MoonSane

Designing Lunar Habitats for Improving Mental Wellness

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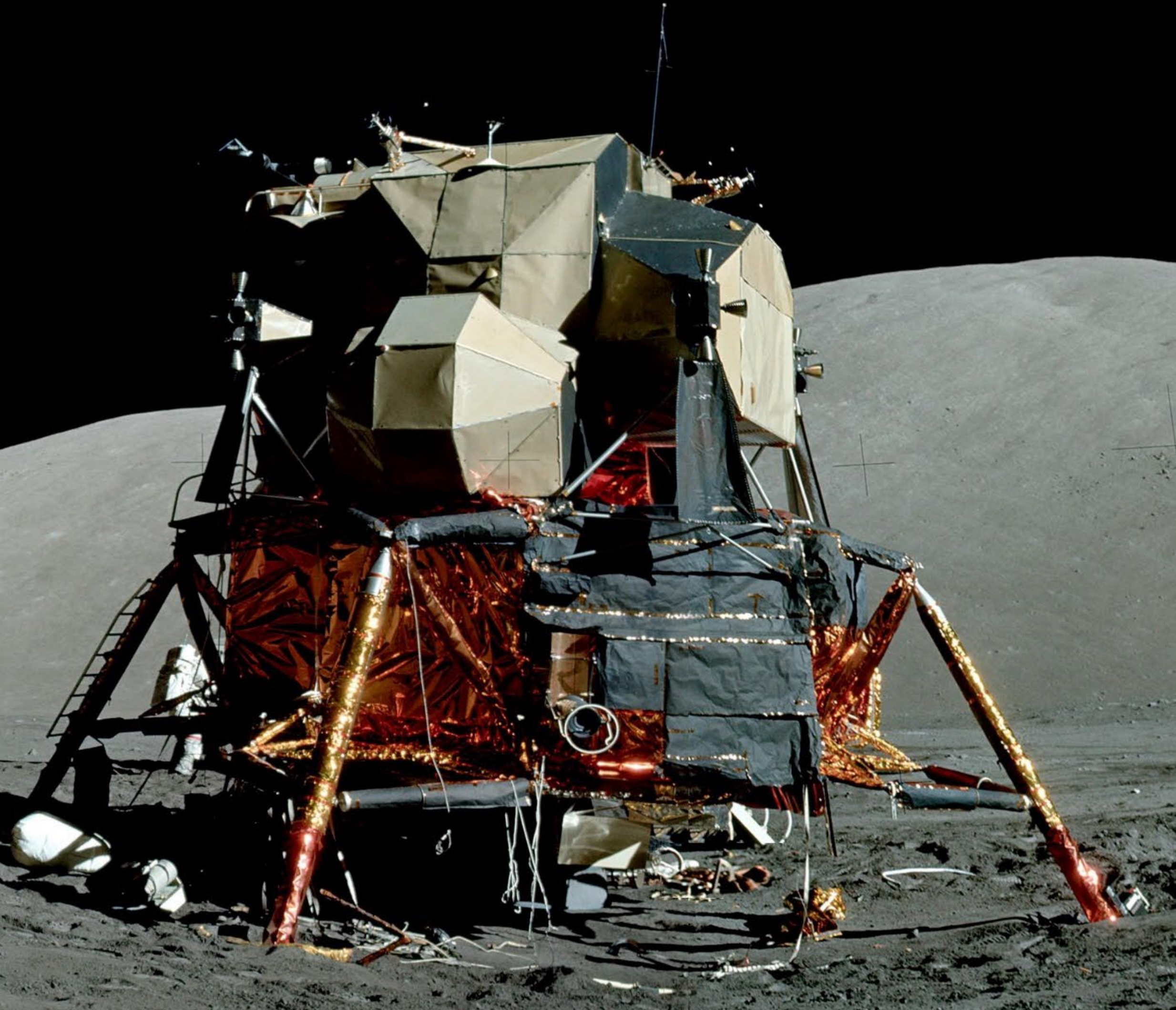
Approaching Lunar Architecture

Blank Canvas

Extreme Environment

Habitat conditions

- Far away from home and family
- Limited social circle
- Habitat is main stimulus



141:01:23 20871, 20890, and 20891 Source: NASA

Views

AS17-136-20411-20425 Source: NASA

AS17-138-21063 (OF300) Source: NASA

Research question

How can human spatial perception be used in the design of Lunar habitats, to mitigate the negative mental health effects of living long-term on the moon?

Scope of habitat solutions

Lighting:
- Allowing the passage of sunlight*
- Habitat day/night cycles
- Improved environmental lighting

Stimulating senses:
- Improved colours of environment
- Reduced noise levels
- Variations in habitat environmental factors
- Comfortable air temp/ humidity
- Nature/plants included on station

Crew interaction:
- Private quarters

Views:
- Views of the habitat from the windows
- More observation windows
- Direct views of earth

Logan M. Smith, "The psychology and mental health of the spaceflight environment: A scoping review." *Acta Astronautica 201*, 2022, 496-512, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2022.09.054.

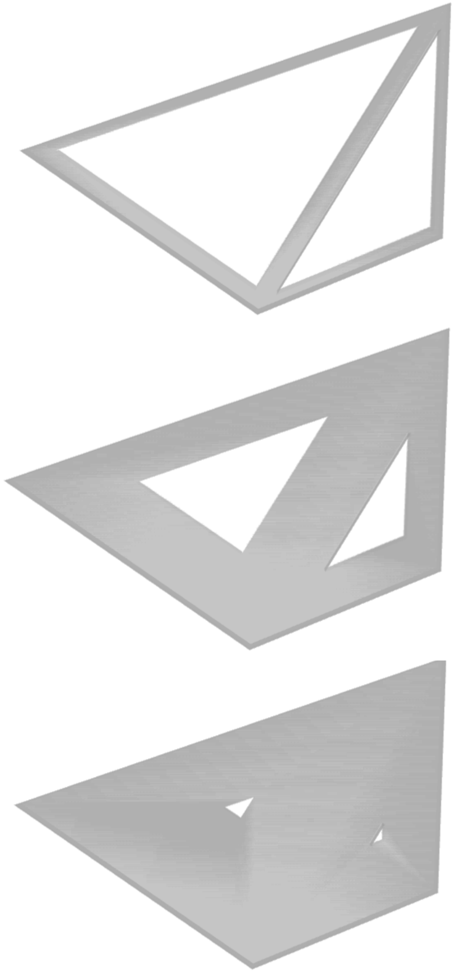
Light

- Experiment: circadian rhythm lamps in the LUNARK module
  - "Waking up to a sunrise inside our sleeping pods was an incredible natural feeling"
  - Stationary

https://www.saga.dk/projects/lunark/circadian

Spatial enclosure

- Enclosed spaces
  - increase stress
  - trigger avoidance
  - Locomotive vs visual permeability
- Enclosure is judged by <u>visual</u> permeability

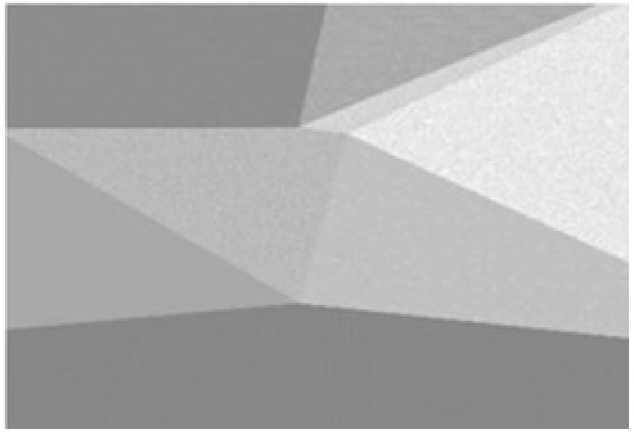


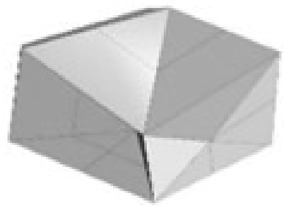
Vartanian, O., Navarrete, G., Chatterjee, A., Fich, L. B., Gonzalez-Mora, J. L., Leder, H., ... & Skov, M. (2015). Architectural design and the brain: Effects of ceiling height and perceived enclosure on beauty judgments and approach-avoidance decisions. *Journal of environmental psychology, 41*, 10-18.

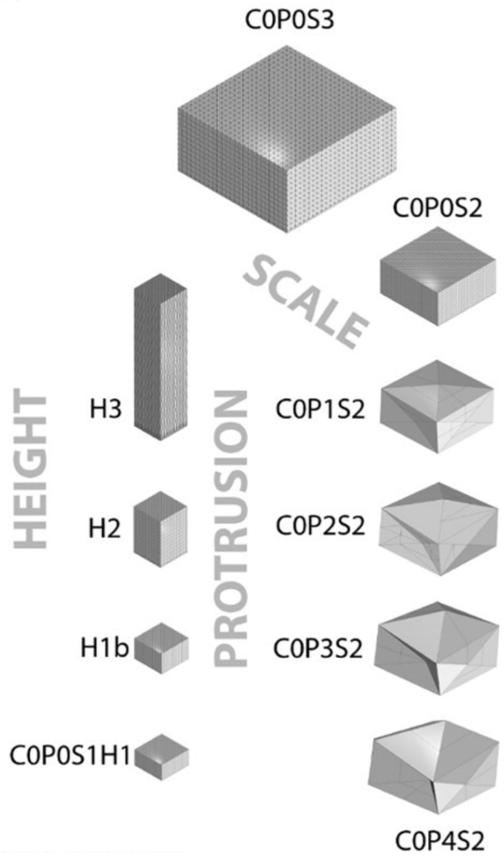
Spatial geometry

Study using VR

- EEG, eye-tracking
- Various rooms, different shapes
  - Symmetric vs asymmetric
  - Proportion
- Asymmetric, angular spaces
  - High pupil dilation- positive interest
  - The more protrusion, the better





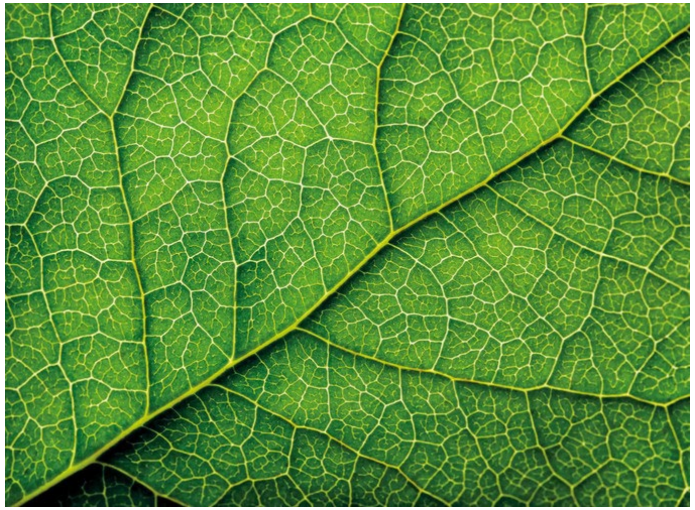


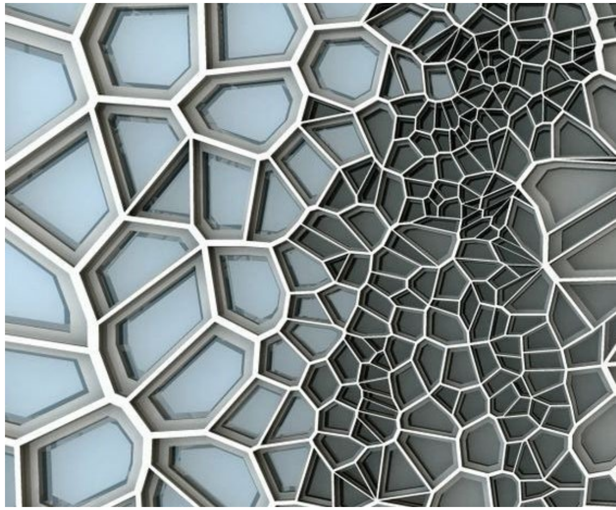
Shemesh, A., Leisman, G., Bar, M., & Grobman, Y. J. (2021). A neurocognitive study of the emotional impact of geometrical criteria of architectural space. *Architectural Science Review*, *64*(4), 394–407. https://doi-org.tudelft.idm.oclc.org/10.1080/00038628.2021.1940827

Natural geometry: fractal patterns

- Repeating shapes
  - Calming effect
  - Hidden in nature: biophilia
  - Dynamic: light shimmer
- Voronoi

Abboushi, B., Elzeyadi, I., Taylor, R., & Sereno, M. (2019). Fractals in architecture: The visual interest, preference, and mood response to projected fractal light patterns in interior spaces. *Journal of Environmental Psychology, 61*, 57-70.

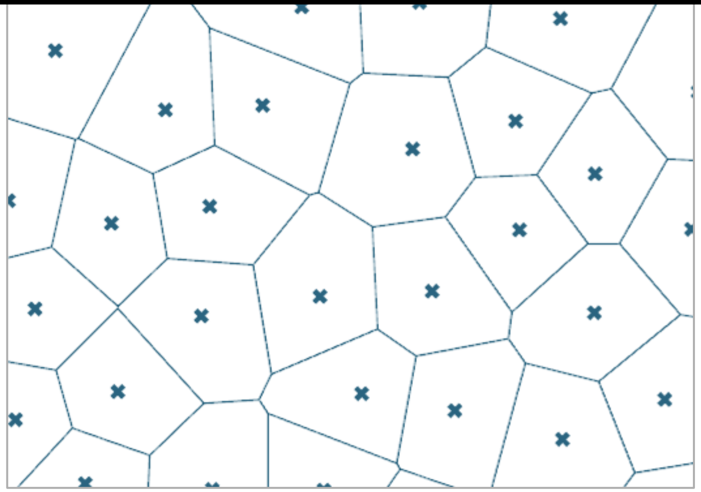


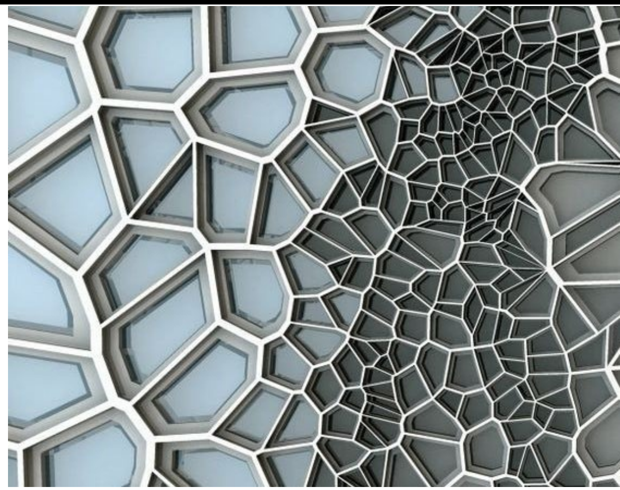


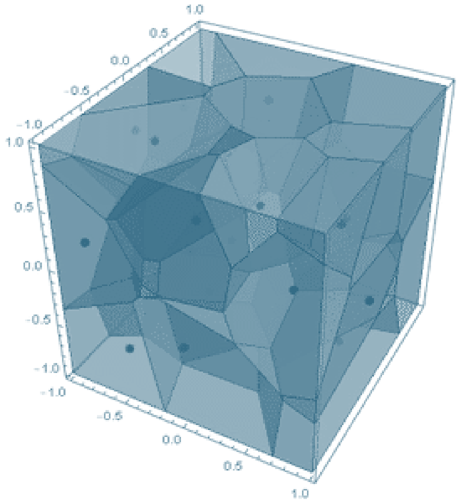
Natural geometry: Voronoi

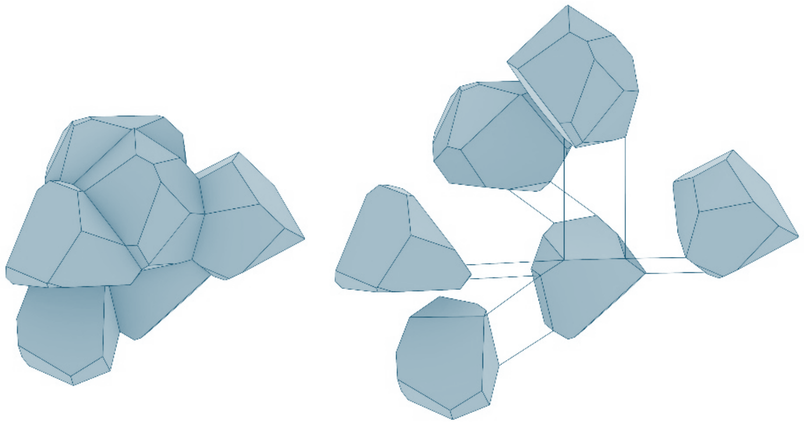
Voronoi
- Point based pattern found in nature
- Scalable cells 2D or 3D
- Facetted geometry

- Seamless fit
- Adjustable density and size
- Extra-terrestrial form language







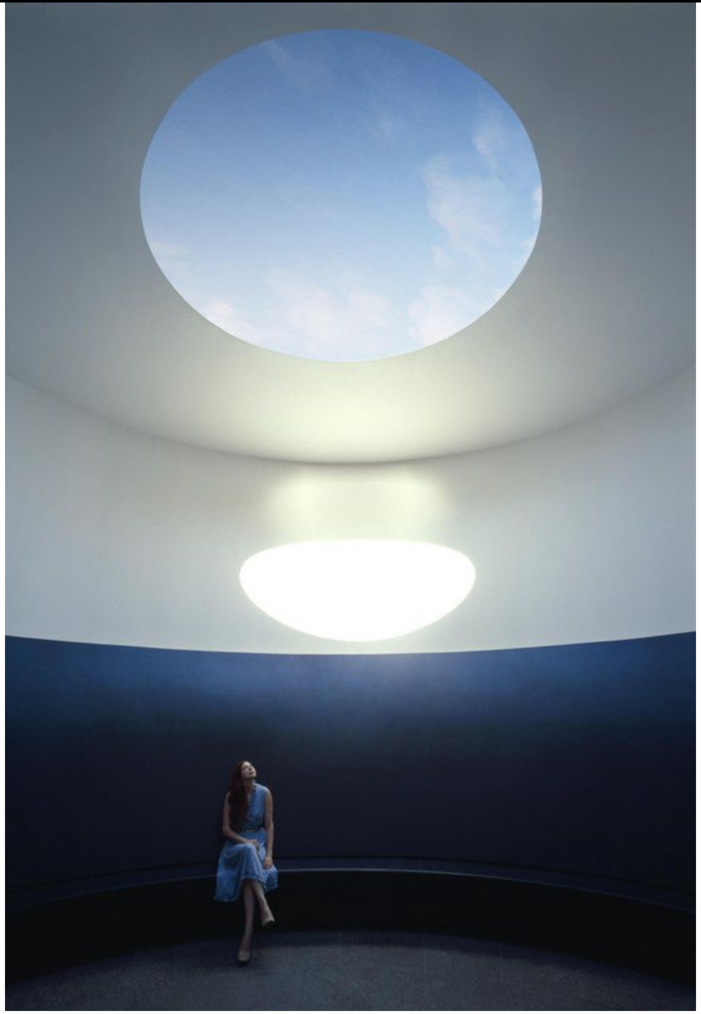


The Overview Effect

- Phenomenon of astronauts who view Earth from space
- Awe-inducing
  - Increased empathy and sense of purpose
  - Decrease in stress hormones

Nezami, A., Persaud, L. M., & White, F. (2021). The overview effect and well-being. In *Expanding worldviews: astrobiology, Big history and cosmic perspectives* (pp. 163-197). Cham: Springer International Publishing.

Earth gazing & “Skyspace”



James Turrell – “Skyspace”

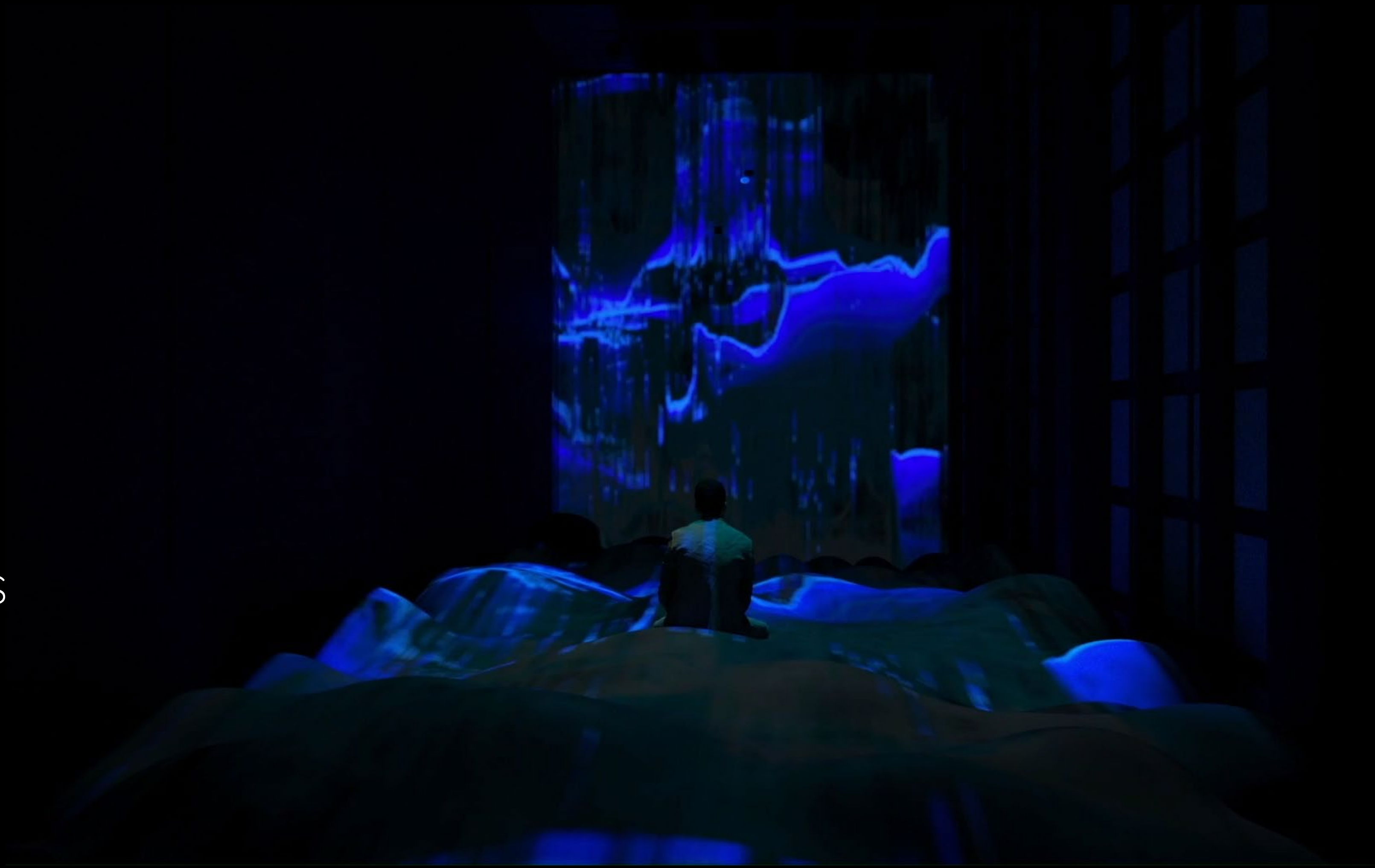
- looking upwards – positive effect
- Earth view incorporated?
- Mood lighting added to increase experience (based on mood of astronaut?)

Colour projection

"EMO"- Xiying Bao

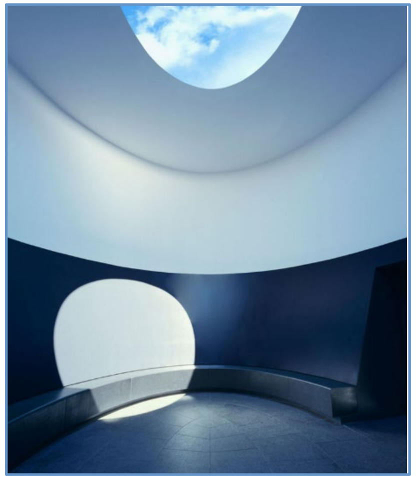
- AI technology: facial recognition
- Changes colours and shapes based on perceived emotion
- Adaptive system monitors wellbeing of crew members
  - **influence/transform emotions as well?**

https://designawards.core77.com/Interaction/104584/Emo.html

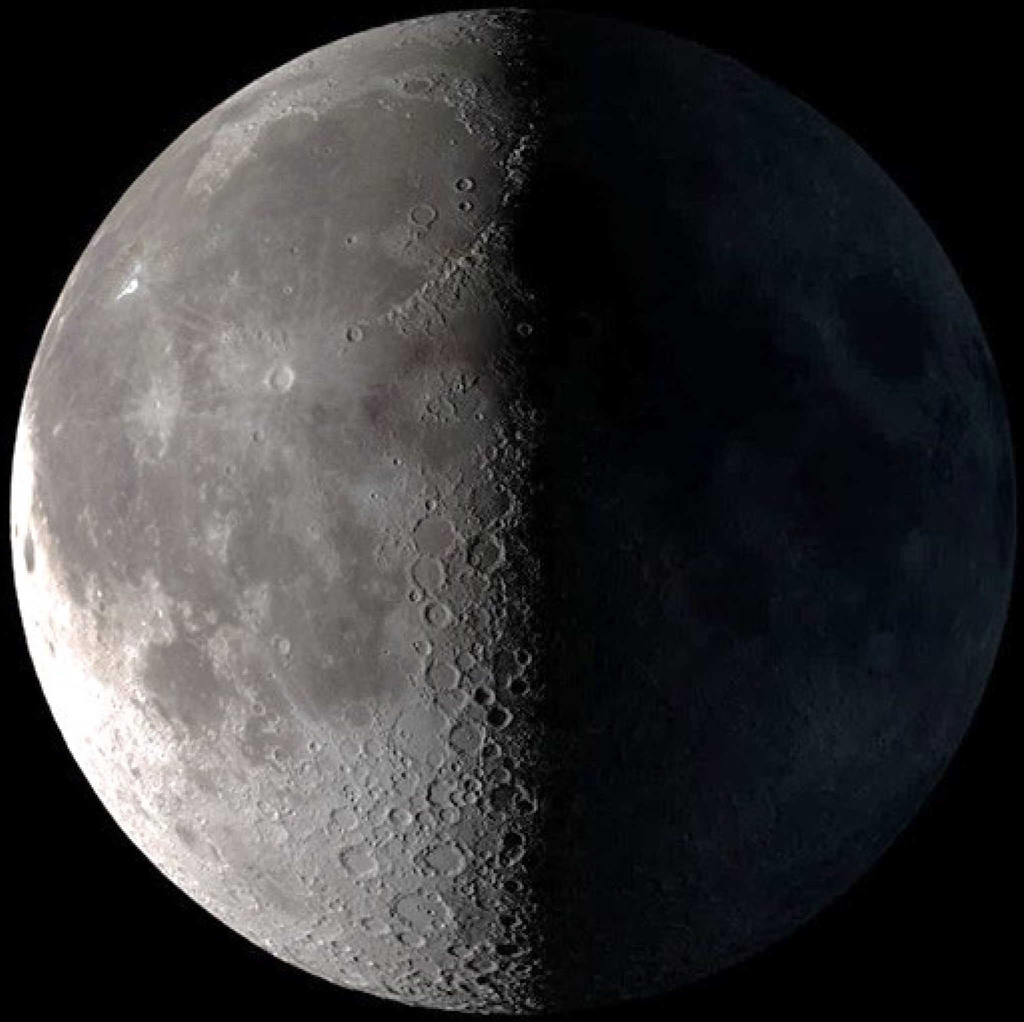


Concept

Designing a Lunar habitat that promotes mental wellness of the crew



Designing Lunar Architecture



Location: Earth view

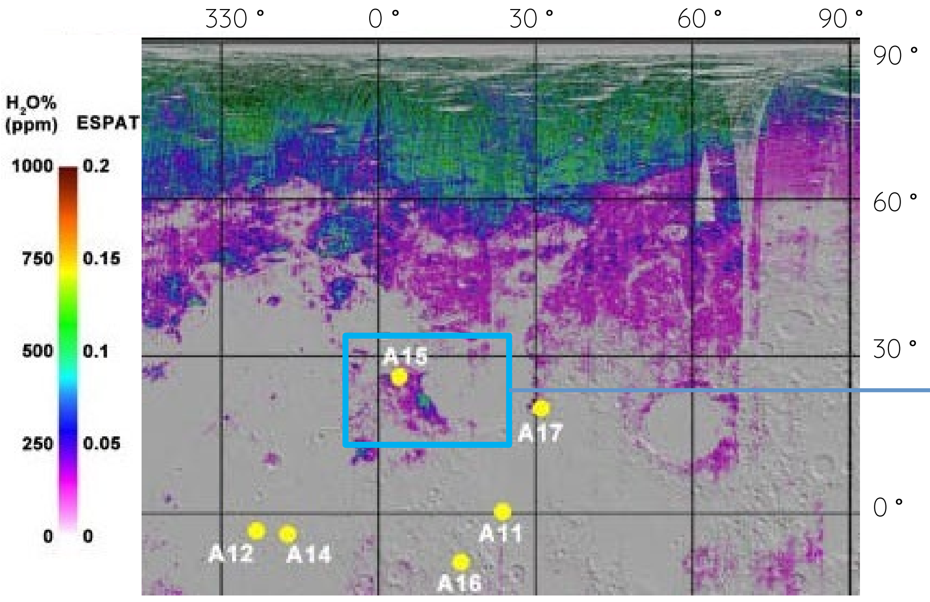
Near side of the Moon

Lunar Equator
- Earth directly overhead
- Desirable for earth view from above

Lunar Poles

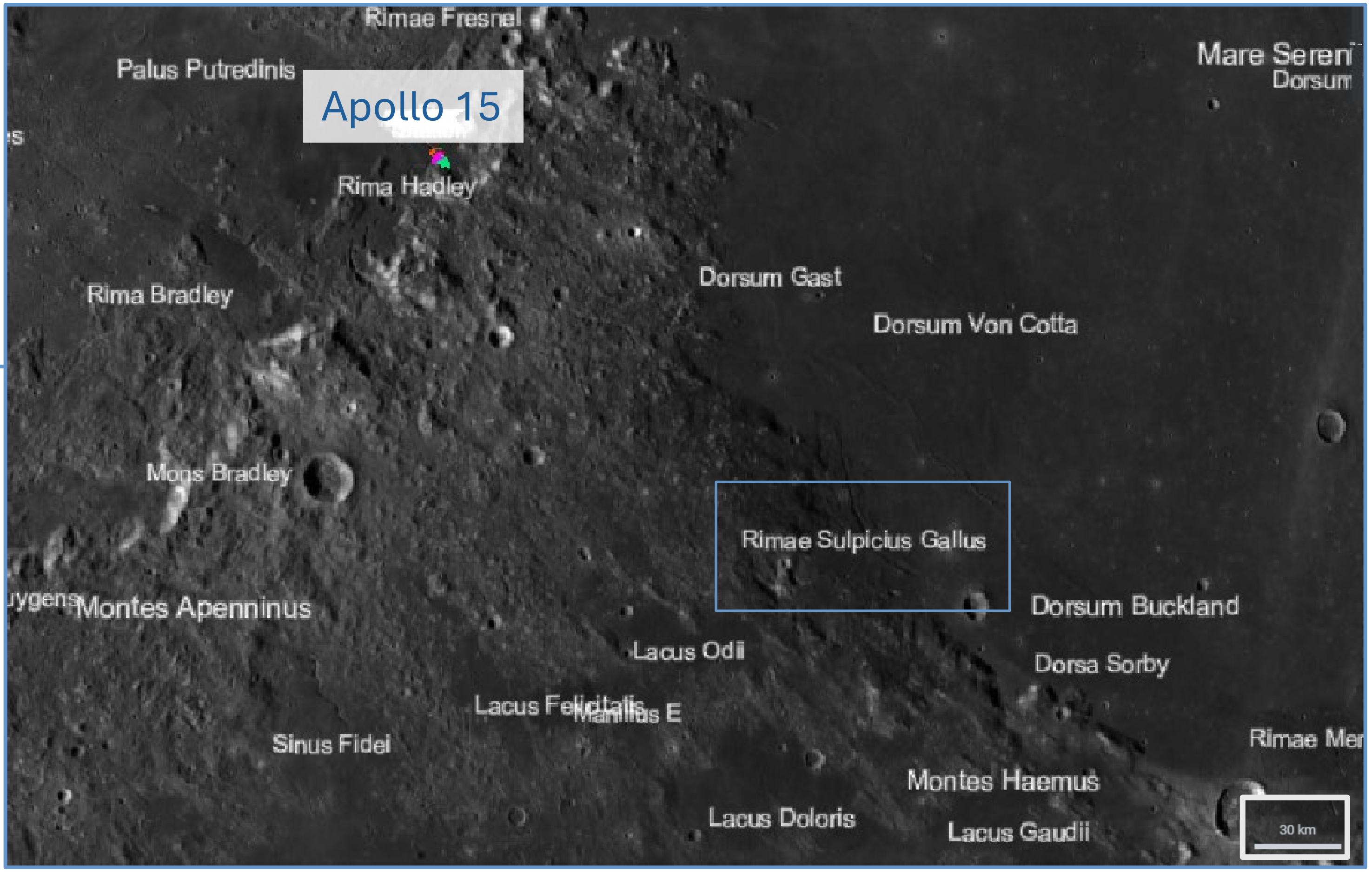
- Earth visible at the horizon
- Sometimes drops below horizon – not visible

Location: Mare Serenitatis



Source: Brown University

Edge of *Mare Serenitatis*
- Presumed water/ice
- Near Apollo 15 landing site



Source: Lunar/LROC Quickmap

Program: main rooms

Main rooms

- Private quarters
  - Sleeping area
- Living quarters
  - Social area, eating area, kitchen
- Research facility
  - Command and control
  - Workspace
- Gym
- Bathroom (&toilet)
- Medical facility
- Antechamber for EVA’s
  - (regolith cleaning and suit doffing)
- Stowage

Additional rooms

- **Garden**
- **Meditation space**
  - earth viewing

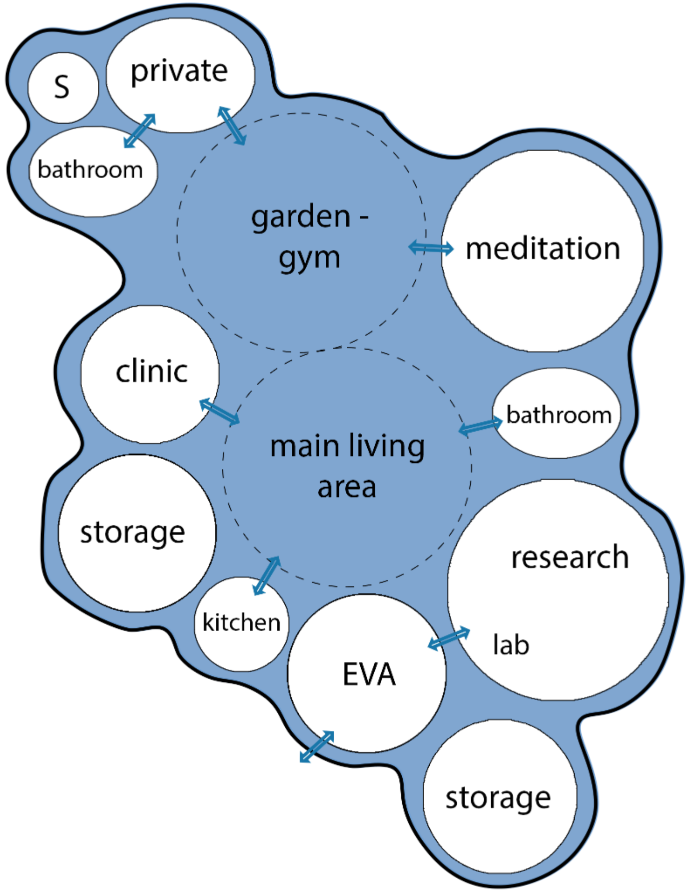
“Minimum volume of **80m3 per person**” (ESA)

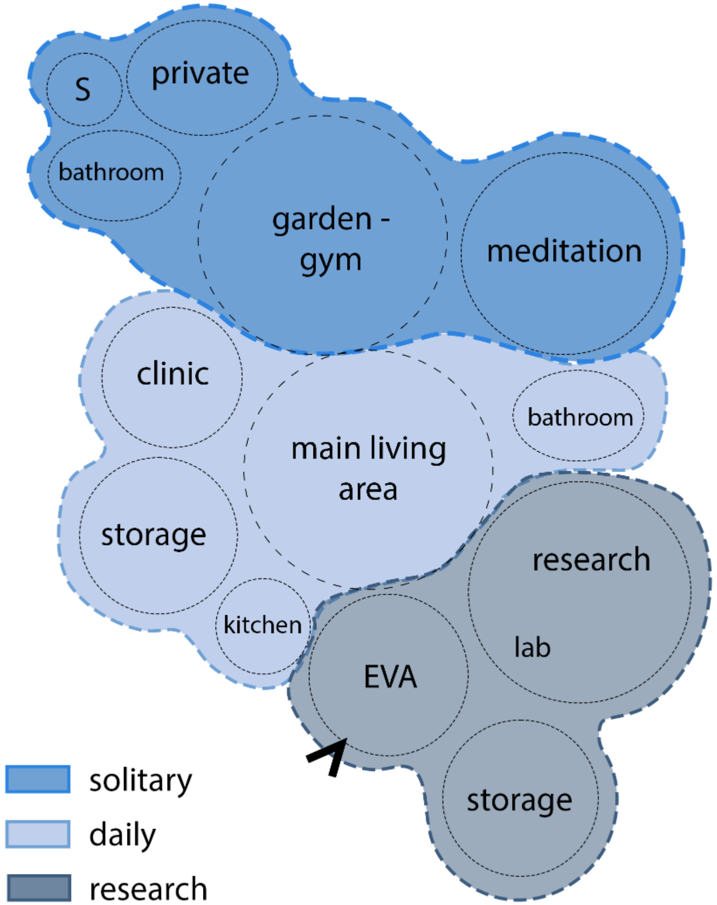
Source: Moon Village CDF Study Report: CDF-202(A) – Issue 1.1 September 2020, page 60.
https://www.lpi.usra.edu/lunar/strategies/ESA-ESTEC_2020_MoonVillageLunarHabitatStudy.pdf

Program: minimum size

Room	m3 (1 person)	%	Same time use	Multiply factor	m3 (6 persons)	%
Private crew quarters	2,5	3%	Yes - but separate	x 6	15	3,5%
Living quarters	13,5	15%	Yes	x 6	81	19,5%
Kitchen	2,5	3 %	Not all	x 2	5	1%
Research facility	11	13%	Yes	x 6	66	16%
Garden	13,5	15%	Yes	x 6	81	19,5%
Gym	8	9%	Not all	x 3	24	5,5%
Bathroom	5	6%	Not all	x 2	10	2,5%
Medical facility	8	9%	Not all	x 2	16	4%
EVA antechamber	8	9%	Not all	x 3	24	5,5%
Storage general	8	9%	Yes	x 6	48	11,5%
Subtotal:	**80**	**91%**			**370**	**88,5%**
Meditation space	8	9%	Yes	x 6	48	11,5%
Total:	**88**	**100%**			**418**	**100%**

Connecting functions 2D

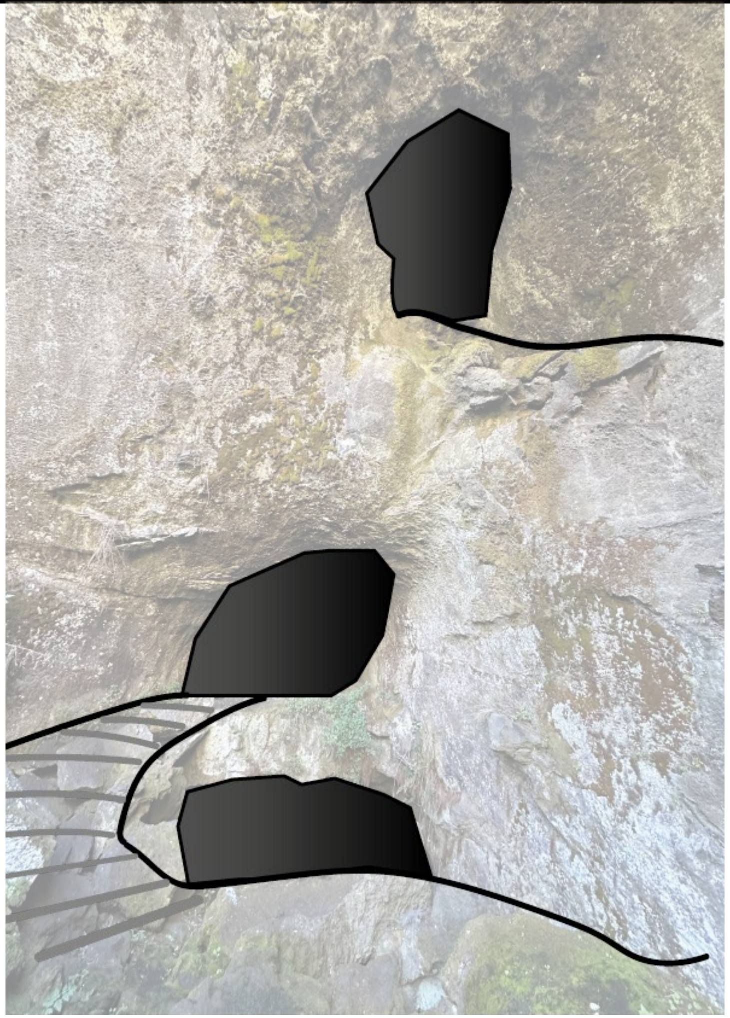




Lava tube mission

- Corridors branching out

Lava tube mission: sketching

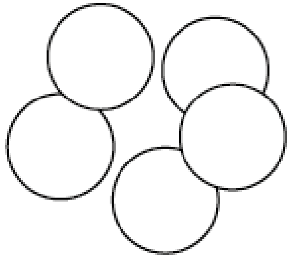


Spatial connection: 3D

- Visually connecting spaces– decreasing confinement
- Dynamic views
- Big atrium that branches out

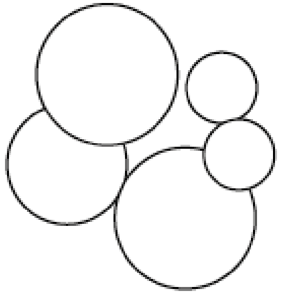
Permeability: computational script

1.Create spheres



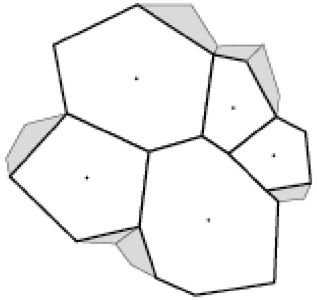
Variables:
- Manual adjustment of position

2. Adjust volume to function



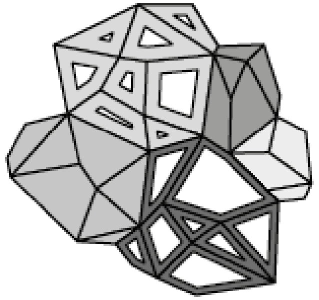
Variables:
- Volume
- Oblongness in x,y,z direction

3. Create Voronoi cells



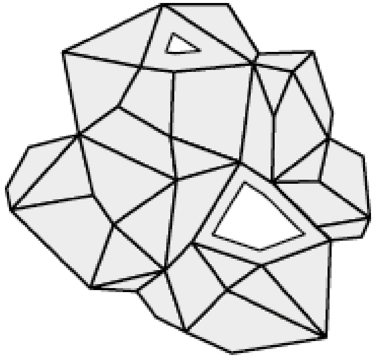
Variables:
- Neighbourhood point count
- Seed
- Sphere position

4. Adjust porosity to function



Variables:
- Porose yes/no
- edge offset openings
- selecting specific faces requiring a diverging porosity

5. Create outer shell

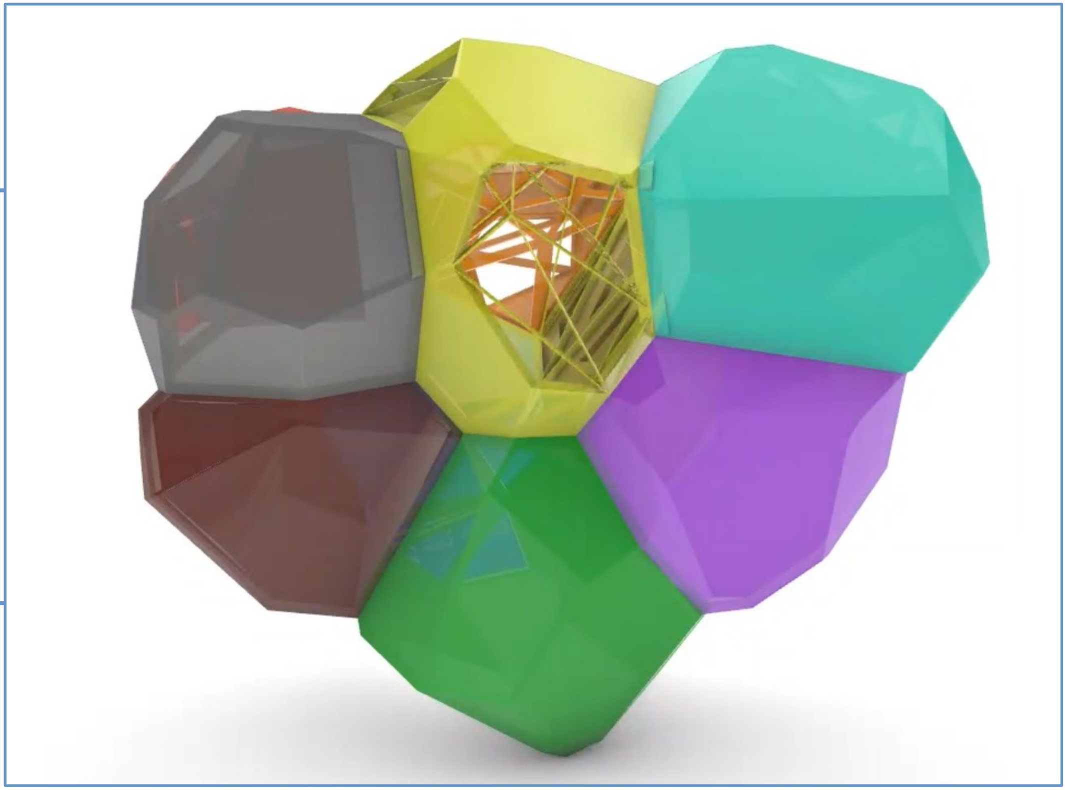


Variables:
- Shell thickness
- selecting specific faces requiring a divergence of porosity
- Opening edge offset distance

Permeability script: results

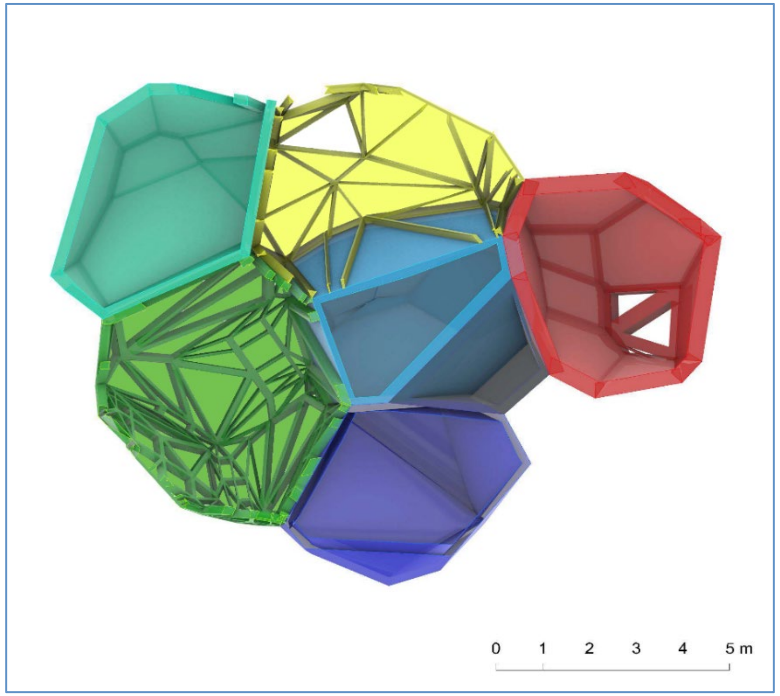
Functions

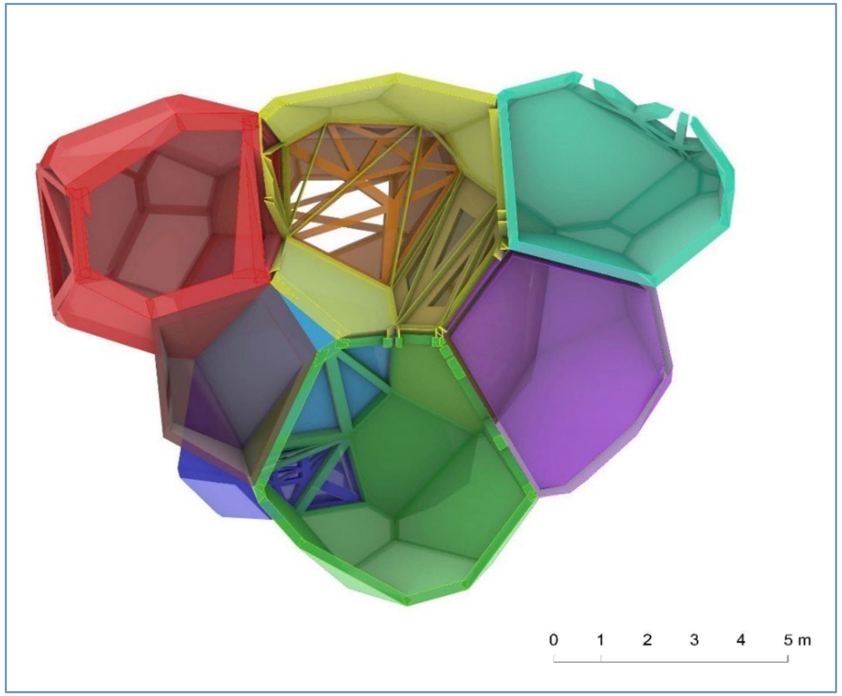
Applying permeability

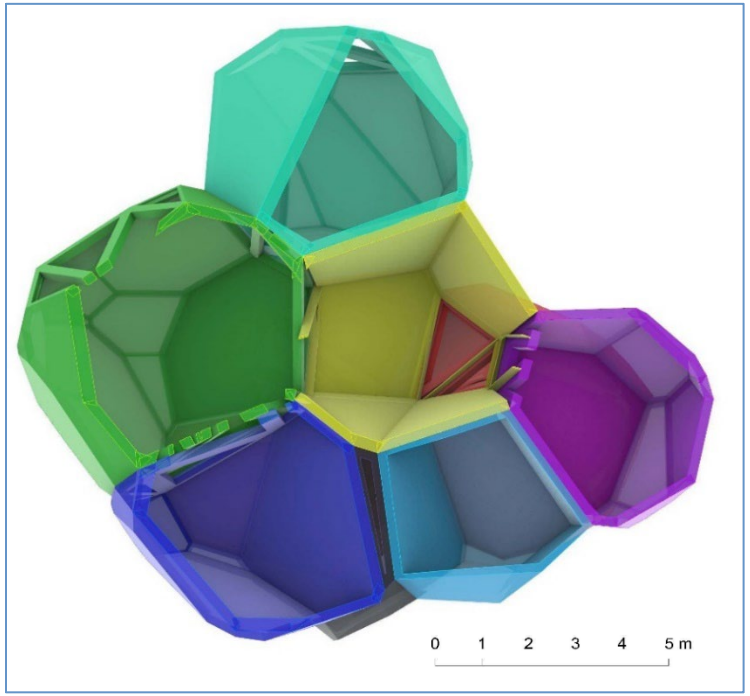


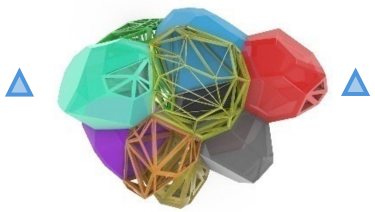
	Function	Permeability
	Living	80%
	Kitchen	62%
	Storage main	16%
	Meditation	10%
	Garden-gym	50%
	Medical	10%
	Private quarters	3%
	Bathroom	0%
	Storage private	0%
	Research	8%
	EVA chamber	5%
	Storage research	0%

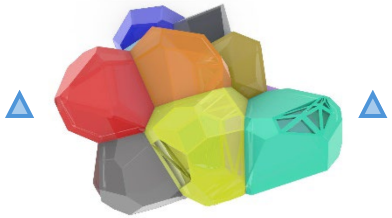
Permeability script: iterations











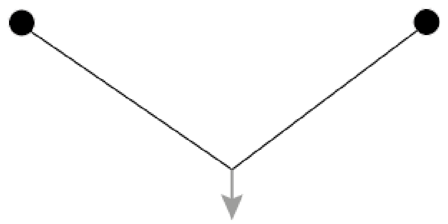
Exterior: Lunar Regolith

Main material:

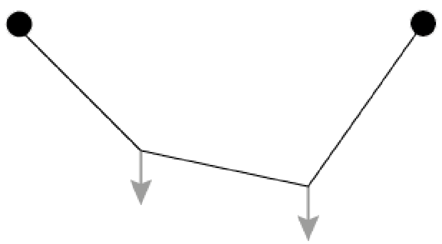
- Lunar Regolith
  - Radiation protection: will require thick walls (1,5+ m)
  - **Strong compressive properties**
  - Weak tensile properties

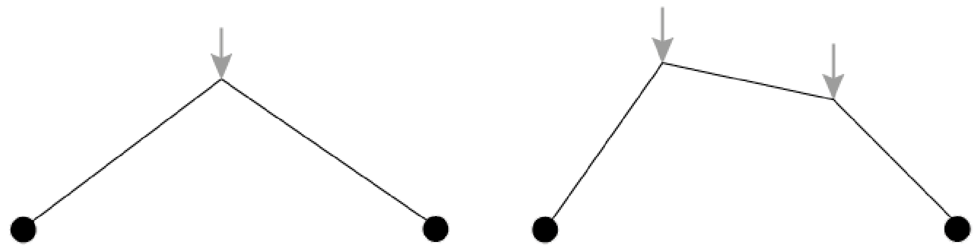
Catenary action

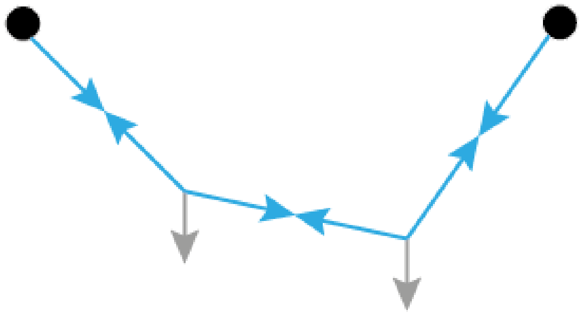
1 weight



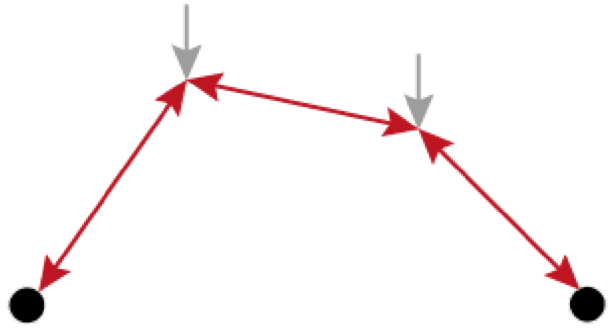
2 weights







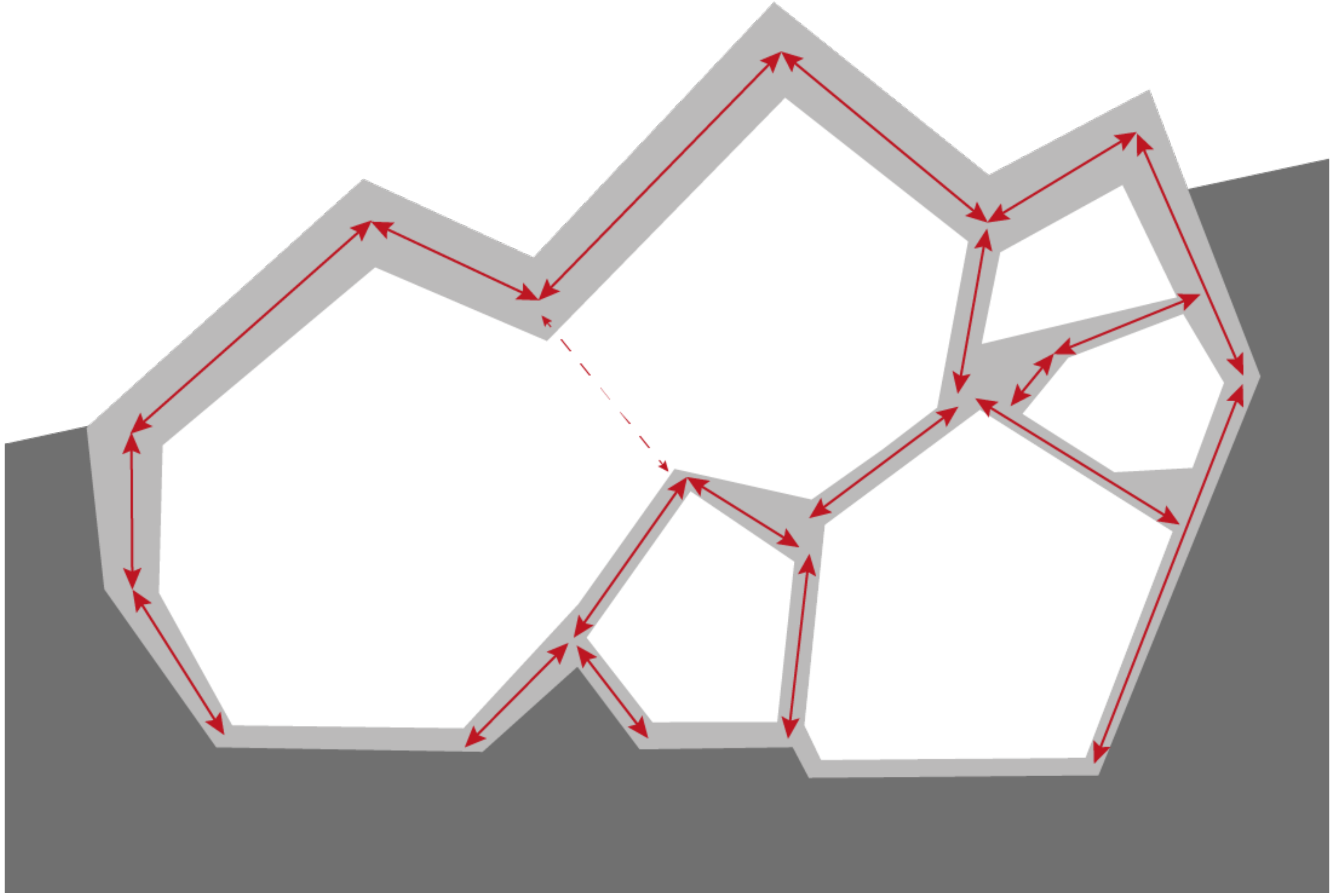
Mapping tensile forces by hanging weights on a cord



Inverted tension shows compression forces

Catenary action: building

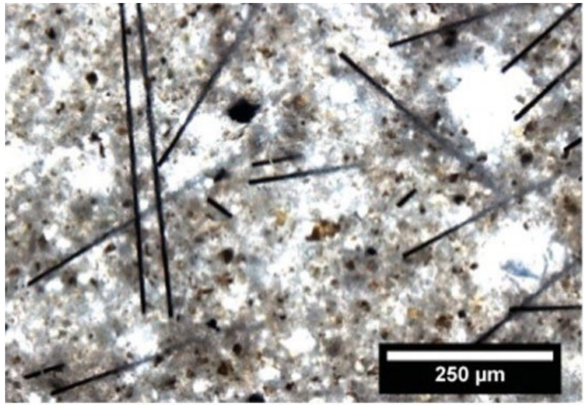
Geometry adjusted to generate mainly compressive forces:



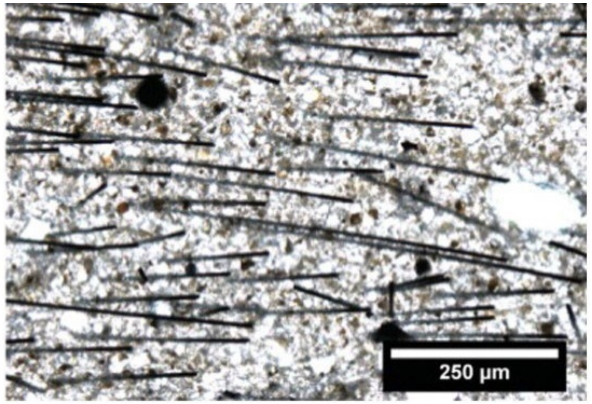
Carbon fibre

Reinforcing Lunar Regolith

- Extract carbon to produce small fibres
- Already applied in concrete
- Add to Regolith mixture
  - improves tensile strength for static and dynamic loading



disorganised



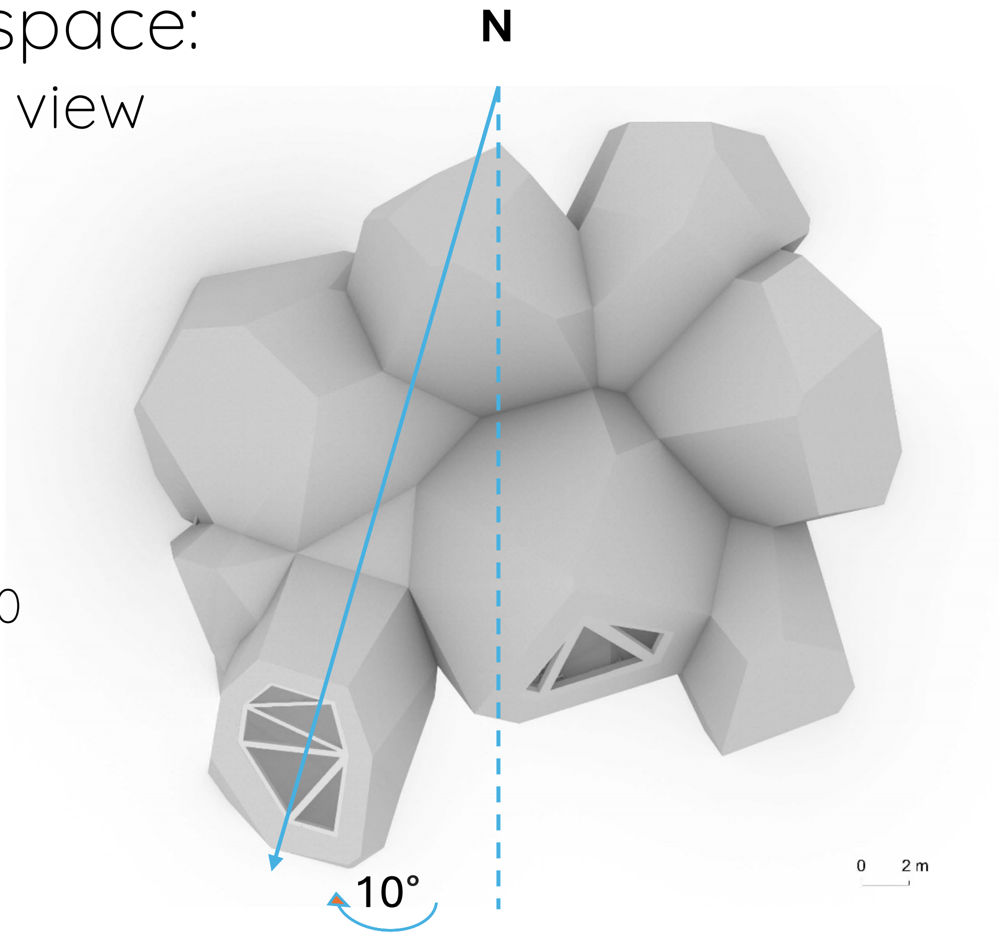
organised

Hambach, M., Möller, H., Neumann, T., & Volkmer, D. (2016). Portland cement paste with aligned carbon fibers exhibiting exceptionally high flexural strength (> 100 MPa). *Cement and Concrete Research*, *89*, 80-86.

Creating views

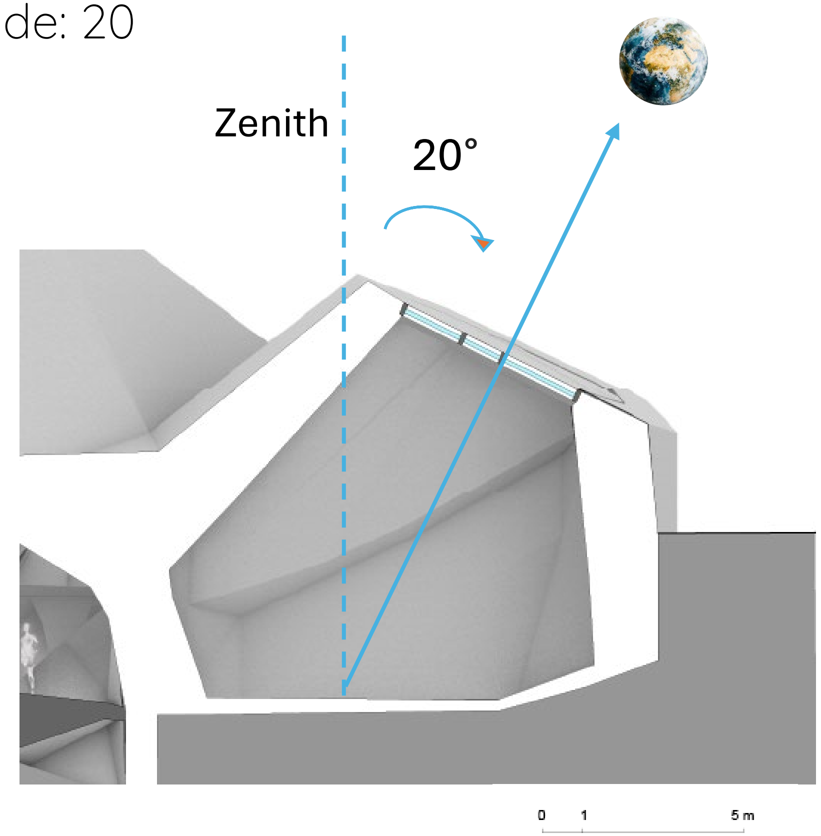
Meditation space:

- Map Earth view

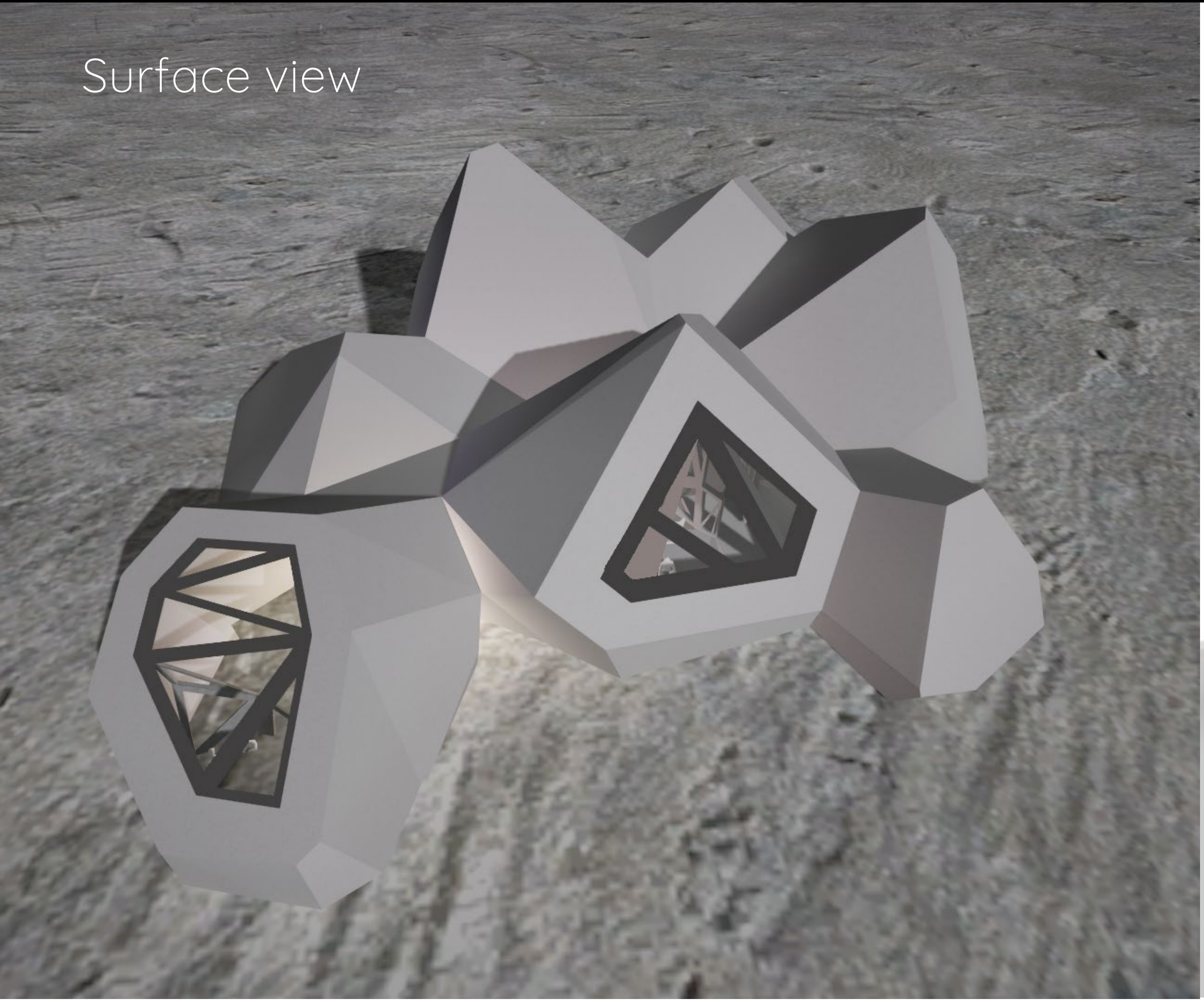


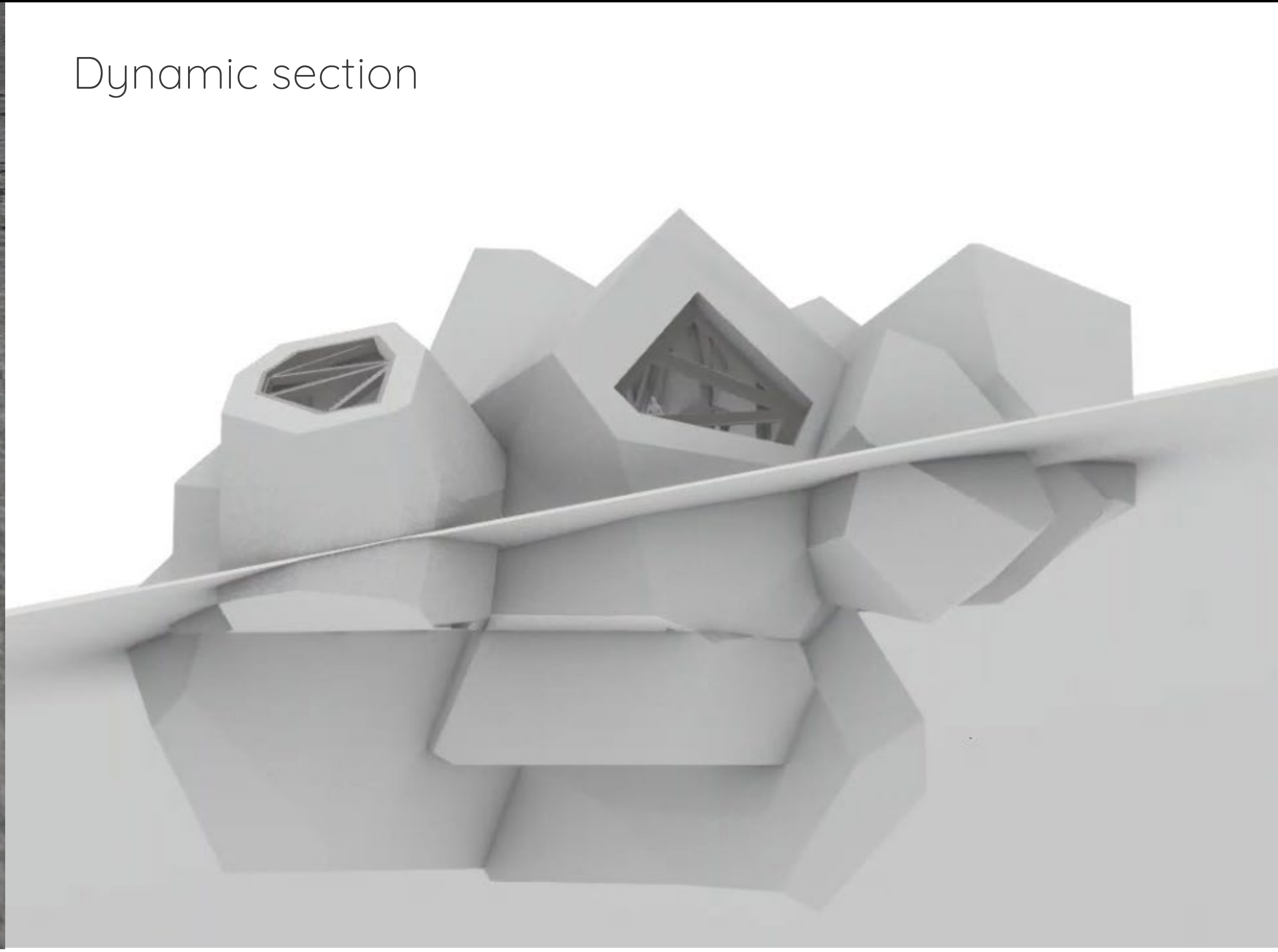
Orientation
Longitude: 10

Sky position
Latitude: 20



Building in location

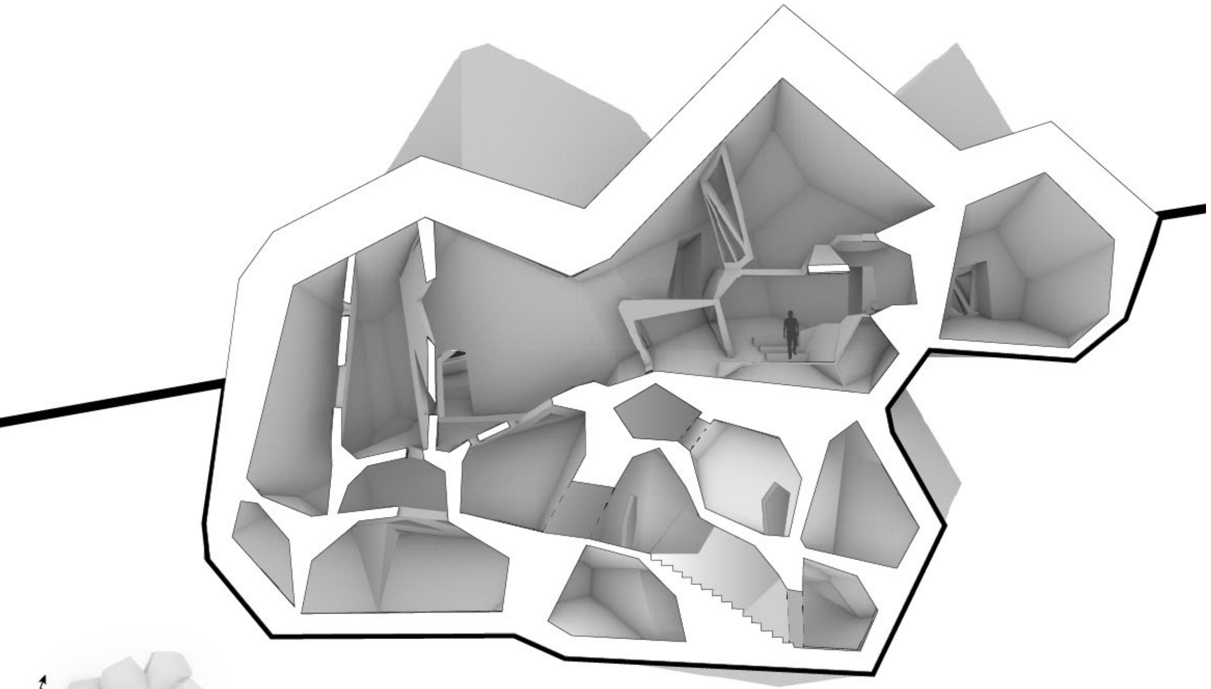




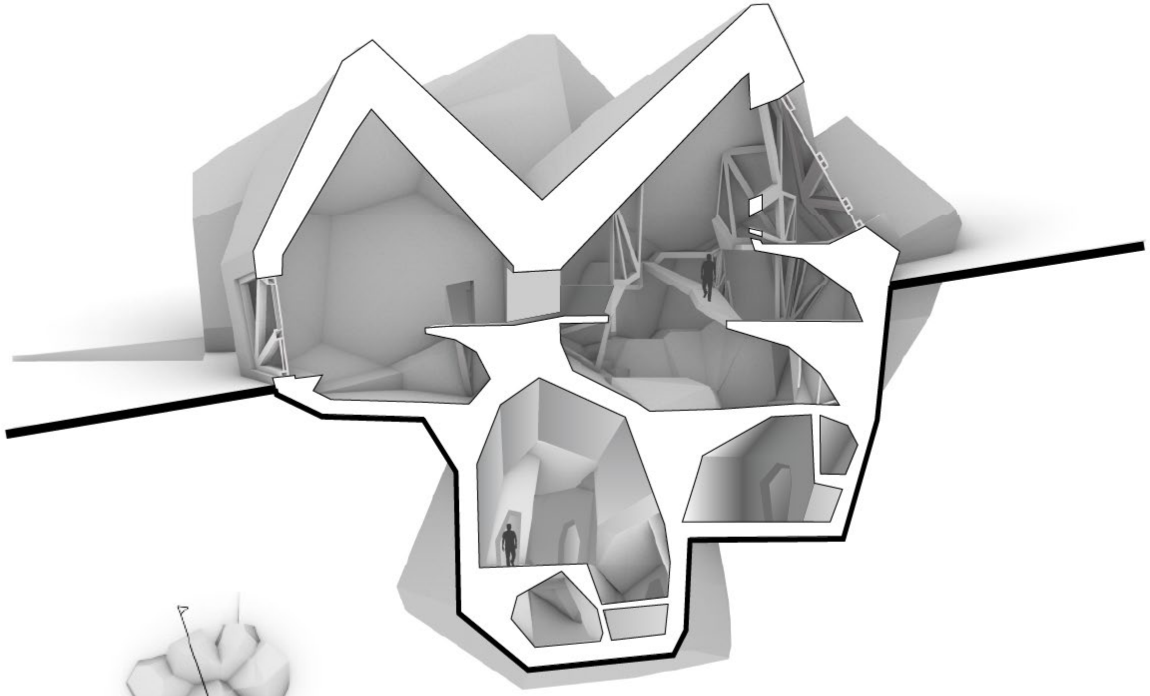
Building in location

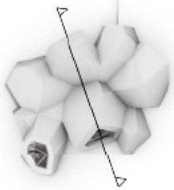
Section

Section A



Section B

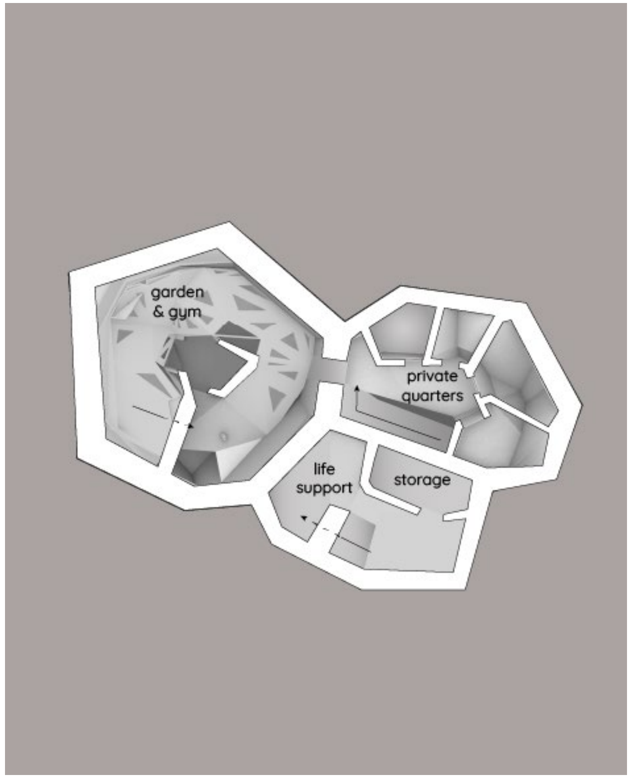




1 : 100

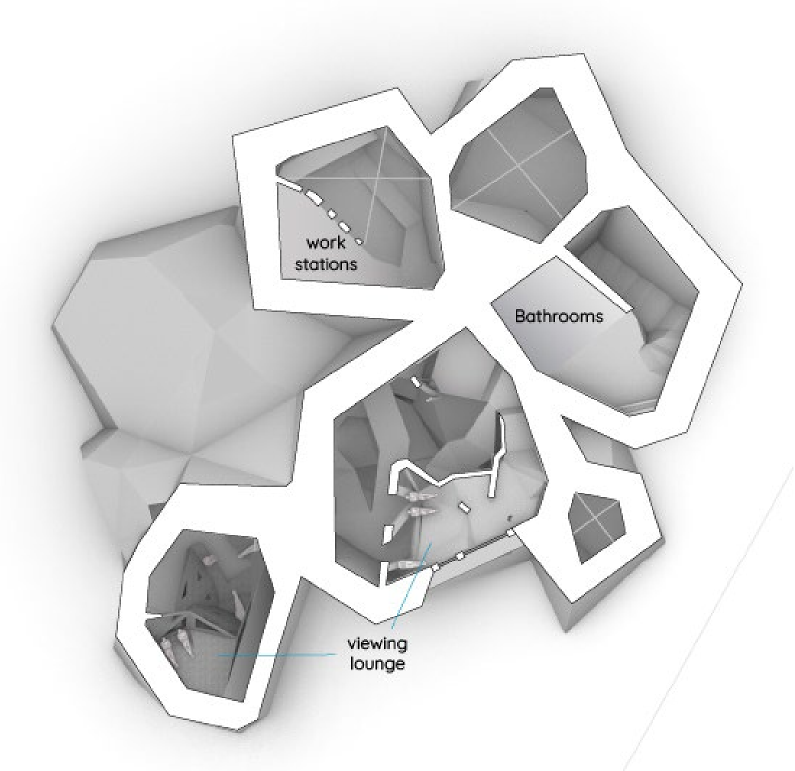
Plans

Plan -1
-6.6 m

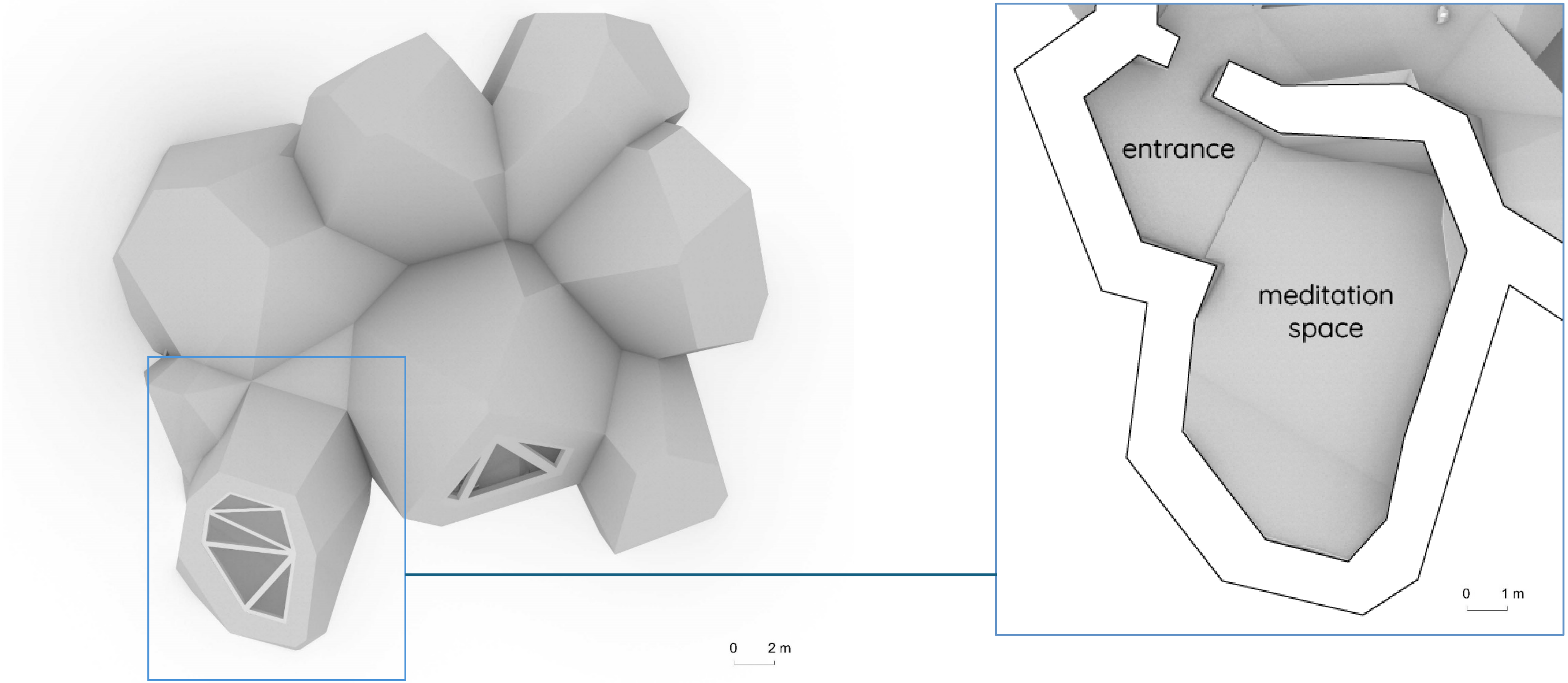


Plan 0
0 m

Plan +1
+3.6 m



Meditation space

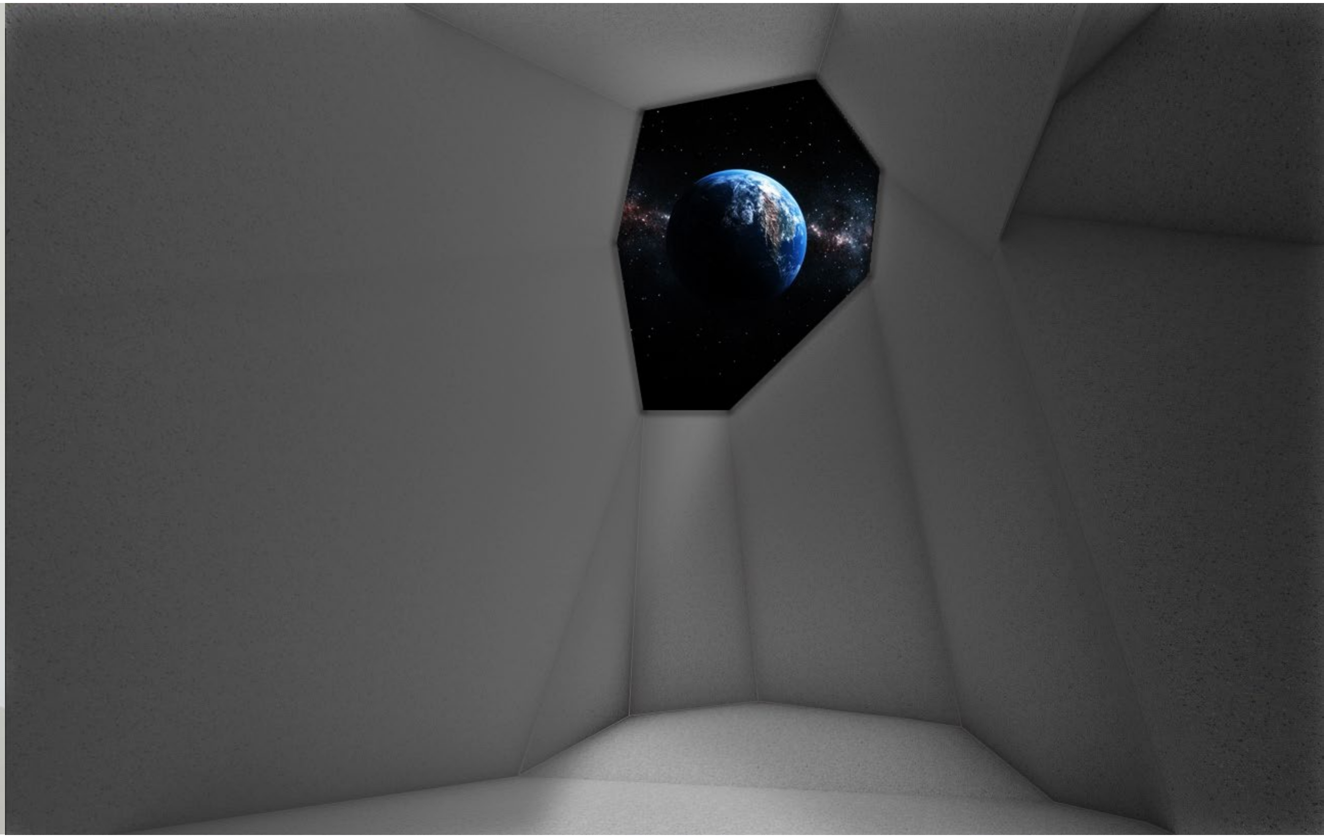


Asymmetric geometry

St. Joseph House - Wolfgang Tschapeller ZT GmbH

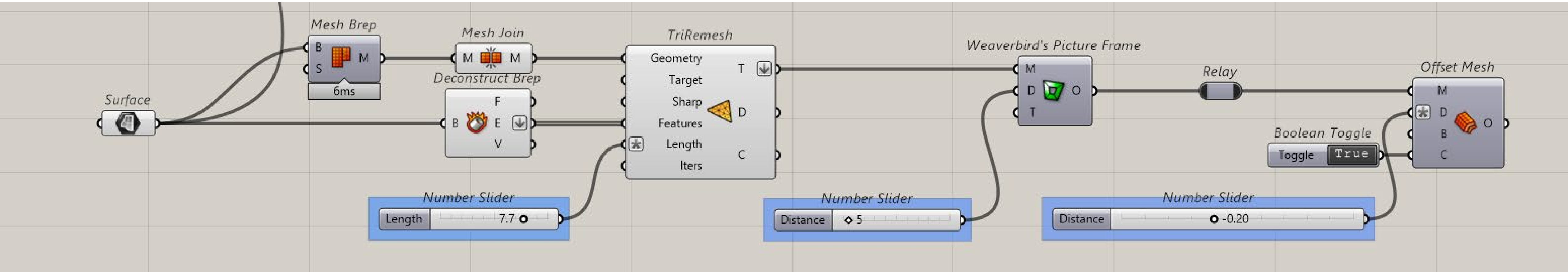
Source: [St. Joseph House / Wolfgang Tschapeller ZT GmbH | ArchDaily]

Interior meditation space



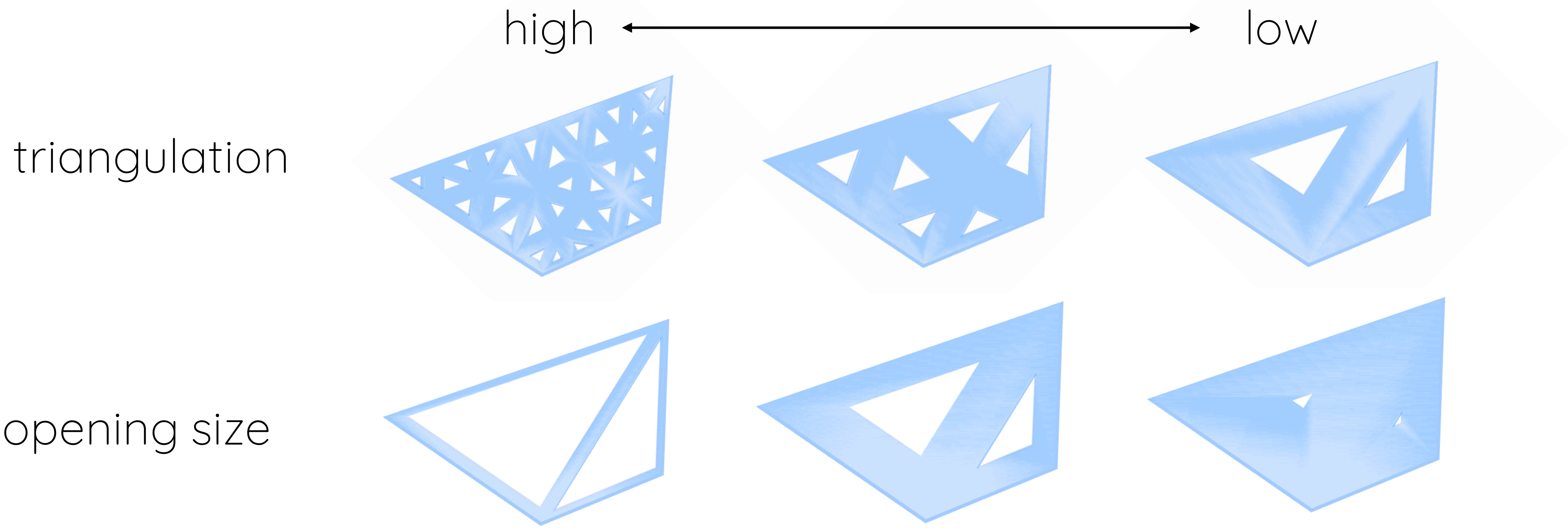
Methodology: computational design

Permeability study: furniture scale

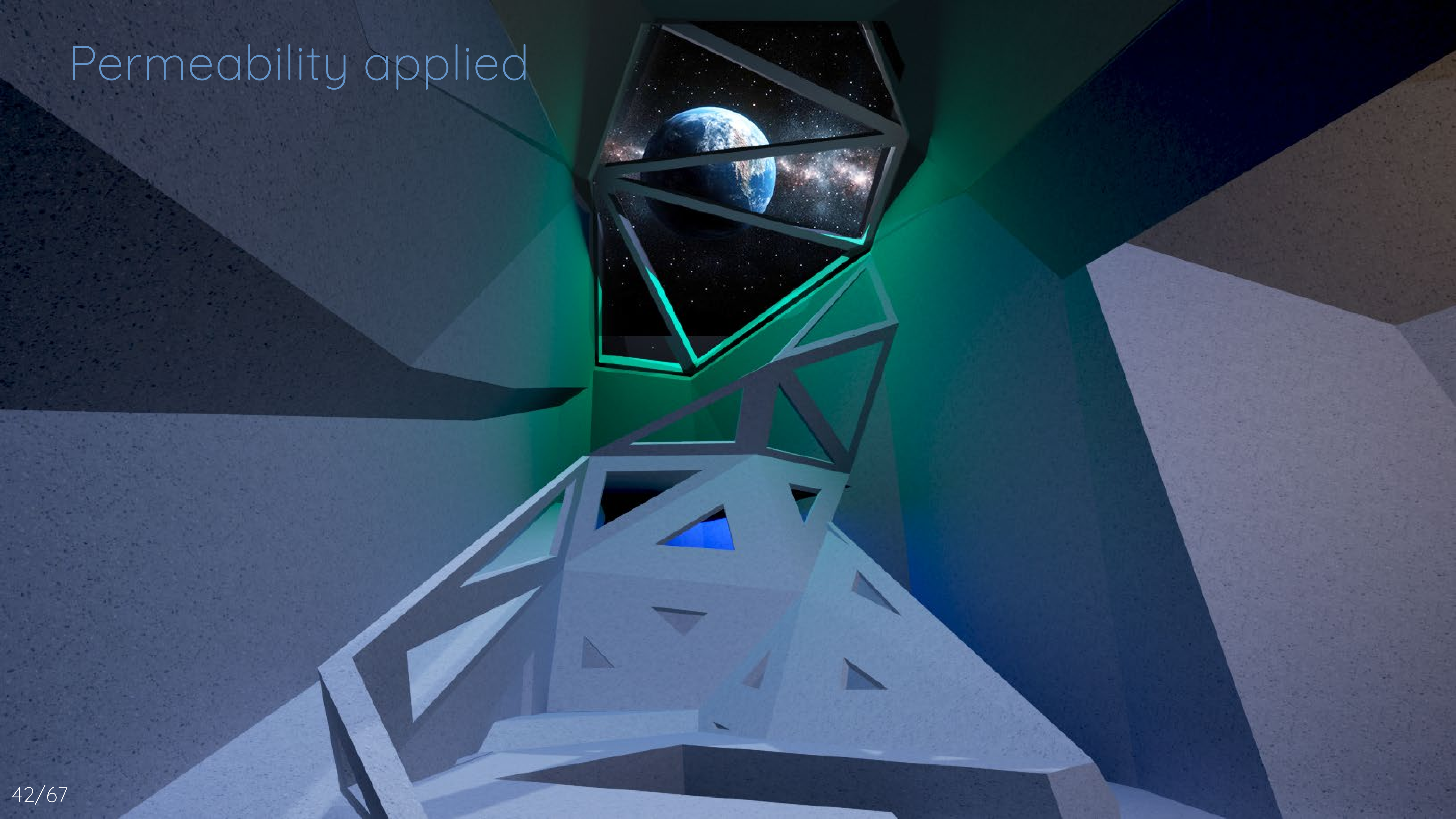


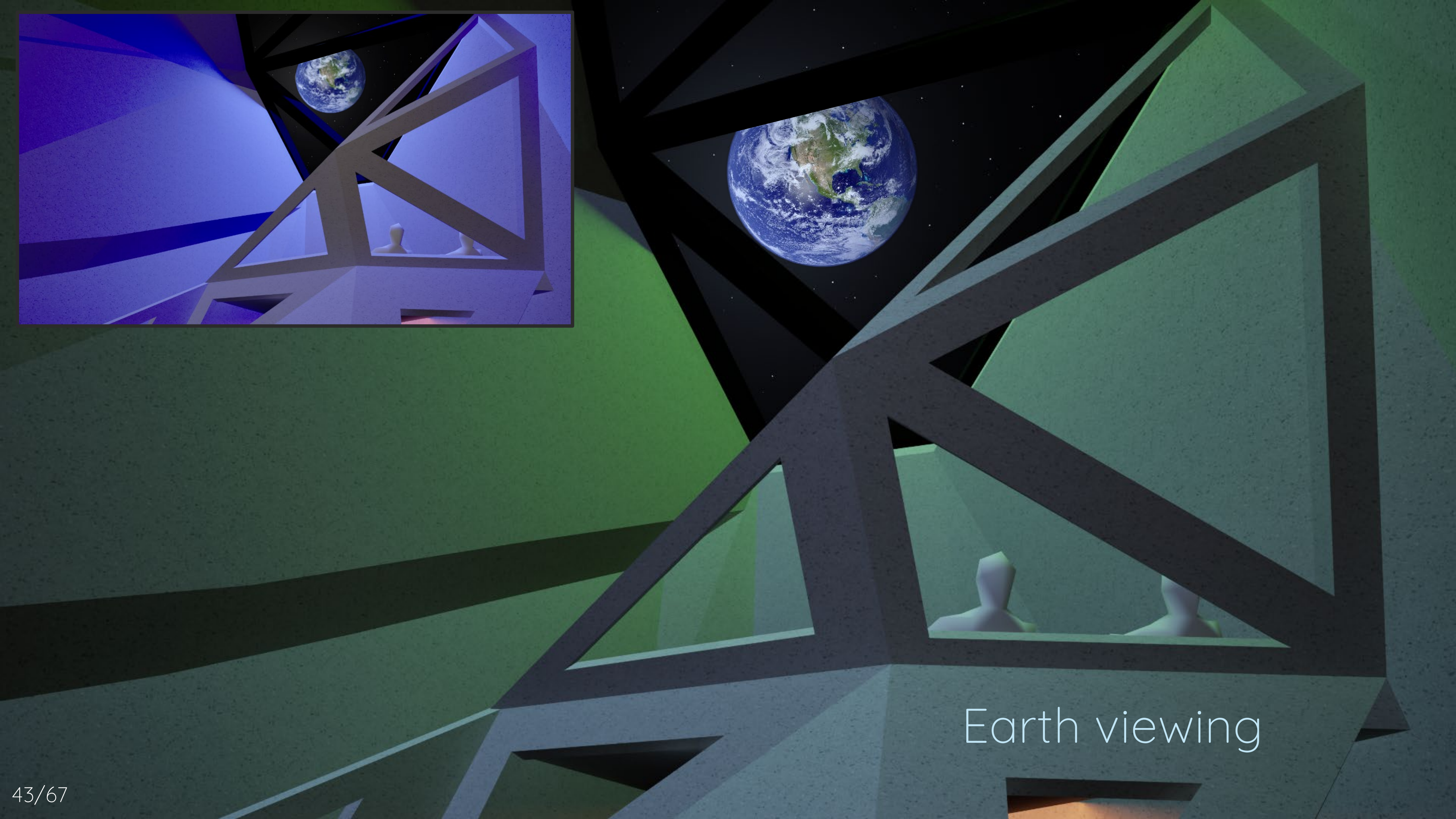
1. triangulation   2. opening size   3. thickness

Permeability script

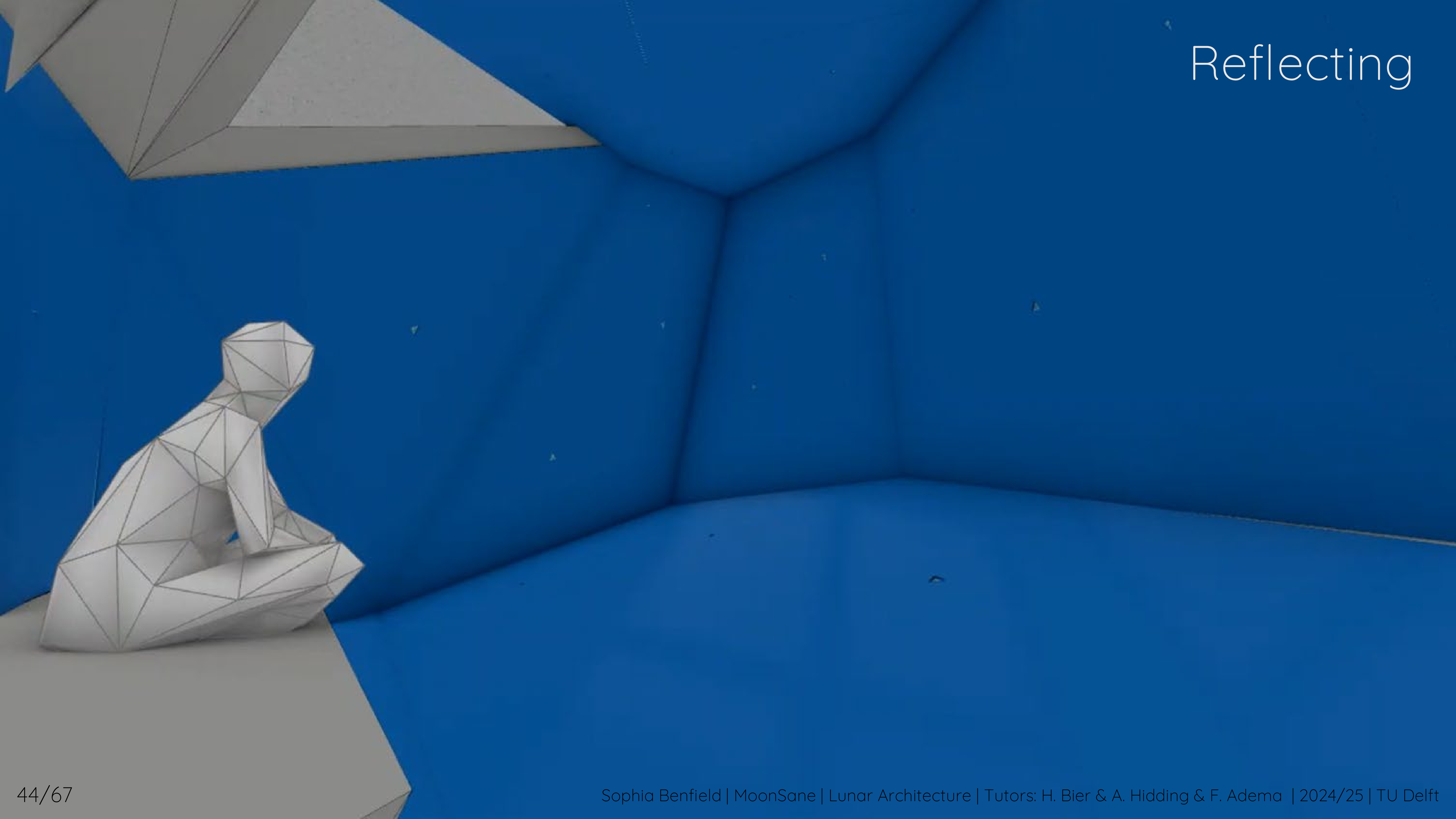


Permeability applied

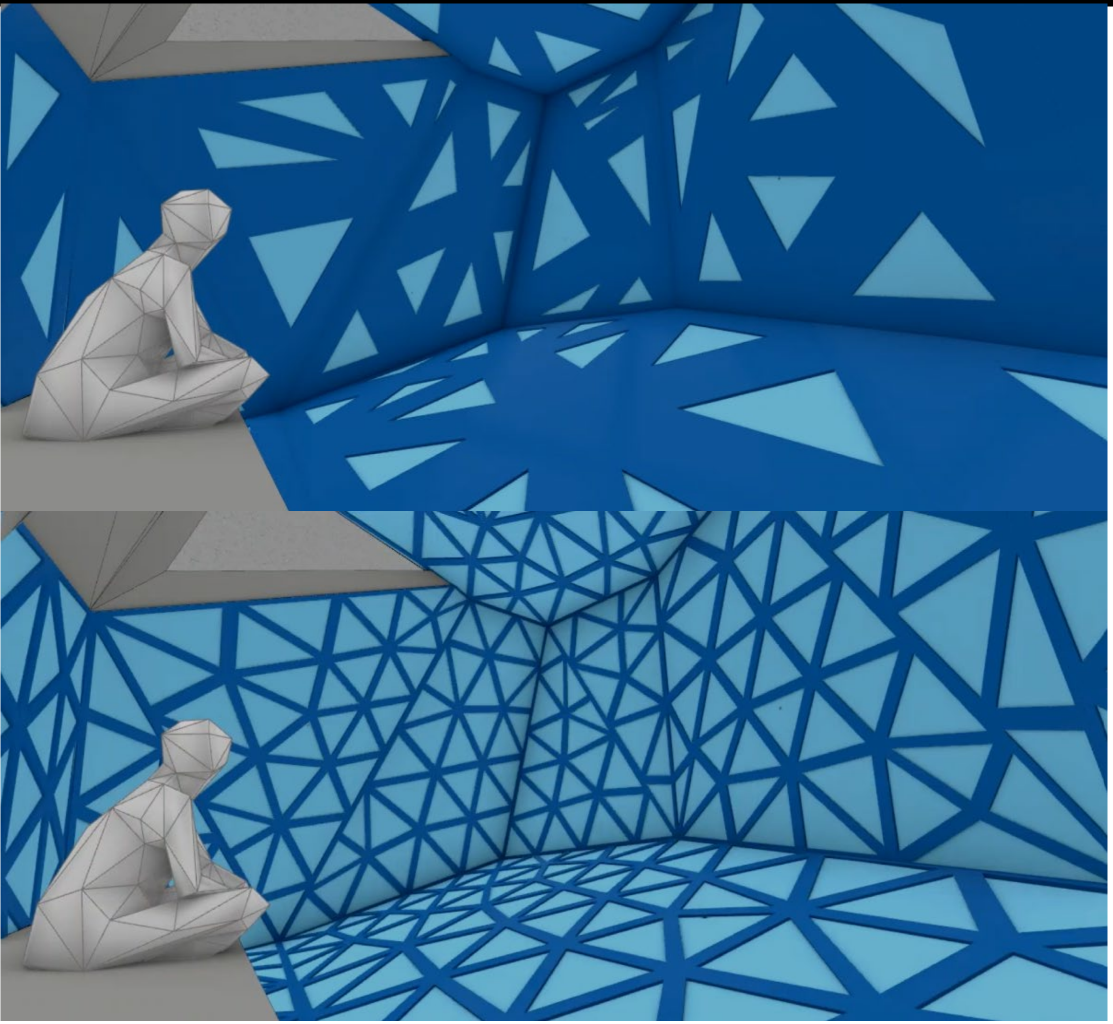



Earth viewing

Reflecting



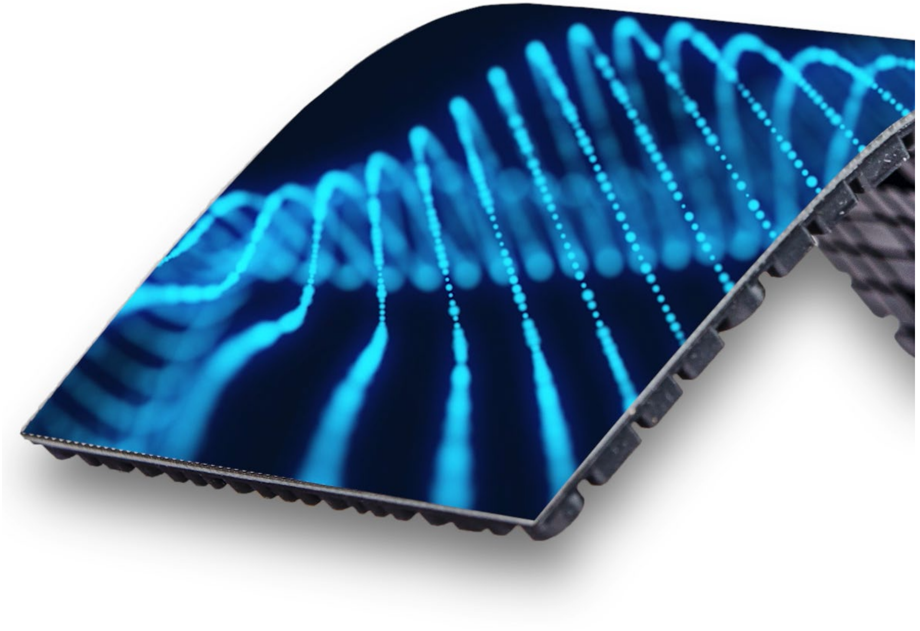
Interior solitude space



Adjustable colour and size

- Monitoring physical state:
  - Heart rate
  - Temperature
- Indicators of stress can inform visuals
  - Calming or uplifting effects

Interior solitude space

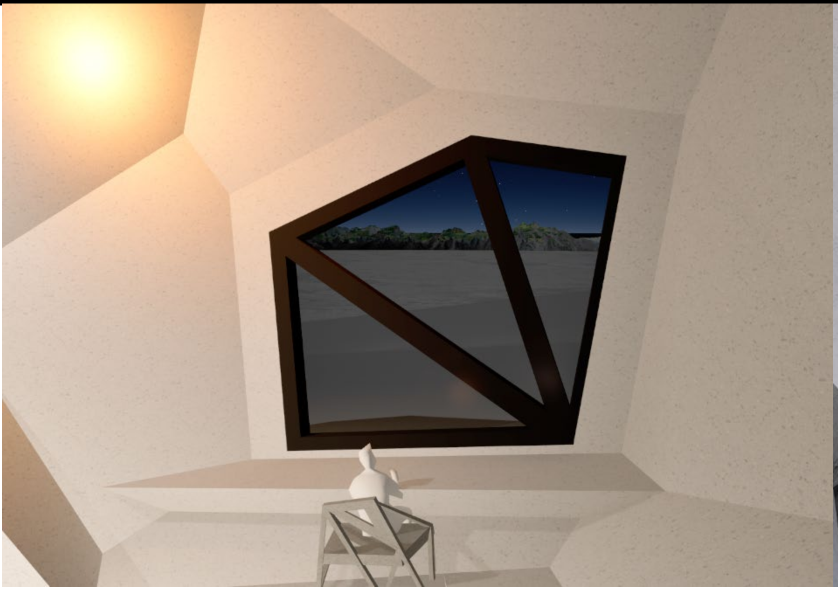


Source: https://pixelflexled.com/product/flexmod/

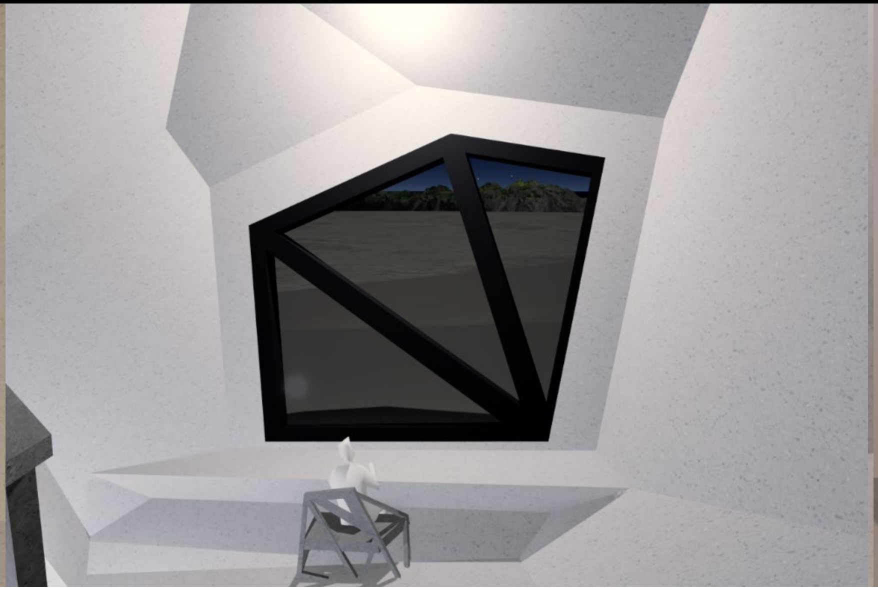
Flexible OLED screens

- Possible in irregular polygons
- Lightweight & energy saving
- Easy front-side maintenance and replacement

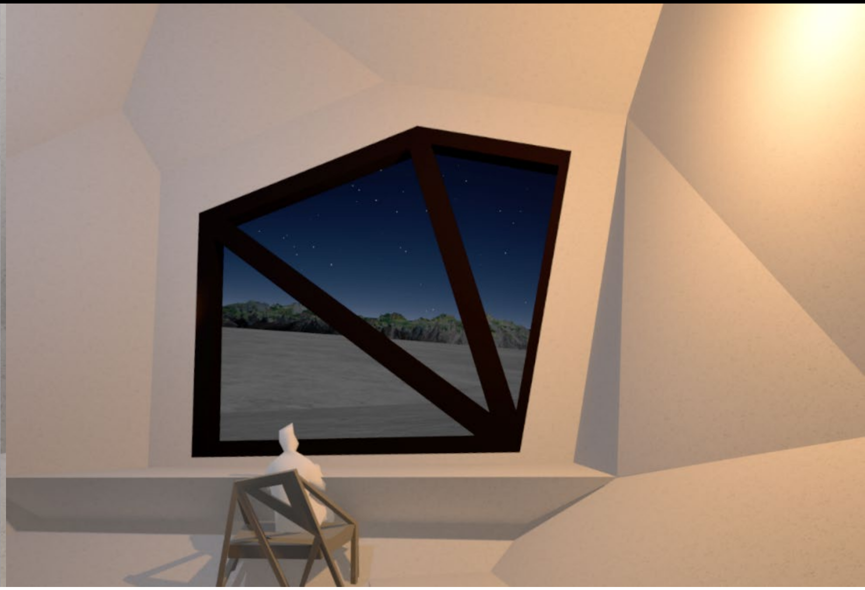
Dynamic daylight simulation



Sunrise

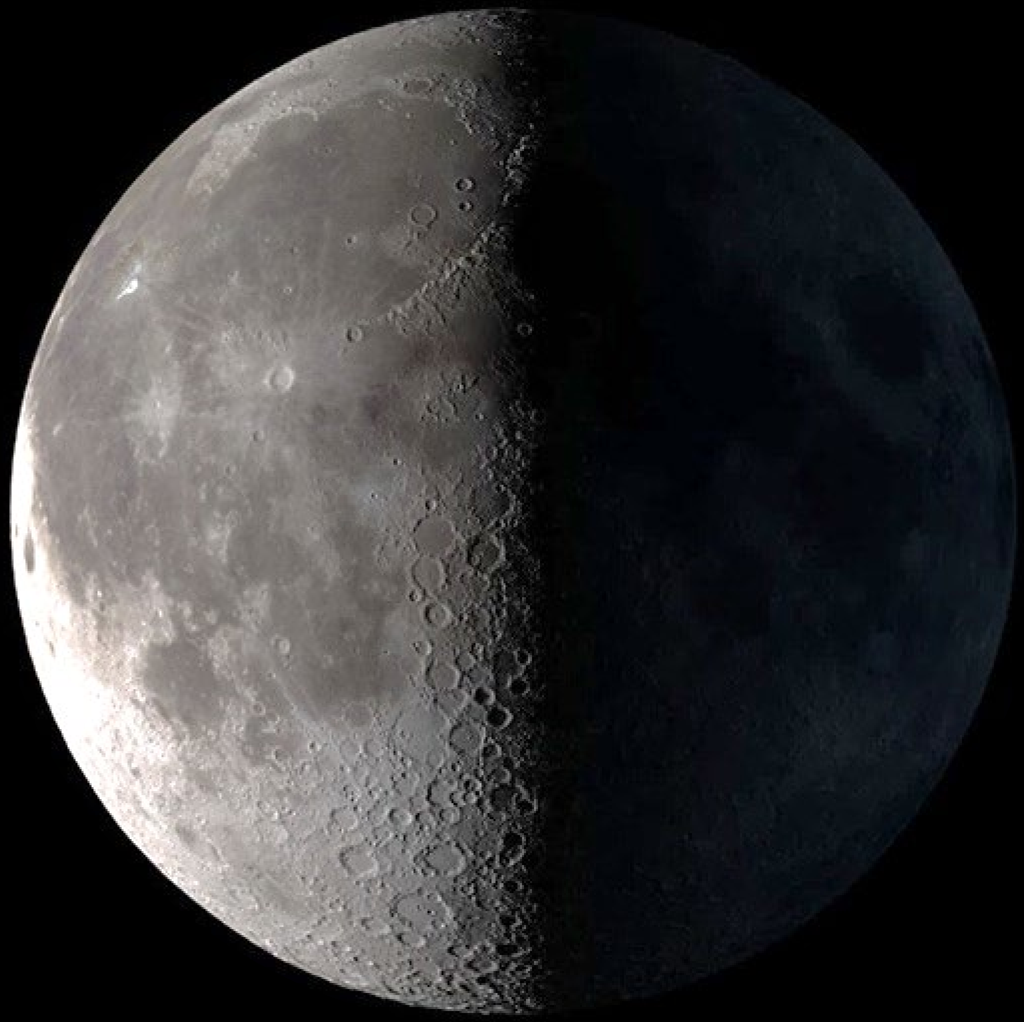


Midday



Sunset

Constructing Lunar Architecture



Workshop: component fabrication

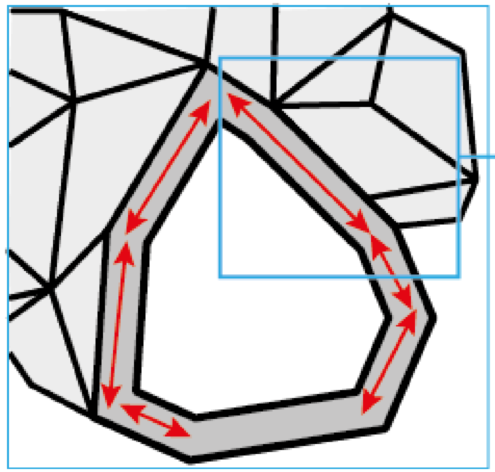
Provides flexibility for Voronoi based geometry

- <u>Component adapted to form</u>

- Tested additive and subtractive method

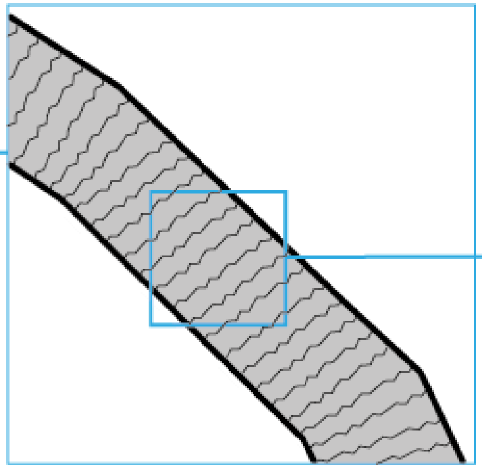
Wall construction

1. Geometry adjusted to compressive forces



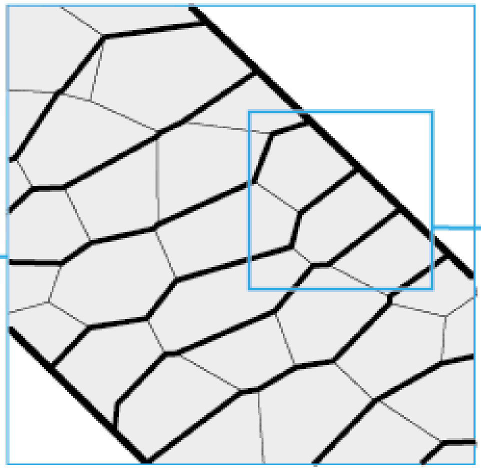
- Roof angles >45
- Mainly compressive forces

2. Dry stacked layers



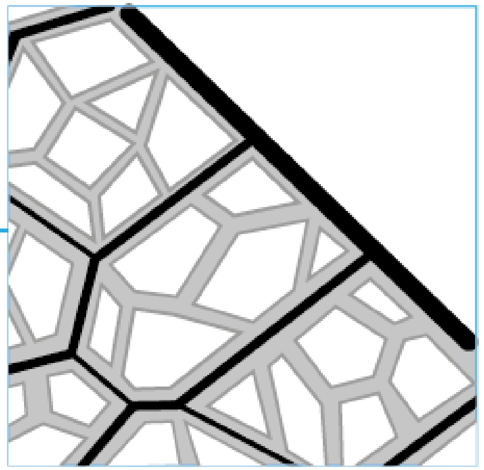
- Robotic assembly layer by layer

3. Voronoi component build-up



- Interlocking of components provides stability

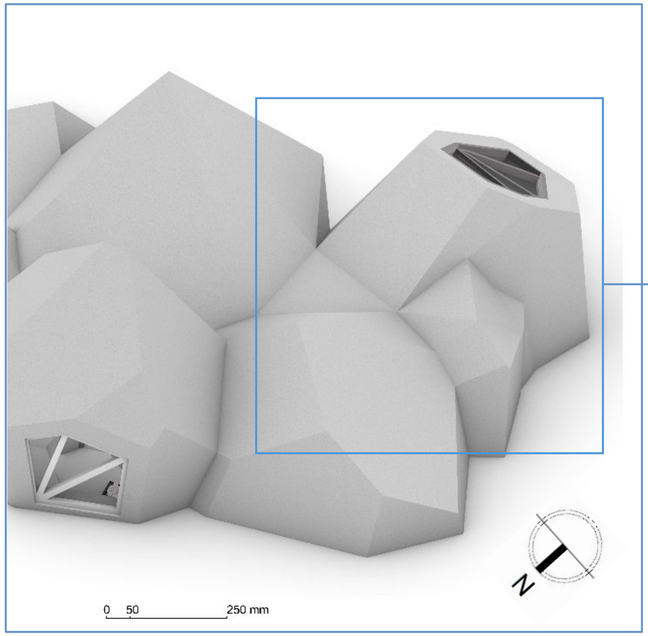
4. Internal structure of components

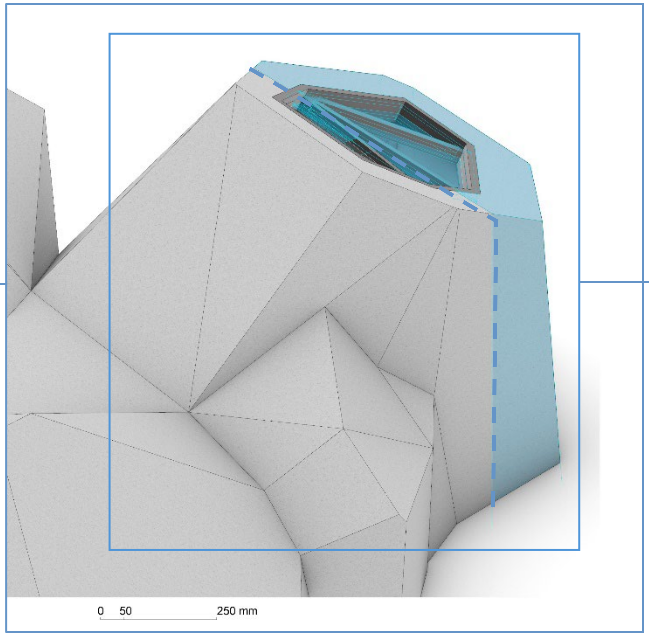


- Only necessary material left for structural integrity
- Less load means less material

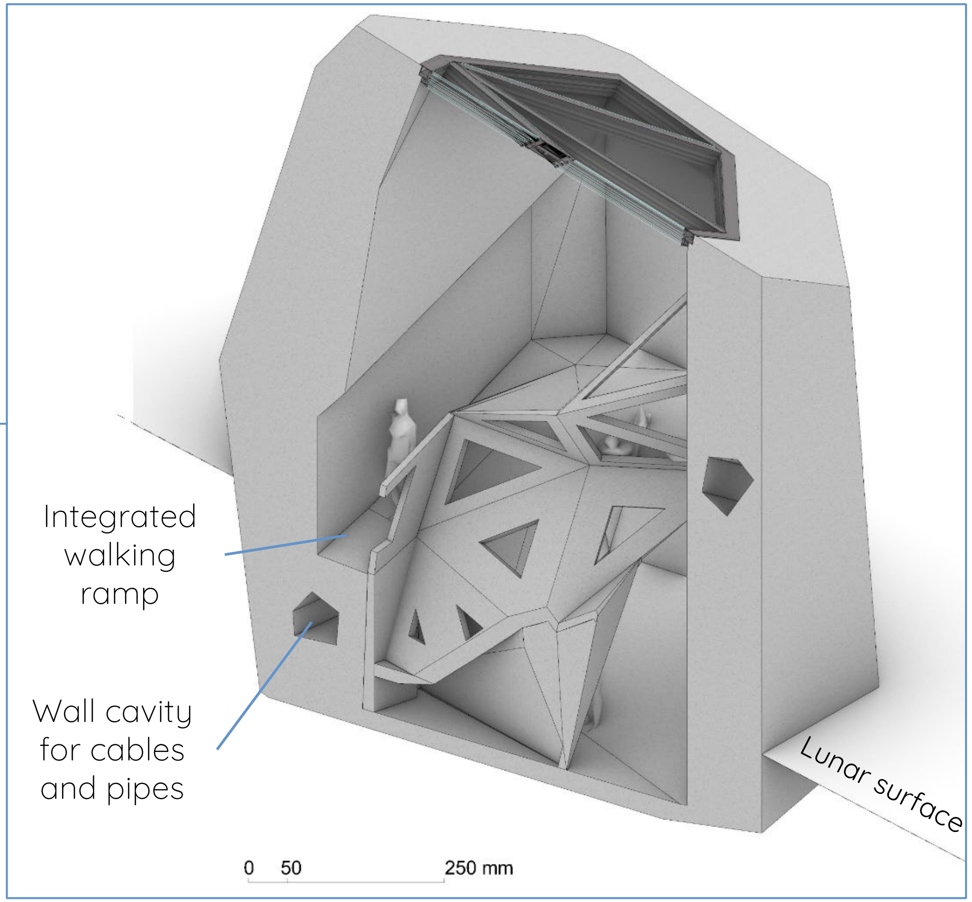
Fragment

North-west perspective

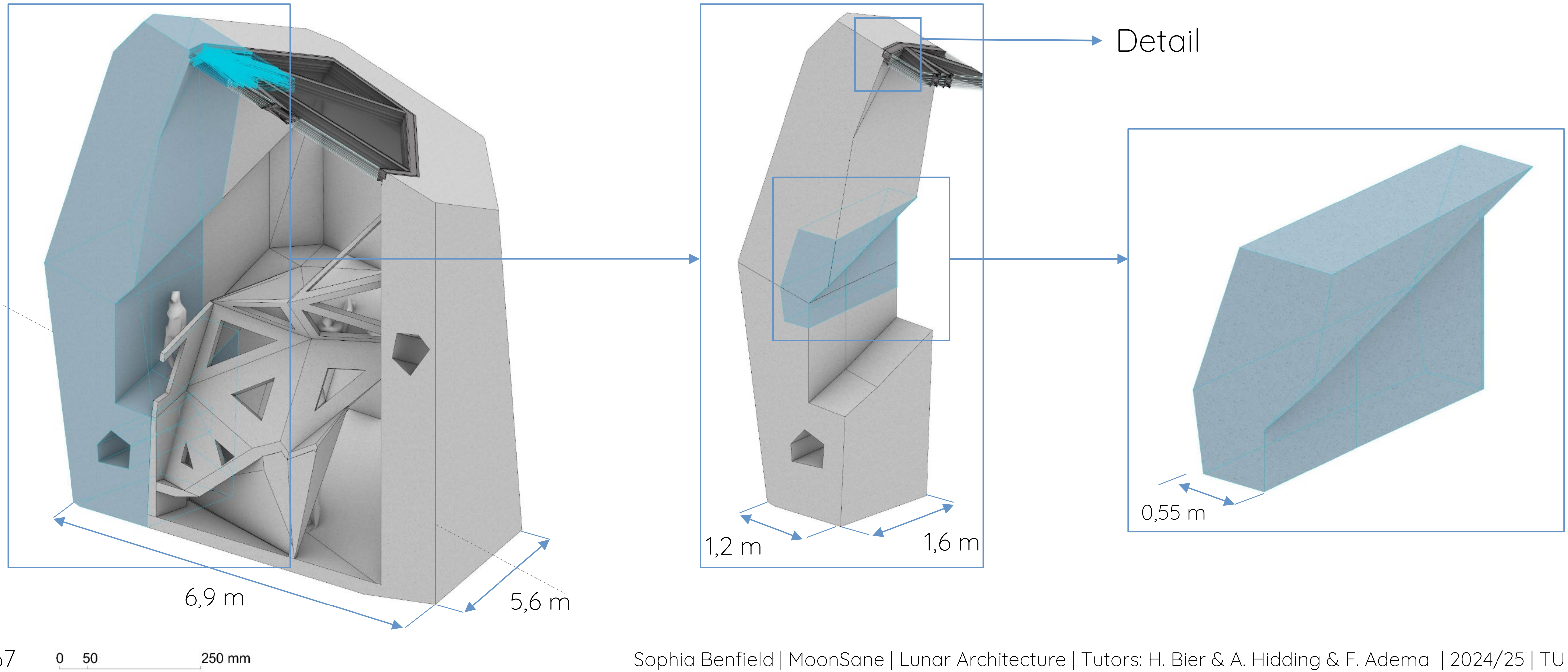




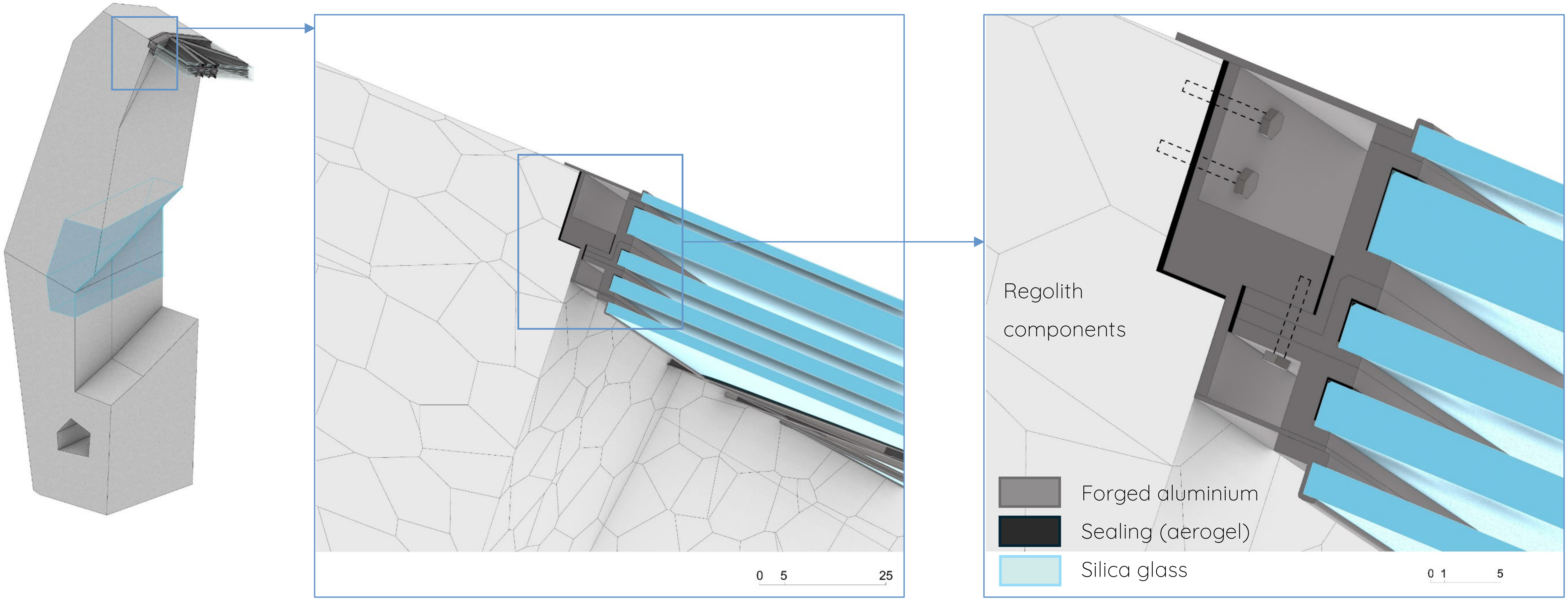
Section



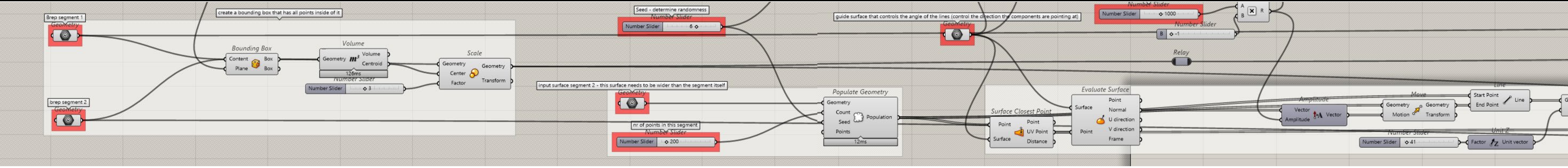
Fragment



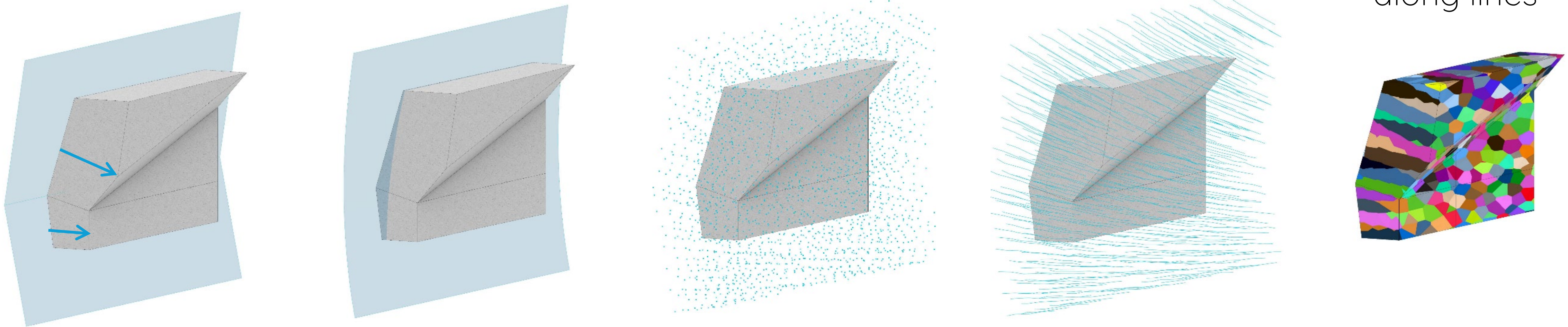
Detail: Window to structure



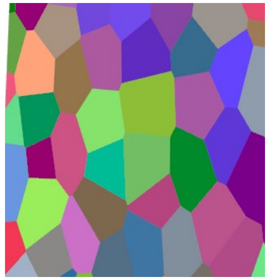
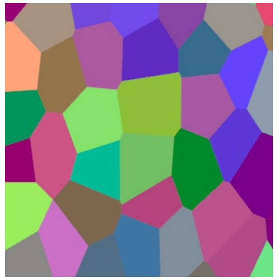
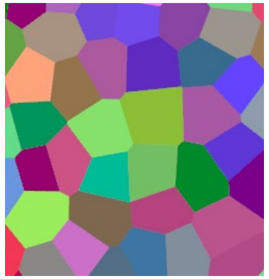
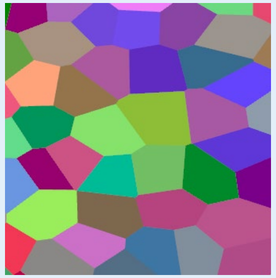
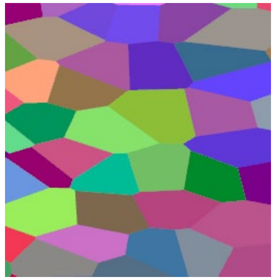
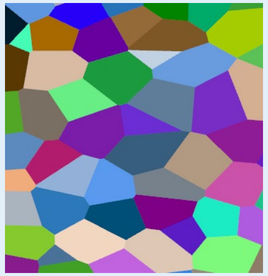
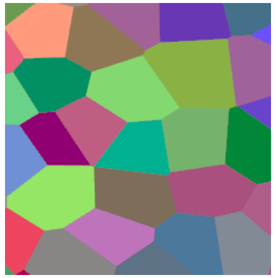
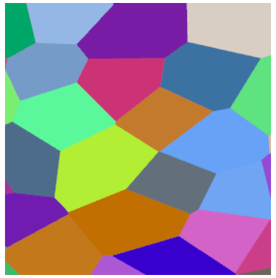
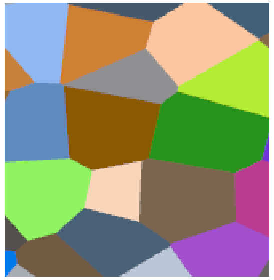
Component script



Component direction	Smoothing surface	Populate with points	Component lines	Voronoi components along lines

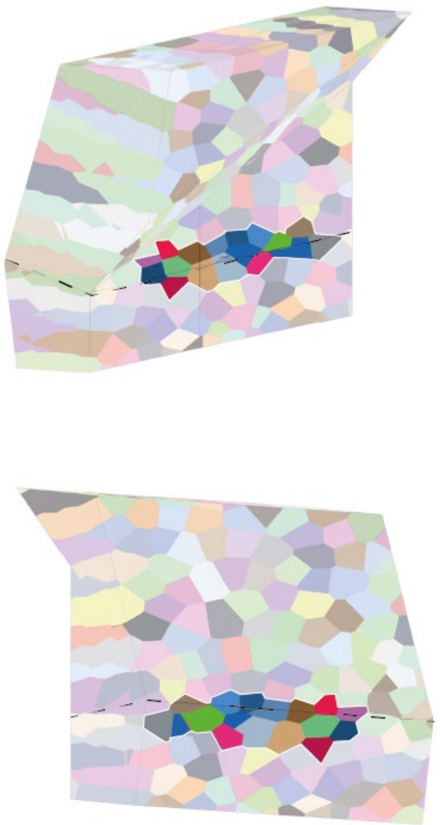


Evaluating components

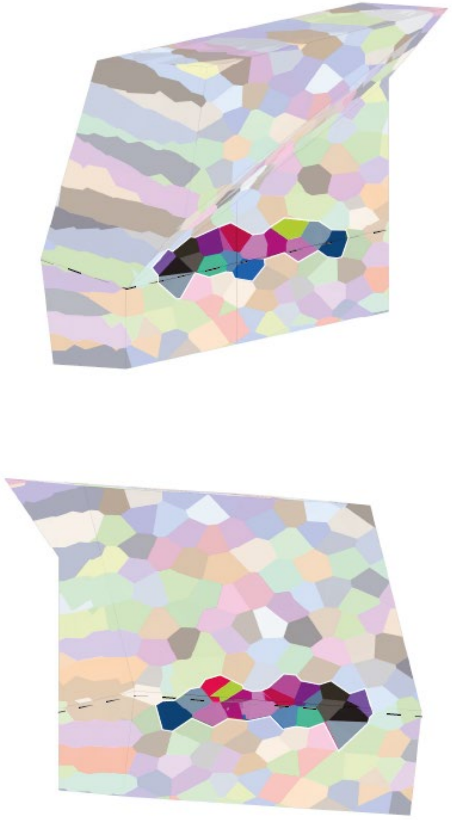
Stretch direction			 ×		
Diameter	 ± 200 mm	 ± 300 mm	 ± 400 mm	 ± 500 mm	 ± 600 mm

Evaluating components

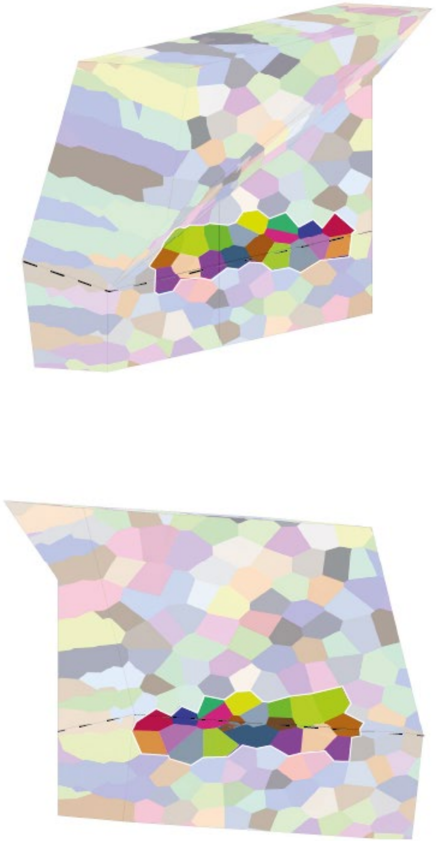
Seed 1



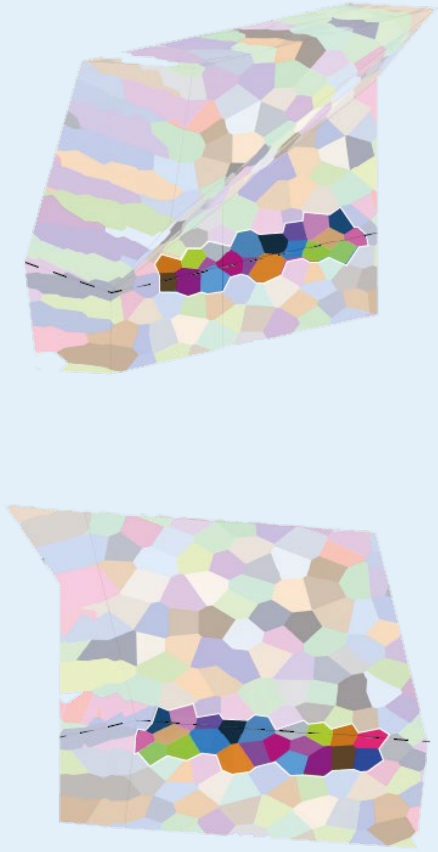
Seed 2



Seed 5

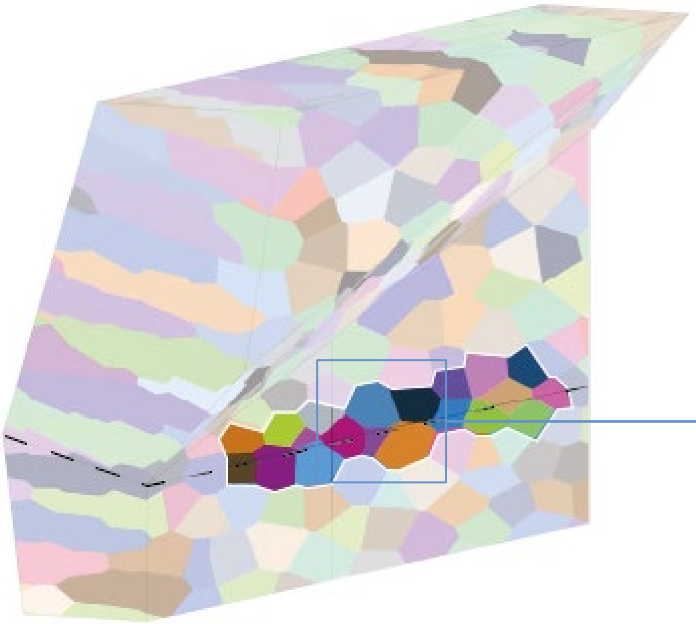


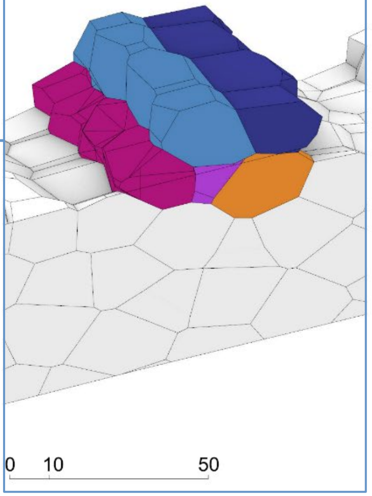
Seed 6

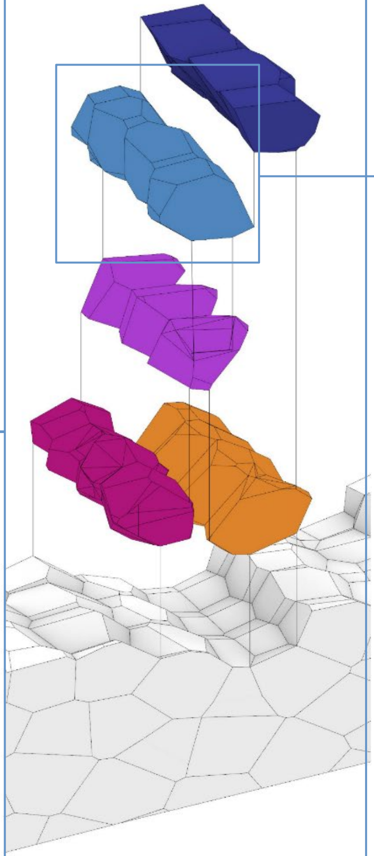


Evaluating components

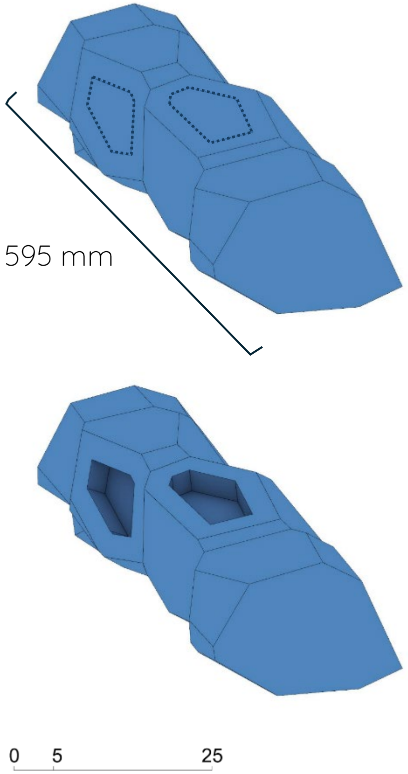
Seed 6



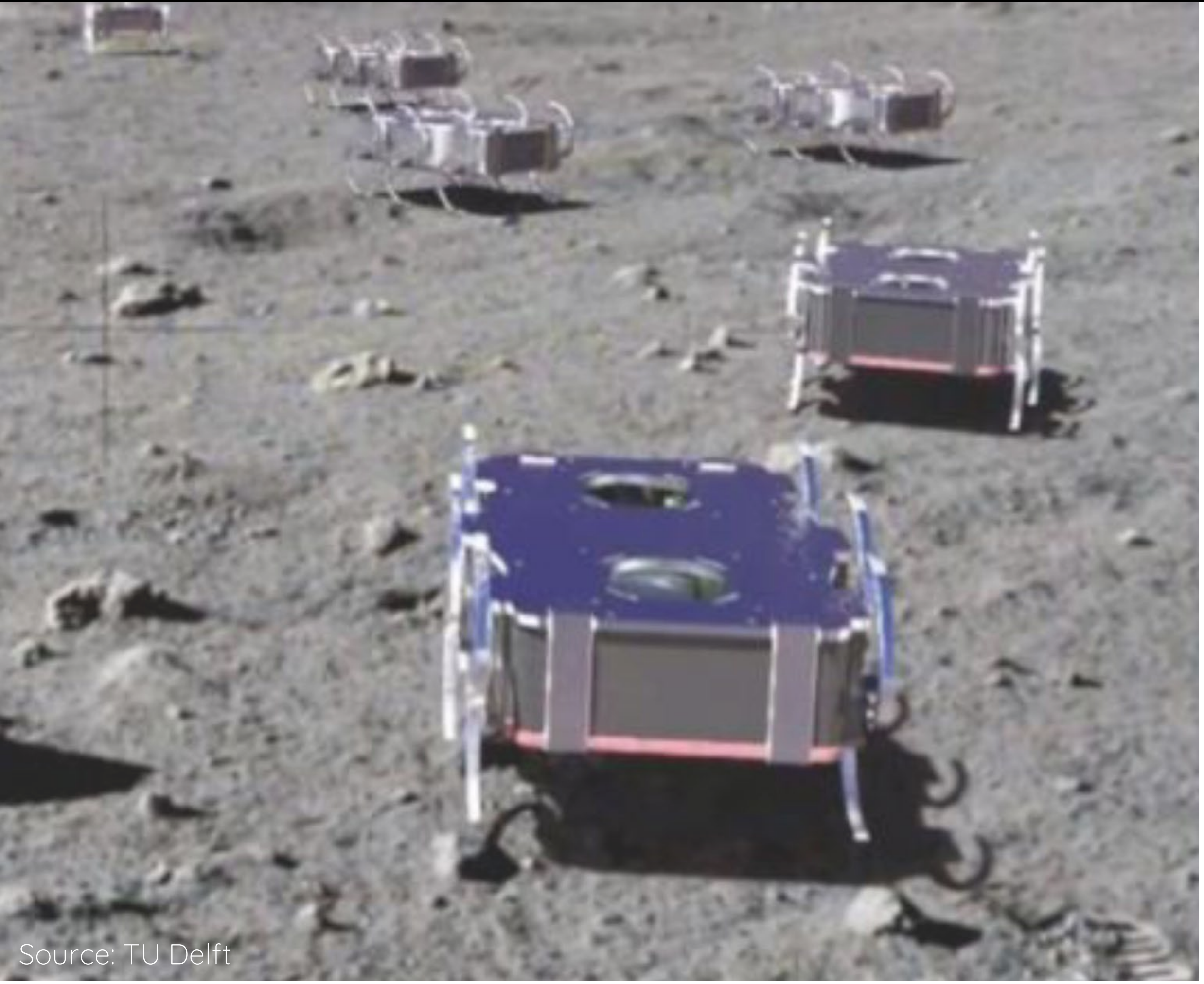




Add gripping holes
for the robot



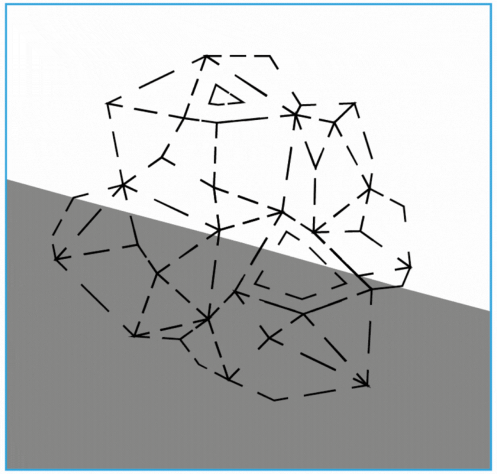
Construction: swarm robotics


Source: TU Delft

- Based on swarms in nature
- Many small robots doing the same task
  - By dividing ground they cover it quickly
- Inter-robot communication
  - Cooperation, organisation

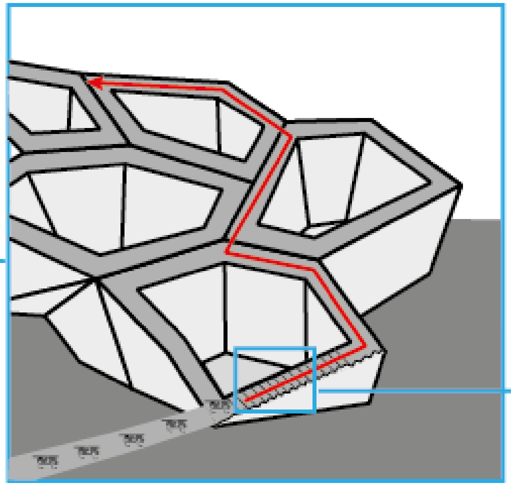
Construction: steps

1.Excavation



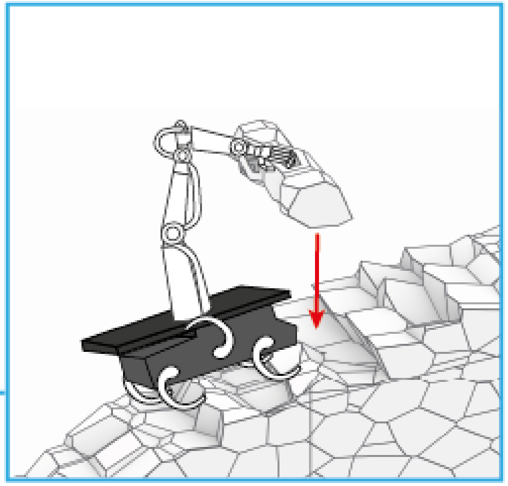
- Step by step excavation of the location
- Swarm robots

2. Layer for layer - create ramp for robots



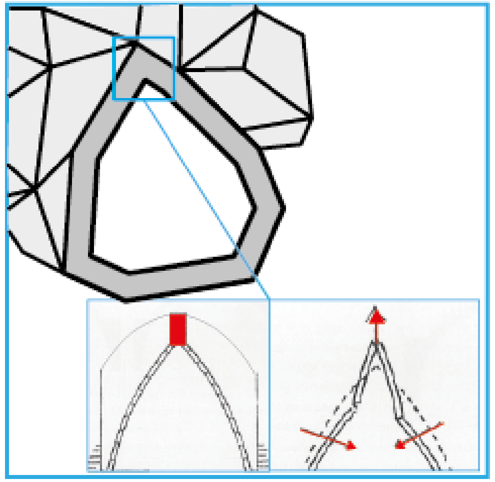
- Walls built up in a continuous ramp
- Provides access for the swarm

3. Stacking components



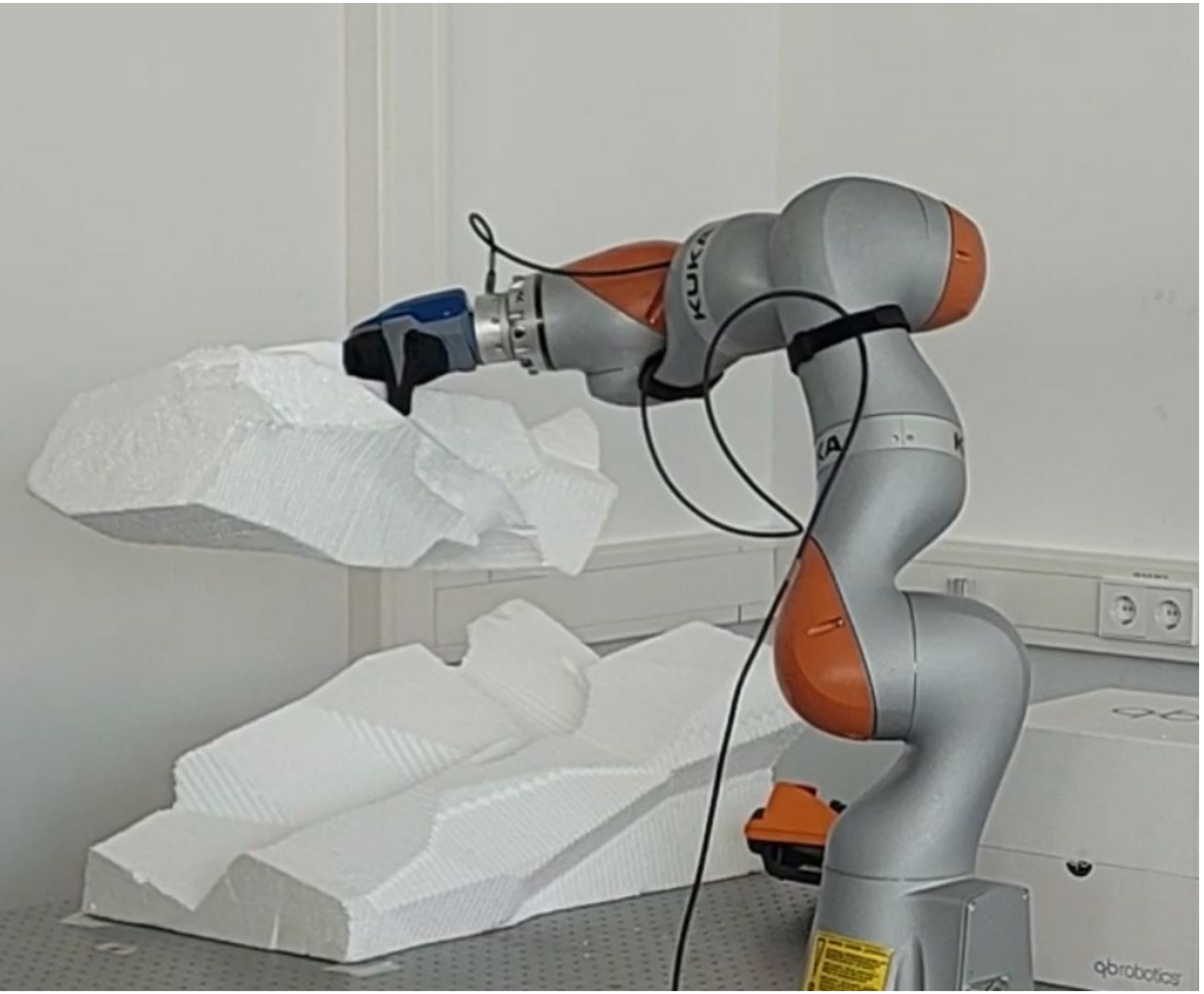
- Components printed
- Components transported and placed in place by swarm

4. Closing the vault: 'keystone'



- Based on Gothic vault constructions
- A keystone stabilises

Construction: human-robot interaction



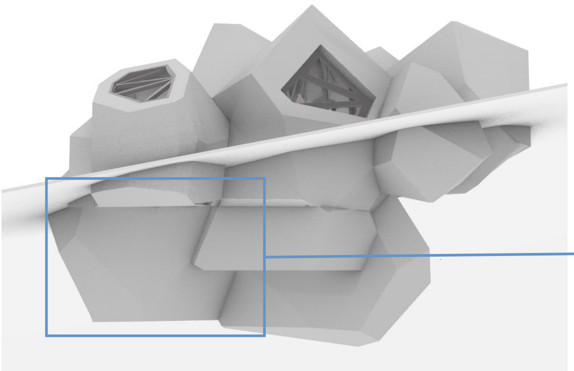
Combine strengths:

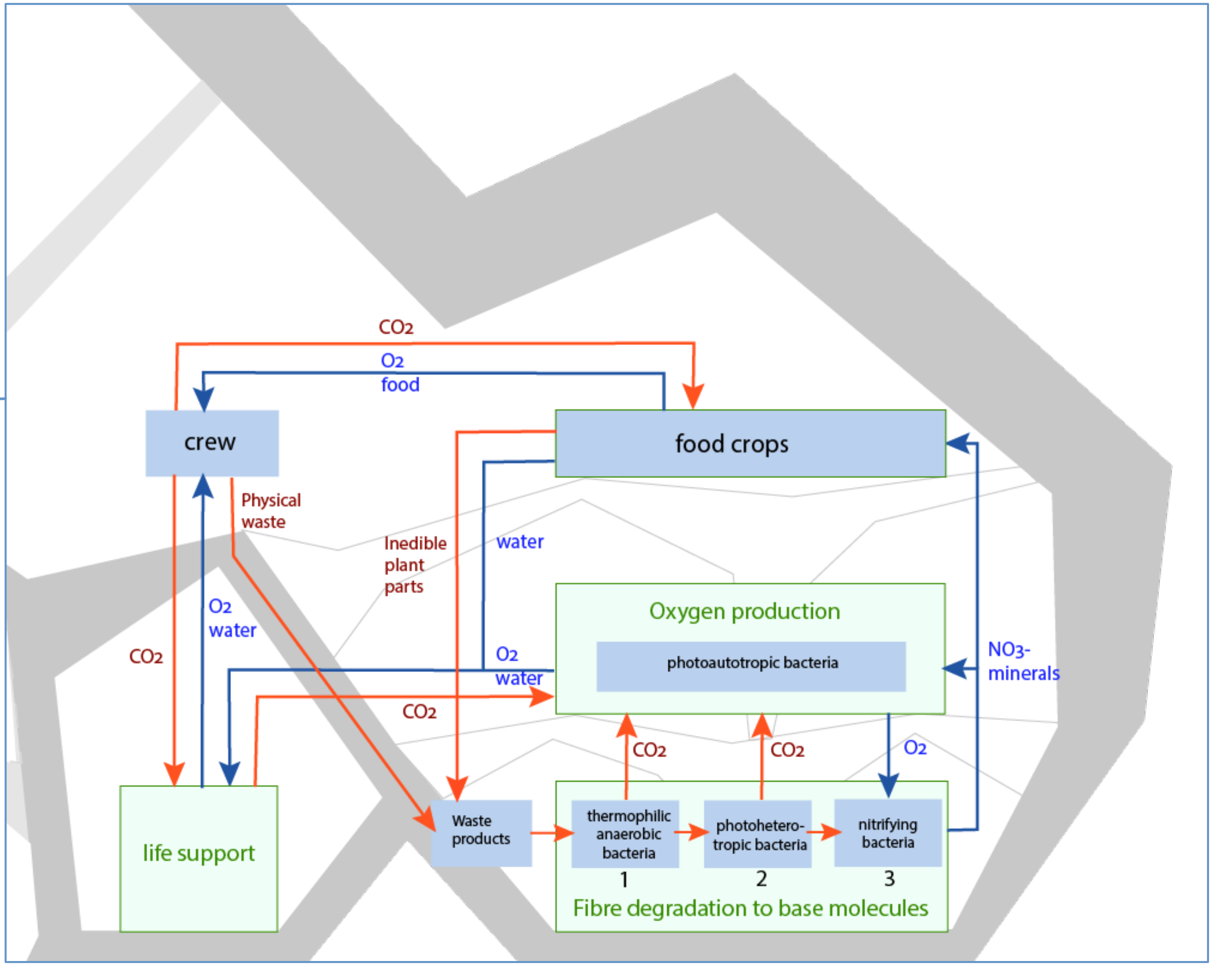
- Robot: heavy lifting
- Human: delicate motor skills

Robot learns

- End goal is to become **autonomous**

Life support: waste





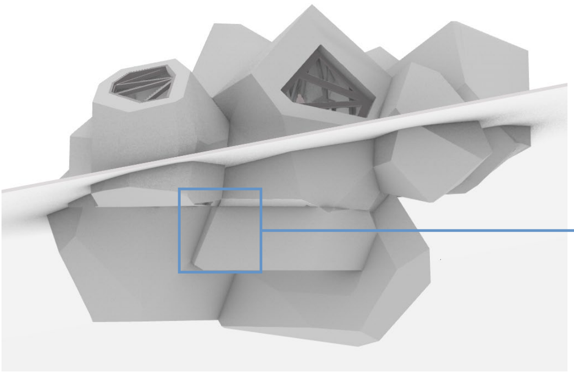
	Closed compartment
	Component
→	Waste product
→	Usable product

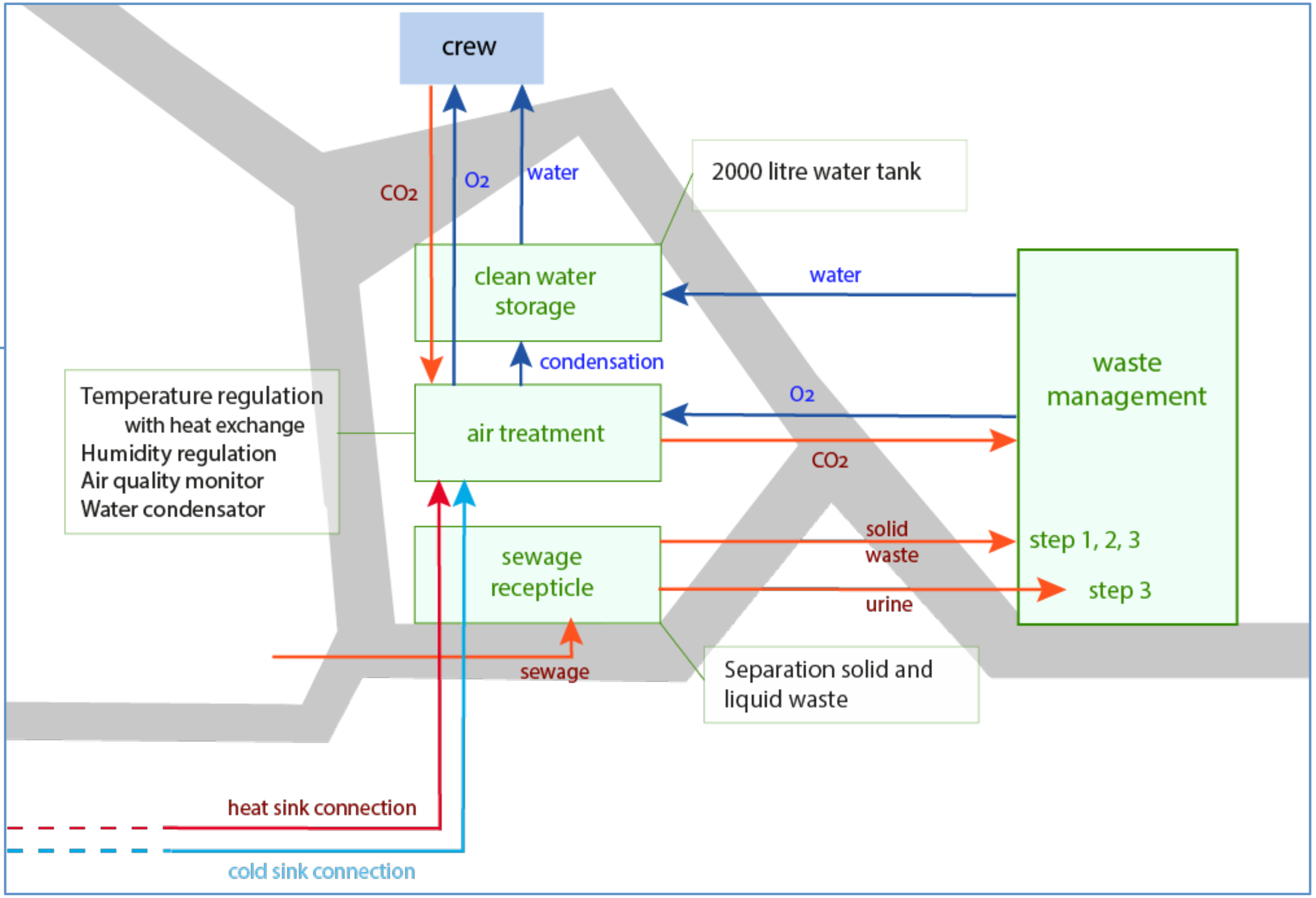
MELiSSA research program

- Closing the waste loop using bacteria and algae

https://www.melissafoundation.org/page/melissa-project

Life support: mechanical systems





Closed compartment

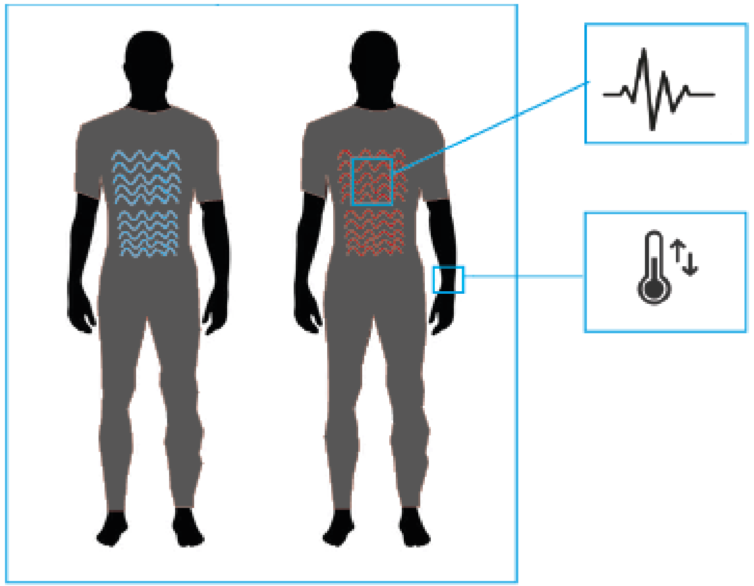
Component

Waste product

Usable product

Personal climate

- **Heating**
- **Cooling**
- **Health monitoring** and adapting schedule accordingly
  - Stress – take a break or meditate etc.
- Adapting **lighting**
  - Personal settings at workstation, private and meditation room

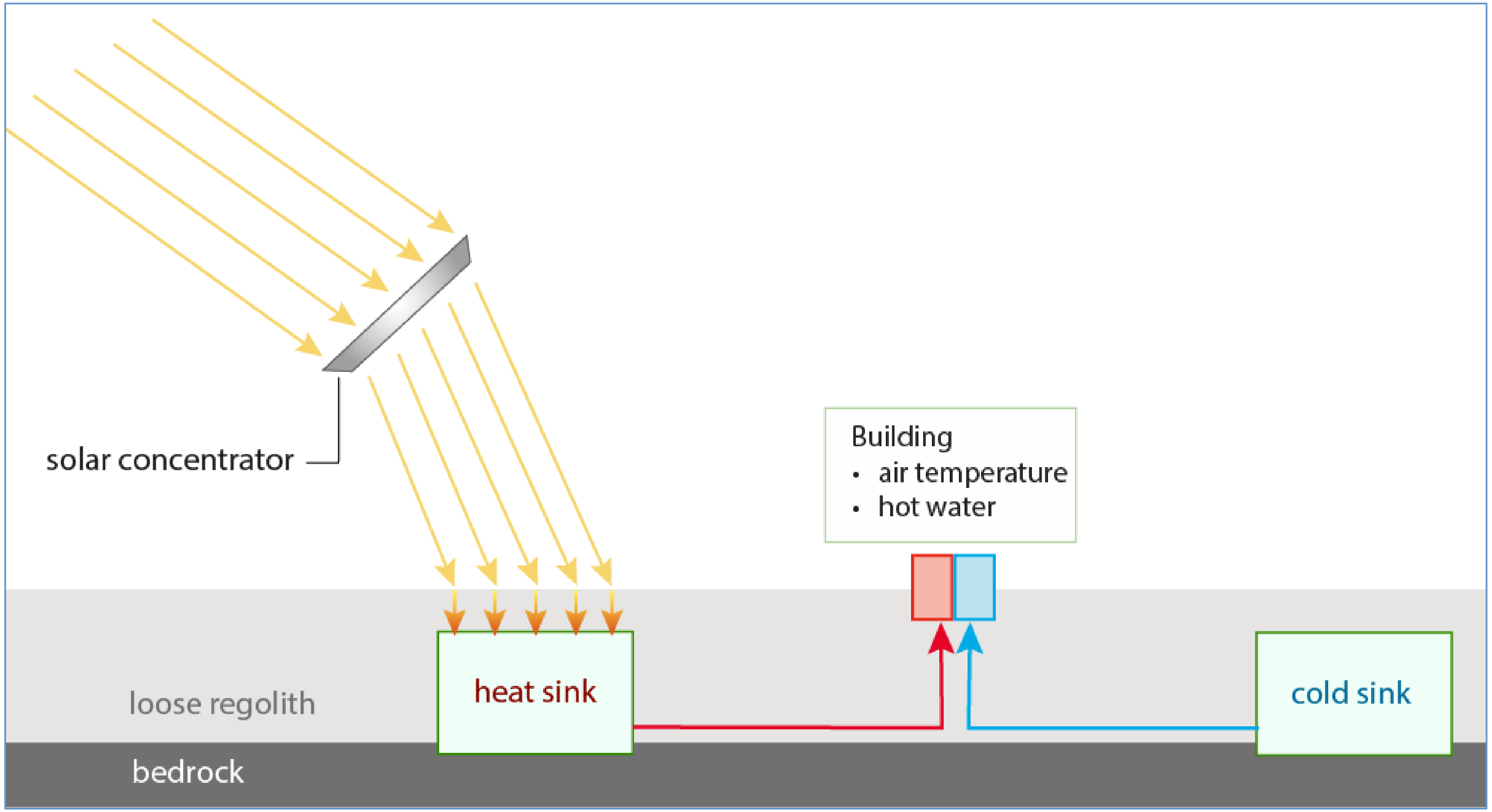


Smart textiles

Why personalisation?

- **Feeling of control in an otherwise uncontrollable setting**

Life support: heating/cooling



Heat and cold production

- Based on ESA research

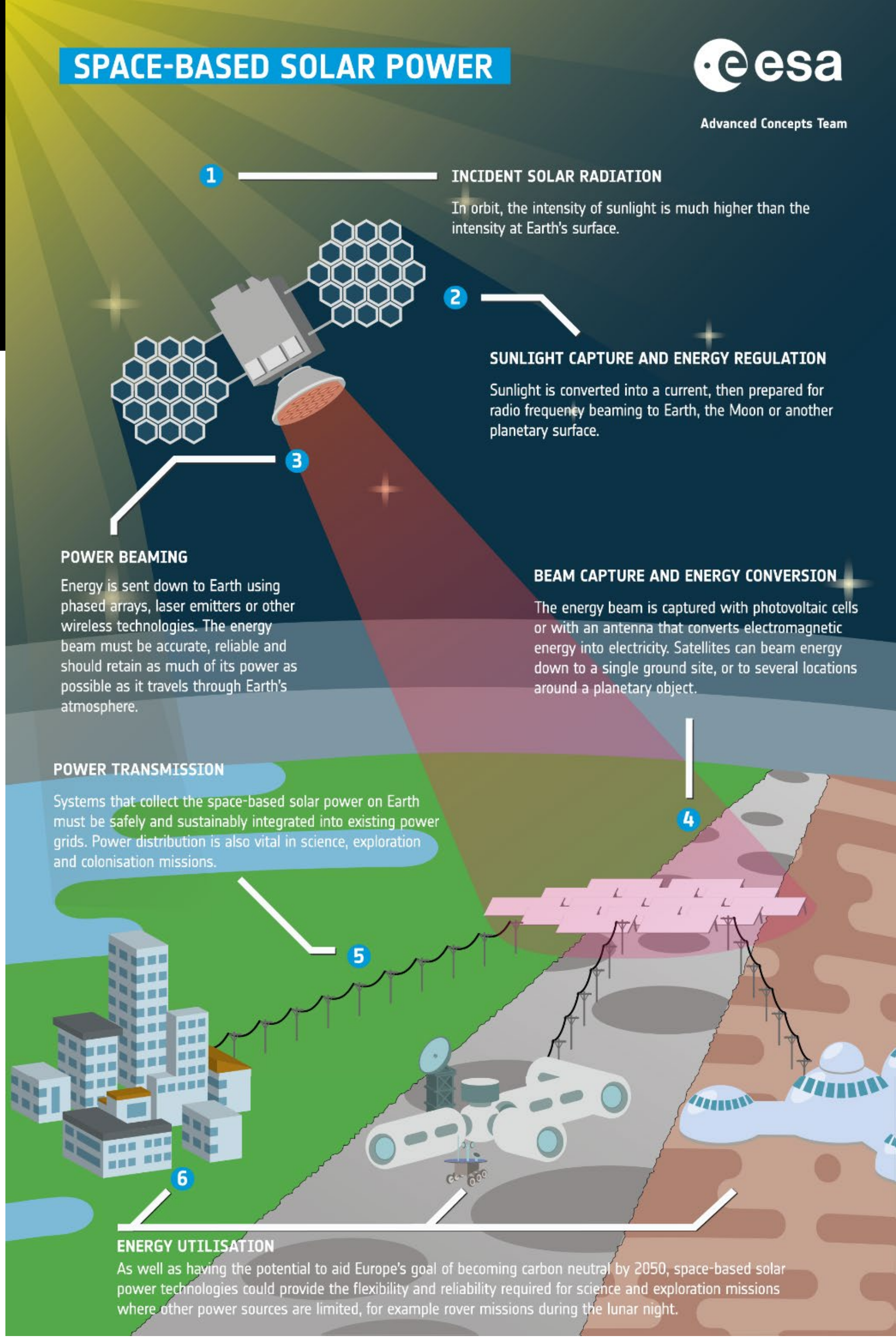
https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/How_to_keep_warm_on_the_Moon

Energy supply

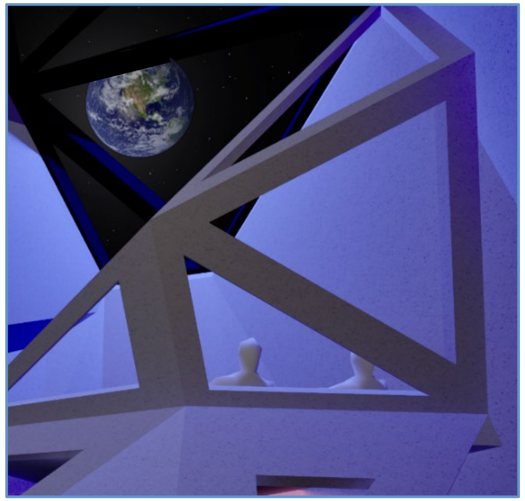
Space-based Solar Power

- Satellites with solar panels
- Collect energy in space and beamed down to converters on the surface
- Distributed to habitats and equipment

https://www.esa.int/Enabling_Support/Space_Engineering_Technology/SOLARIS/Space-Based_Solar_Power_overview

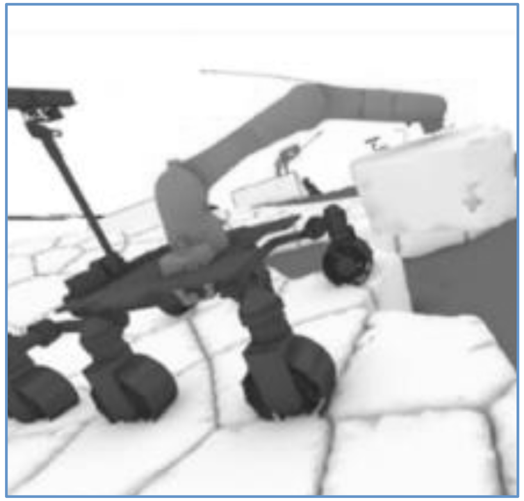


Summary & relevance



Mental health improvement by spatial design

In-situ resource utilisation



3D-printing & robotic assembly


Q & A