MoonSane

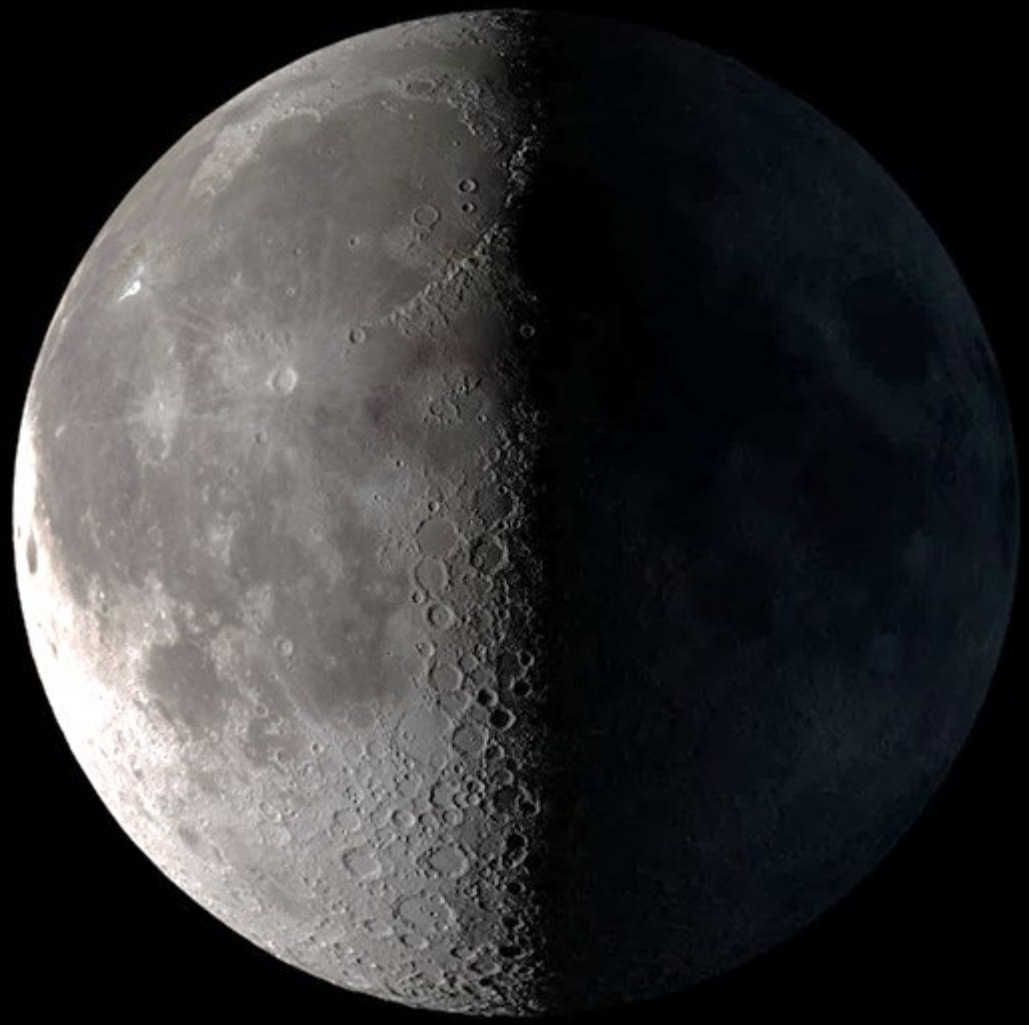
Designing Lunar Habitats for Mental Wellness

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

Approaching Lunar Architecture

Carte Blanche

Utopia



Extreme Environment

Dystopia

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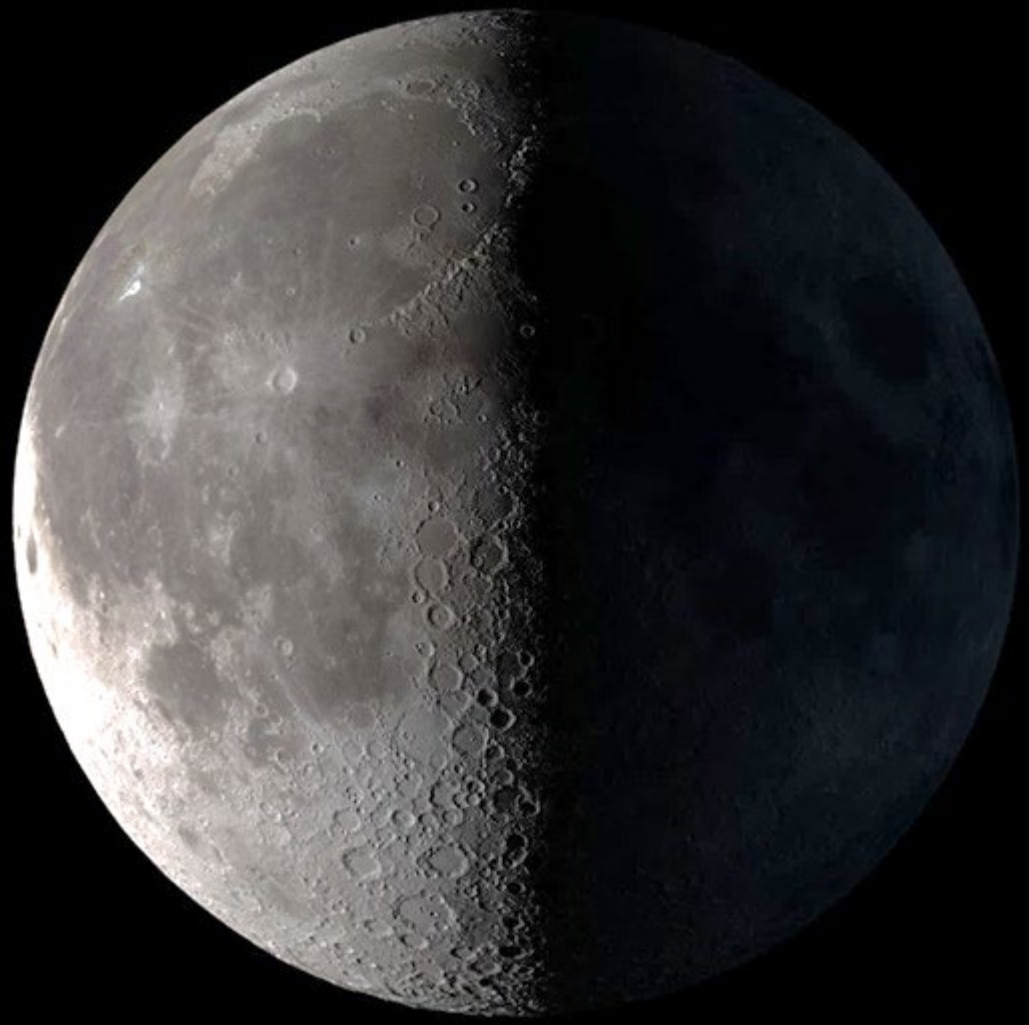


Extreme Environment

Dystopia

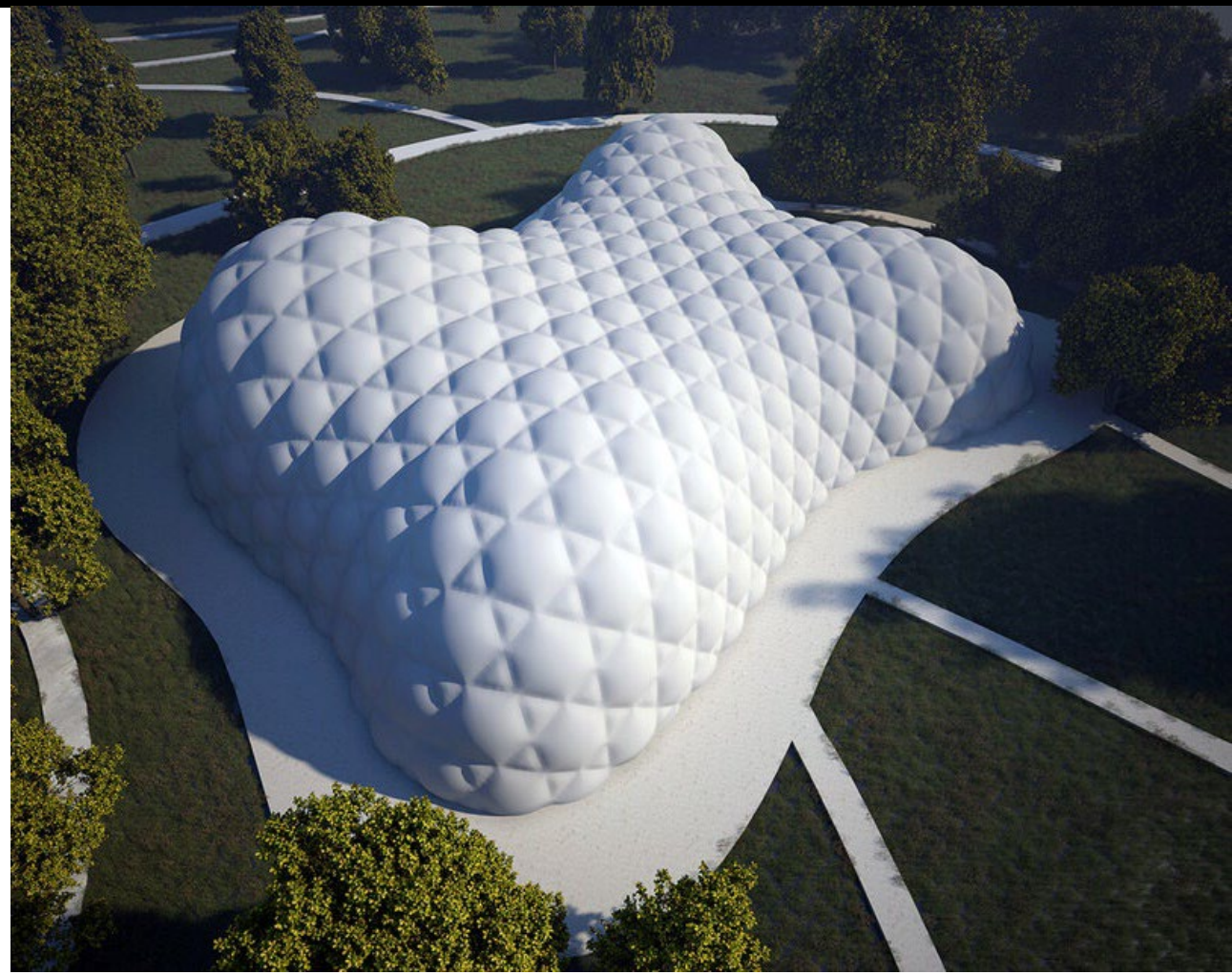
Physical conditions

The Moon

- No atmosphere
- Radiation on surface
- 1 day/night cycle = 28 Earth day/night cycles
- Temperatures between -121° C to 133° C (equator)
- Partial gravity: 1,62 m/s² (1/6 of Earth gravity)
- Barren rock surface – no vegetation
- Statically charged regolith

No Atmosphere

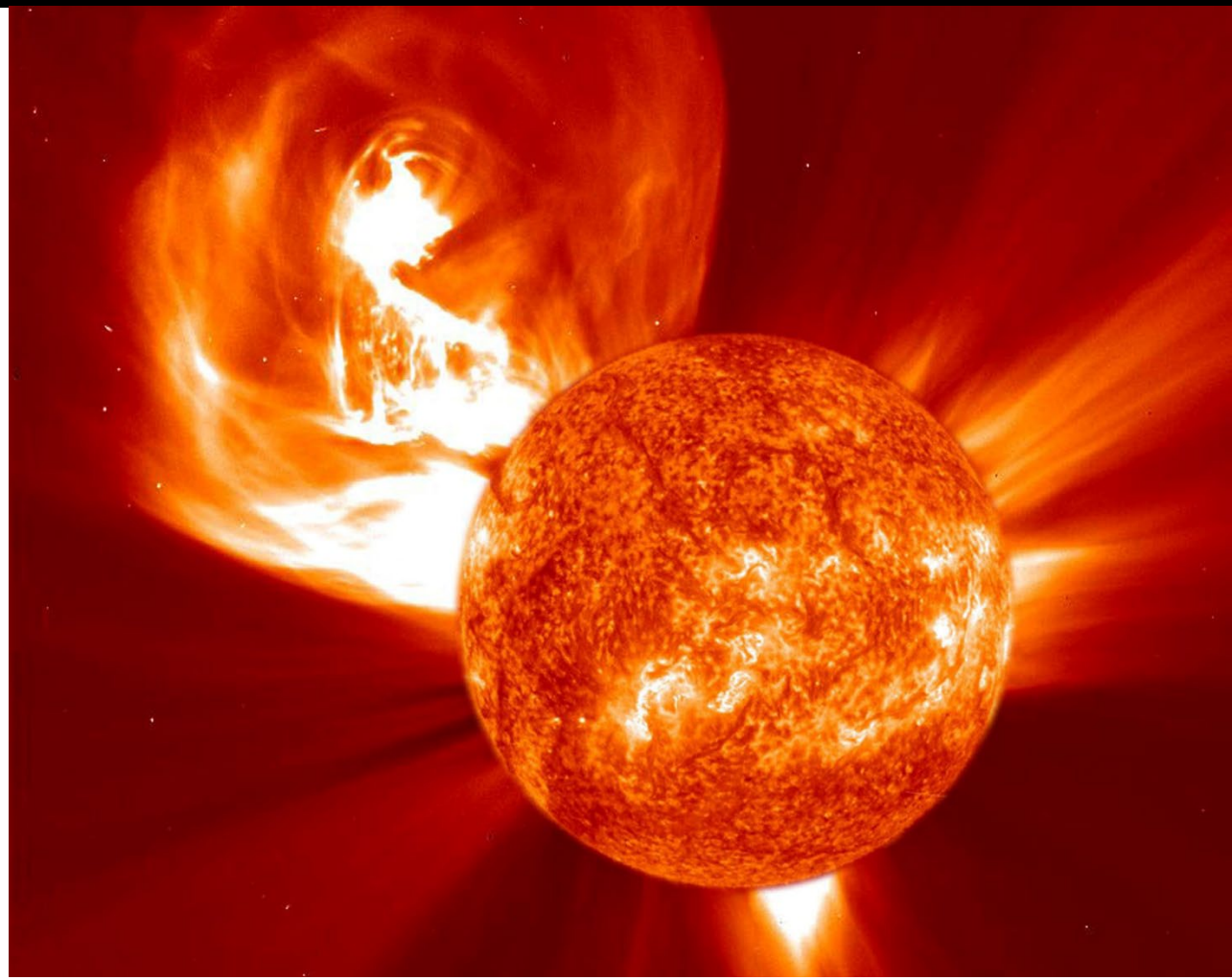
- Recreating Earth atmosphere in habitat necessary
- Hermetically sealed
- Inflatables
- Airlocks



Konakovic Lukovic, Mina & Panetta, Julian & Crane, Keenan & Pauly, Mark. (2018). Rapid deployment of curved surfaces via programmable auxetics. ACM Transactions on Graphics. 37. 1-13. 10.1145/3197517.3201373.

Radiation

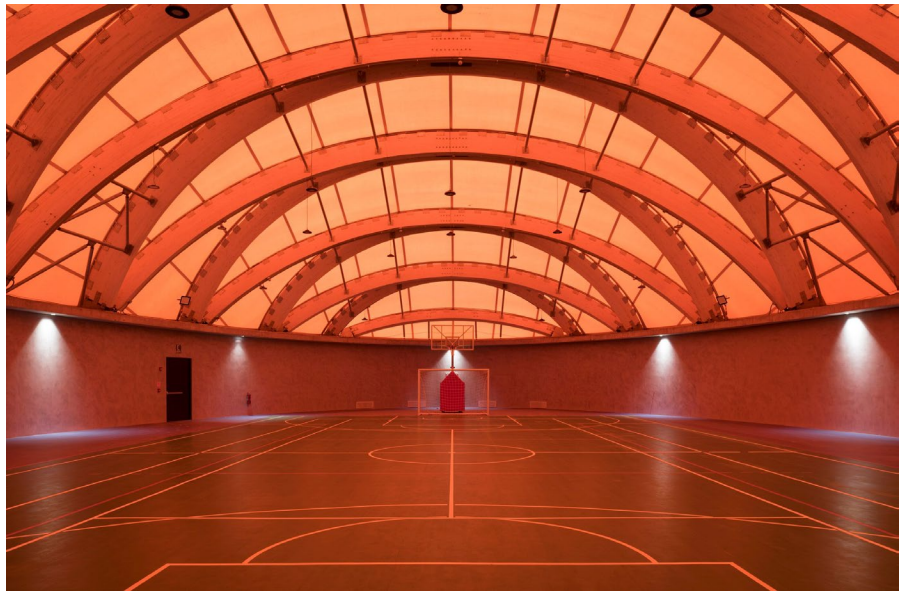
- Gamma rays; Cosmic rays; Solar Flares
- Materials
  - Regolith layers at least meters thick
  - Low secondary rad: water layer and polyethylene
  - Layering best option
- Underground
  - Excavation?
    hard underground layer (Apollo 11)
  - Lava Tube shelter – safe but access difficult?



Radiation: Going underground

ALMA Observatory Sports Centre (Atacama Desert)

- Benjamín Murúa Architects
- Radiation protection:
  - Double membrane made of PVC and carbon fibre filaments
- Stable temperature due to sunken position (geothermal)
  - Barely any additional heating/cooling
- Light dispersion through membrane



https://www.dezeen.com/2023/07/27/benjamin-murua-aquitectos-sports-centre-chile/

Day/Night cycle

- Circadian rhythm on Earth is 24 hours
- Influences hormone cycles
- Disrupted rhythm affects i.e. sleep, alertness and mental health
- Astronauts at greater risk due to lack of light variation

Figure 2. Color variation of light throughout the day.

Caballero-Arce, C., Vigil de Insausti, A., & Benlloch Marco, J. (2012, July). Lighting of space habitats: Influence of color temperature on a crew's physical and mental health. In *42nd International Conference on Environmental Systems* (p. 3615).

Extreme temperatures

LUNARK Module (Greenland)

- SAGA
- Tested for up to -45 Celsius
- Lightweight & expandable
- Algae life-support system
- Material
  - Carbon fiber sandwich panels
  - Foam core for extra insulation
  - Aluminium frame

Partial gravity: 1.62 m/s²

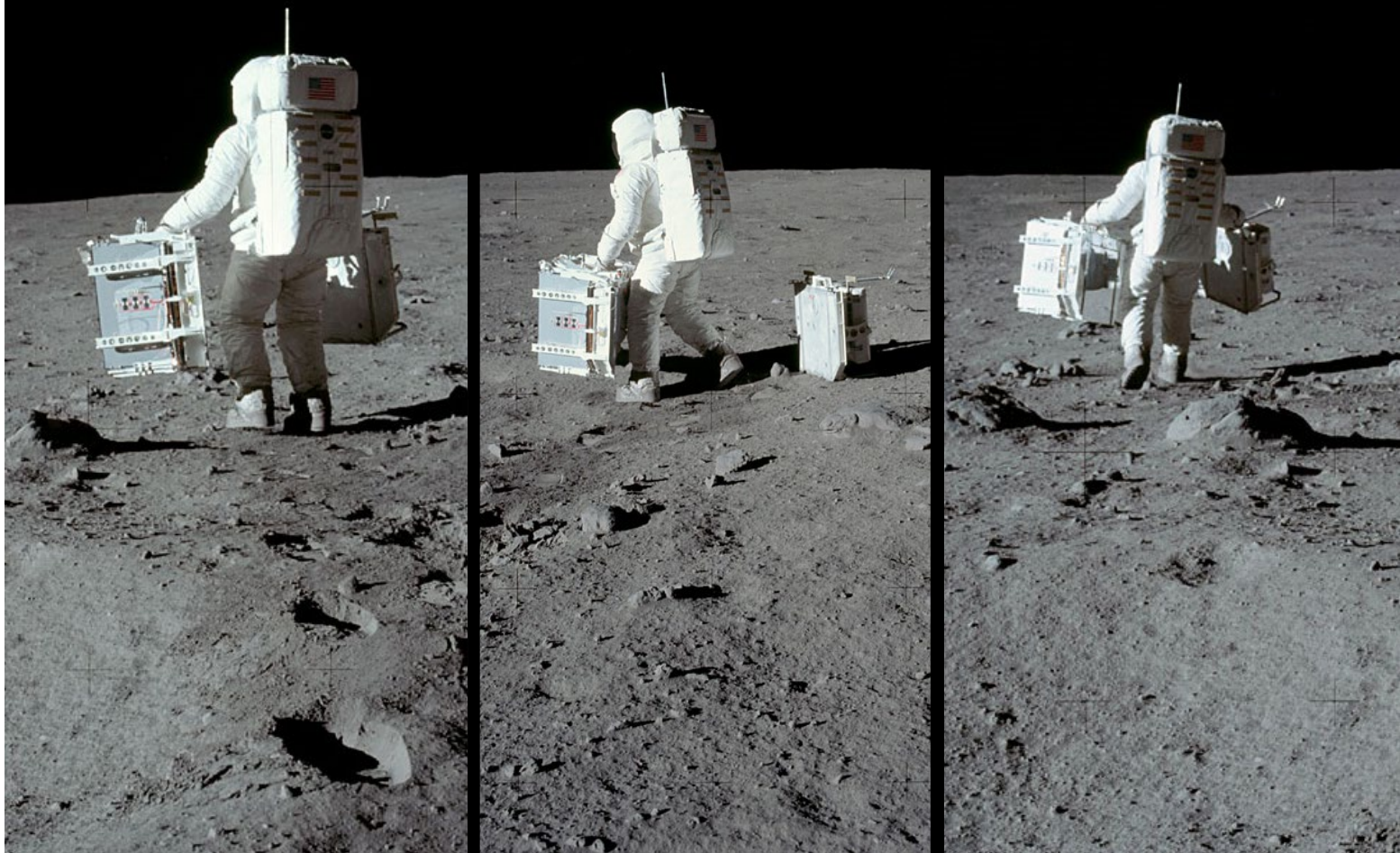
- Physiological effects of lower gravity conditions include
  - calcium loss
  - fluid shifts – affects taste of food
  - skeletal changes
  - muscle mass loss
  - vestibular alterations

  (NASA [MSIS], 1995 p. 178)
- Ergonomic design necessary

AS17-162-24083 (OF300) Source: NASA

Partial gravity: crew experience Apollo 11

- 1/6 of Earth **but** according to crew logs, an object weighs 1/10 of Earth weight
- Suited mobility similar to unsuited on Earth
- Difficult to assess level areas



Psychological conditions

Overview of stressors

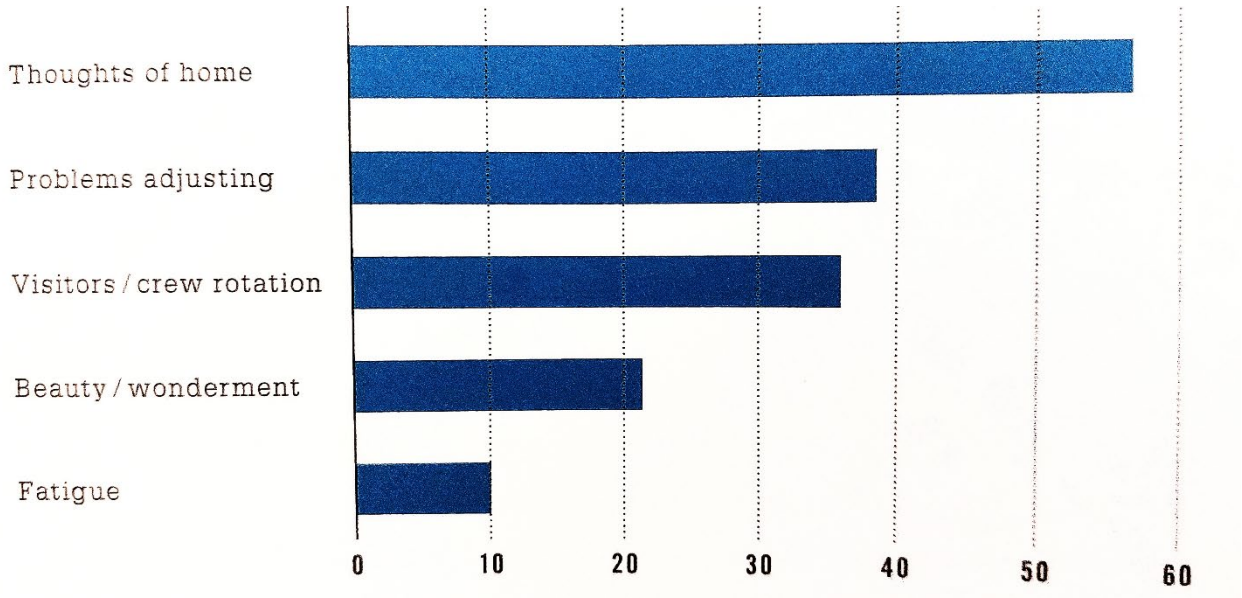
Table 3
Known spaceflight stressors.

Physiological/Physical Stressors	Psychological Stressors	Psychosocial Stressors	Human Factor Stressors	Habitability Stressors
Radiation [31,33]	Isolation [27,31,32,33,34,36,40]	High team coordination demands [31]	Variations in work/rest levels [27,31,32,34,35,36,37,38,39,40]	Limited hygiene [31]
Altered sense of time [27,31,32,33,34,38]	Confinement [27,31,32,33,36]	Interpersonal tension with ground crew [31,33,38,39]	Limited external exchange of information [31]	Chronic exposure to vibration/noise [31,32,33,34]
Altered circadian rhythms [27,31,33,38]	Limited possibility for rescue [27,31,33]	Family life disruptions [31,36,38]	Limited equipment, facilities, and supplies [31,37]	Limited sleep facilities [31]
Decreased sunlight exposure [31]	Potential for loss of life [31,33]	Enforced interpersonal contact [31,33,40]	Risk associated with equipment failure [31,35,37]	Lighting/illumination [31,33,34]
Microgravity [31,32,33]	System/mission complexity [31,32]	Crew factors/demographic factors [31,32,33,34,35,37,38,39]	Adaptation to the artificial environment [31]	Lack of privacy[31,] [32,33,34,38,39]
Environmental sensory deprivation [31,39]	Hostile external environment [31,32,33]	Multicultural issues [31,34,36]	Technology-interface challenges [31,33,34,37]	Isolation from support systems [31]
Sleep disturbance [31]	Altered sensory stimuli [31,33,35]	"Host-Guest" phenomenon [31]	Use of equipment in microgravity [31]	Reliance on artificial life support [32]
Space Adaptation Syndrome (SAS) [31,32]	Disruptions in sleep [27,31,33,35,38,40]	Social conflict [27, 31,35,36,37,38,39,40]	Shift changes [32,40]	Colors of the environment [33,39]
Limits of performance [32]	Limited comforts [31,32,37]	Leadership stressors [32,33,34,39,40]	Desynchronization [32]	Shapes of the environment [33,39]
Cognitive decrements [32]	Decision-making stresses [32]	Social skills [32,37,39]	Autonomy [32,35]	Instrument displays [33]
Physical fatigue [32,33]	Motivation changes [27,32]	Personality differences [32,33,34,39,40]	Competency/skill demands [32]	Overall habitat aesthetics [33]
Spatial illusions [32]	Productivity pressures [32,33,40]	Human reliability/errors [32,39]	Mission duration [35,36,37]	Habitat odors [33]
Prolonged deviations from normal body posture [33]	Emotion/mood changes [32]	Organization/chain of command issues [32]	Work underload [36]	Sudden accelerations/decelerations [33]
Magnetic fields [33]	Mental fatigue [32]	Communication demands [32]		Poor air ventilation [33]
Pain/sickness [33,36]	Cumulative effect of multiple stressors [32]	Sexuality [33]		Toxic agents [33]
Decreased motor coordination [33]	Boredom [32,34,38,39]	Decreased crew cohesiveness over time [33,34,39]		Food restrictions/limitations [31,33,35]

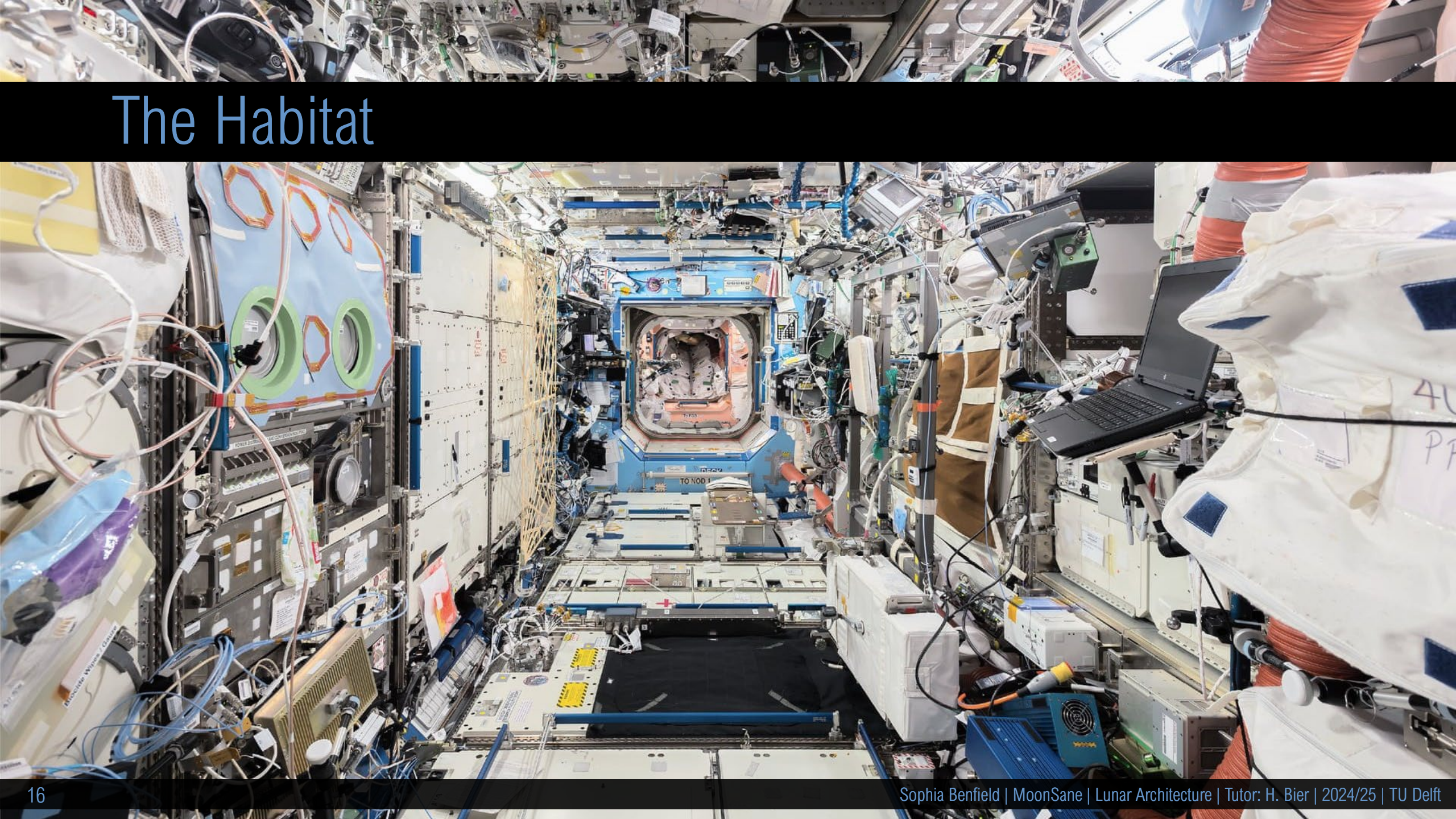
Logan M. Smith, "The psychology and mental health of the spaceflight environment: A scoping review." *Acta Astronautica 201*, 2022, 496-512, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2022.09.054.

Main concerns

- Far away from home and family
- Isolation/confinement due to hostile outside conditions
- Monotony inside and outside
- Limited social circle



The Habitat



The Habitat

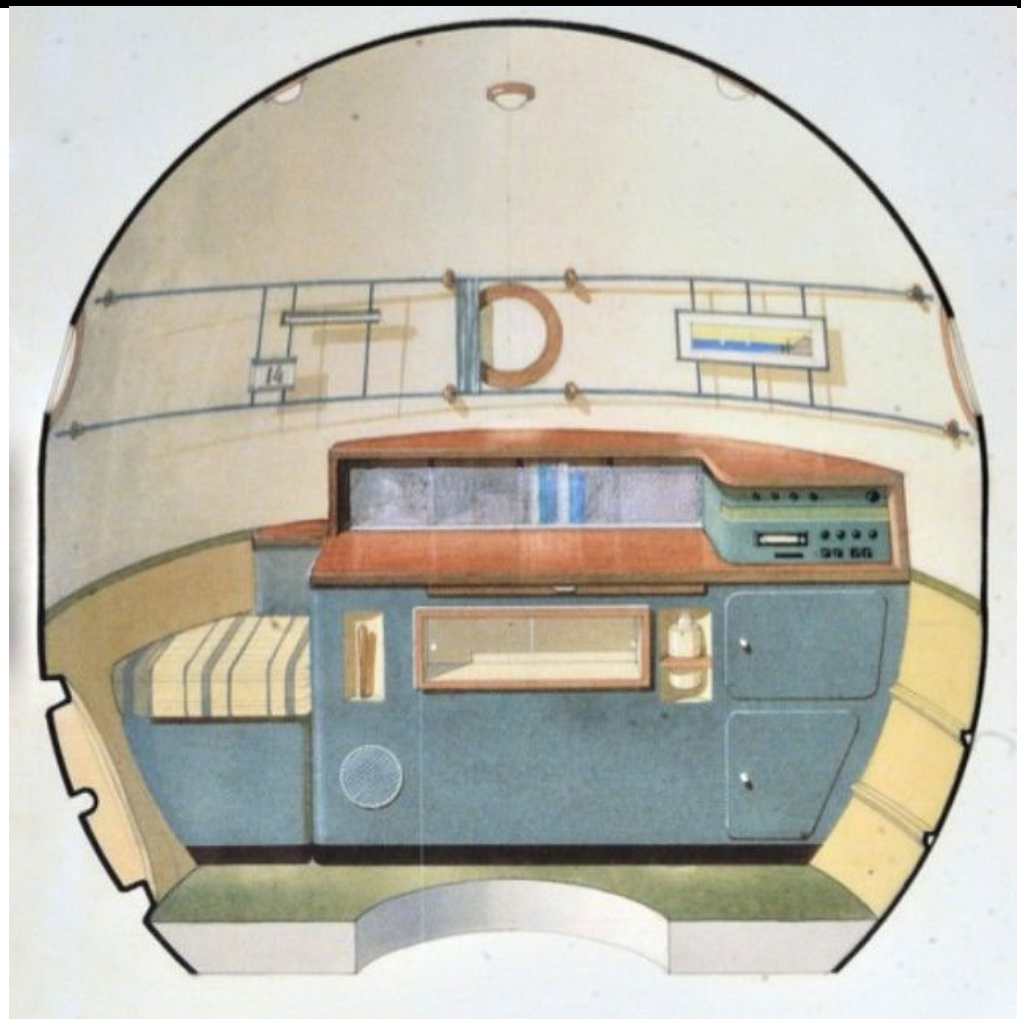
- Boredom due to lack of stimuli by interior
- Research by Hekkert (2006) shows disinterest to create dislike for a space, causing **impatience and frustration**

Galina Balashova

- Russian architect, worked on MIR and Soyuz projects
- First architect to be involved in space architecture design

Galina Balashova

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



The View

AS17-136-20745-20762 Source: NASA

Only variations of grey/brown dust and rocks

Pitch-black sky

- No atmosphere
- No stars

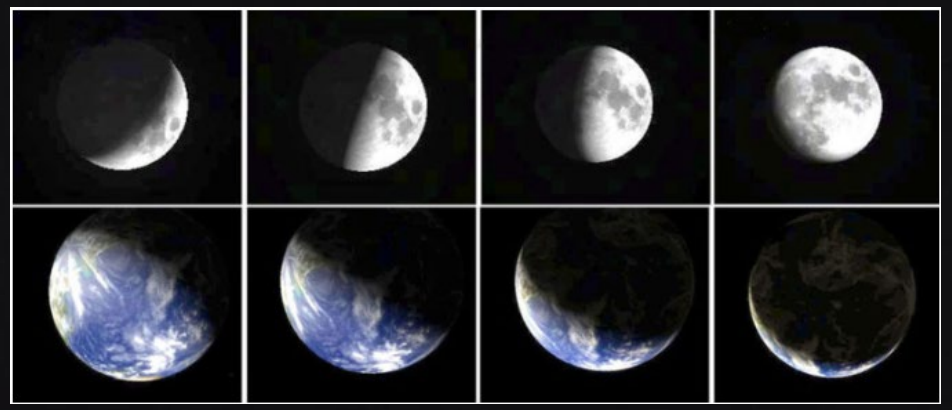
AS17-147- 22469 to 22476 Source: NASA

“Distances on the lunar surface are deceiving” crew report Apollo 11

Compact horizon: “Because the Moon is smaller than Earth, its horizon will look shorter and closer.” crew report Apollo 11

AS17-138-21063 (OF300) Source: NASA

Earth View



AS17-138-21063 (OF300) Source: NASA

“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)

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?

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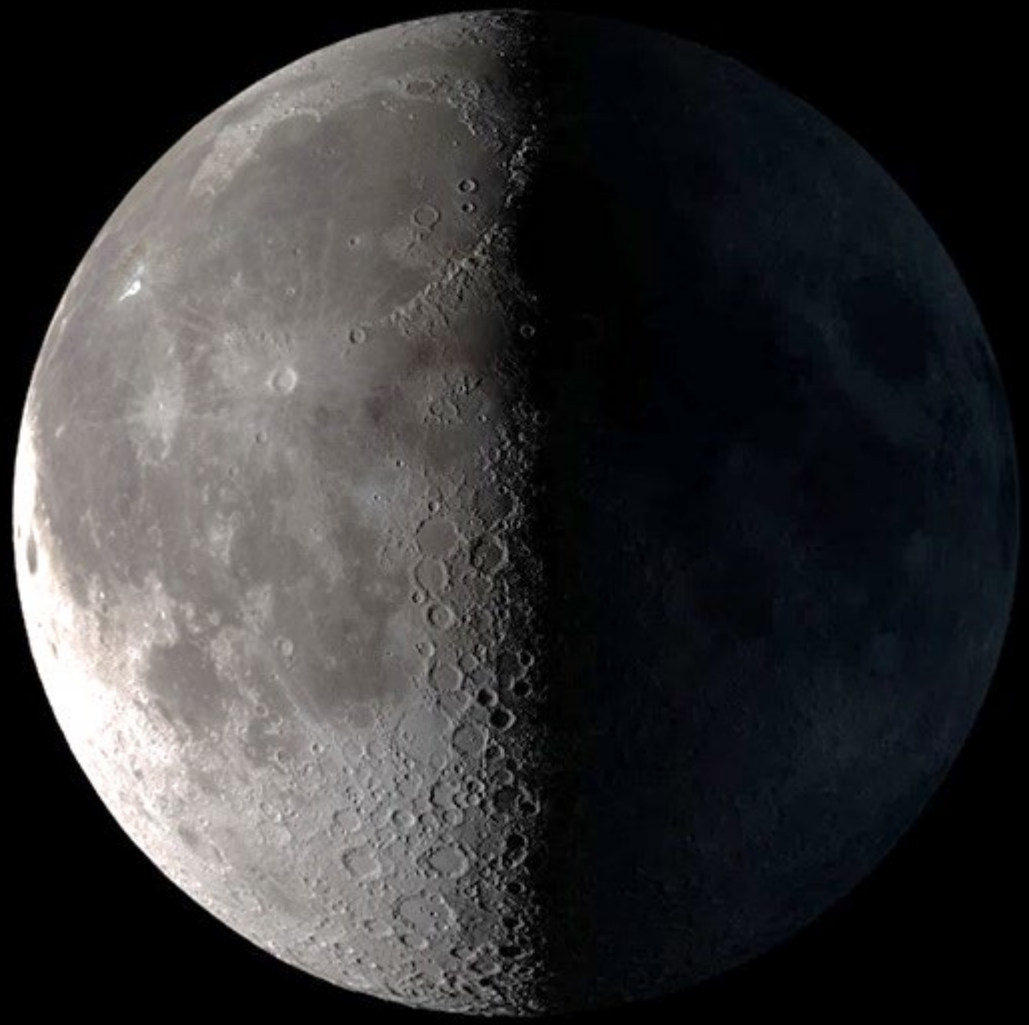

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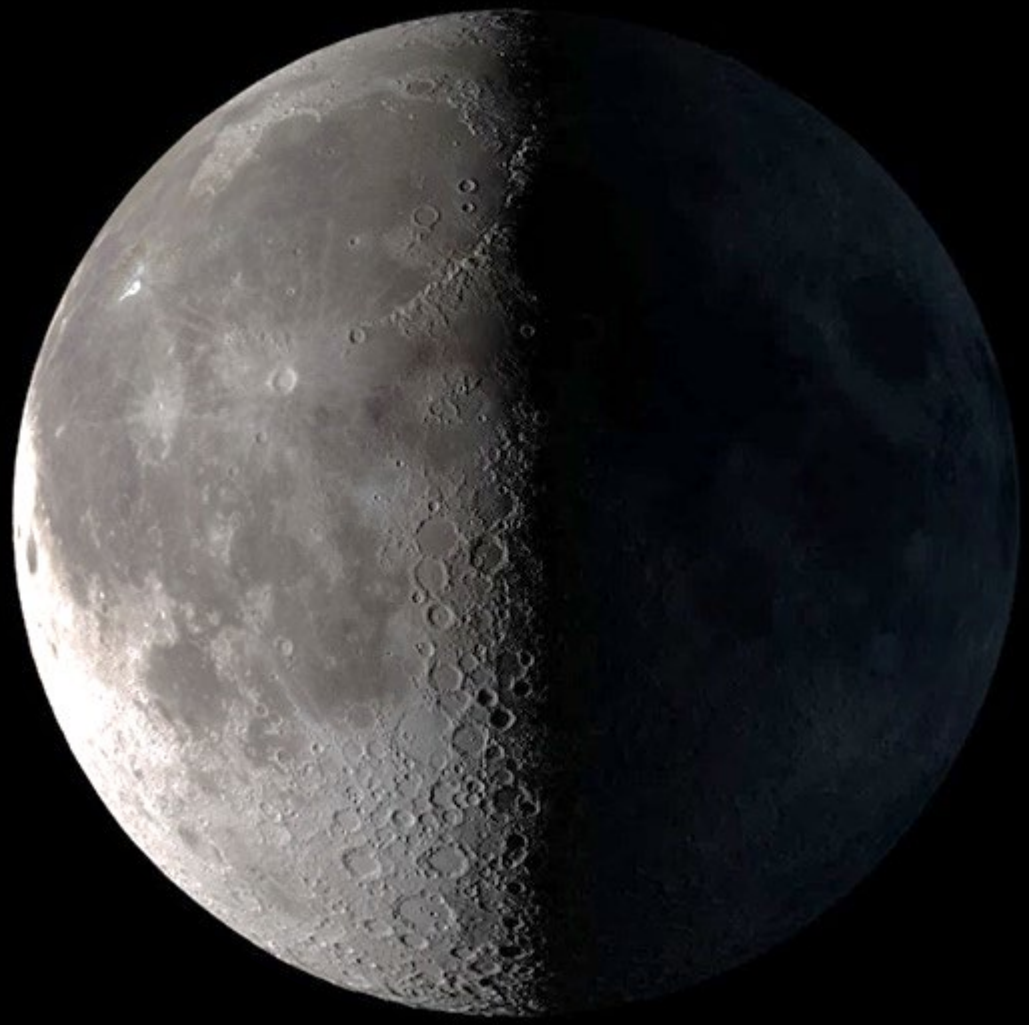


Extreme Environment

Dystopia

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*

Not applicable:
Artificial gravity
Habitat directional cues

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 and function
- Screens simulating windows
- Virtual reality

Light

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

Darkness – Absence of Light

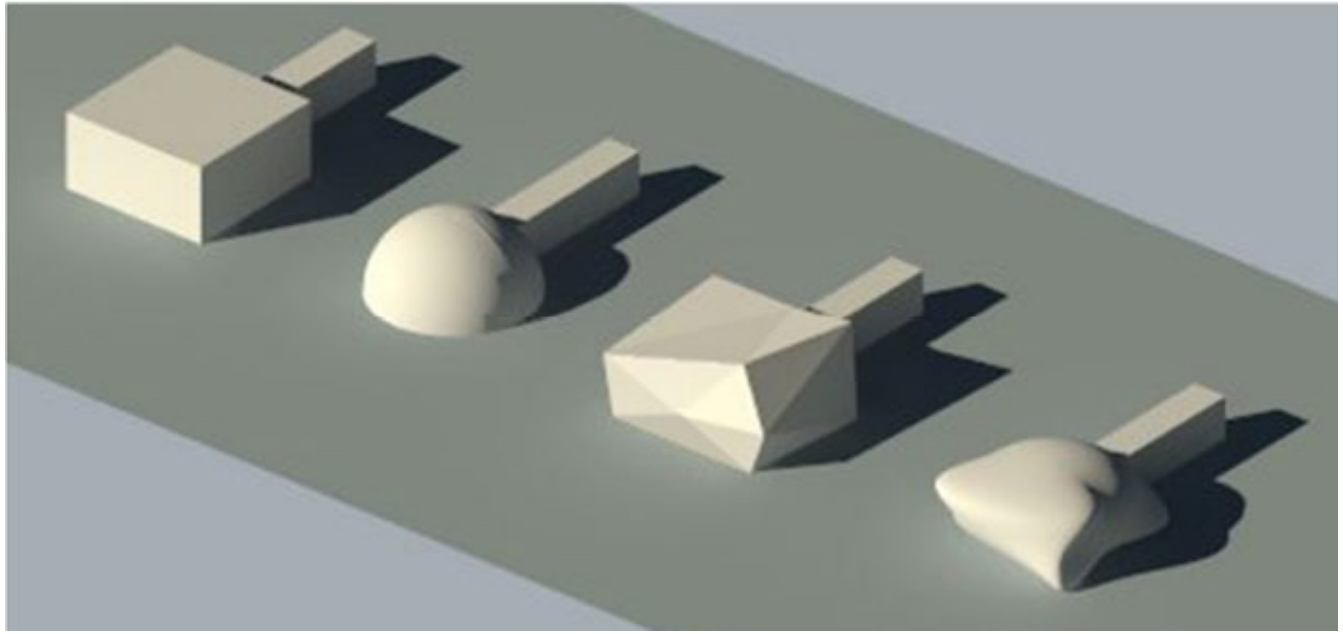
Darkness scarcity - light pollution

- Go into deep, untouched nature; open sea etc.

- The Moon is still untouched by artificial lighting
- Darkness brings calm, ultimate rest: we need dark to sleep/rest
- Polar region
  - Mental breakdown in eternal *summer*, not winter

Geometry

- Soft vs Angular
- Symmetric vs Asymmetric
- Associated functions
- Experts (designers) vs Non-experts



Y. Ikeda, C. M. Herr, D. Holzer, S. Kaijima, M. J. Kim. M, A, Schnabel (eds.), Emerging Experience in Past,Present and Future of Digital Architecture, Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA 2015, 000–000. © 2015, The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong

Geometry

Table 1

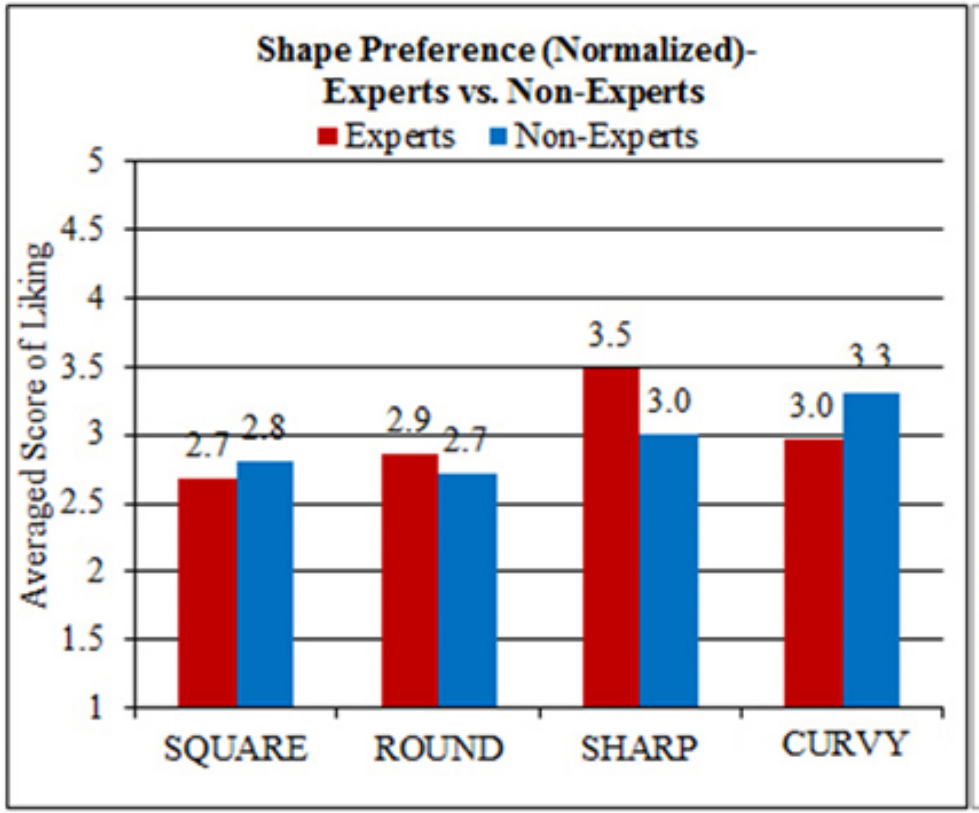
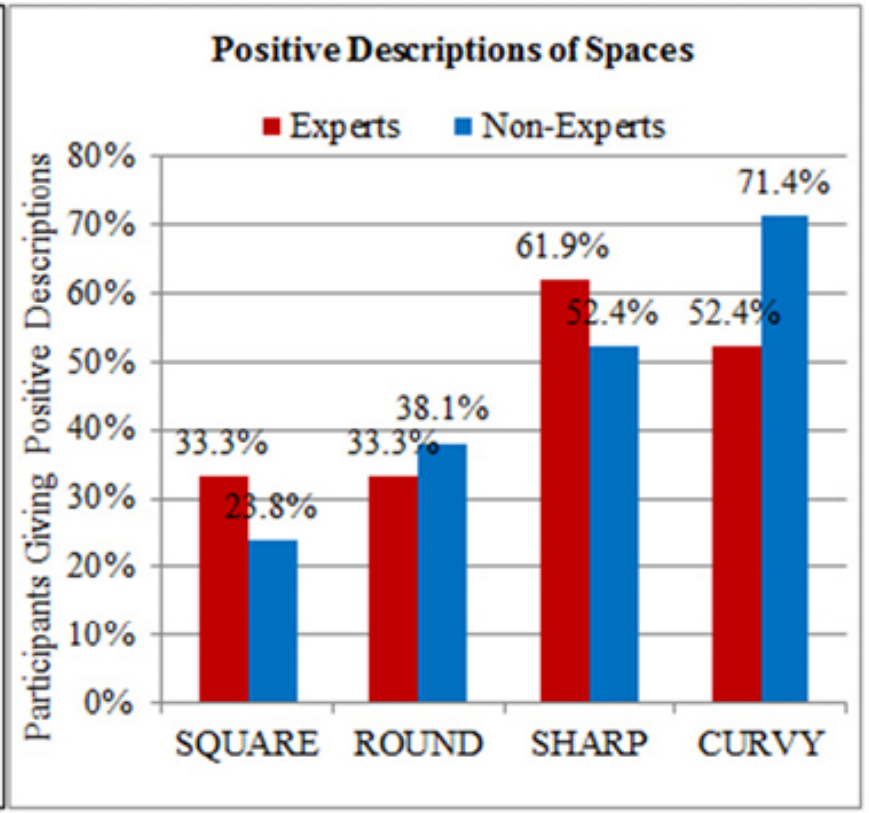


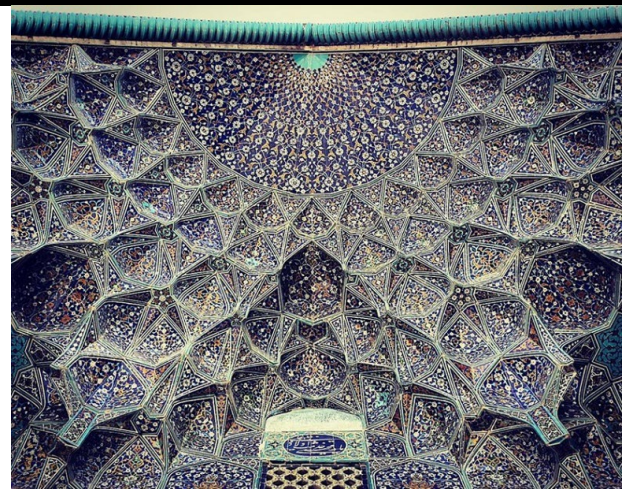
Table 2



Geometry

Fractal patterns

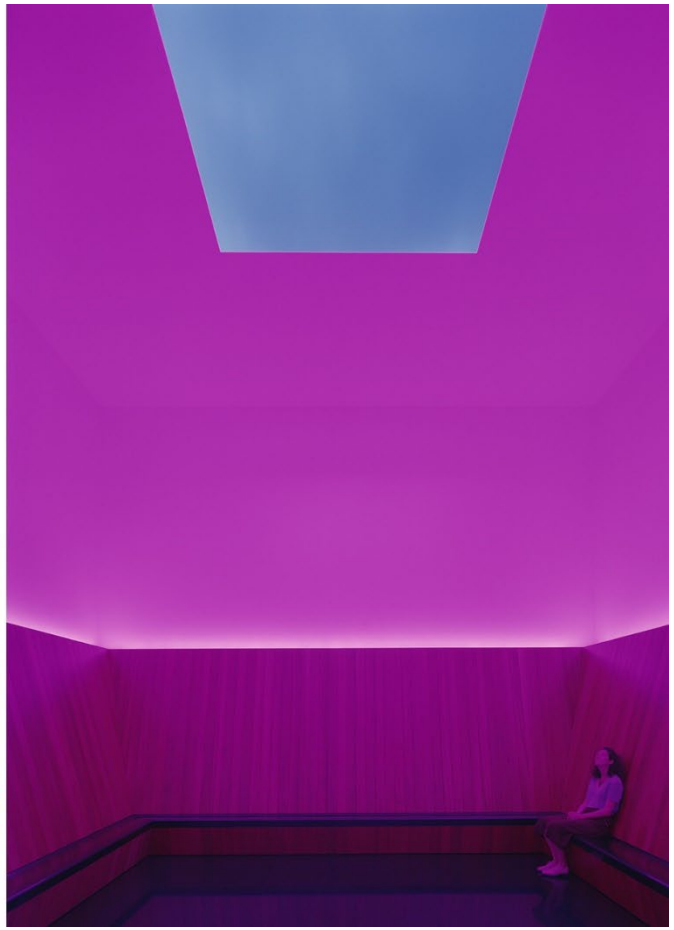
- Repeating pattern into infinity
  - looks the same at any scale
- Nature based – biomimicry
  - Calming: suspected baseline for biophilia
- Engages the mind by following pattern – hypnosis
- Dynamic fractal patterns

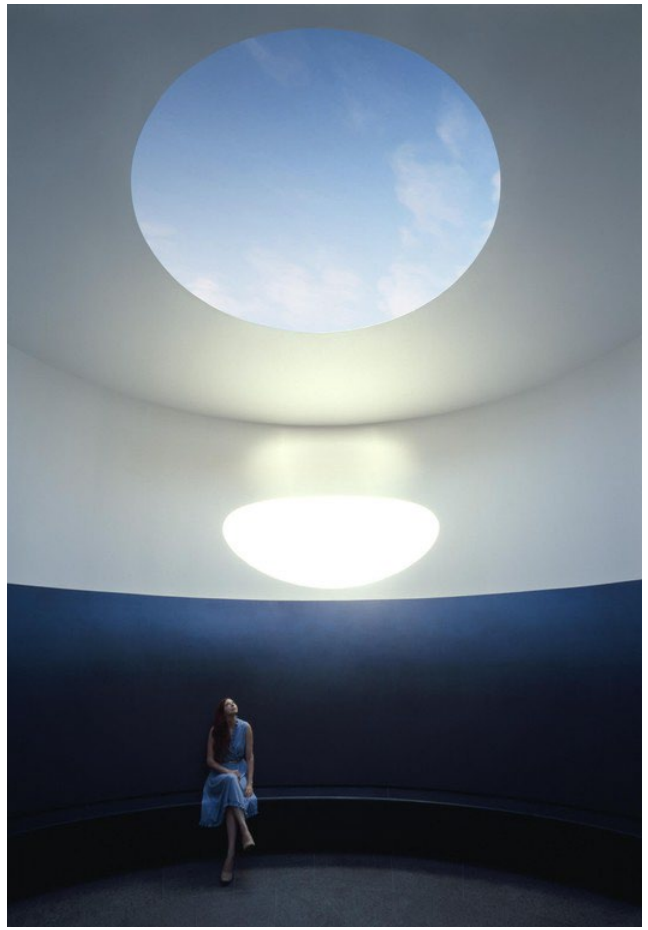


Real Views: Earth Gazing

- Phenomenon found in astronauts who view Earth from space
- Awe-inducing
  - Increased empathy and sense of purpose
- Inhibits fight/flight system
- Decrease in stress hormones
- Can be recreated with digital means (VR/screen)

Real Views: Earth Gazing & ‘Skyspace’





James Turrell – Skyspace

- looking upwards – positive effect
- Earth view incorporated?
- Real sky view or live stream – depends on location
- Mood lighting added to increase experience (based on mood of astronaut?)

Artificial Views

- Space habitat simulation 7 day trial
  - He, X., & Jiang, A. (2023, July). A 7-Day Space Habitat Simulated Task: Using a Projection-Based Natural Environment to Improve Psychological Health in Short-Term Isolation Confinement. In *International Conference on Human-Computer Interaction* (pp. 399-414). Cham: Springer Nature Switzerland.
  - 20 people in isolation with natural artificial views
  - Virtual Reality test method

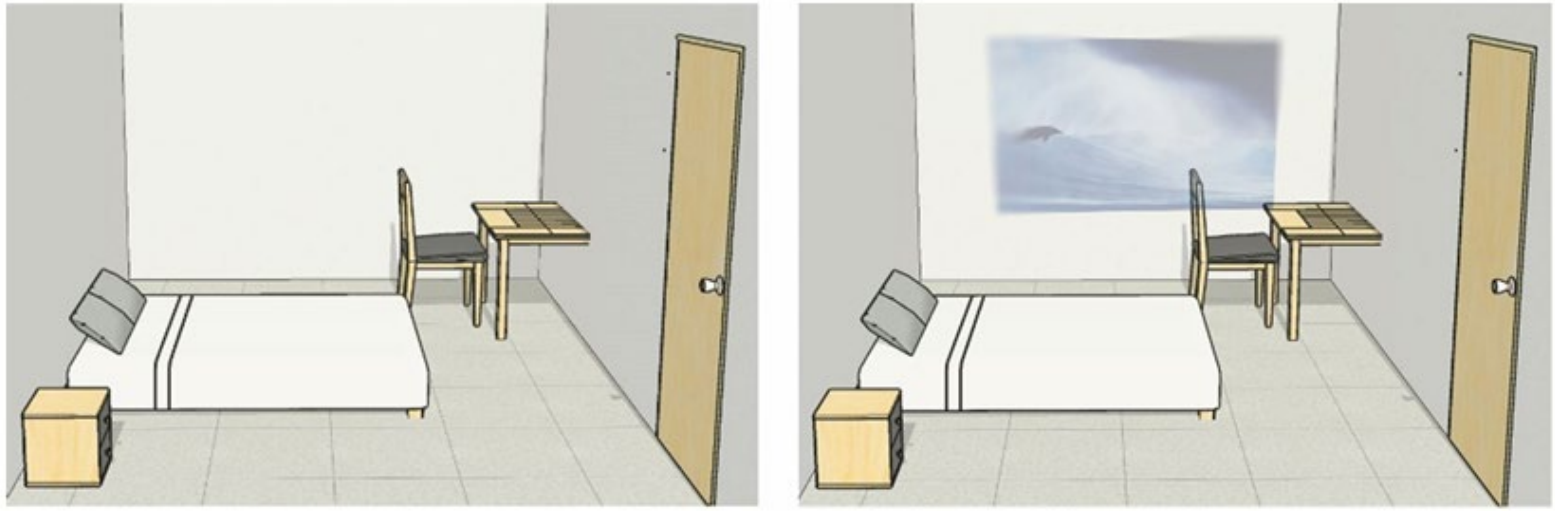


Fig. 2. Computer recreation of the simulated isolation environment.

Artificial Views

- Positive influence first four days
- Still increase in anxiety after 4 days in all test subjects

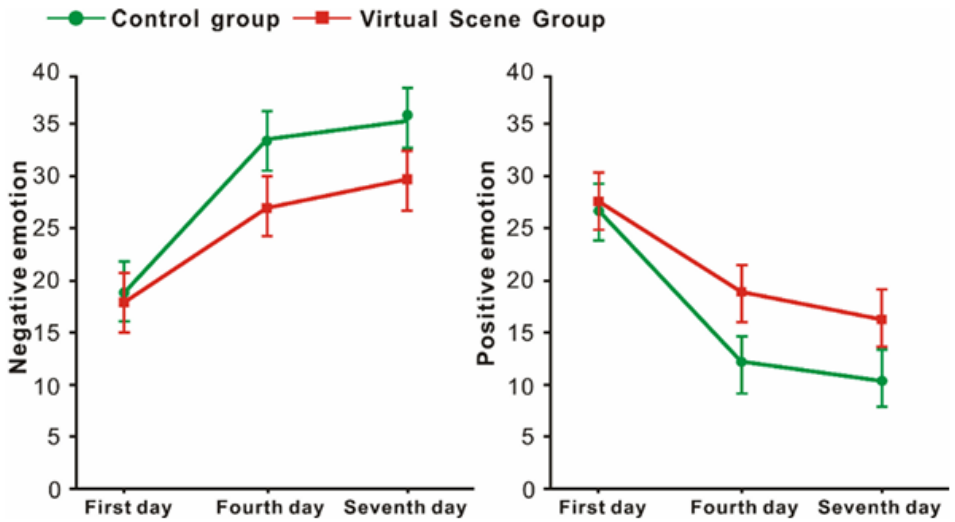


Fig. 4. Emotion levels of the virtual scene group and the control group on the first, fourth, and seventh days (error bars indicate standard errors of the variables).

Artificial Views

- The effect of virtual reality forest and urban environments on physiological and psychological responses
  - Yu, C. P., Lee, H. Y., & Luo, X. Y. (2018). The effect of virtual reality forest and urban environments on physiological and psychological responses. *Urban forestry & urban greening*, *35*, 106-114.

Artificial Views

Urban views: Increased fatigue and decreased self-esteem

Forest view: Increased vigor and decreased negative emotions

Artificial views: VR vs Screens

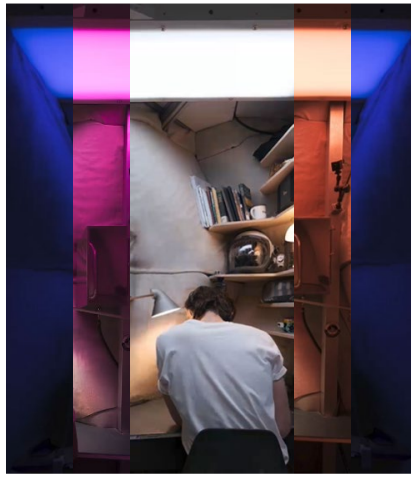
- VR can be more immersive: complete change of scenery
- Effective for exercise
- Conscious influence – time-out needs to be taken
- VR headset is cumbersome and impractical

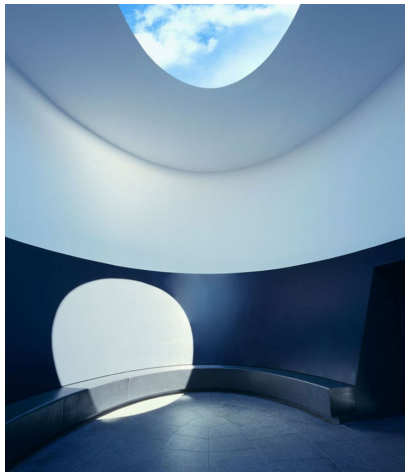
- Screens are less immersive
- Screens add to everyday life
- Unconscious influence
- Screens easily operated and incorporated in design

Maybe combining in Augmented reality?

Concept

Designing a Lunar habitat that promotes mental wellness of the crew



Design approach: Bottom Up

- Usually architectural design from big to small scale
- This research requires initial focus on the interior
- Start with spatial requirements and progress towards final location implementation

Program: Requirements

ESA-CDF:

“ Minimum accommodation functionalities:

- Sleeping space, ideally private quarters
- Dining and communal activities
- Work space
- 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)
- Storage

Additional rooms

- Garden
- Meditation space
  - earth viewing
  - silence

Program: Size

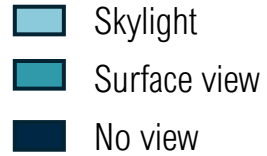
Room	m3 (1 person)	%	Same time use	Multiply factor	m3 (6 persons)	%
Private crew quarters	2,5	3%	Yes - but separate	x 6	15	3,5%
Living quarters	13,5	15%	Yes	x 6	81	19,5%
Kitchen	2,5	3 %	Not all	x 2	5	1%
Research facility	11	13%	Yes	x 6	66	16%
Garden	13,5	15%	Yes	x 6	81	19,5%
Gym	8	9%	Not all	x 3	24	5,5%
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%**

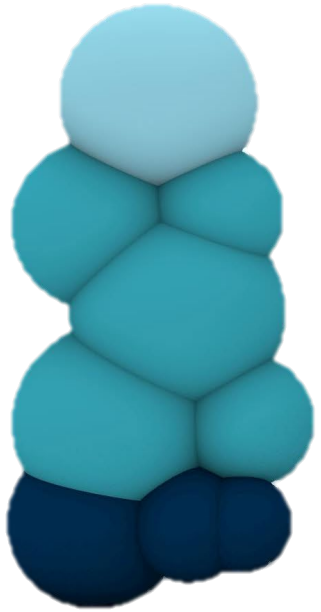
Program: Overview

Room	Volume m3	View (real)	View (art.)	Light	Geometry
Private crew quarters	15	Earth?	-	Darkness & sunrise/set	Curved
Living quarters Kitchen	81 5	Earth & Surface	Nature	Full day/night cycle - dynamic	Curved
Research facility	66	Surface	Nature	Daylight - dynamic	Angular
Garden Gym	81 24	Garden	VR?	Plant growth appropriate – good visibility	Angular
Bathroom	10	-	-	Good visibility	-
Medical facility	16	-	Nature	Daylight	Curved
EVA antechamber	24	Surface?	-	Good visibility	Angular
Storage	48	-	-	Good visibility	-
Meditation space	48	Earth	-	Multicolour/mood	Curved

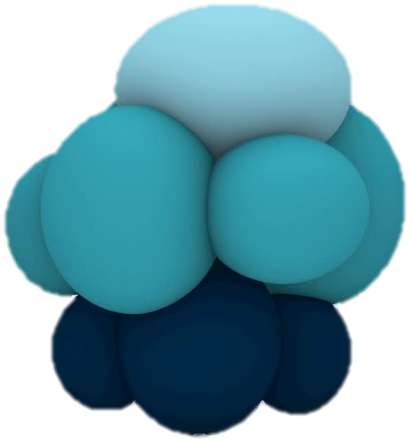
Connecting spaces

Hierarchy based on views

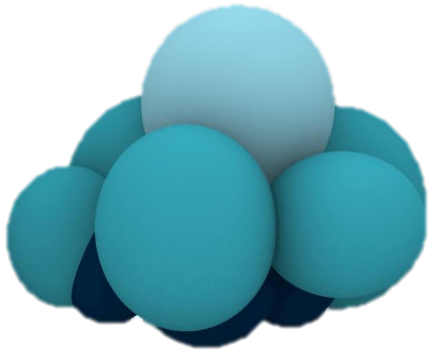




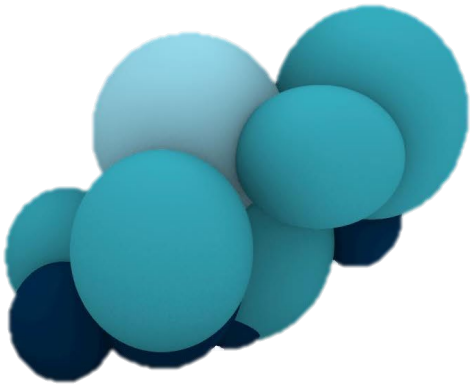
Stacked



Compact



Sheltered



On a slope

Connecting spaces

Vertical distribution of connected spaces within larger space

Vertical corridors

- fire poles concept

Columns

White Tower – Tor Alva

3D-printed columns

https://www.dezeen.com/2024/03/07/tor-alva-tallest-3d-printed-tower/

Outer Shell

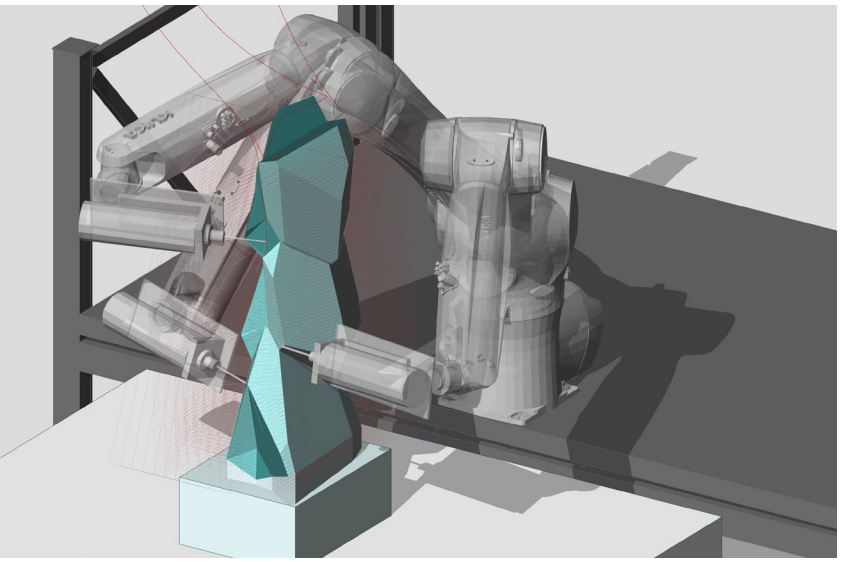
Thick Regolith Shell

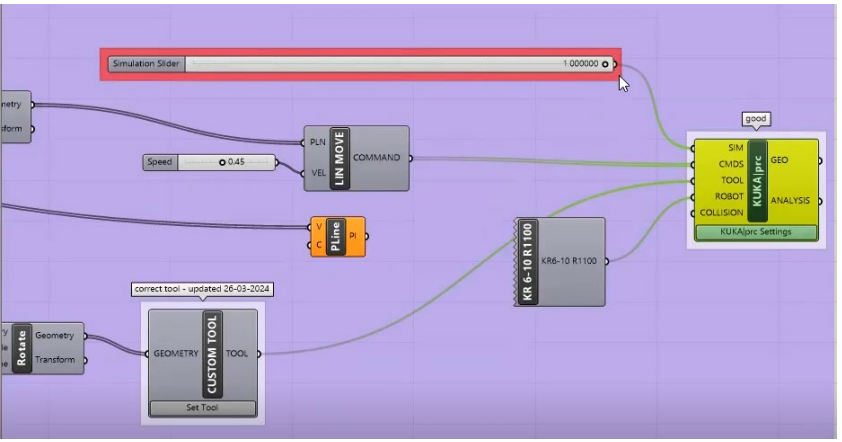
https://www.snohetta.com/projects/the-arc.

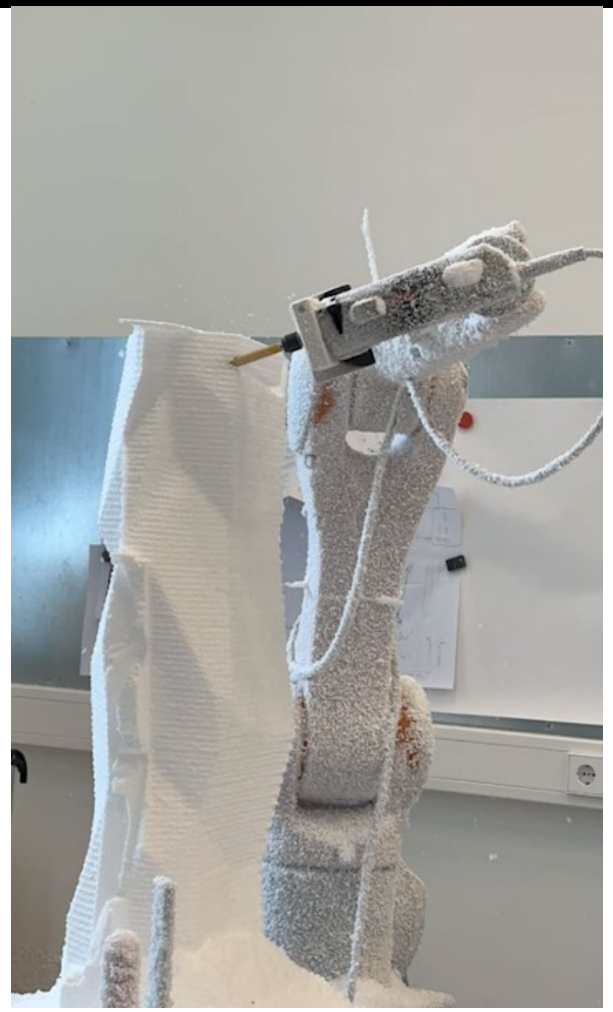
Components

Top skylight

Workshop

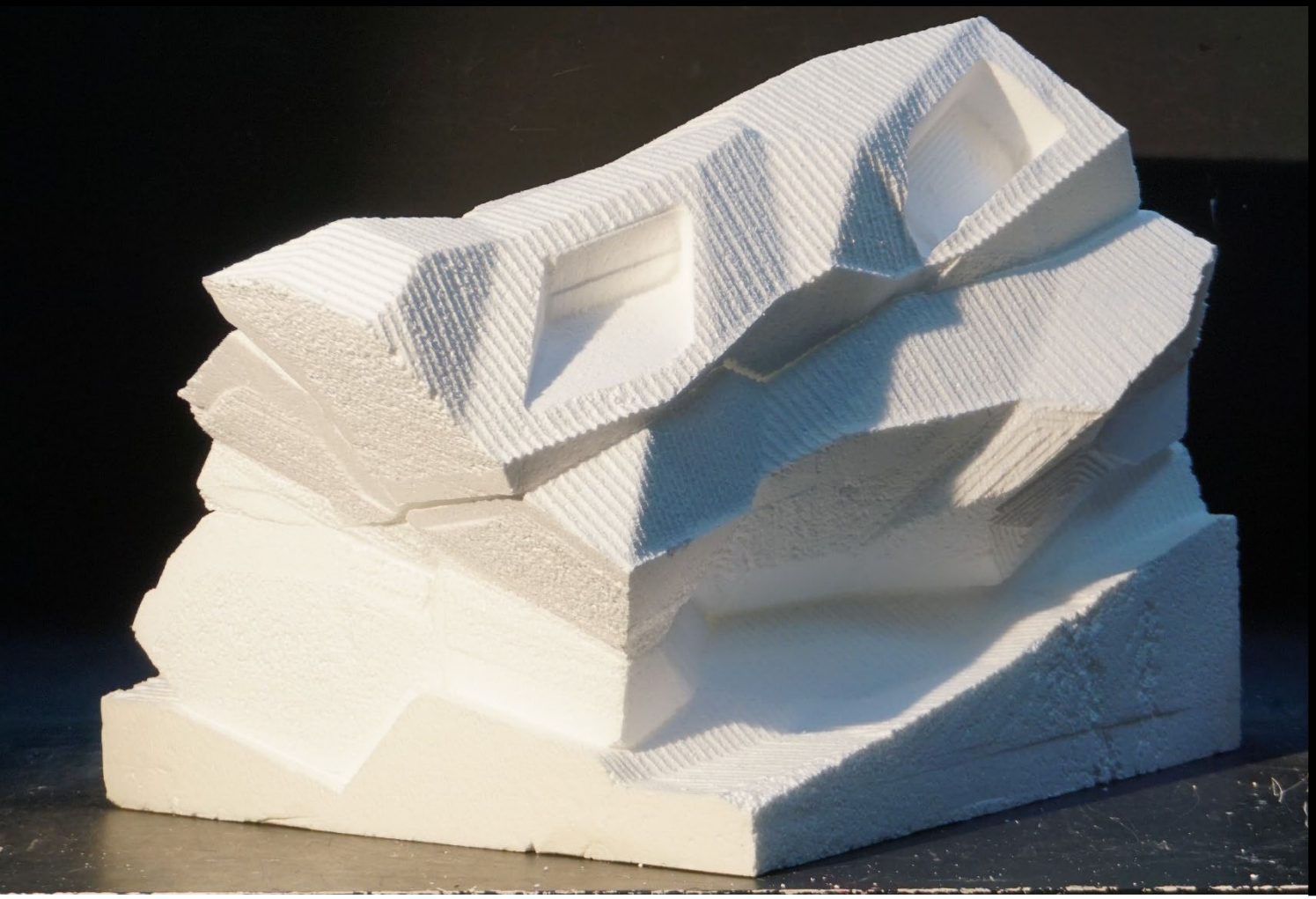


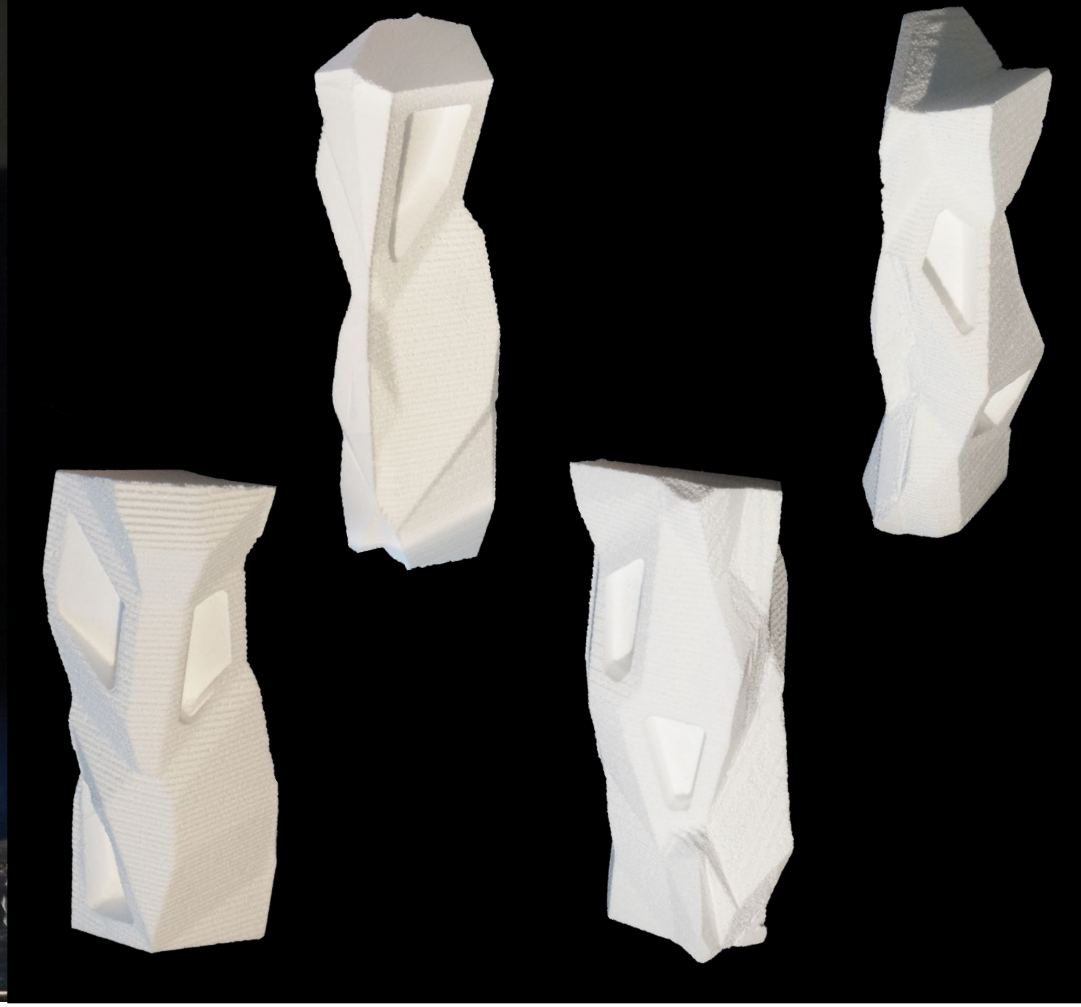




- Good interlocking of components necessary for a stacked structure
- Voronoi based:
  - Enough interlocking surfaces
  - Easily generated digitally
- Complex process:
  - Each component unique
  - Mass customisation process

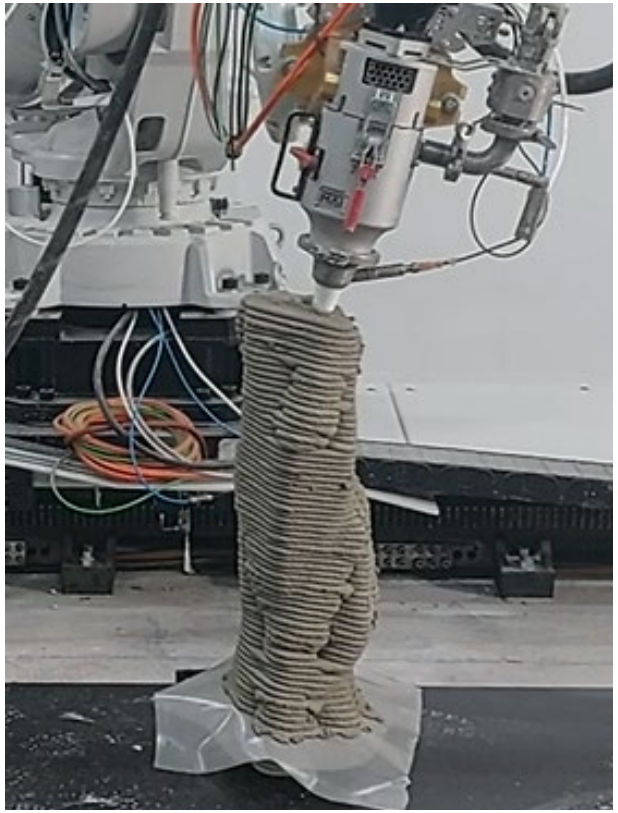
Workshop: End Result





Workshop: Vertico

Vertical printing of component with cement & milling



Location: Earth view

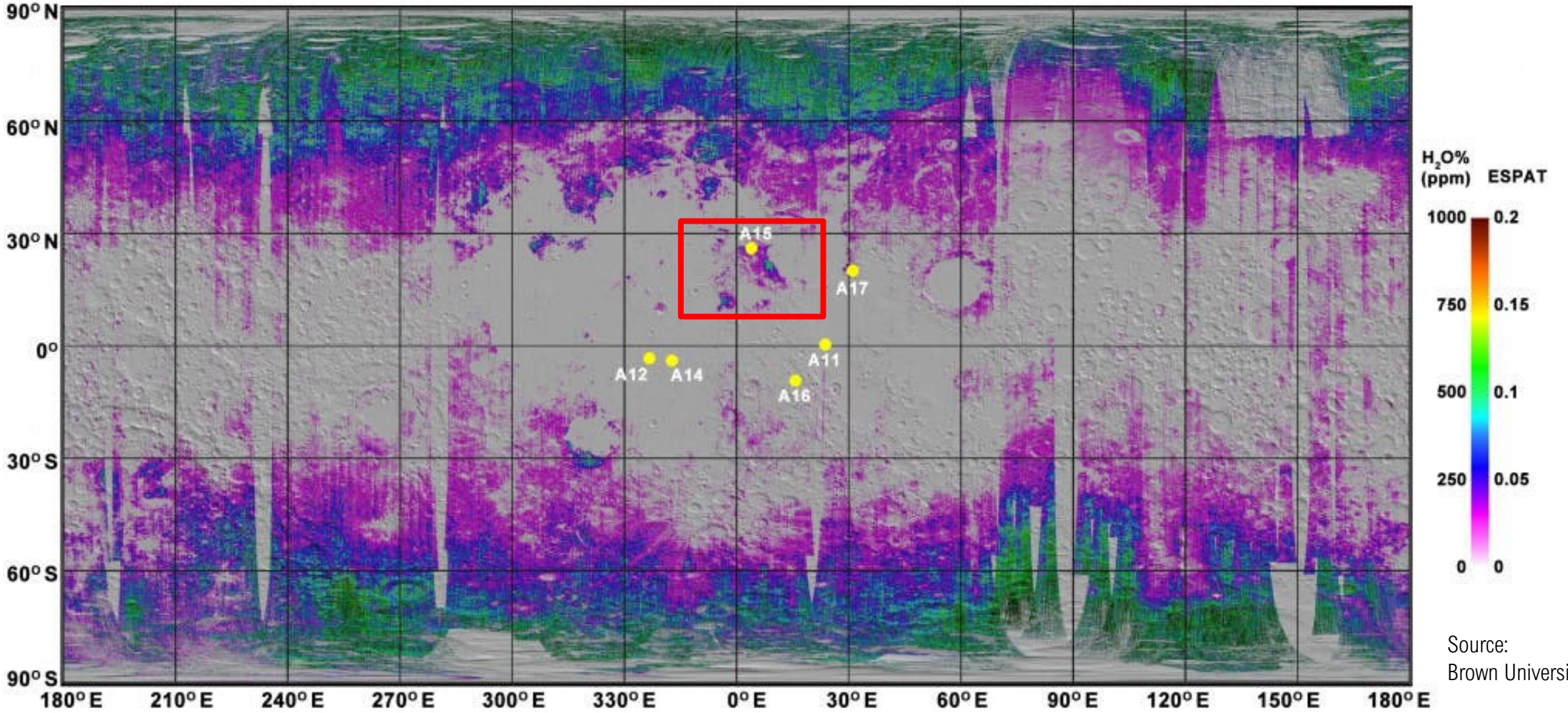
Lunar Equator

- 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: Shackleton Crater

Near landing site Apollo15

Foot of ‘Montes Apenninus’