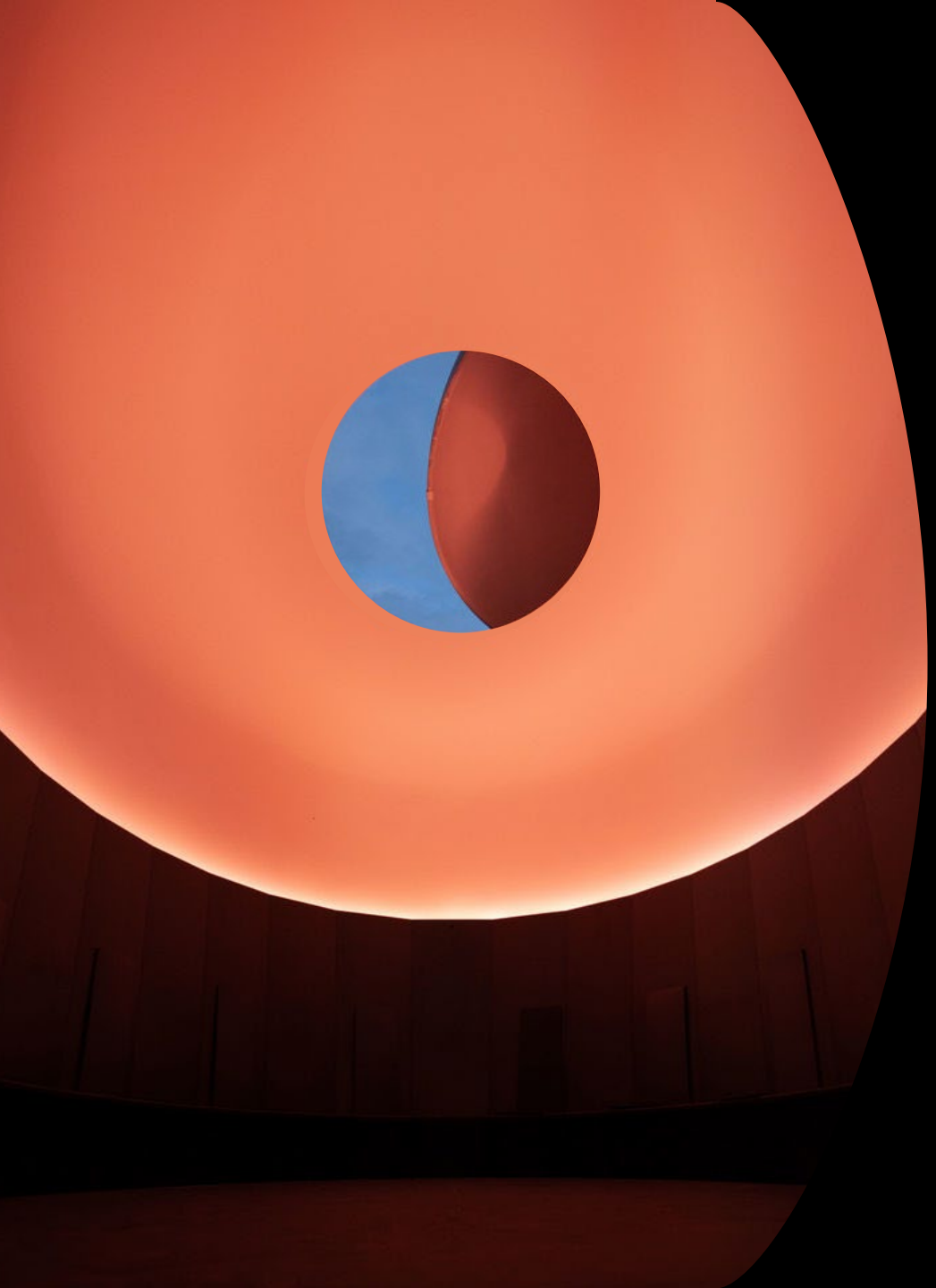


MoonSane

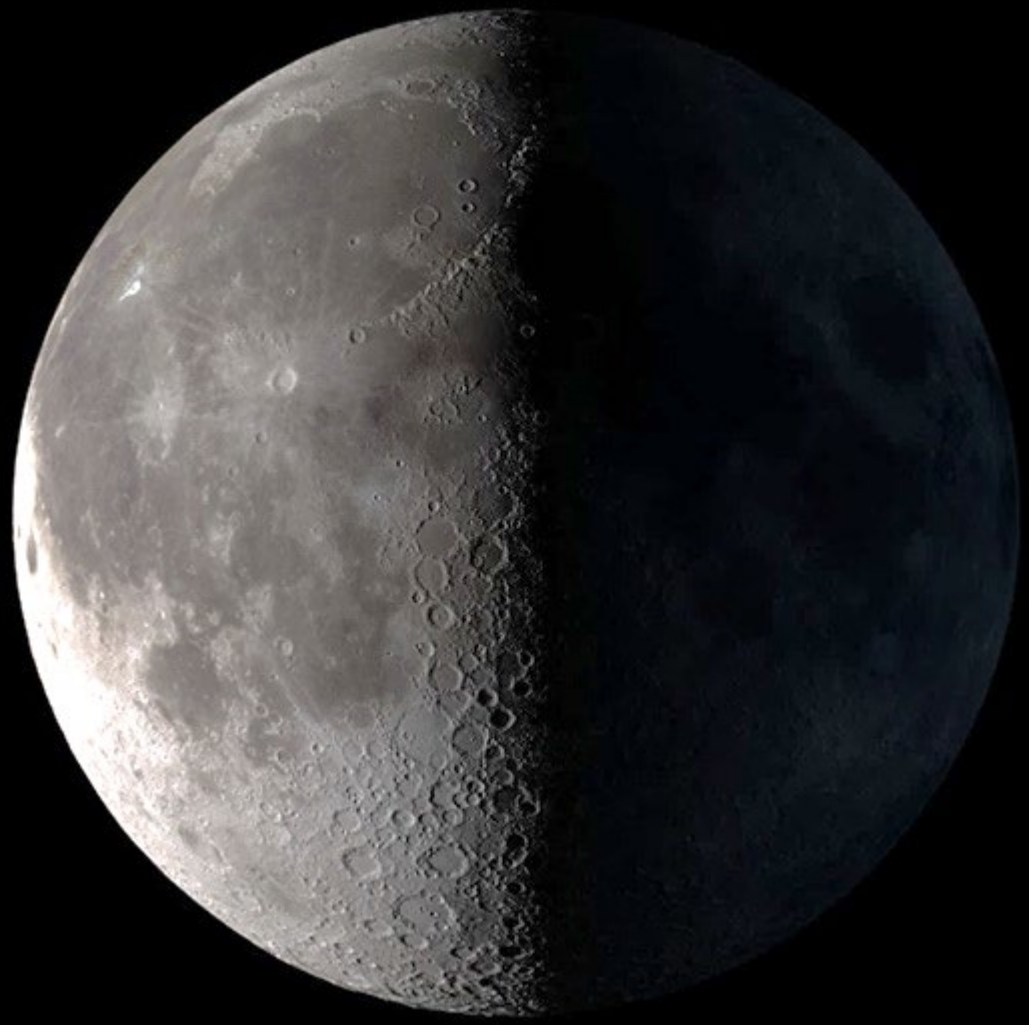
Designing Spatial Serenity for Lunar Habitats

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

Approaching Lunar Architecture

Carte Blanche

Extreme Environment



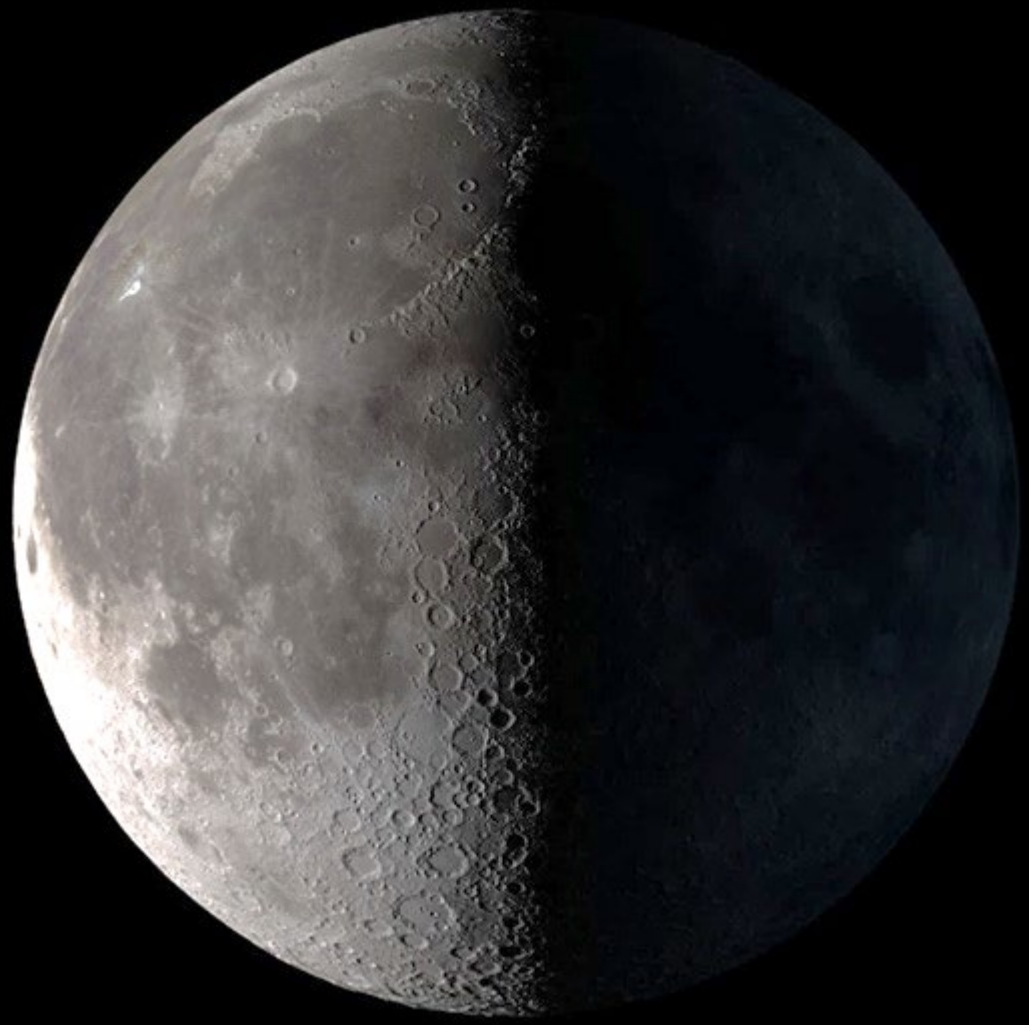
Utopia

Dystopia

Approaching Lunar Architecture

Carte Blanche

Utopia

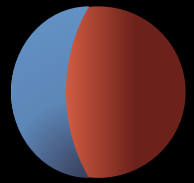


Extreme Environment

Dystopia

Physical conditions

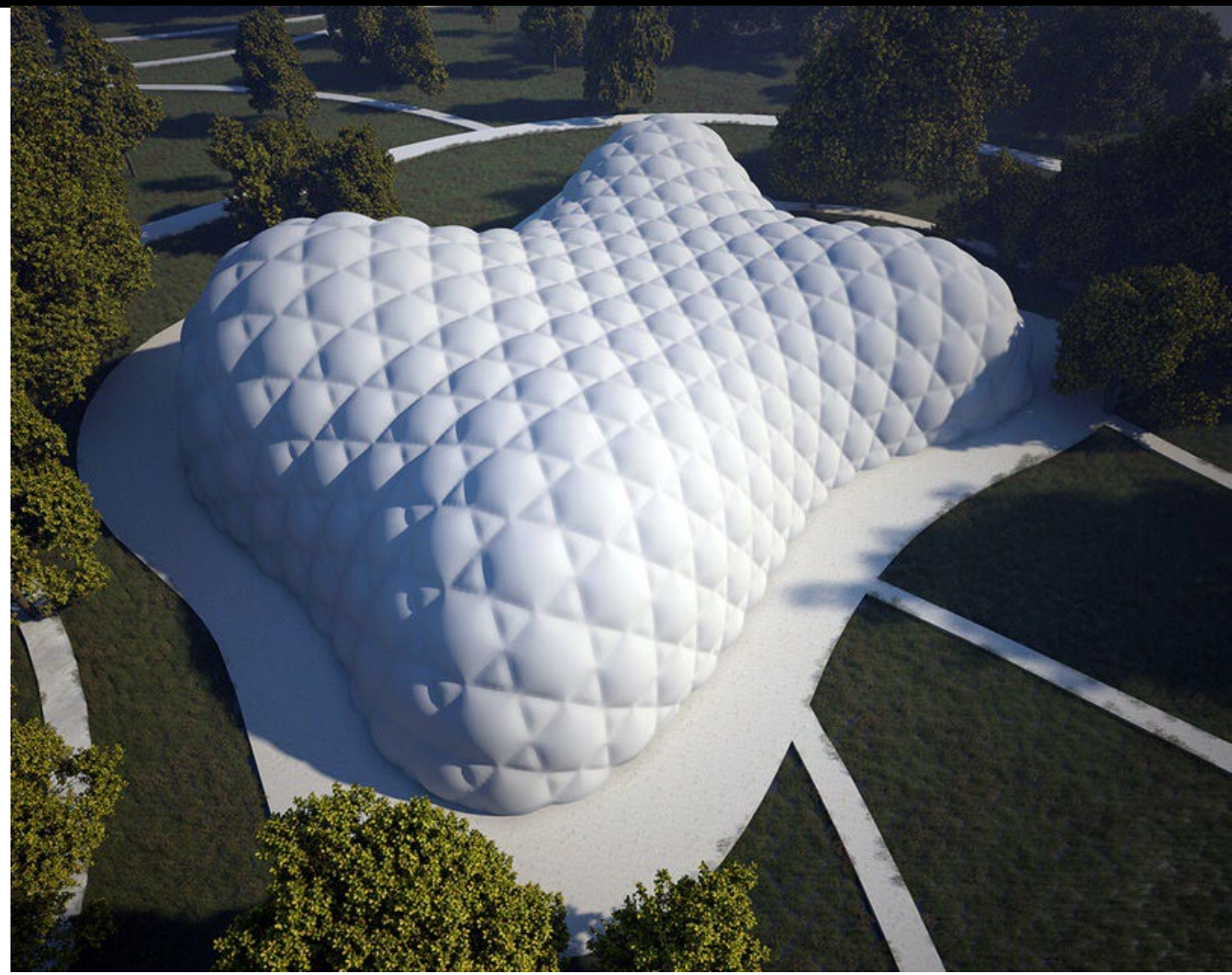
The Moon



- 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
- Only frozen water

No Atmosphere

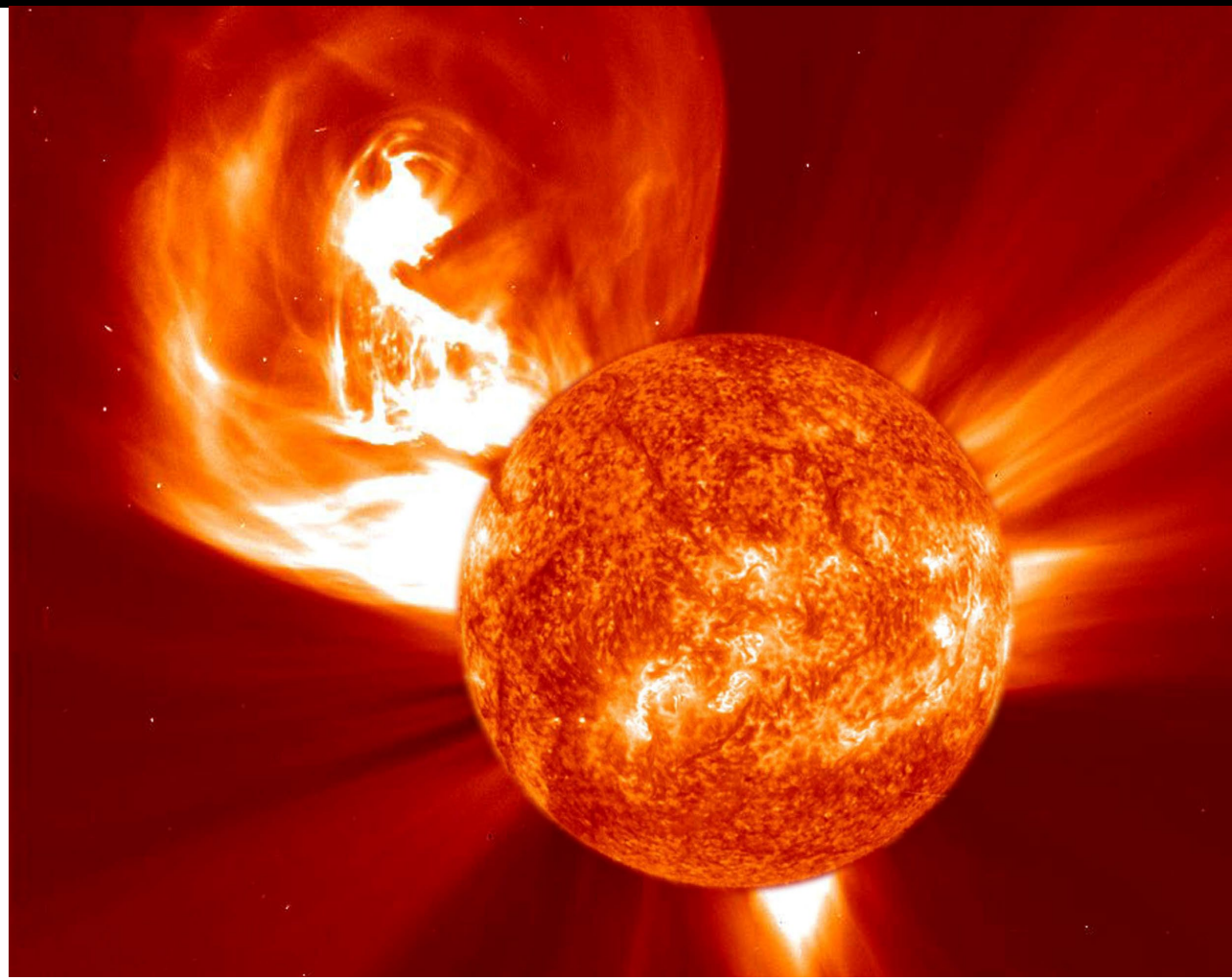
- Recreating Earth atmosphere in habitat necessary
- Inflatables
- Hermetically sealed
- Airlocks



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?



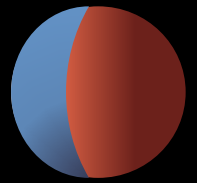
Day/Night cycle

- Circadian rhythm on Earth is 24 hours
- Influences hormone cycles
- Disrupted rhythm affects a.o. 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).

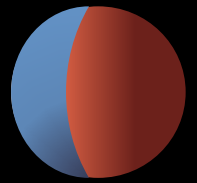
Partial gravity: 1.62 m/s²



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

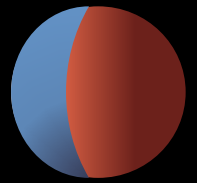
  (NASA [MSIS], 1995 p. 178)
- Ergonomic design necessary, though no chair restraints necessary

Partial gravity: crew experience



- 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

Going underground



- Extreme environments:
  - Desert architecture
  - Bunker architecture
  - Polar architecture

- “Shelters for the apocalypse”
  - Nuclear disaster
  - WW3
  - Climate disaster

Dystopian

Dystopian atmosphere:

- ‘impersonal’ (1); clinical; minimalist
- No room for individuality/ for the greater good

(1) https://www.archdaily.com.br/br/889083/cinema-e-arquitetura-equals-a-arquitetura-da-impessoalidade

Dystopian

Bunker architecture

- Bunker for hire in South Dakota
- LED screens to mimic sky

https://www.dezeen.com/2017/01/11/vivos-xpoint-south-dakota-bunker-field-worlds-largest-survival-shelter-community/

Underground House Plan B

- Sergey Makhno Architects

Characteristics:

- Ukraine war shelter
- Playing with light, screens and (fake) greenery to create illusion of outside coming in
- Round shapes, curved walls
- Gray, concrete-like materials
- Neutral colours, calm/pensive environment

https://www.dezeen.com/2020/07/02/underground-house-plan-b-bunker-architecture-ukraine/

Realistic

Constraints:

- Limits of materials
- Development of technologies
- Adapting to the environment

LUNARK

- Artificial circadian light system
- Solar panel façade
- Expandable, lightweight module
  - Easy to transport
- Can function to -45 degrees, tested in Greenland
  - Should be -175

Psychological conditions

Overview of stressors

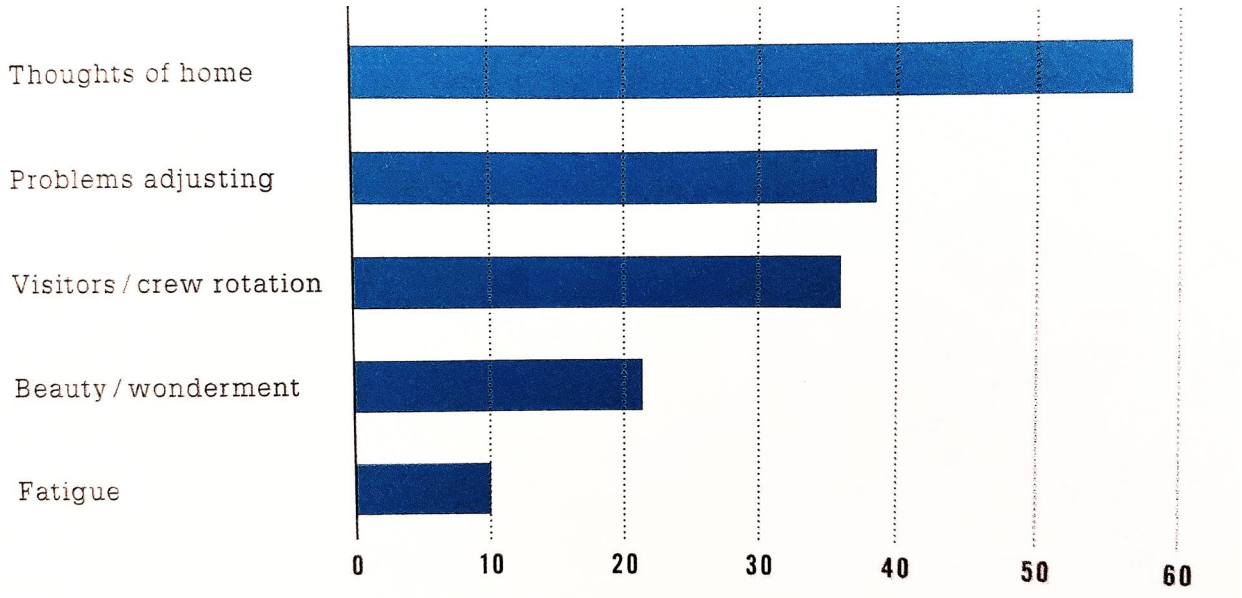
Table 3
Known spaceflight stressors.

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**

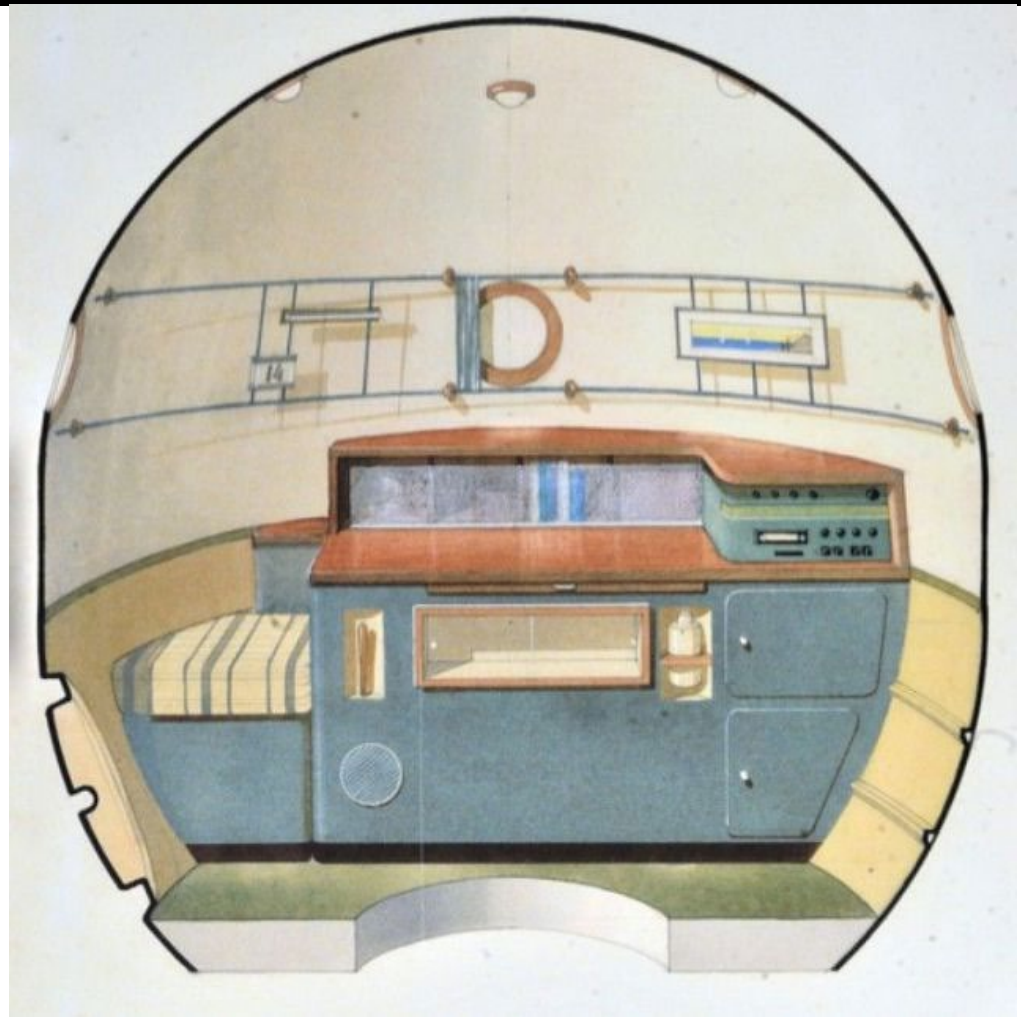
AS17-137-20990 (QF300) Source: NASA

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

- Only variations of grey/brown dust and rocks
- Pitch-black sky
  - No atmosphere to scatter light into a blue sky
  - No stars during Lunar daytime due to sunlight reflection

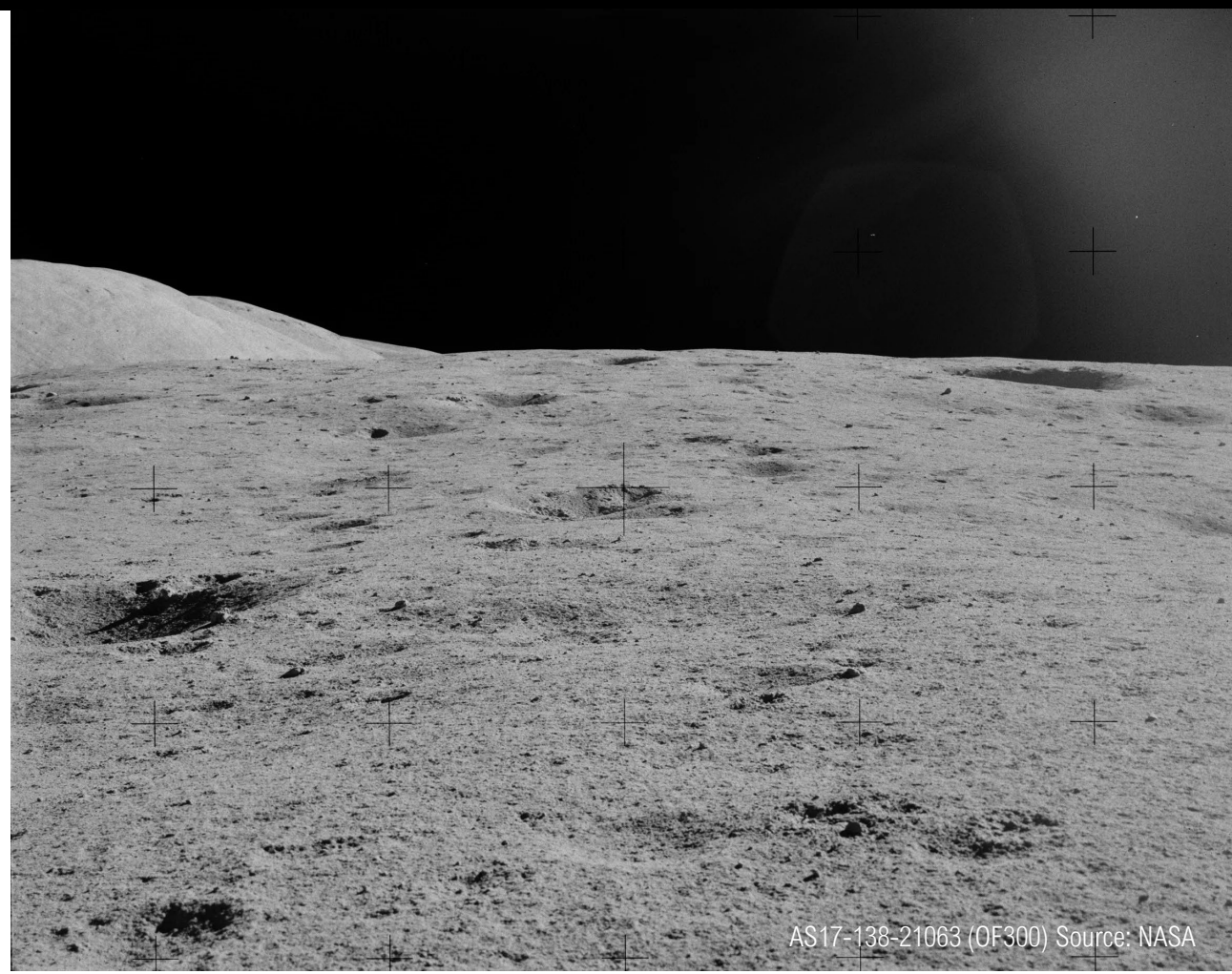
The View

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

“Because distance judgment is related to the accuracy of size estimation, it is evident that these skills may require refinement in the lunar environment.”

- Compact horizon

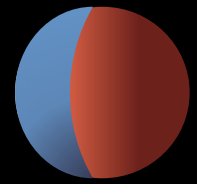
“Because the Moon is smaller than Earth, its horizon will look shorter and closer. To someone standing on a level Earth surface, the horizon is 3 miles away, but to astronauts on the Moon, it’ll be only 1.5 miles away, making their surroundings seem confined.”


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

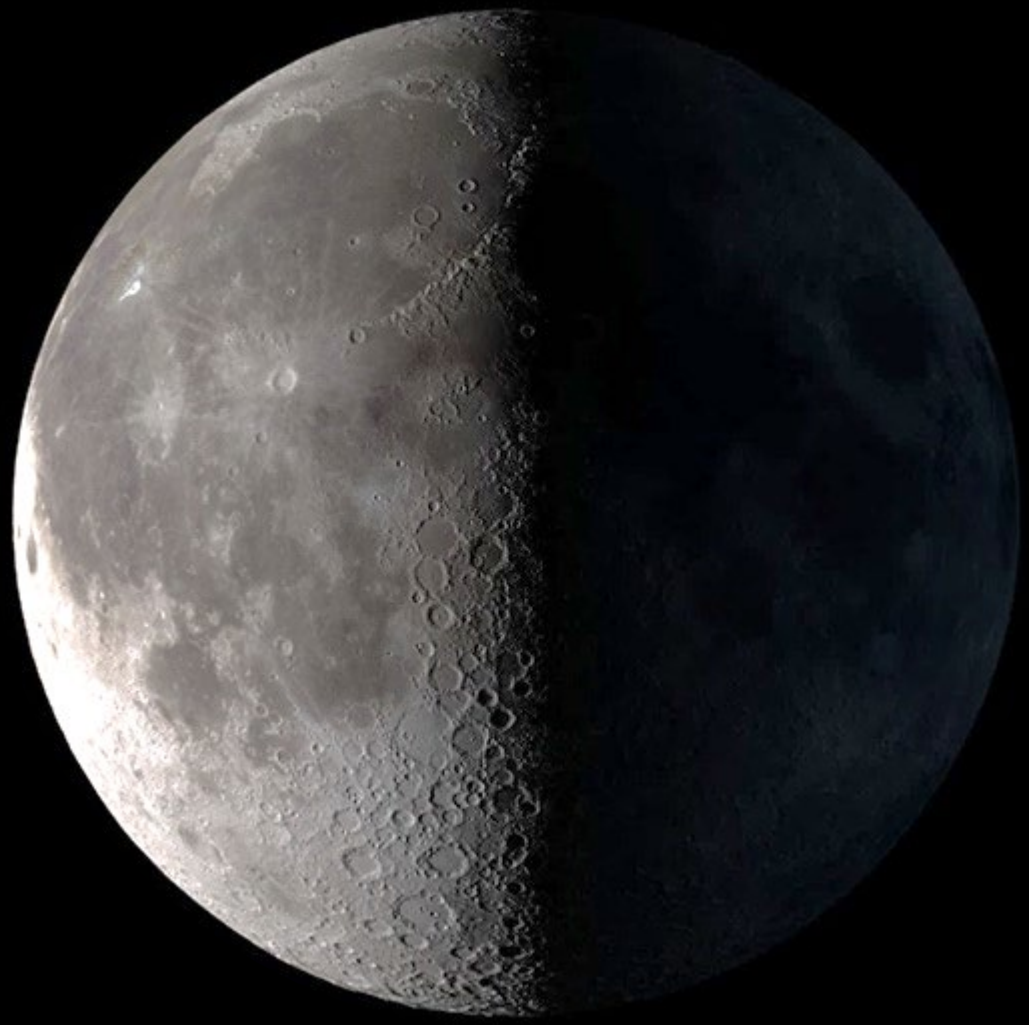


How can human spatial perception be used in the design of Lunar habitats to mitigate the negative mental health effects of living long-term on the moon?

Approaching Lunar Architecture

Carte Blanche

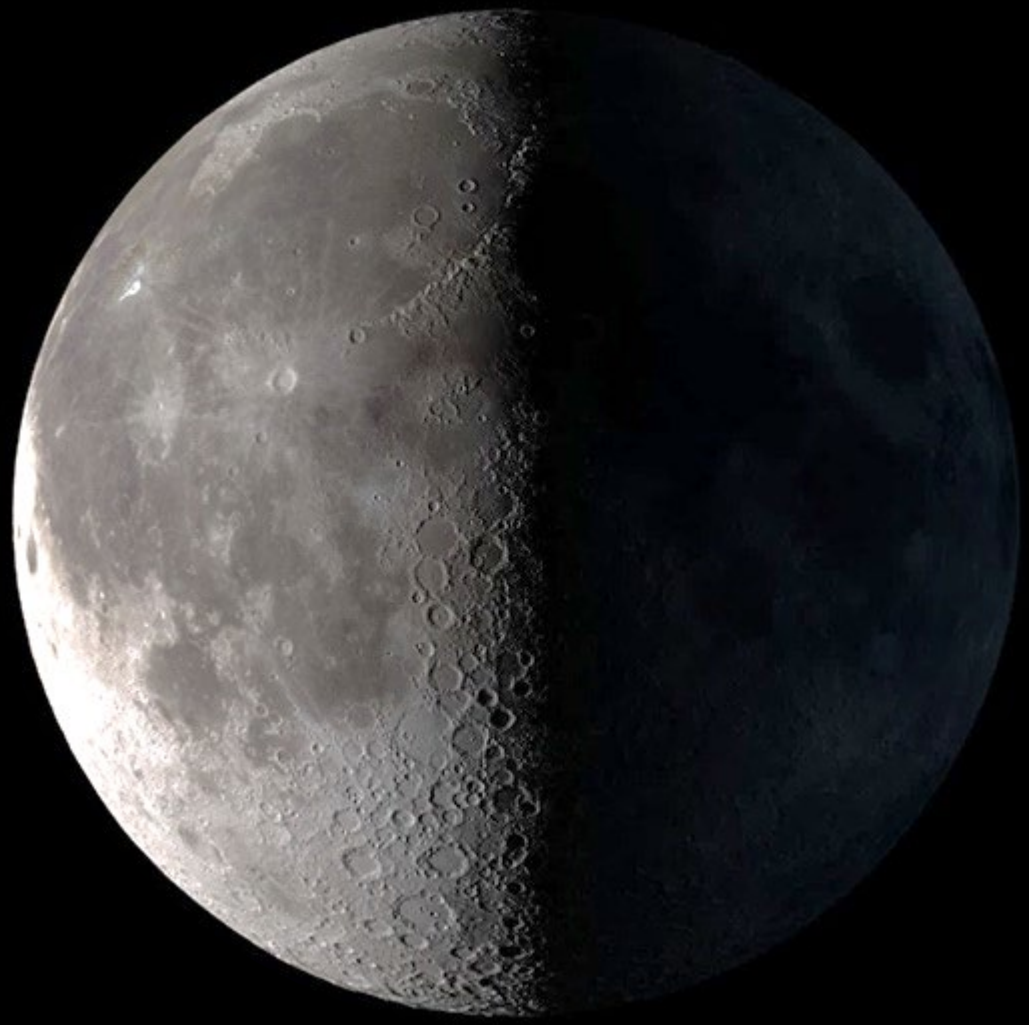
Extreme Environment



Utopia

Dystopia

Approaching Lunar Architecture



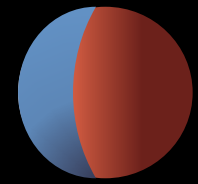
Carte Blanche

Extreme Environment

Utopia

Dystopia

Scope of habitat solutions



Crew contact: (PRIVACY)
- Private quarters

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

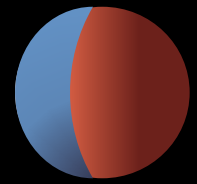
Lighting: (CIRCADIAN RHYTHM)
- Allowing the passage of sunlight*
- Habitat day/night cycles
- Improved environmental lighting

Views: (ISOLATION/CONNECTION TO HOME)
- 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.

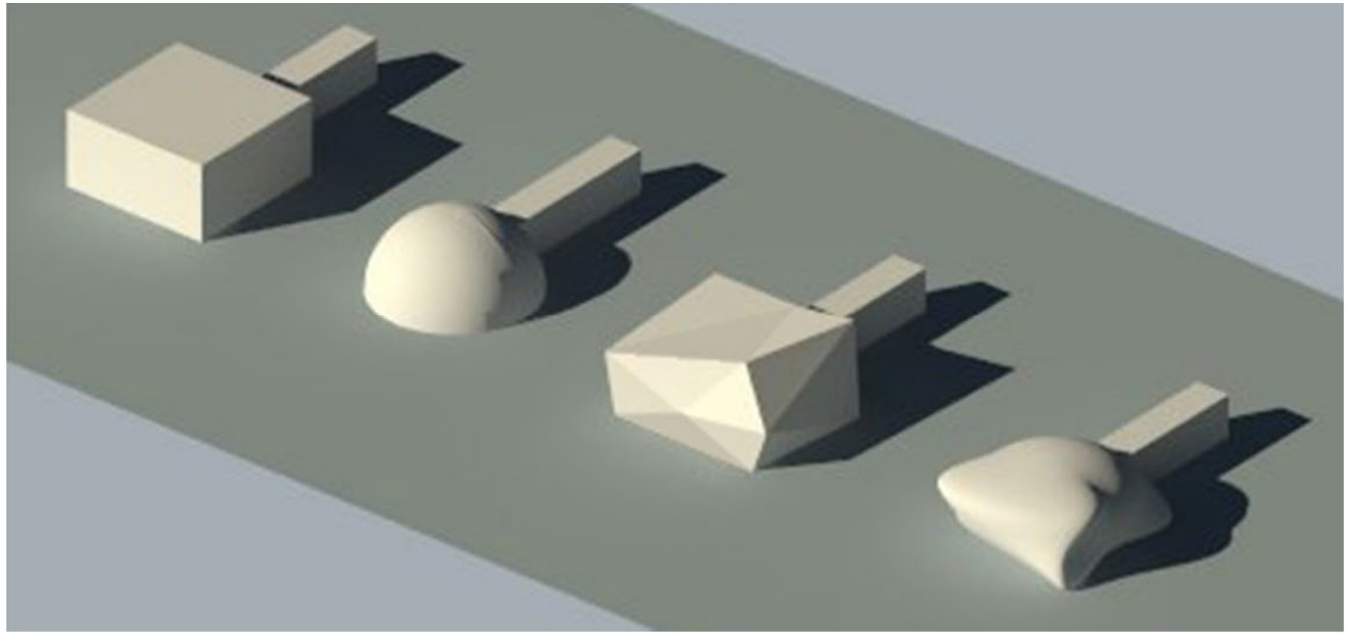
Additional possibilities



- Spatial geometry and function
- Screens simulating windows
- Virtual reality

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

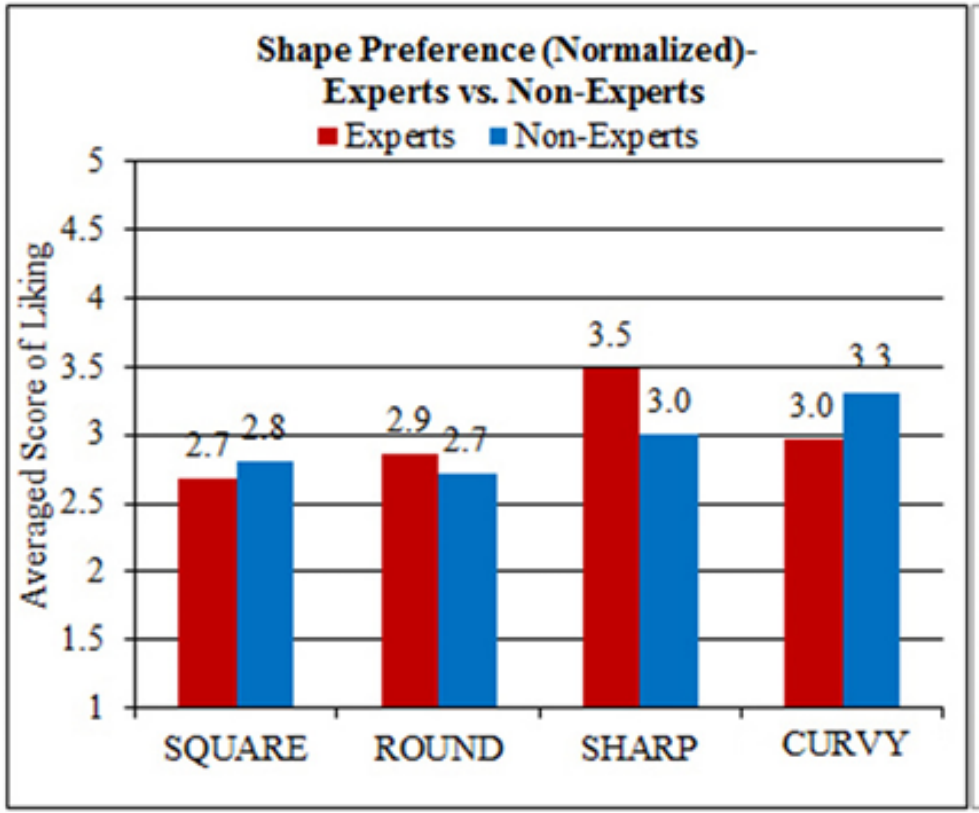
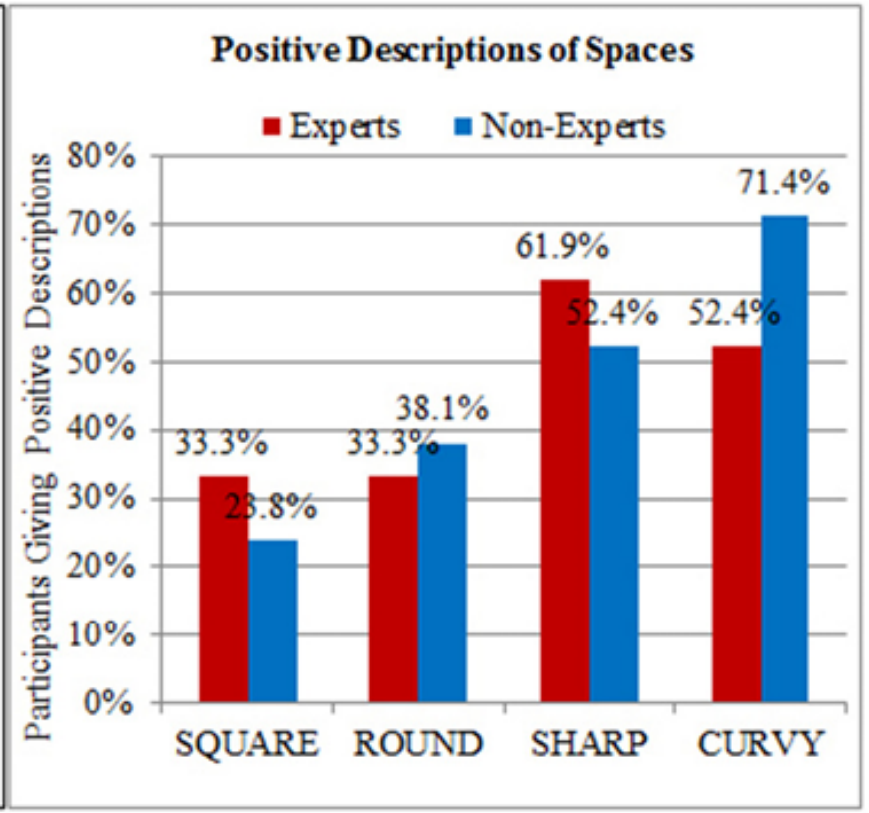
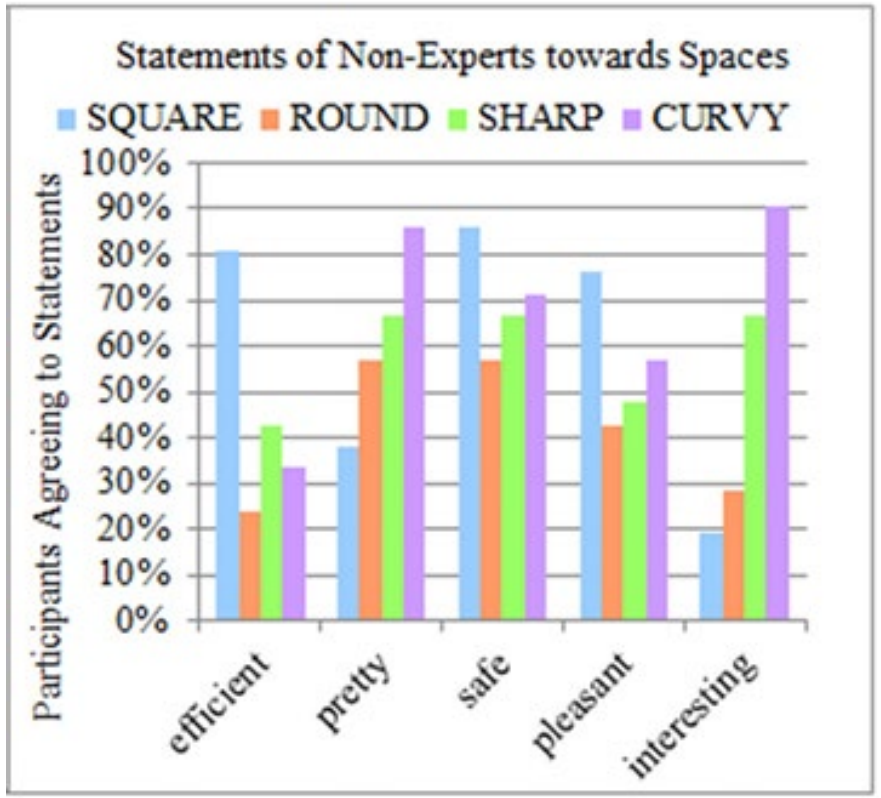


Table 2



Geometry

Table 4

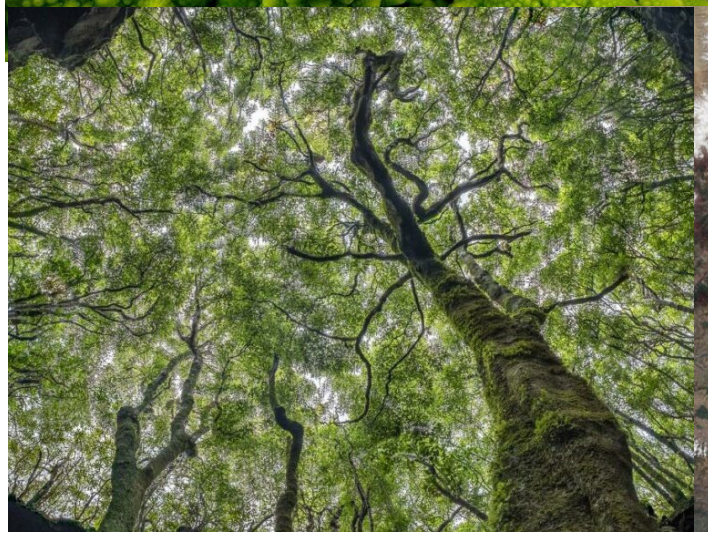


- Square considered safe and efficient: **familiar**
- Curved considered interesting and pretty
- Asymmetric rooms most interesting

Geometry

Fractal patterns

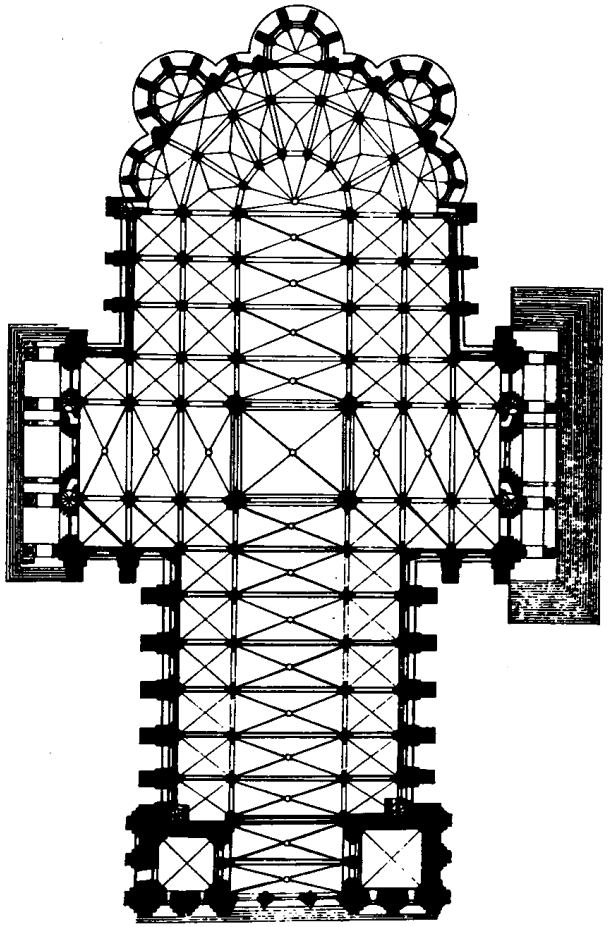
- Repeating pattern into infinity
  - looks the same at any scale
- Nature based - biomimicry
  - Tree branches
  - Arteries
- Dynamic fractal patterns:
  - Light through water
  - Foliage in the wind

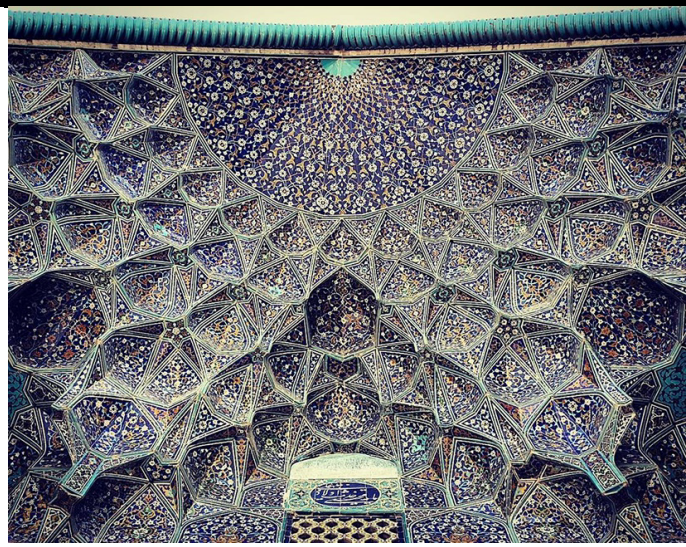


Geometry

Fractal patterns effects

- Calming: suspected baseline for biophilia
- Engages the mind by following pattern – hypnosis
- In design/ architecture:





Lighting

- Relevant experiment: circadian rhythm lamps in the LUNARK module
- Stationary



Darkness – Absence of Light

Difficult to find absolute darkness these days due to light pollution

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

- Moon is still untouched by artificial lighting
- Darkness brings calm, ultimate rest: we need dark to sleep/rest
- Mental breakdowns from people living near the poles: in eternal *summer*, not winter, because they cannot sleep well

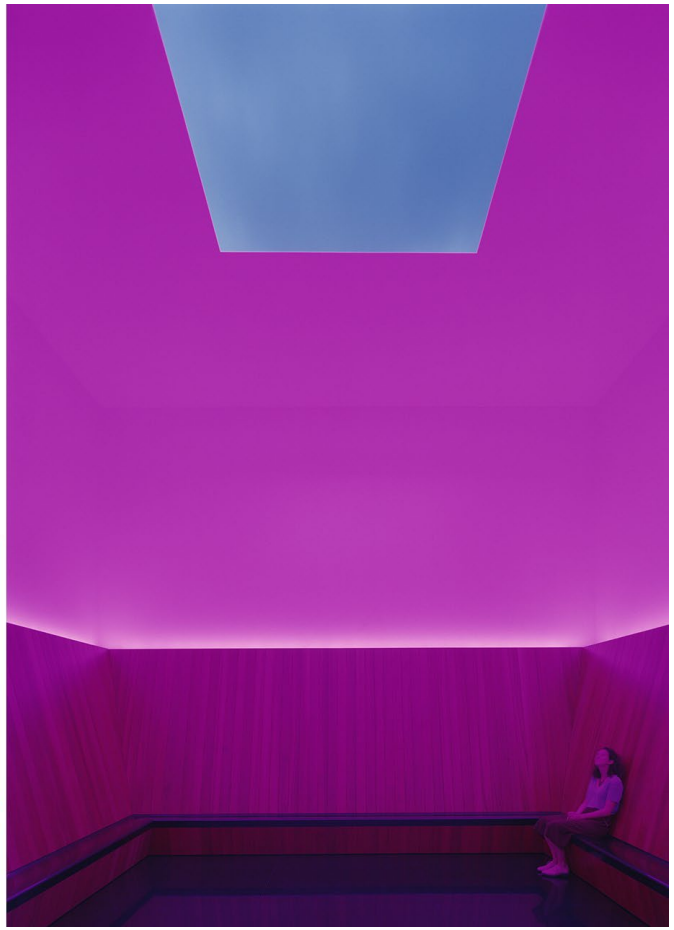
"As Norwegian poet Jon Fosse wrote, 'You can never see further than in the dark'."

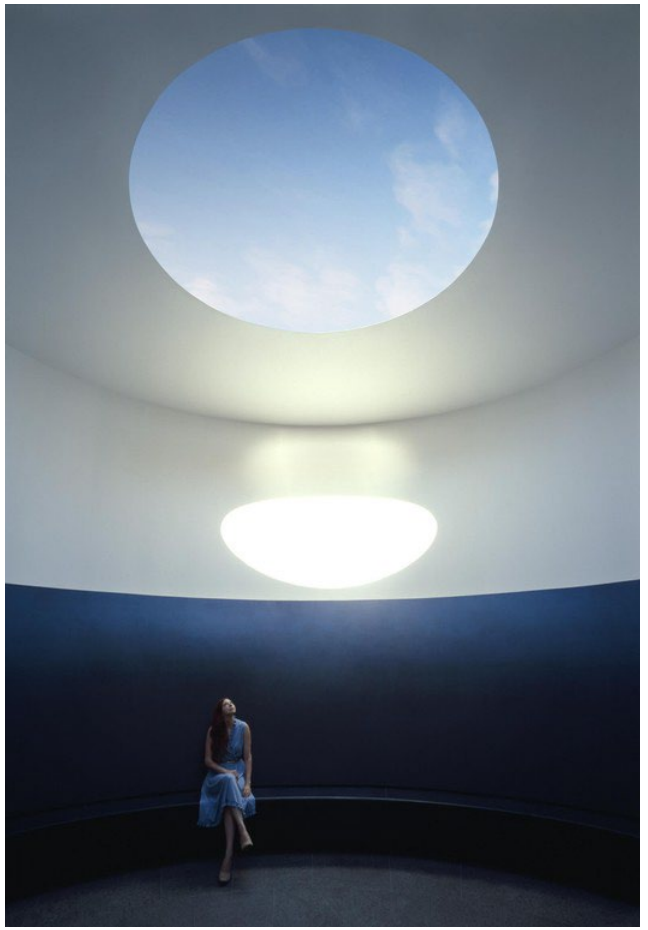
In praise of darkness, a waning reserve – Sigri Sandberg in The Architectural Review 2020

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)

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: Sky view


Sergey Makhno Architects


Sergey Makhno Architects

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

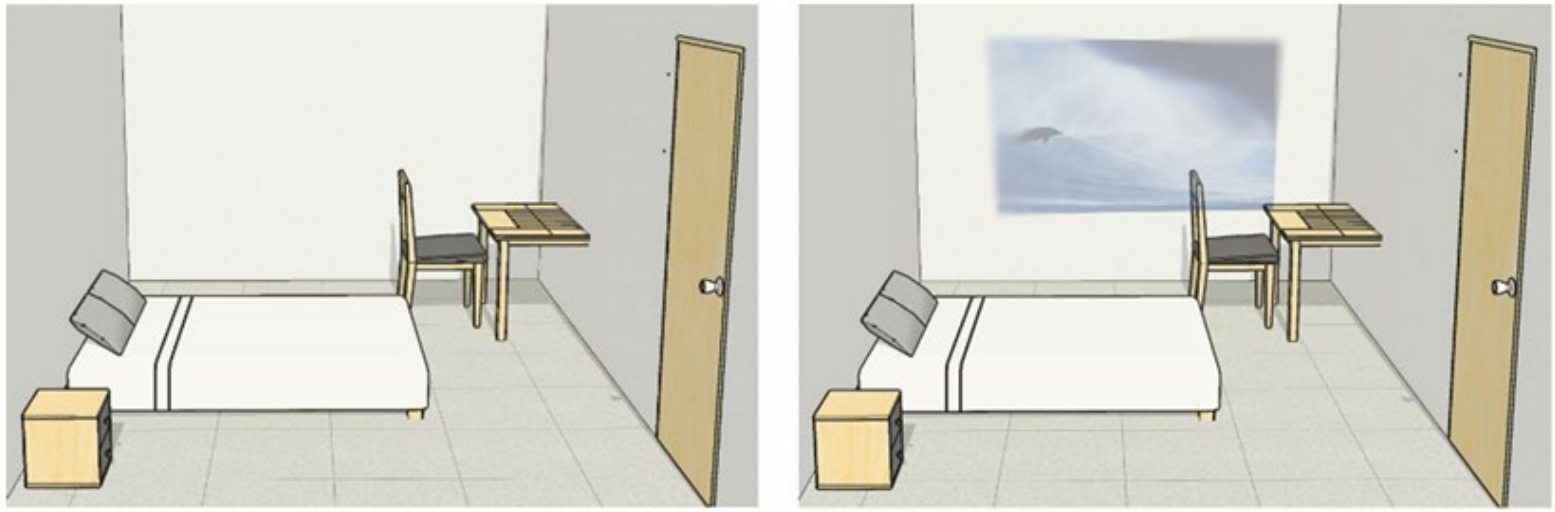


Fig. 2. Computer recreation of the simulated isolation environment.

Artificial views

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

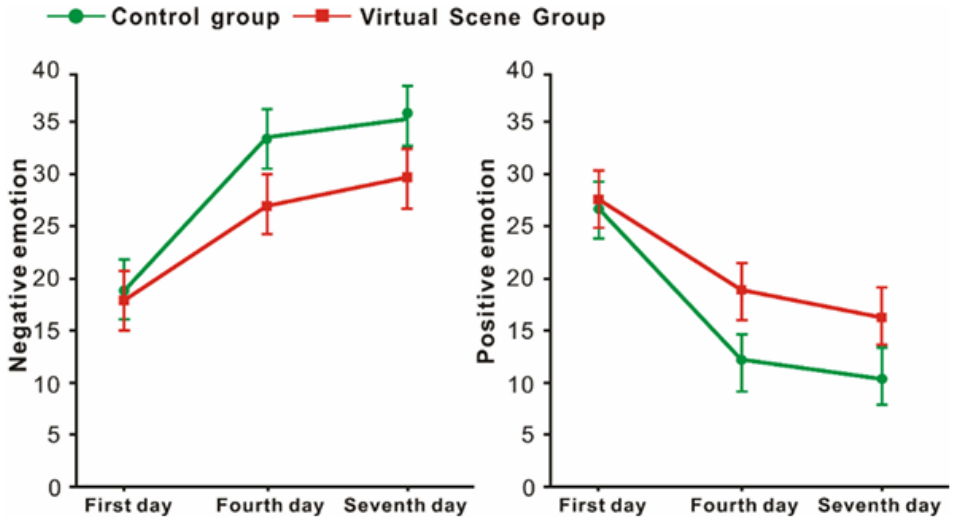


Fig. 4. Emotion levels of the virtual scene group and the control group on the first, fourth, and seventh days (error bars indicate standard errors of the variables).

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

(a)

(b)

Urban views: Increased fatigue and decreased self-esteem

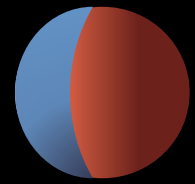
Artificial views

(c)

(d)

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

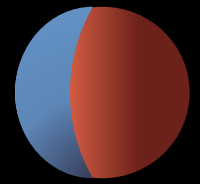
- Screens are less immersive
- Screens add to everyday life
- Unconscious influence
- Screens easily operated and incorporated in design (already done)

Maybe combining in Augmented reality?

Artificial views: review

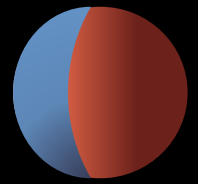
- **Fake window** vs no window
- **Nature** vs Urban
- Virtual reality vs ?Augmented reality? vs **Screens**

Design approach: Bottom Up



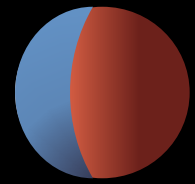
- Usually architectural design from big to small scale
- This research requires initial focus on the interior
- Start with spatial requirements and progress towards final location implementation

Design approach: Bottom Up



1. Program: required spaces and sizes
2. Interior geometry– different functions and moods
3. Creating views: artificial or real
4. Connections: affinity and locations of spaces
5. Outer shell
6. Implement created volume in location

1. Program



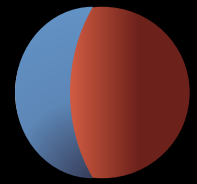
Main rooms

- Living quarters
  - Social area, eating area
- Sleeping quarters
  - Private rooms
- Kitchen
- Bathroom
  - Toilet separate
- Exercise/ gym
- Research facility

Additional rooms

- Command & control
- Food growing facility
- Meditation room
  - earth viewing
  - silence
- Storage

1. Program



Main rooms

- Living quarters
  - Social area, eating area
- Sleeping quarters
  - Private rooms
- Kitchen
- Bathroom
  - Toilet separate
- Exercise/ gym
- Research facility

Additional rooms

- Command & control
- Food growing facility
- Meditation room
  - earth viewing
  - silence
- Storage

2. Interior attributes

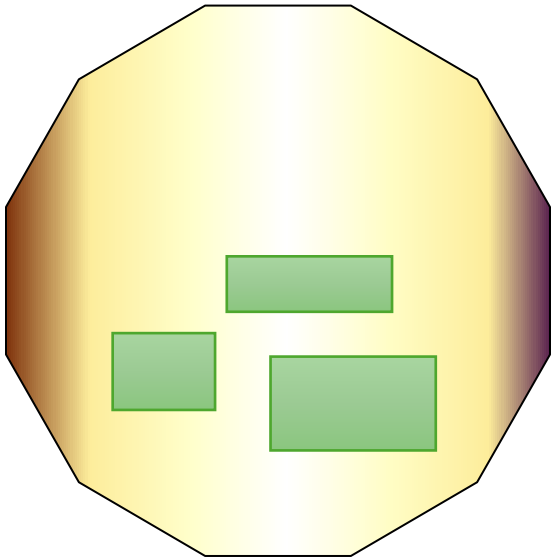
Living

Function: **atrium; multipurpose room; eat, socialise, greenery**

Angular / Curved

Light scheme: **Full Earth cycle simulation - moving**

View: **side windows; either real or nature simulations**



2. Interior attributes

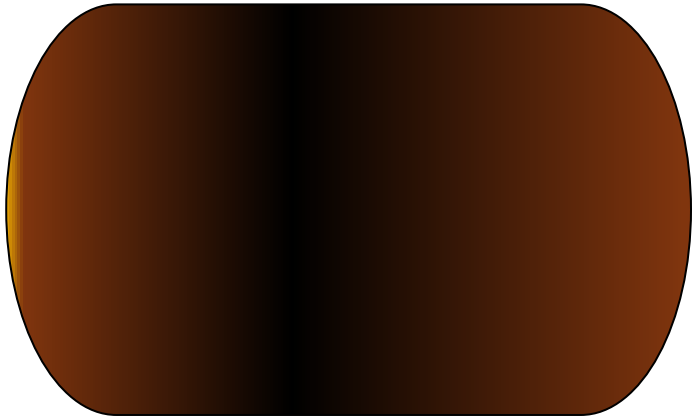
Sleeping

Function: **privacy; sleep.**

Angular / **Curved**

Light scheme: **Darkness, red light morning and evening**

View: **none**



2. Interior attributes

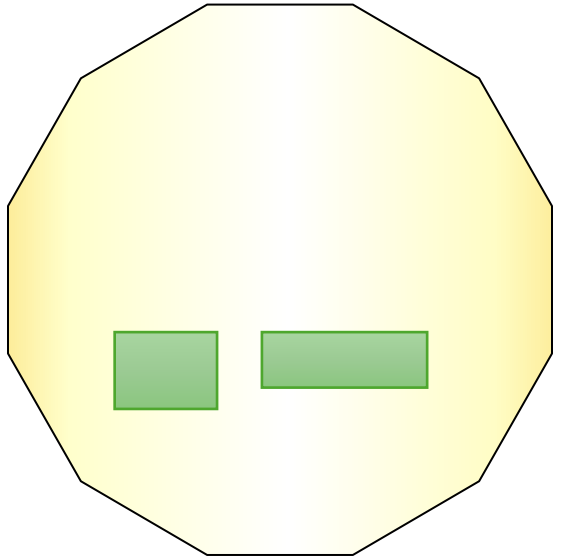
Research

Function: **work; focus; productivity; creativity**

Angular / Curved

Light scheme: **Daylight - bright**

View: **side windows; either real or nature simulations**



2. Interior attributes

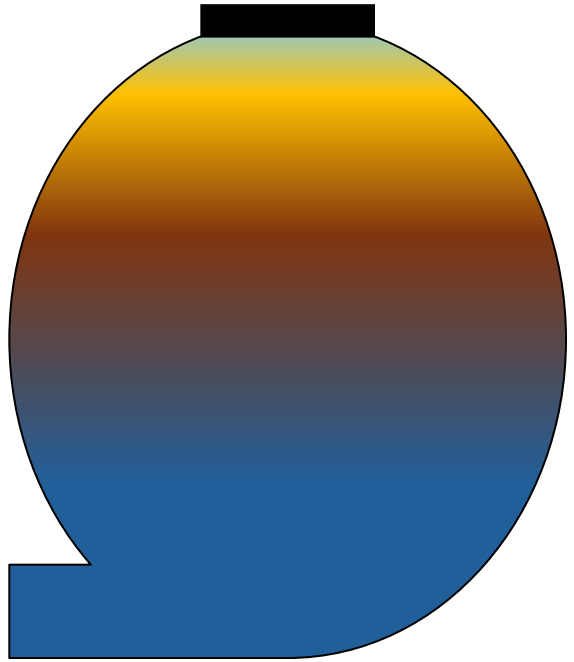
Meditation

Function: **silence; earth gazing.**

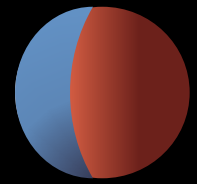
Angular / **Curved**

Light scheme: **Mood lighting**

View: **Ceiling; Earth/sky**



3. Creating Views

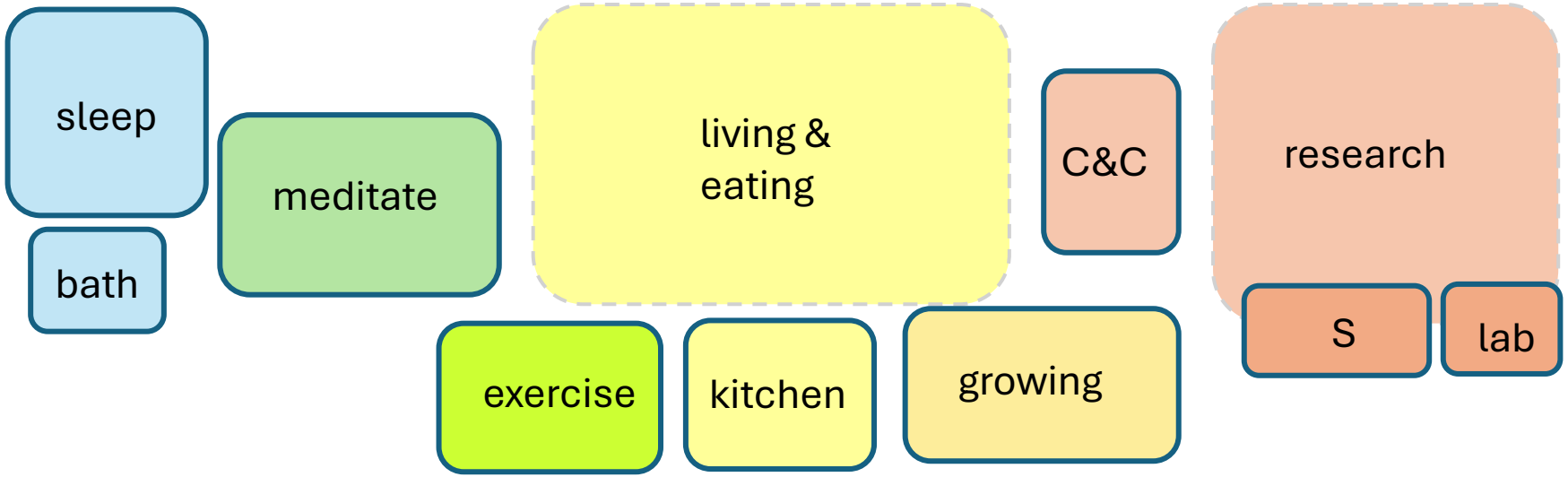


1. What kind?

4. Connecting spaces

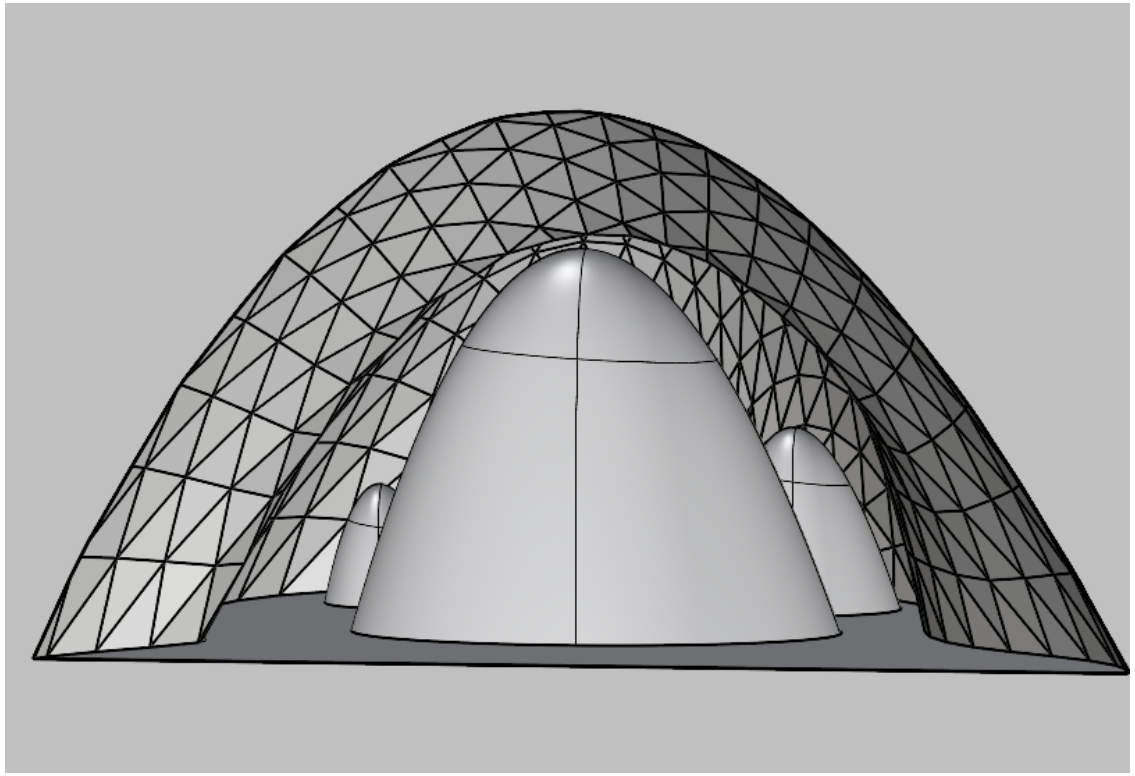
Transition:

Private – Semi-communal – Communal – Professional

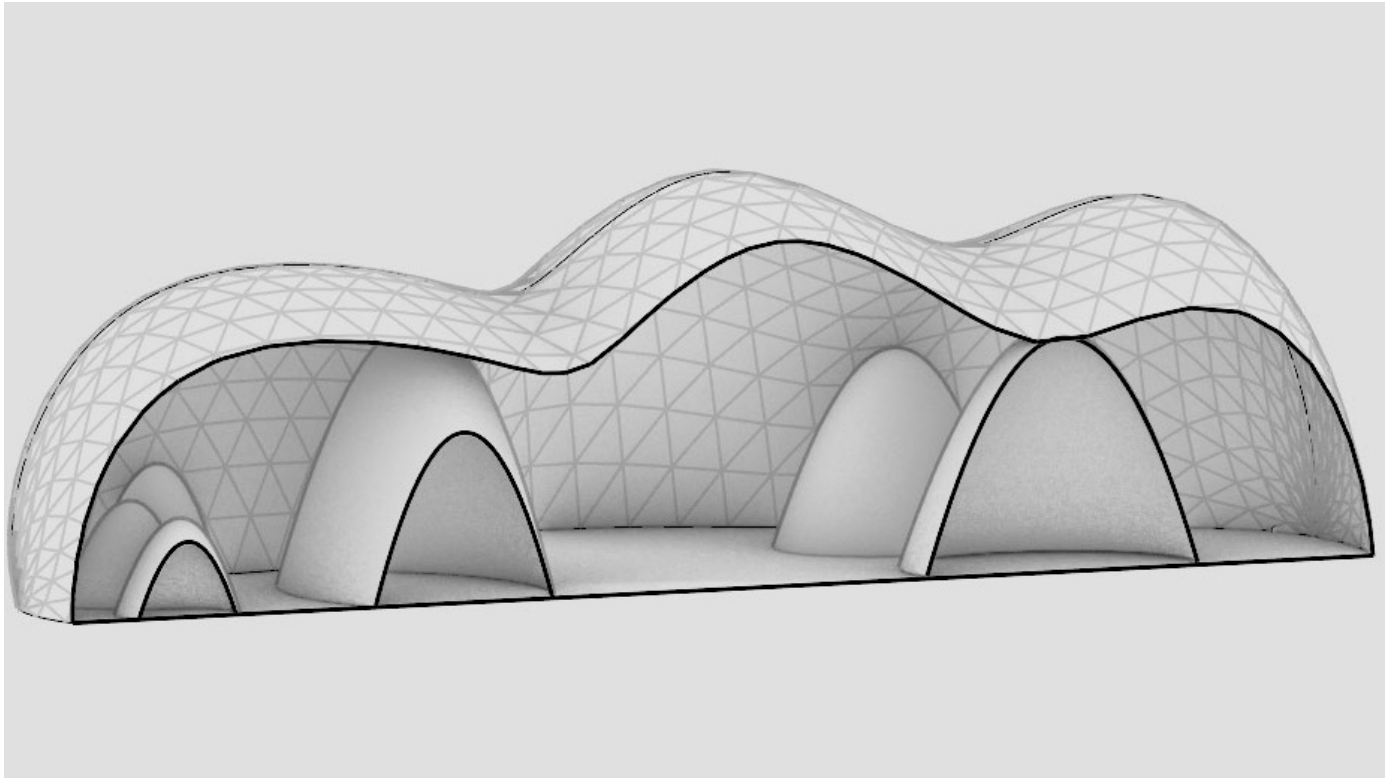


4. Connecting spaces

Closed volumes breaking up main space



Creates new rooms and corridors



5. Outer Shell

3D printing fragments

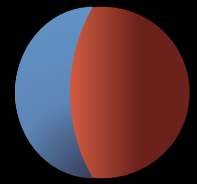
Curved shell for compression

Closed volumes breaking up main space – structural?

6. Location

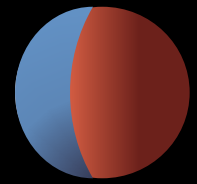
1. Radiation Protection in Lavatube

Radiation



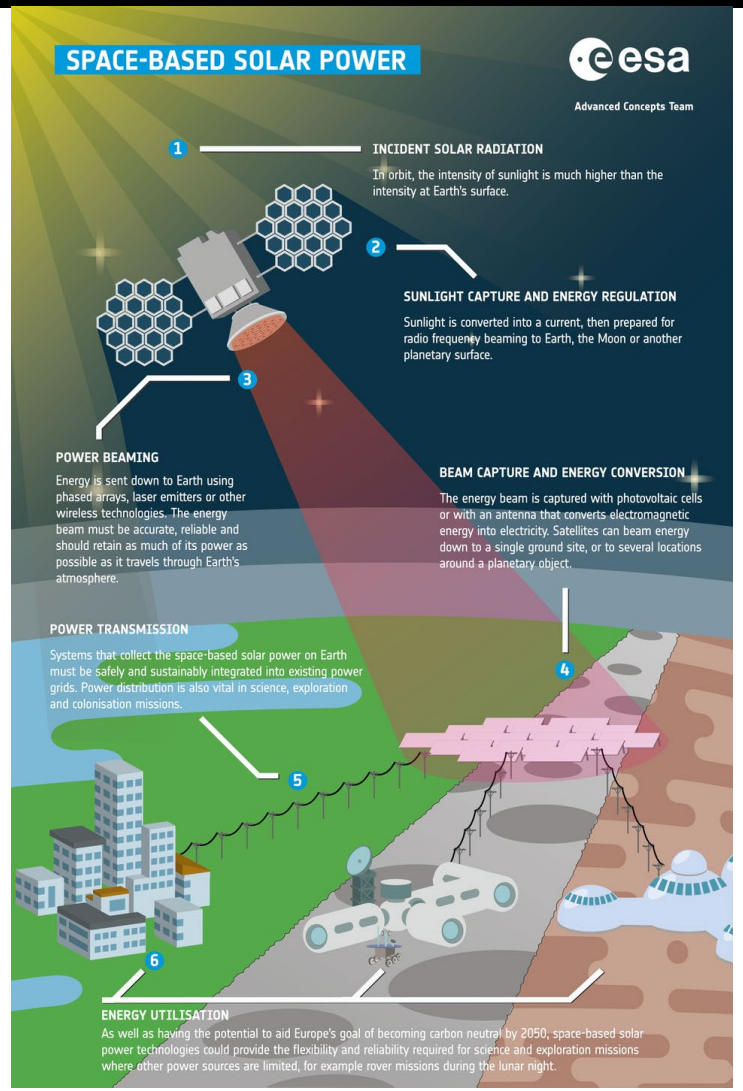
- Layered approach
- Regolith – metal frame with polyethylene – regolith
- Water storage above spaces
- Go underground far enough – lava tube

Construction



- Swarm robotics
- Components
- ISRU

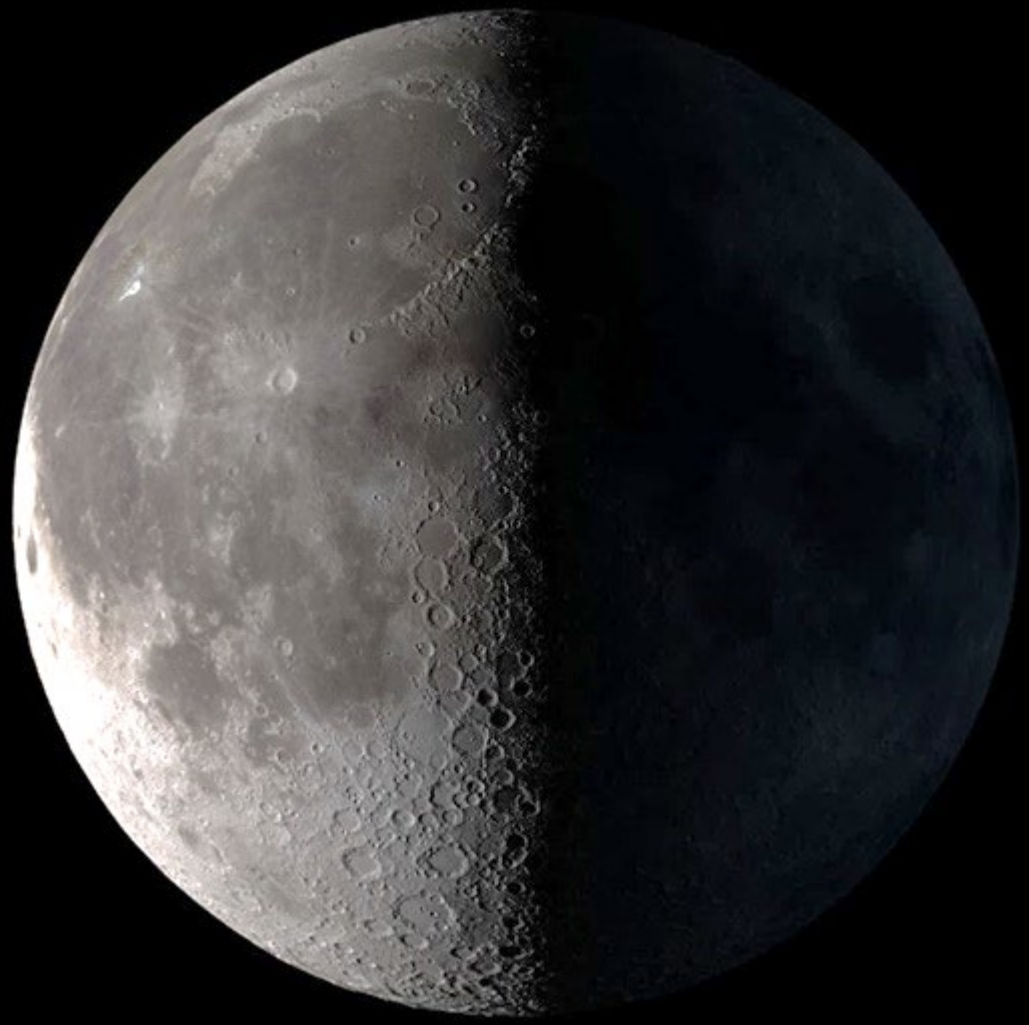
Energy supply



Approaching Lunar Architecture

Carte Blanche

Extreme Environment



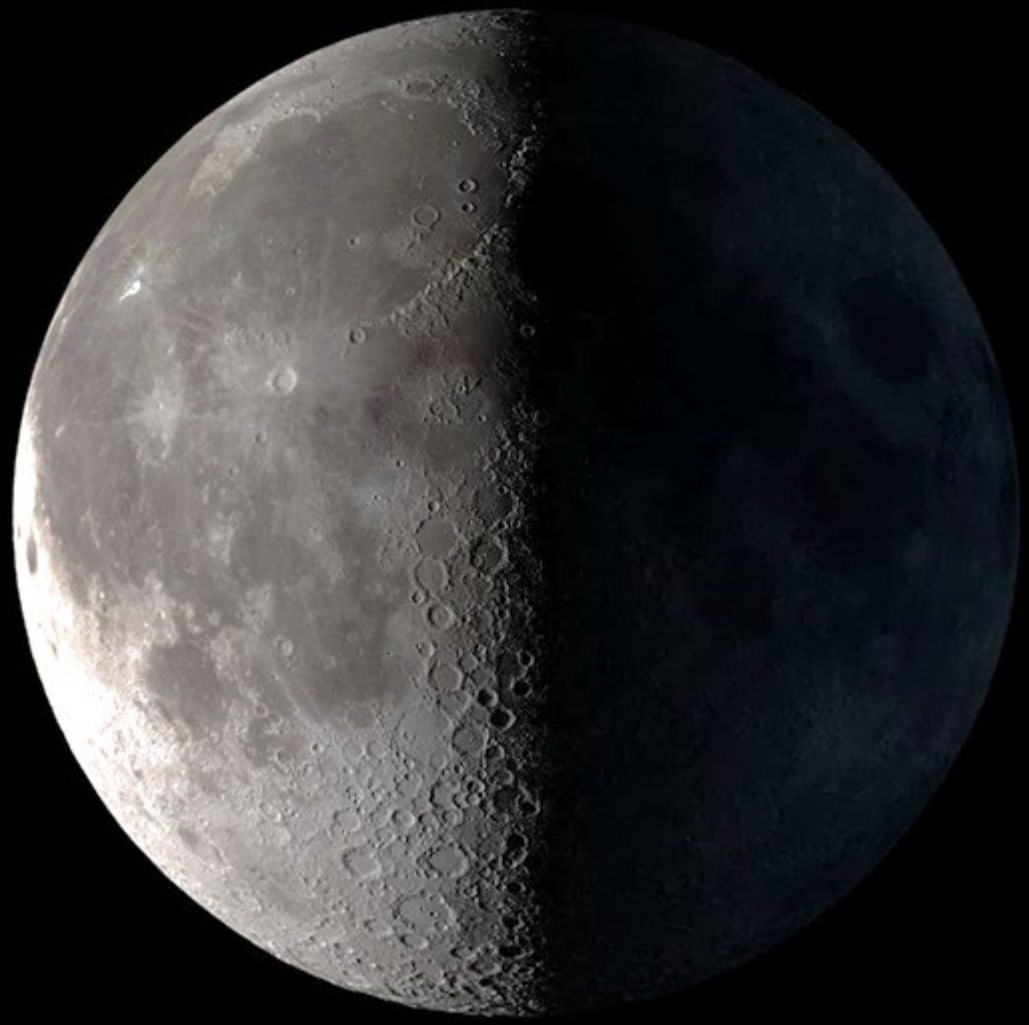
Utopia

Dystopia

Approaching Lunar Architecture

Carte Blanche

Extreme Environment



Utopia

Dystopia