# Bioreceptive Habitats

Engineering a bioreceptivity-oriented design strategy through digital and physical experimentation

Msc Thesis Presentation
TU DELFT
2021-22

Student
Dimitrios Ntoupas

Mentors:
Serdar Asut and Barbara Lubelli

# Introduction

# Problem Statement

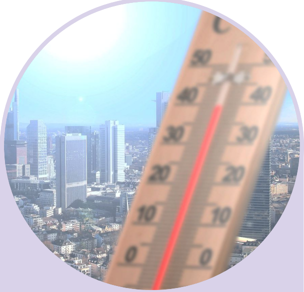
By 2050 70% of the world population is projected to live in urban areas. [UN,2018] Urbanization creates several environmental challenges including loss of biodiversity, heat stress, increased air pollution. Today, there are several strategies of introducing vegetation and photosynthetic systems in the urban tissue aiming passive climate control, reducing carbon dioxide, aiding water and storm management and offering biodiversity on urban scale.

# Subproblem

Green facades, where vegetation is grown next to the building have been proven unsuccessful in many cases. What is more, they require extra costs, additional structural systems, maintenance and mechanical irrigation.

loss of biodiversity

inlovewiththemed.com




heat stress

static.euronews.com

air pollution

ozbreed.com.au

additional systems

cdn.pixabay.com

# Design Vision

Secondary Architectural Skin

geoplastglobal.com

Architectural Bark

c1.wallpaperflare.com

**Biodeterioration**

Any undesirable change in the properties of a material caused by the vital activities of organisms and is classified in three categories. i) physical or mechanical ii) chemical and iii) aesthetical (J.Hueck, 1965)

≠

**Bioreceptivity**

The aptitude of a material to be colonized by one or several groups of living organisms without necessarily undergoing any biodeterioration.

The totality of material properties that contribute to the establishment, anchorage and development of fauna and/or flora. (J.Guillitte, 1995)

# Design Vision


i.pinimg.com/originals/a3

Introducing bioreceptivity on buildings and architecture

# Bioreceptivity

1 Primary

2 Secondary

3 Tertiary

4 Quaternary

(source of images: San Martin et al, 2021)

# Bioreceptivity

1 Primary

2 Secondary

3 Tertiary

4 Quaternary

Is the initial potential of a building material to be biocolonized and its <u>properties remain identical</u> to the properties of its initial state.

(source of images: San Martin et al, 2021)

# Bioreceptivity

## 1 Primary

Is the initial potential of a building material to be biocolonized and its properties remain identical to the properties of its initial state.

## 2 Secondary

Secondary bioreceptivity is derived because of primary bioreceptivity, mainly because of weathering.

## 3 Tertiary

## 4 Quaternary

(source of images: San Martin et al, 2021)

# Bioreceptivity

1 Primary

Is the initial potential of a building material to be biocolonized and its properties remain identical to the properties of its initial state.

2 Secondary

Secondary bioreceptivity is derived because of primary bioreceptivity, mainly because of weathering.

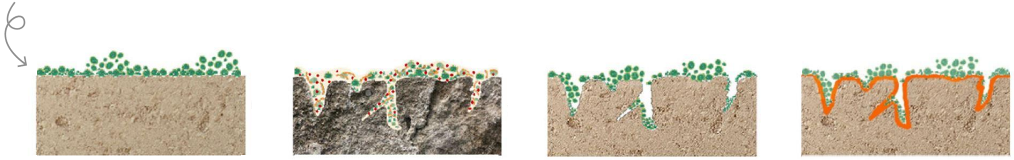
3 Tertiary

Is considered is influenced by human actions and can cause physical changes to a material. (i.e. by post-treatment techniques)

4 Quaternary

(source of images: San Martin et al, 2021)

# Bioreceptivity



## 1 Primary

Is the initial potential of a building material to be biocolonized and its properties remain identical to the properties of its initial state.

## 2 Secondary

Secondary bioreceptivity is derived because of primary bioreceptivity, mainly because of weathering.

## 3 Tertiary

Is considered is influenced by human actions and can cause physical changes to a material. (i.e. by post-treatment techniques)

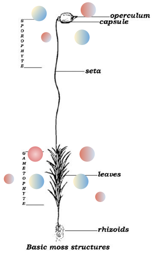
## 4 Quaternary

Quaternary bioreceptivity occurs when other materials are added to an existing one, leaving residues

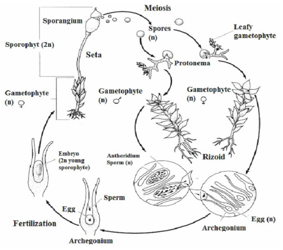
(source of images: San Martin et al, 2021)

# Mosses

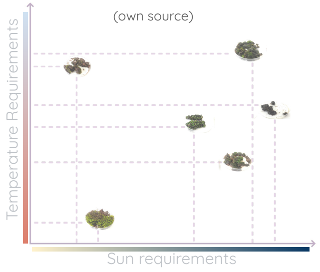
bryophytes.science.oregonstate.edu




bryophytes.science.oregonstate.edu




(own source)




1

Don't have roots.

~

Absorb nutrients and water by their skin and leaves by osmosis

~

Don't need soil as a substrate.

Supports their integration in building elements because they cannot cause biodeterioration.

2

Can be reproduced sexually and asexually

~

Can travel huge distances (=over 12.000km)

Water and wind benefits their initiation and propagation.

3

There are more than 20.000 species with different climatic requirements.

They could be adapted in different locations and conditions and contribute to environmental and social sustainability

# + Benefits

greencitysolutions.de

gardeningknowhow.com

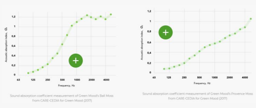
ec.europa.eu/programmes/horizon2020

www.123rf.com/photo_89447060

## Air purification

Cryptogams uptake more than 3.9 Pg. carbon and 49 Tg. nitrogen per year globally

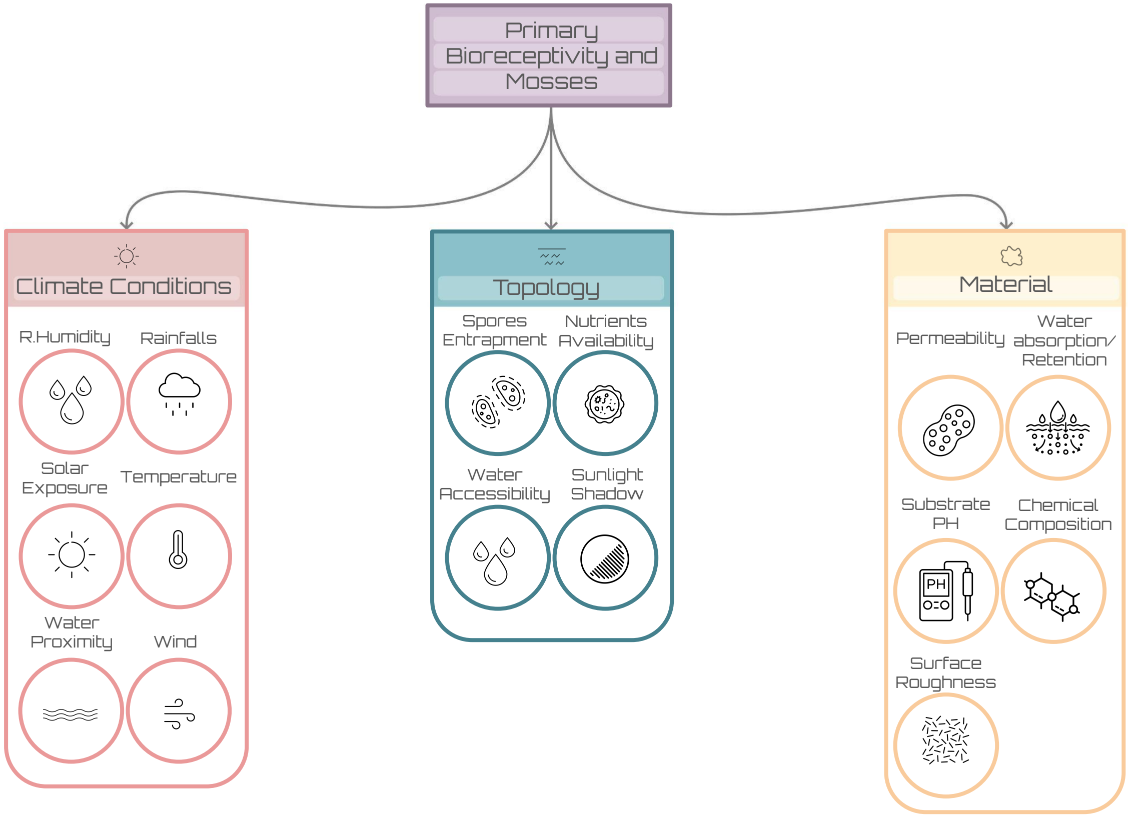
## Acoustics



## Cooling down Method


## Aesthetics

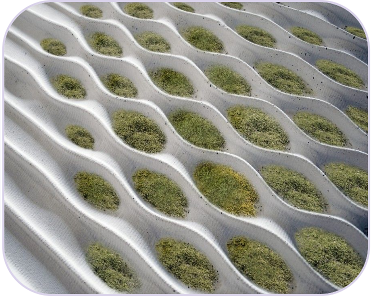
# Bioreceptive Factors




(own source)

# References

(Richard Beckett et al, 2019)



(Richard Beckett & Marco Cruz et al, 2016)

(Pierre Oskam, Max Latour, 2021)

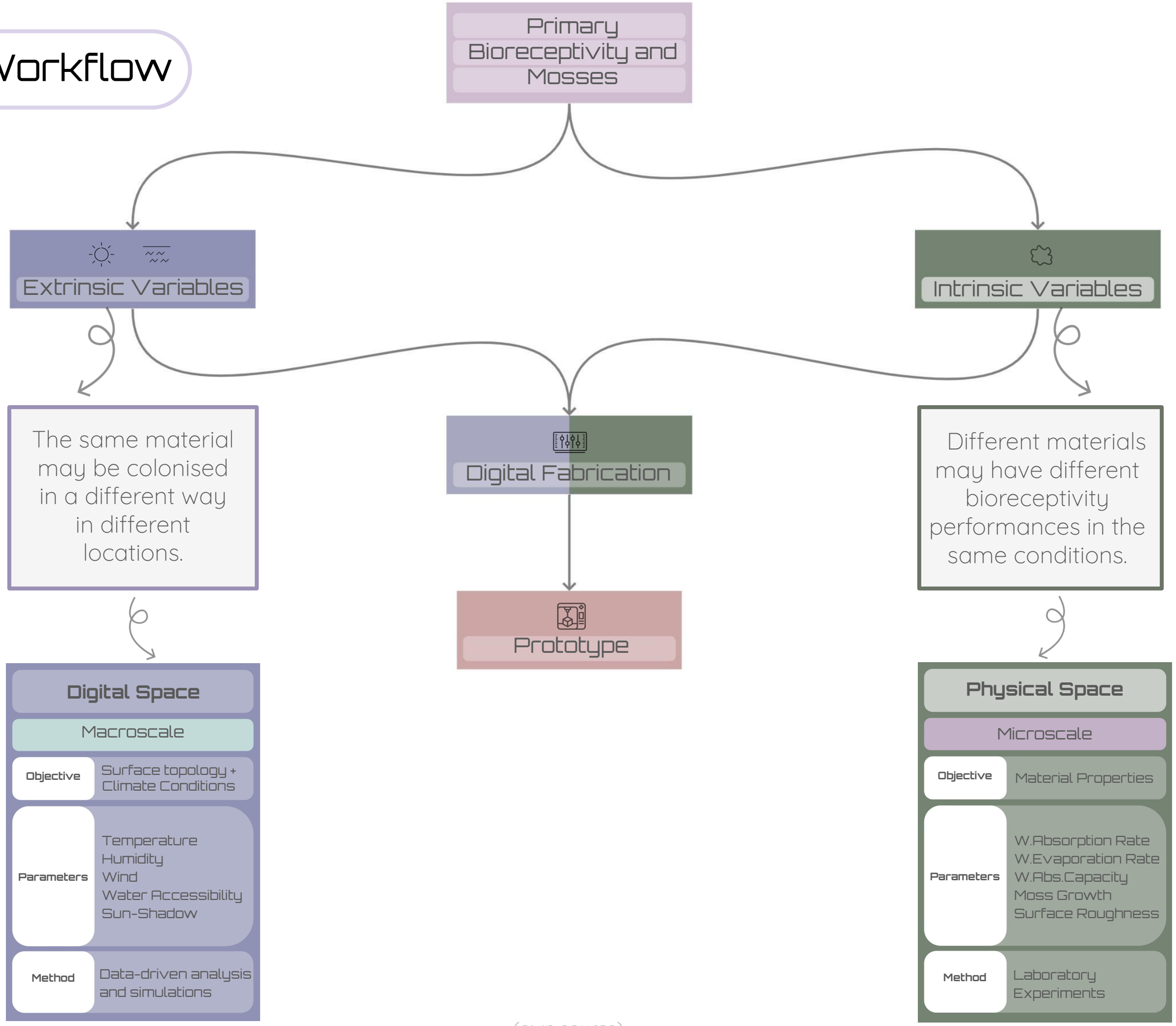
(K.F.Mustafa, 2020)

(Marco Cruz et al, 2016)

The majority focuses mainly on bioreceptive pattern-making and materials; **not on its parametrization**

A material can be bioreceptive but **it will not be biocolonized if the appropriate conditions do not occur**

# General Workflow




(own source)

## Main Research Question

How can computational performance analysis and optimization, in combination with digital fabrication, open new possibilities and support the use of bioreceptive materials in building envelopes?

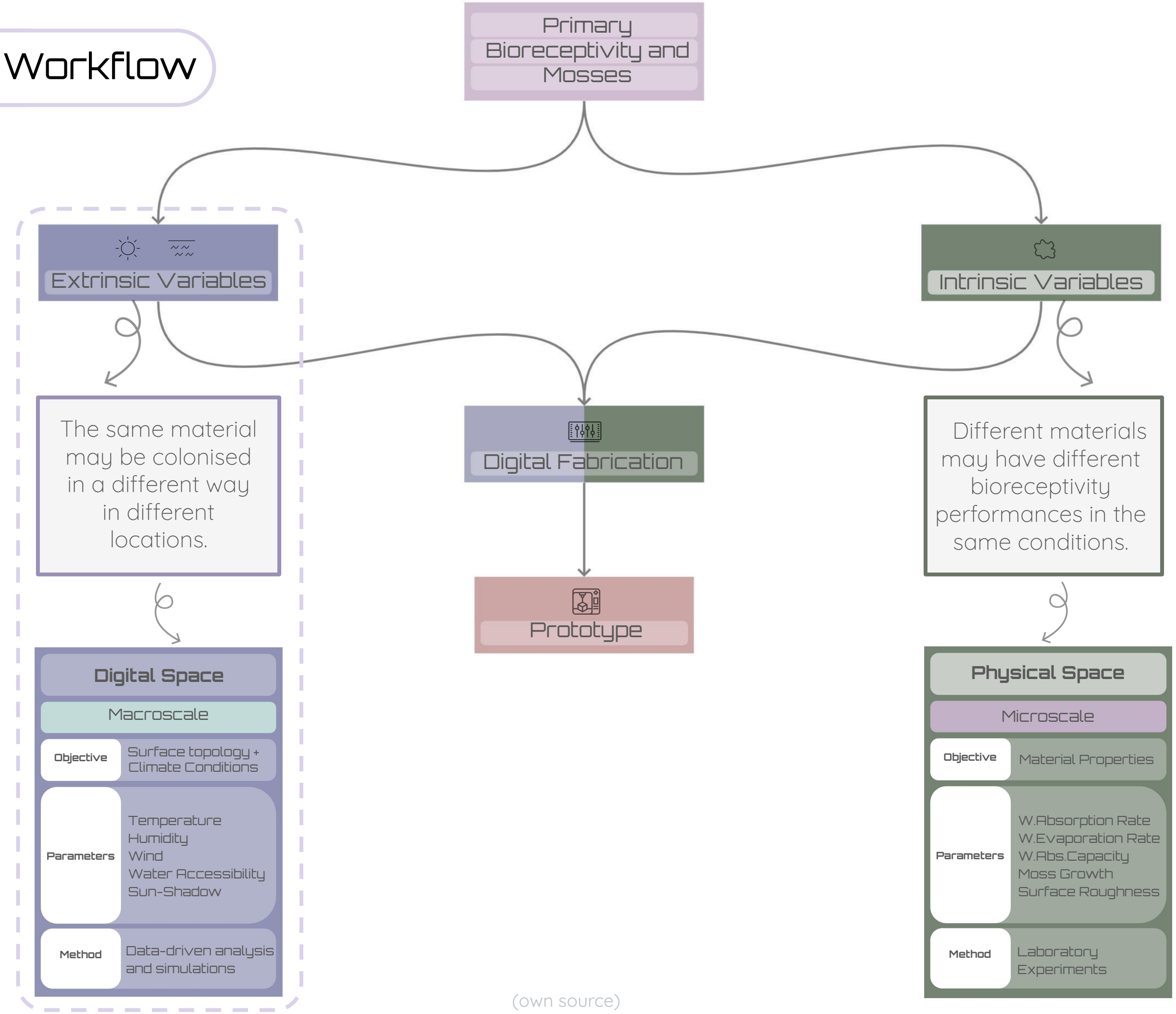
### Sub Research Questions

How can surface topology modifications improve the bioreceptivity performance of building envelopes, by taking into account environmental variables?

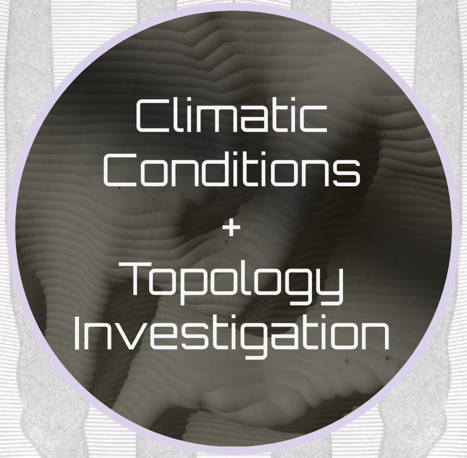
How does the composition of lime-based mortars affect their bioreceptivity and how can this be improved?

How can digital fabrication support the production of customizable bioreceptive mortar elements?

# General Workflow




(own source)



# Climatic Conditions + Topology Investigation

# Parametrization

A material can be bioreceptive but **it will not be biocolonized if the appropriate conditions do not occur**

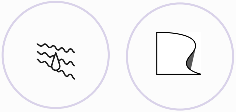
## How can we make sure, it will be biocolonized?

+

### Location

Climatic conditions

### Topology



Topology can create favorable conditions

# Parametrization

Location

## 1.

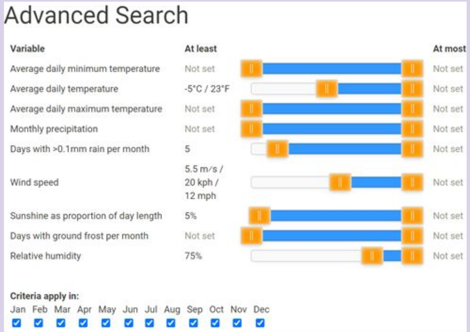
Climatic Requirements

| | |
|---|---|
| Air Temperature | -5 to 25°C. |
| Relative Humidity | Higher than 75% |
| Wind Speed | Higher than 20km/h |
| Rain Frequency | 5 days per month |
| Sunlight | 5% sunlight per day |

(Based on Literature)

## 2.

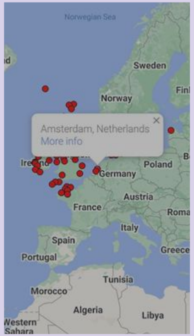
Setting Limits




(www.climatefinder.com)

## 3.

Recorded Locations with similar climatic conditions




(www.climatefinder.com)

## 4.

Recorded Locations with available climatic data


(www.ladybug.tools/epwmap)

Amsterdam

# How can topology support bioreceptivity and mosses?

By protecting mosses from direct sunlight that dries out their skin and rhizoids.

It can direct water over them and provide them with nutrients and water content.


(M.Shahda, 2020)

self-shading

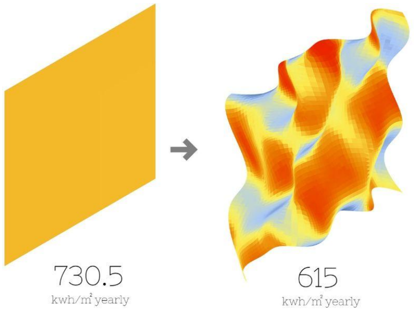
+

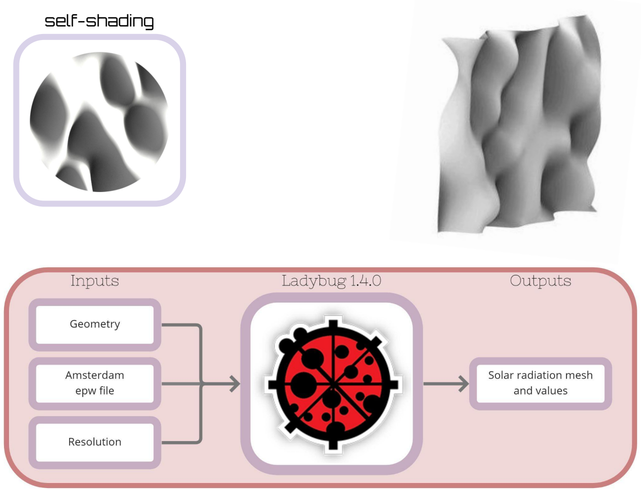
water direction

Script Generation.

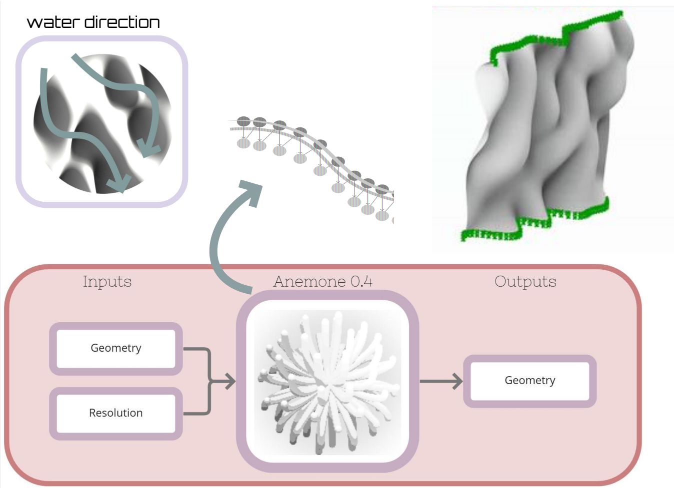
# Proof of Concept

Topology




Solar Radiation Analysis

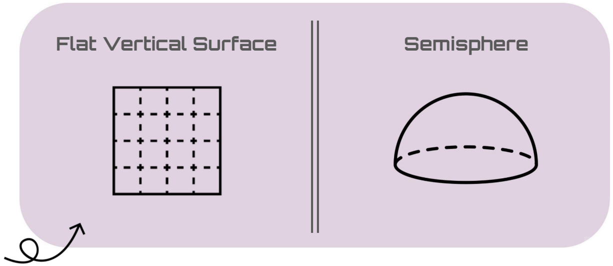



Simplified water flow analysis

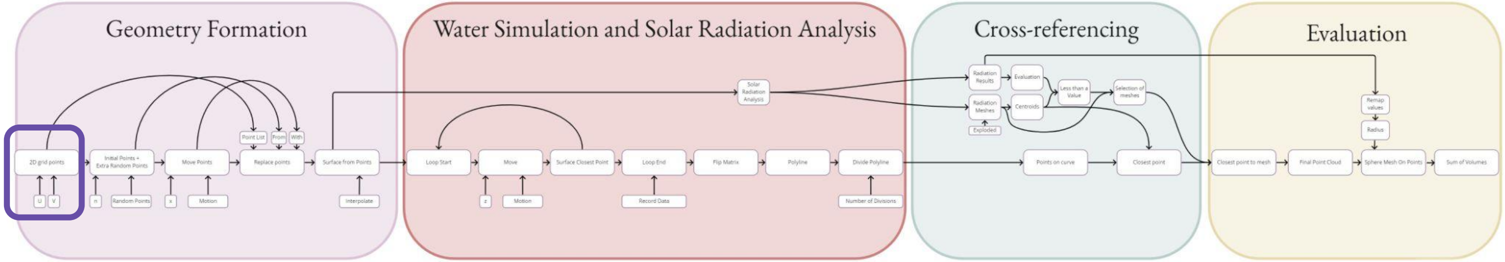
Script Generation.

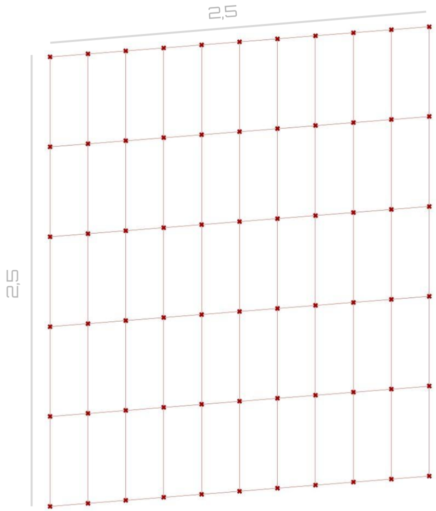
(own source)

# Script Generation



# Script Generation

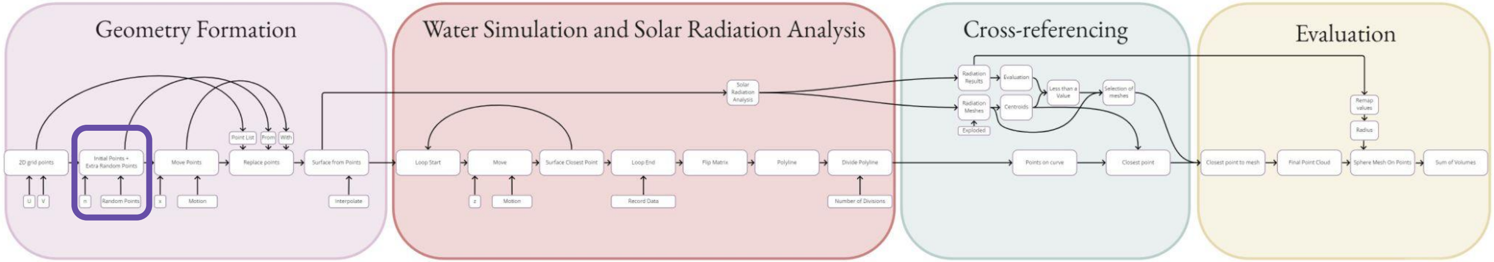


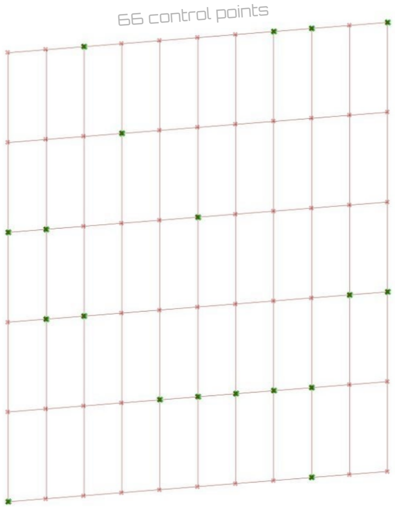






(own source)

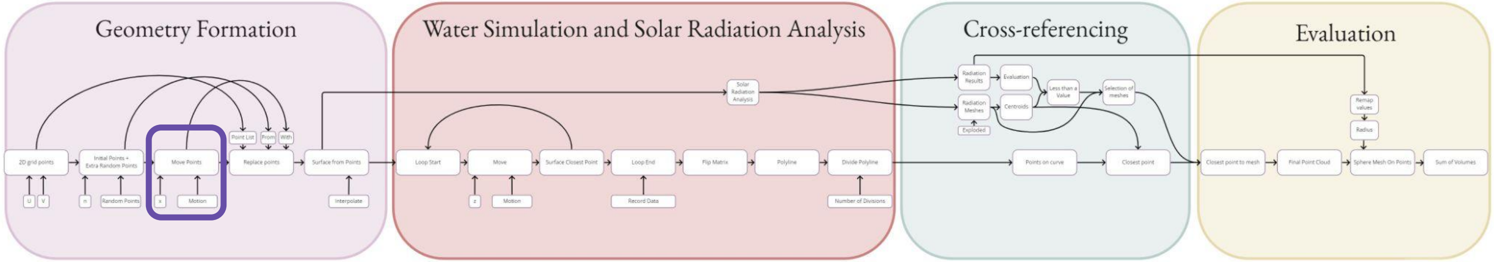
# Script Generation

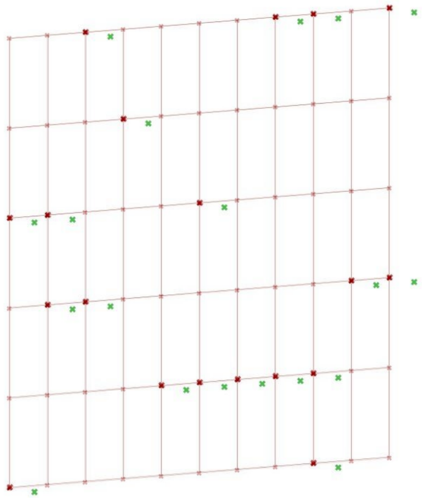



(own source)

# Script Generation

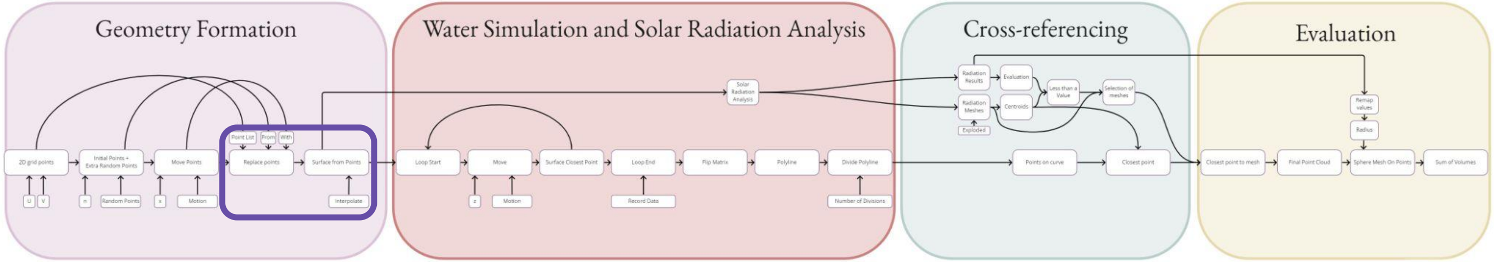


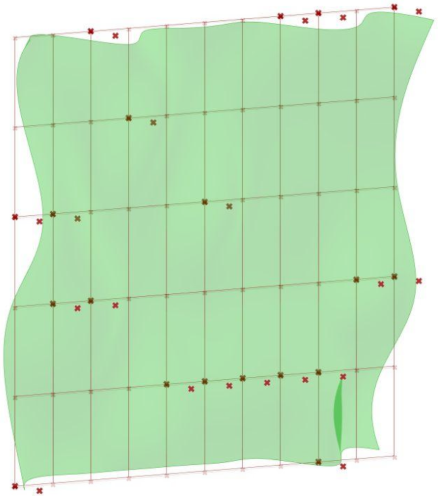





(own source)

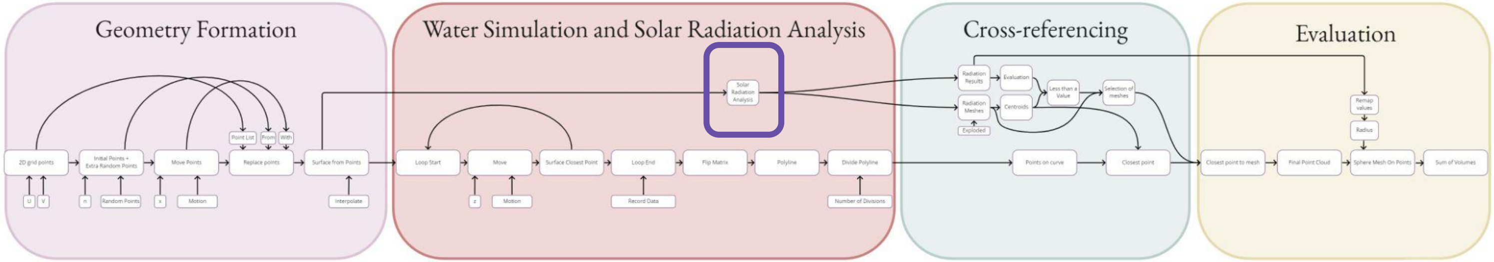
# Script Generation

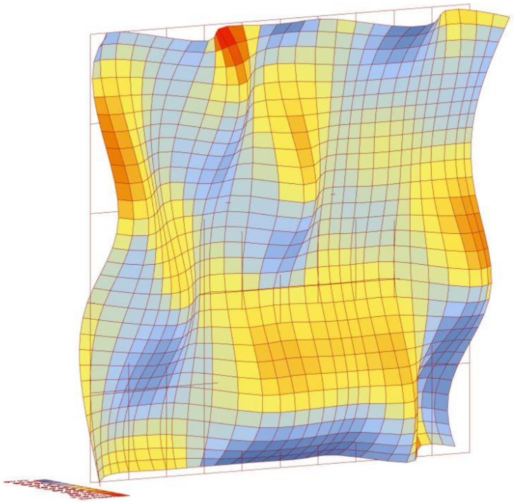


(own source)

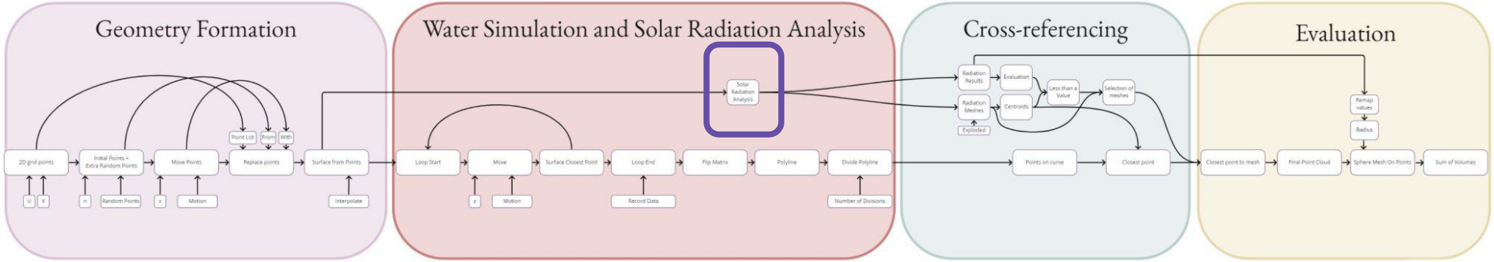
# Script Generation

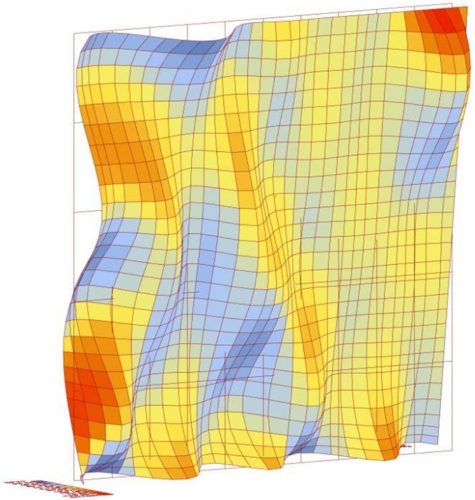


(own source)

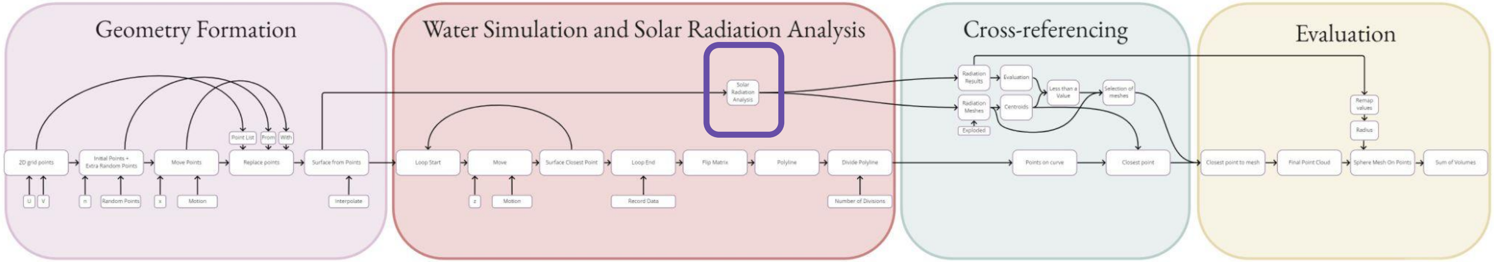
# Script Generation

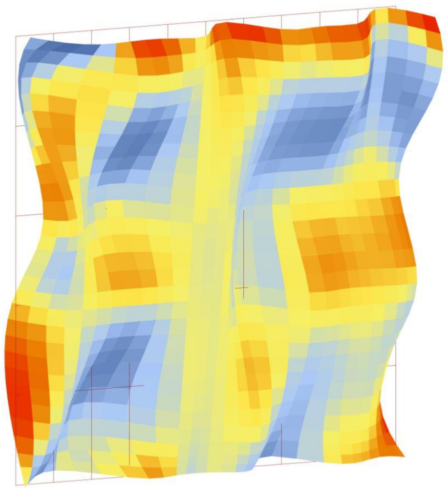


(own source)

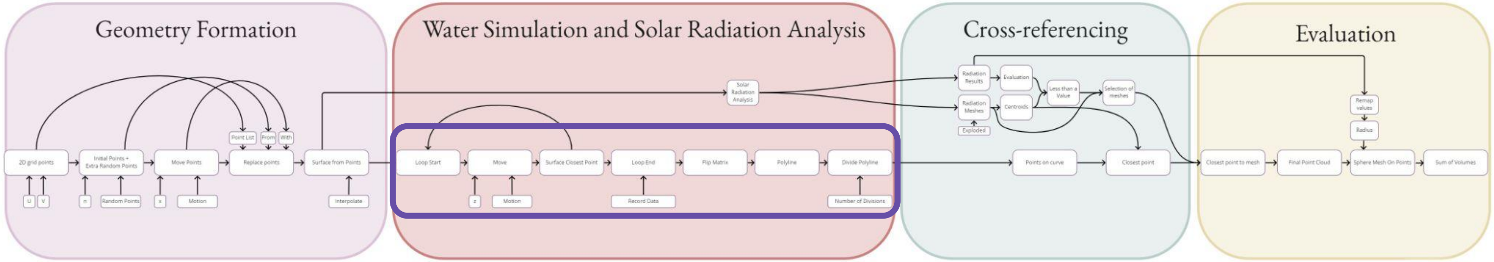
# Script Generation

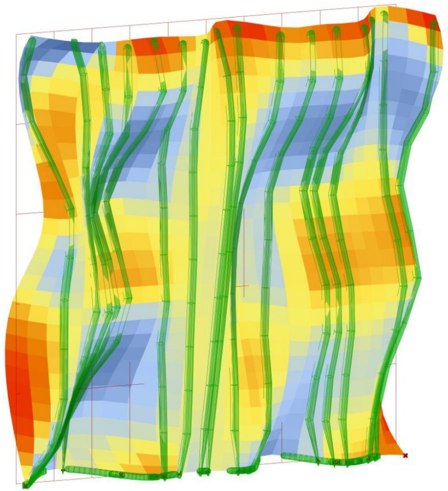


(own source)

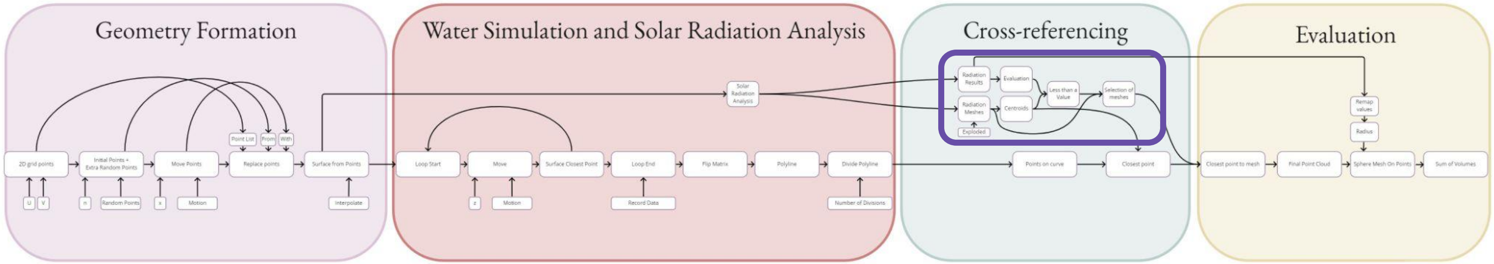
# Script Generation

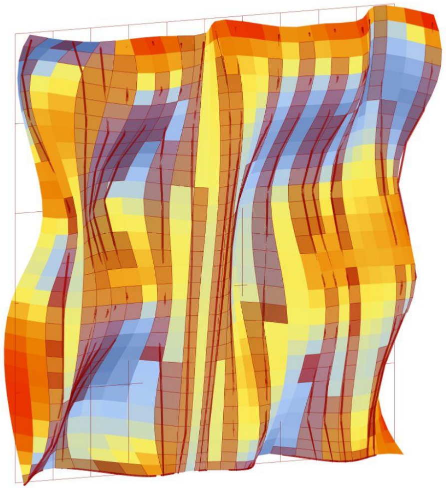


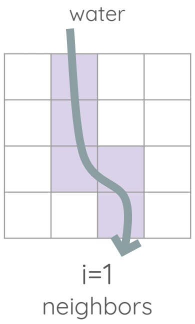



(own source)

# Script Generation

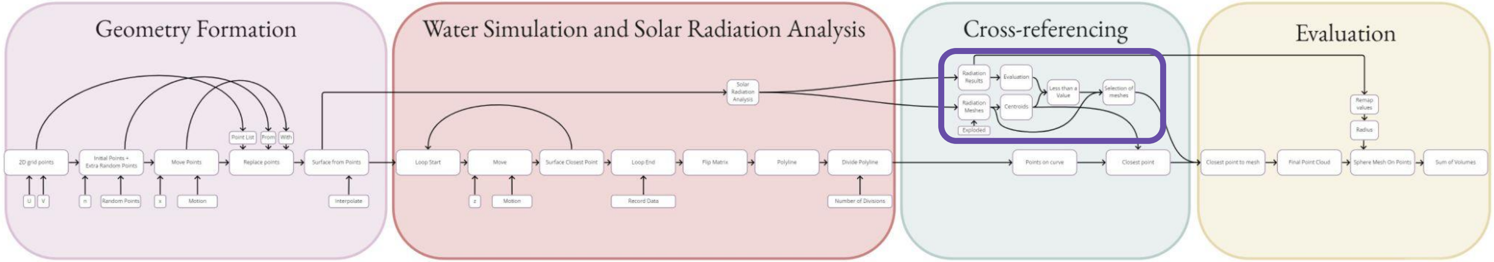


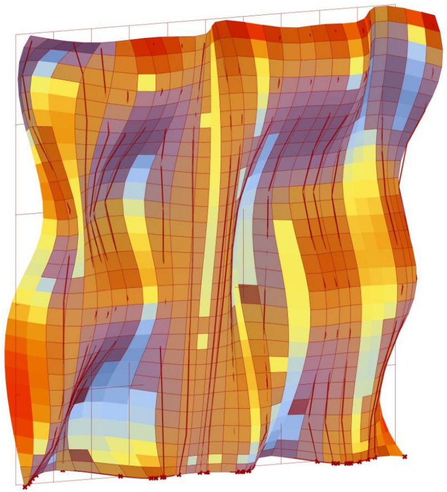



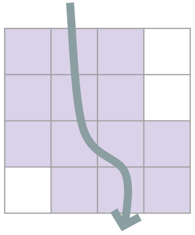



(own source)

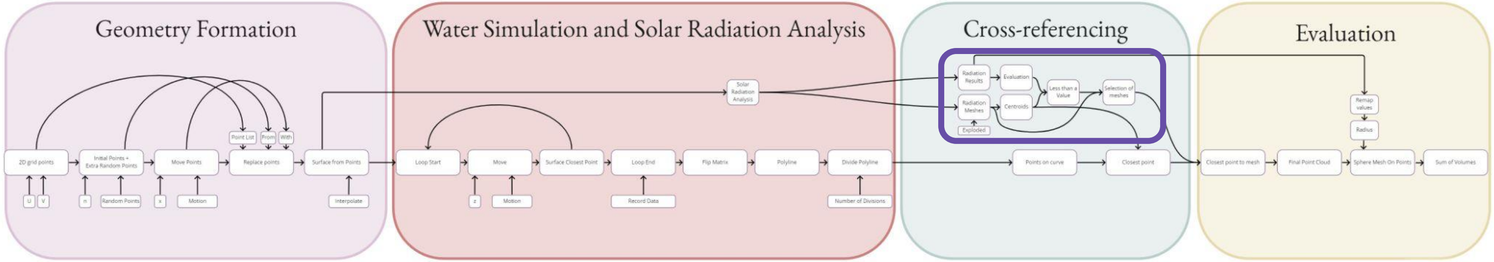
# Script Generation

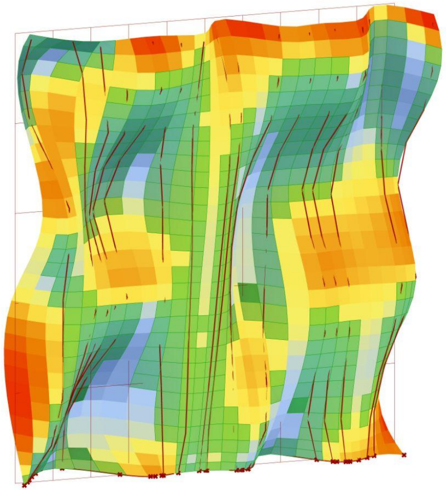




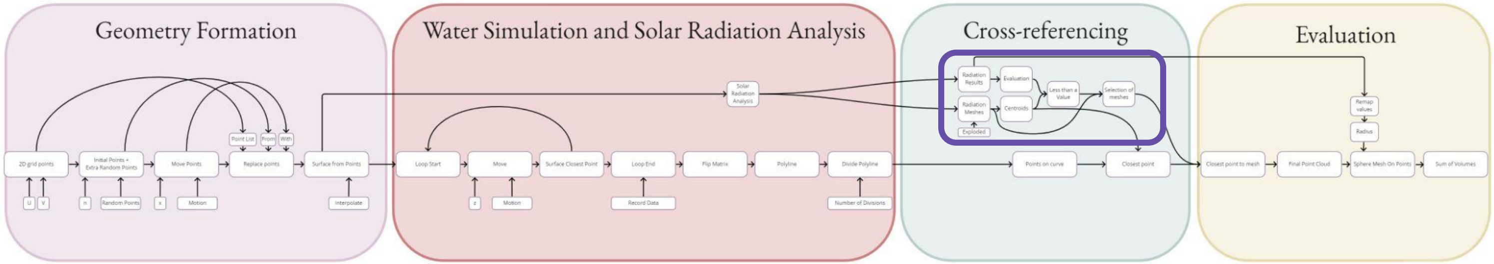
# Script Generation

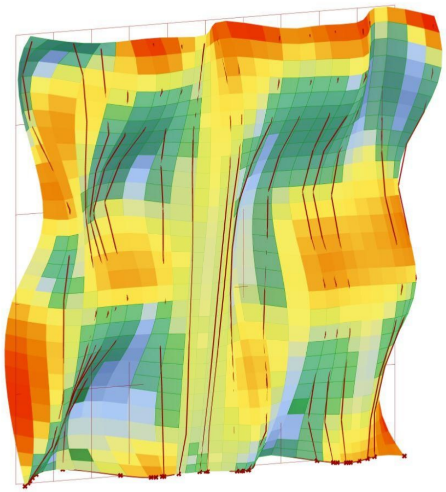



(own source)

# Script Generation

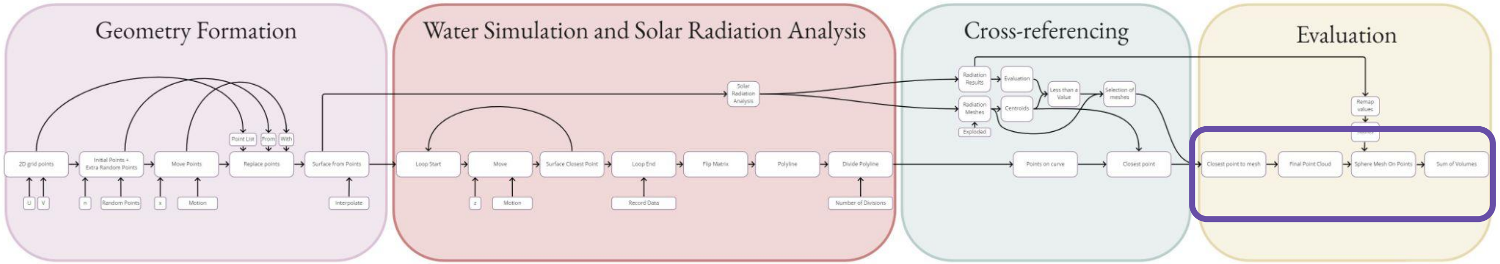


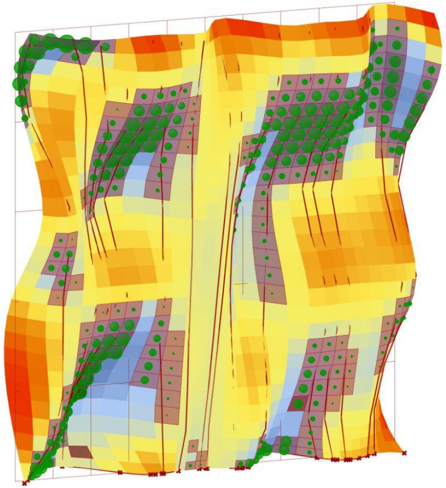



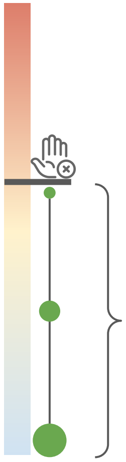



(own source)

# Script Generation





Smallest sphere = Less Shadow

Evaluation Method
(=addition of all spheres' volumes)

Biggest sphere = More Shadow

(own source)

# ↑ Optimization

Original concept:

Optimization (automated)

Geometry Formation → Water Simulation and Solar Radiation Analysis → Cross-referencing → Evaluation

Simplification:

Optimization (automated)

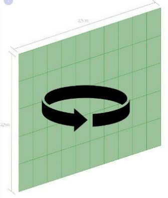
Geometry Formation → Solar Radiation Analysis → Evaluation → Water Simulation Analysis → Evaluation

Optimization

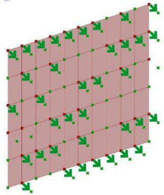
Opossum 2.4.4

Optimization solver

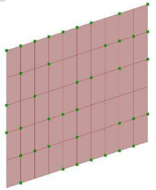
## Genomes



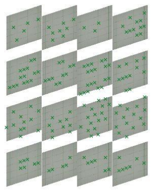
Orientation
0-360°



Distance
0-0.3 m.



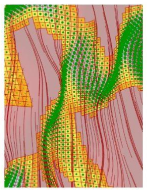
Control points
0-40.



Configurations
Min 700.

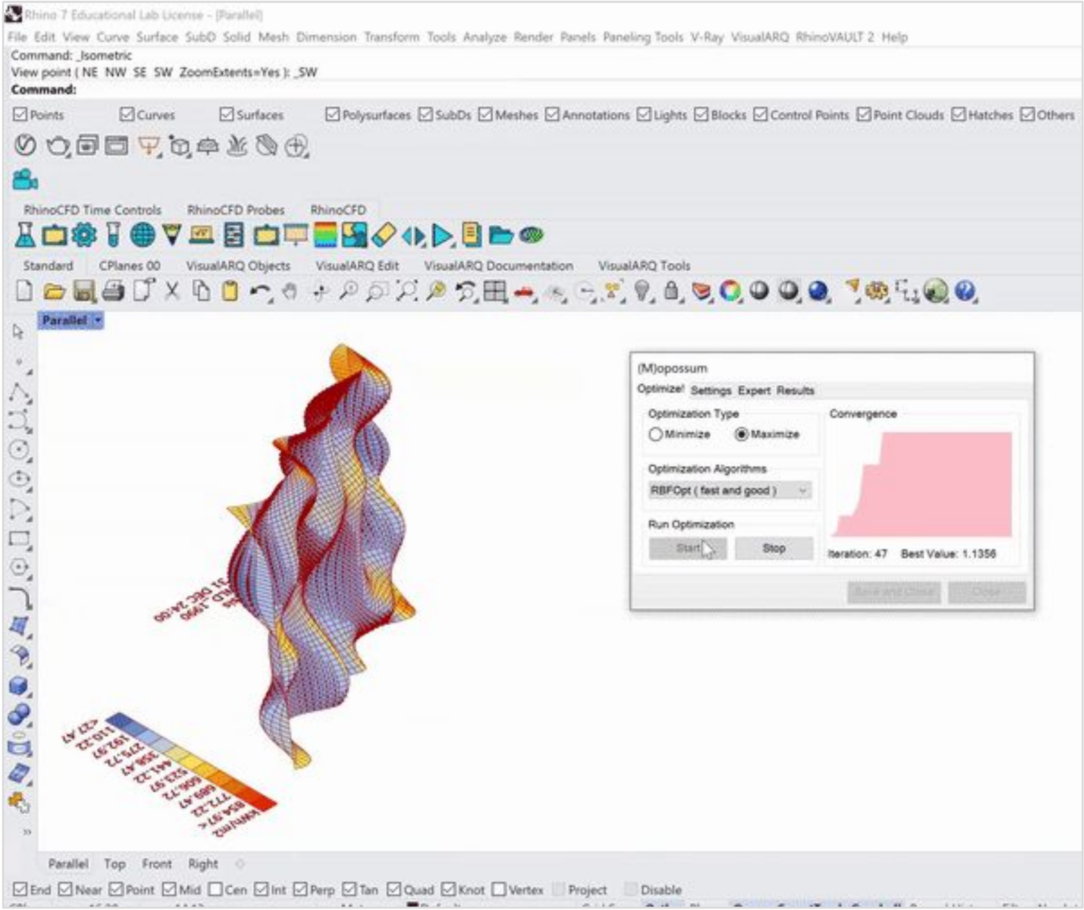
1 2 3 4

## Objective



Sum of volumes

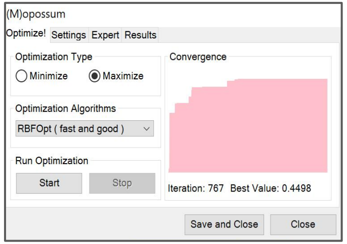
# ↑ Optimization

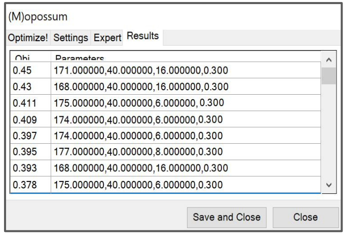


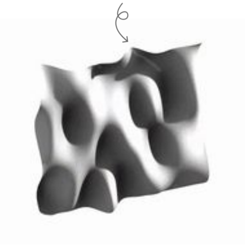

(own source)

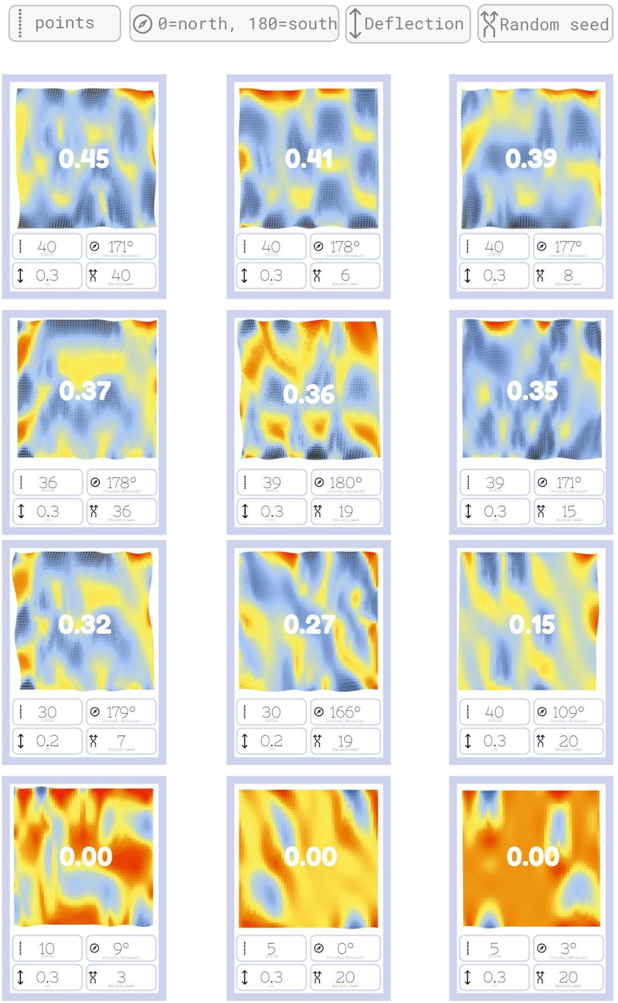
# ↑ Optimization

Opossum 2.4.4





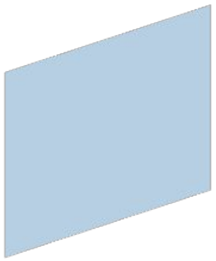

(own source)

## Remarks:

**Orientation** has the highest influence in the scores. **North** orientation had the best scores due to the low sunlight levels.


**The bigger the depth** of surfaces' deflection, **the more self-shading** they create

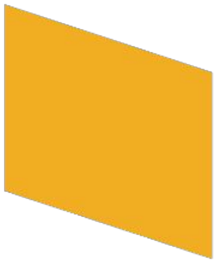
# Qualitative Comparative Analysis



226 kWh
per square meter yearly

## North-facing surface

Lowest solar radiation



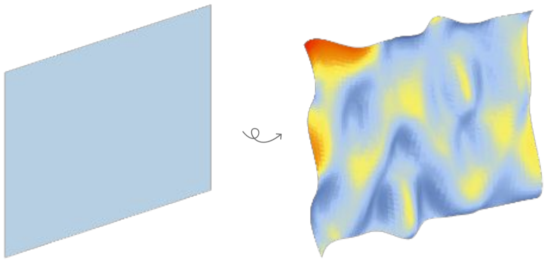
730 kWh
per square meter yearly

## South-facing surface

Highest solar radiation

(own source)

# Qualitative Comparative Analysis

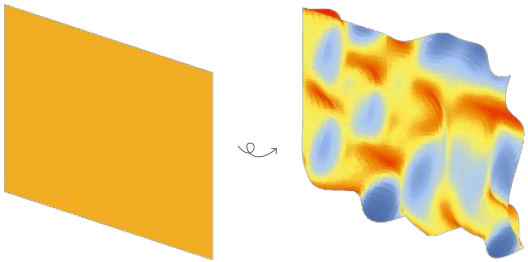


226 kWh
per square meter yearly

224 kWh
per square meter yearly

## North-facing surface

Lowest solar radiation



730 kWh
per square meter yearly

615 kWh
per square meter yearly

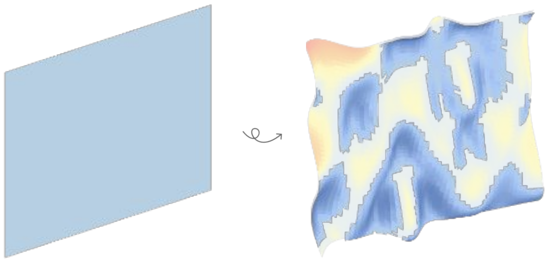
## South-facing surface

Highest solar radiation



(own source)

# Qualitative Comparative Analysis

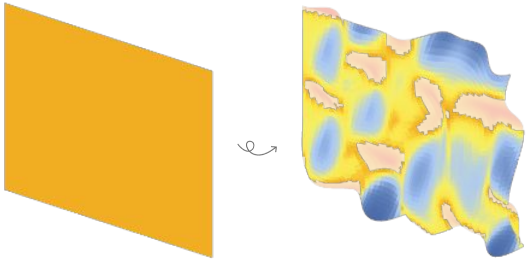


226 kWh
per square meter yearly

56%<226 kWh
per square meter yearly

## North-facing surface

Lowest solar radiation



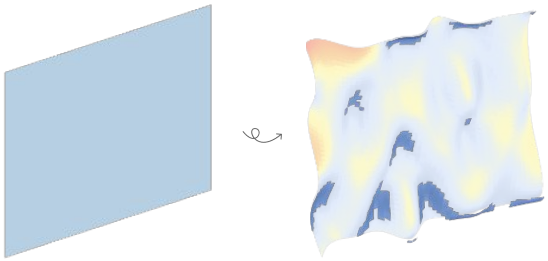
730 kWh
per square meter yearly

70%<730 kWh
per square meter yearly

## South-facing surface

Highest solar radiation

(own source)

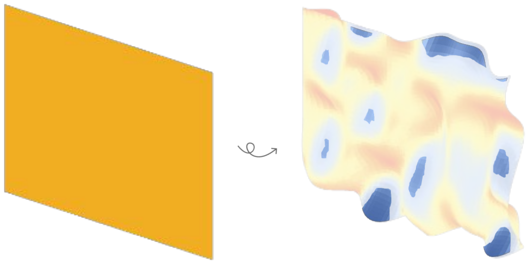


226 kWh
per square meter yearly

15%<113 kWh
per square meter yearly

## North-facing surface

Lowest solar radiation



730 kWh
per square meter yearly

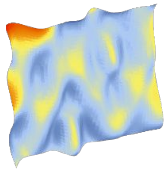
15%<365 kWh
per square meter yearly

## South-facing surface

Highest solar radiation

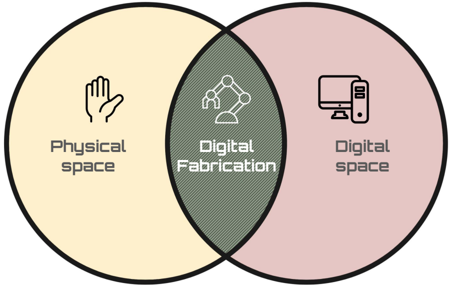
(own source)

# Usefulness



Surface complexity creates self-shading spaces while regulating water

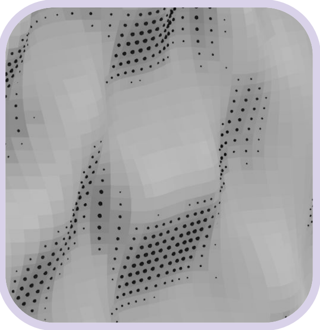
It is critical to ensure that the produced geometries will be as similar to the ones that were simulated on a digital model. This can be achieved through digital fabrication.




Transformation of data into physical products through machine control

(own source)

# Additive Manufacturing



Surface complexity
High level of detail


Mass-Customization
Each produced topology is unique.

Material wastage

Transportation Storage

Labor Intensity

Safety

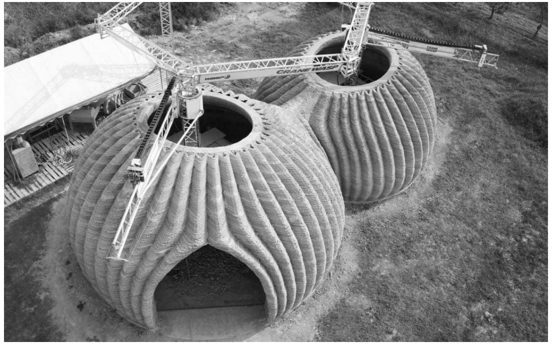
Energy Sustainability

Cost

Material Limitation

Speed

SWNA, 2020, concrete



WASP, 2021, adobe

MX3D, 2019, steel

# 3D printed green walls

## Remarks:

Greenery is not biologically integrated in the design it need high maintenance
Mechanical water irrigation is needed in the majority of existing proposals, hence it consumes energy
External parameters are not taken into account and this contributes to plants non-adaptability

**How can these issues be tackled?**

Through the integration of bioreceptive materials in building structures

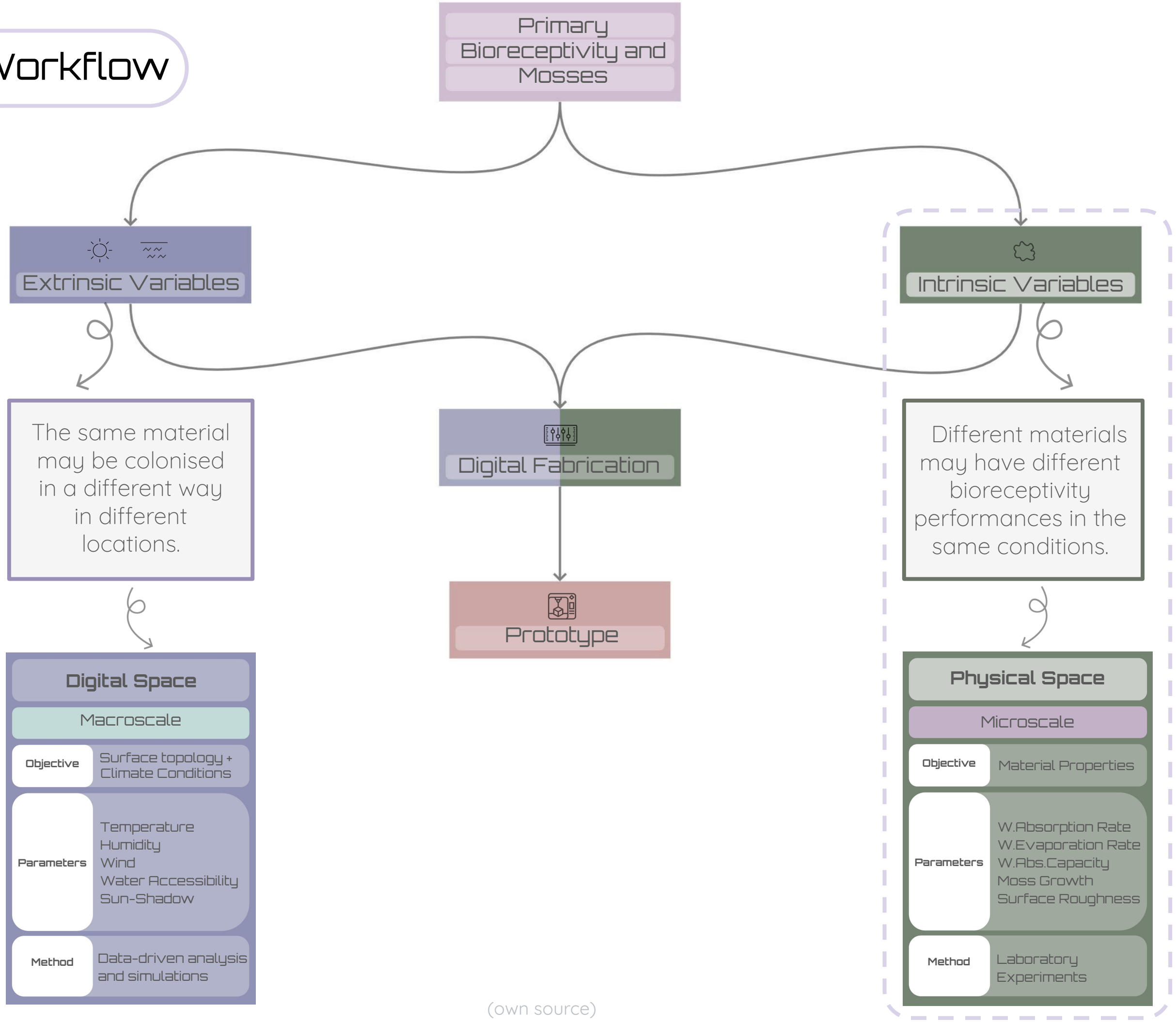
WINSUN, 2020


WINSUN, 2020

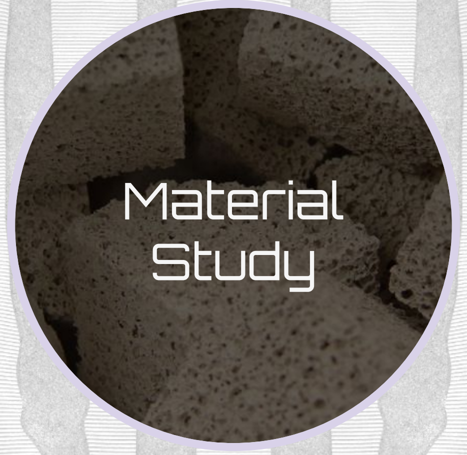
BIGREP, 2020,

WINSUN, 2020

# General Workflow

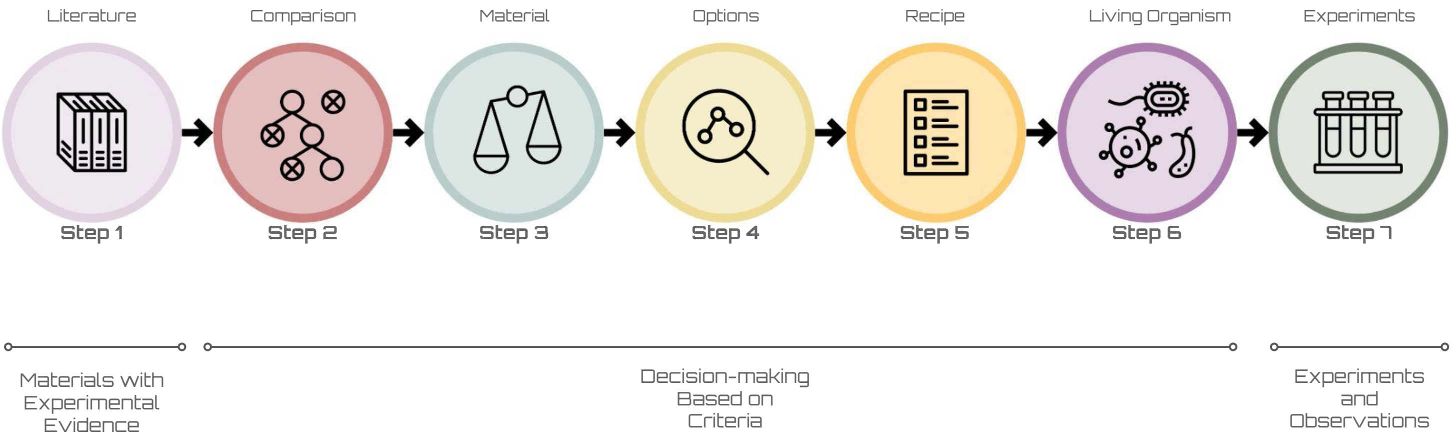



(own source)

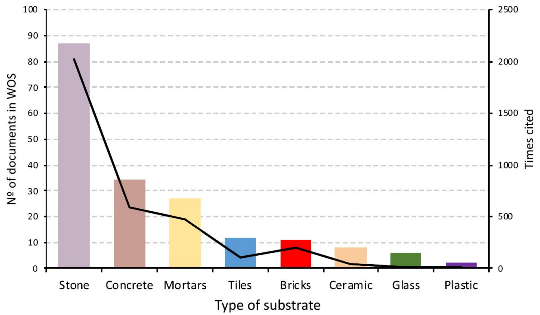


# Material Study

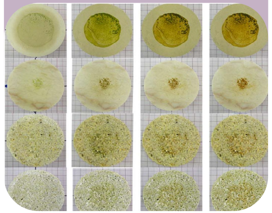
# Material Methodology



# Bioreceptive Materials

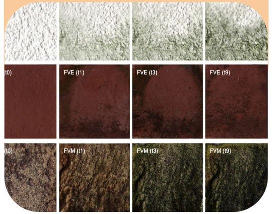



Stone
(A.Z.Miller et al, 2010)



Concrete
(M.Veeger et al, 2021)

Ceramics
(Marco D'Orazio et al, 2014)



Mortars
(Marco D'Orazio et al, 2014)

| Material Attributes | Stone | Concrete | Ceramics | Mortars |
|---|---|---|---|---|
| Chemical Composition | ✓ | ✓ | ✓ | ✓ |
| Surface Roughness | ✓ | ✓ | ✓ | ✓ |
| W. Absorption Capacity | ✓ | ✓ | ✓ | ✓ |
| W. Retention | ✓ | ✓ | ✓ | ✓ |
| Total Porosity | ✓ | ✓ | ✓ | ✓ |
| Weathering | ✓ | ✓ | — | — |

Materials' **chemical compositions, surface roughness and water transport behavior** influence their primary bioreceptivity

(own source)

# Comparison

**Criteria**

1. Form Complexity
2. Material Composition
3. Circularity

| | Stone | Concrete | Ceramics | Mortars |
|---|---|---|---|---|
| Form Complexity | - | ++ | ++ | ++ |
| Composition | - | + | + | ++ |
| Circularity | ++ | + | + | + |

(own source)

# Binder and type of mortar

## Binder's Choice

| | Cement | Lime |
|---|---|---|
| Bioreceptivity Performance | - | + |
| Embodied Energy | - | + |

## Type of Mortar

| | Non-hydraulic Mortars | Hydraulic Mortars |
|---|---|---|
| Outdoor application | - | + |
| Time demand | - | + |

**Hydraulic lime-based mortars**

## 1. Lime-based mortar mixtures

| code name | binder | aggregate | b/a |
|---|---|---|---|
| Hst2 | NHL | 0.08-2 mm | 1:2 |
| Hsf2 | NHL | 1-2 mm | 1:2 |
| Hvt2 | NHL + vermiculite | 1-2 mm | 1:2 |
| Hst4 | NHL | 0.08-2 mm | 1:4 |
| Hsf4 | NHL | 1-2 mm | 1:4 |
| Hvt4 | NHL + vermiculite | 1-2 mm | 1:4 |

| code name | binder | aggregate | b/a |
|---|---|---|---|
| ATst2 | Hydrated lime and trass | 0.08-2 mm | 1:2 |
| ATsf2 | Hydrated lime and trass | 1-2 mm | 1:2 |
| ATvt2 | Hydrated lime and trass + vermiculite | 1-2 mm | 1:2 |
| ATst4 | Hydrated lime and trass | 0.08-2 mm | 1:2 |
| ATsf4 | Hydrated lime and trass | 1-2 mm | 1:4 |
| ATvt4 | Hydrated lime and trass | 1-2 mm | 1:4 |

(Based on B.Lubelli et al, 2020)

## 2. Characterization and comparison of the mortars

| | Hst2 | Hsf2 | Hvt2 | | ATst2 | ATsf2 | ATvt2 |
|---|---|---|---|---|---|---|---|
| porosity | 21,5% | 30,8% | 42,7% | porosity | 24% | 30,6% | 47,5% |
| water absorption rate | 0,16 g/cm2 per 160s | 0,18 g/cm2 per 160s | 0,34 g/cm2 per 160s | water absorption rate | 0,20 g/cm2 per 160s | 0,22 g/cm2 per 160s | 0,40 g/cm2 per 160s |
| bio receptivity | 1/5 | - | 2/5 | bio receptivity | 2/5 | - | 4/5 |

| | Hst4 | Hsf4 | Hvt4 | | ATst4 | ATsf4 | ATvt4 |
|---|---|---|---|---|---|---|---|
| porosity | 27,9% | 39,2% | 50% | porosity | 26,5% | 30,6% | 54,1% |
| water absorption rate | 0,14 g/cm2 per 160s | 0,17 g/cm2 per 160s | 0,30 g/cm2 per 160s | water absorption rate | 0,17 g/cm2 per 160s | 0,20 g/cm2 per 160s | 0,32 g/cm2 per 160s |
| bio receptivity | - | 2/5 | 3/5 | bio receptivity | 5/5 | - | - |

(Based on B.Lubelli et al, 2020)

## 3. Conclusions

- Binders with lower b/a (=1/4) ratio had better overall performance by offering high open porosity.
- Mortars based on Natural Hydraulic Lime had the best bioreceptivity performance.
- Vermiculite's addition boosted their performance, acting as a water reservoir.

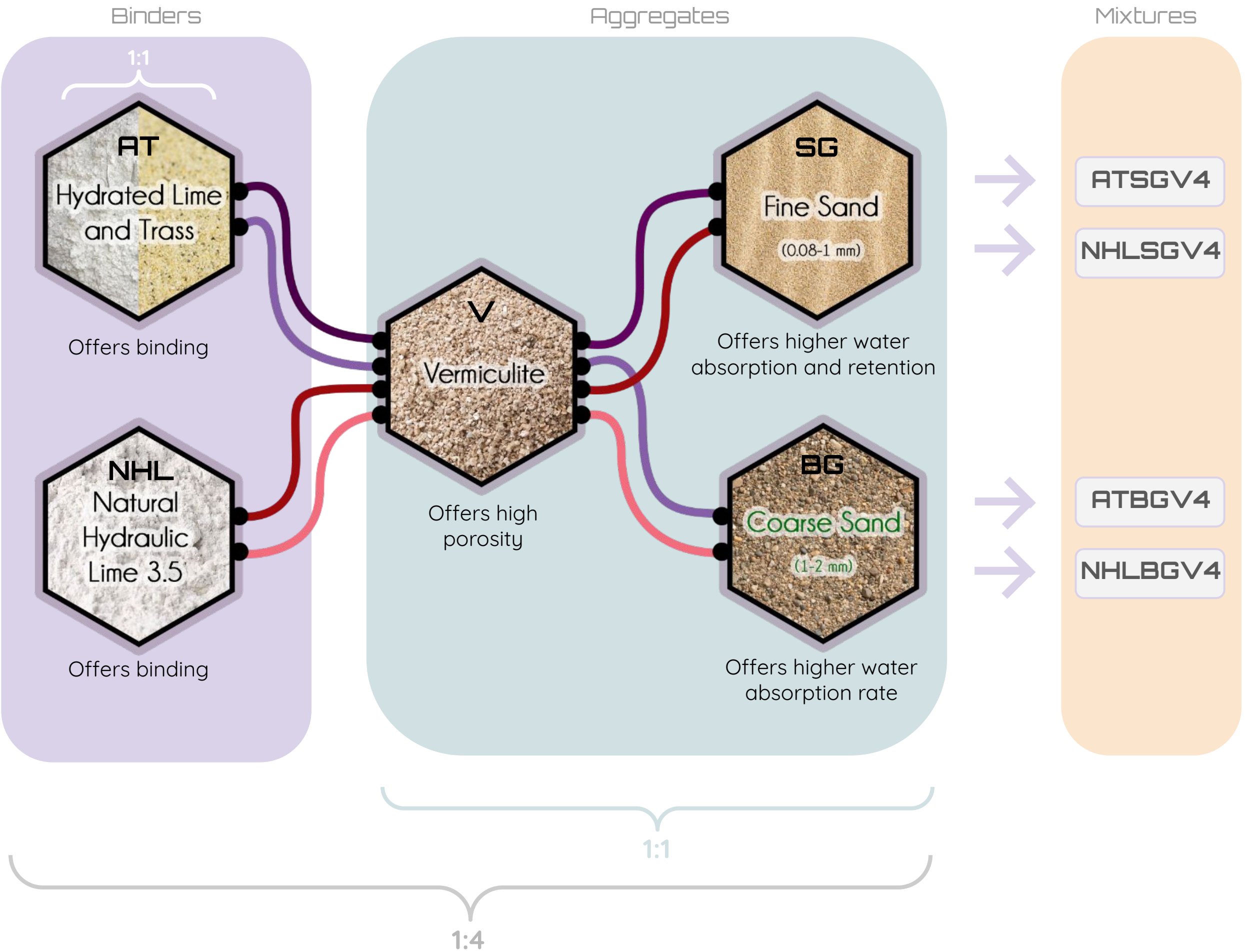
# Targets

| Material Properties | | Goal | | How |
|---|---|---|---|---|
| Main Targets | | | | size distribution of aggregates or b/a ratio |
| High Water Absorption rate<br>Allows rain water to enter to the material faster. | → | Macropores | → | **Coarse grains / gap graded**<br>Or lower b/a ratio |
| High water retention<br>Leads to slower water loss which offers nutrients for a longer period of time. | → | Micropores | → | **Thin grains / well graded**<br>or b/a |
| Surface Roughness<br>Offers protection | → | Grain size or post-process | → | **Grain size** |
| High Open Porosity<br>Offers higher permeability | → | Macropores | → | **Coarse grains / gap graded**<br>or lower b/a ratio |

**Micropores**: Small pores have the capability of holding water against gravity force thanks to their high capillarity effect.

**Macropores**: Macropores lead to a better permeability because they are wide enough to hold water against gravity force.

# Final Composition



# Tortula Muralis

| Cymbalaria muralis | Pseudofumaria lutea | Tortula Muralis | |
|---|---|---|---|
| Light, medium and heavy soils | Light, medium soils | Do not necessarily need soil as a substrate. | ✓ |
| Mildly acid, neutral and basic (mildly alkaline) soils | Mildly acid, neutral and basic (mildly alkaline) soils | Base-rich substrate, like limestone, concrete, bricks. (Fletcher, 1995). | ✓ |
| **pH: 3-11** | **pH: 3-11** | **pH:7-14** | ✓ |
| Semi-shade, no shade | Semi-shade | Semi-shade, Light shade | ✓ |
| Moist substrates | Moist substrates | Moist substrates | ✓ |
|  pfaf.org |  pfaf.org |  pfaf.org | |

= the most popular type of moss AND easily found in the Netherlands

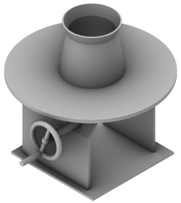
(own source)

# Mortars' preparation

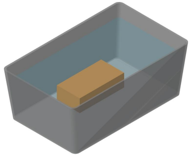
preparation

**1.**
Material Weighing

**2.**
Mixing with water



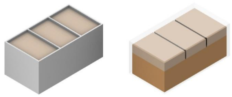
**3.**
Workability test for consistency



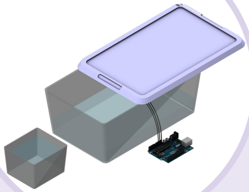
**4.**
Submerging bricks in water

**5.**
Casting material by dividing each specimen in three.

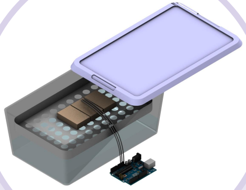
curing



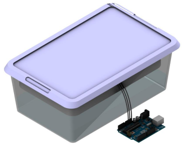
**6.**
Keeping the specimens under 100% R.H. by wrapping them with plastic foil for 7 days.



**7.**
Creating conditions with 65% R.H. by dissolving salt in water and measuring it with arduino sensor.



**8.**
Putting specimens inside the plastic box after the R.H. is stabilized.

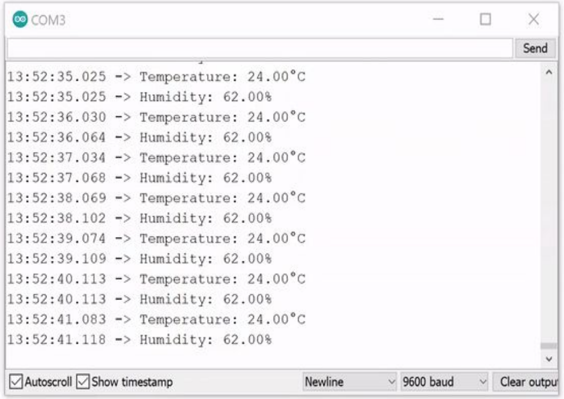


**9.**
Tracking R.H. on a daily basis for 21 days based on NEN.

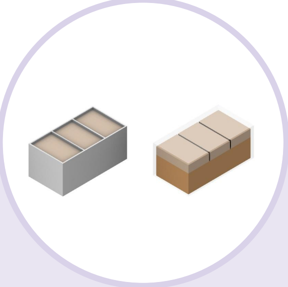
**10.**
Weighting specimens until their weight is stable.

(own source)

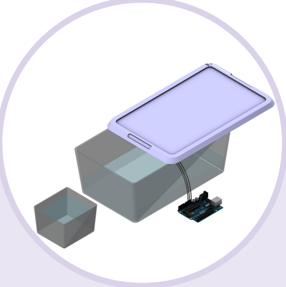
# Mortars' curing



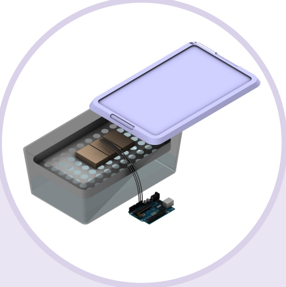

curing



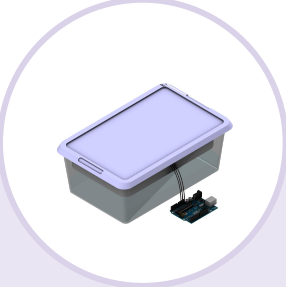
**6.**
Keeping the specimens under 100% R.H. by wrapping them with plastic foil for 7 days.



**7.**
Creating conditions with 65% R.H. by dissolving salt in water and measuring it with arduino sensor.



**8.**
Putting specimens inside the plastic box after the R.H. is stabilized.



**9.**
Tracking R.H. on a daily basis for 21 days based on NEN.

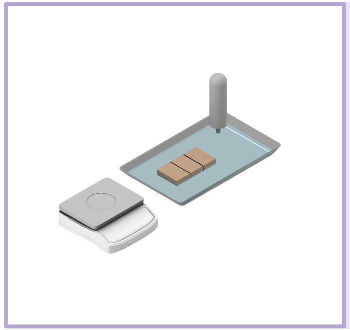
**10.**
Weighting specimens until their weight is stable.



(own source)

## Dual Target:

To examine if moss is compatible with chosen lime-based mortars
To examine If water transport behavior influences moss growth on these substrates



### 1. Water absorption rate
(lab conditions)

1. Weigh all specimens and measure their volume.

2. Fill with water a container up to 3mm making sure that water level remains constant using a bottle.

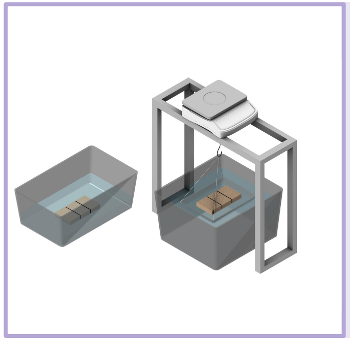
3. Immerse in water and weigh every: 1 min, 3 min, 5 min, 10 min, 15 min, 30, min 45 min, 60 min. 2h, 3h, 4h, 6h, 8h, 24 h.

### 3. Water evaporation rate
(lab conditions)

1. Weigh all specimens and measure their volume.

2. Put tape around specimens leaving one side open in order the water to evaporate only from one side.

3. Weigh every 4,8,24 hours every day for a week and then once every week.

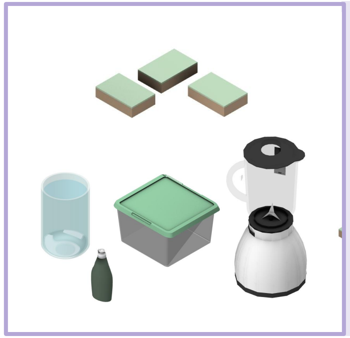


### 2. Water absorption capacity
(lab conditions)

1. Weigh all specimens and measure their volume.

2. Immerse all specimens in water for 24h.

3. Weigh under atmospheric pressure.



### 4. Moss Growth
(lab conditions)

1. Collect tortula muralis.

2. Dry mosses

3. Pulverize them until they become powder.

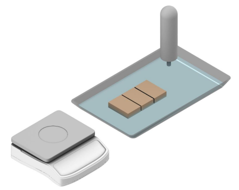
4. Spray surfaces with a mix of sodium calcinate and distilled water and apply.

5. Track them visually every week.



(own source)

# Experiments

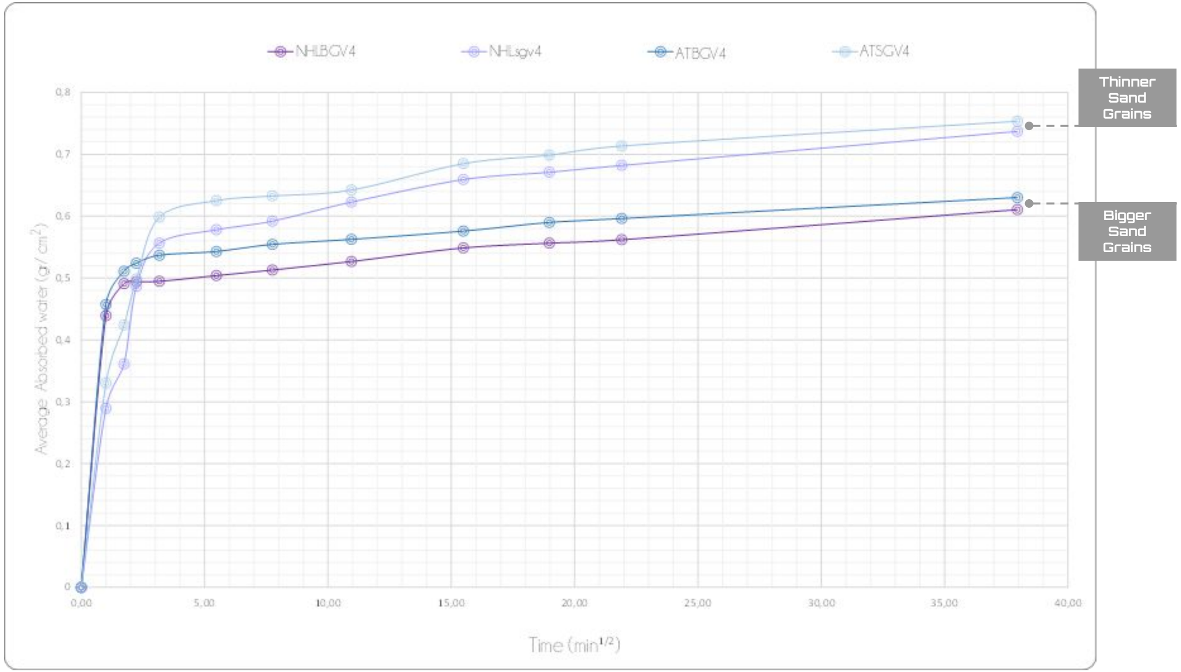


## 1.
## Water absorption rate
(lab conditions)

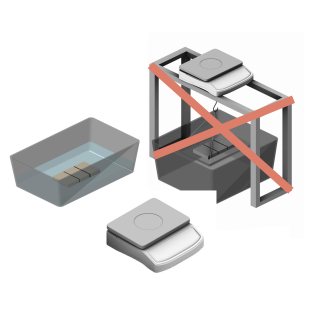
1. Weigh all specimens and measure their volume.

2. Fill with water a container up to 3mm making sure that water level remains constant using a bottle.

3. Immerse in water and weigh every: 1 min, 3 min, 5 min, 10 min, 15 min, 30, min 45 min, 60 min. 2h, 3h, 4h, 6h, 8h, 24 h.

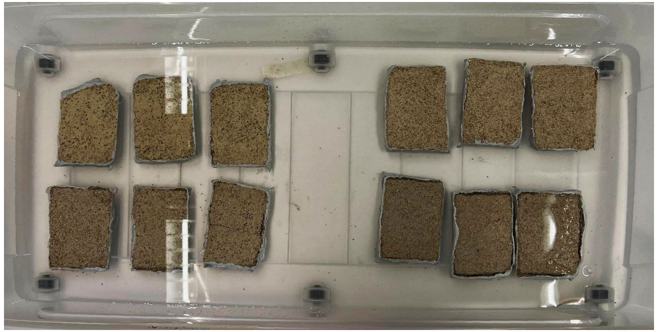


# Experiments



## 2.
## Water absorption capacity
(lab conditions)

1. Weigh all specimens and measure their volume.
2. Immerse all specimens in water for 24h.
3. Weigh under atmospheric pressure.



| | | | |
|---|---|---|---|
| NHLBGV4 | | | |
| 1b | 162,74 | 204,49 | 26% |
| 1c | 192,28 | 240,67 | 25,2% |
| 2c | 140,52 | 175,57 | 24,9% |
| average % weight gain | | | 25,3% |
| NHLsgv4 | | | |
| 2a | 196,19 | 252,47 | 28,7% |
| 2b | 180,12 | 240,65 | 33,6% |
| 2c | 179,02 | 239,09 | 33,6% |
| average % weight gain | | | 31,9% |
| ATBGV4 | | | |
| 1a | 220,51 | 275,61 | 25,0% |
| 1b | 188,13 | 235,42 | 25,1% |
| 1c | 163,85 | 205,8 | 25,6% |
| average % weight gain | | | 25,2% |
| ATSGV4 | | | |
| 2a | 186,23 | 246,95 | 32,6% |
| 2b | 177,21 | 235,12 | 32,7% |
| 2c | 175,04 | 233,89 | 33,6% |
| average % weight gain | | | 33,0% |

NHLBGV4: Bigger Sand Grains

NHLsgv4: Thinner Sand Grains

ATBGV4: Bigger Sand Grains

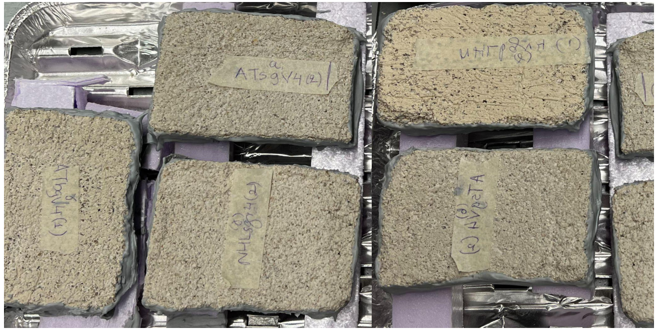
ATSGV4: Thinner Sand Grains

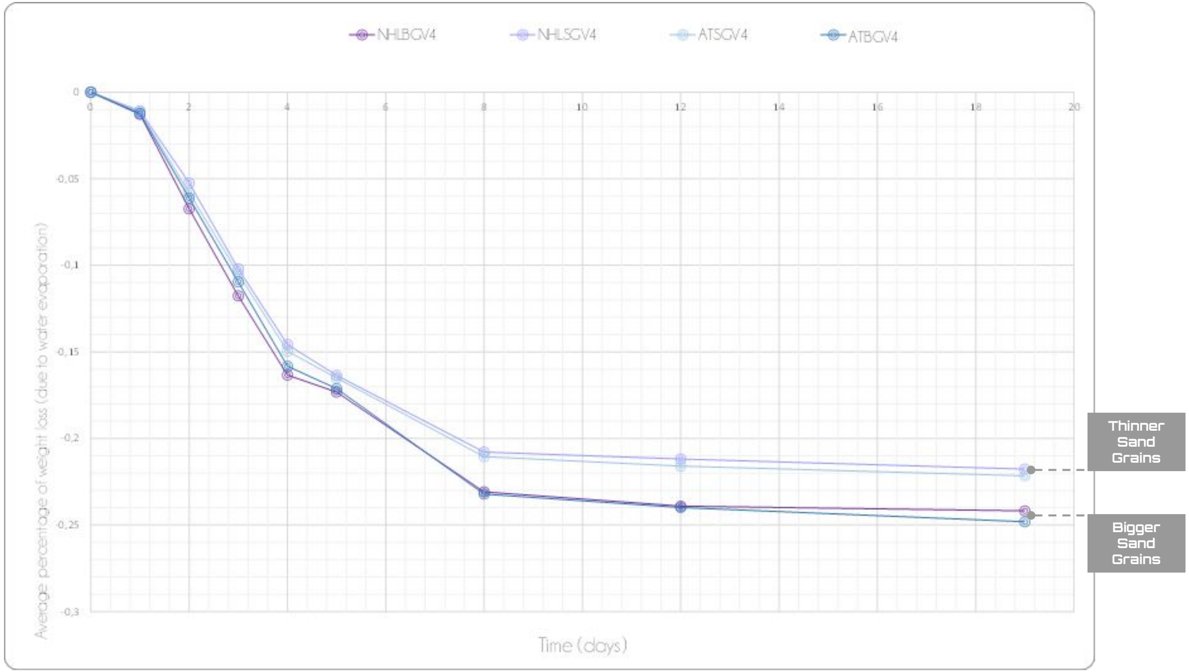
## 3.
## Water evaporation rate
(lab conditions)

1. Weigh all specimens and measure their volume.

2. Put tape around specimens leaving one side open in order the water to evaporate only from one side.

3. Weigh every 4,8,24 hours every day for a week and then once every week.








(own source)

# Experiments

## 4.
## Moss Growth
(lab conditions)

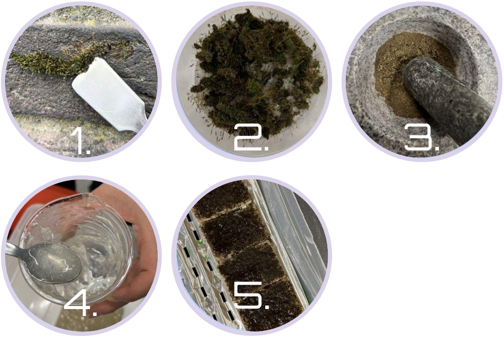
1. Collect tortula muralis.

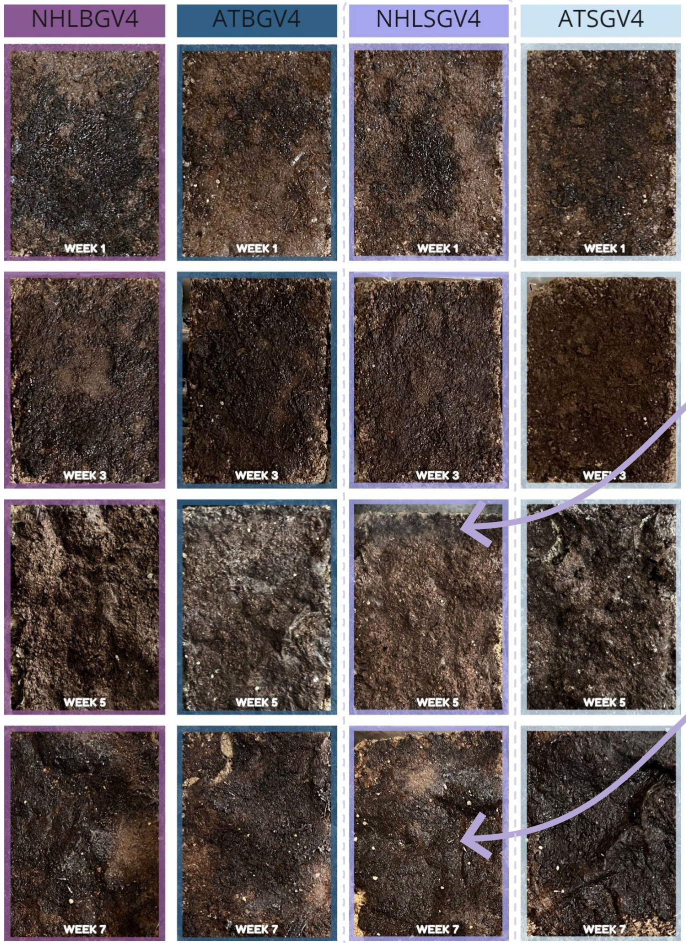
2. Dry mosses

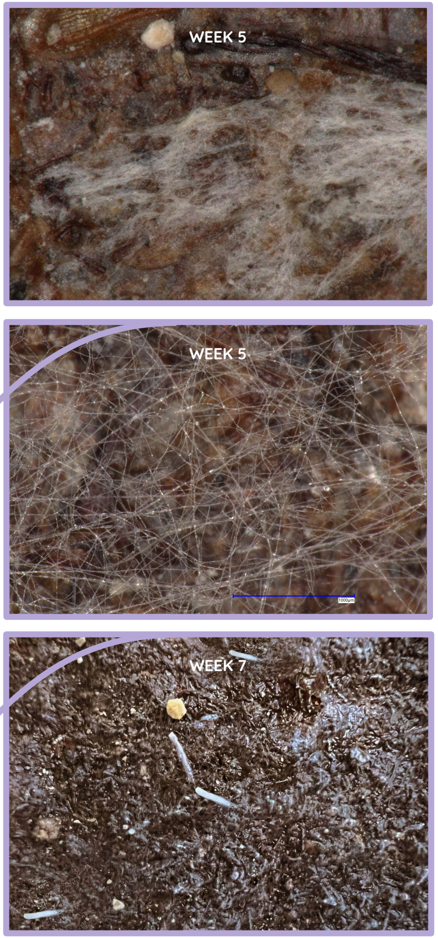
3. Pulverize them until they become powder.

4. Spray surfaces with a mix of sodium calcinate and distilled water and apply.

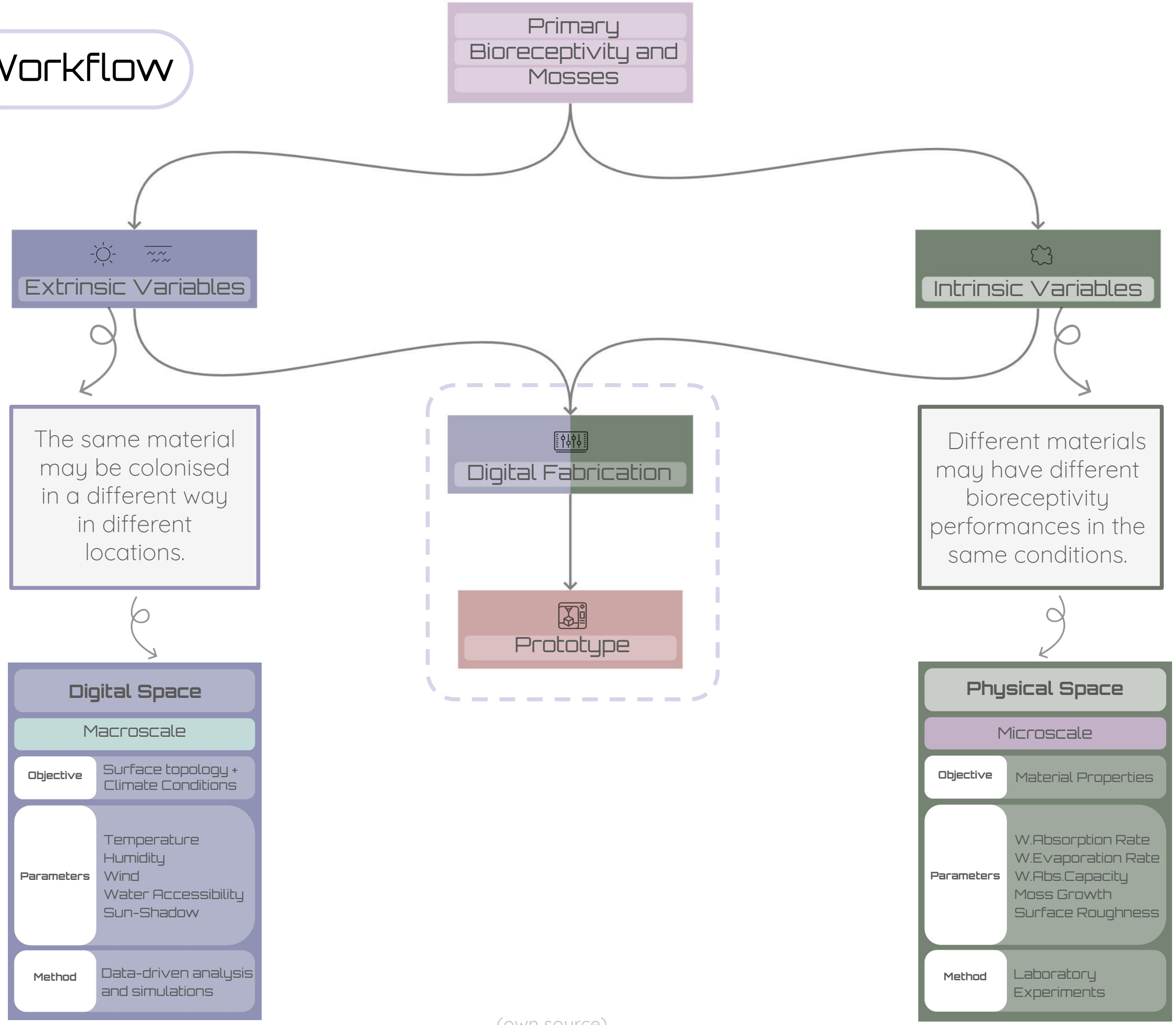
5. Track them visually every week.



# General Workflow

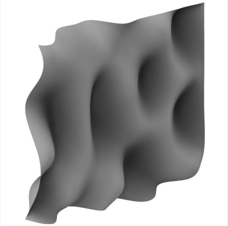



(own source)

# Bioreceptivity Oriented Design

## How can the most promising topology and mortar be integrated in a bioreceptivity-oriented design approach ?

Offers the most optimal shaded conditions for mosses' growth



Most promising topology

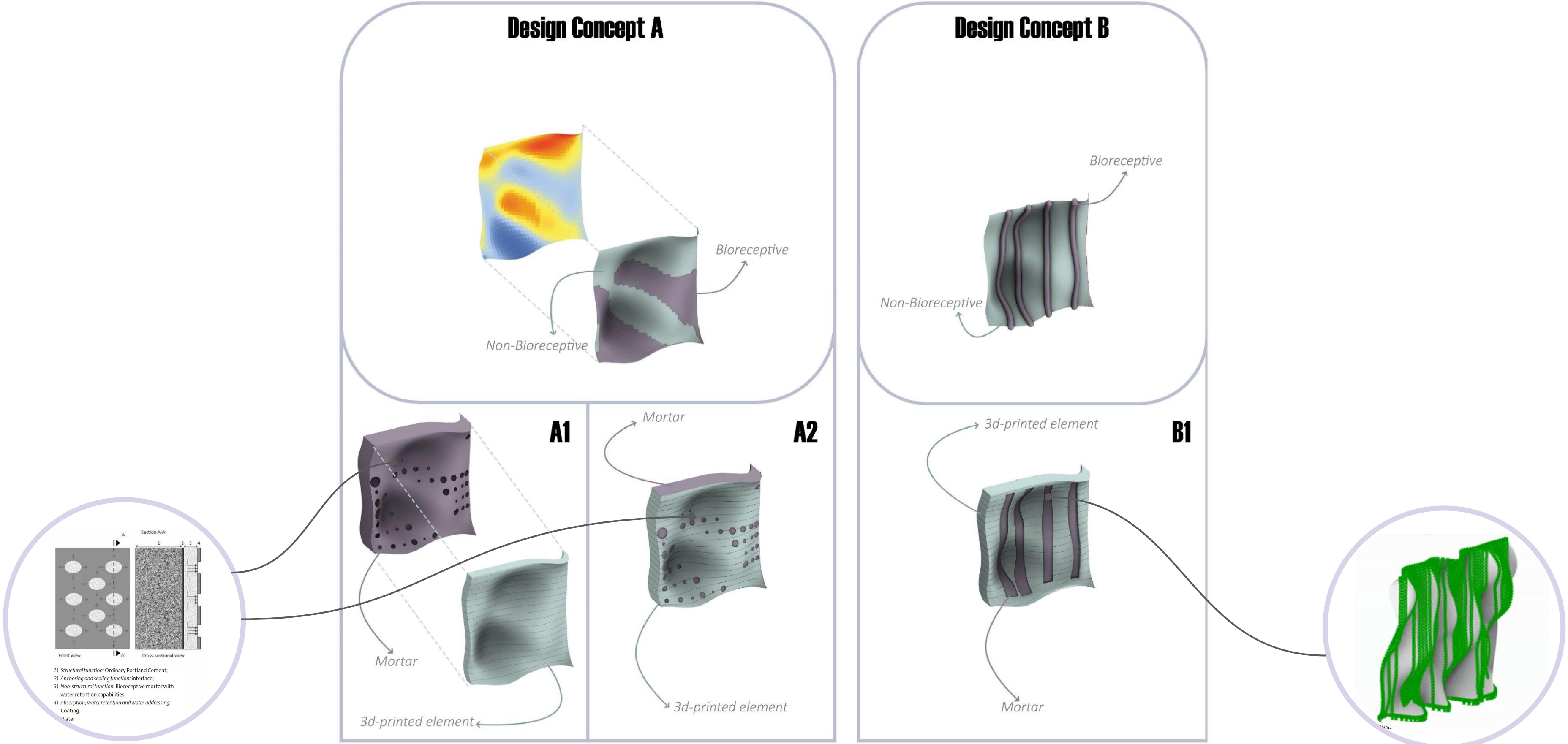
+

Offers high water absorption capacity and retention


Most promising mortar

Their performance cannot be evaluated due to the limited timeframe
But the following proposals seek to **create realistic ways of combining these two aspects**.

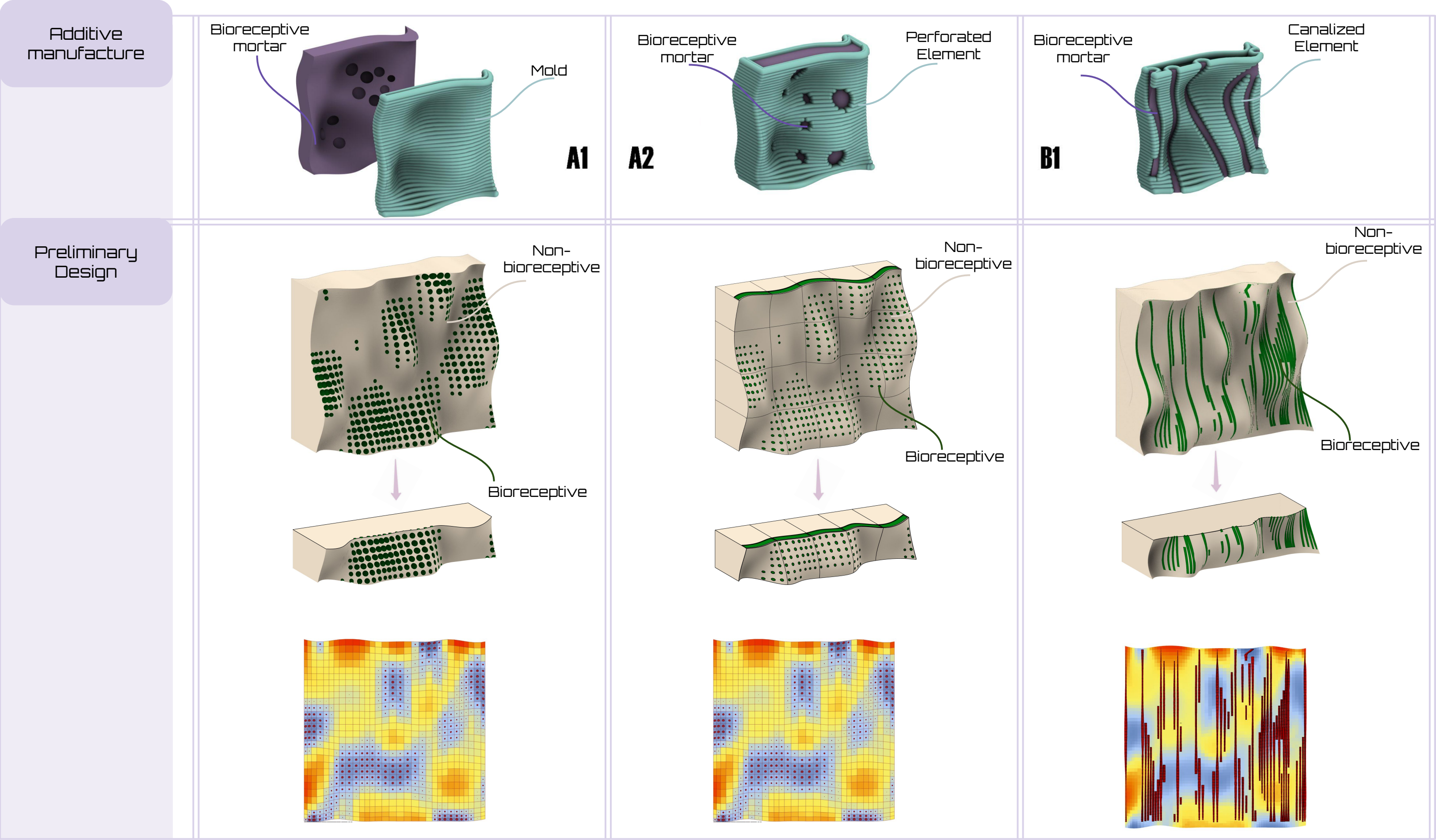
# Preliminary Designs




Cambridge
University Press
2016

# Approach

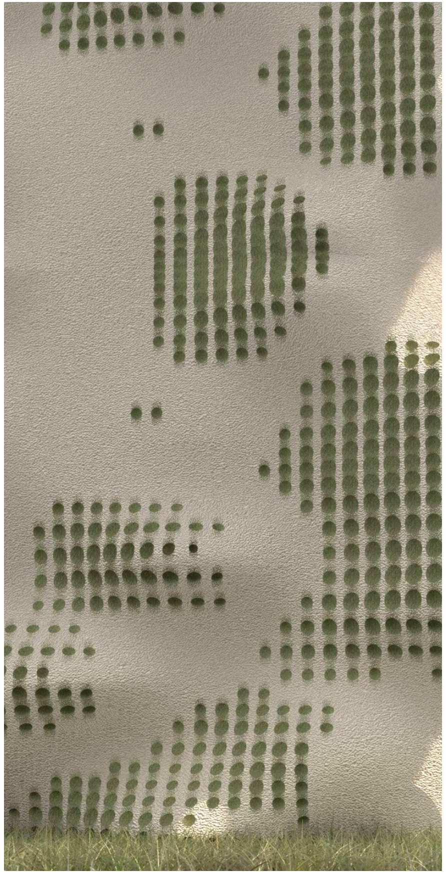
The selected mortar cannot be extruded and its mechanical performance is low.
Additive manufacturing can support its fabrication and integration in a structure by creating a composite element.



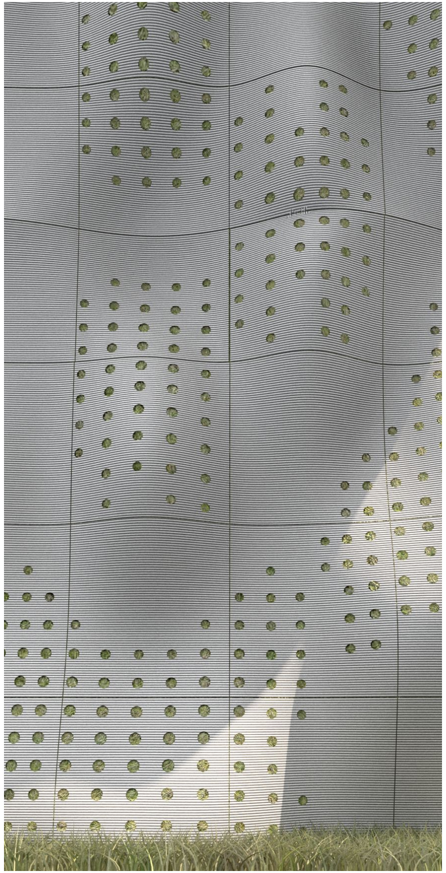
# Renderings

Non-bioreceptive parts need to be made by an extrudable material with low open porosity, low water absorption rate and retention and good compatibility with mortars.

A1



A2

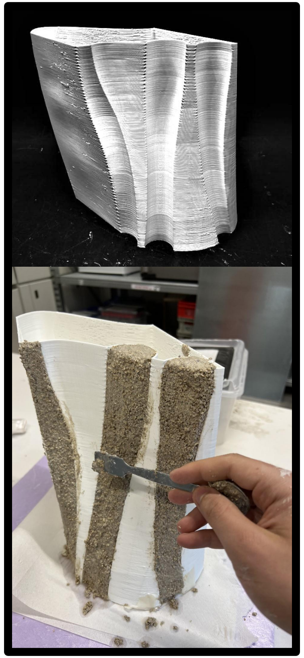


B1

A1

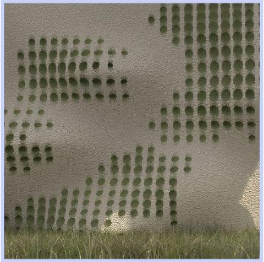
A2

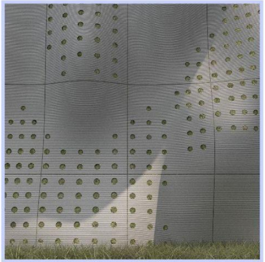
B1



(own source)

# Comparison

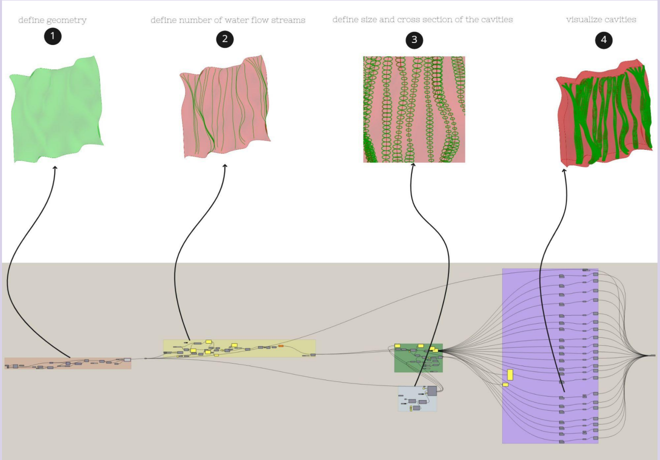




| | A1 | A2 | B1 |
|---|---|---|---|
| Design Complexity | 5 | 2 | 4 |
| Feasibility | 1 | 3 | 5 |
| Labor Intensity | 2 | 4 | 5 |
| Durability | 1 | 3 | 5 |
| Time Demand | 1 | 3 | 4 |

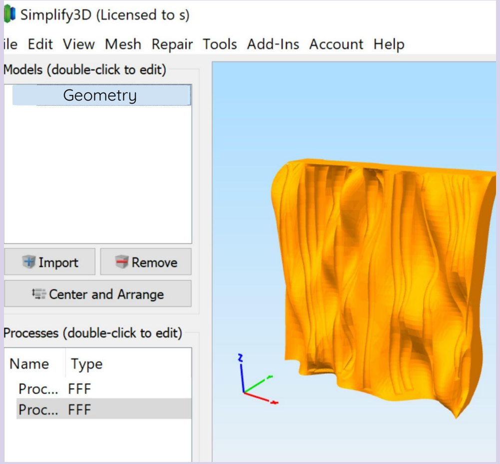
(own source)

# Digital Fabrication Workflow



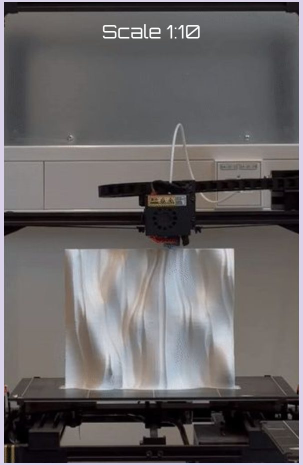

## 1. Generative Design

The user needs to define several design parameters like the number of the cavities, their cross-section and size.




## 2. Path planning for production

The slicer can automatically convert solid volumes to hollow ones, saving costs and time

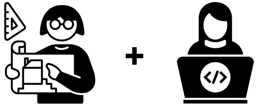



## 3. 3d-printing

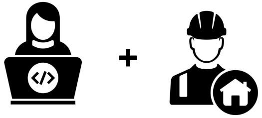
The geometry is produced.


## 4. Apply Mortar

The bioreceptive mortar is placed inside the cavities.

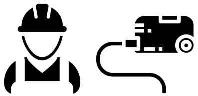


Designer + Computational Designer



Computational Designer + Specialized Engineer

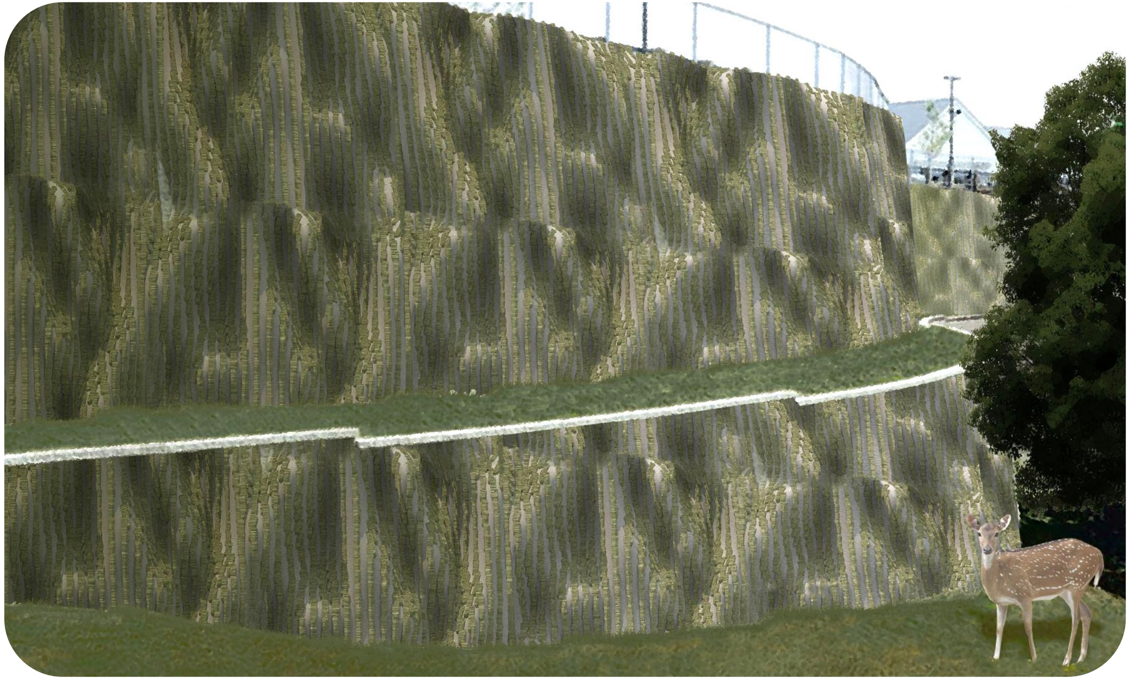
3d printer



Mortar application

# Design Vision

# Design Vision

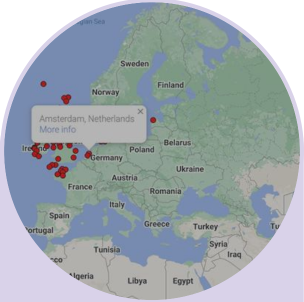


# Design Vision

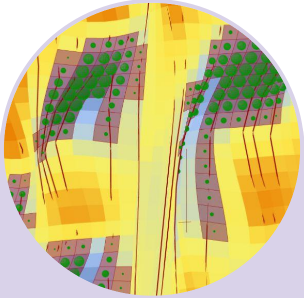
# Conclusions

# Conclusions

**How can computational performance analysis / surface topology modifications improve the bioreceptivity performance of building envelopes, by taking into account environmental variables?**




Can act as a **consulting mechanism** for predicting if a location supports bioreceptivity



Enables the **generation, optimization, comparison and evaluation** of design alternatives

Topological modifications can **decrease solar radiation and regulate water** which can support bioreceptivity

There is a wide **uncertainty about to what extent** the topological modification can improve bioreceptivity

# Conclusions

**How does the composition of lime-based mortars affect their bioreceptivity and how can this be improved?**


influences their **pore size and pore structure** which in turn has an impact on their **water transport behaviour** and thus in bioreceptivity.

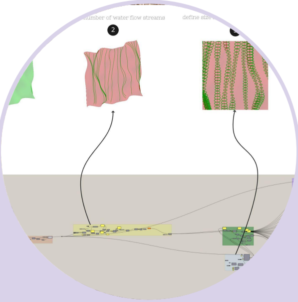

Mortar made of NHL, Vermiculite and thin sand grains can be considered **bioreceptive**. This is thanks to its **high water absorbing capacity and retention.**


**Natural hydraulic lime 3.5 had a better bioreceptivity** performance than hydrated lime with trass.


It is **not clear** if its composition and roughness are sufficient for mosses' growth.
Estimated period of time would be **18-20 weeks.**

# Conclusions

**How can digital fabrication support the production of customizable bioreceptive mortar elements?**



The parametrization of the whole process which demonstrates how **generative scripts can become toolpaths** and eventually lead to **customized design solutions.**

It creates a **synergetic workflow** that results in the creation of a new **architectural expression** while overcoming mortars' **structural limitations.**

## Limitations

- Bioreceptivity is a complex long-term process; **limited time within thesis' scope**
- Environmental Conditions; **unpredictable climate change.**
- **Limited Experimental Research**; hard to understand a material's bioreceptive performance in the long term

## Recommendations

- **Physical experiments** exploring topology's influence on bioreceptivity
- **Other methods of topology manipulation and evaluation** could be tested and compared with the present one.
- A method for **moss growth evaluation** needs to be constructed in order to be able to compare different specimens.
- Further research of bryophytes' **favorable conditions** need to be conducted regarding their exact solar exposure limits.

# Thank you all!

Questions?