MoonSane

Designing Lunar Habitats for Improving Mental Wellness

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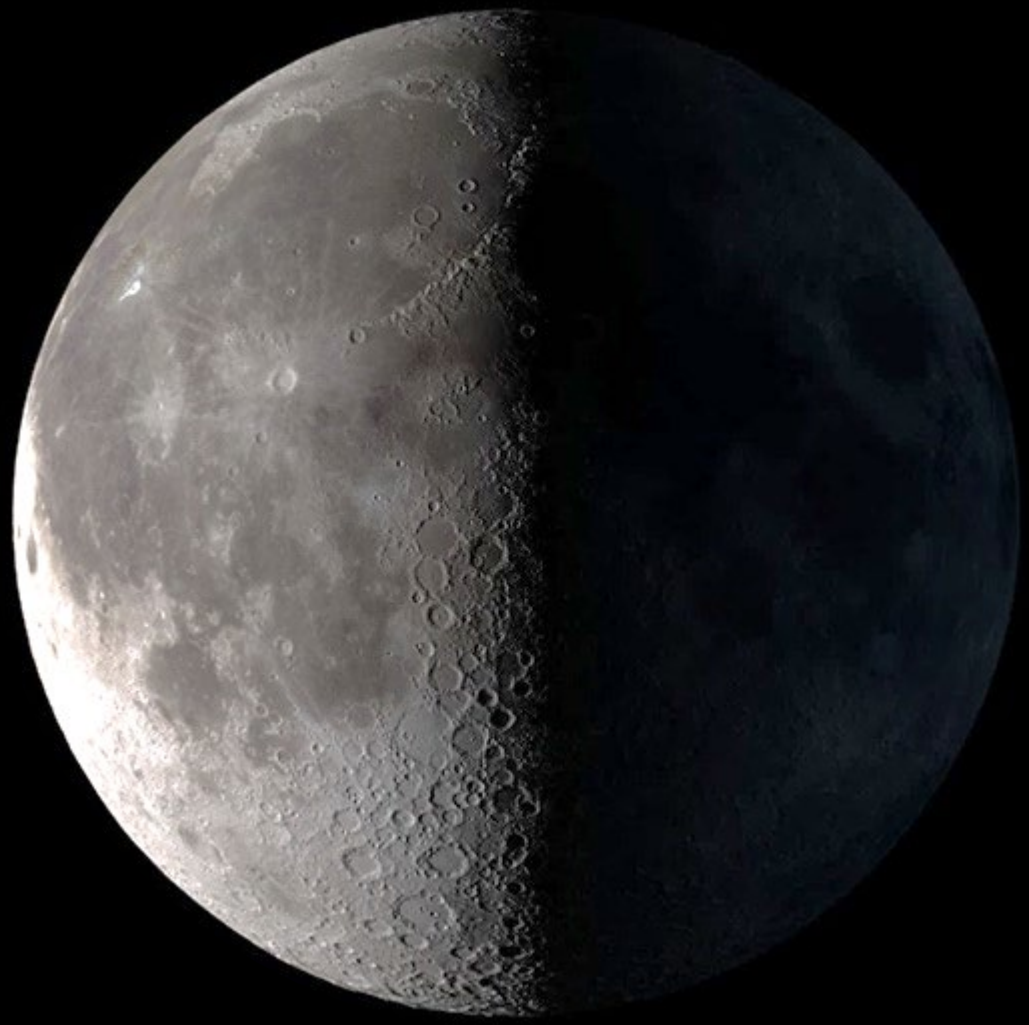
Approaching Lunar Architecture

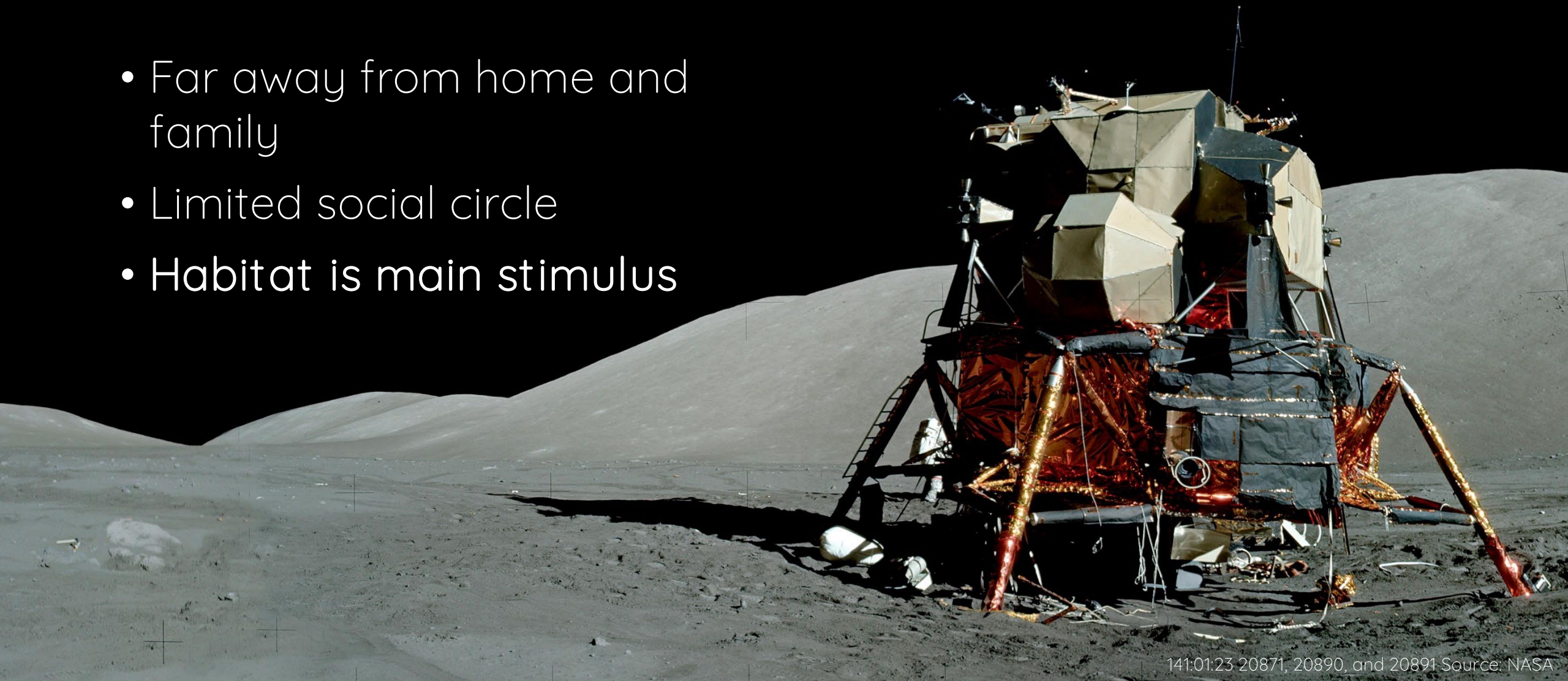
Blank Canvas



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

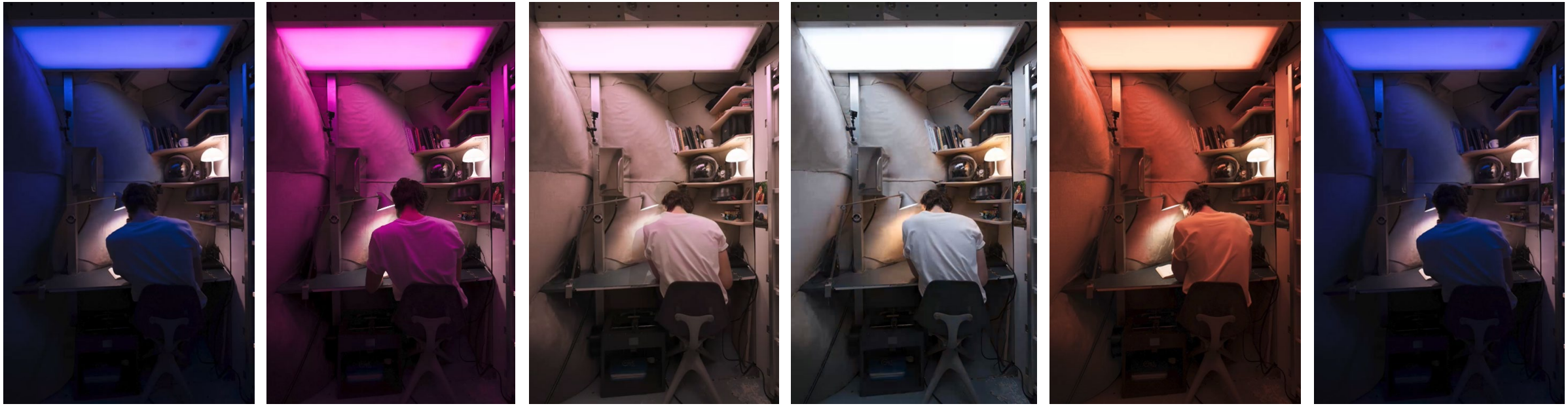
Crew interaction:
- Private quarters

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.

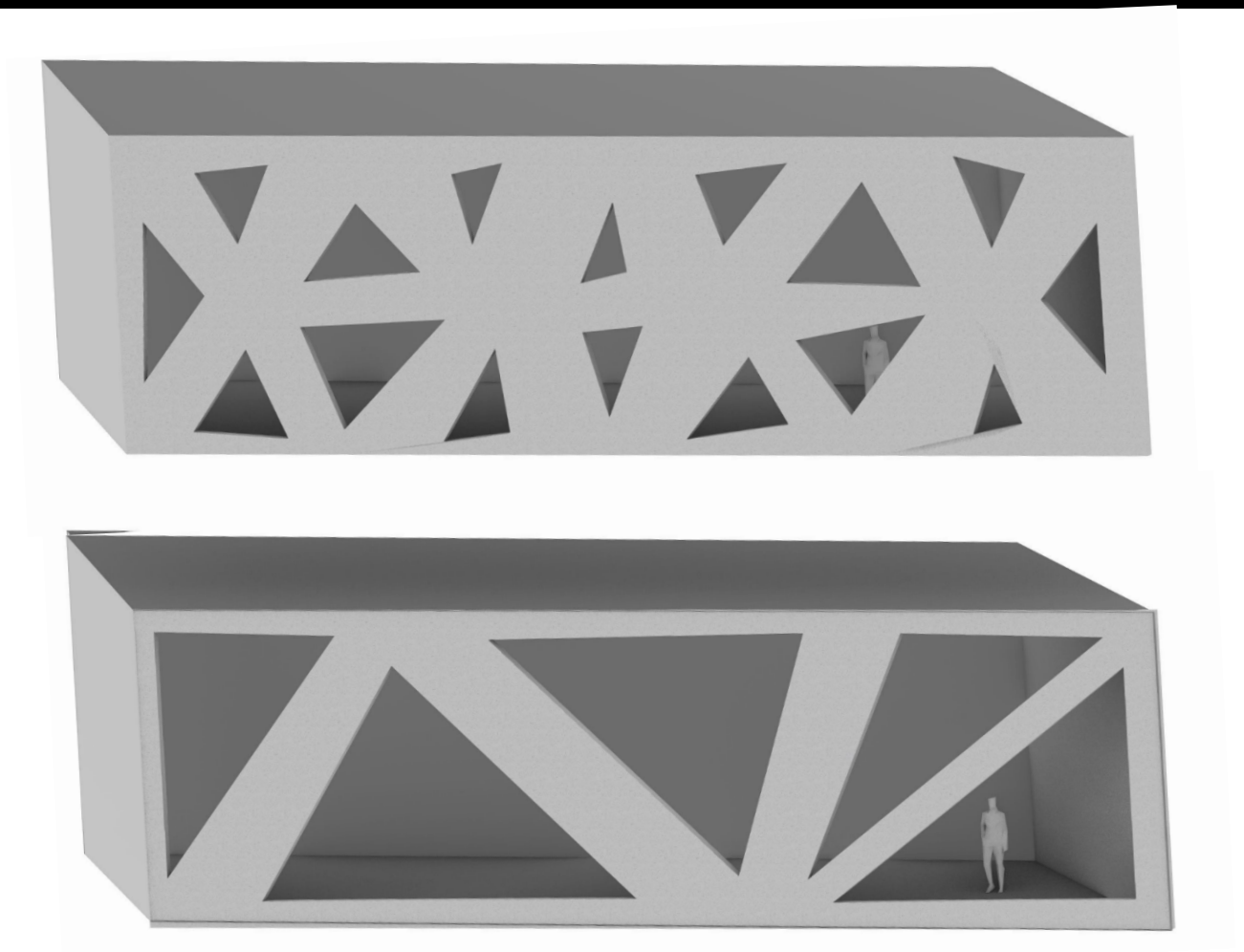
Light

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



Spatial enclosure

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

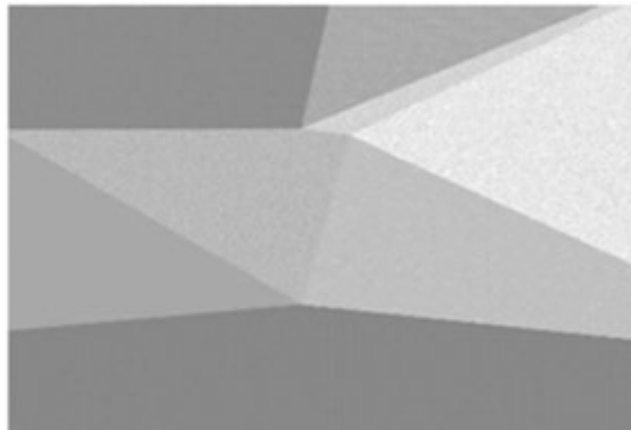


Vartanian, O., Navarrete, G., Chatterjee, A., Fich, L. B., Gonzalez-Mora, J. L., Leder, H., ... & Skov, M. (2015). Architectural design and the brain: Effects of ceiling height and perceived enclosure on beauty judgments and approach-avoidance decisions. *Journal of environmental psychology, 41*, 10-18.

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



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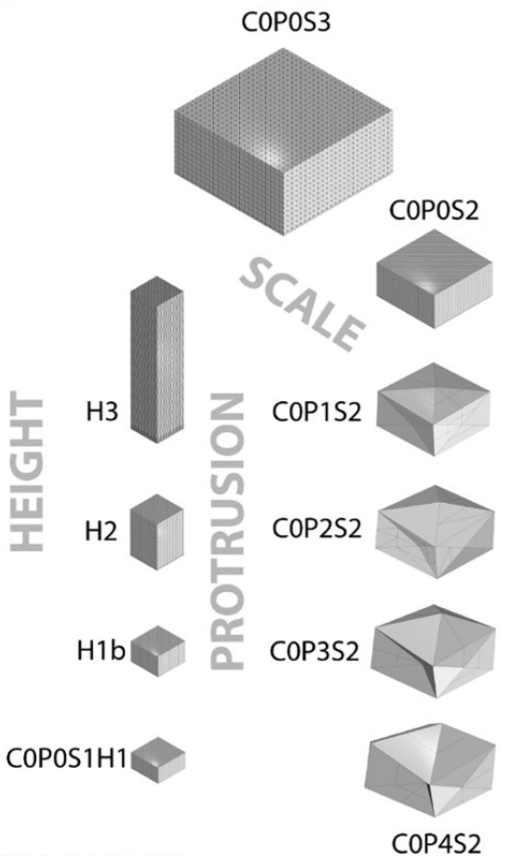
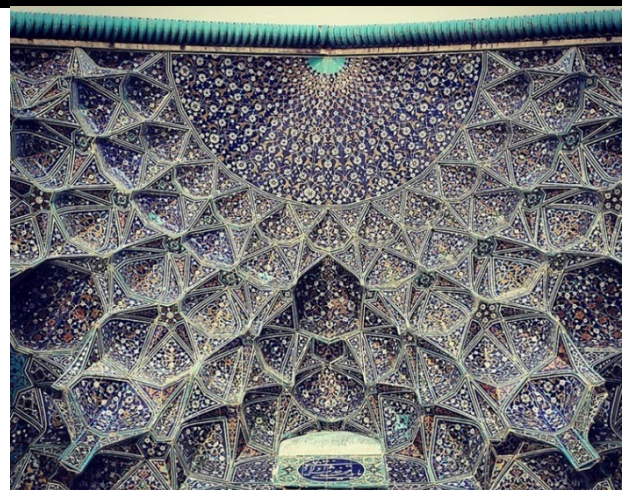
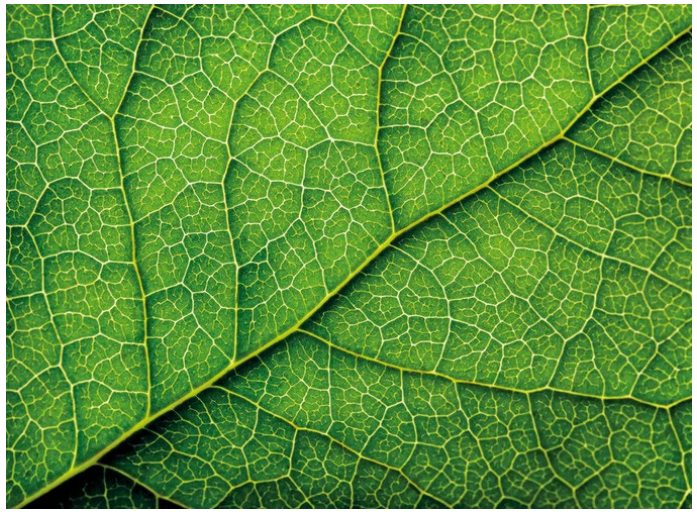


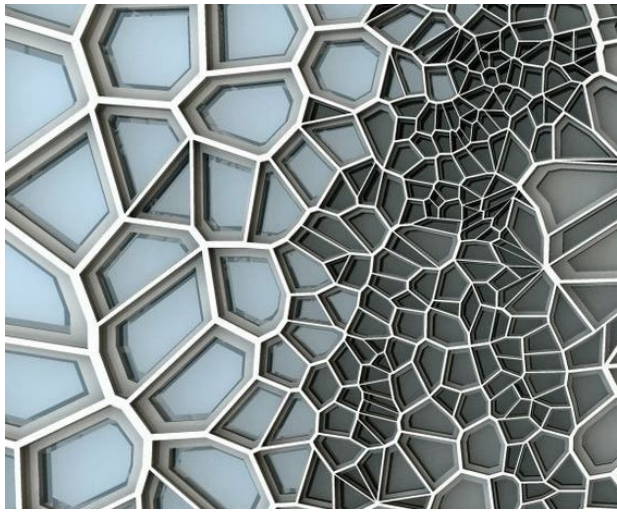
Shemesh, A., Leisman, G., Bar, M., & Grobman, Y. J. (2021). A neurocognitive study of the emotional impact of geometrical criteria of architectural space. *Architectural Science Review*, *64*(4), 394–407. https://doi-org.tudelft.idm.oclc.org/10.1080/00038628.2021.1940827

Natural geometry: fractal patterns

- Repeating shapes
  - Calming effect
  - Hidden in nature: biophilia
  - Dynamic: light shimmer
- Voronoi
  - Point based pattern found in nature
  - Scalable
  - Facetted geometry



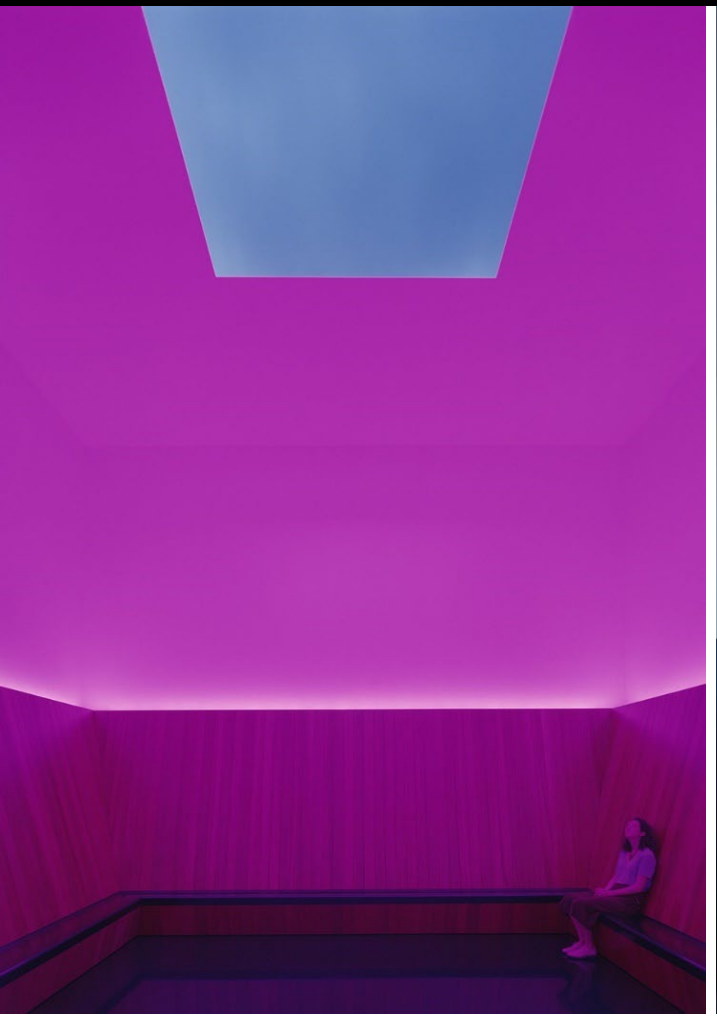


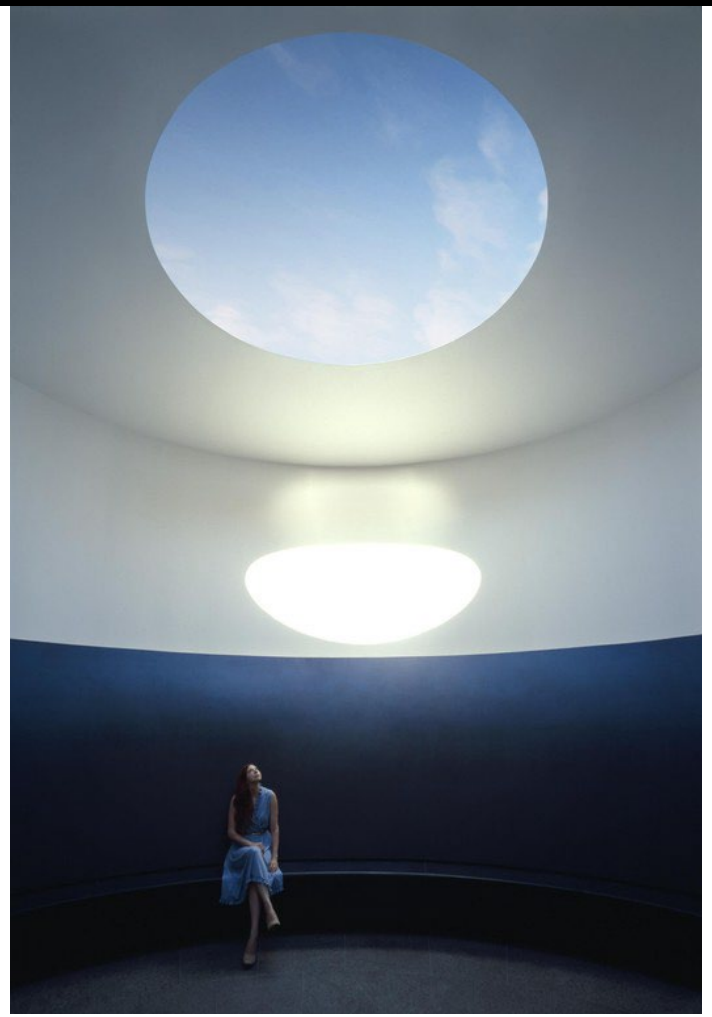


The Overview Effect

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

Earth gazing & “Skyspace”





James Turrell – “Skyspace”

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

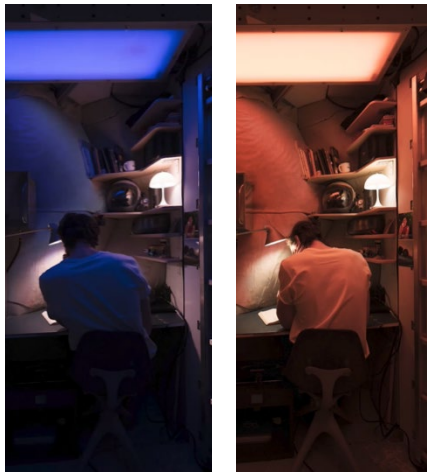
Colour projection

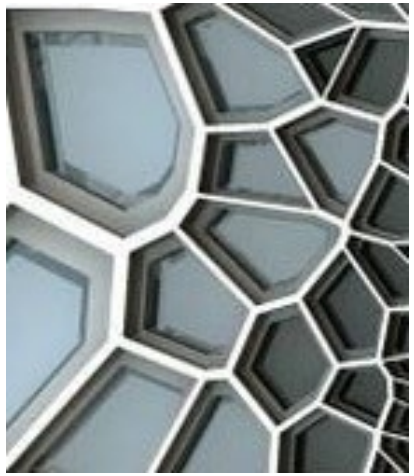
"EMO"- Xiying Bao

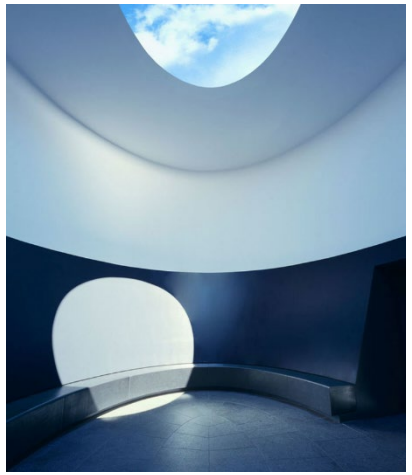
- AI technology: facial recognition
- Changes colours and shapes based on perceived emotion
- Adaptive system monitors wellbeing of crew members
  - influence/transform emotions as well?

Concept

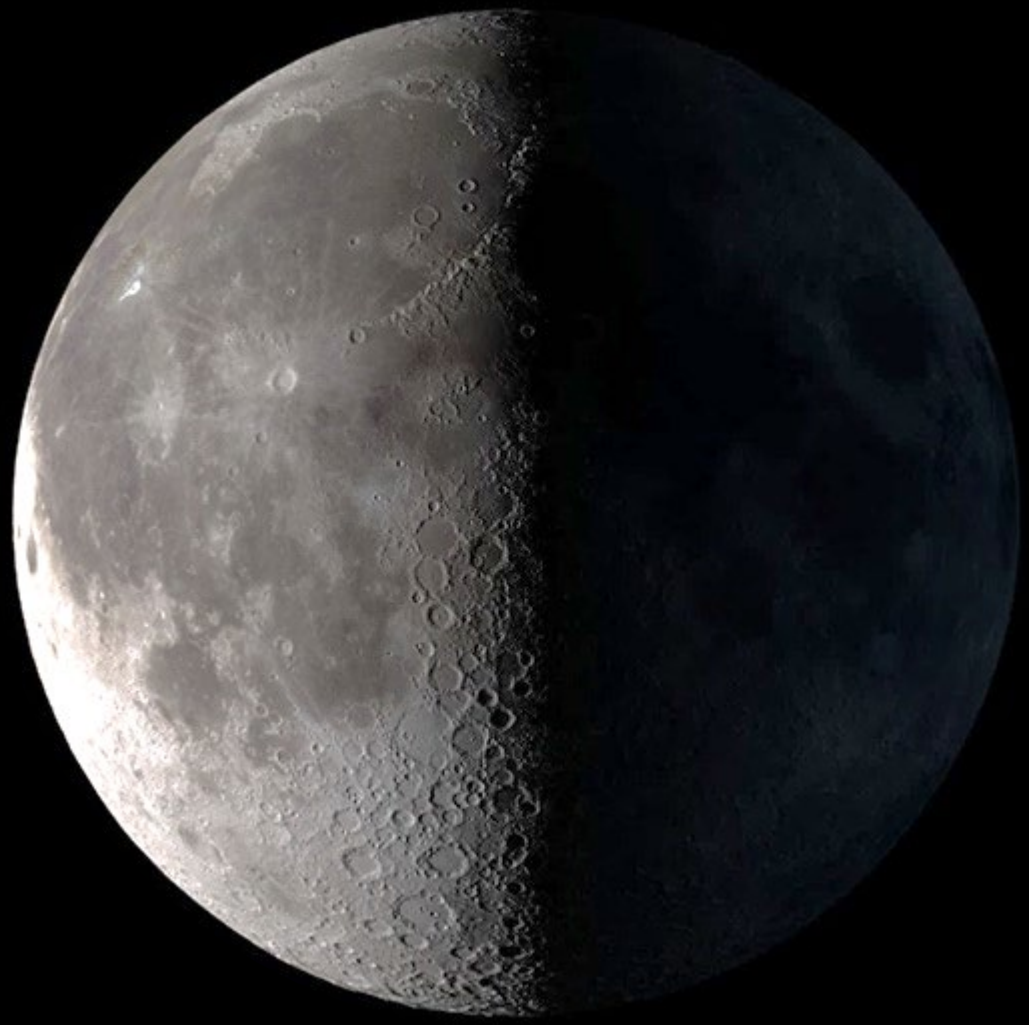
Designing a Lunar habitat that promotes mental wellness of the crew







Designing Lunar Architecture



Location: Earth view

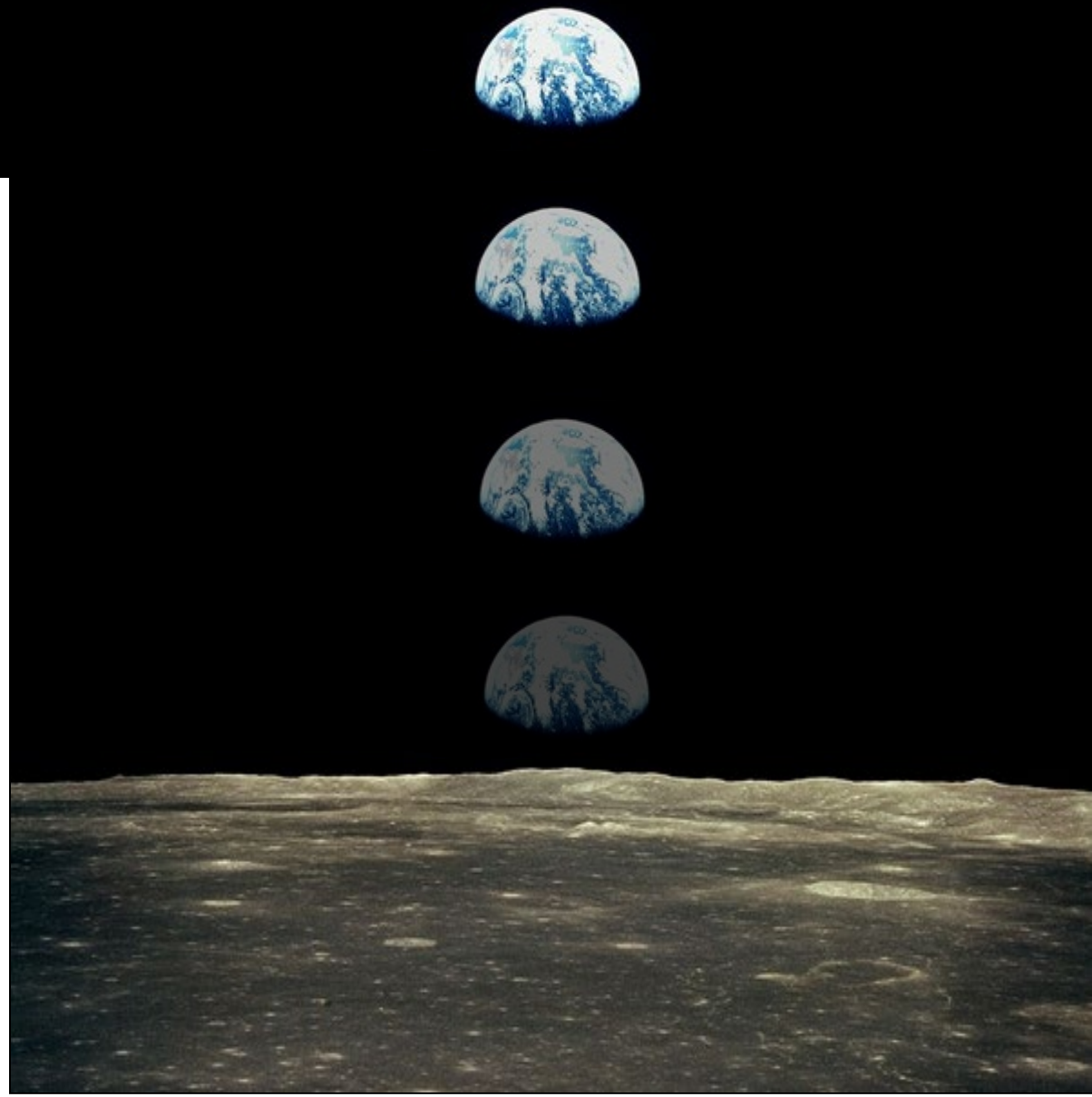
Near side of the Moon

Lunar Equator

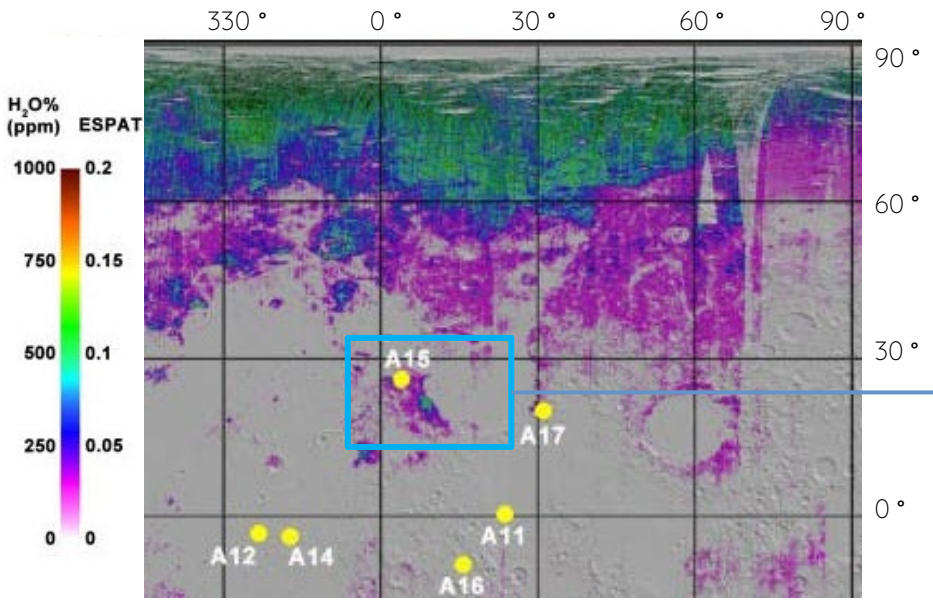
- Earth directly overhead
- Desirable for earth view from above

Lunar Poles

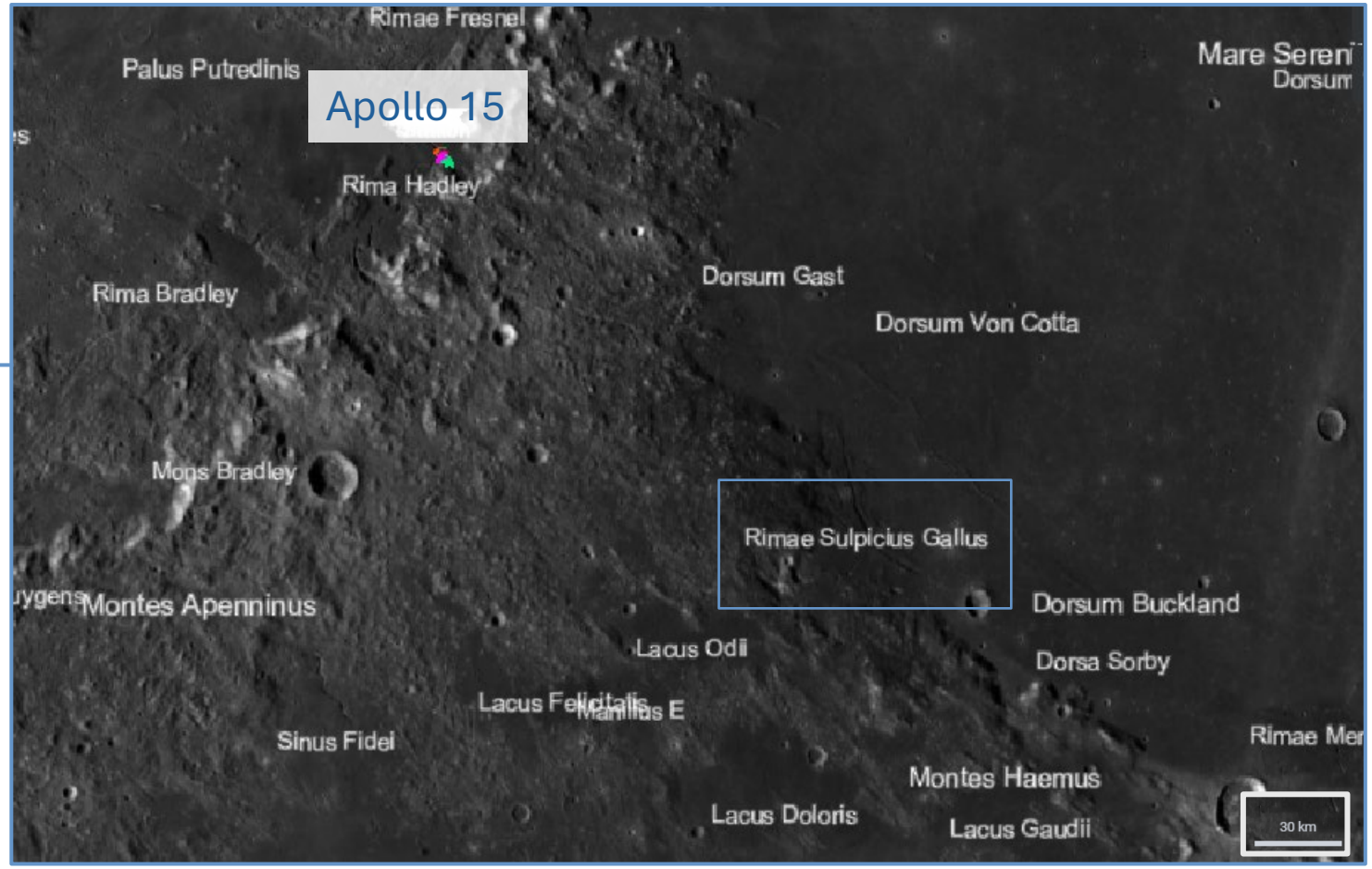
- Earth visible at the horizon
- Sometimes drops below horizon – not visible



Location: Mare Serenitatis



Source: Brown University



Source: Lunar/LROC Quickmap

Edge of *Mare Serenitatis*

- Presumed water/ice
- Near Apollo 15 landing site

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

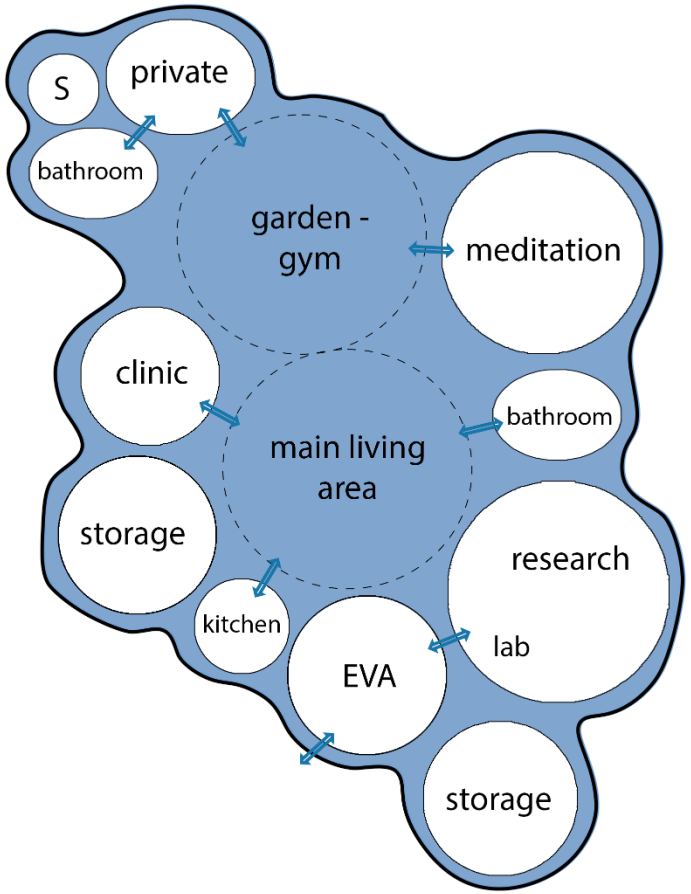
- Garden
- Meditation space
  - earth viewing

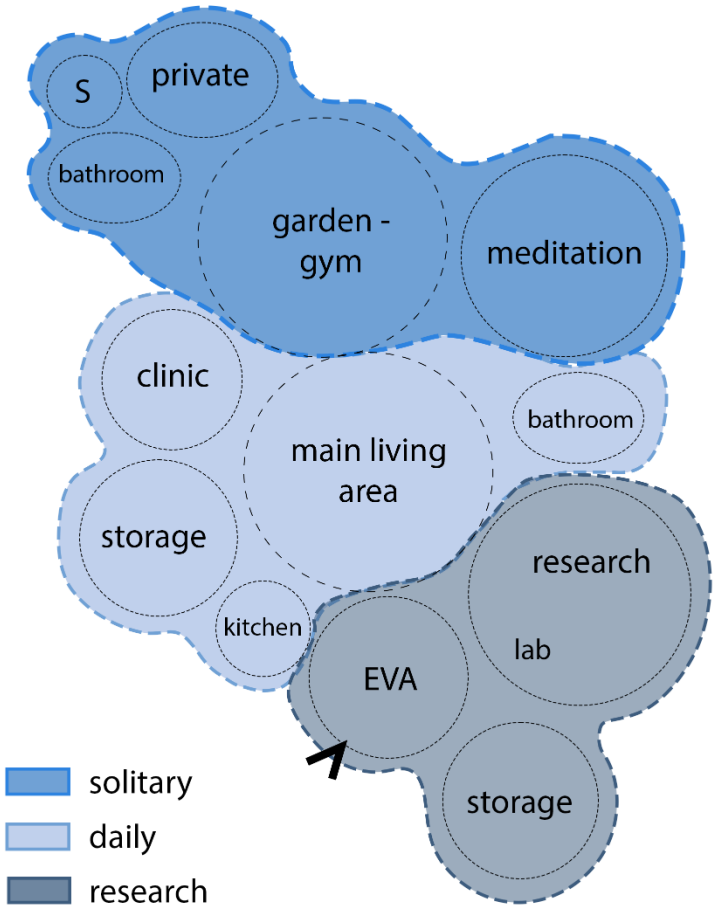
"Minimum volume of **80m3 per person**" (ESA)

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

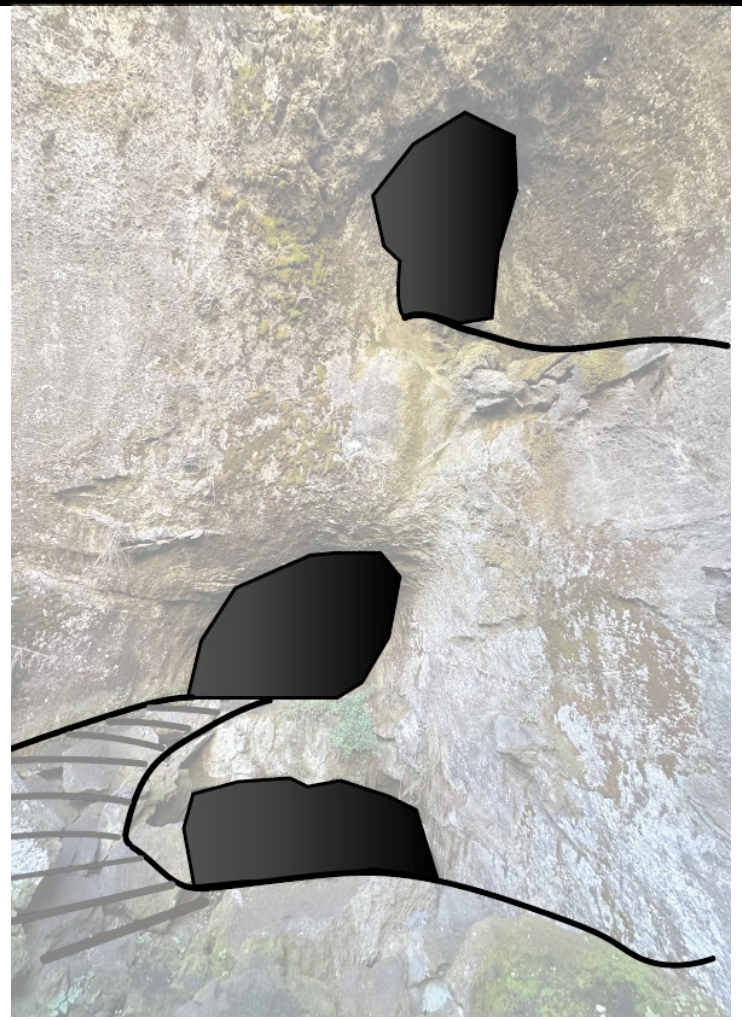




Lava tube mission

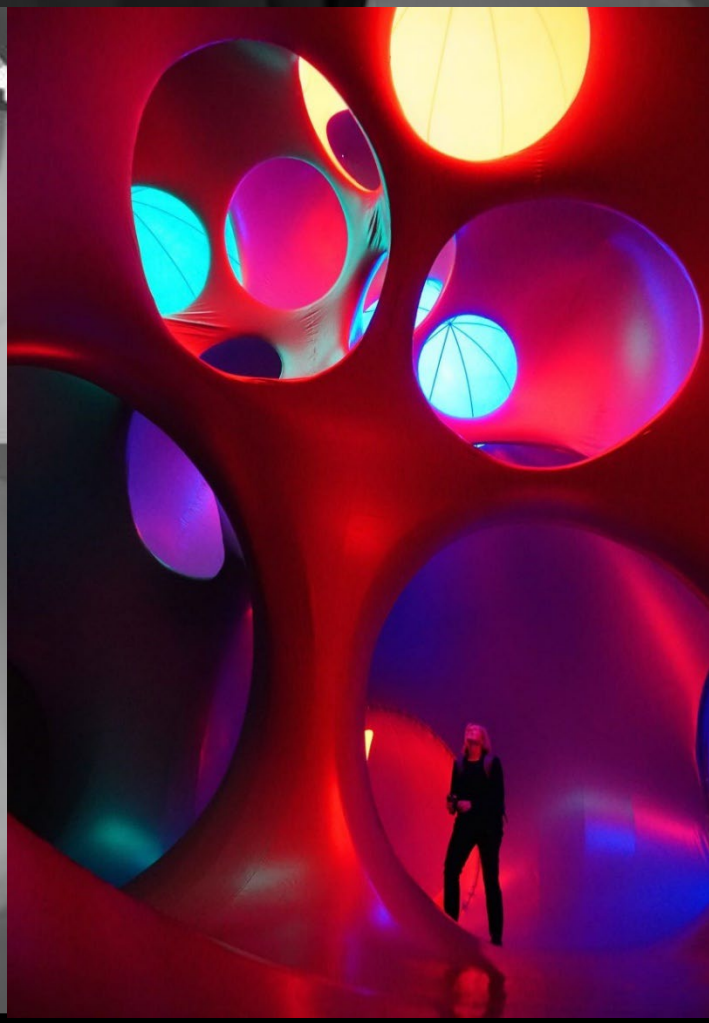
- Corridors branching out

Lava tube mission: sketching



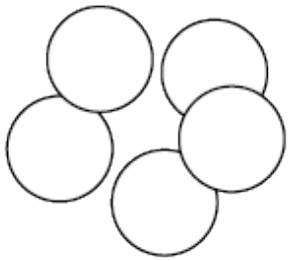
Spatial connection: 3D

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



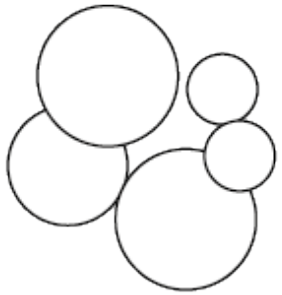
Permeability: computational script

1.Create spheres



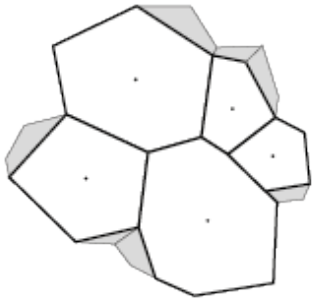
Variables:
- Manual adjustment of position

2. Adjust volume to function



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

3. Create Voronoi cells

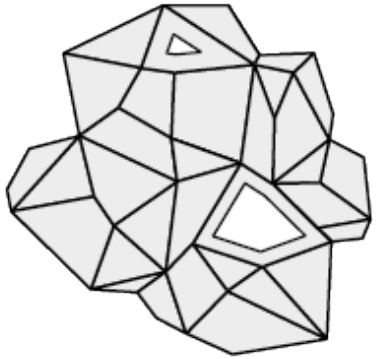


Variables:
- Neighbourhood point count
- Seed
- Sphere position

4. Adjust porosity to function

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

5. Create outer shell

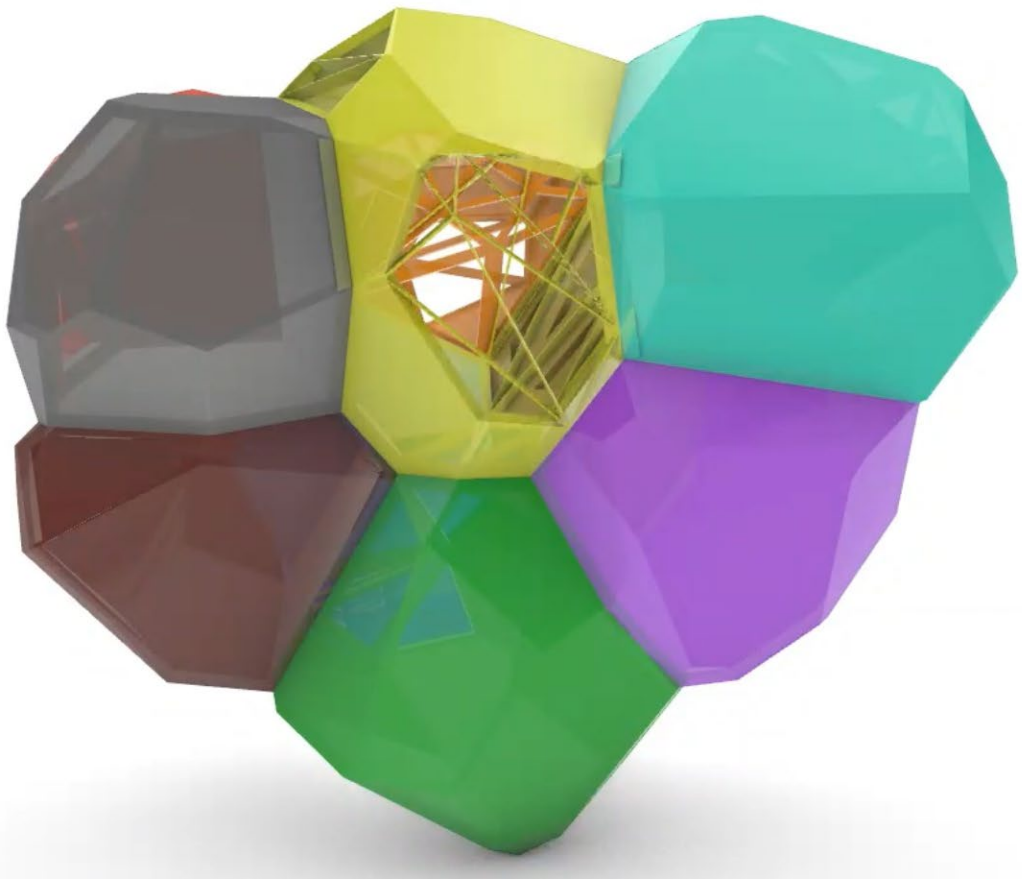


Variables:
- Shell thickness
- selecting specific faces requiring a divergence of porosity
- Opening edge offset distance

Connecting 3D: double atrium

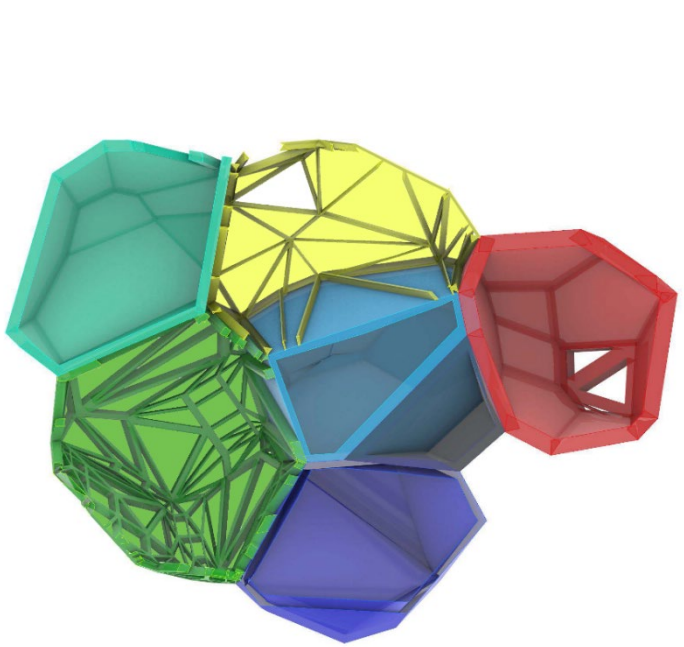
	Function
	Living
	Kitchen
	Storage main
	Meditation
	Garden-gym
	Medical
	Private quarters
	Bathroom
	Storage private
	Research
	EVA chamber
	Storage research

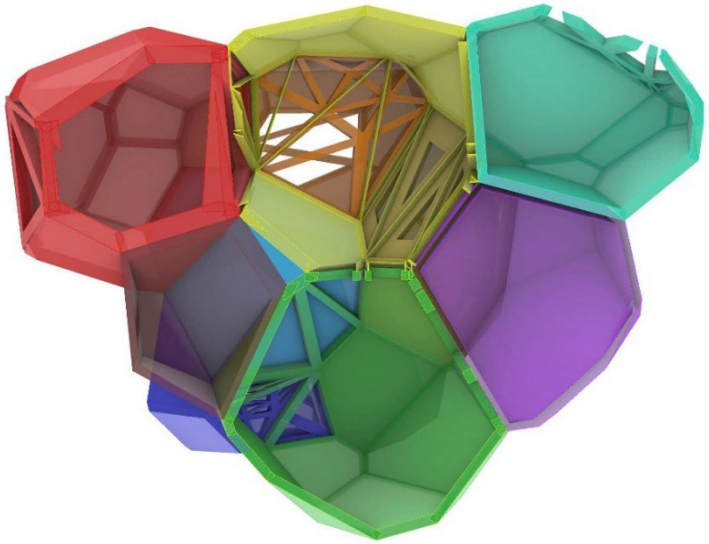
Permeability: Voronoi

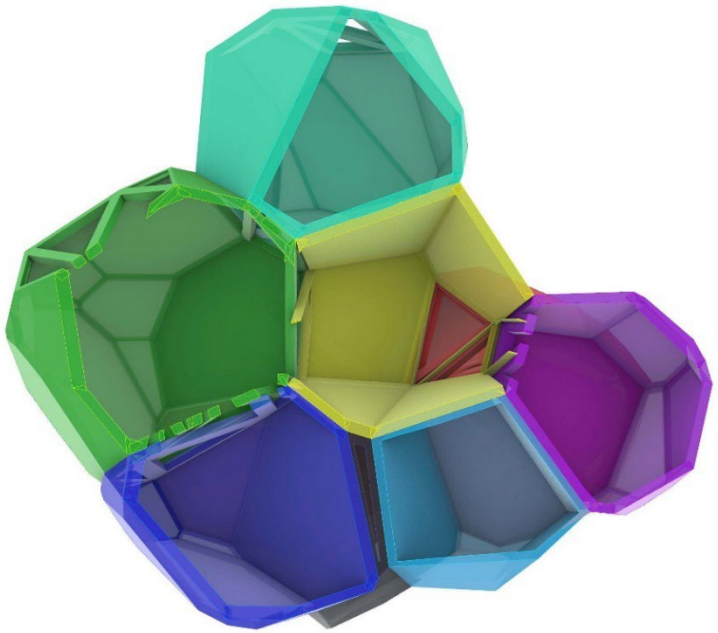


	Function	Permeability
	Living	80%
	Kitchen	62%
	Storage main	16%
	Meditation	10%
	Garden-gym	50%
	Medical	10%
	Private quarters	3%
	Bathroom	0%
	Storage private	0%
	Research	8%
	EVA chamber	5%
	Storage research	0%

Permeability: iterations

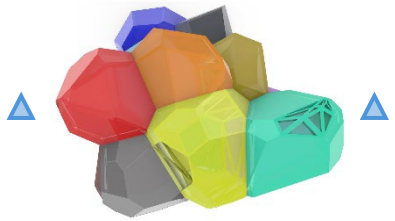






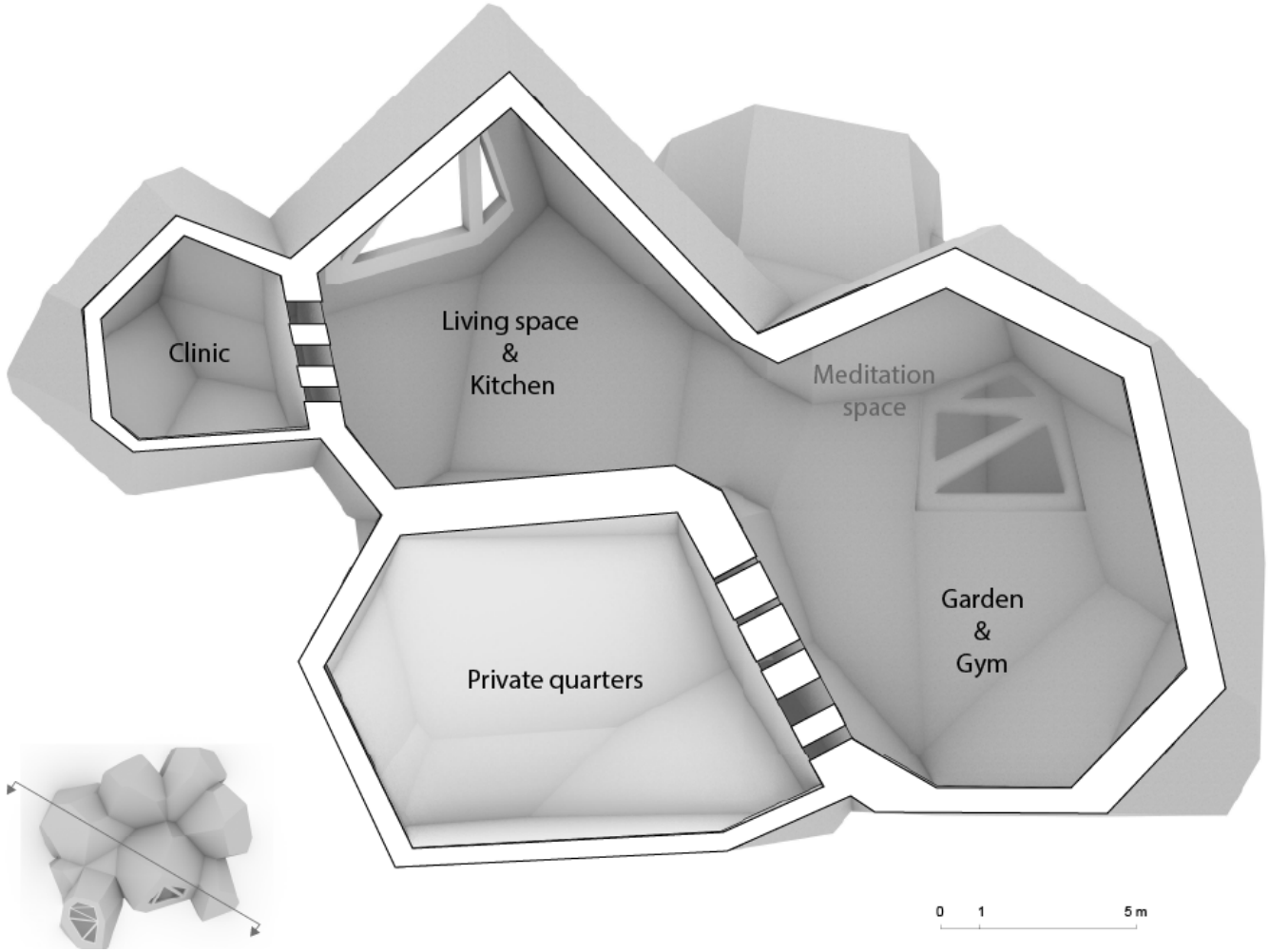
0 1 2 3 4 5 m

0 1 2 3 4 5 m



0 1 2 3 4 5 m

Final iteration



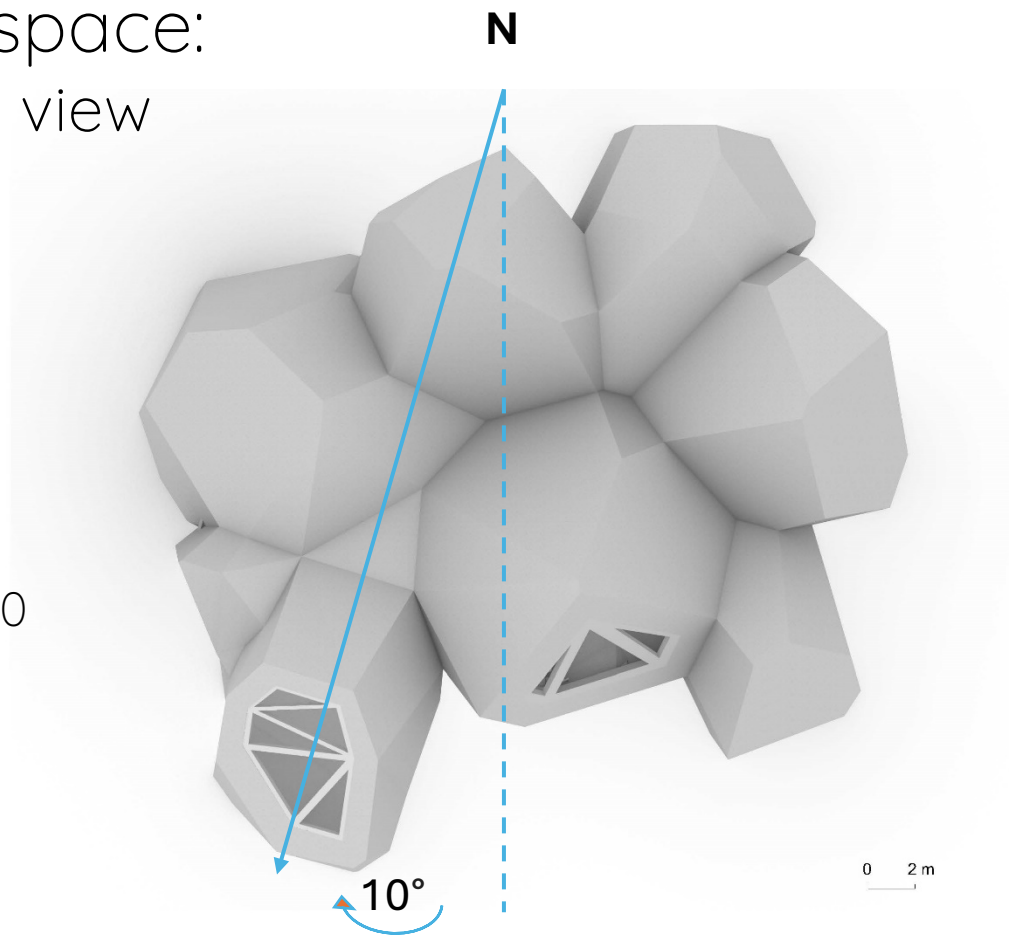
- More centred atria:
  - Garden
  - Living area + kitchen
- Two levels created
  - Daytime
  - Private
- Access private quarters through garden

Creating views

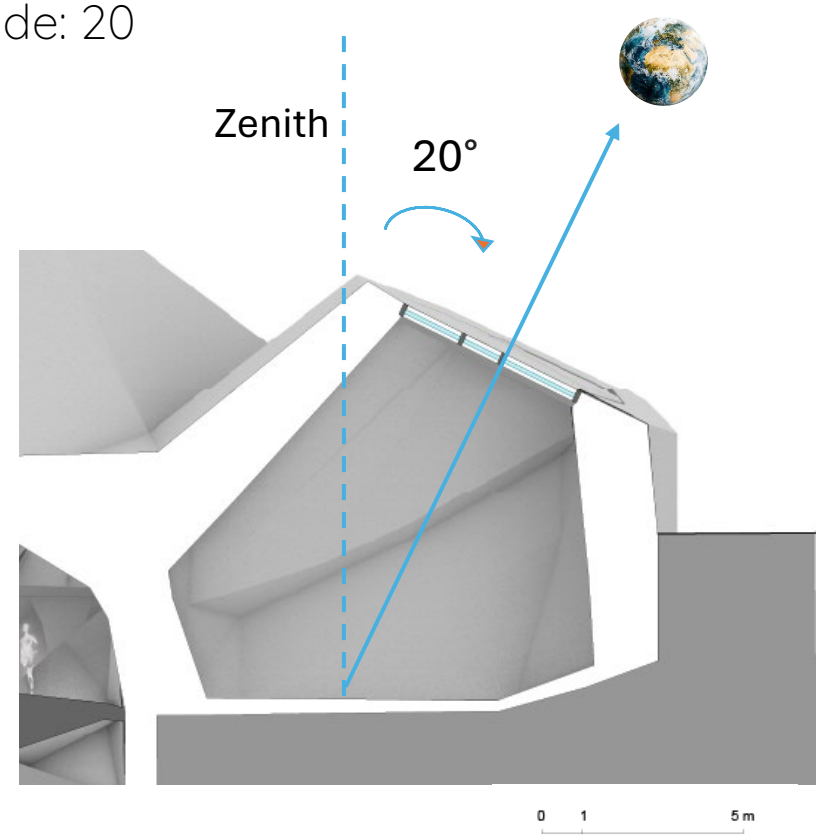
Meditation space:

- Map Earth view

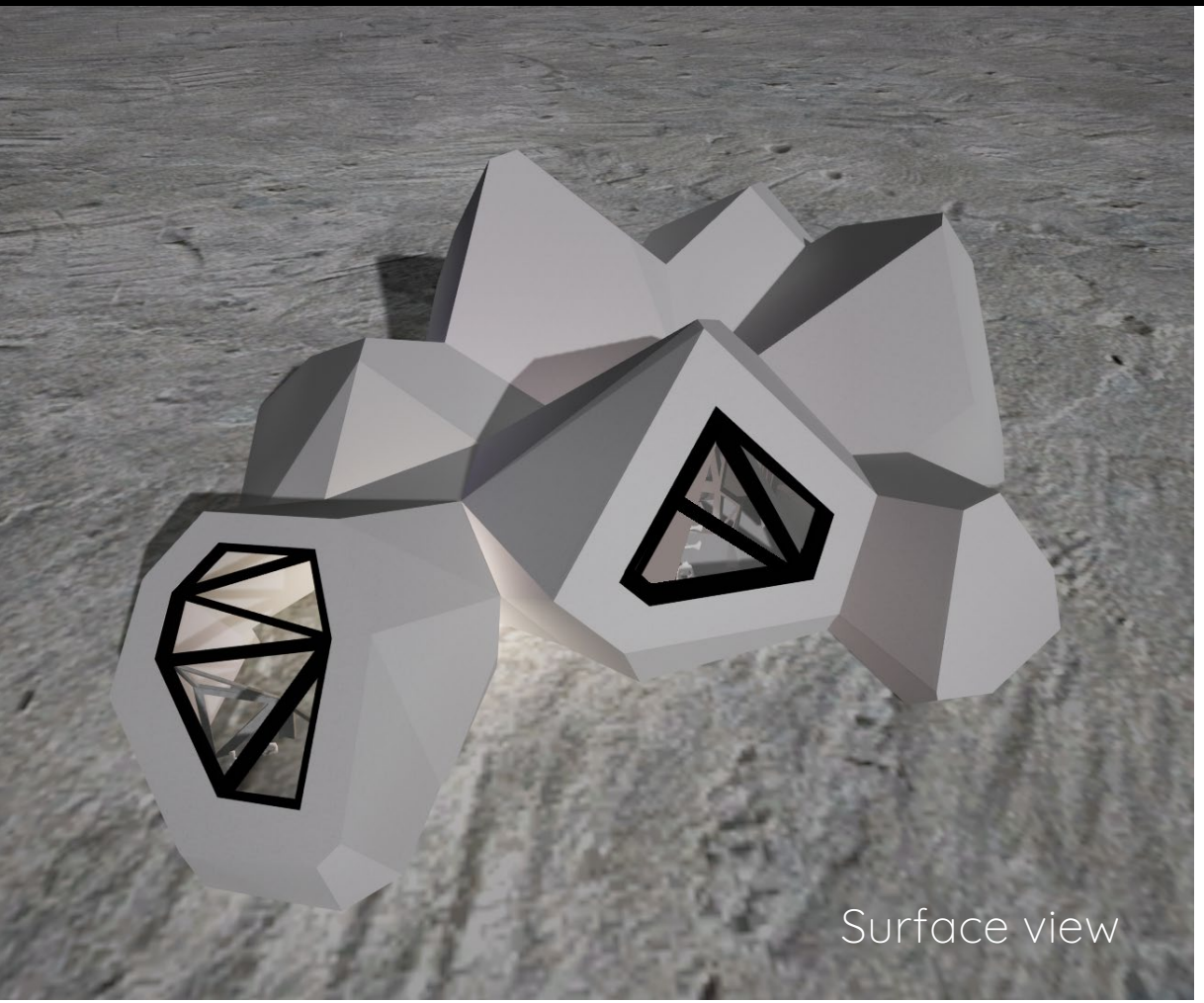
Orientation
Longitude: 10

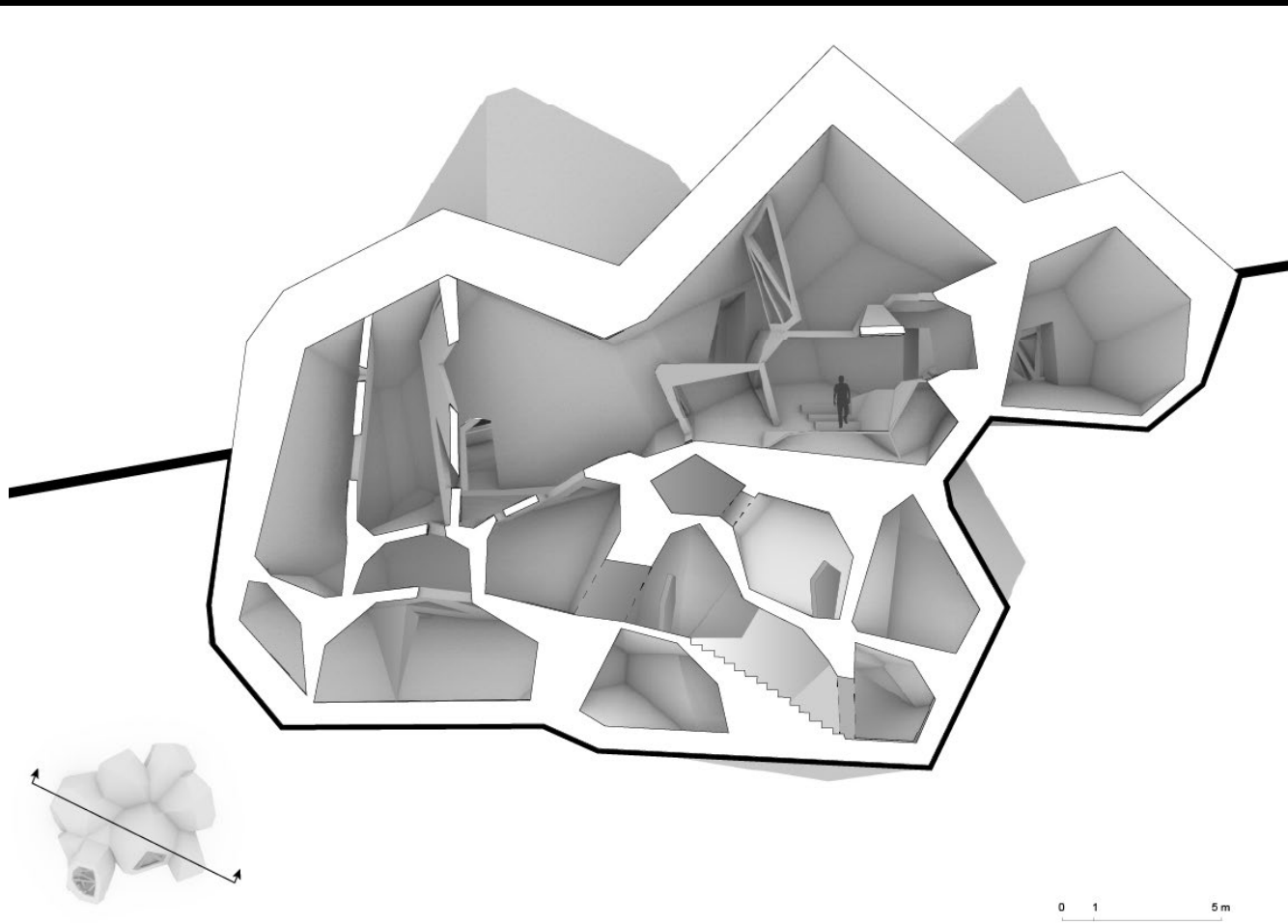


Sky position
Latitude: 20



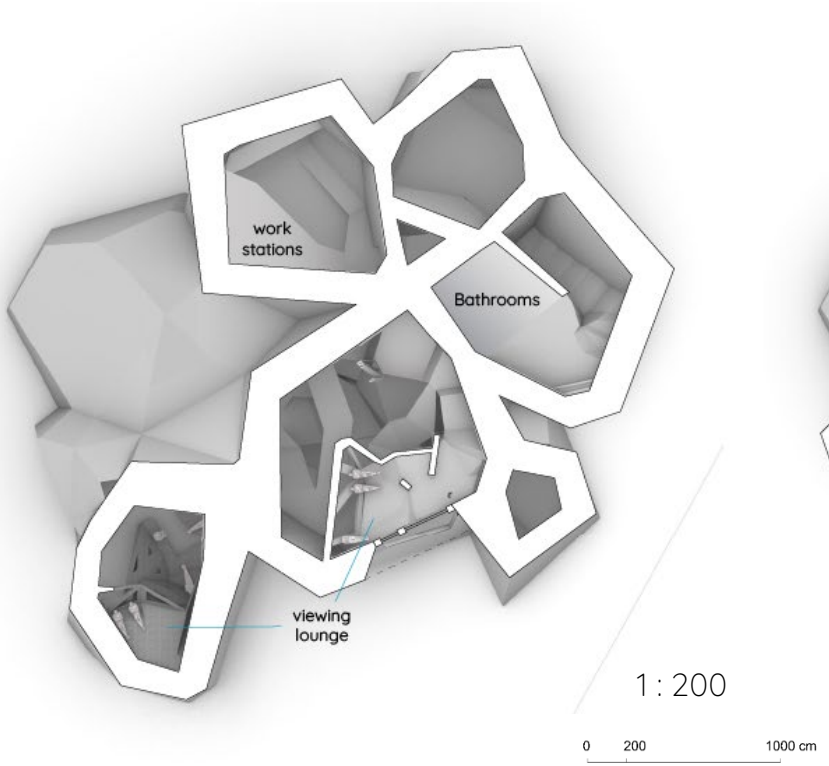
Building in location



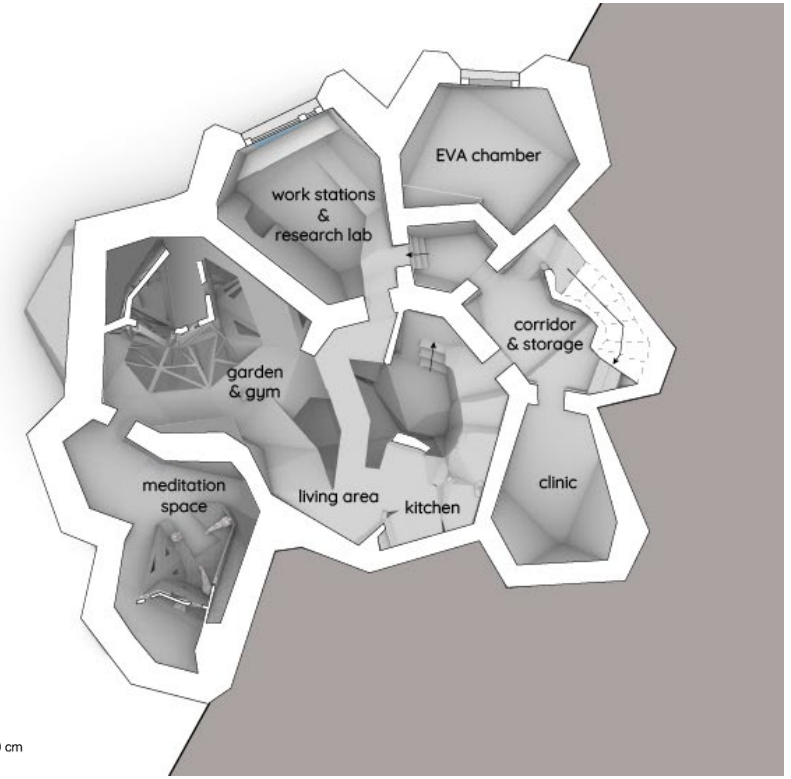


Plans

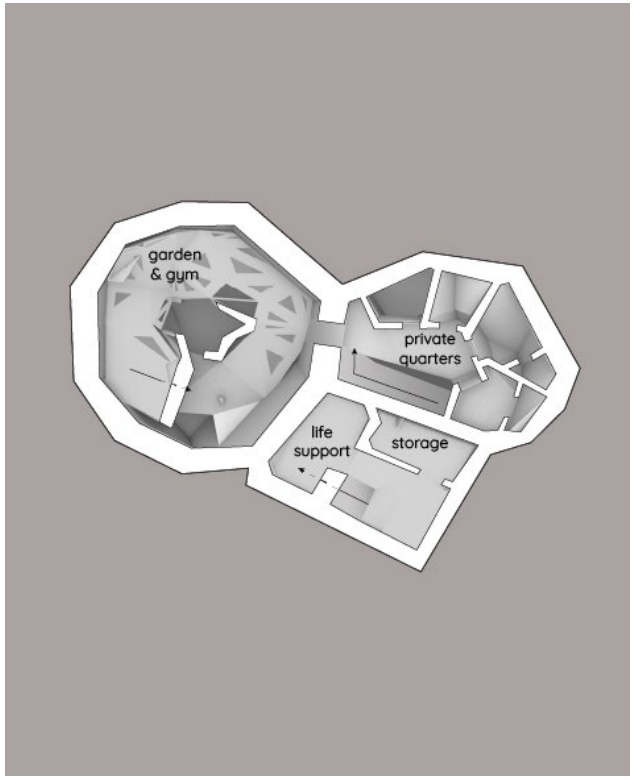
Plan +1
+3.6 m



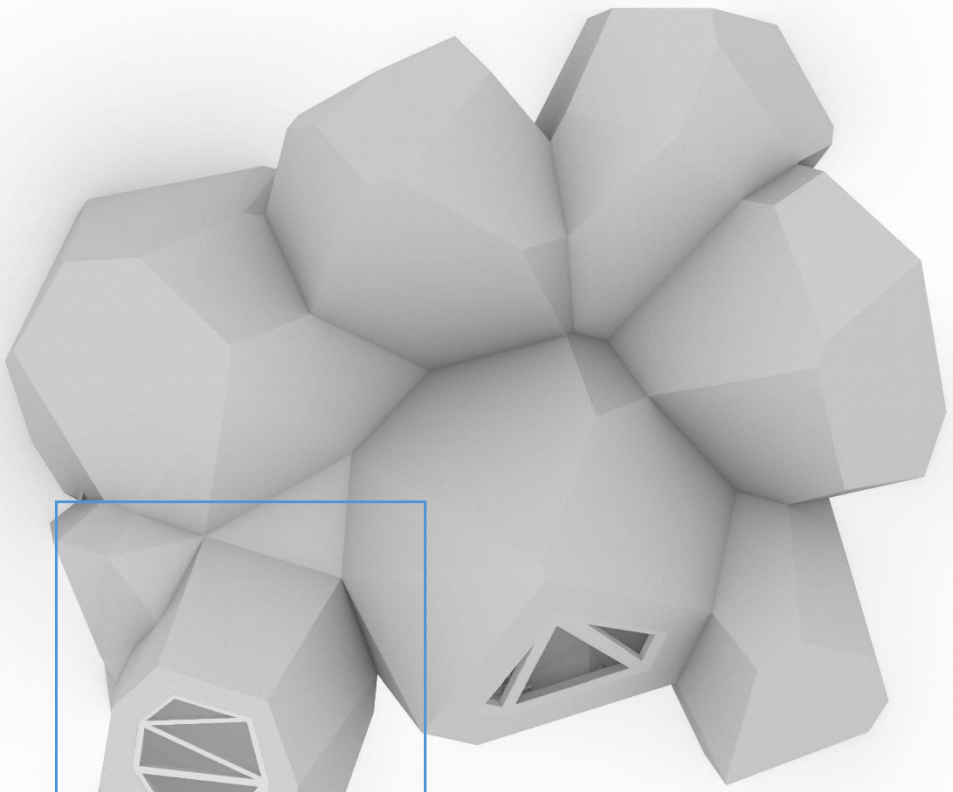
Plan 0
0 m



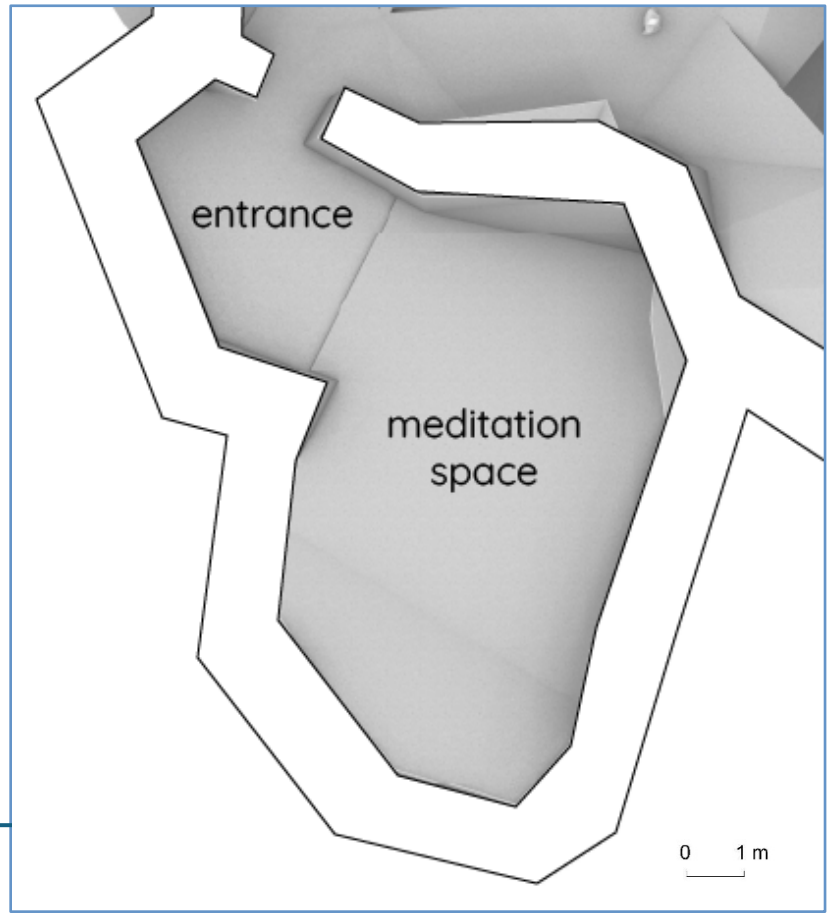
Plan -1
-6.6 m



Meditation space



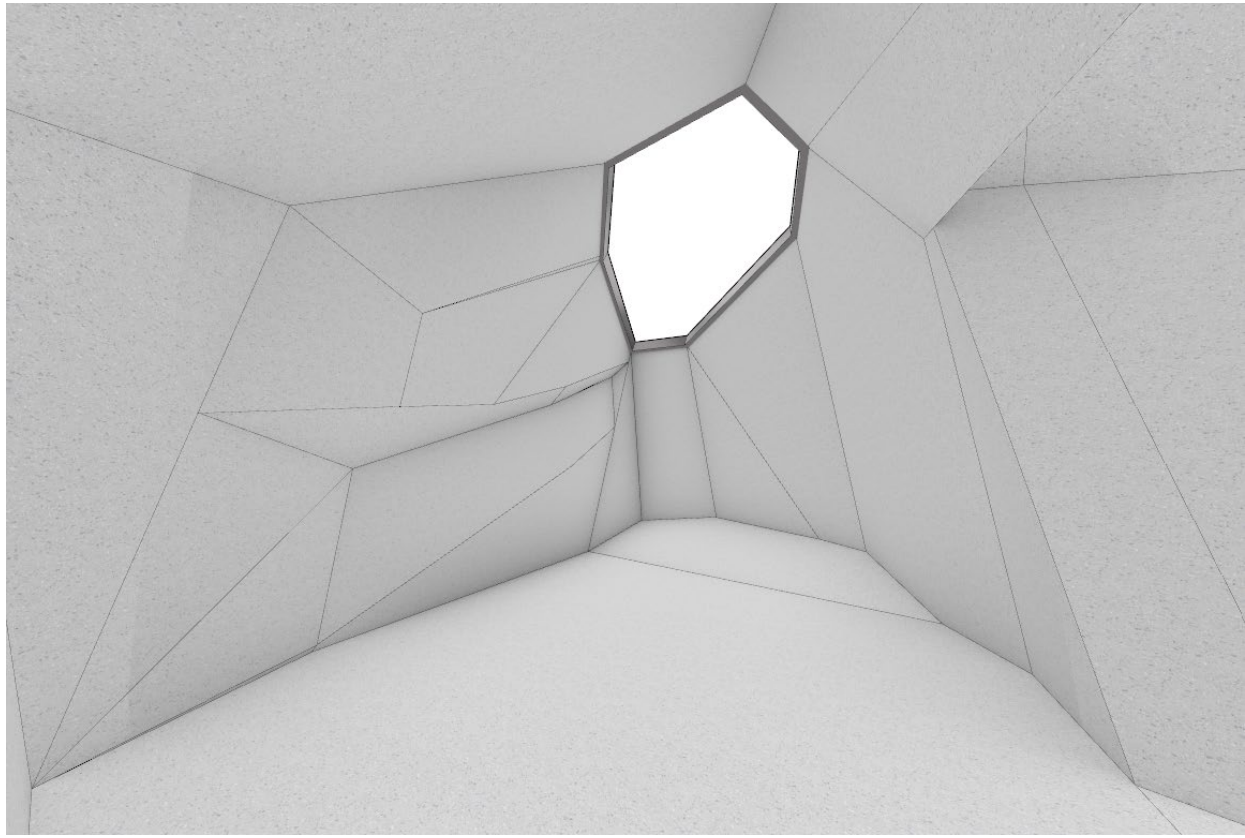
0 2 m



Asymmetric geometry

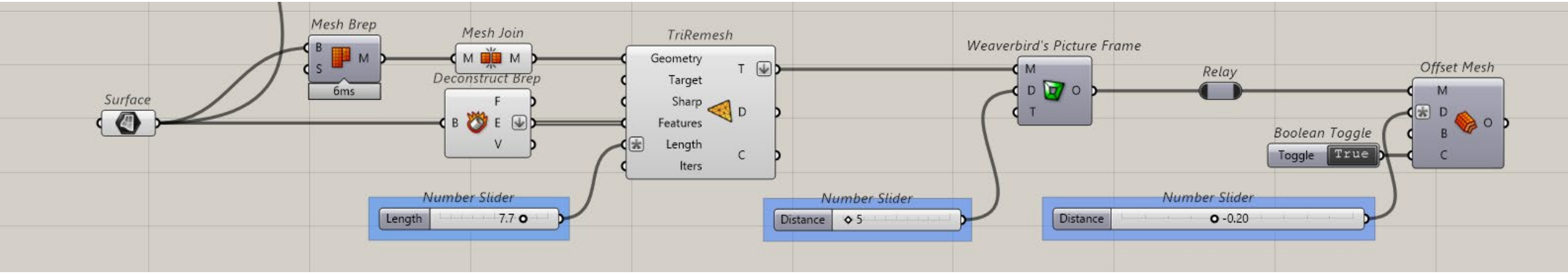
St. Joseph House - Wolfgang Tschapeller ZT GmbH

Interior meditation space



Methodology: computational design

Permeability study: furniture scale

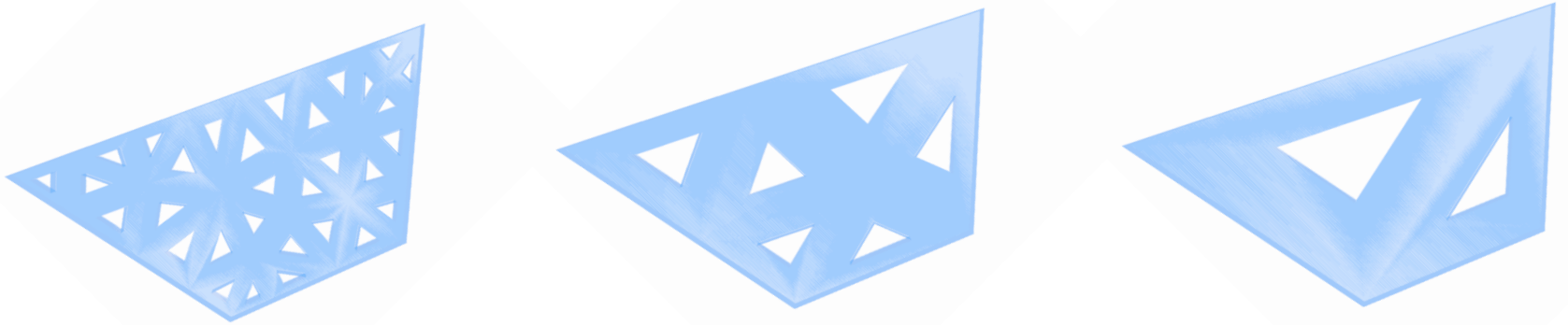


1. triangulation 2. opening size 3. thickness

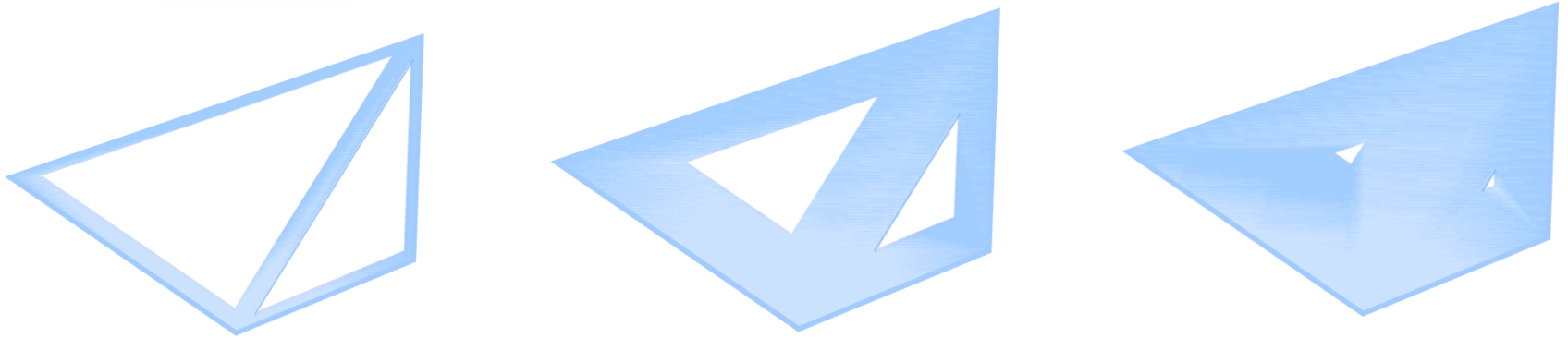
Permeability script

high ⟷ low

triangulation

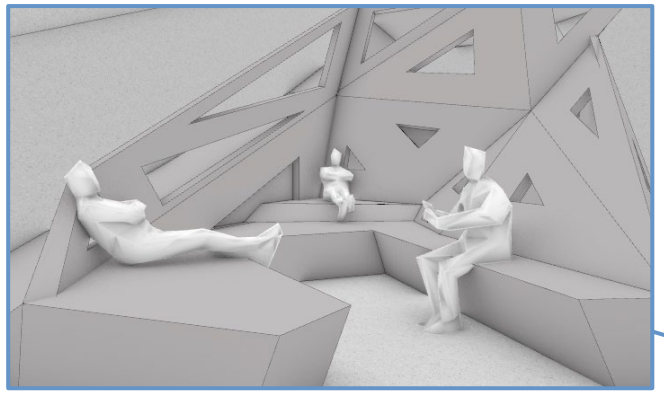


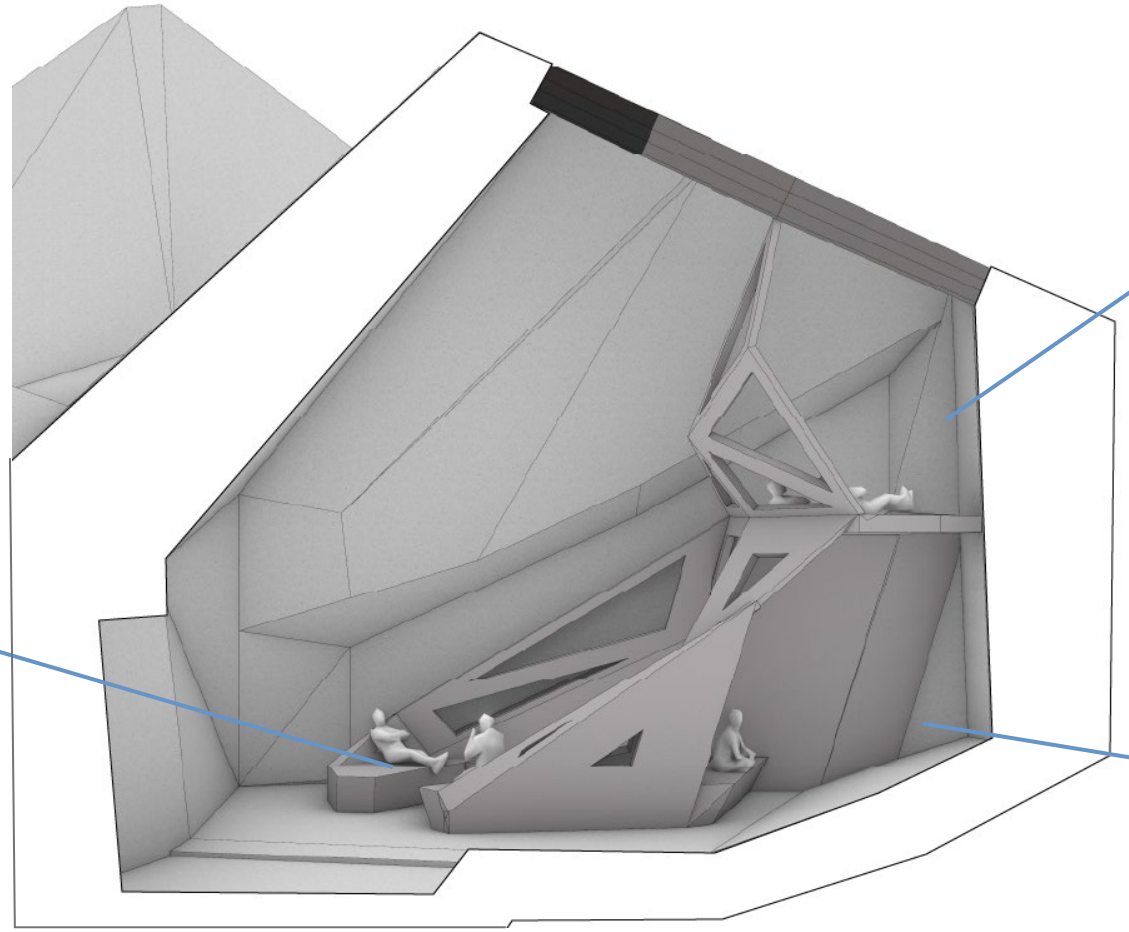
opening size



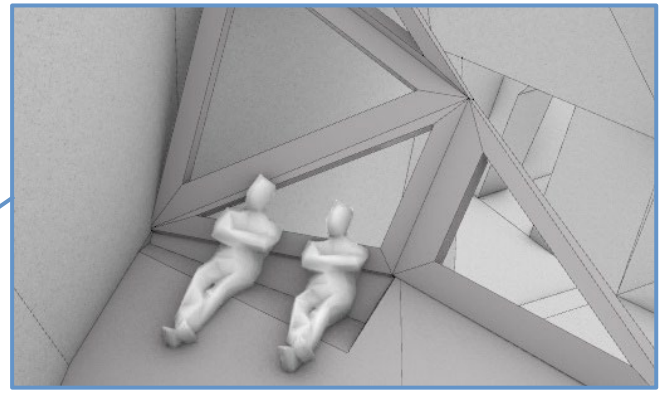
Interior division

Relaxing

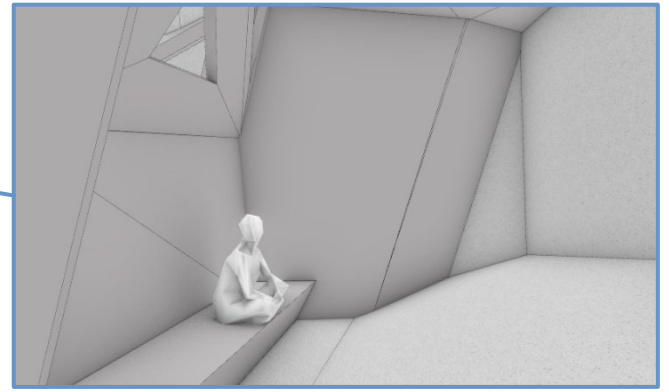




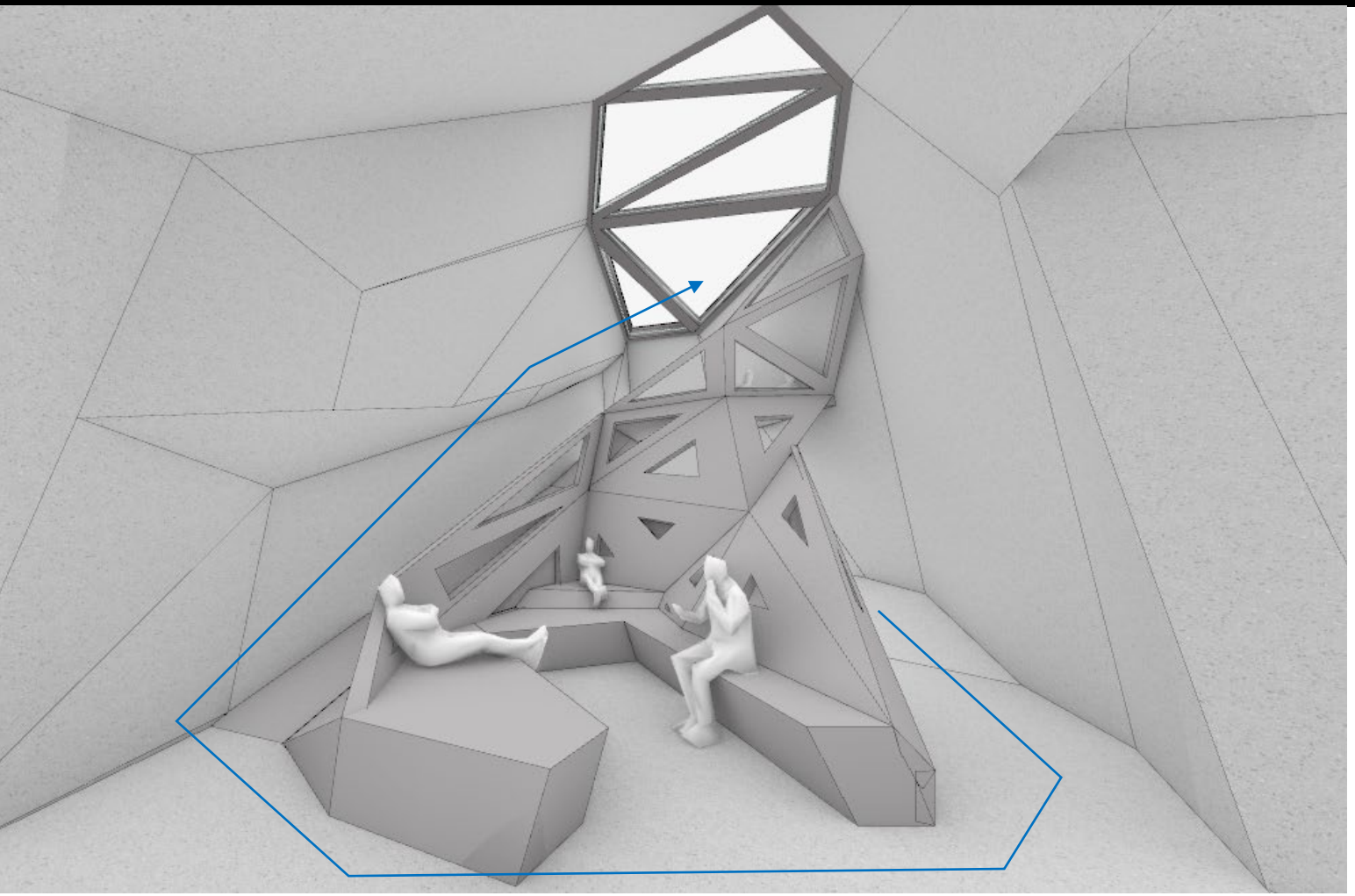
Earth viewing



Reflecting



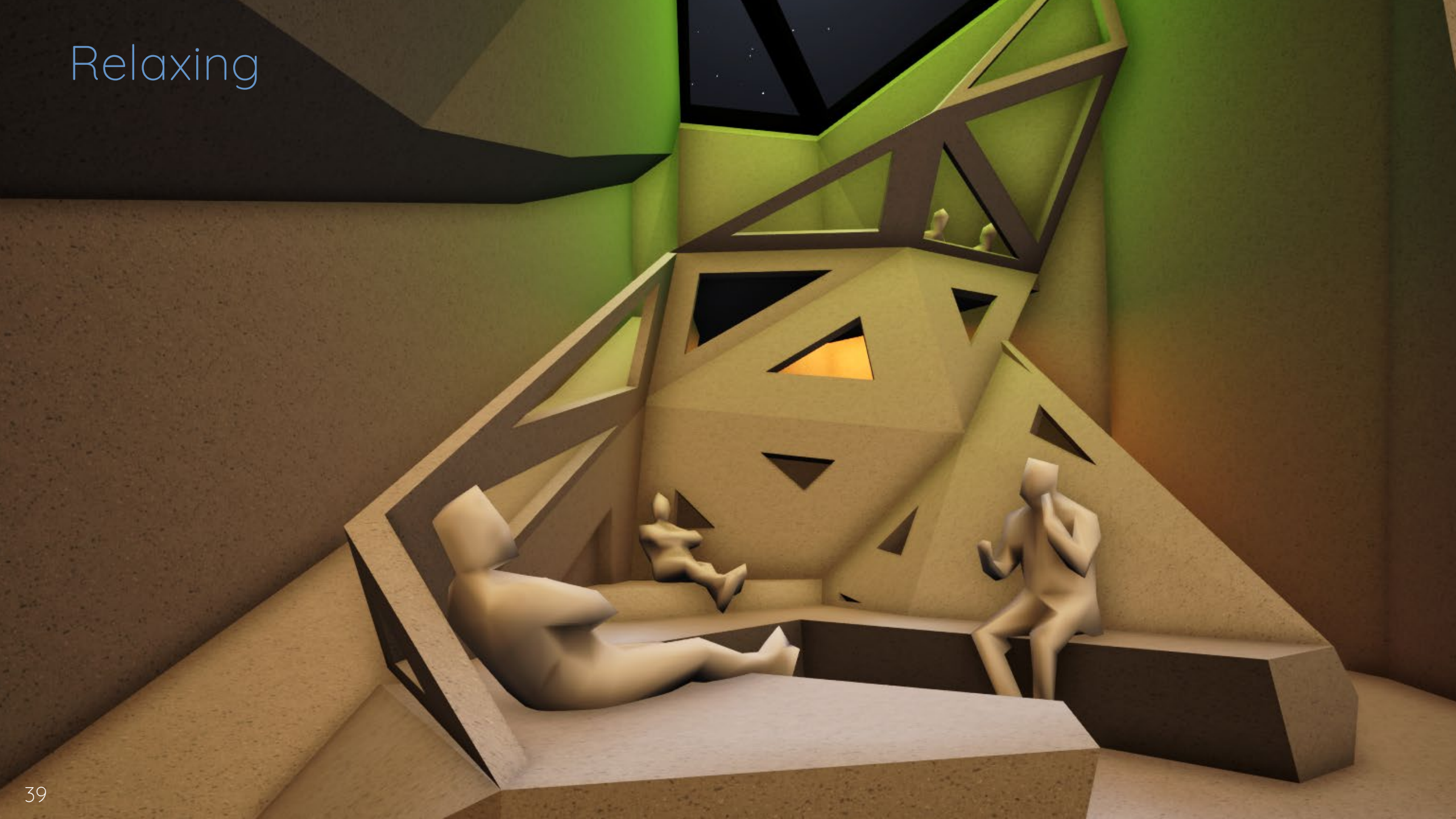
Permeability gradient

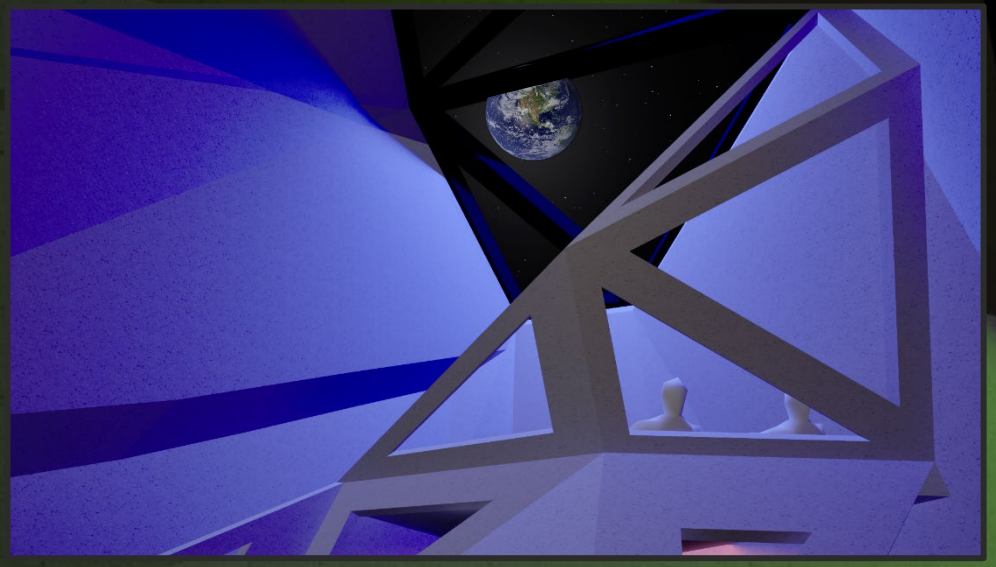


Increasing permeability

- The closer you get to the outside view - more open

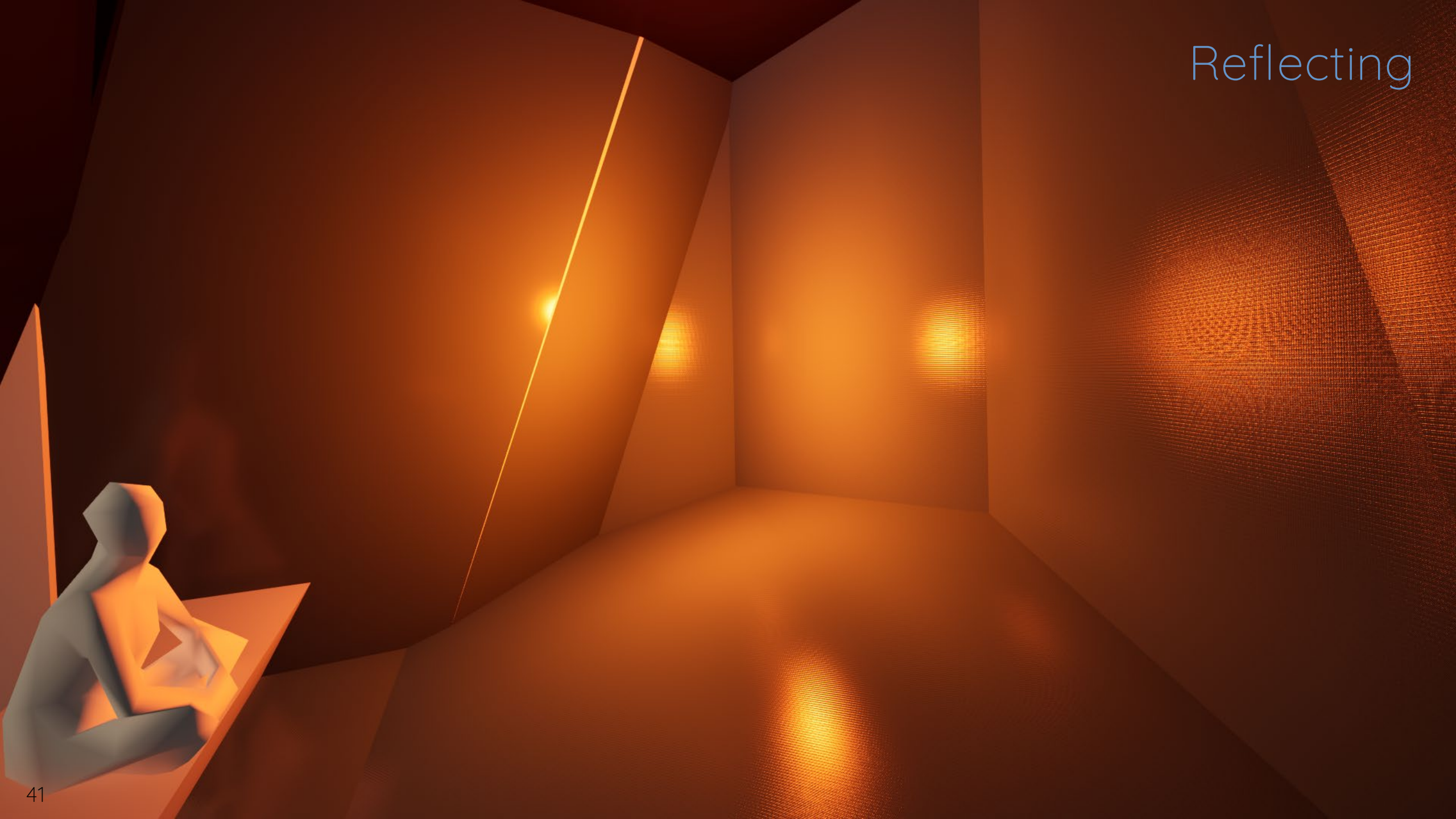
Relaxing



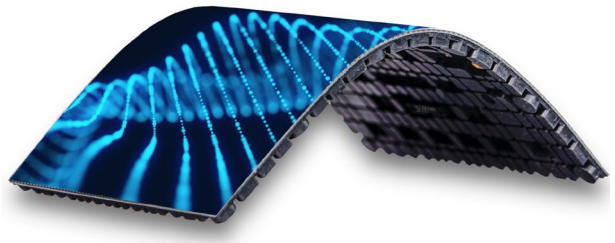


Earth viewing

Reflecting



Interior solitude space



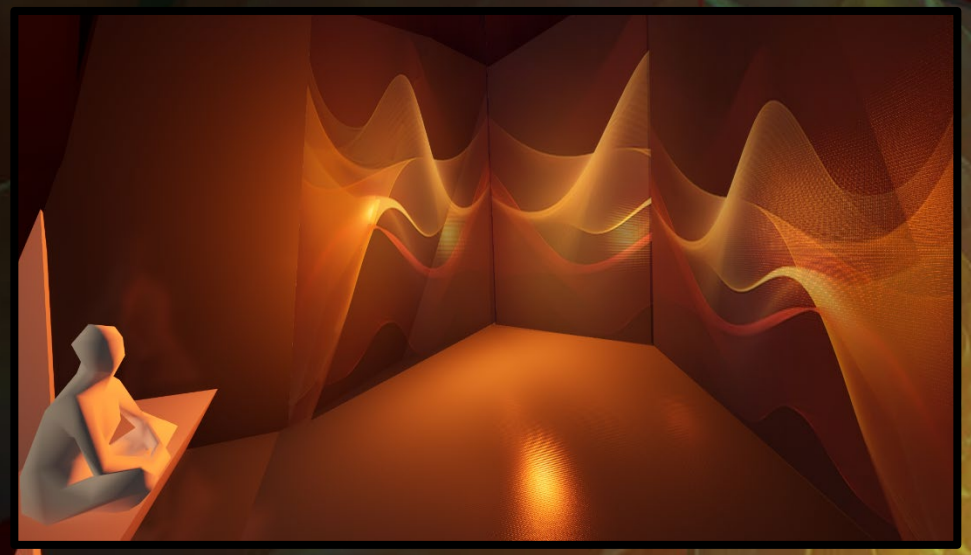
Flexible OLED screens

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

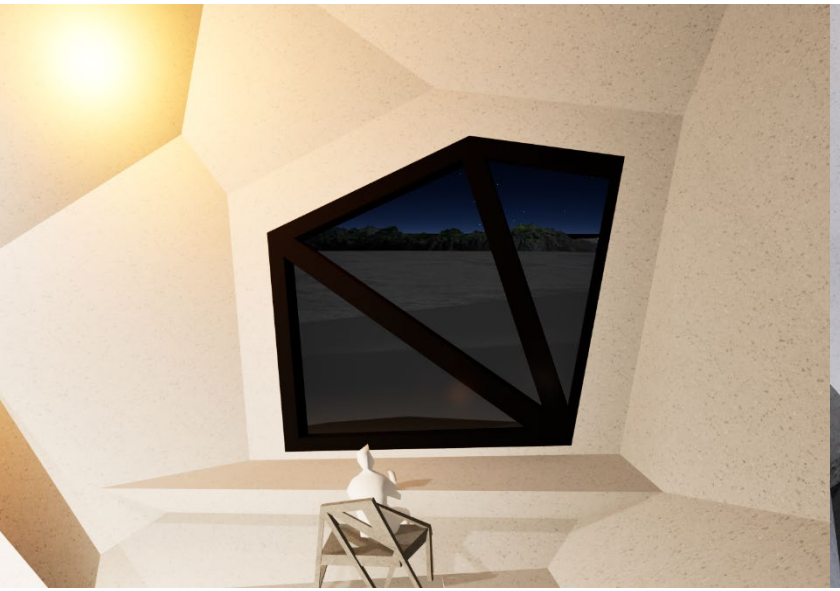
Adjustable colour and pattern

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

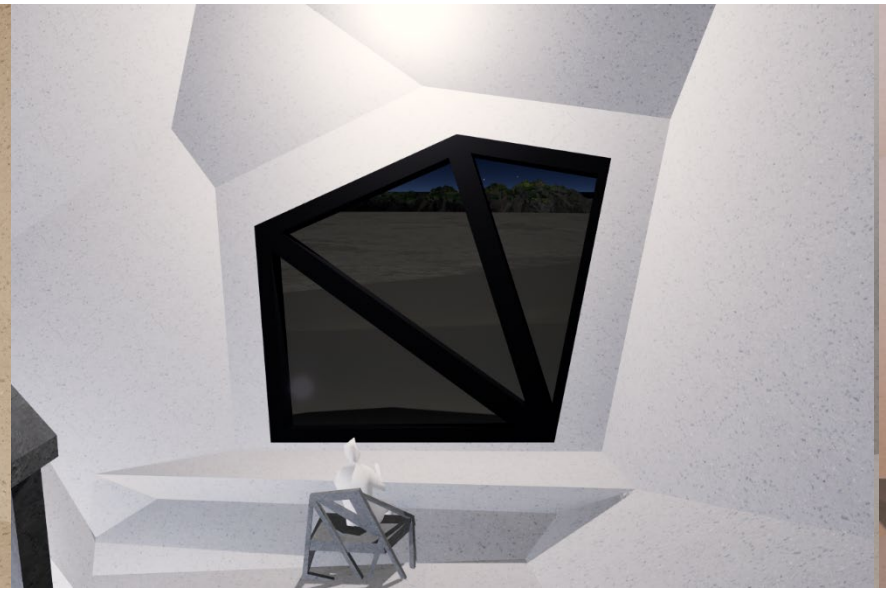
Reflecting



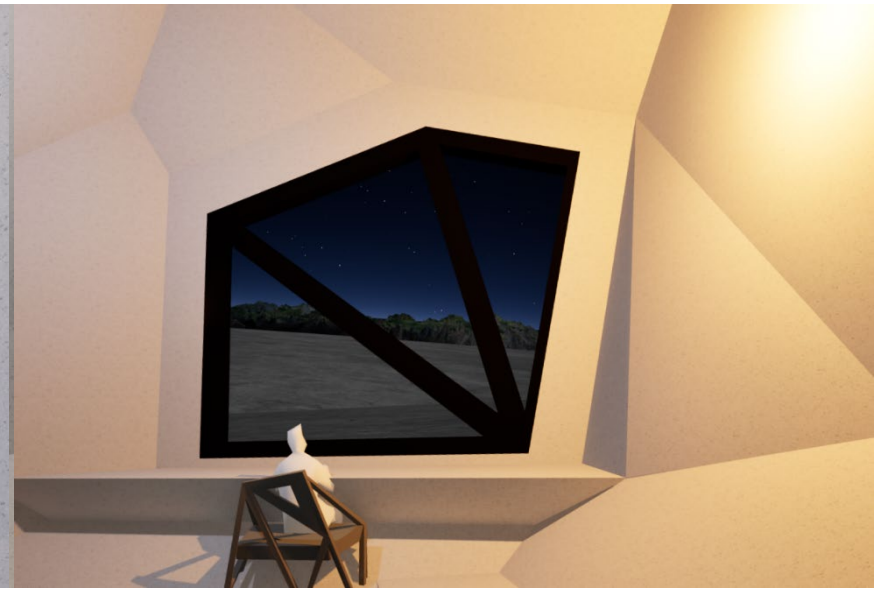
Impression daylight simulation



Sunrise

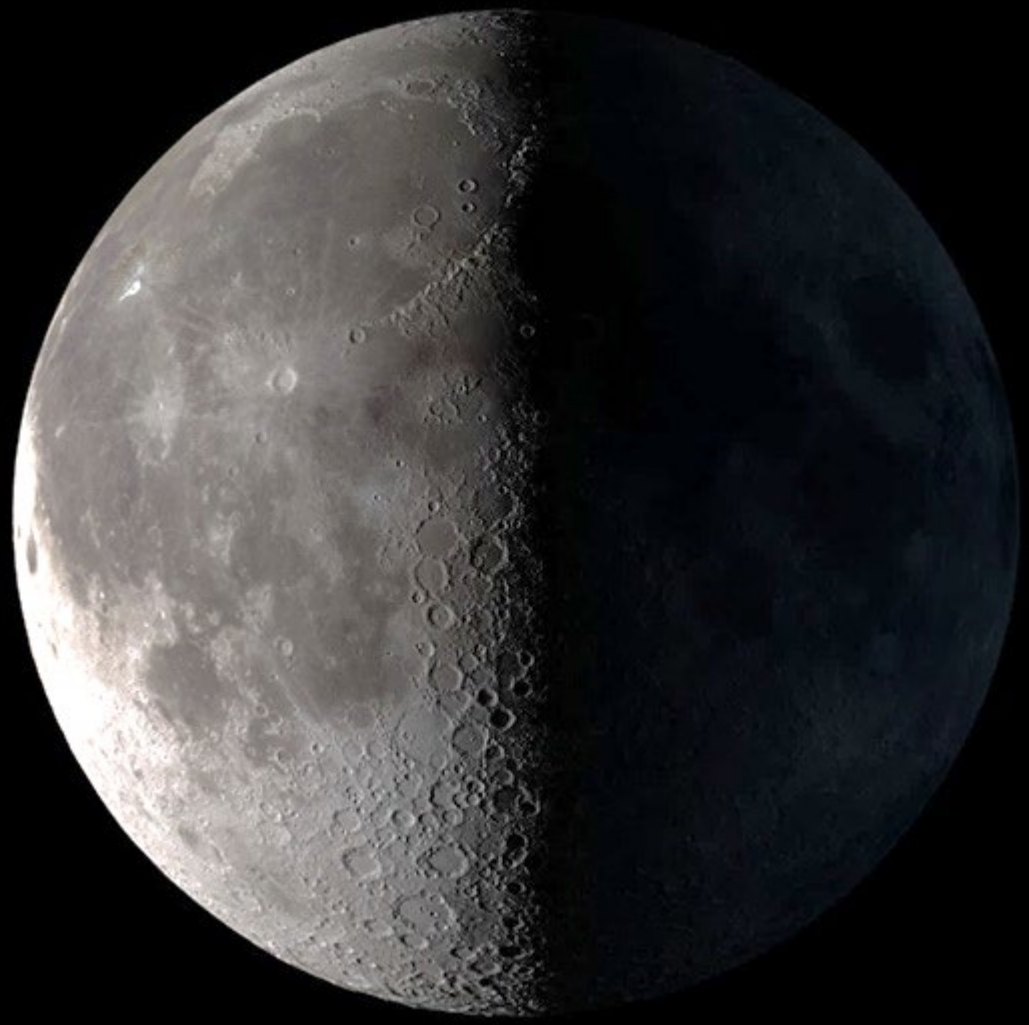


Midday



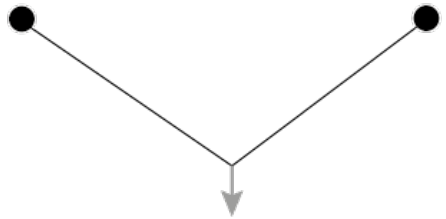
Sunset

Constructing Lunar Architecture

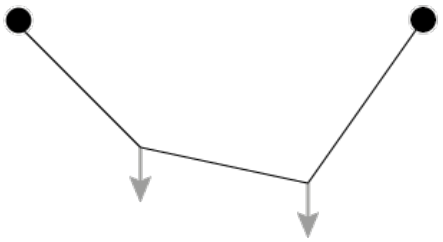


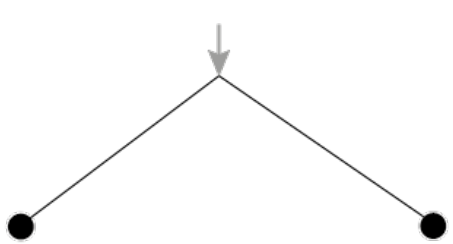
Catenary action

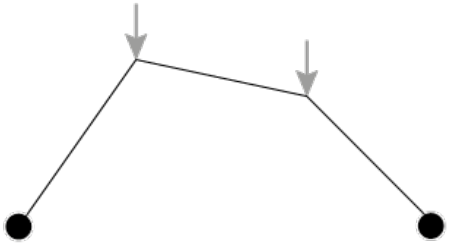
1 weight

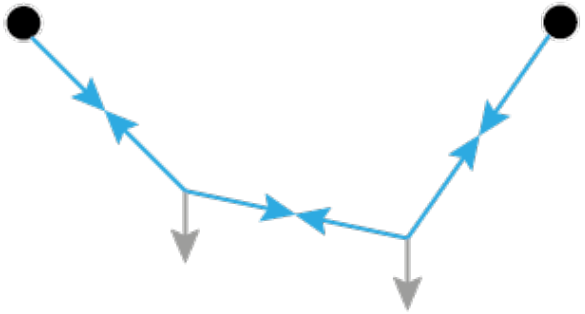


2 weights

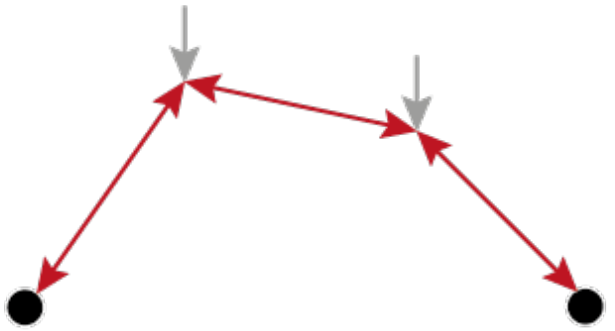








Mapping tensile forces by hanging weights on a cord



Inverted tension shows compression forces

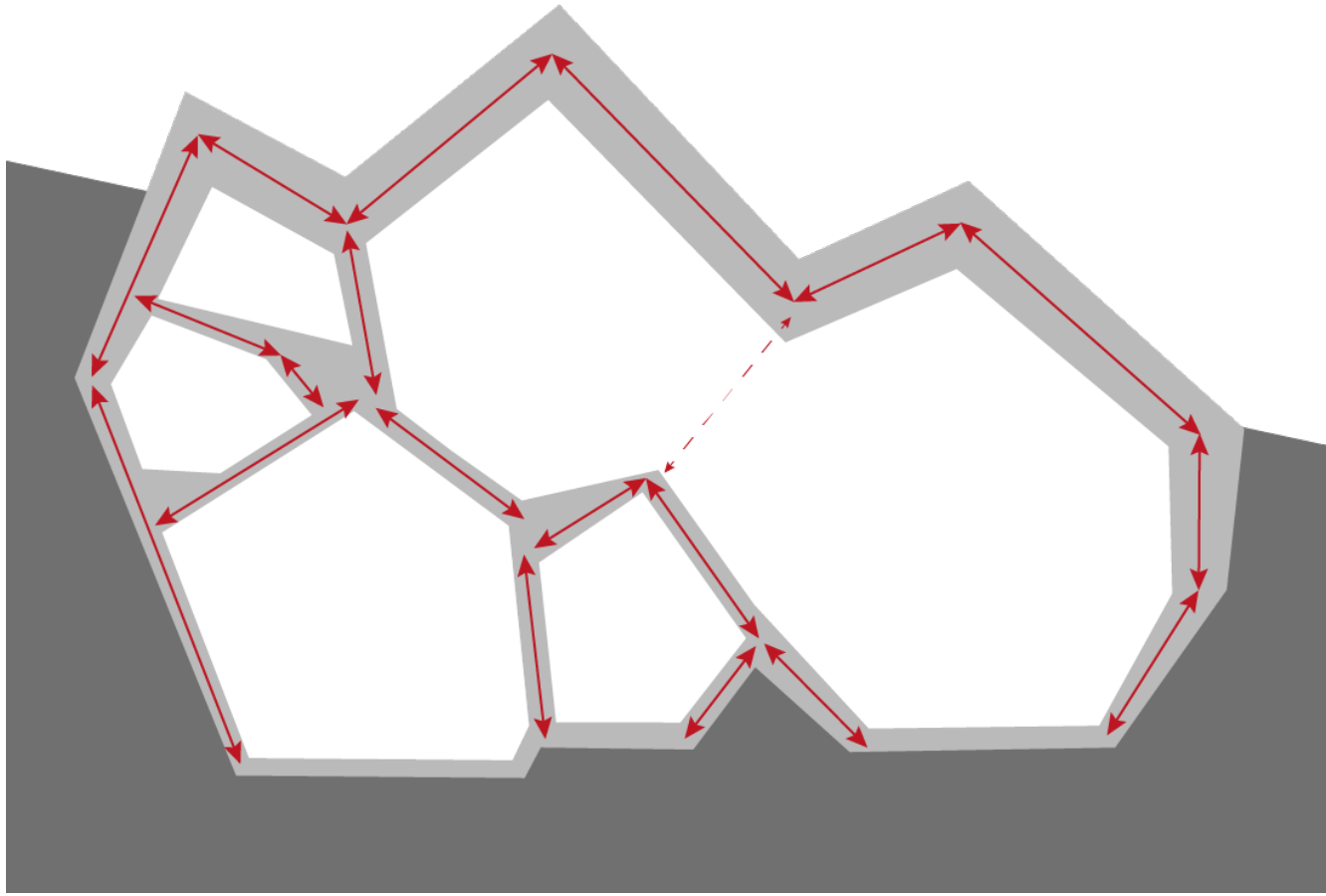
Lunar Regolith

Main material:

- Lunar Regolith
  - **Strong compressive properties**
  - Weak tensile properties

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

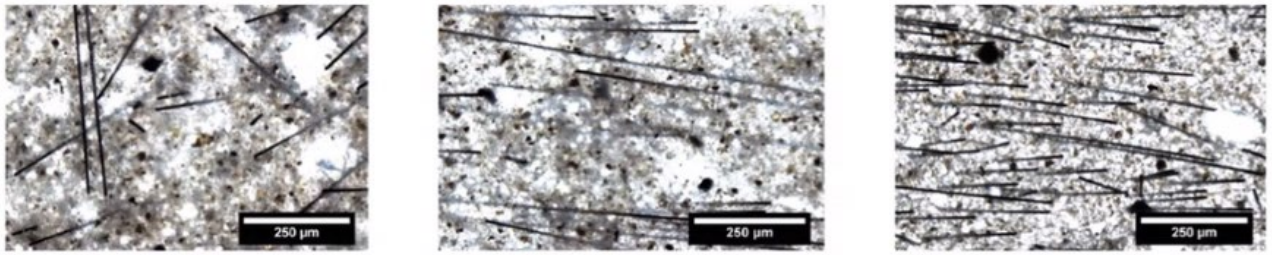
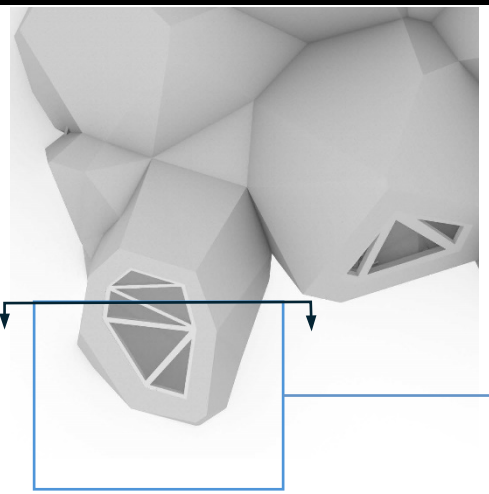


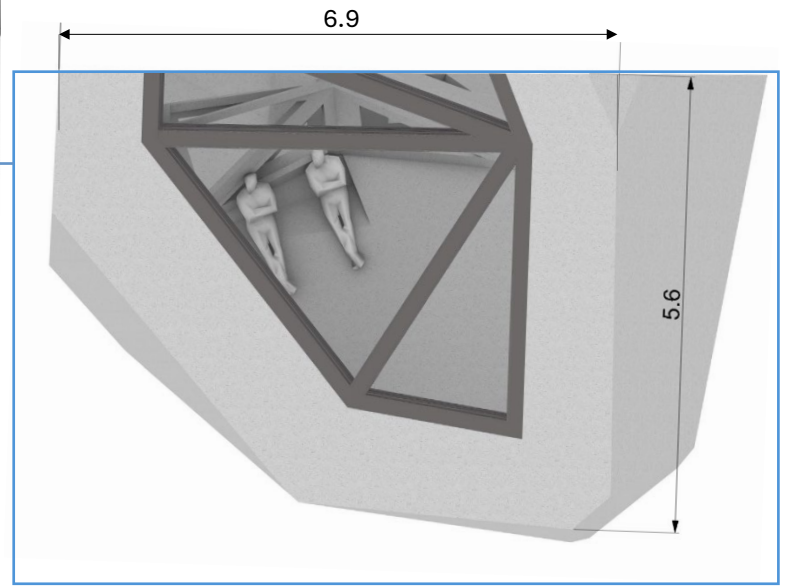
Fig. 1: Thin sections of randomly distributed carbon fibers (left) and nozzle-aligned carbon fibers at 1 (middle) and 3 percent by volume (right) (Rutzen et al., 2021).

Lauff, P., Pugacheva, P., Rutzen, M., Weiß, U., Fischer, O., Volkmer, D., Peter, M. A., & Grosse, C. U. (2021). Evaluation of the Behavior of Carbon Short Fiber Reinforced Concrete (CSFRC) Based on a Multi-Sensory Experimental Investigation and a Numerical Multiscale Approach. *Materials*, *14*(22), 7005. https://doi.org/10.3390/ma14227005

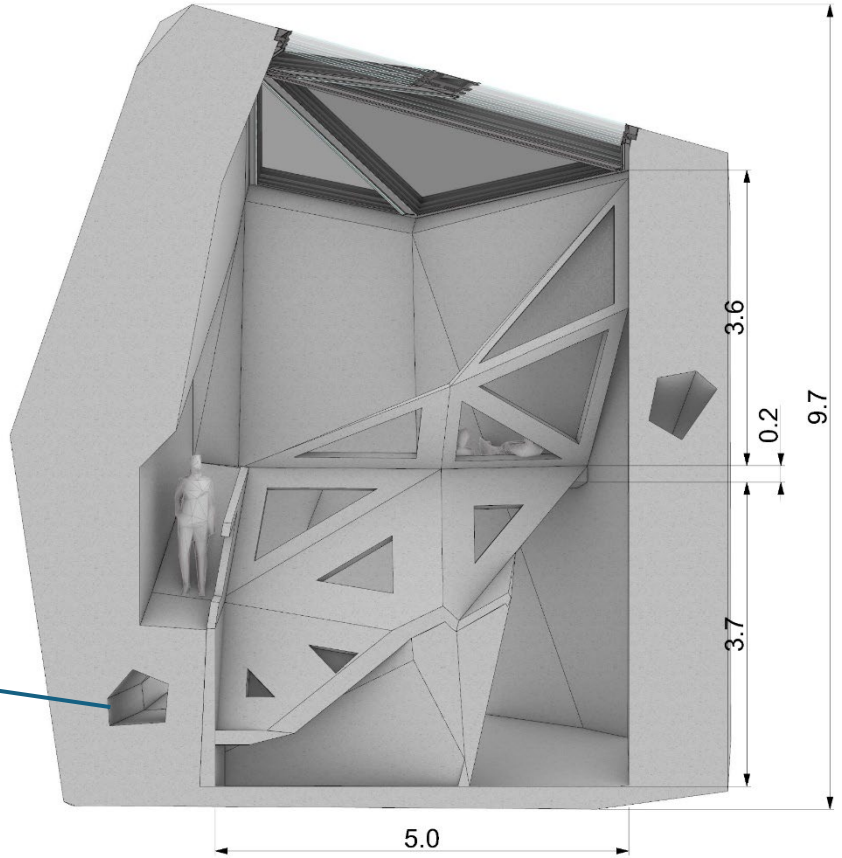
Fragment



Top view



Section



Wall cavity
for cables
and pipes

0 50 250

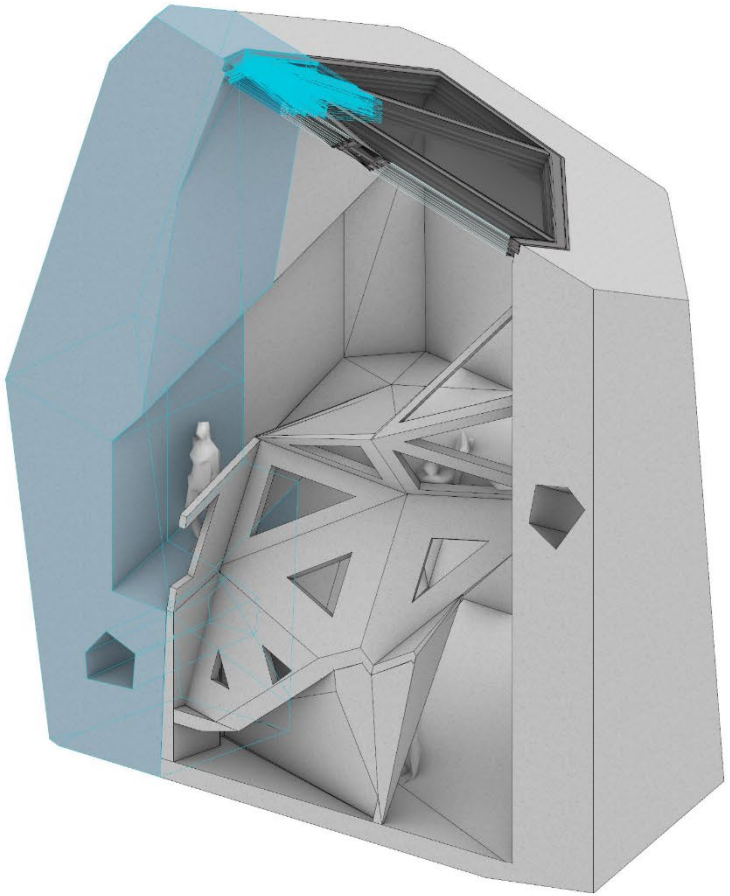
Workshop: component fabrication

Provides flexibility for Voronoi based geometry

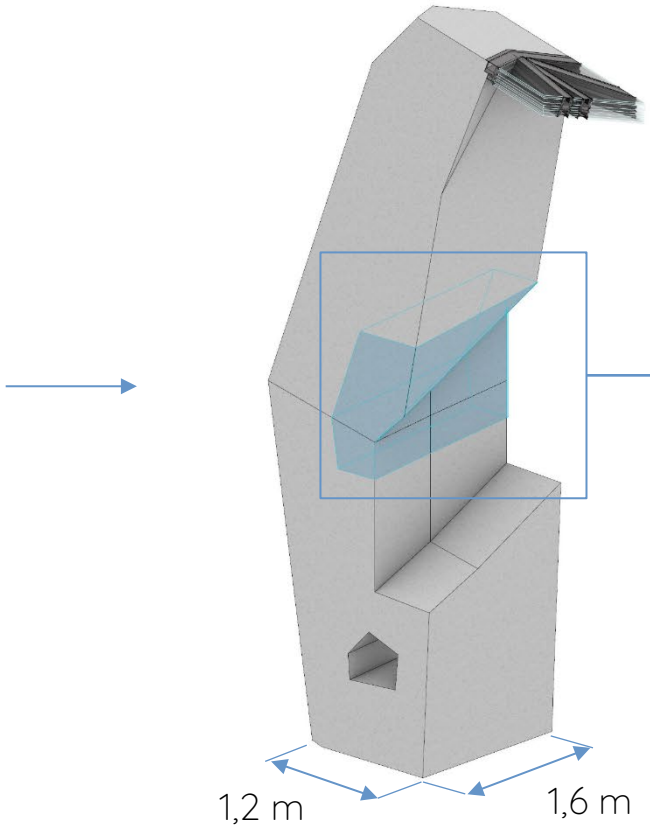
- Component adapted to form

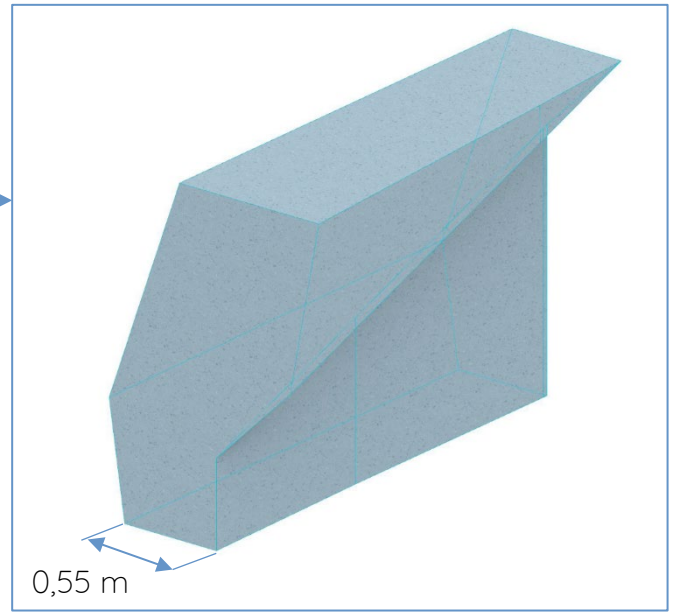
- Tested additive and subtractive method

Fragment

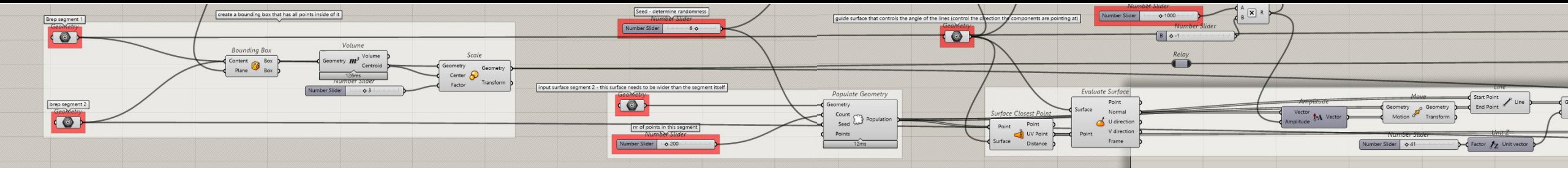


0 50 250 mm

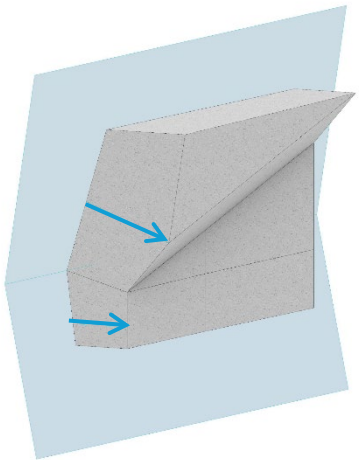




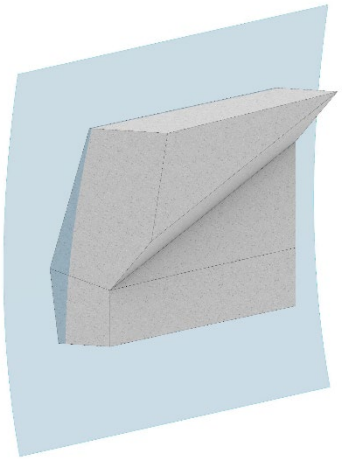
Component script



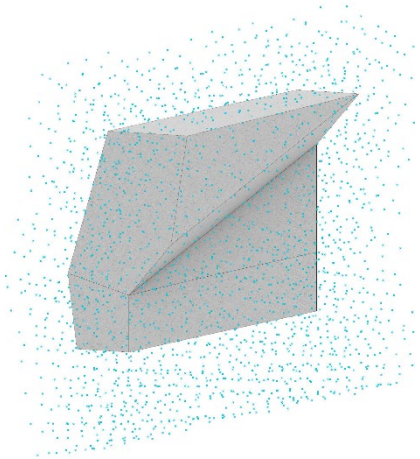
Component direction



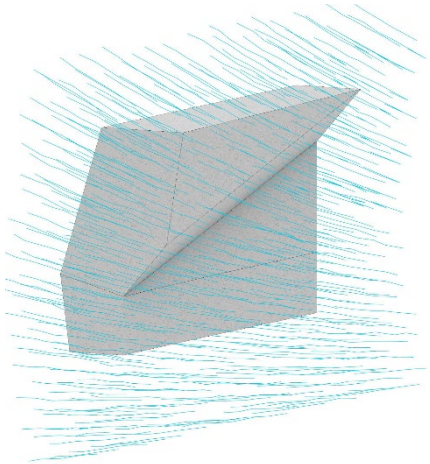
Smoothing surface



Populate with points

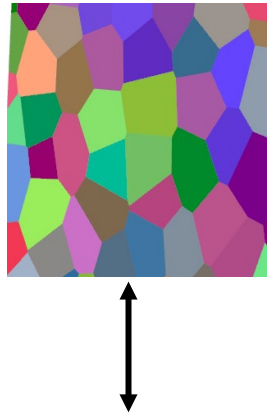
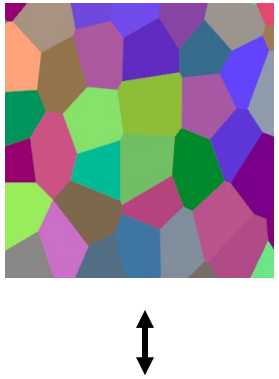
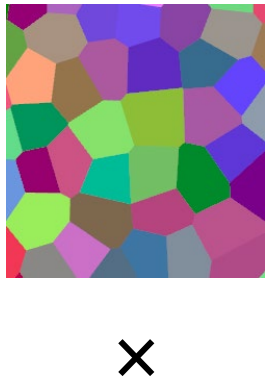
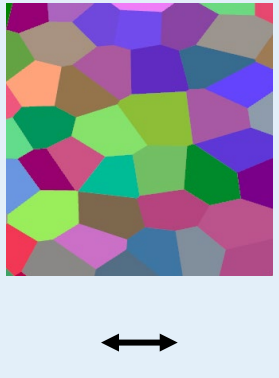
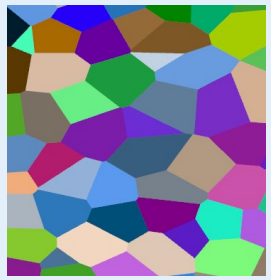
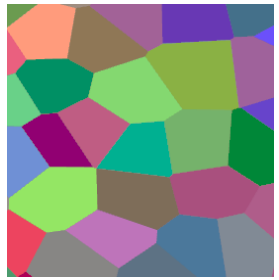
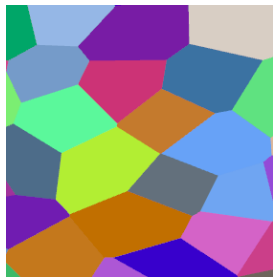
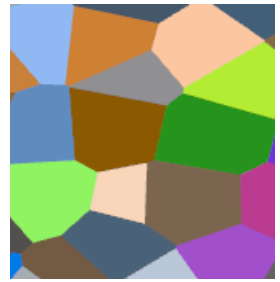


Component lines



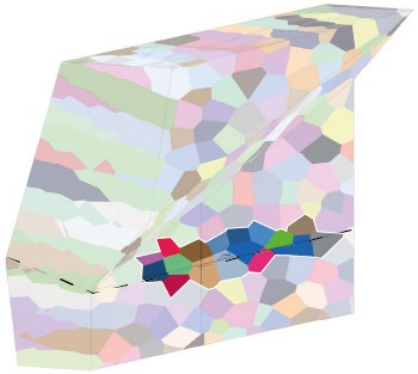
Voronoi components along lines

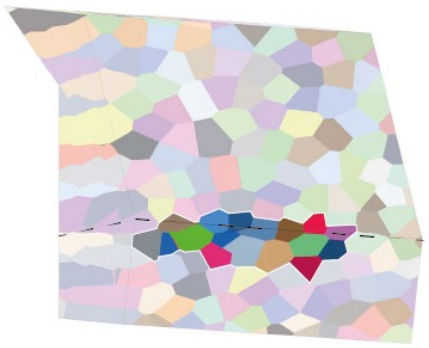
Evaluating components

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

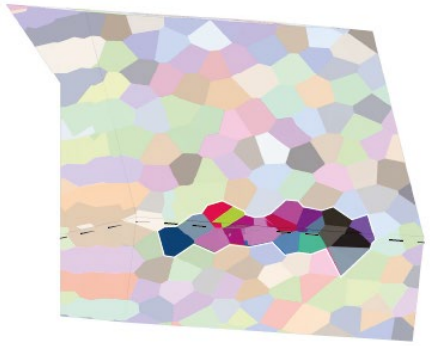
Evaluating components

Seed 1

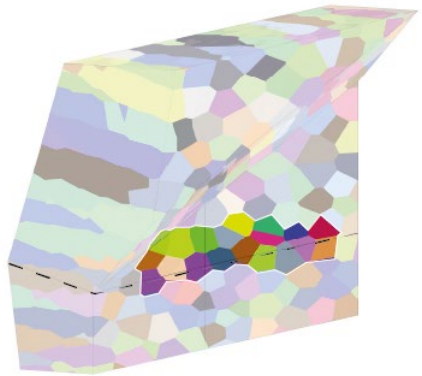




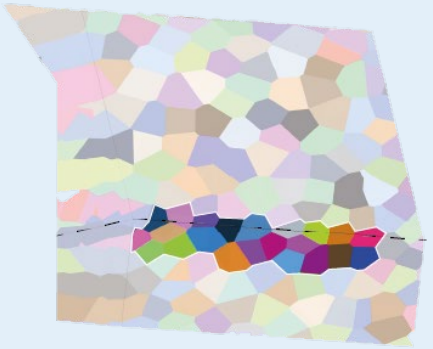
Seed 2



Seed 5

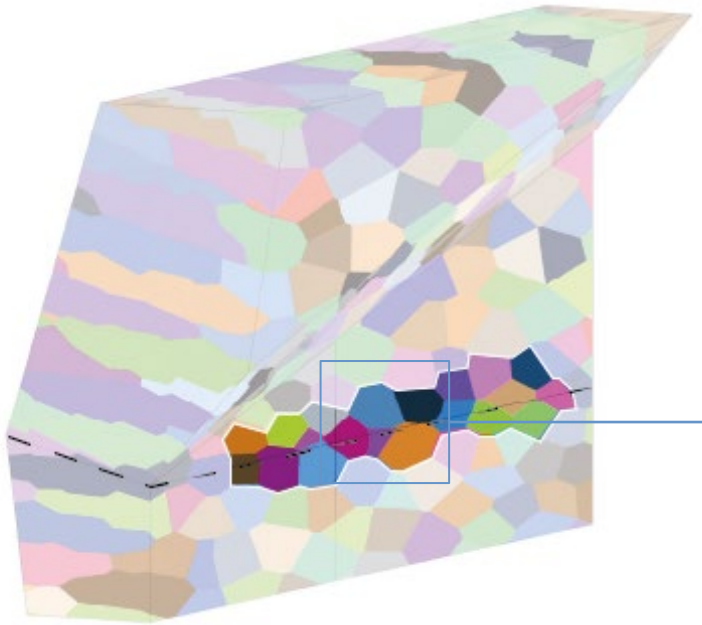


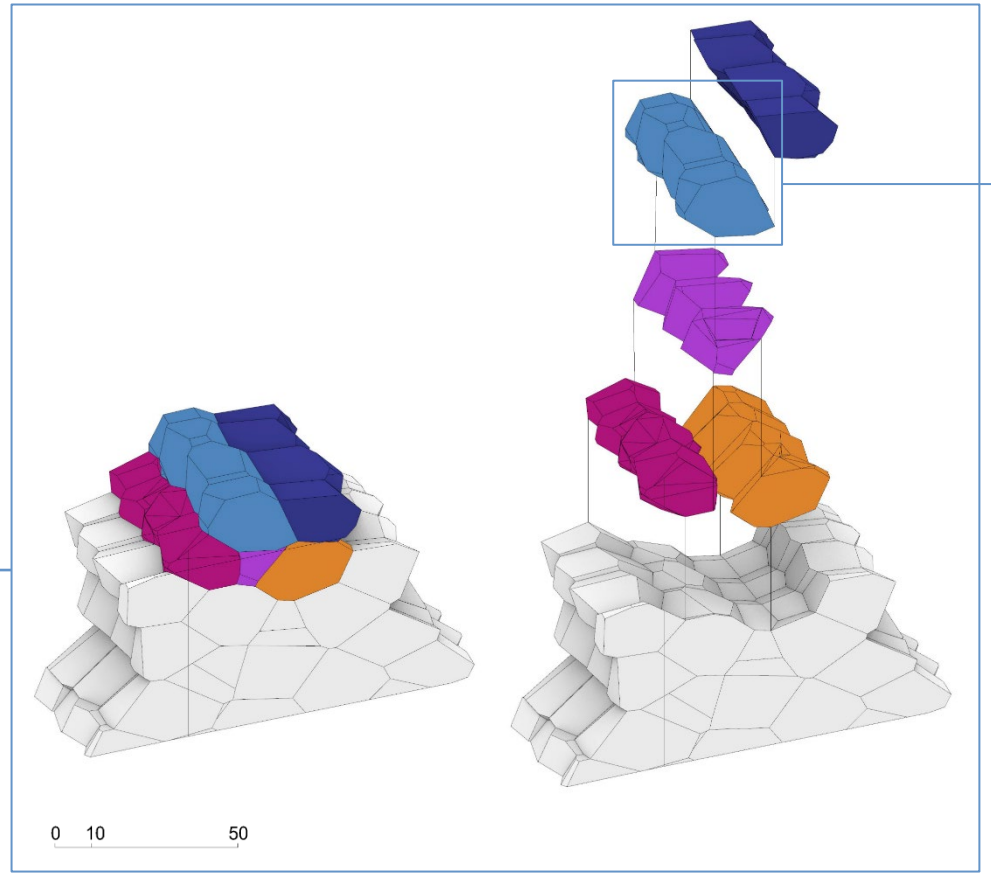
Seed 6



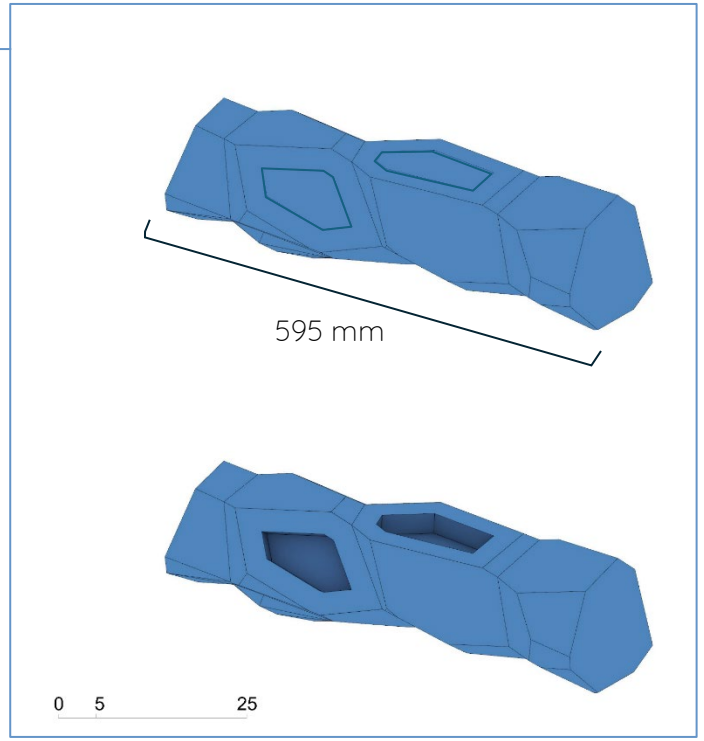
Evaluating components

Seed 6

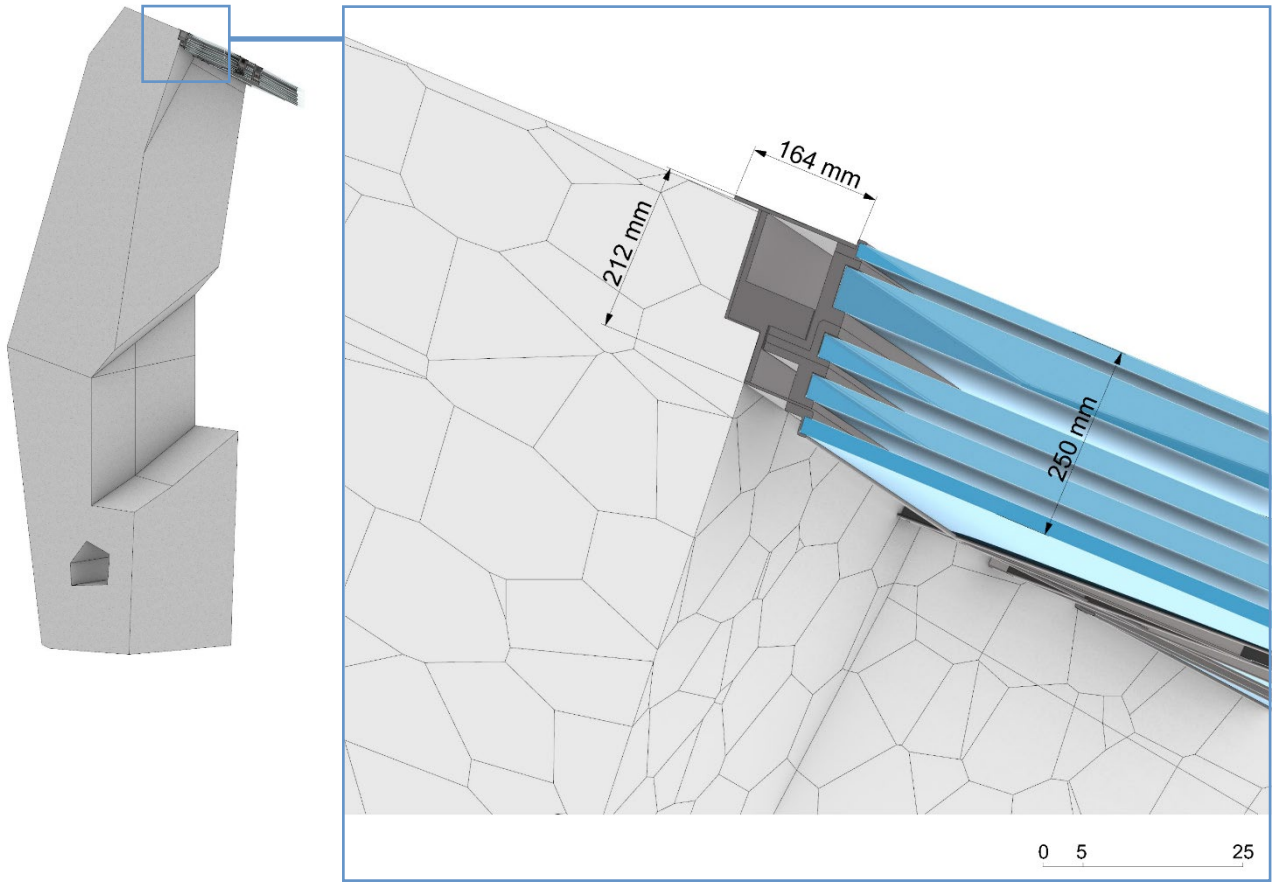


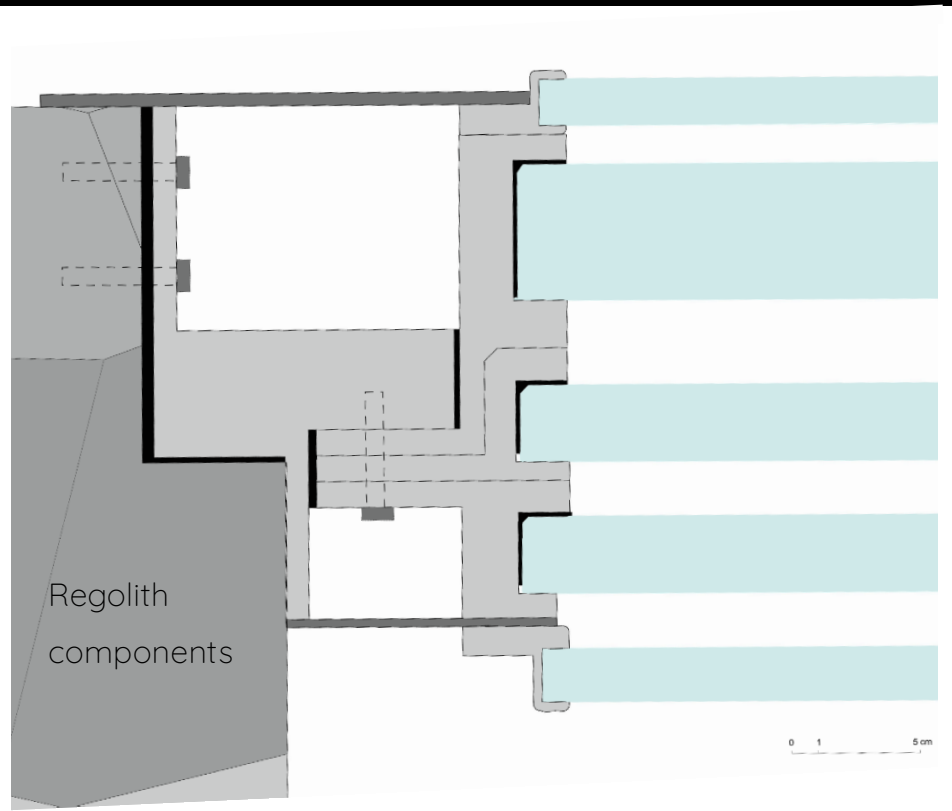


Add gripping holes for the robot



Detail 1: Window to structure





Windows ISRU

Compound	Concentration (%)
SiO_2	42-48
TiO_2	1-7
Al_2O_3	12-27
FeO	4-18
MgO	4-11
CaO	10-17
Na_2O	0.4-0.7
K_2O	0.1-0.6
MnO	0.1-0.2
Cr_2O_3	0.2-0.4

Silica – silicon dioxide

- Major component of Lunar Regolith: 42+%
- Extraction?
- 3D printing windows is possible

ISS windows: 4 layers of fused silica

Windowpanes ISRU

Compound	Concentration (%)
SiO_2	42-48
TiO_2	1-7
Al_2O_3	12-27

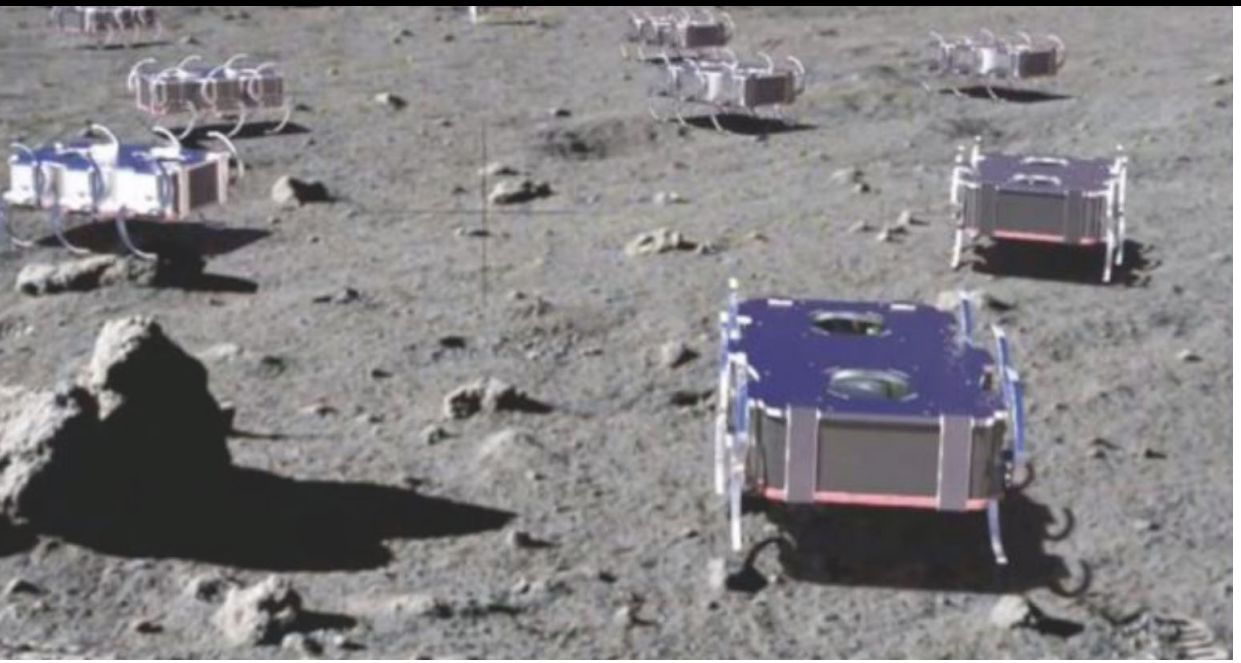
Source: ESA

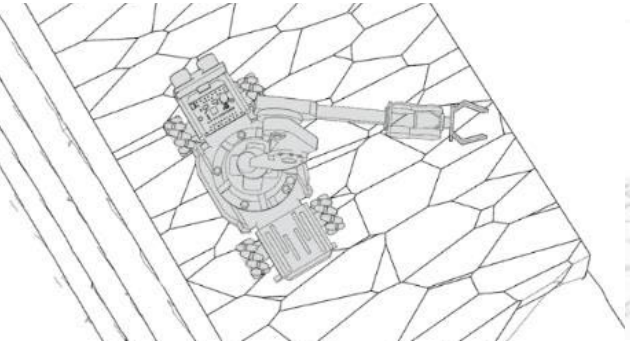
Metal alloy extraction

- Oxygen extraction Regolith:
  - Leaves a metal mix including aluminium
  - Oxygen as byproduct for life support

ISS windowpanes are from forged aluminium

Construction: swarm robotics





- Excavation
- Regolith collected by robot swarm
- Components 3D printed with Regolith
- Components carried to location by swarm
- Placed in location (human-robot interaction)

Construction: human-robot interaction

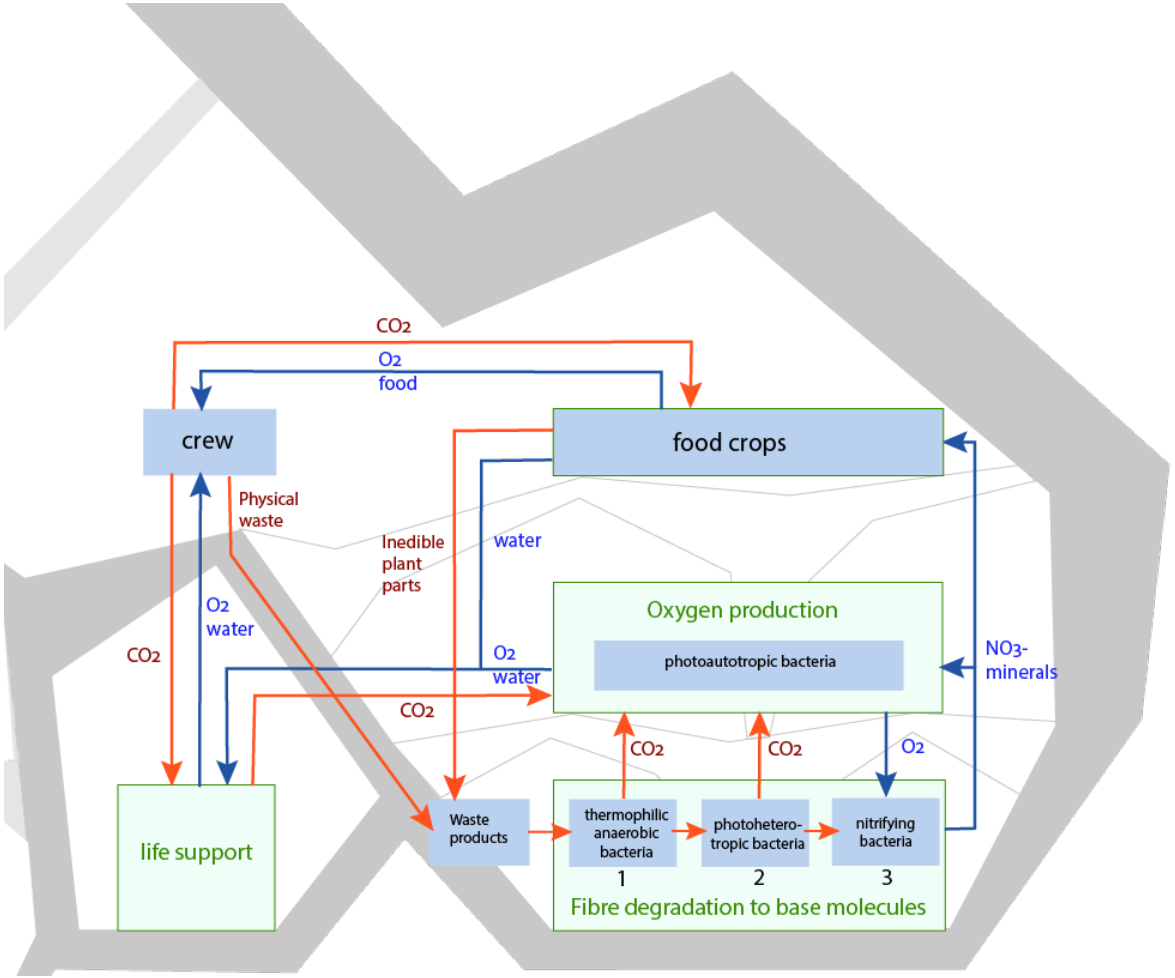
Combine strengths:

- Robot: heavy lifting
- Human: delicate motor skills

Robot learns

- End goal is to become **autonomous**

Life support: waste



MELiSSA research program

- Closing the waste loop using bacteria and algae

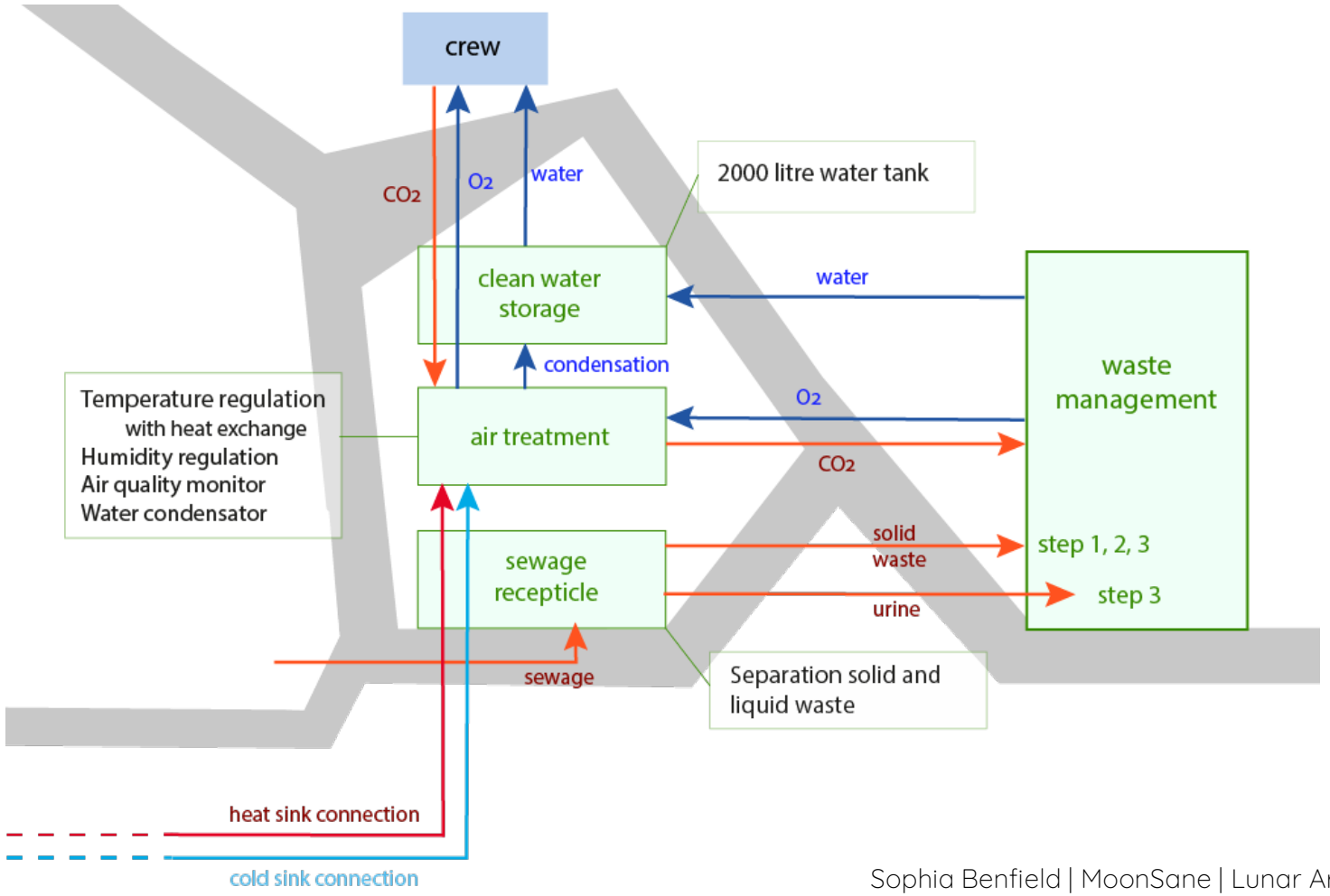
Closed compartment

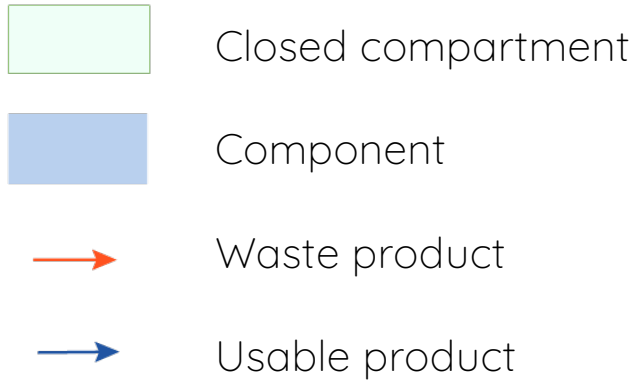
Component

Waste product

Usable product

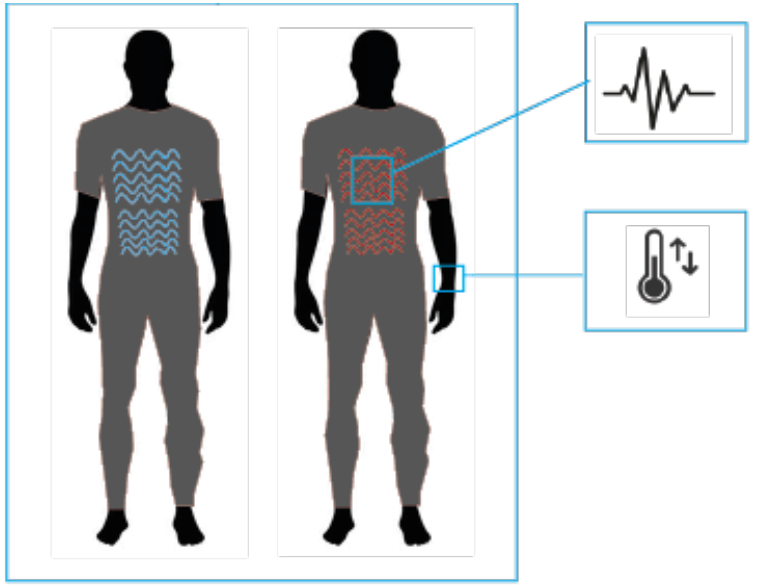
Life support: mechanical systems





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

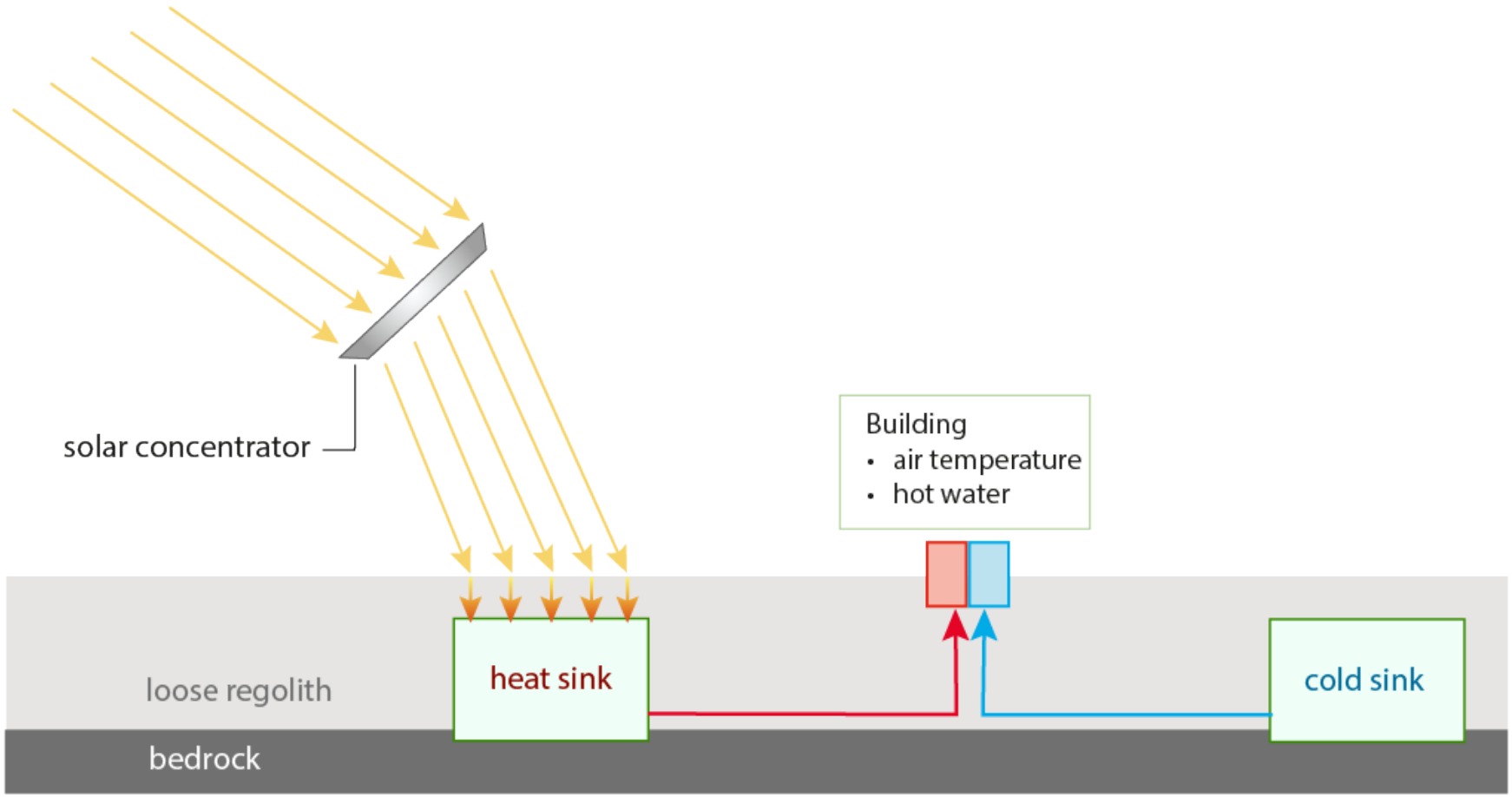


Smart textiles

Why personalisation?

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

Life support: heating/cooling



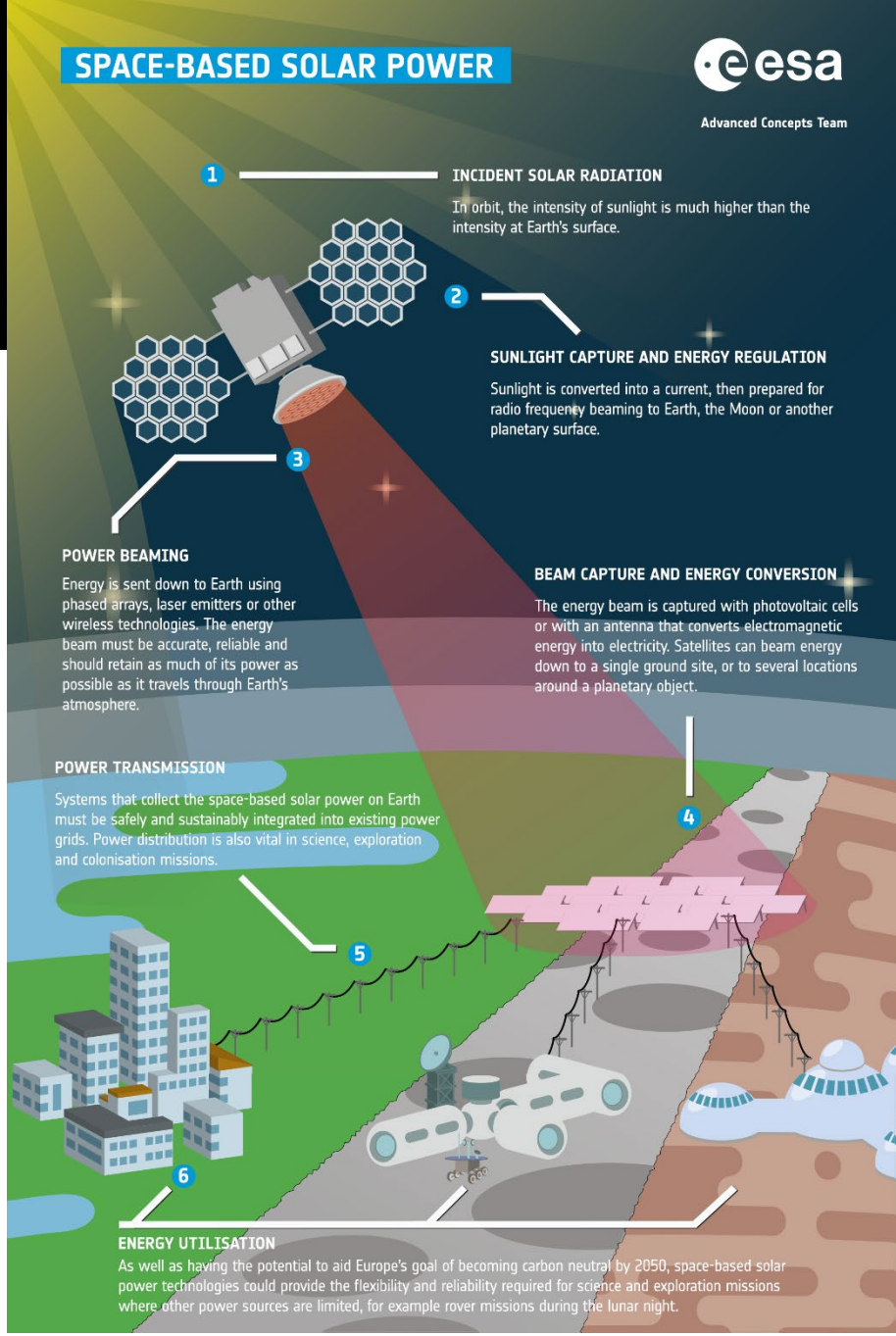
Heat and cold production

- Based on ESA research

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



Societal Relevance

Construction:

- In situ resource utilisation
- Stacking strategy according to catenary systems
- Robotic assembly

Climate:

- Closing the waste loop

Mental health improvement by spatial design:

- Pandemic
  - Confinement caused mental distress
- Medical facilities
  - Hospital, dentist etc.
- Working environment
  - Stress and burn-out prevention

Next steps

- Refine visuals
- Develop pattern strategy for meditation space screens
  - Which factors are relevant?
- Scale model of meditation space
  - Integrate colour changes lighting


Q & A