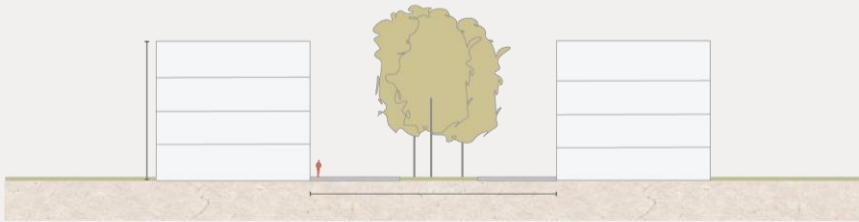
LCZ3 – Compact lowrise

Building plan fraction
60%

Canyon aspect
1

Building height
+/- 7.5m

Field survey

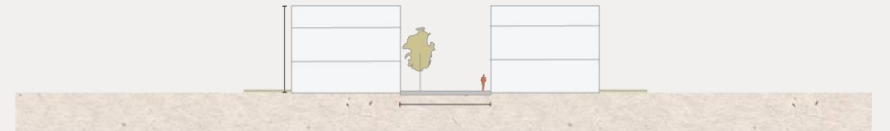


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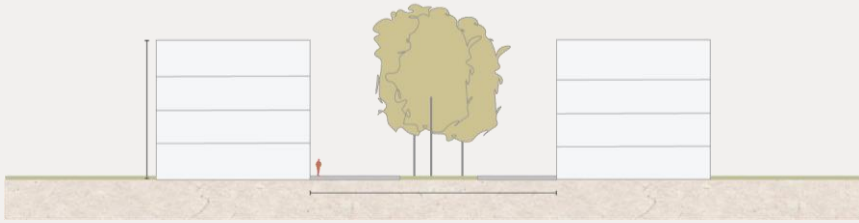
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Building height
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Field survey

Match literature with real life scenario

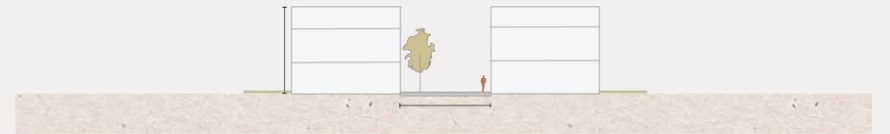


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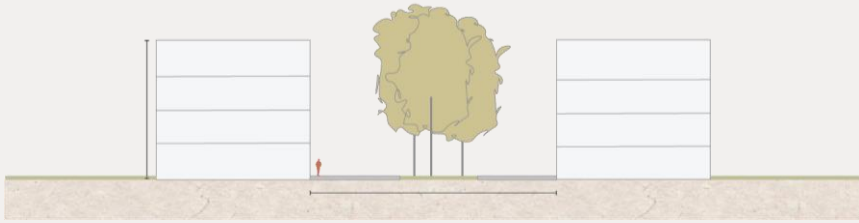
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Field survey

The bryophyte growth in the midrise area will be more abundant.

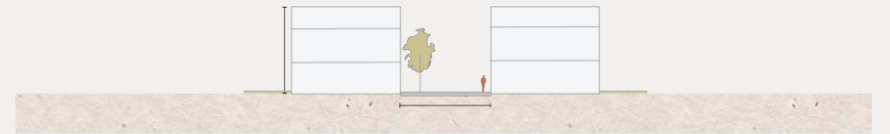


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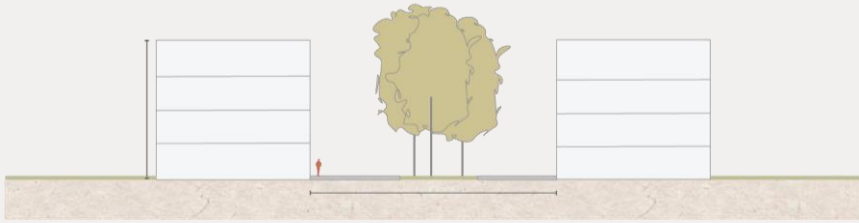
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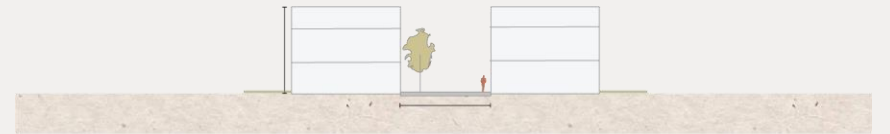


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LCZ5 – Open midrise



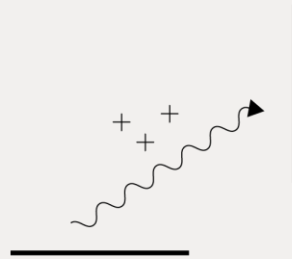
LCZ3 – Compact lowrise



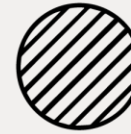
Field survey



Surrounding
green



Horizontal
surfaces



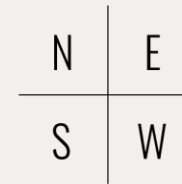
Shading



Moisture



Surface
roughness

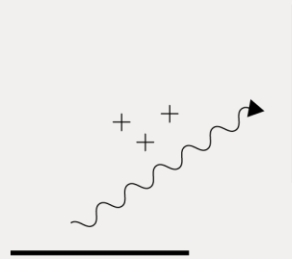


Orientation

Field survey



Surrounding green



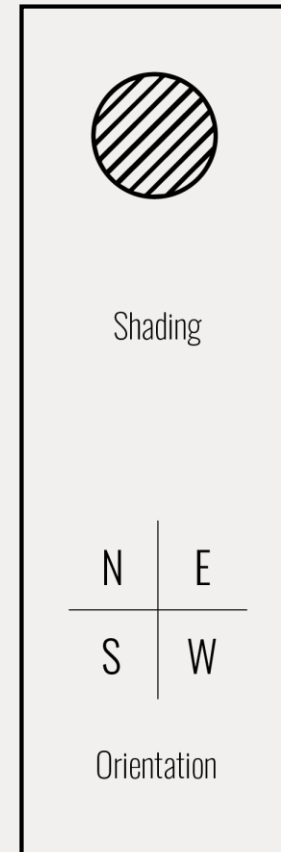
Horizontal surfaces



Moisture



Surface roughness



Shading

N

E

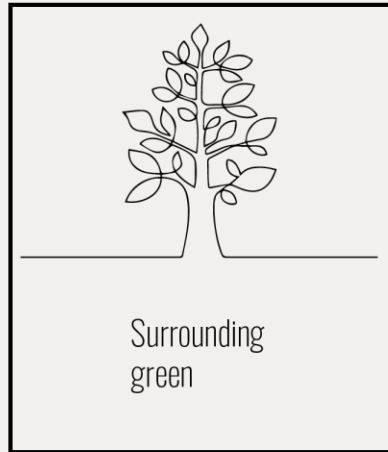
S

W

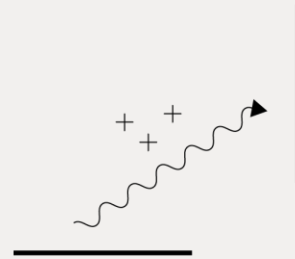
Orientation

Solar radiation

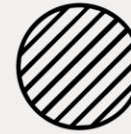
Field survey



Humidity



Horizontal surfaces



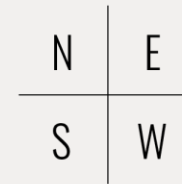
Shading



Moisture



Surface roughness

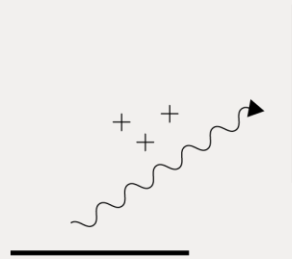


Orientation

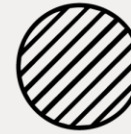
Field survey



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green



Horizontal
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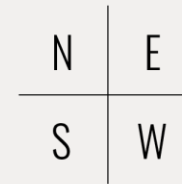
Shading



Moisture

Surface
roughness

Water availability

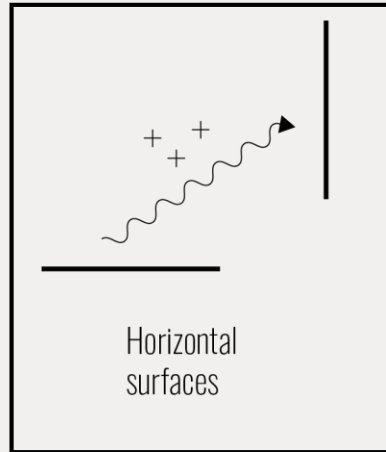


Orientation

Field survey

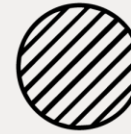


Surrounding
green



Horizontal
surfaces

Surface angle



Shading



Moisture



Surface
roughness



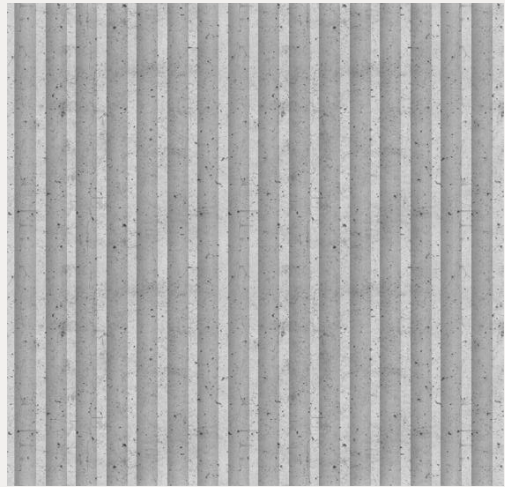
Orientation

Design tool

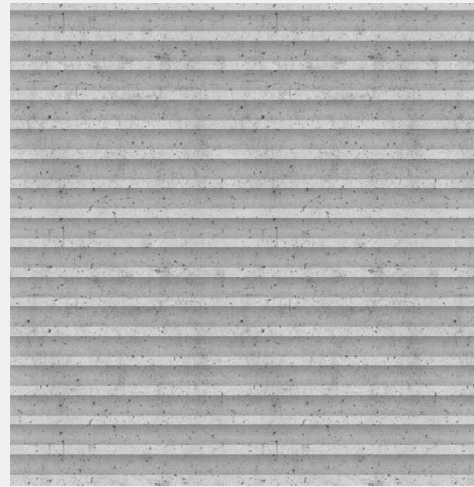
Designing the panel geometry

Design tool

Designing the panel geometry



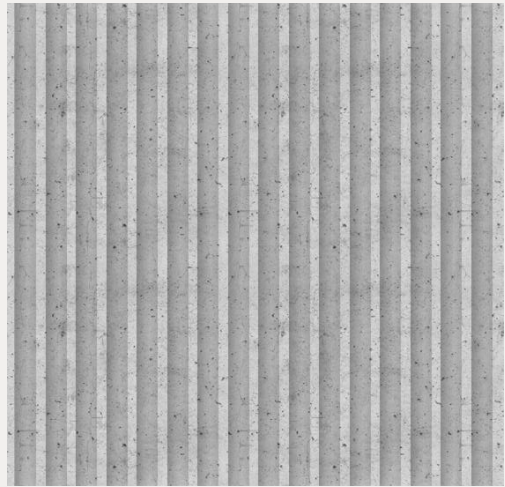
Vertical pattern



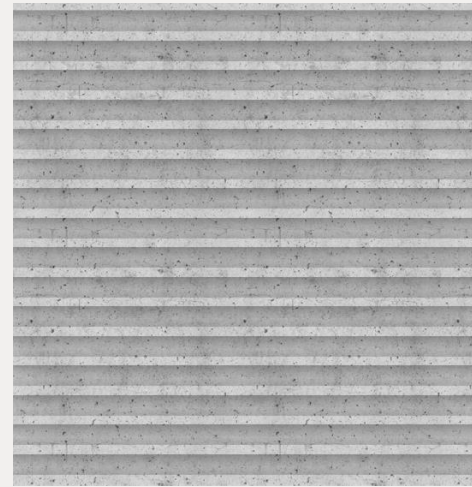
Horizontal pattern

Design tool

Designing the panel geometry



Vertical pattern



Horizontal pattern

Self shading geometry

Design tool

Designing the panel geometry

[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

[4] Visibility

[5] Coverage

Design tool

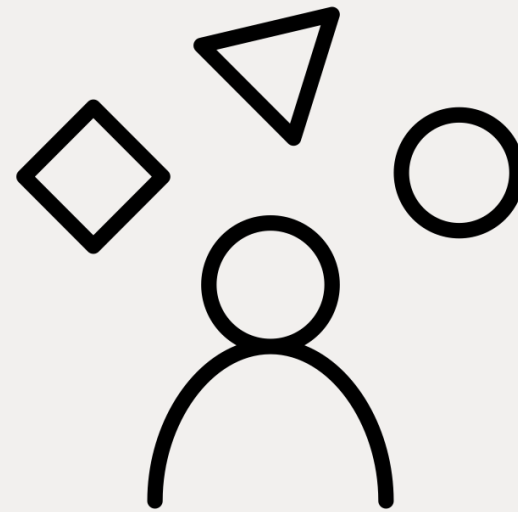
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Designer

Design tool

[1] Design concept

[2] Moisture

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Section



Section

Design tool

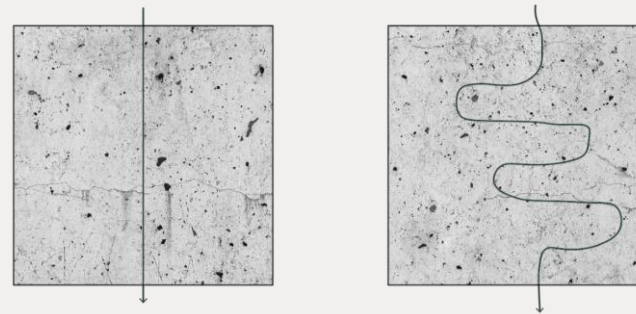
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Planview

Design tool

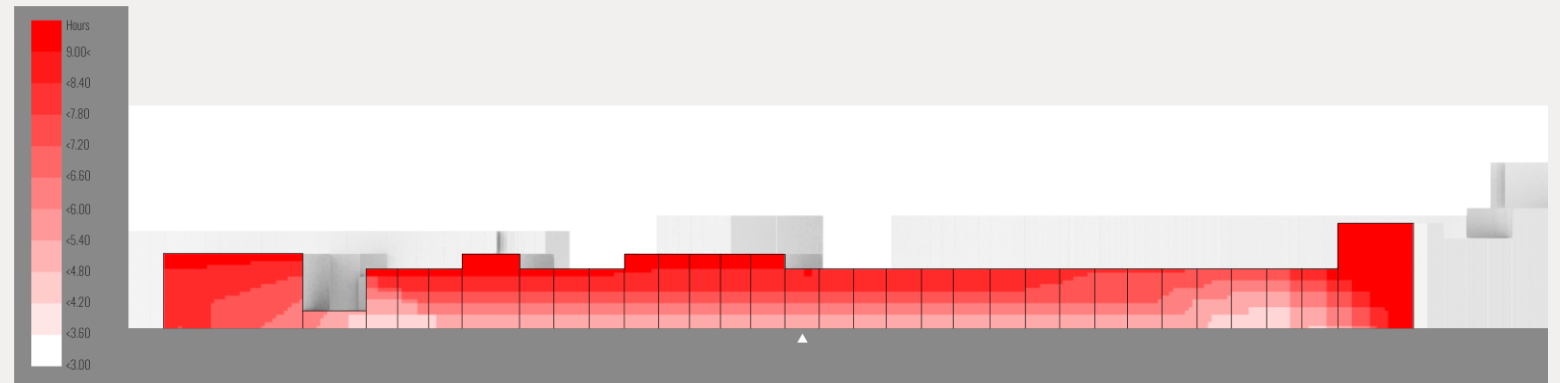
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Radiation analysis design location 21st of June

Design tool

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Visibility on bryophytes

Design tool

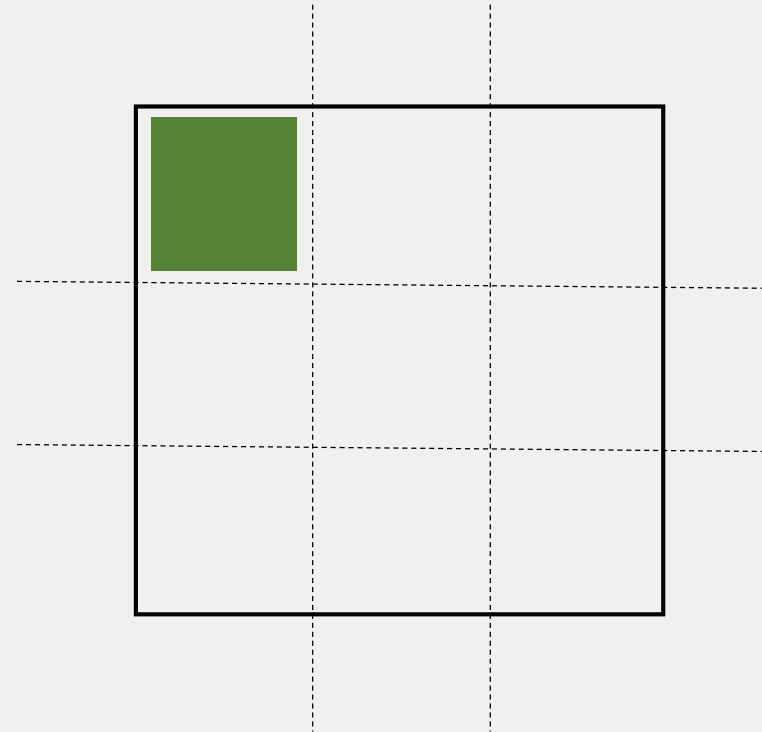
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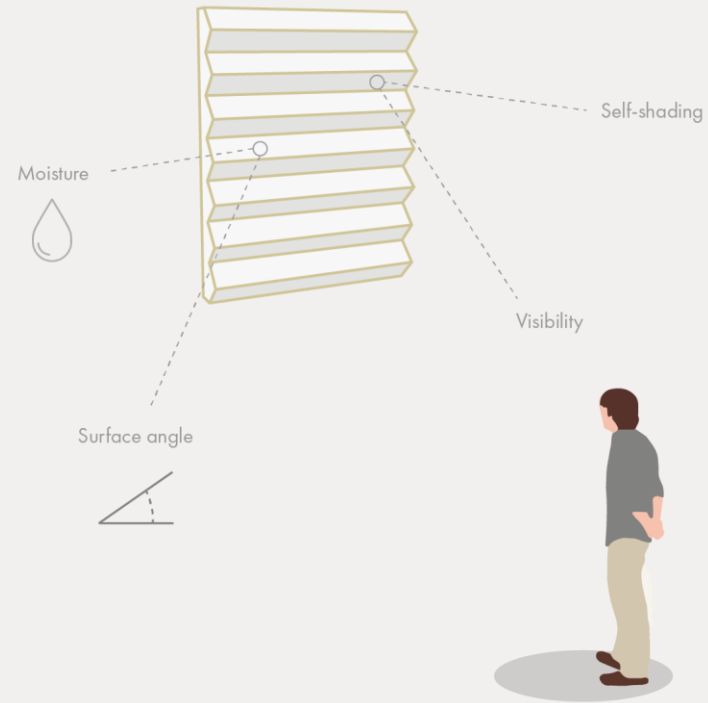
[3] Radiation measurements/shading assessment

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Design tool



Design tool



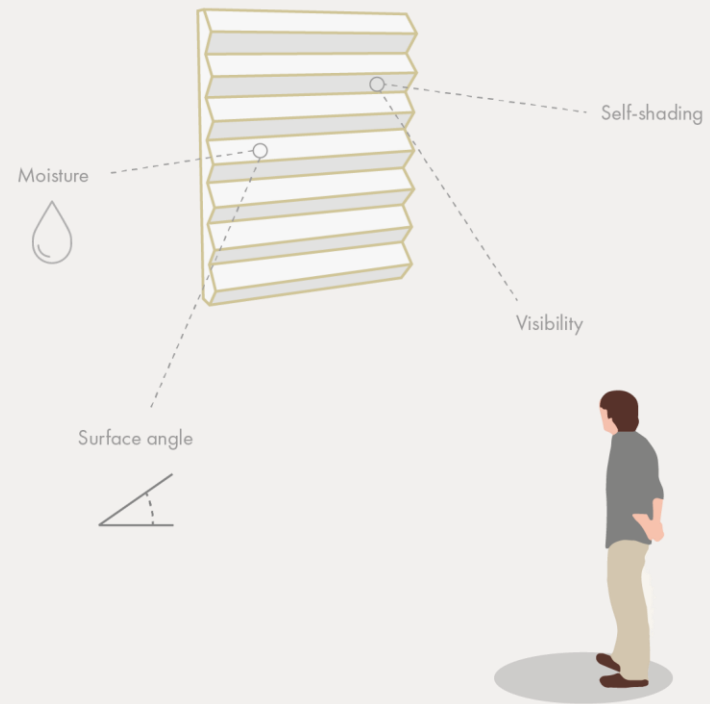
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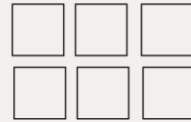
[4] Visibility

[5] Coverage



②

Facade panel design



How to design a bioreceptive facade panel in urban environmental conditions of The Netherlands?

Design



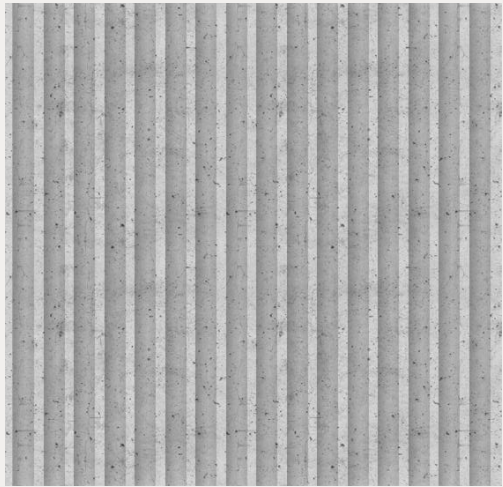
Worst case scenario in representative neighborhood

Design

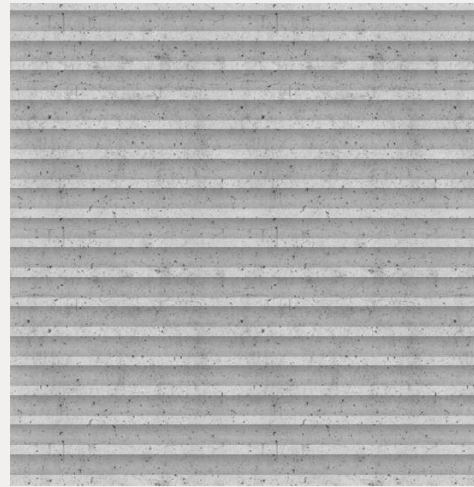


Worst case scenario in representative neighborhood

Design

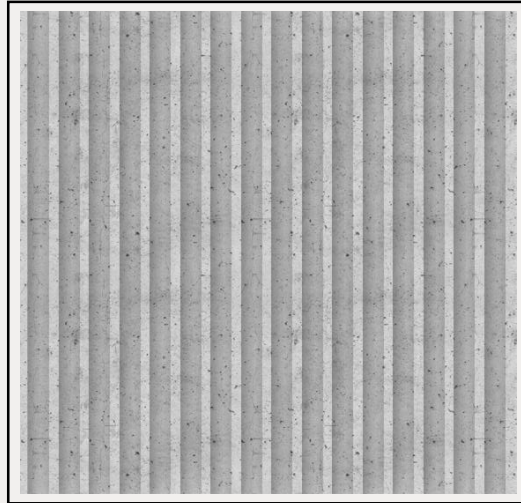


Vertical pattern

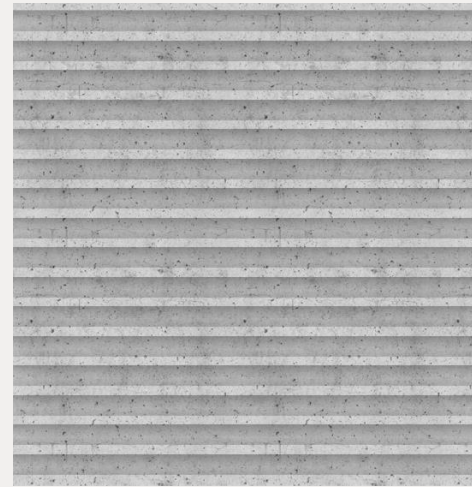


Horizontal pattern

Design



Vertical pattern



Horizontal pattern

Panel design 1

[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

[4] Visibility

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(Freepik, n.d.)

Panel design 1



[1] Design concept

[2] Moisture

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Panel design 1

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[5] Coverage



Panel design 1

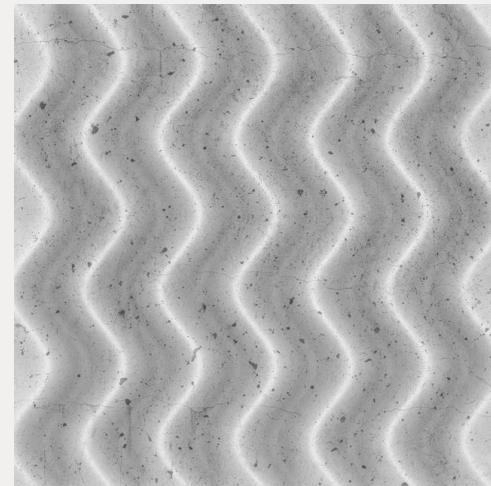
[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

[4] Visibility

[5] Coverage



Zigzagged



Panel design 1

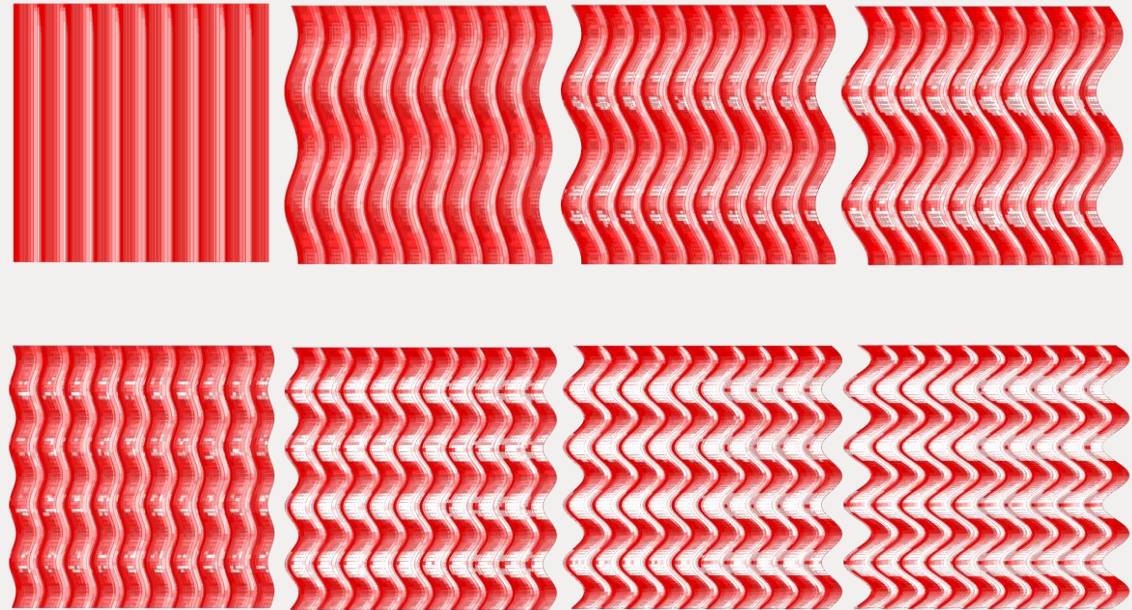
[1] Design concept

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[4] Visibility

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Radiation on panel variations

Panel design 1

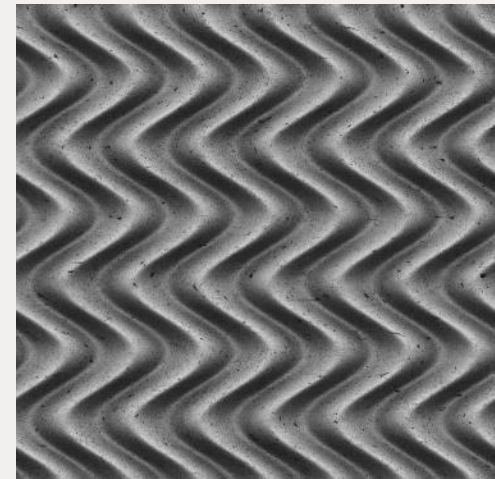
[1] Design concept

[2] Moisture

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[4] Visibility

[5] Coverage



Zigzagged

Panel design 1

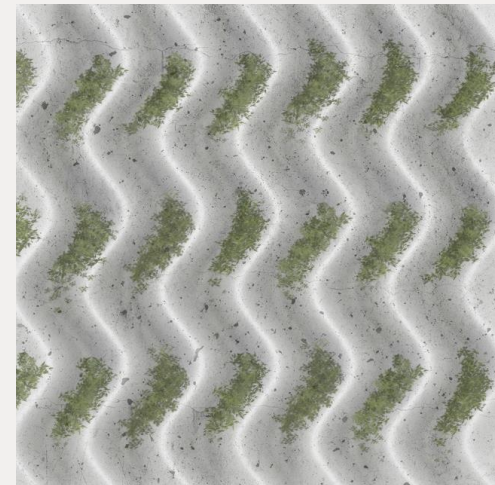
[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

[4] Visibility

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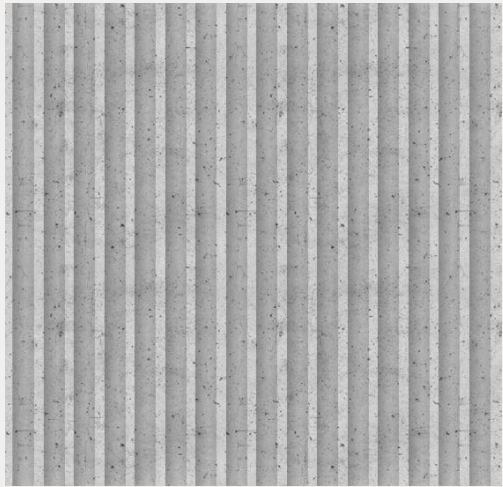
Surface angle

Panel design 1

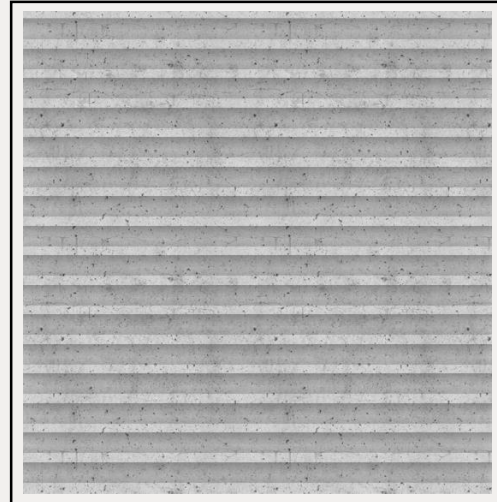


Variation		01	02	03	04	05	06	07	08
Curve 1	A	25	25	25	25	25	25	25	25
	F	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Curve 2	A	0	20	30	40	10	20	30	40
	F	0.02	0.02	0.02	0.02	0.04	0.04	0.04	0.04
Length	(mm)	500	537	586	630	516	644	725	884
Radiation	(h)	2.62	2.59	2.20	1.79	2.39	1.66	1.49	1.47

Design



Vertical pattern



Horizontal pattern

Panel design 2

[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

[4] Visibility

[5] Coverage



Field observations

Panel design 2

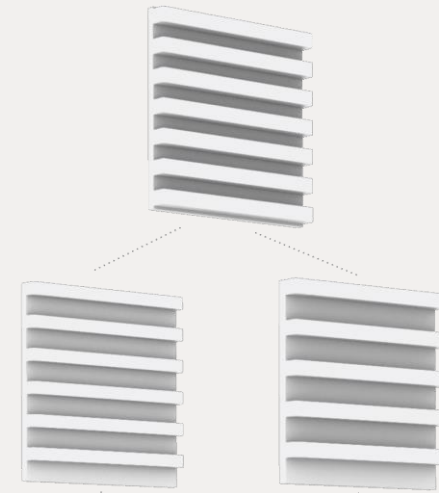
[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

[4] Visibility

[5] Coverage



Panel design 2

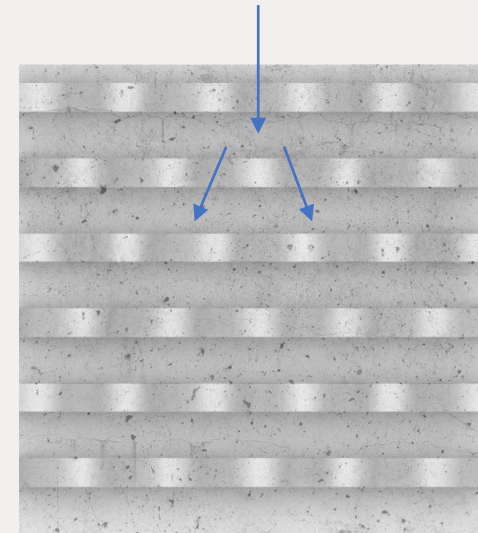
[1] Design concept

[2] Moisture

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Waterflow

Panel design 2

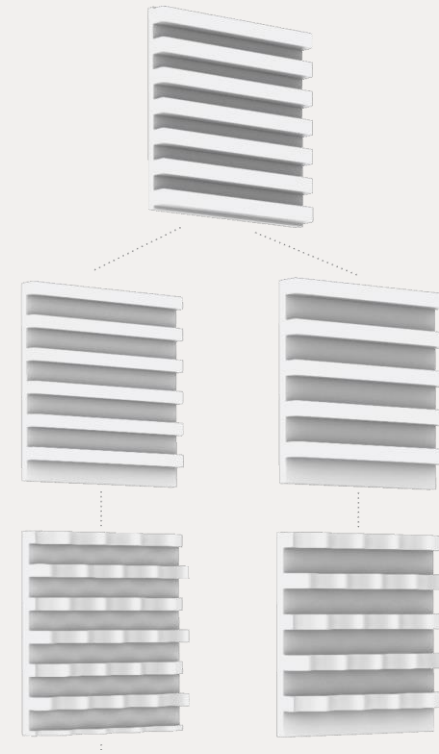
[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

[4] Visibility

[5] Coverage



Panel design 2

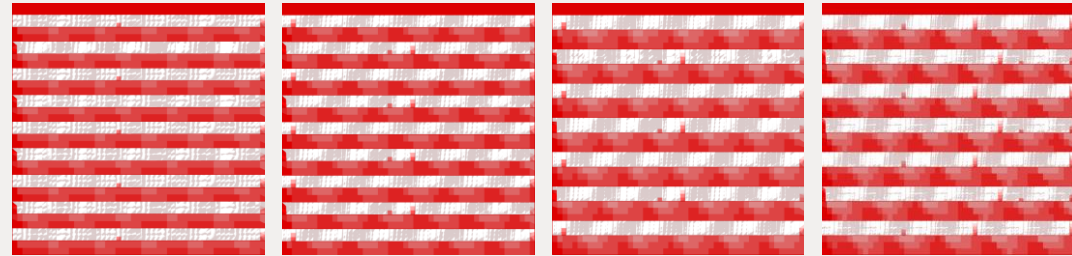
[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

[4] Visibility

[5] Coverage



Radiation on panel variations

Panel design 2

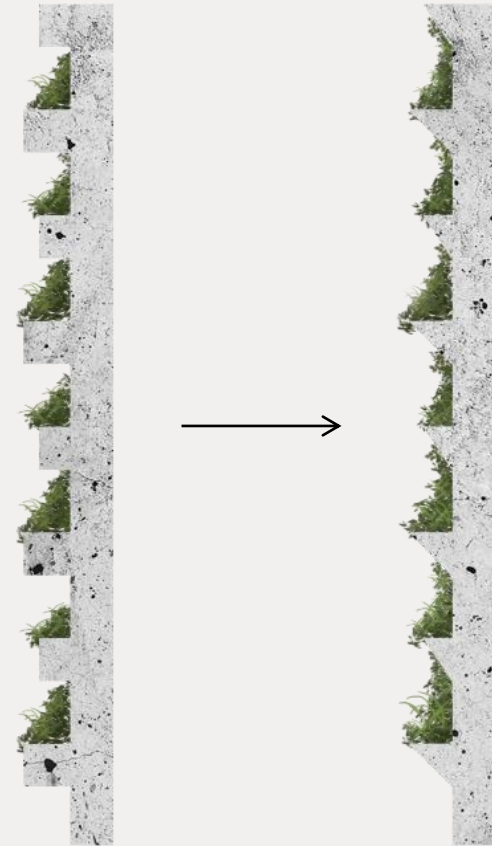
[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

[4] Visibility

[5] Coverage



Section

Panel design 2

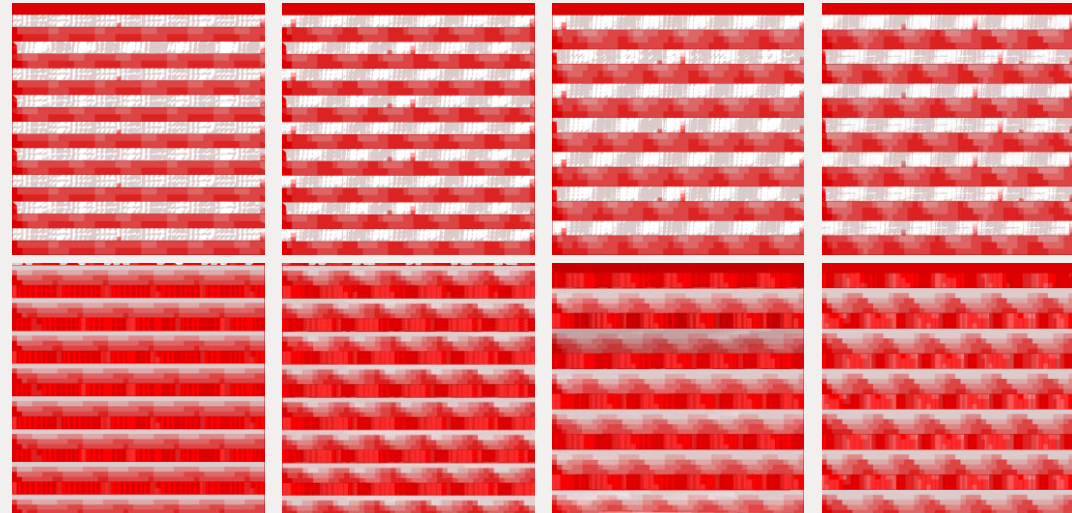
[1] Design concept

[2] Moisture

[3] Radiation measurements/shading assessment

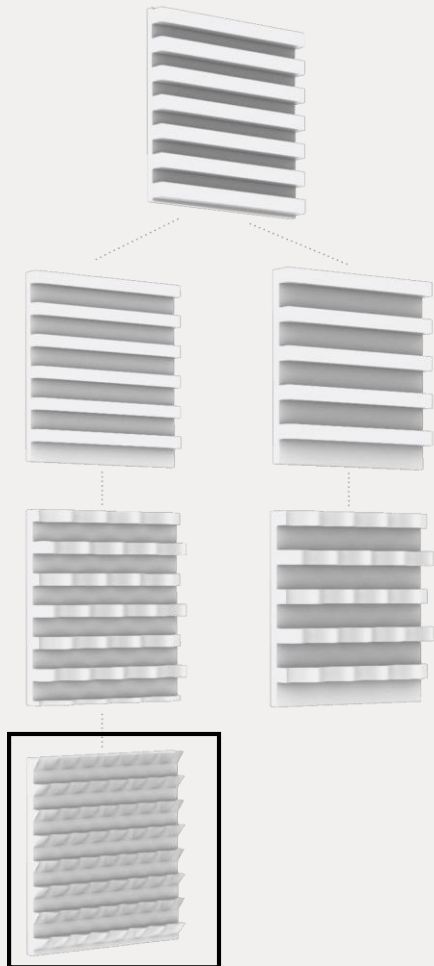
[4] Visibility

[5] Coverage



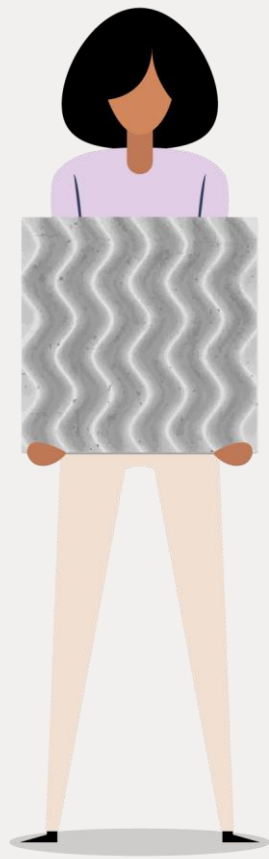
Radiation on panel variations

Panel design 2

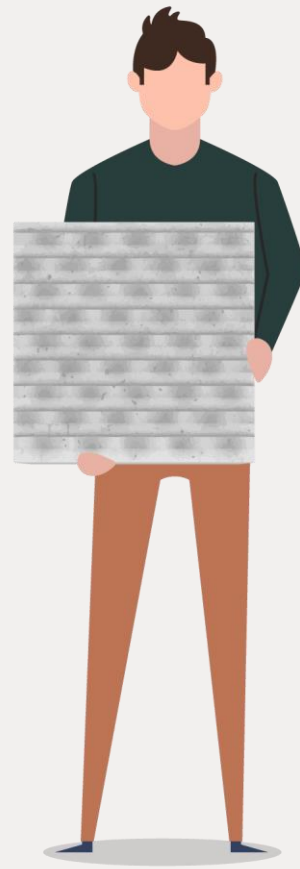


Nmr.	R.1.1	R.1.2	R.2.1	R.2.2	T.1.1	T.1.2	T.2.1	T.2.2
Section	Rectangular				Triangular			
Variation	1		2		1		2	
Amplitude	5	10	10	15	5	10	10	15
Radiation (h)	2.10	2.14	2.32	2.33	1.77	1.76	1.90	1.91

Panel 1

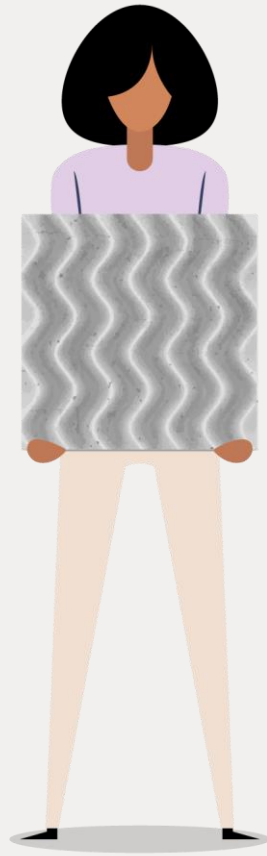


Panel 2

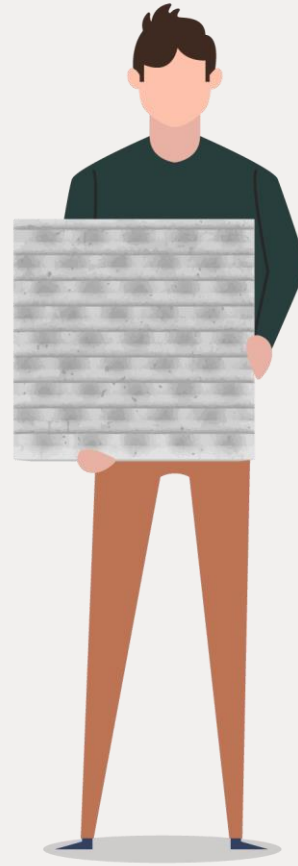


Comparison

Panel 1

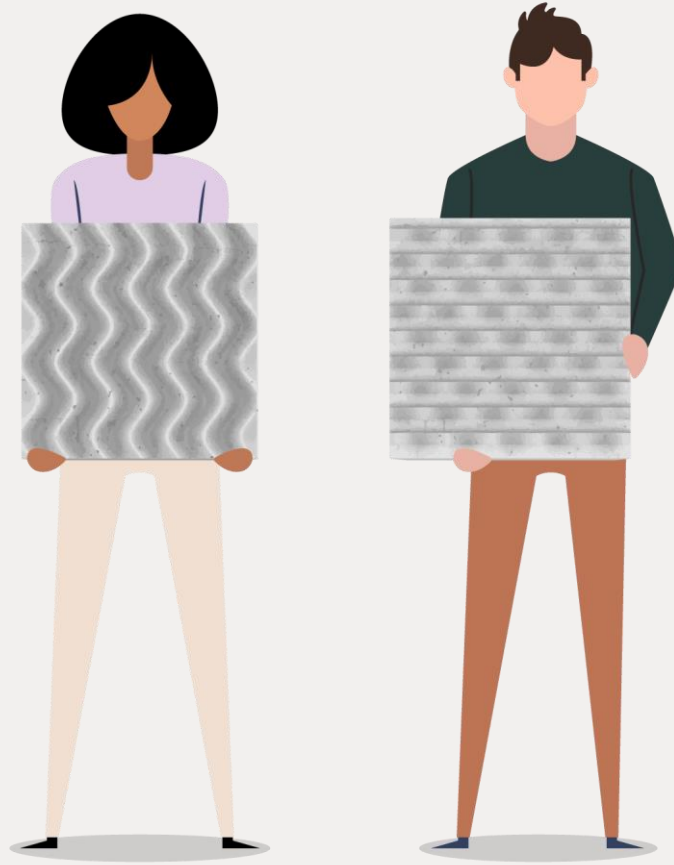
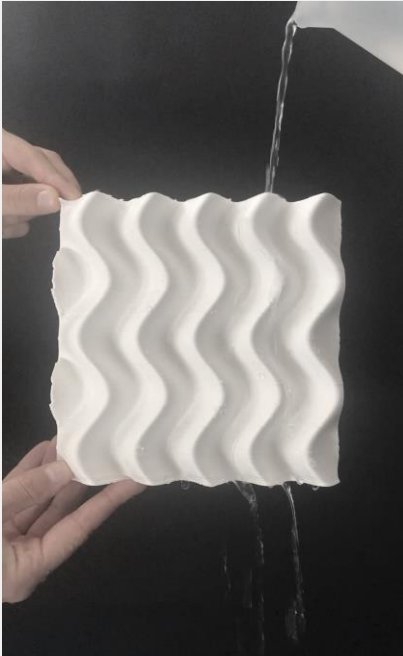


Panel 2

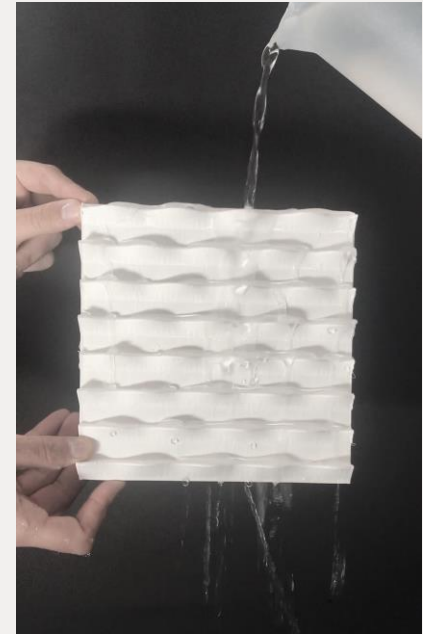


Comparison; Moisture

Panel 1

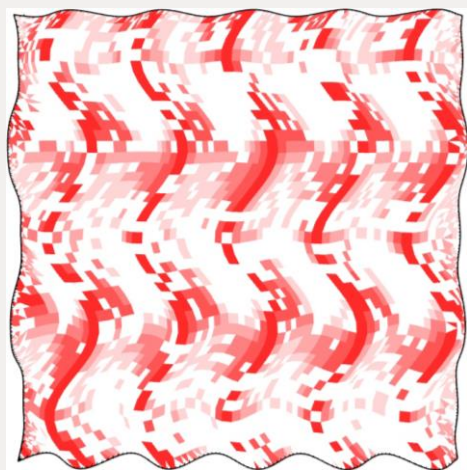


Panel 2

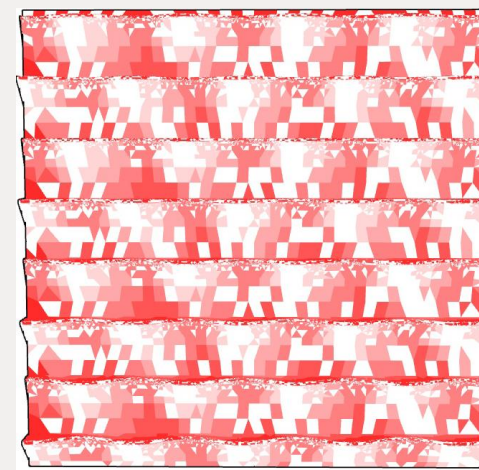


Comparison; Radiation

Panel 1



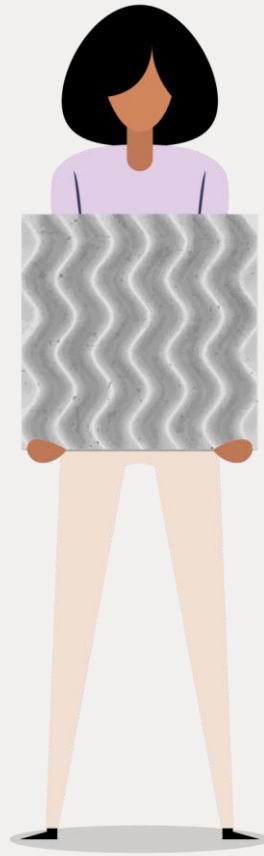
Panel 2



Comparison; Coverage

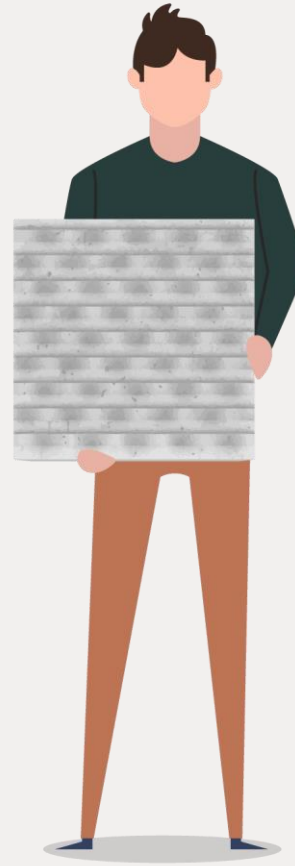
Panel 1

- Surface area; 0.29m²
- Downward facing surface; 0.06m²



Panel 2

- Surface area 0.25 m²
- Downward facing surface; 0.09m²



Comparison

Panel 1

Panel 2

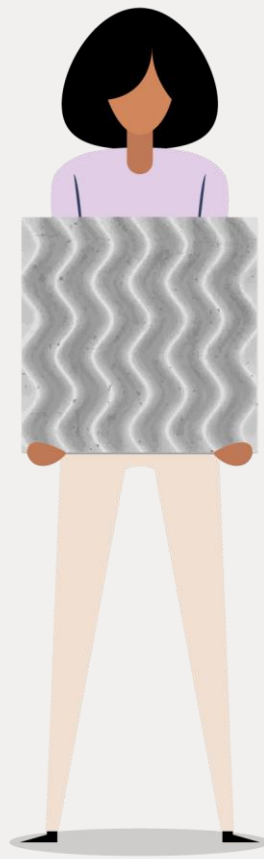
- Radiation; panel 1 performs better in terms of average sun hours on the panel, especially as H increases.
- The surface area of panel 1 is more than panel 2, this means the coverage is potentially higher.
- The surface angle of panel 1 is more suiting for bryophytes; less downward facing surfaces. This influences the coverage positively.



Comparison

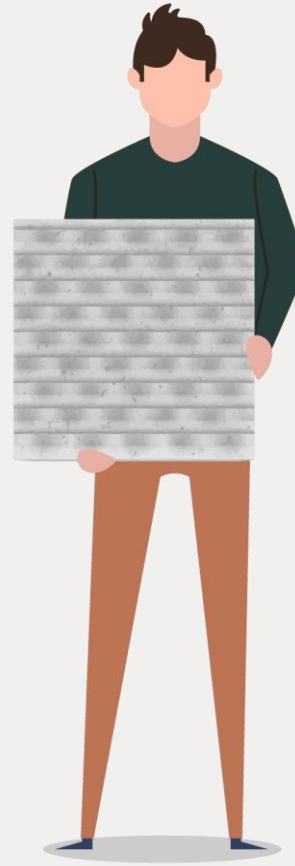
Panel 1

- Radiation; panel 1 performs better in terms of average sun hours on the panel, especially as H increases.
- The surface area of panel 1 is more than panel 2, this means the coverage is potentially higher.
- The surface angle of panel 1 is more suiting for bryophytes; less downward facing surfaces. This influences the coverage positively.



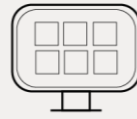
Panel 2

- Moisture; in terms of moisture panel 2 seems more promising. The panel extends the water flow and is able to retain water.



3

Simulations



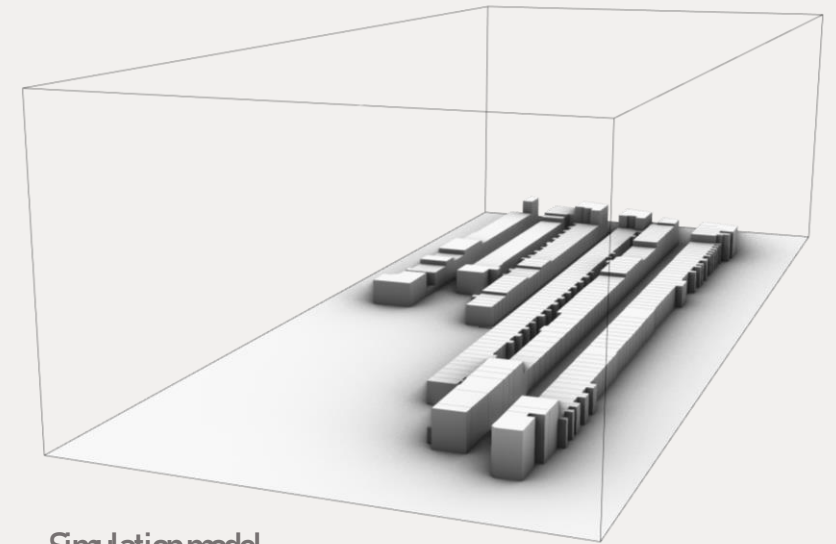
**What is the impact of bioreceptive facade panels on the urban environment
in The Netherlands?**

Climate simulations

- Goal: Measuring direct factors of bryophytes presence in the urban climate at street height in the urban canyon
- Temperature and humidity
- ENM-met climate modelling software

Climate simulations

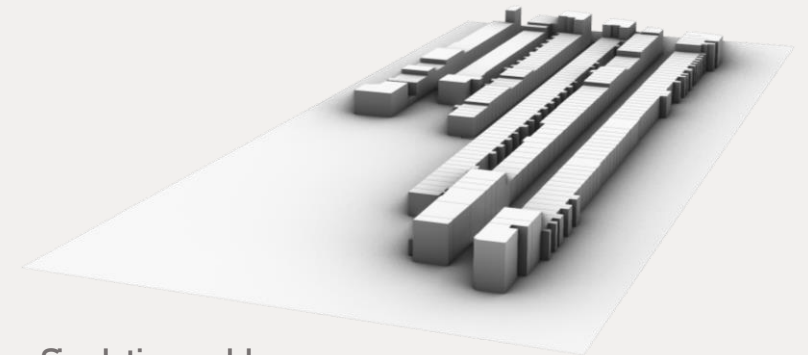
- Goal: Measuring direct factors of bryophytes presence in the urban climate at street height in the urban canyon
- Temperature and humidity
- ENM-met climate modelling software
- Boundary model of different meteorological parameters



Simulation model

Climate simulations

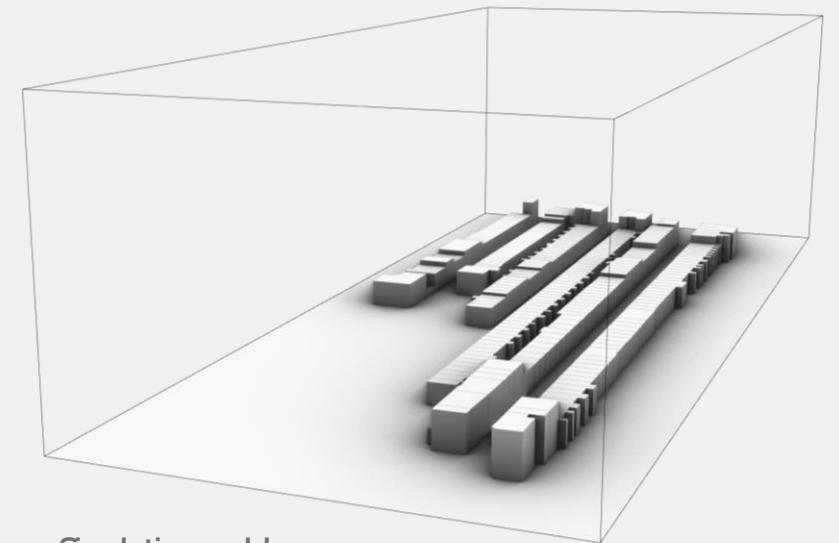
- Goal: Measuring direct factors of bryophytes presence in the urban climate at street height in the urban canyon
- Temperature and humidity
- ENM-met climate modelling software
- Main 3D model including materials, vegetation and soil



Simulation model

Simulation input

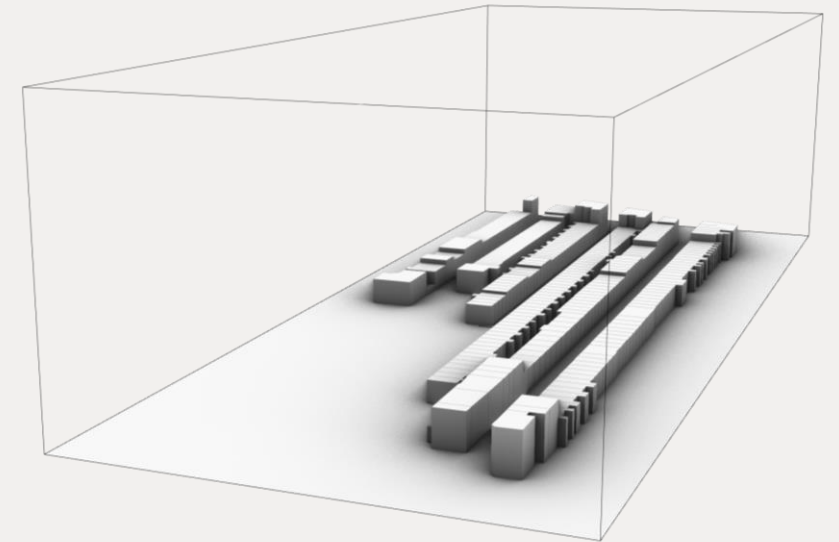
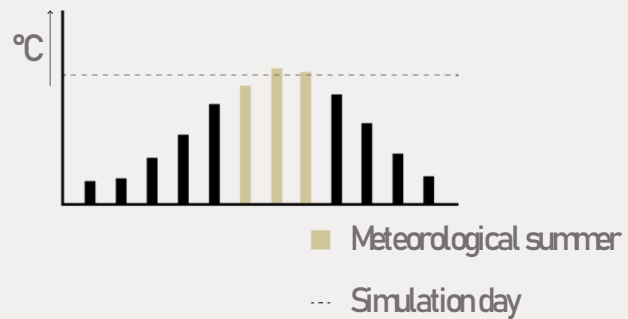
- Weather data from EPWfile (Rotterdam)
- 24 h simulation, starting at sunrise



Simulation model

Simulation input

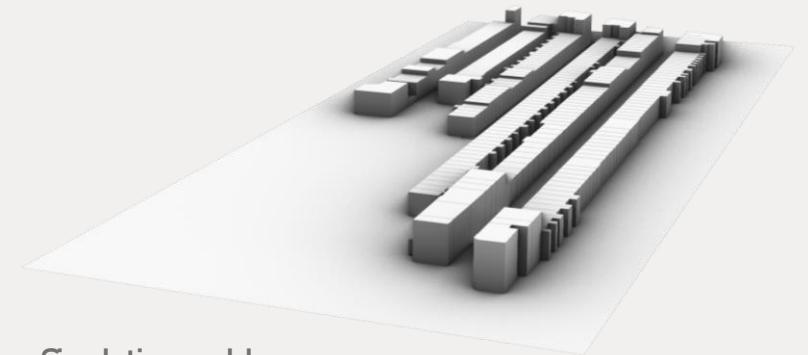
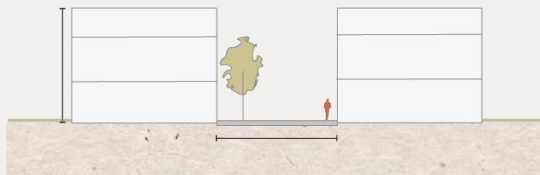
- Weather data from EPWfile (Rotterdam)
- 24 h simulation, starting at sunrise
- Average summer day in The Netherlands ($\approx 25^{\circ}\text{C}$)



Simulation model

Simulation input

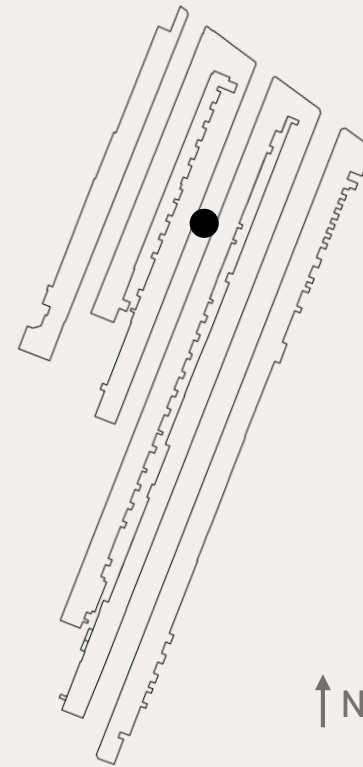
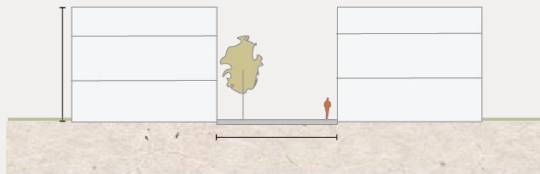
- LCZ3 – Compact lowrise
- Middle street
- Receptor (1.5m)



Simulation model

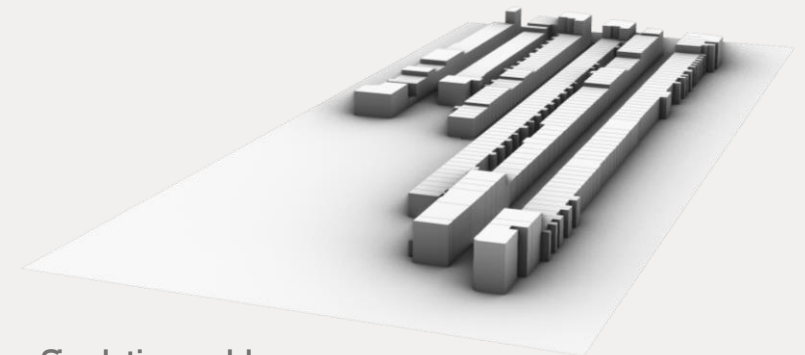
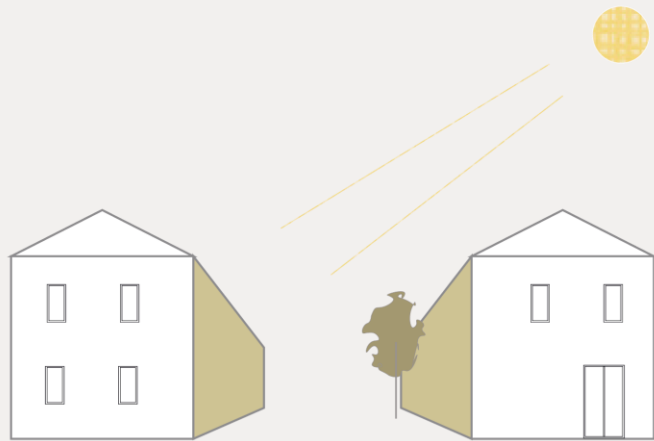
Simulation input

- LCZ3 – Compact lowrise
- Middle street
- Receptor (1.5m)



Simulation input

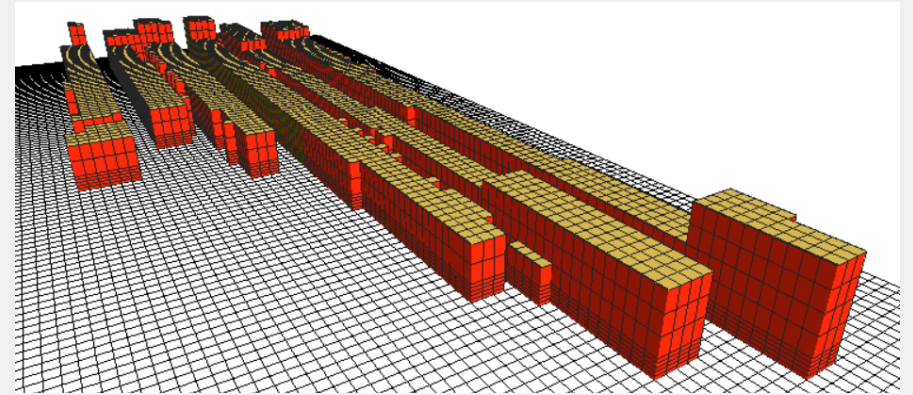
- LCZ3 – Compact lowrise
- Middle street
- Receptor (1.5 m)
- Gardens simplified into grass surface
- Façade greening applied to SE and NW facing facades



Simulation model

Simulation input

- LCZ3 – Compact lowrise
- Middle street
- Receptor (1.5 m)
- Gardens simplified into grass surface
- Façade greening applied to SE and NW facing facades
- Simplification model to 3m x 3m grid

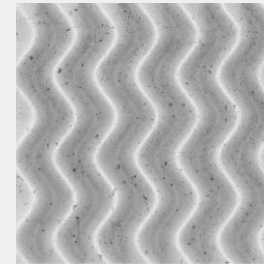


Simulation model

Façade panel properties

- Panel coverage;

Panel 1



Coverage ratio=
surface area ratio panel * mass coverage panel *
window-to-wall ratio

$$1.8 * 0.8 * 0.82 = 1.18$$

Façade panel properties; scenario 1

- Façade coverage; 70%

All closed surface covered



Façade panel properties; scenario 2

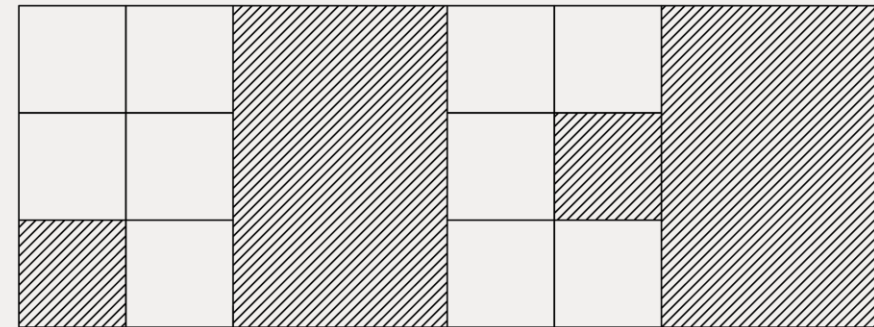
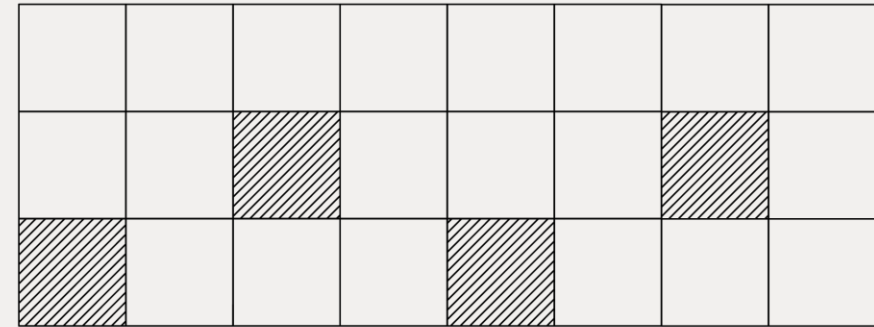
- Facade coverage; 40%

Least amount of coverage



Façade panel properties

- Moss surface area=façade coverage*panel coverage
- Façade coverage in configuration



Bryophyte properties



Greening variable	Value(s)	Reference
Plant layer thickness	2-3 cm 3 cm	Field observations (chapter ... section ...) K., Katoh, Katsurayama, Koganei, & Mizunuma, 2018
With/without substrate	without	Design factor
LAI	6 to 140 4 to 22.5 0.5 to 6.7 2.9 to 26.1	Glime, 2017 Hanson & Rice, 2013 Bond-Lamberty & Gower, 2006 Niinemets & Tobias, 2019
Leaf angle	0.3 0.35 to 0.87	Wu et al., 2013 Falster & Westoby, 2003
CO2 fixation (C3/C4 fixation)	C3 No measured C4	ENVI-met, n.d. Hanson & Rice, 2013
Leaf type Grass/deciduous/conifer	Conifer	Hanson & Rice, 2013
Albedo	0.2 0.2 0.08-0.09 / 0.05-0.06 0.13 to 0.19 0.2	ENVI-met, n.d. Houldcroft, 2009 K., Katoh, Katsurayama, Koganei, & Mizunuma, 2018 Wood & Oliver, 2004 Declet-Barreto et al., 2012
Transmittance	0.3	ENVI-met, n.d.
Plant height	0.25	Default
Root zone depth	0.5	Default
Leaf area profile	0.15	Default
Root area profile	0.1	Default
Season profile	1	ENVI-met, n.d. (Not implemented yet)

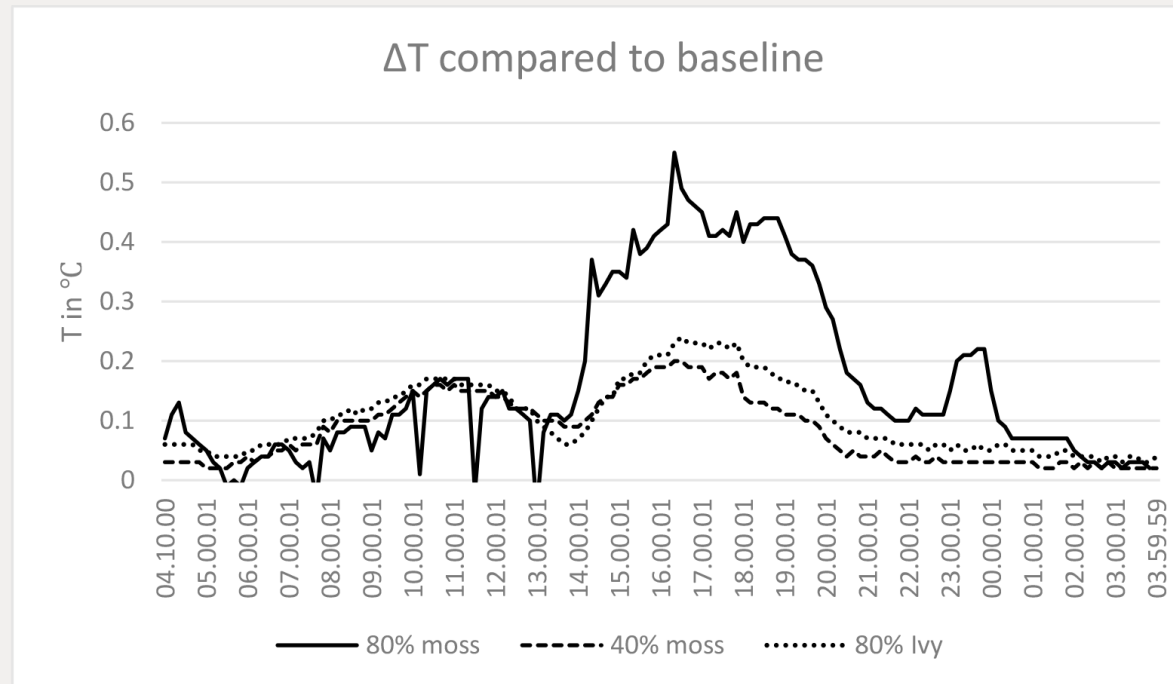
Simulations

- Simulation 1: Baseline measurement – no greening present (red brick facades)
- Simulation 2: Measurement scenario 1 – Moss
- Simulation 3: Measurement scenario 2 – Moss

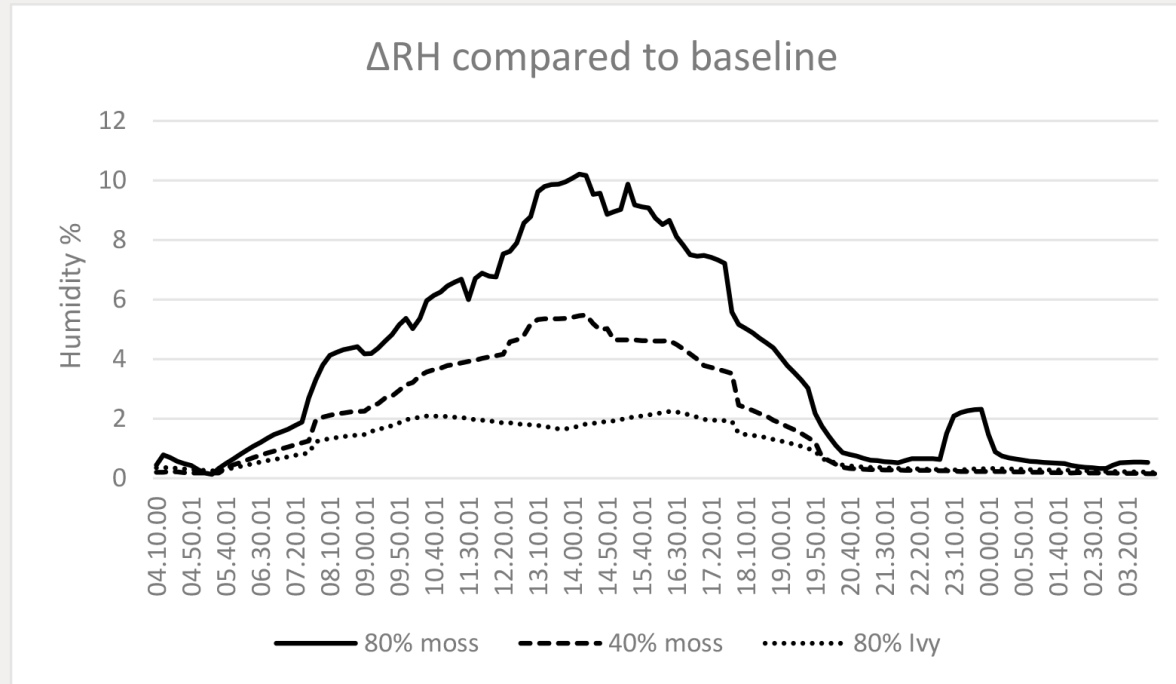
Simulations

- Simulation 1: Baseline measurement – no greening present (red brick facades)
- Simulation 2: Measurement scenario 1 – Moss
- Simulation 3: Measurement scenario 2 – Moss
- Simulation 4: Measurement scenario 1 – Ivy facade

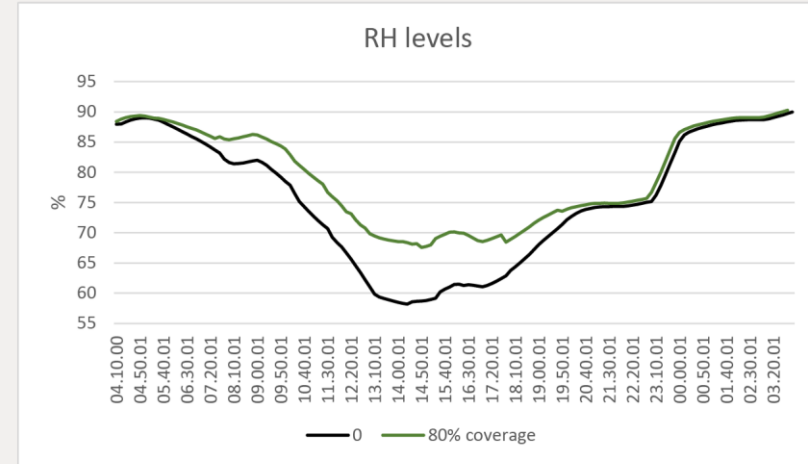
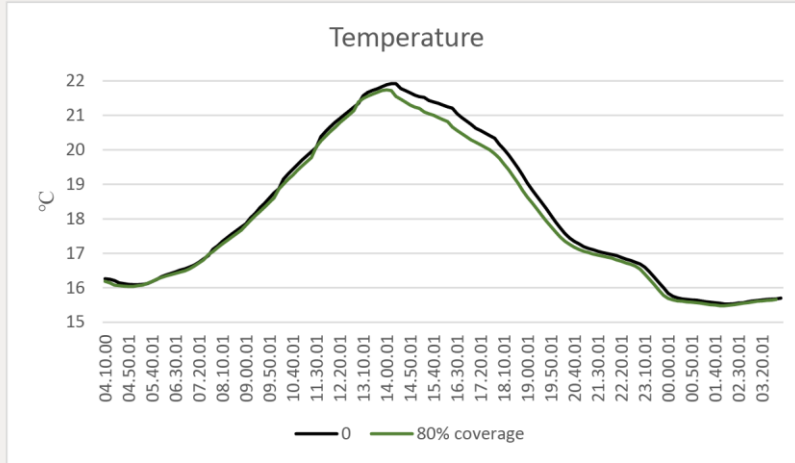
Temperature reduction



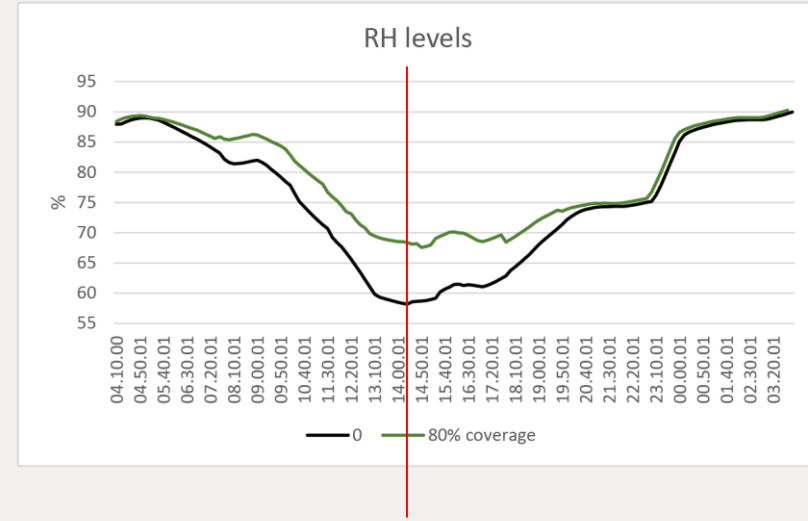
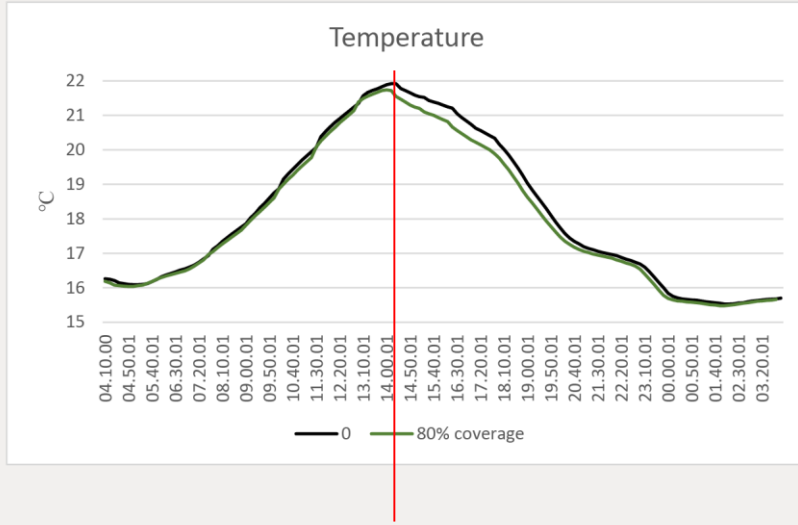
Relative humidity



Profiles



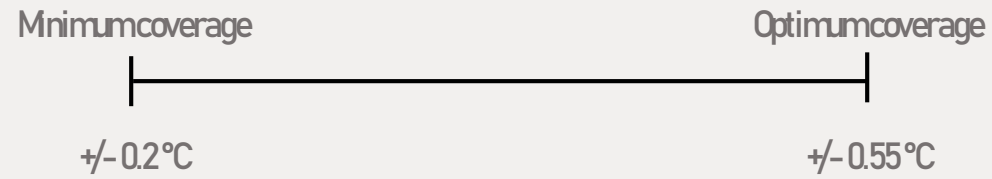
Profiles



Conclusion

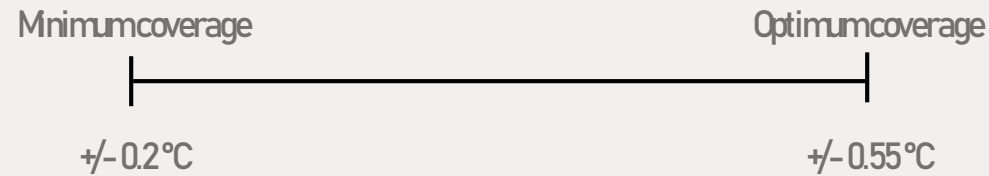
Conclusion

- The simulations show the maximum outdoor temperature reduction during an average summer day in an urban canyon at screen height of a representative urban configuration in The Netherlands is a range between

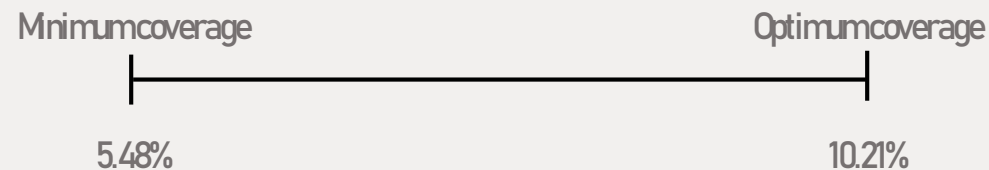


Conclusion

- The simulations show the maximum outdoor temperature reduction during an average summer day in an urban canyon at screen height of a representative urban configuration in The Netherlands is a range between



- The simulations show the maximum outdoor relative humidity increase during an average summer day in an urban canyon at screen height of a representative urban configuration in The Netherlands is a range between

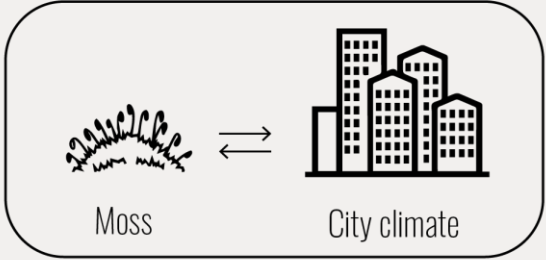


Conclusion

- The bioreceptive façade panels perform better in terms of temperature reduction and humidity increase compared to competitive green wall Ivy
 - The bioreceptive façade panels change the time profiles of the humidity levels, with the Ivy greening this effect is not present

Discussion

- The results are an indication for moss facade in one single climatic condition and configuration.
 - Orientation
 - Different seasons
 - Wind direction/speed
- Influence plant properties, Ivy and Moss facade



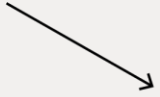
①
Design tool

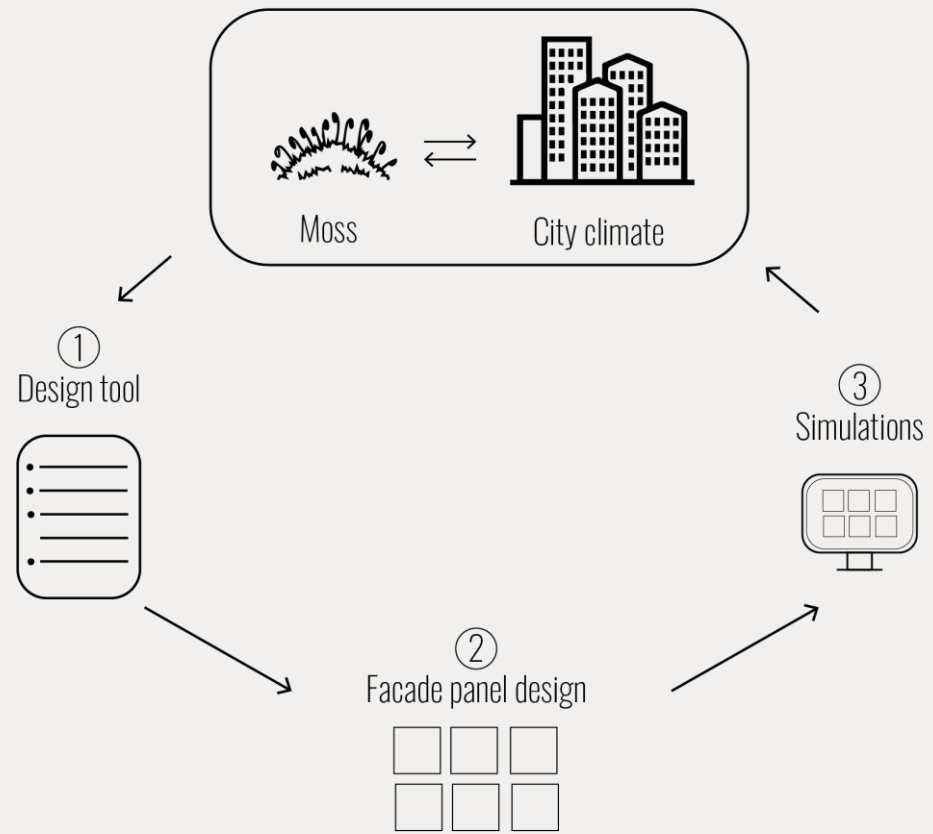


②
Facade panel design



③
Simulations





Conclusions/discussion

Are bioreceptive façade panels an effective measure to improve city climates in The Netherlands?

Conclusions/discussion

Are bioreceptive façade panels an effective measure to improve city climates in The Netherlands?
Limits of the urban climate

- Dormant bryophytes can lose their aesthetic value (dormant mosses turn brown), their ability to reduce air temperature (evaporation) and partially their ability to improve air quality (photosynthesis, purify air)
 - High levels of solar radiation damages bryophytes

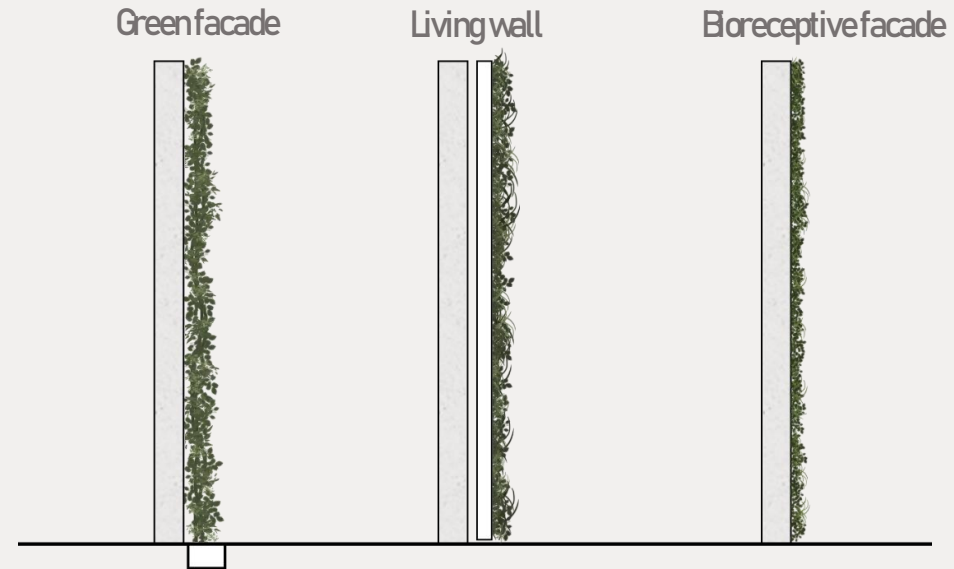
Conclusions/discussion

Are bioreceptive façade panels an effective measure to improve city climates in The Netherlands?
The impact of bryophytes

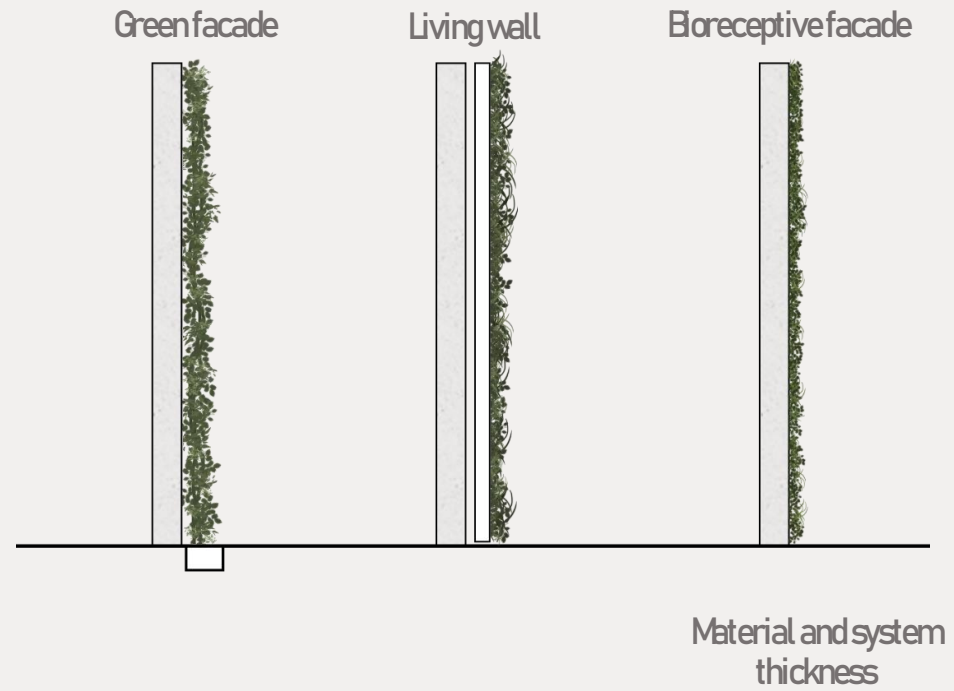
- Outdoor temperature reduction seems little but still many variables of influence, indoor temperature reduction neglected.
 - Promising humidity level increase; contributes to their own habitat conditions.
 - Temperature and humidity profiles change.
 - Mosses seem more promising than Ivy façade.

Discussion

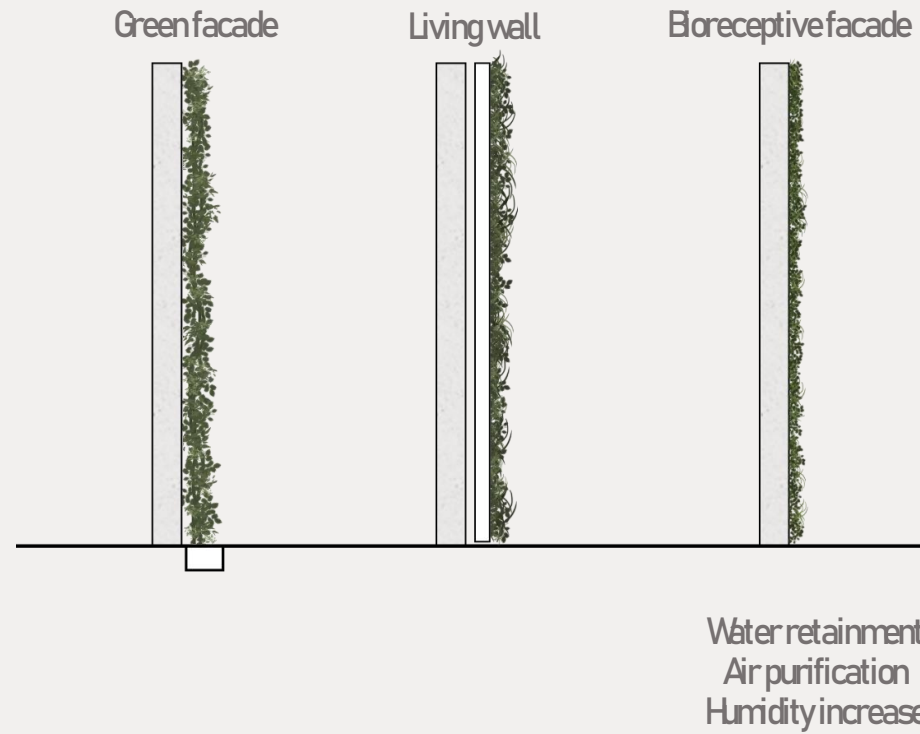
Are bioreceptive façade panels an effective measure to improve city climates in The Netherlands?
Bryophytes as façade system



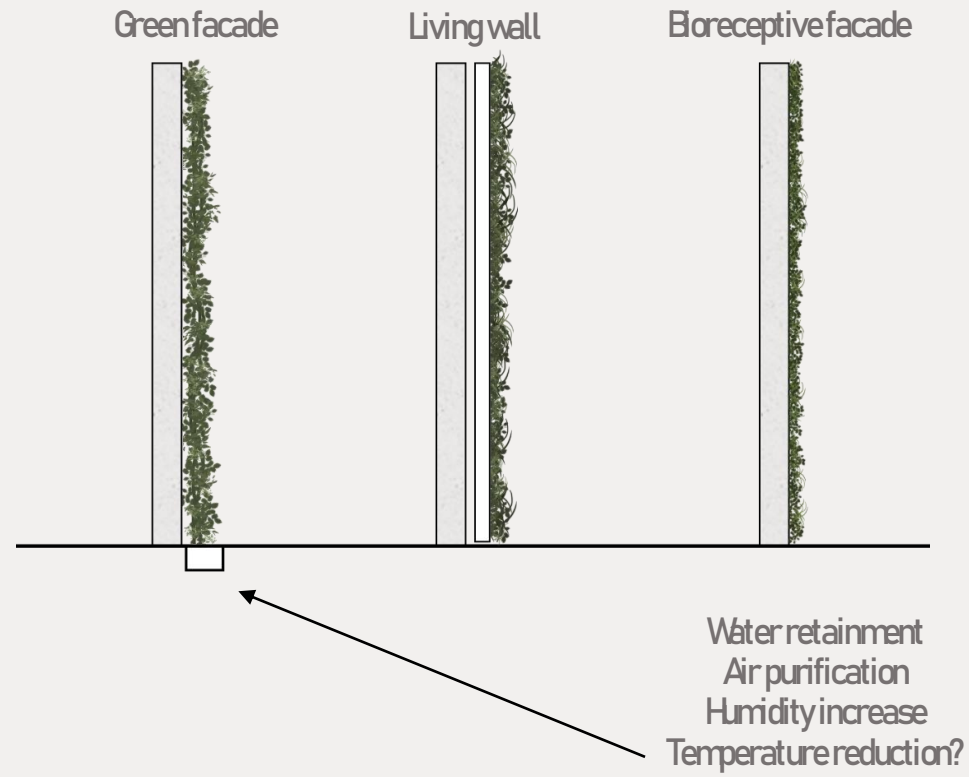
Discussion



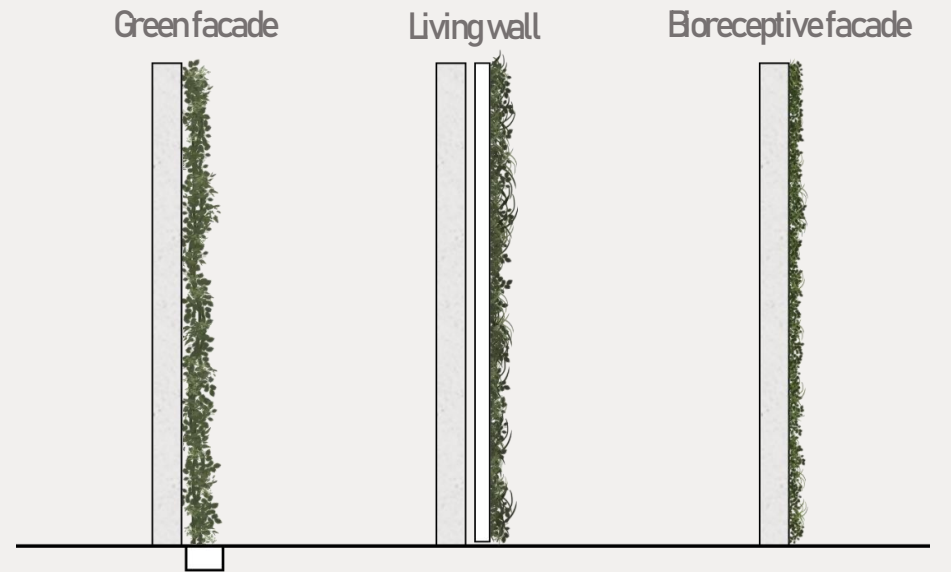
Discussion



Discussion



Discussion



Water retainment
Air purification
Humidity increase
But;
Limited by dormancy

Discussion

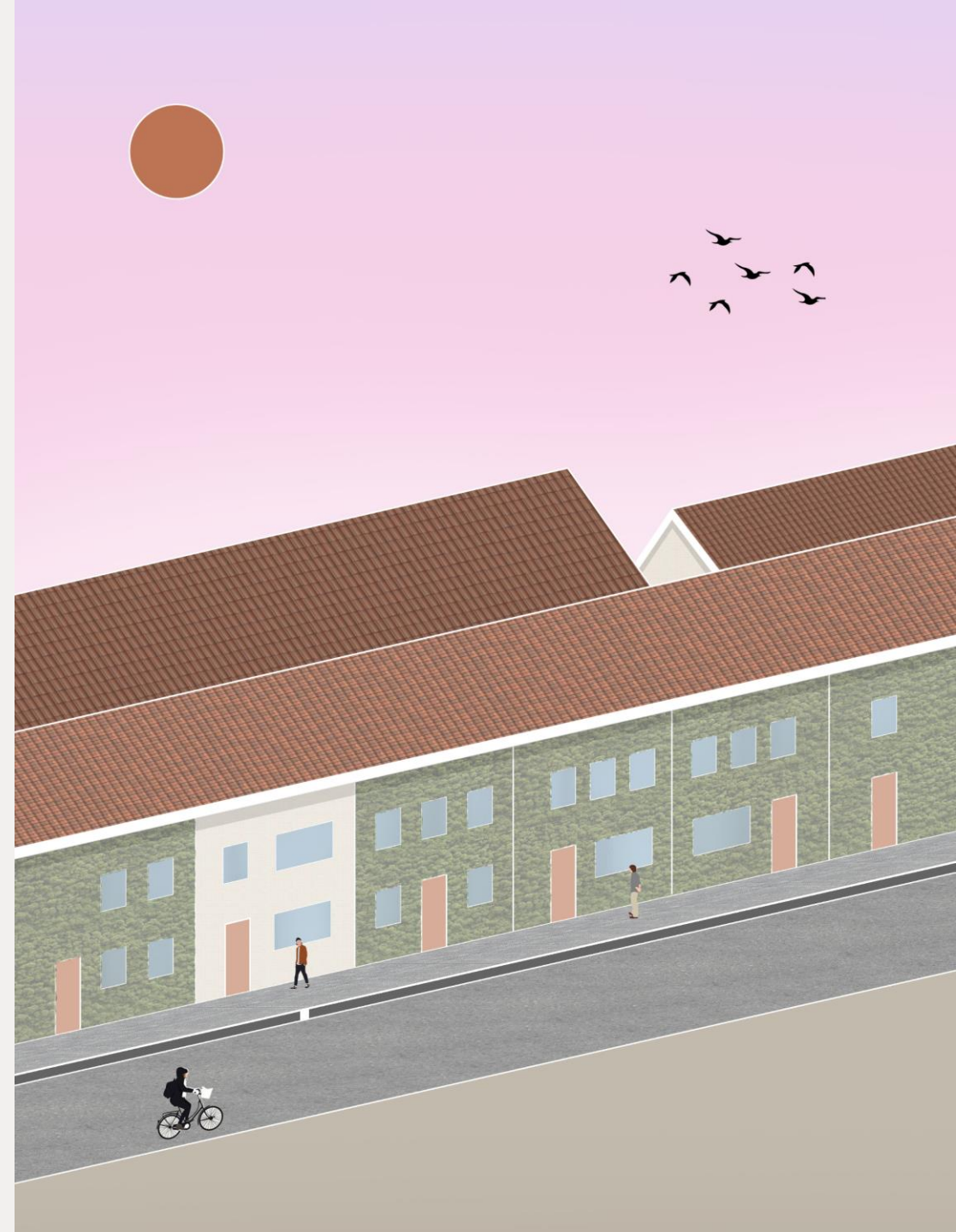


Promising for continuing research

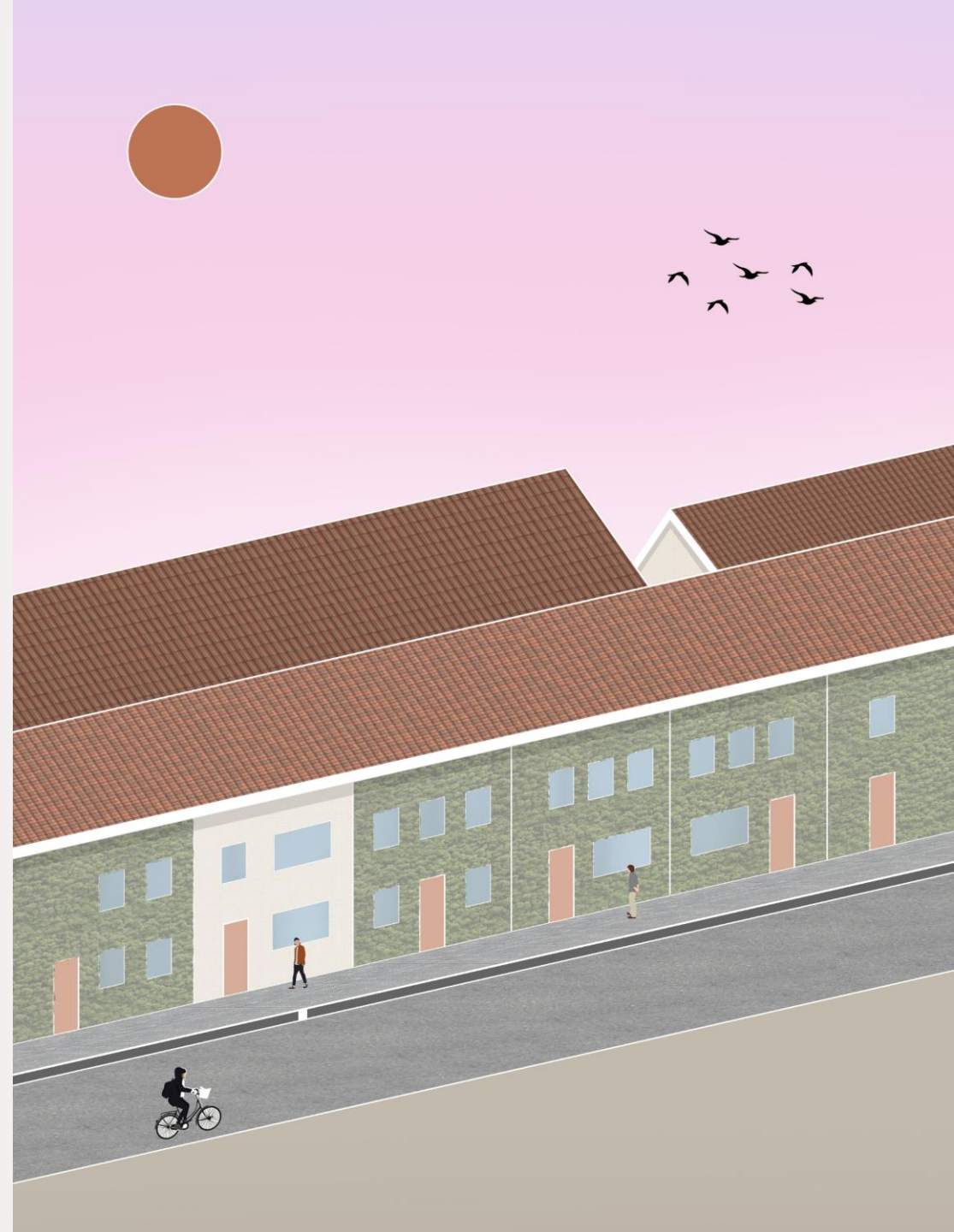


Promising for continuing research

- Relationship between exterior/interior temperature and bryophytes
- Physical plant properties of bryophytes and species selection
- Field testing panel geometries, optimize coverage and material



Thank you for listening!



References

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