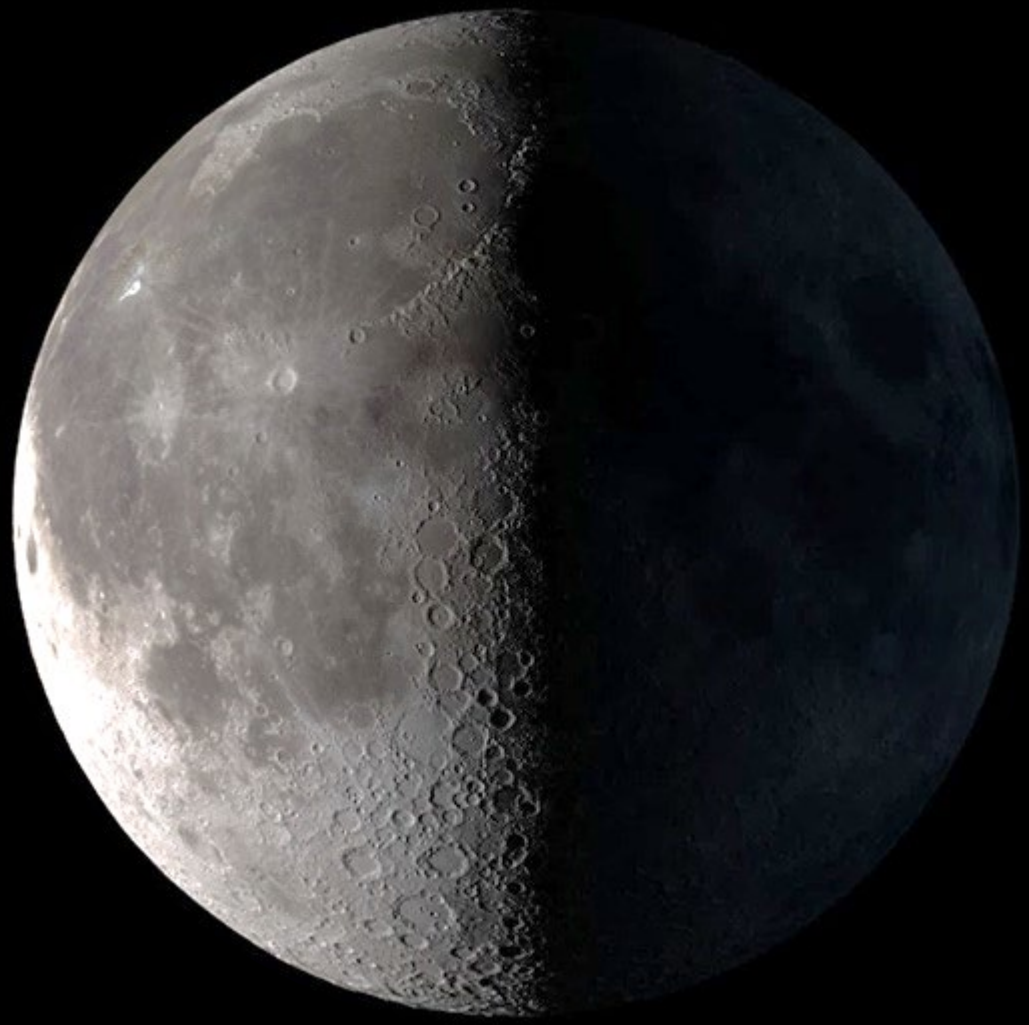
MoonSane

Designing Lunar Habitats for Improving Mental Wellness

Sophia Benfield | MoonSane | Lunar Architecture | Tutor: H. Bier & A. Hidding | 2024/25 | TU Delft

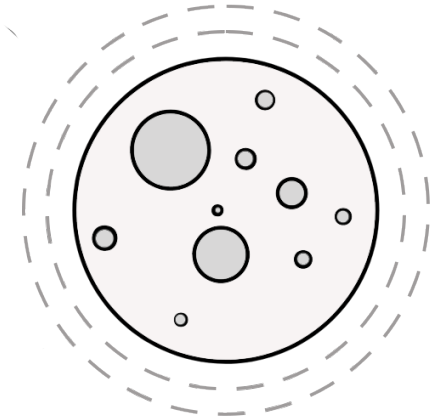
Approaching Lunar Architecture

Blank Canvas

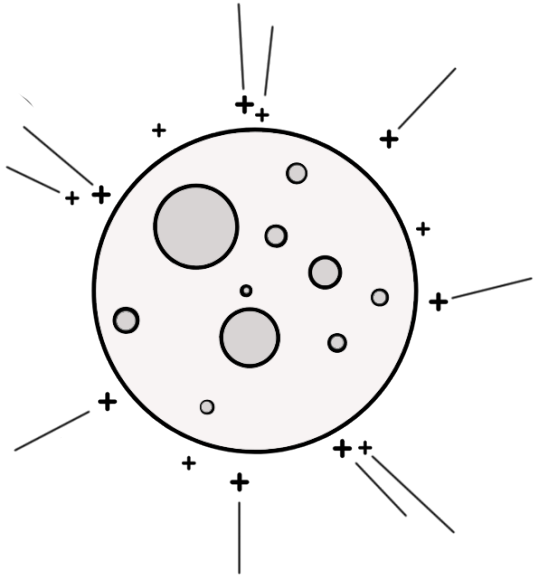


Extreme Environment

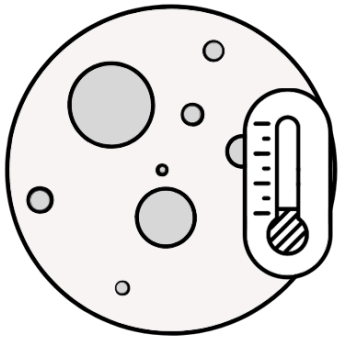
Surface conditions



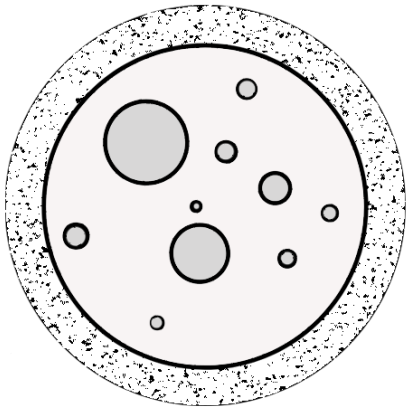
No atmosphere



High radiation levels



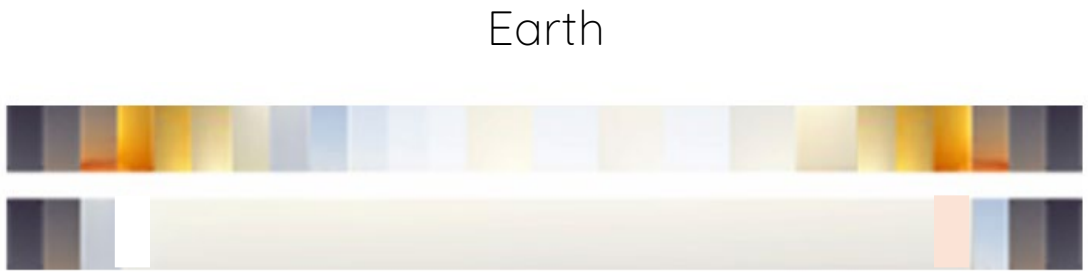
Extreme temperatures



Regolith layer

Day/night cycle

- 1 Moon day = 28 Earth days
  - Circadian rhythm Earth: 24 hours
- Disrupted rhythm affects
  - Sleep, alertness and mental health



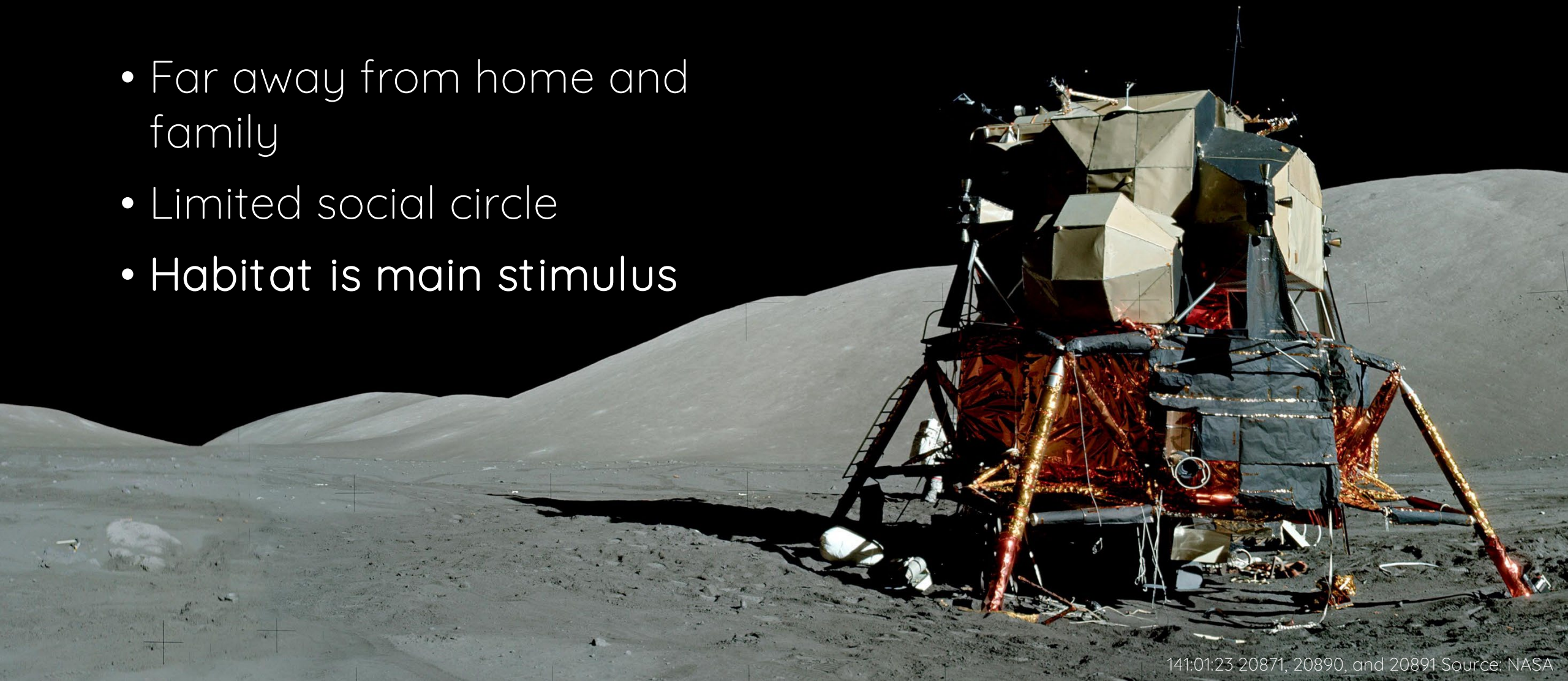
Views

AS17-136-20411-20425 Source: NASA

AS17-138-21063 (OF300) Source: NASA

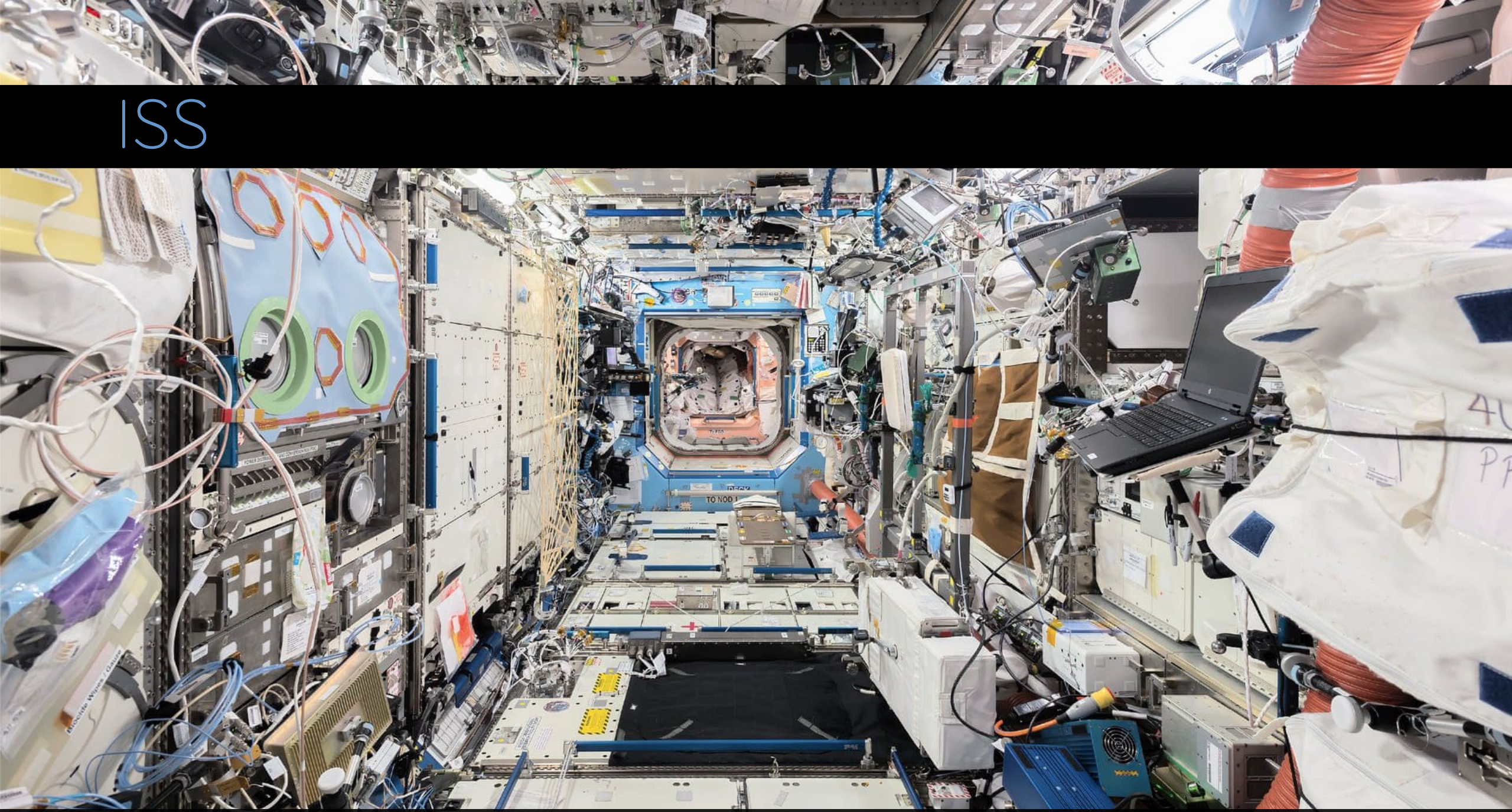
Habitat conditions

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

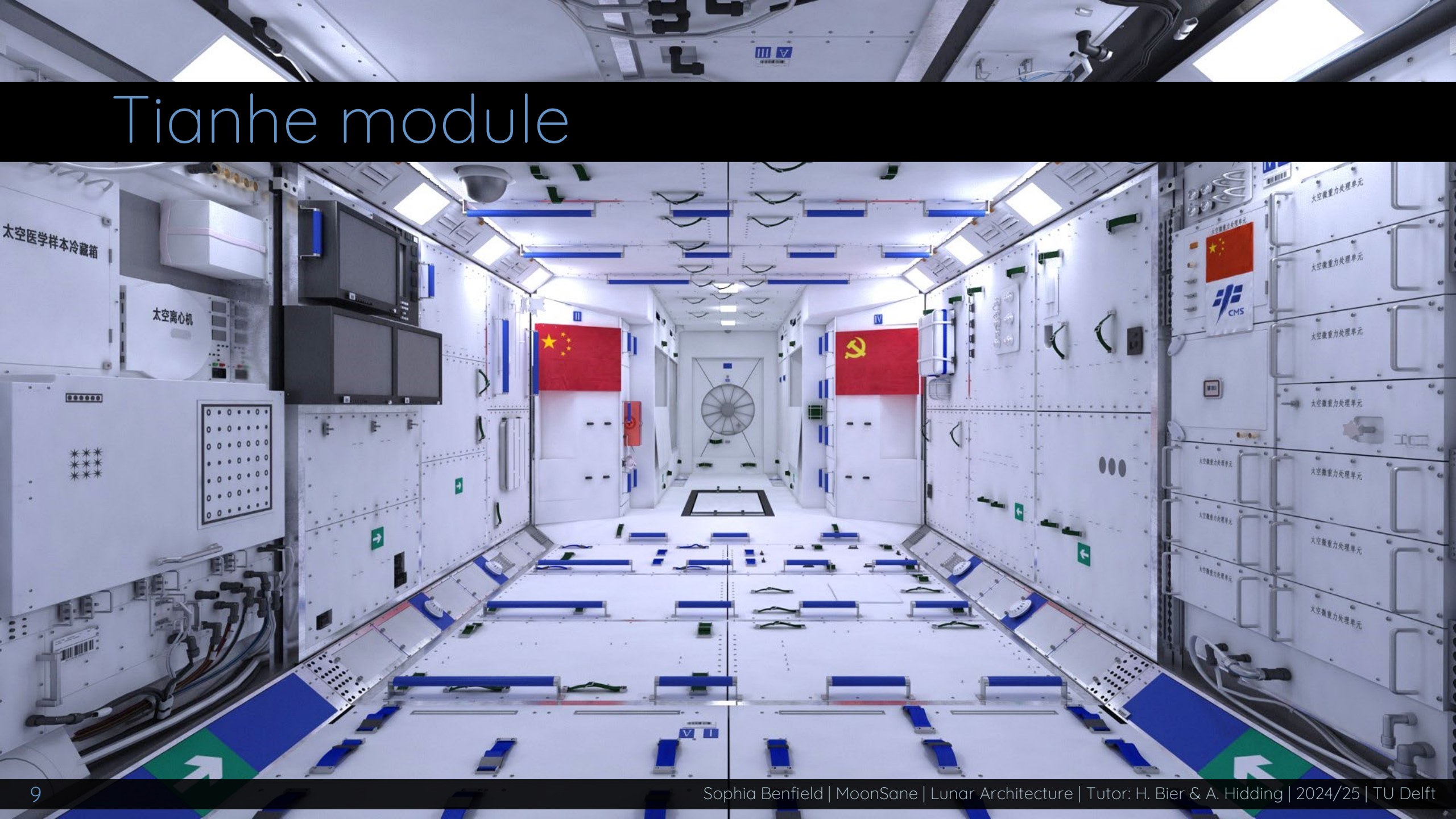


141:01:23 20871, 20890, and 20891 Source: NASA

ISS

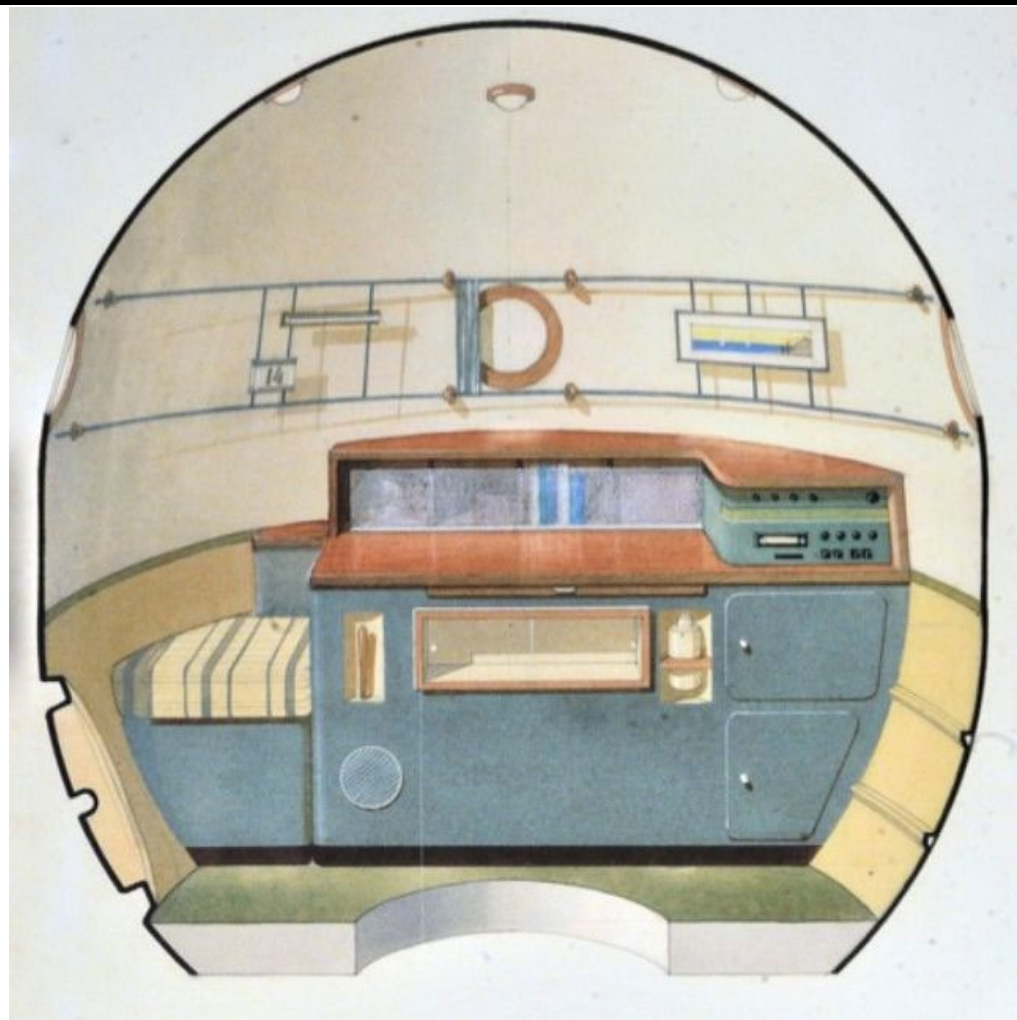


Tianhe module



Galina Balashova

- Colour to distinguish floor from ceiling in 0-gravity
- Added own artwork as embellishment of the interior



“The more tools you can give people to maintain a good psychological state, the more successful the mission is likely to be,”

- Jay Buckey

(former astronaut and Professor of Medicine)

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

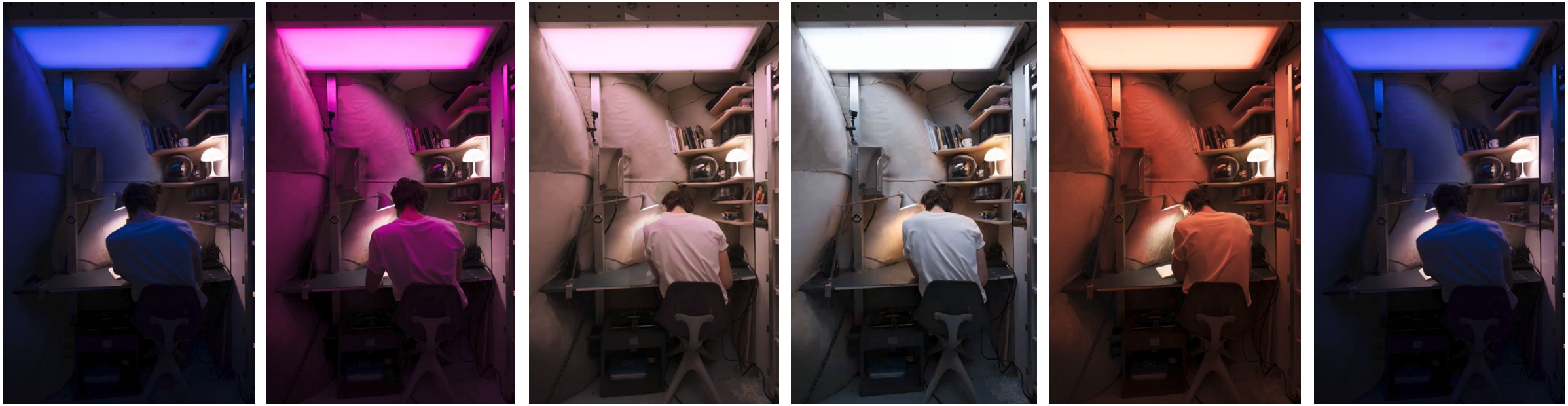
Logan M. Smith, "The psychology and mental health of the spaceflight environment: A scoping review." *Acta Astronautica 201*, 2022, 496-512, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2022.09.054.

Additional possibilities

- Spatial geometry
- Screens simulating windows

Light

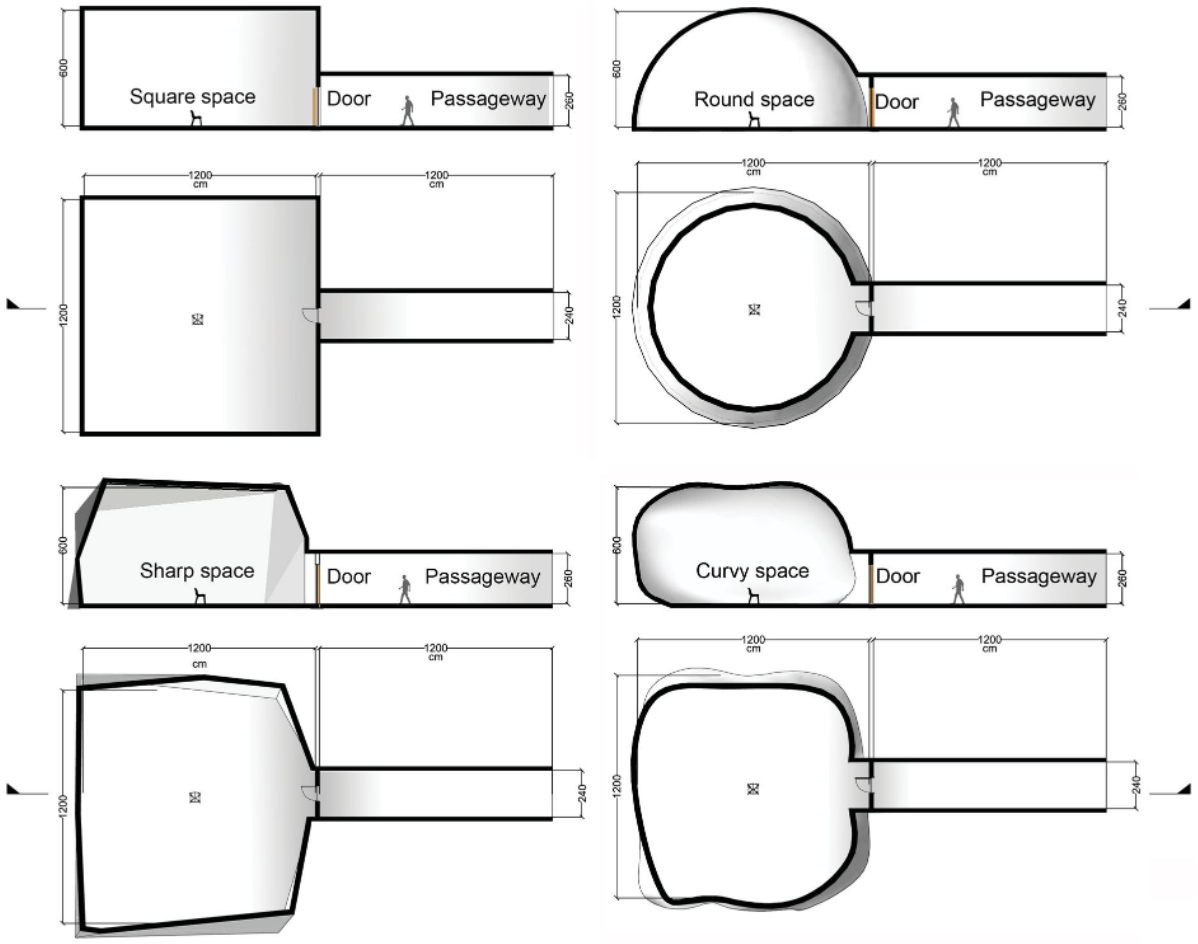
- Experiment: circadian rhythm lamps in the LUNARK module
  - “Waking up to a sunrise inside our sleeping pods was an incredible natural feeling ”
  - Stationary



Spatial geometry

Study using VR

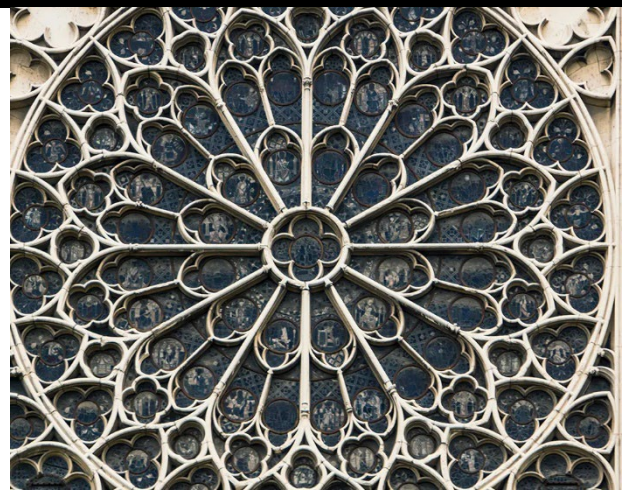
- Asymmetric spaces general preference
- Curved: leisure activities
- Angular: studying/working

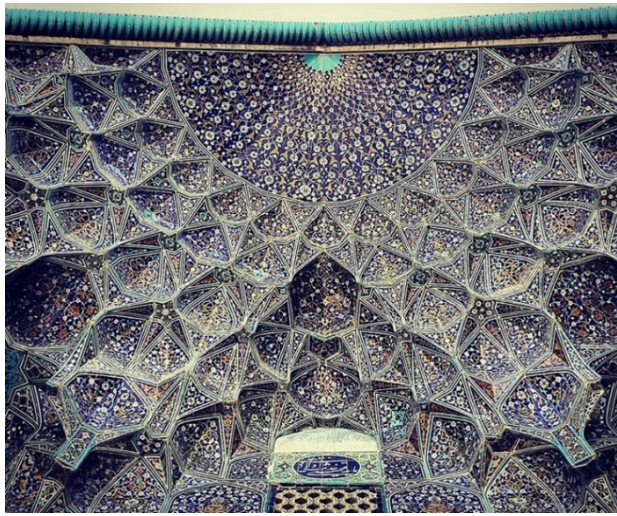


Shemesh, A., Talmon, R., Karp, O., Amir, I., Bar, M., & Grobman, Y. J. (2016). Affective response to architecture – investigating human reaction to spaces with different geometry. *Architectural Science Review*, *60*(2), 116–125.

Geometry: fractal patterns

- Repeating shapes
  - Calming effect
  - Hidden in nature: biophilia
- Dynamic fractal patterns
  - Light through foliage
  - Light reflection on water

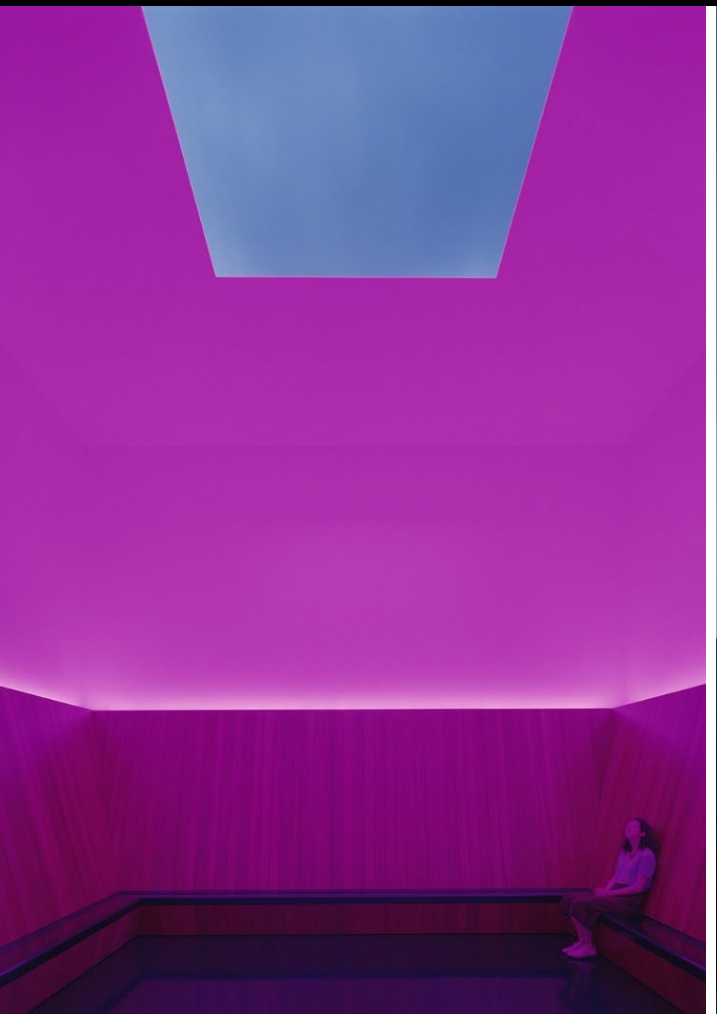



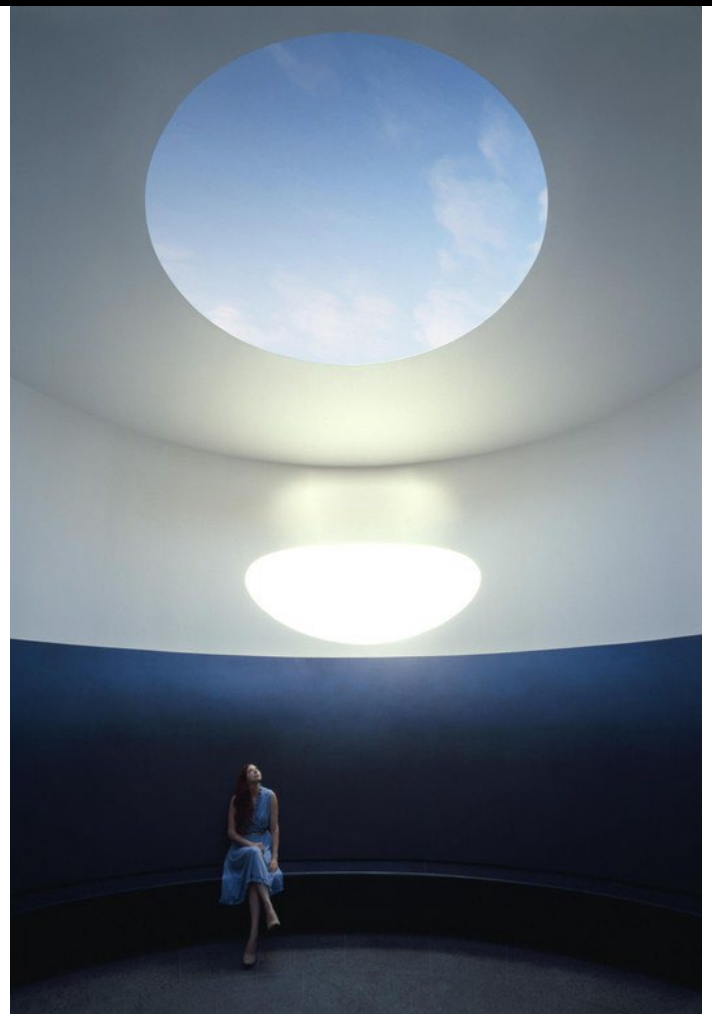


Real views: Earth gazing

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

Real views: 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 that monitors wellbeing of crew members
  - influence/transform emotions as well?

https://studentawards.mediaarchitecture.org/mab/project/11

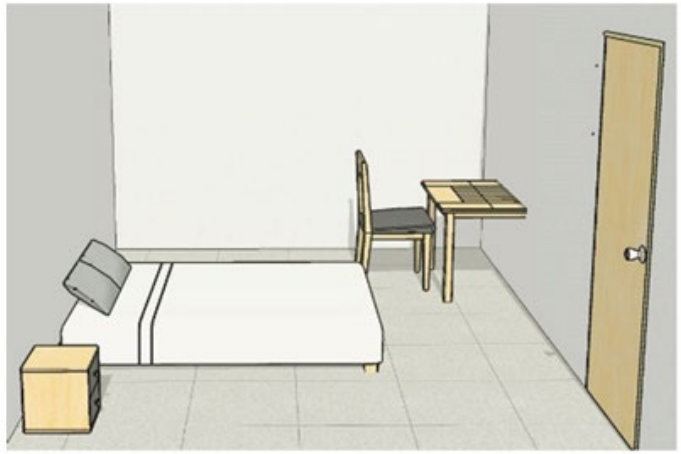
Artificial views

Space habitat simulation 7-day trial

- He, X., & Jiang, A. (2023, July).

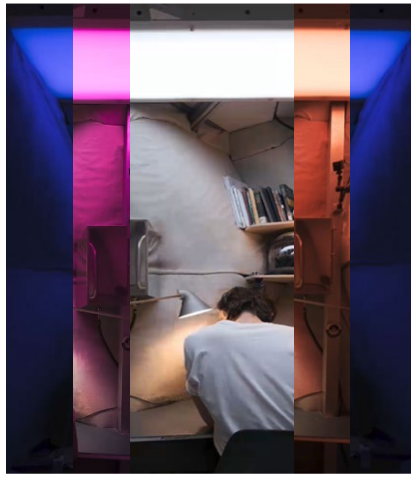
- Virtual Reality experiment
- 20 people in isolation **with or without** artificial views of nature

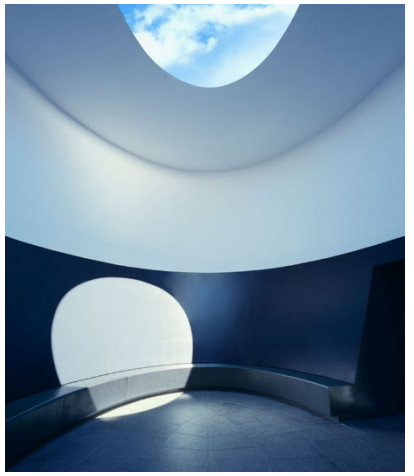
- Decreased feeling of isolation
- Needs to be a nature view



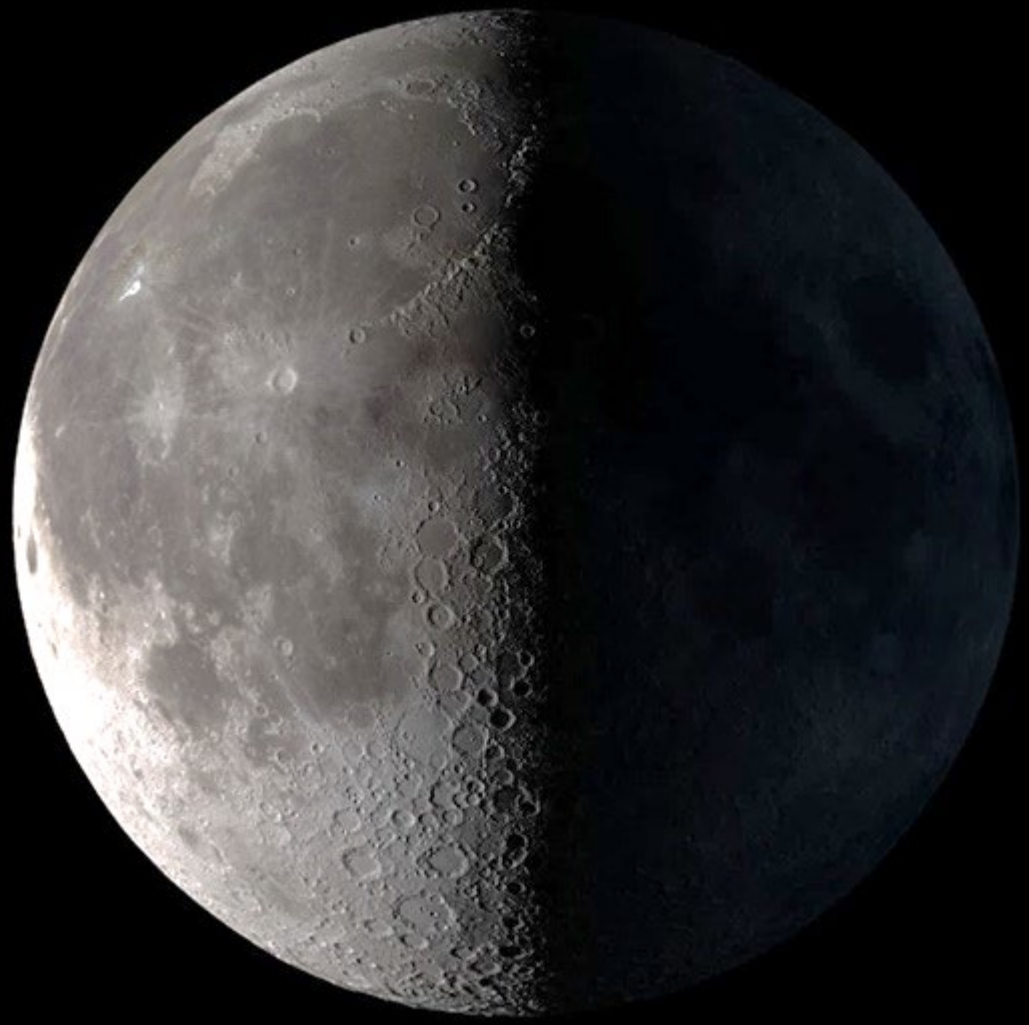
Concept

Designing a Lunar habitat that promotes mental wellness of the crew





Designing Lunar Architecture



Location: Earth view

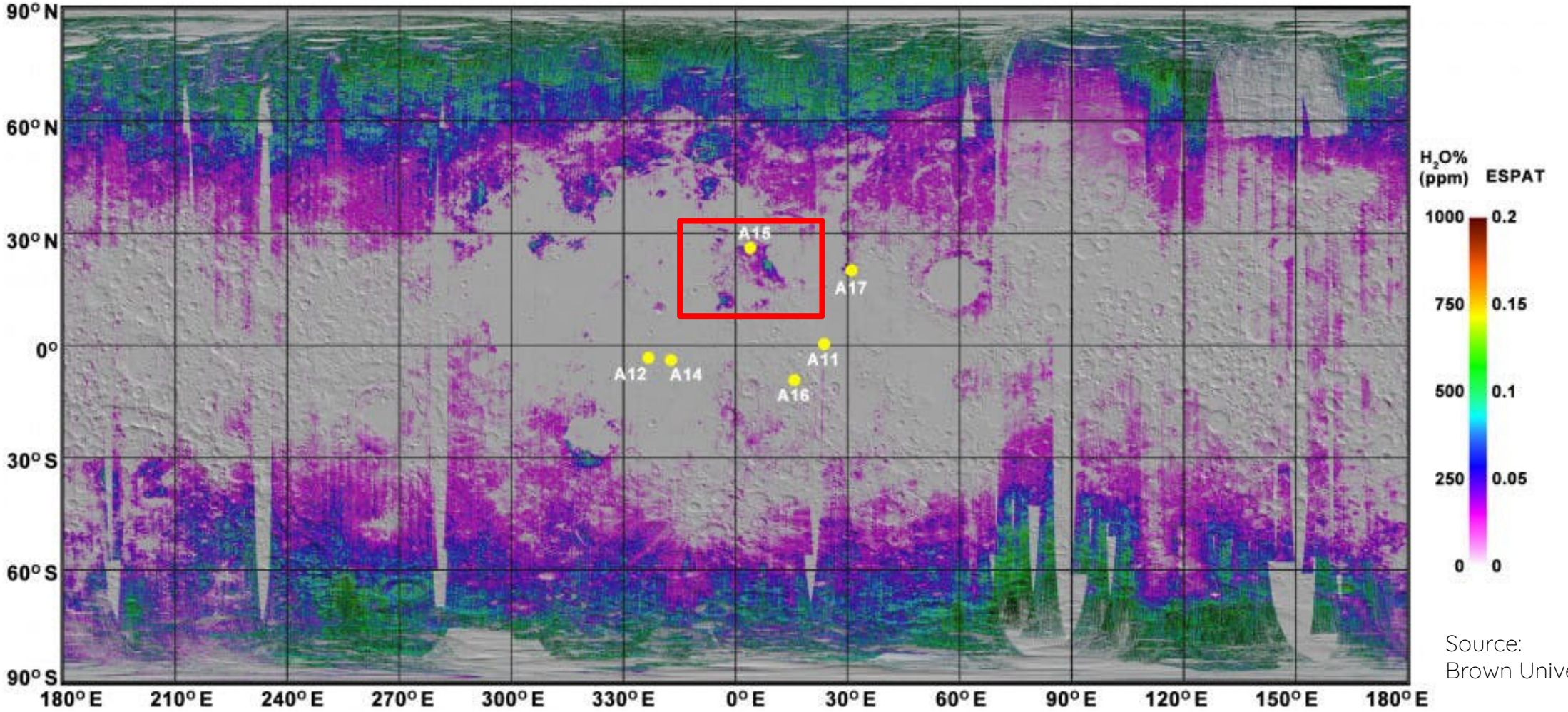
Lunar Equator

- Earth directly overhead
- Desirable for earth view from above

Lunar Poles

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

Location: water



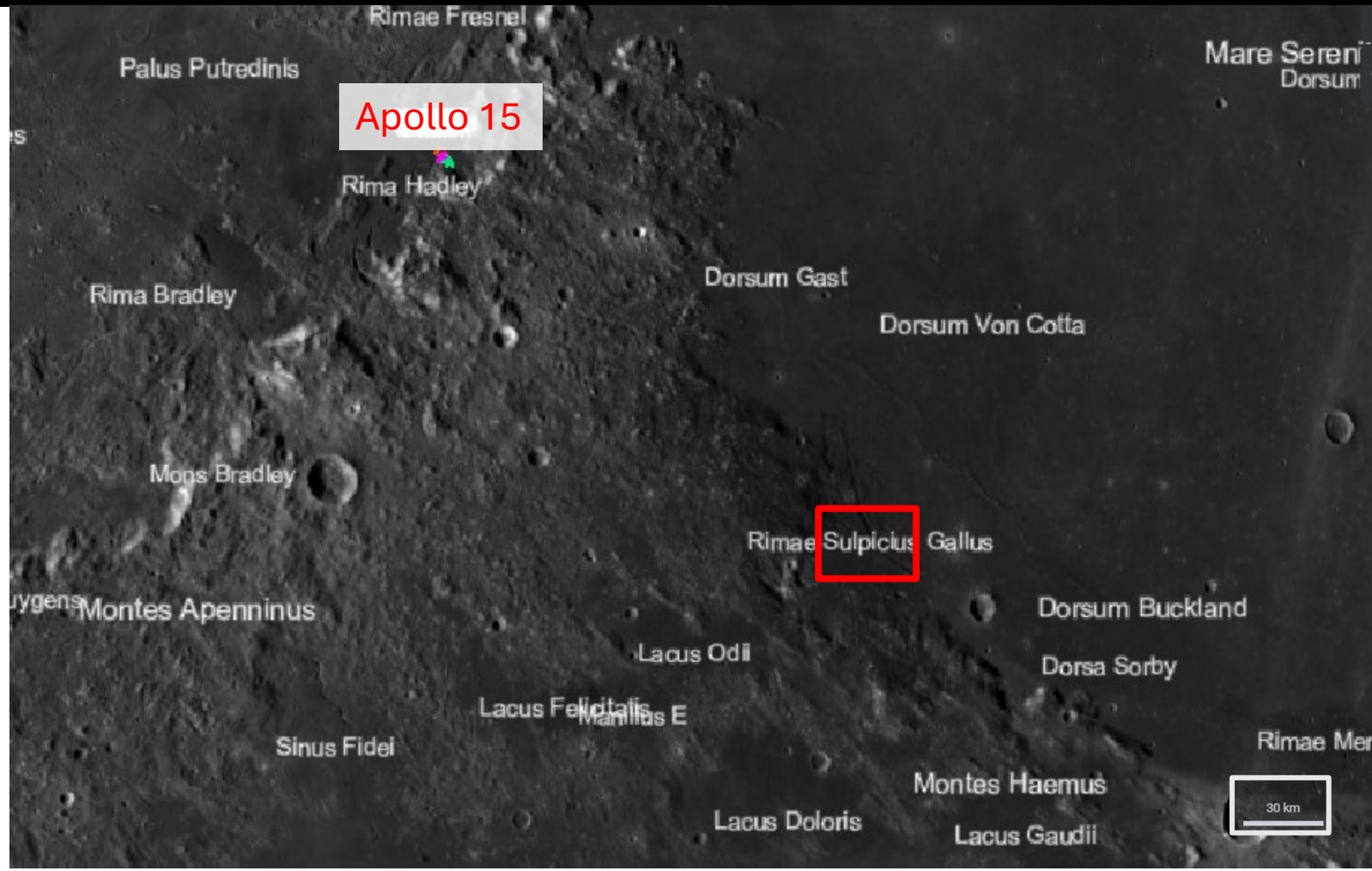
Source:
Brown University

Location: Mare Serenitatis

Near landing site Apollo15

- *Montes Apenninus*

Edge of *Mare Serenitatis*

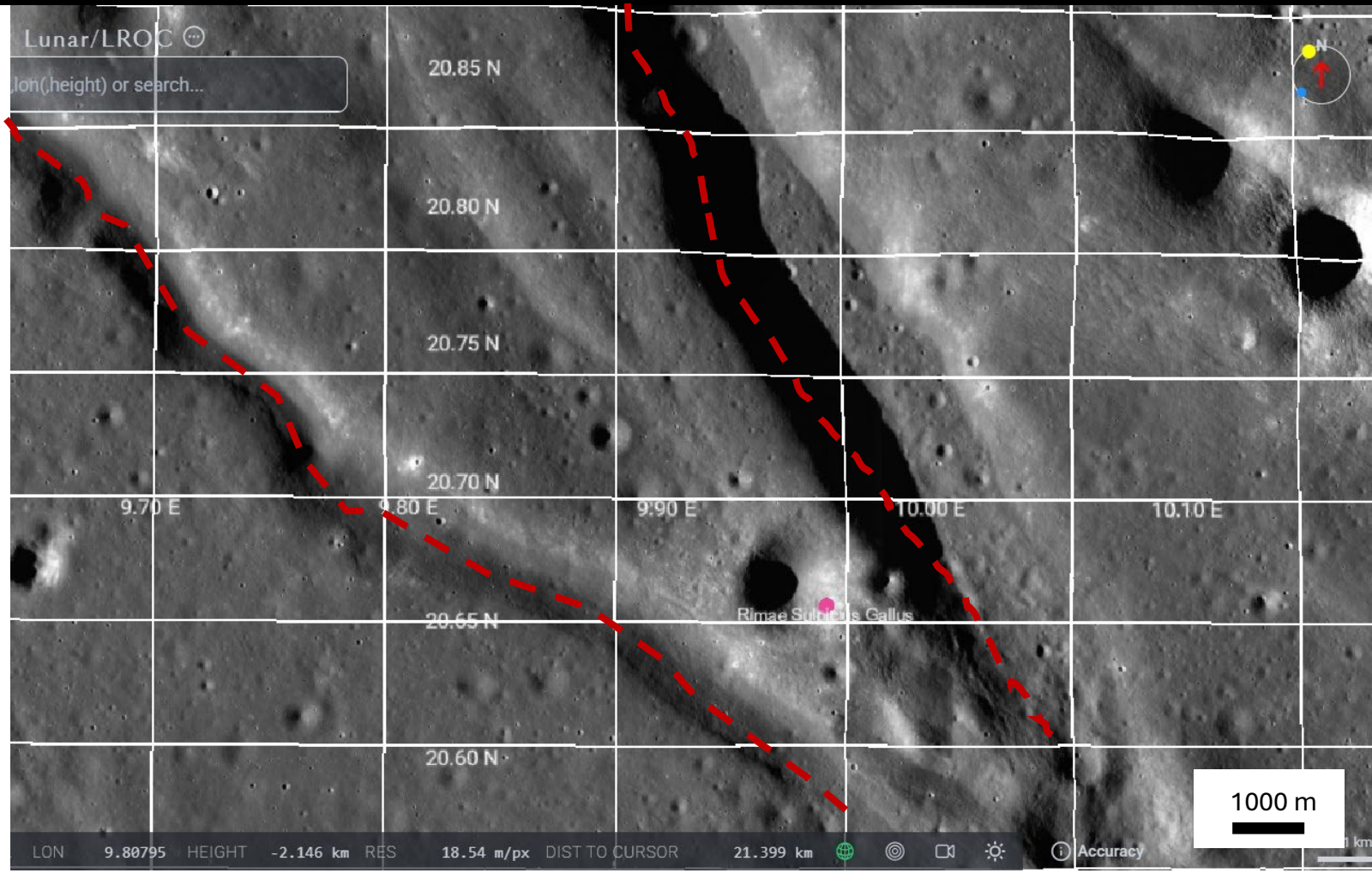


Source: Lunar/LROC Quickmap

Location: Mare Serenitatis

Edge of *Mare Serenitatis*

- *Rimae Sulpicious Gallus*
- Narrow depressions in surface



Source: Lunar/LROC Quickmap

Program: requirements

ESA-CDF:

“ Minimum accommodation functionalities:

- Sleeping space, ideally private quarters
- Dining and communal activities
- Workspace
- Exercise area and equipment
- EVA suit donning and doffing
- Medical care
- Hygiene
- Translation portals or pass-throughs
- Stowage area ”

(p 59-60)

“Minimum net habitable volume of about

80m3 per person”

(p 60)

Program: translating to 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

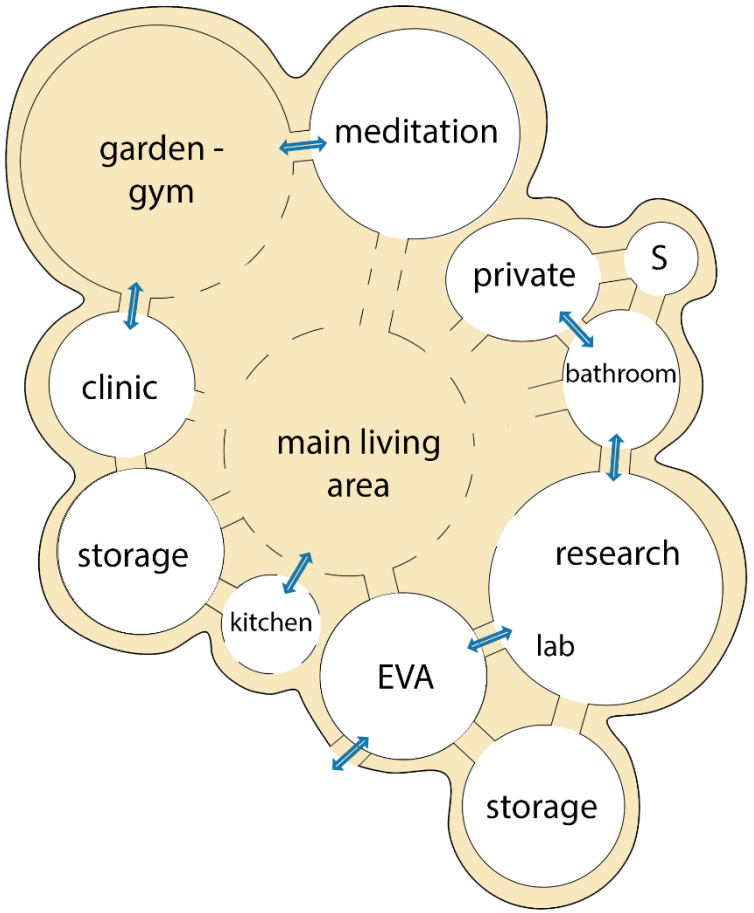
Additional rooms

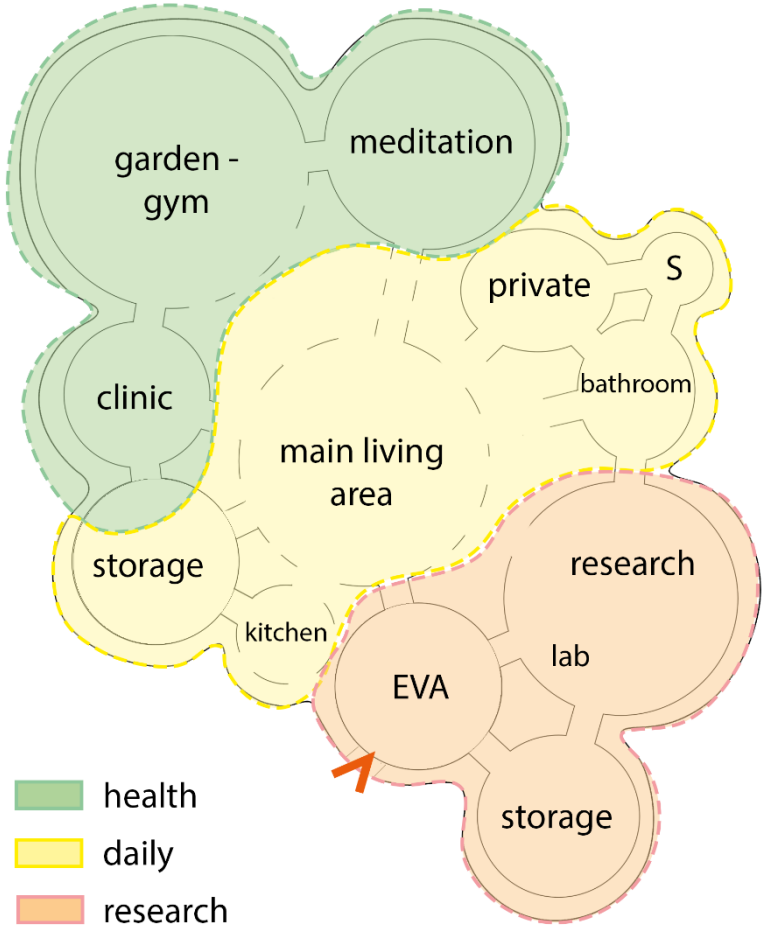
- Garden
- Meditation space
  - earth viewing

Program: 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





Connecting 3D: compact

- Garden underutilised
- Kitchen impractical
- No clear zoning

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

Connecting 3D: double atrium

- Garden new atrium – lower level
- Views: needs met

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

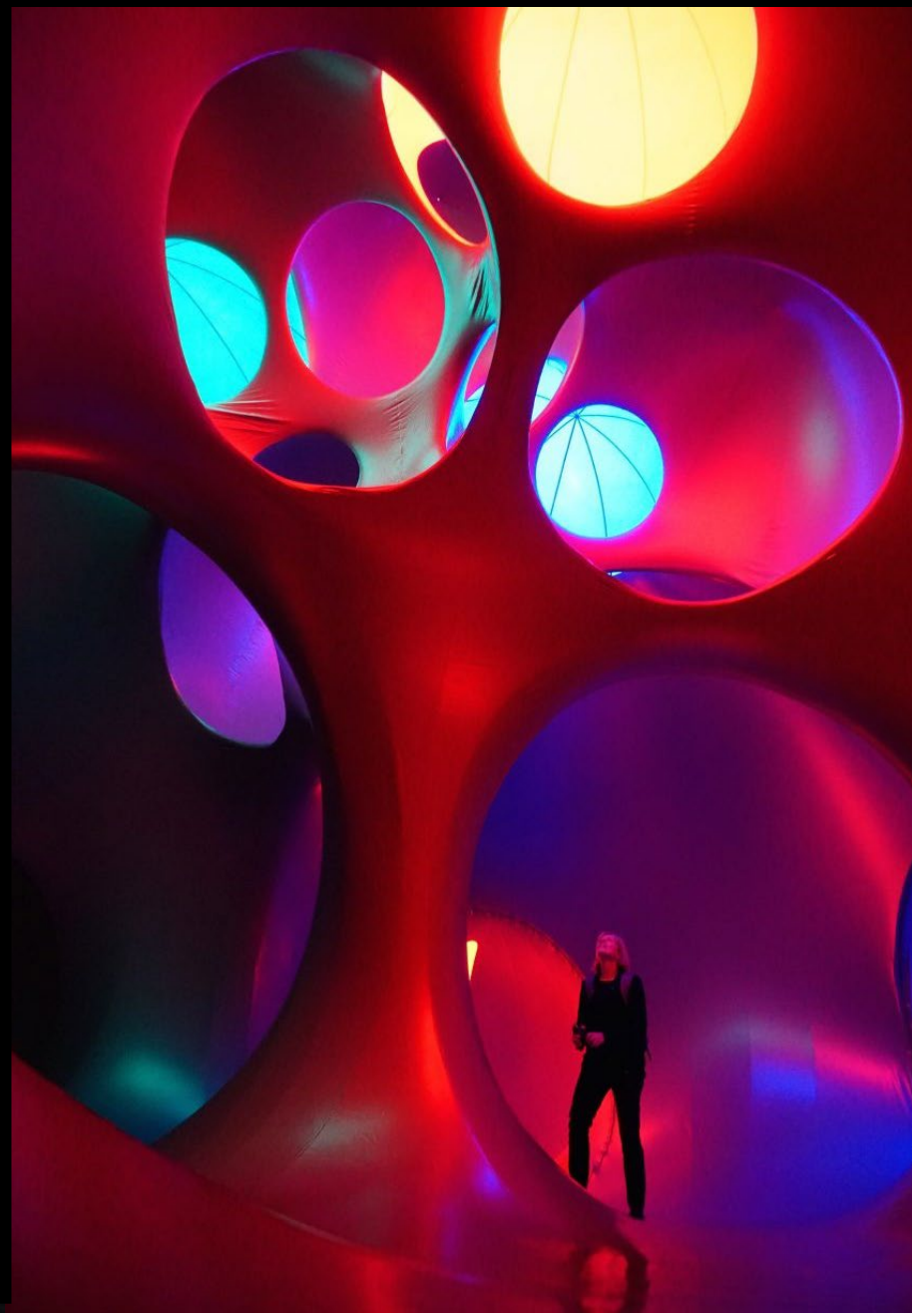
Spatial connection

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

Lava tube mission

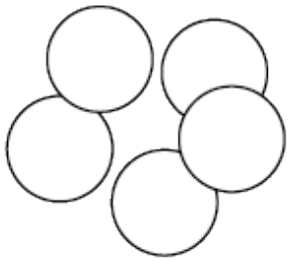
- Corridors: Dynamic views

Corridor views: Daedalum



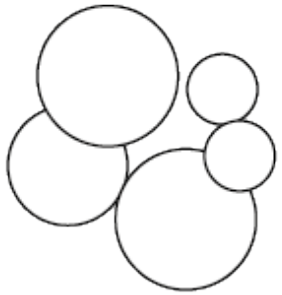
Porosity: computational script

1.Create spheres



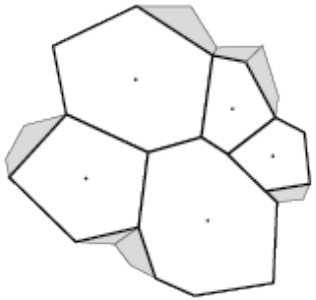
Variables:
- Manual adjustment of position

2. Adjust volume to function



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

3. Create Voronoi cells

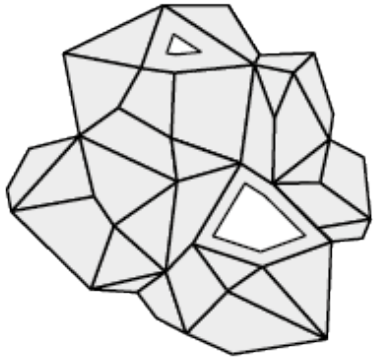


Variables:
- Neighbourhood point count
- Seed
- Sphere position

4. Adjust porosity to function

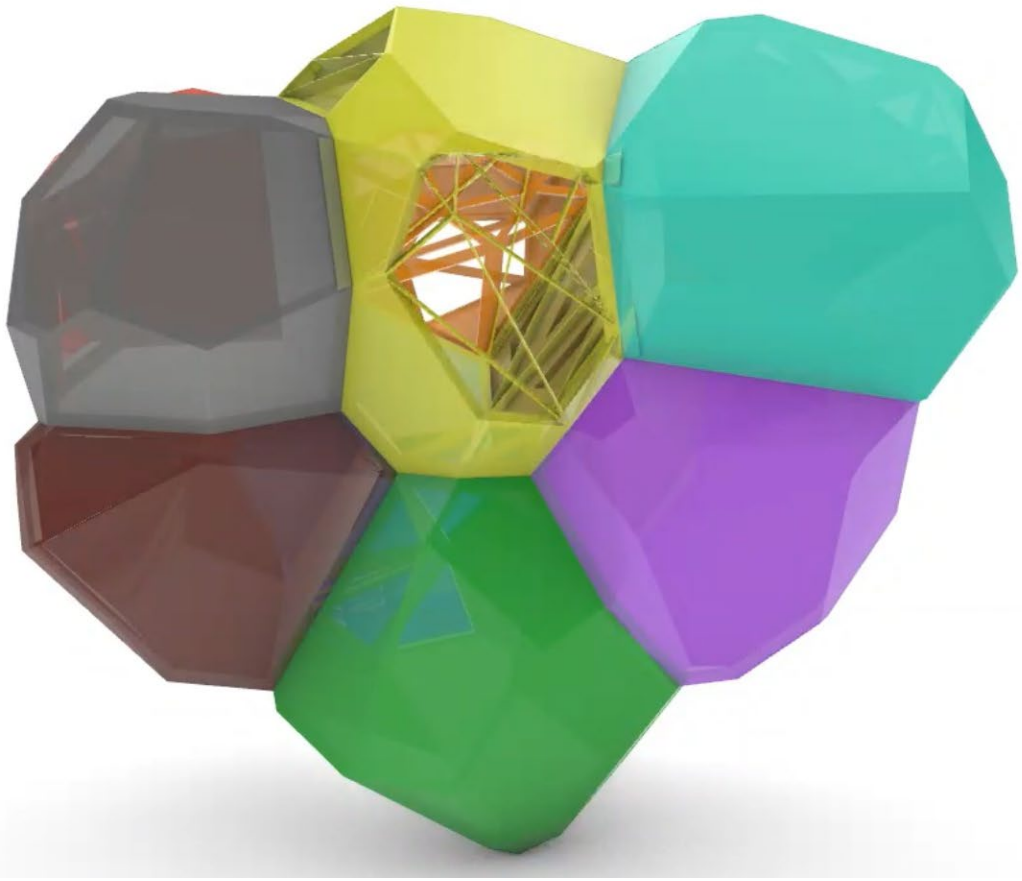
Variables:
- Porose yes/no
- edge offset openings
- selecting specific faces requiring a diverging porosity

5. Create outer shell



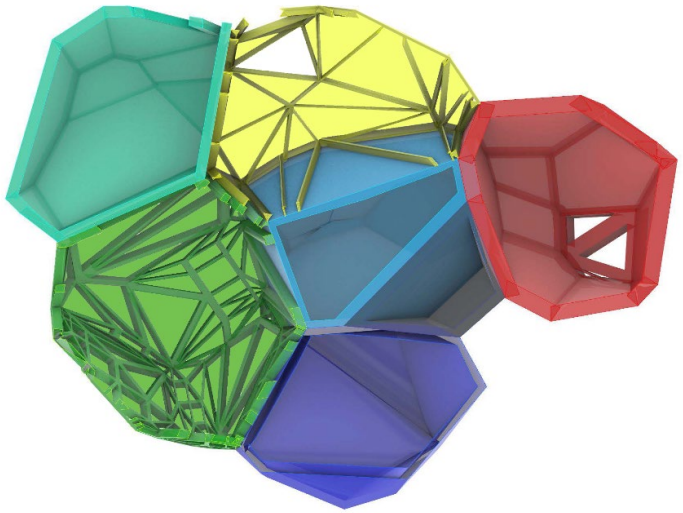
Variables:
- Shell thickness
- selecting specific faces requiring a divergence of porosity
- Opening edge offset distance

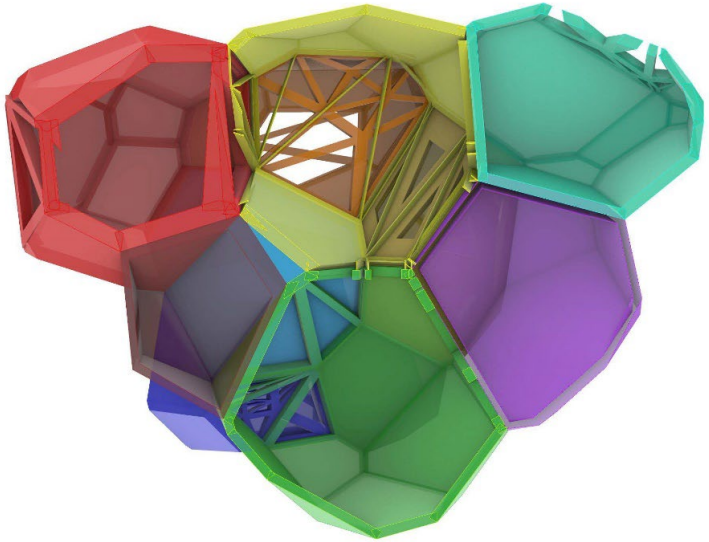
Porosity: Voronoi

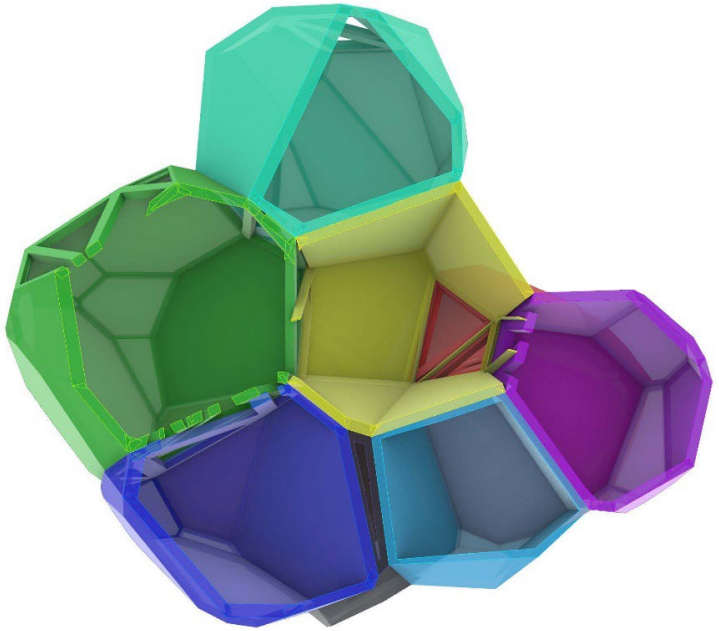


	Function	Porosity
	Living	80%
	Kitchen	62%
	Storage main	16%
	Meditation	7%
	Garden-gym	40%
	Medical	0%
	Private quarters	3%
	Bathroom	0%
	Storage private	0%
	Research	8%
	EVA chamber	5%
	Storage research	0%

Porosity: iterations







0 1 2 3 4 5 m

Iteration 1: section

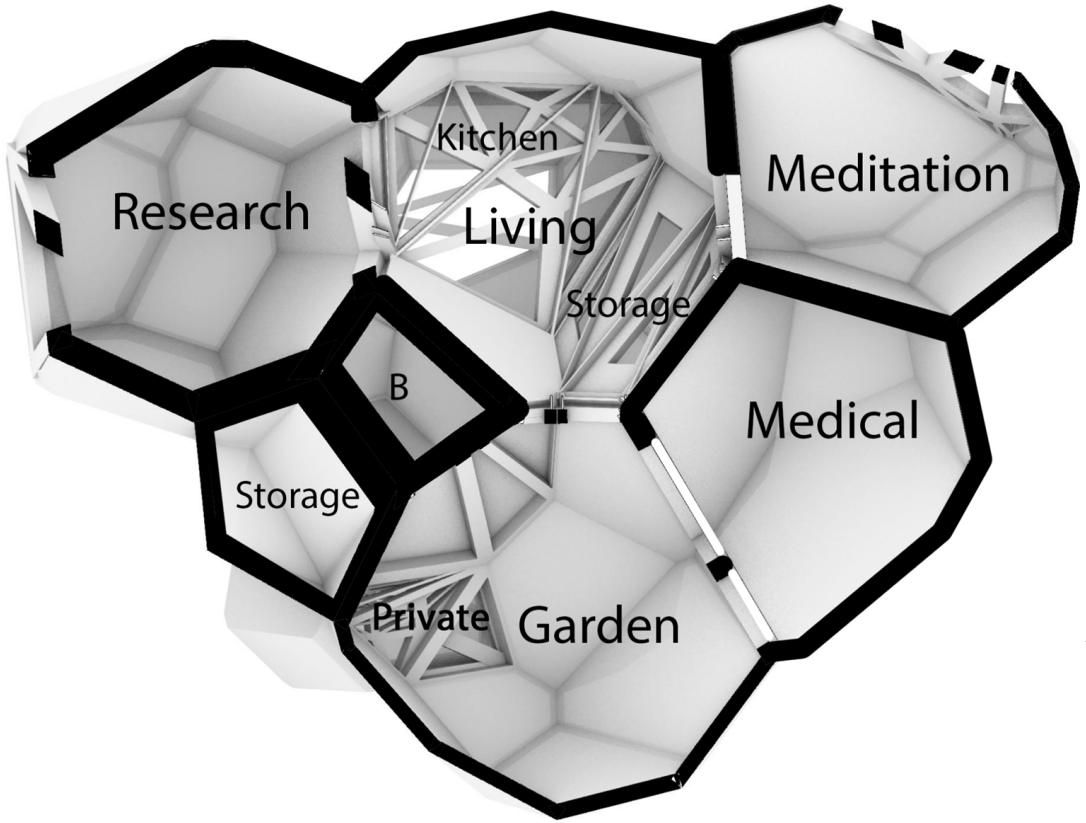
0 1 2 3 4 5 m

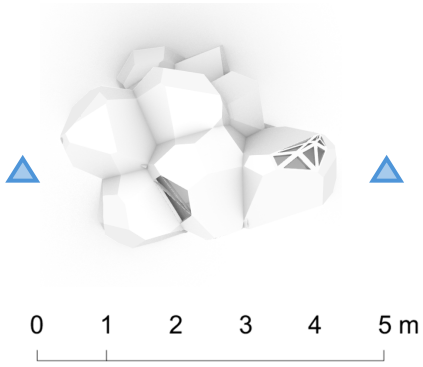
Iteration 2: section

0 1 2 3 4 5 m

Iteration 3: section

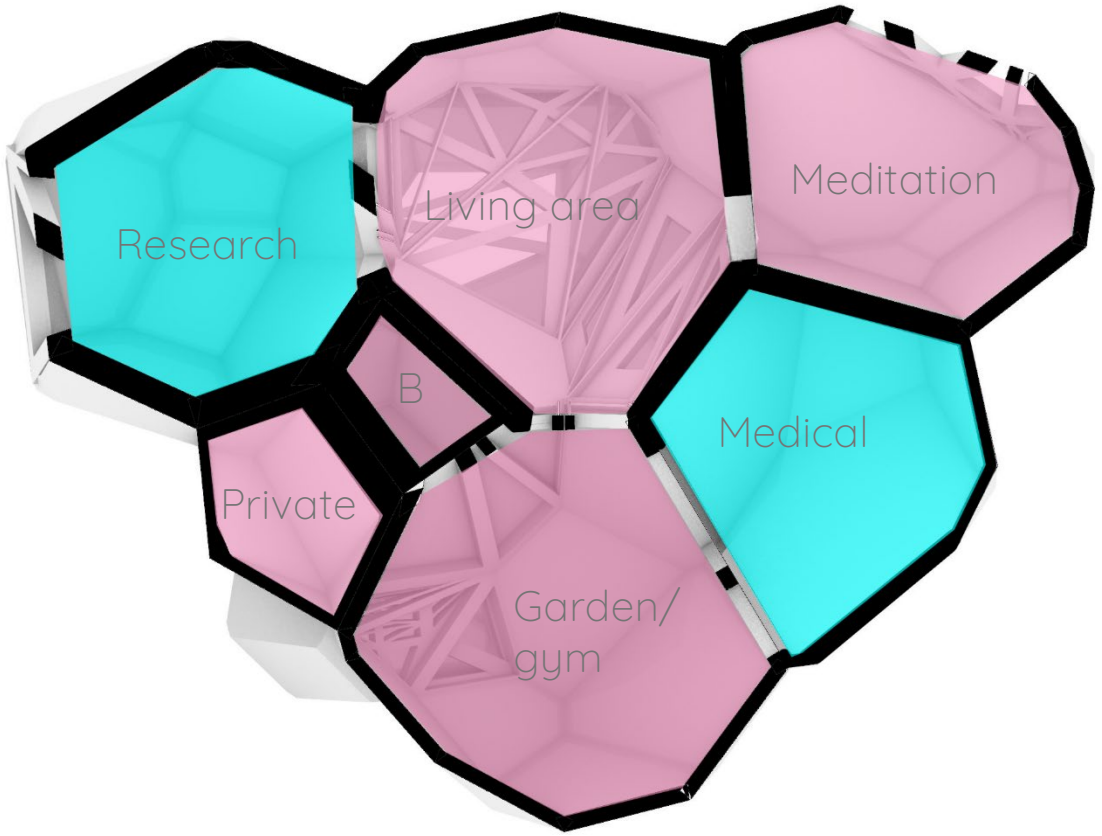
Iteration 2





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

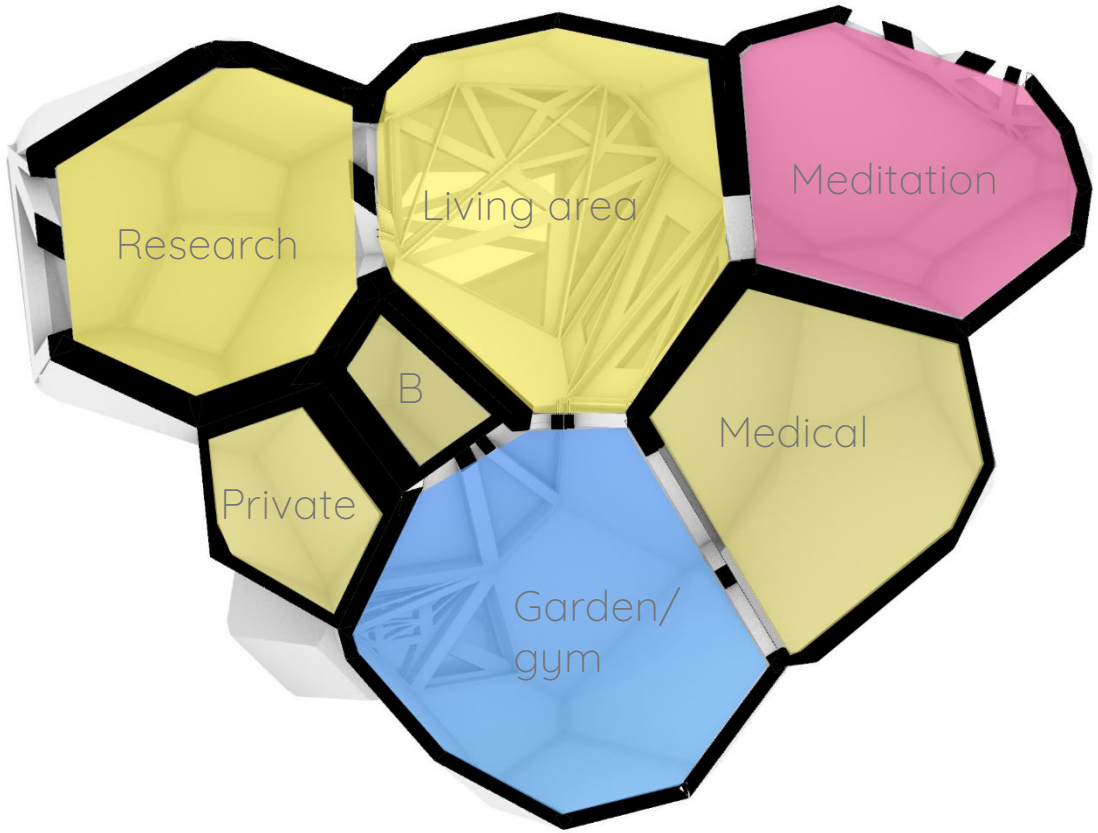
Interventions: spatial geometry



Angular character

Curved character

Interventions: light & projection

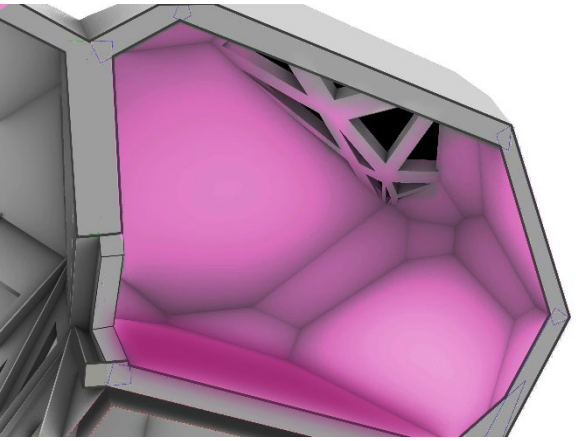


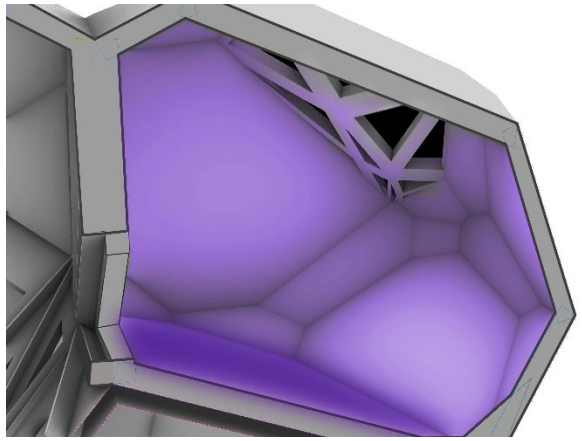
Daylight simulation

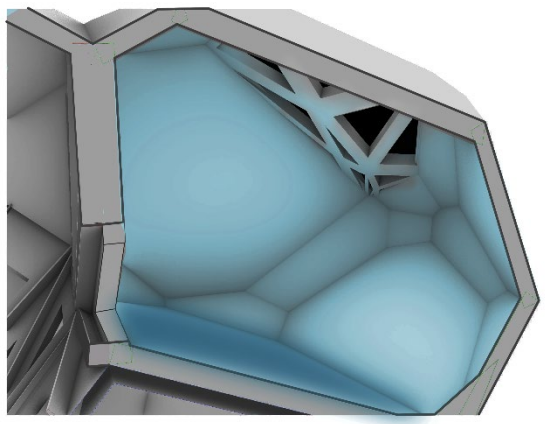
Adjustable colour projection

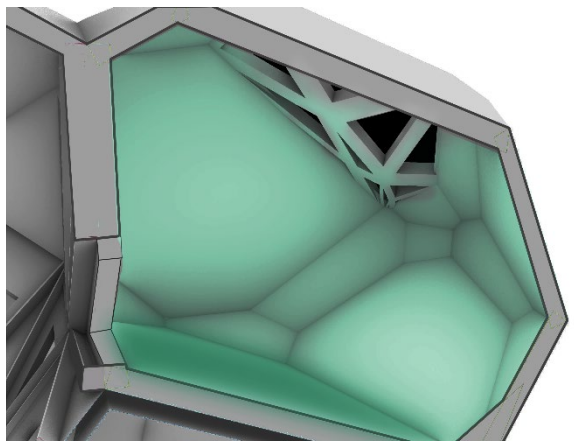
Dynamic fractal projection

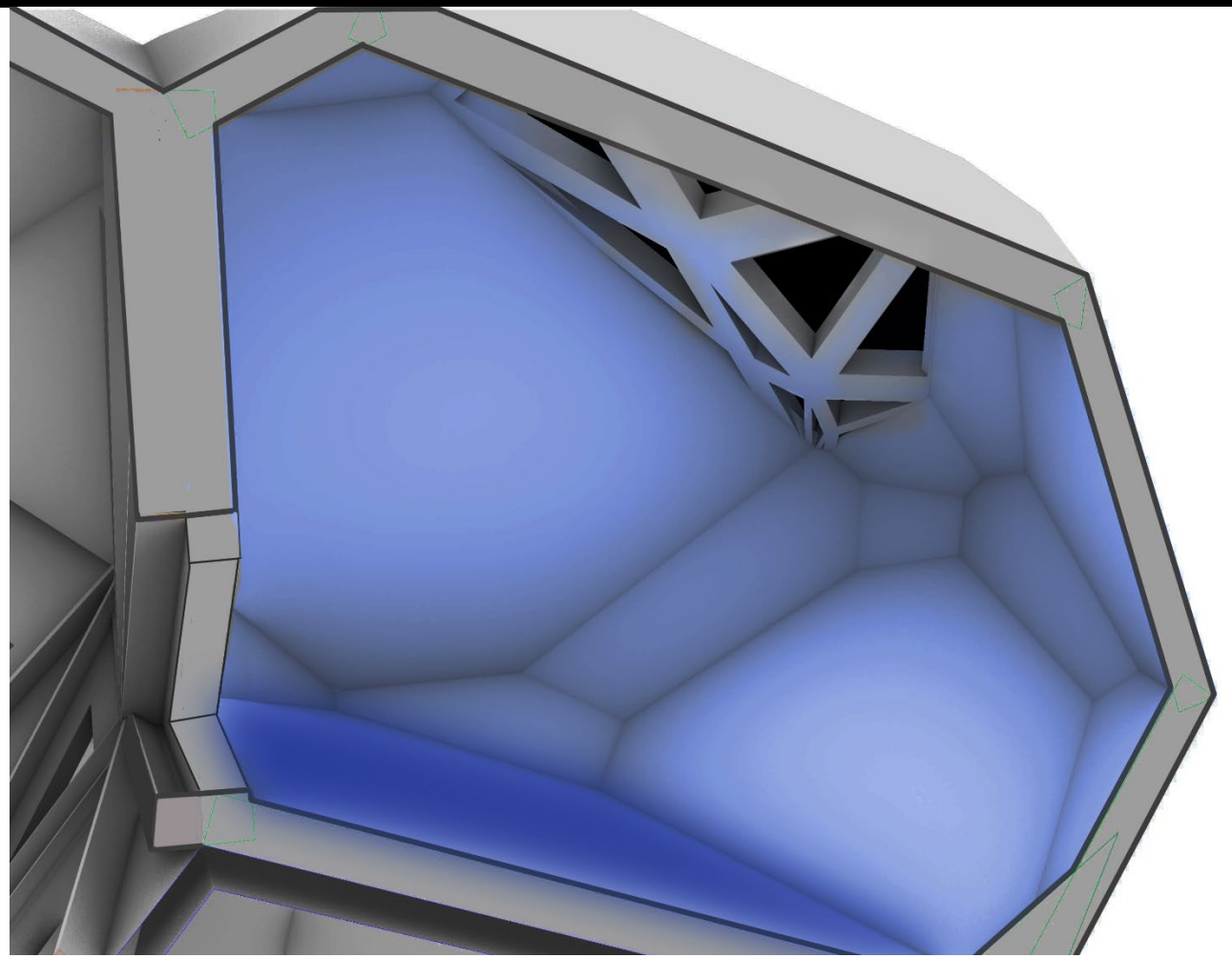
Impression meditation space





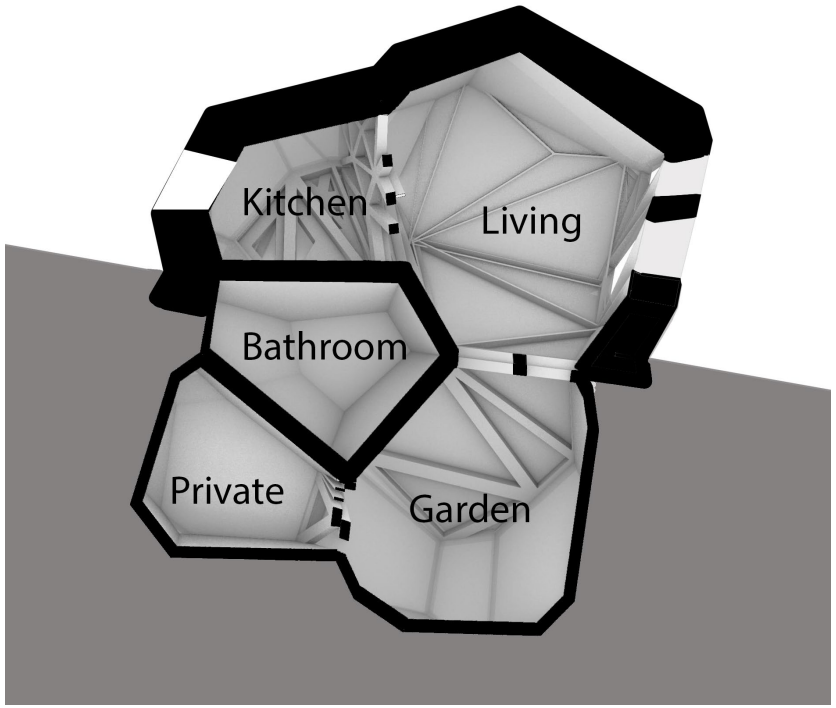




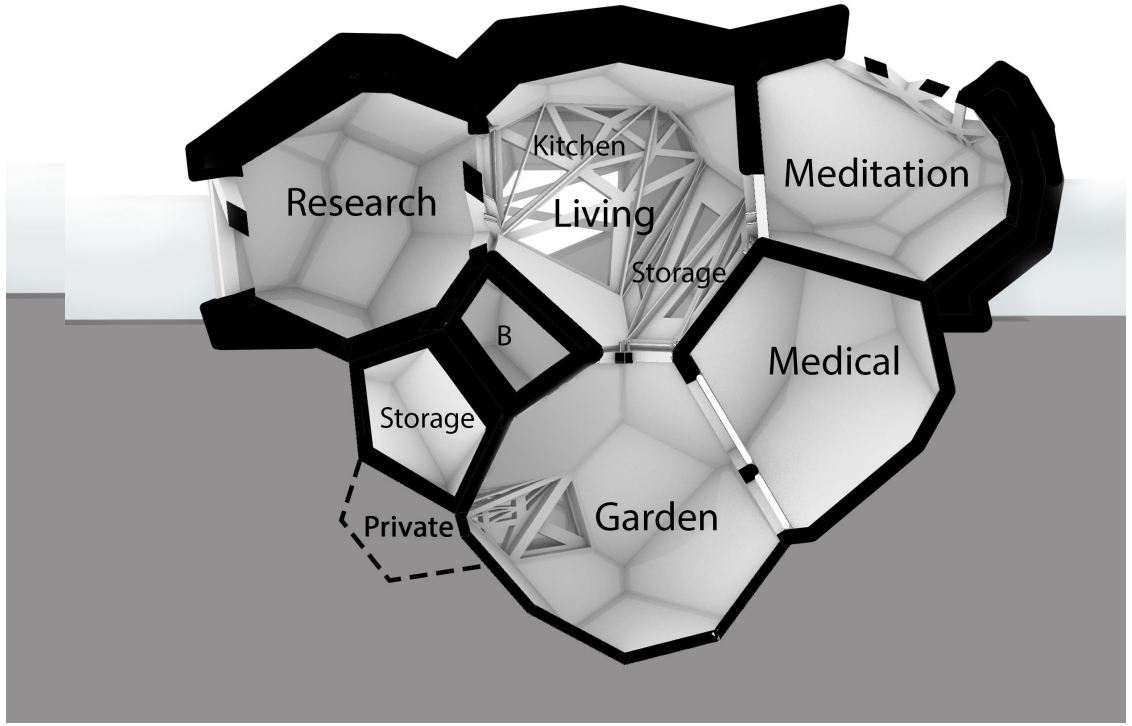


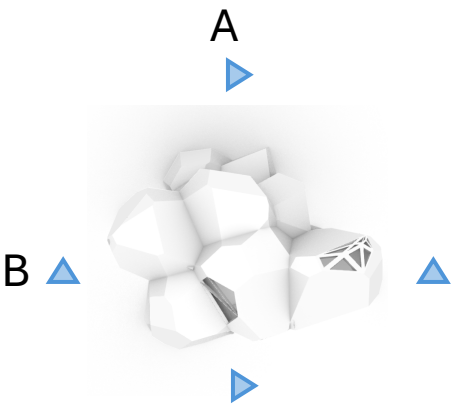
Iteration 2 in location

Section A



Section B



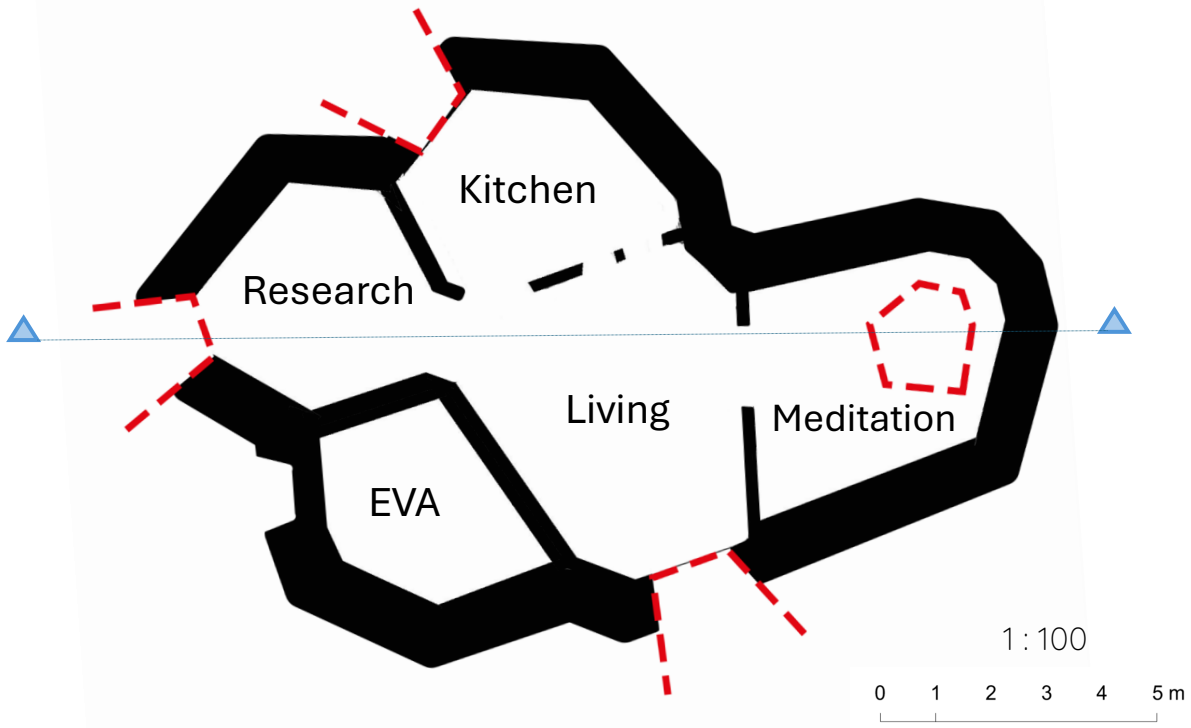


1 : 100

0 1 2 3 4 5 m

Views

Plan top level



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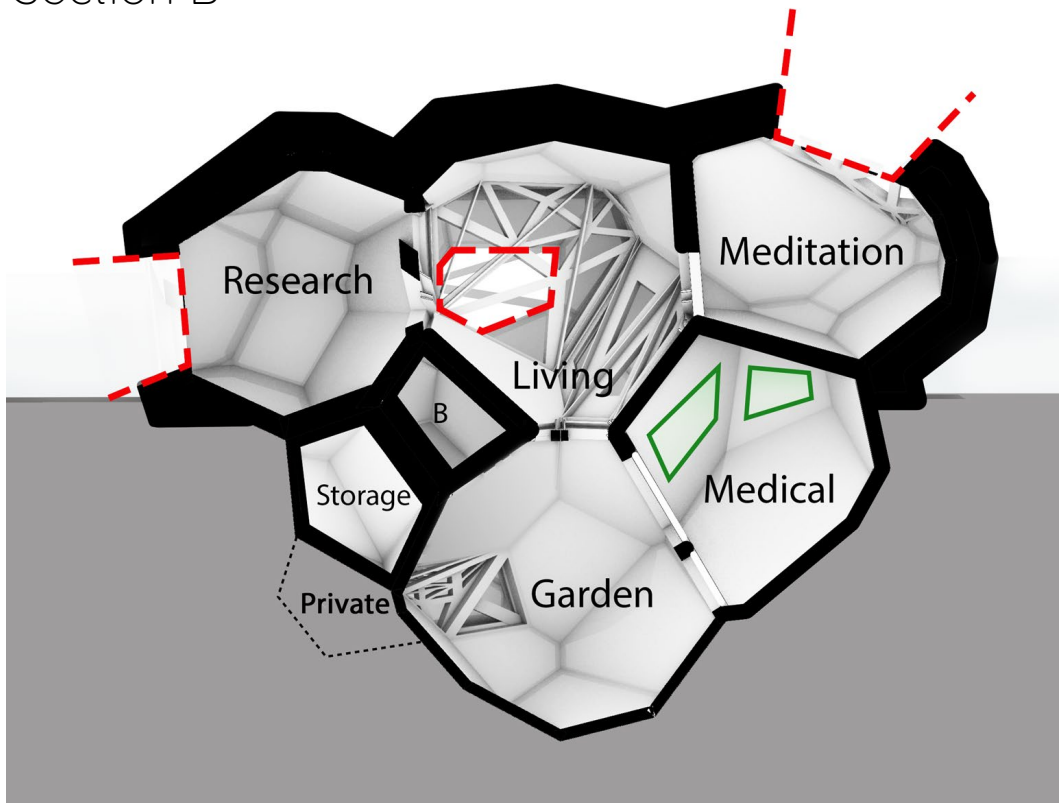
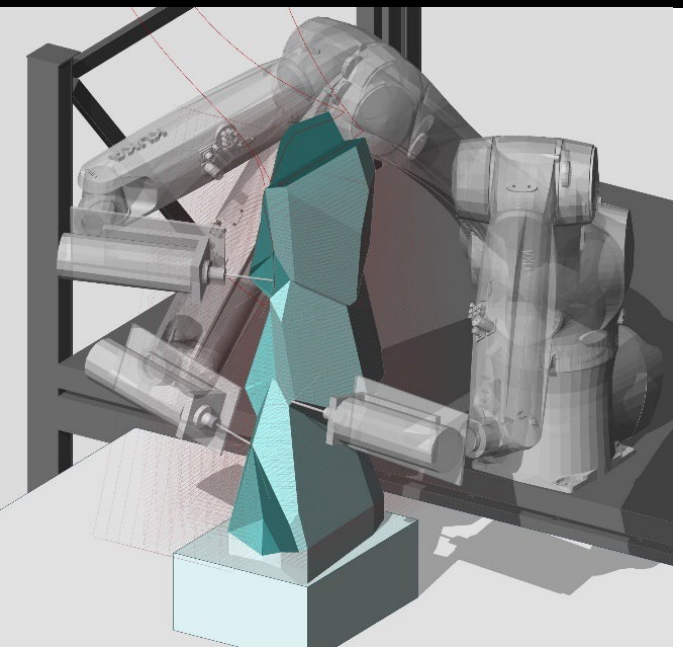
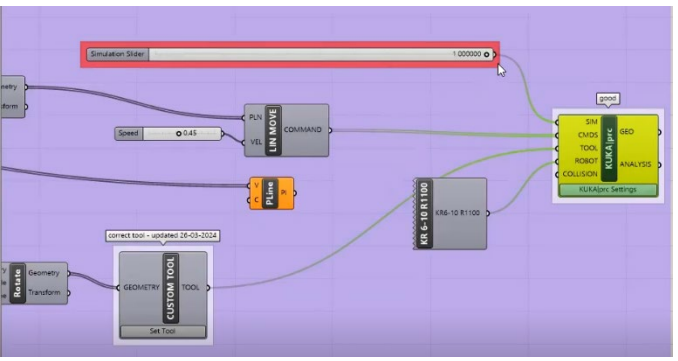
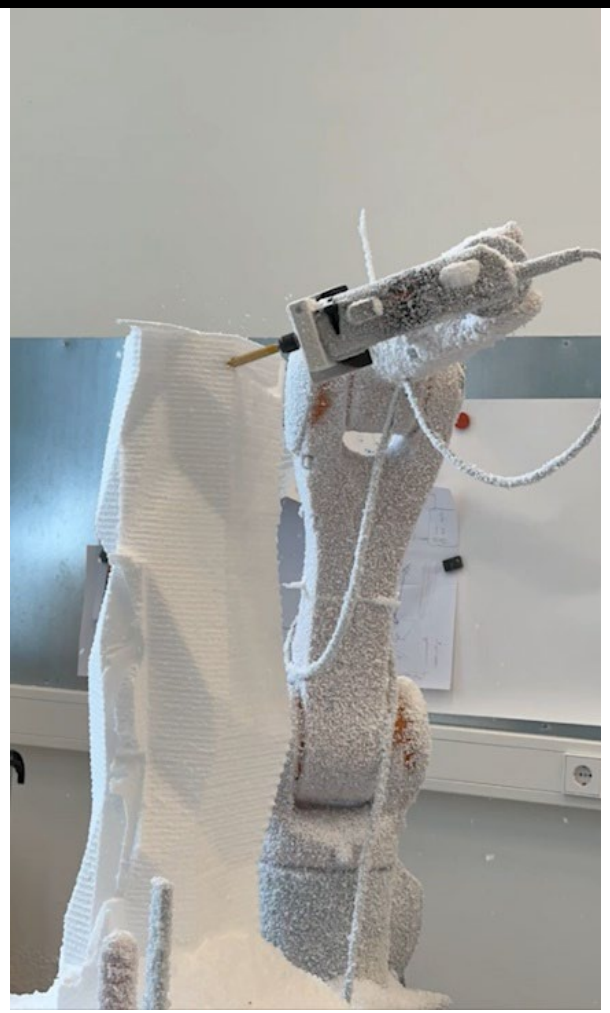


Workshop







Building above ground:

- Thick outer shell
- Use of Lunar Regolith for additive printing
- Interlocking components necessary for a stacked structure

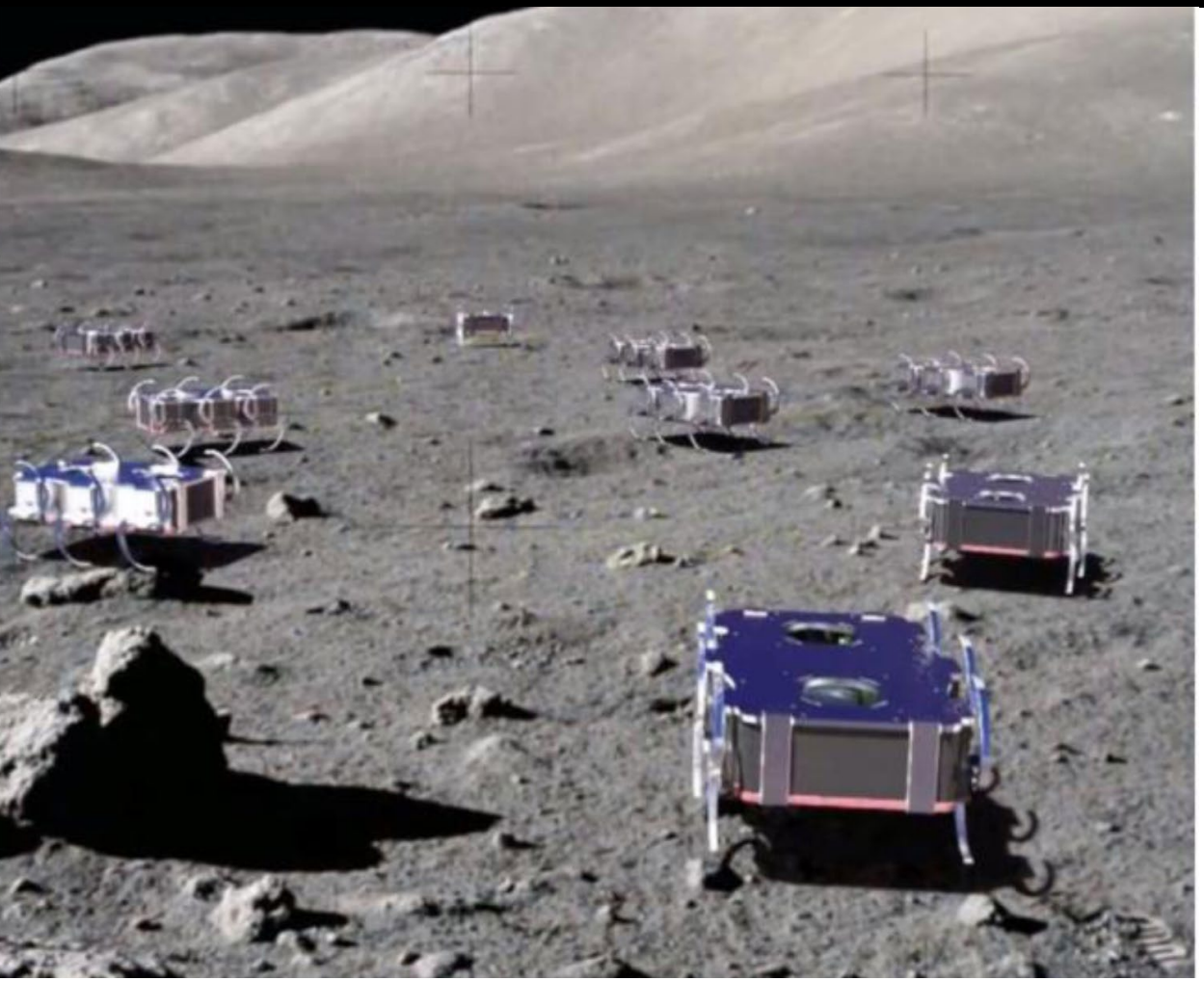
Workshop

Organic forms in design

- Flexibility for room requirements mental health
  - Curved or Angular

- Voronoi: component adapted to form

Construction: swarm robotics

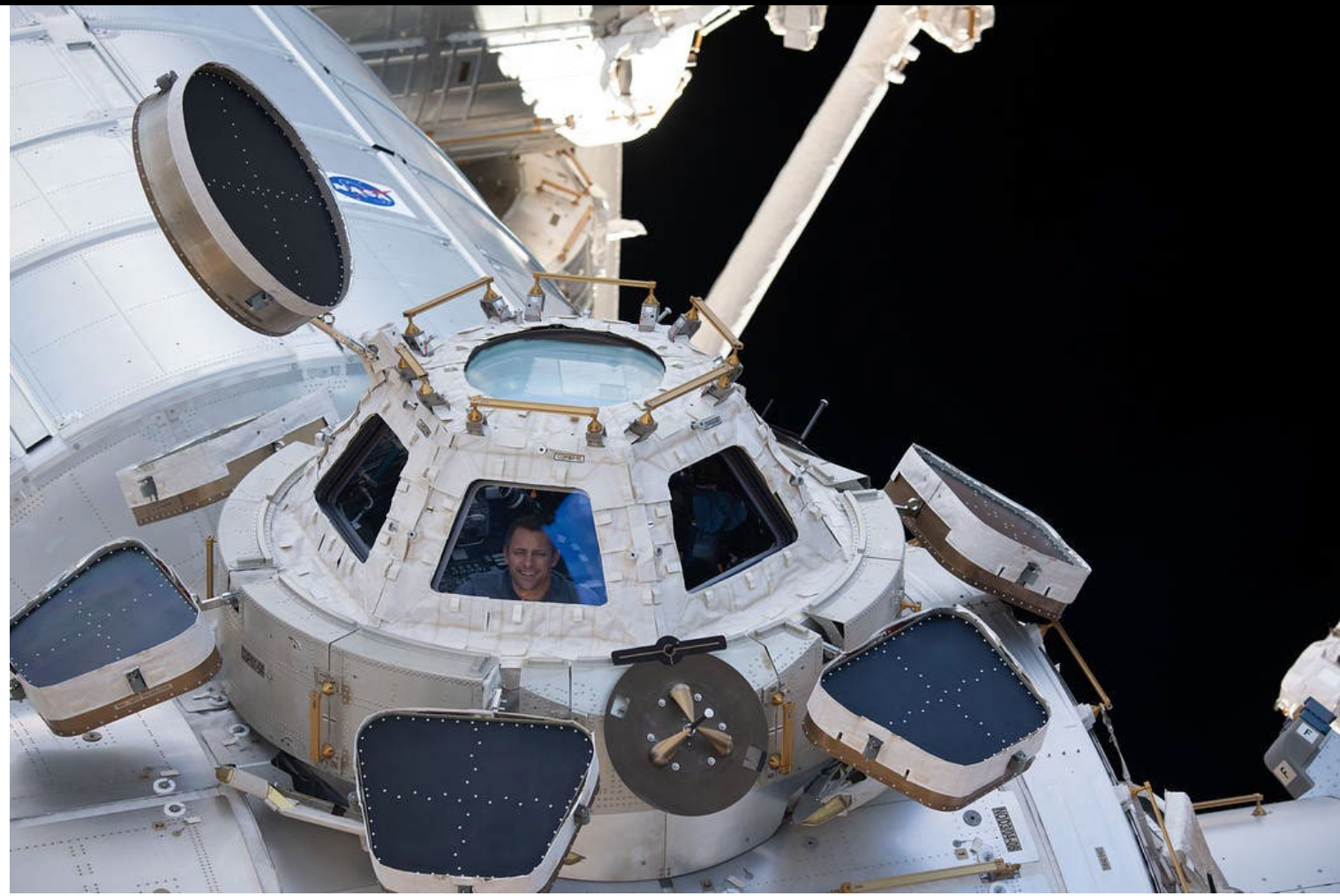


1. Excavation
2. Regolith gathered by swarm
   - brought to printer
3. Components printed
4. Carried by worker robots to location
5. Placed in correct location

Windows and radiation

Current use:

- ISS Cupola window
  - 4 layers of fused silica and borosilicate
  - Thick shutters



Windows and radiation

ISRU:

- Silica – silicon dioxide
  - major component of Lunar Regolith: 42+%
  - extraction?
  - 3D printing windows is possible

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

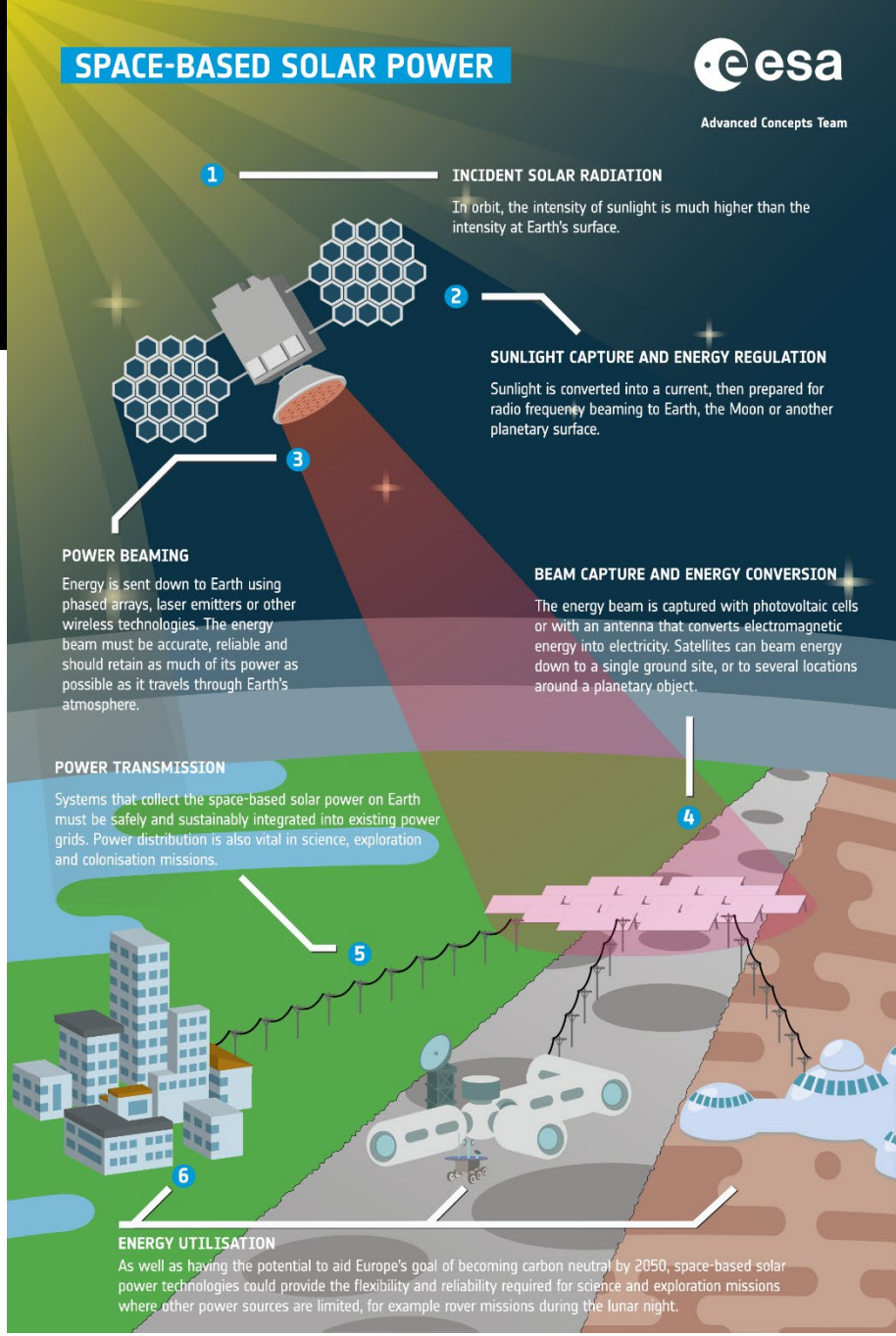
Energy supply

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

ESA campaign

Astrostrom design



Next steps

Architectural design:

- Form finding - optimisation
- Interior design - integrating geometry and furniture
- Light and projection integration
- Envelope design
- Products:
  - Definitive plans, sections and elevations
  - Prototypes and visuals

Building technology:

- Materialisation - ISRU and reuse
- Construction:
  - Internal structure
  - External shell
  - Incorporating windows & shutters
  - Assembly: robots and/or humans
- Products:
  - Fragment
  - Details


Q & A

P2 – graduation manual

P2
Design studio ✗ • graduation plan based on template (see student portal) ? • urban draft / master plan (on an appropriate scale) ✓ • programme of requirement ✓? • draft design (plans, sections, elevations) 1:500 / 1:200
Research studio • urban draft / master plan (on an appropriate scale) • programme of requirement • draft design (plans, sections, elevations) 1:1000 / 1:500 • graduation plan based on template (see student portal)