P1 Presentation

MoonScape

Rethinking Human Habitat Enclosures on the Moon

LA&I Graduation Studio 2024/25

Regina Tania Tan

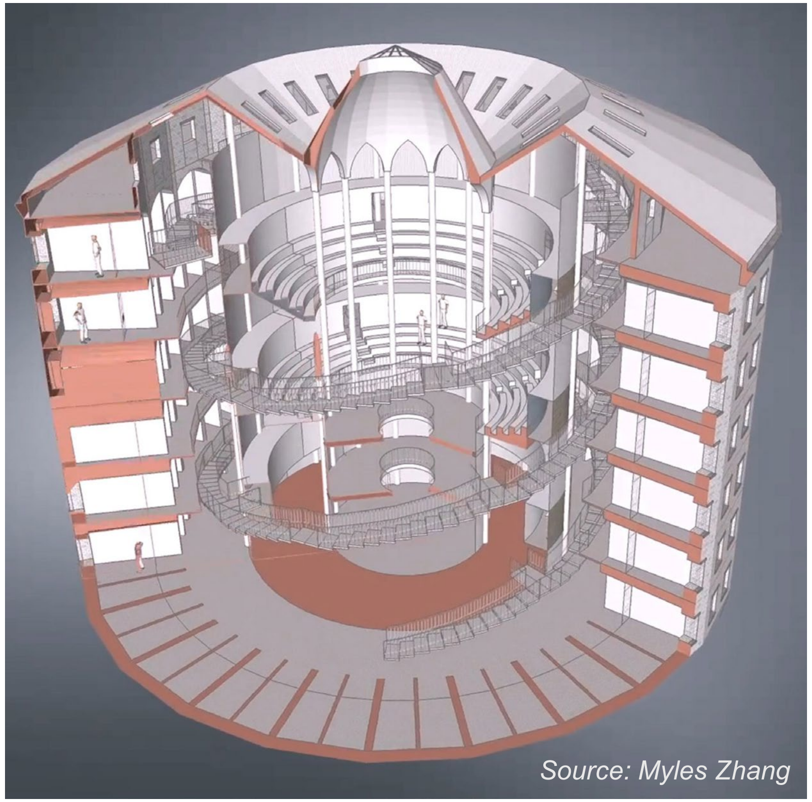
Existing Research on Space Colonisation: Focus on non-human actors

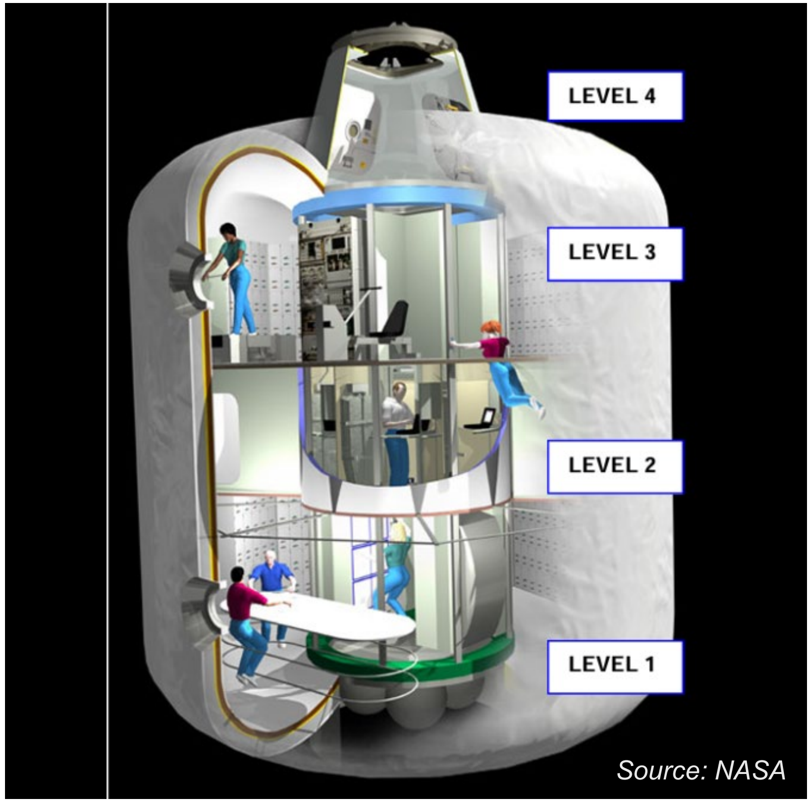
"The gap between space and terrestrial robots", David Rodriguez (EPFL), DSI Symposium 2024

efficiency, control, technology, performance

Human de-centered design

Spatial similarity of ISS TransHab and The Panopticon





The Panopticon

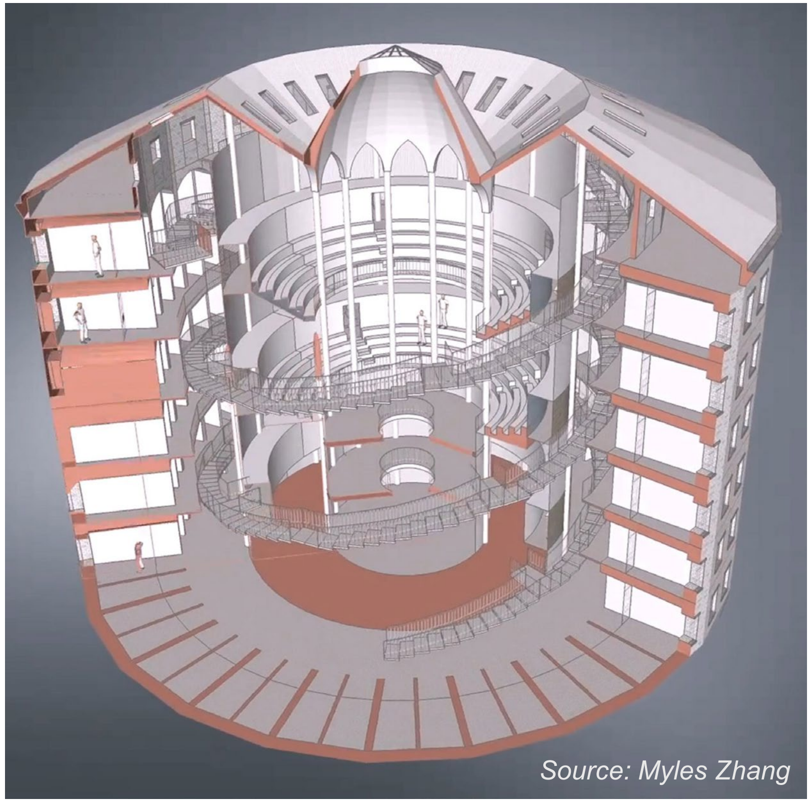
Form derived to enable central surveillance of every inmate's cell (inhuman, dehumanizing)

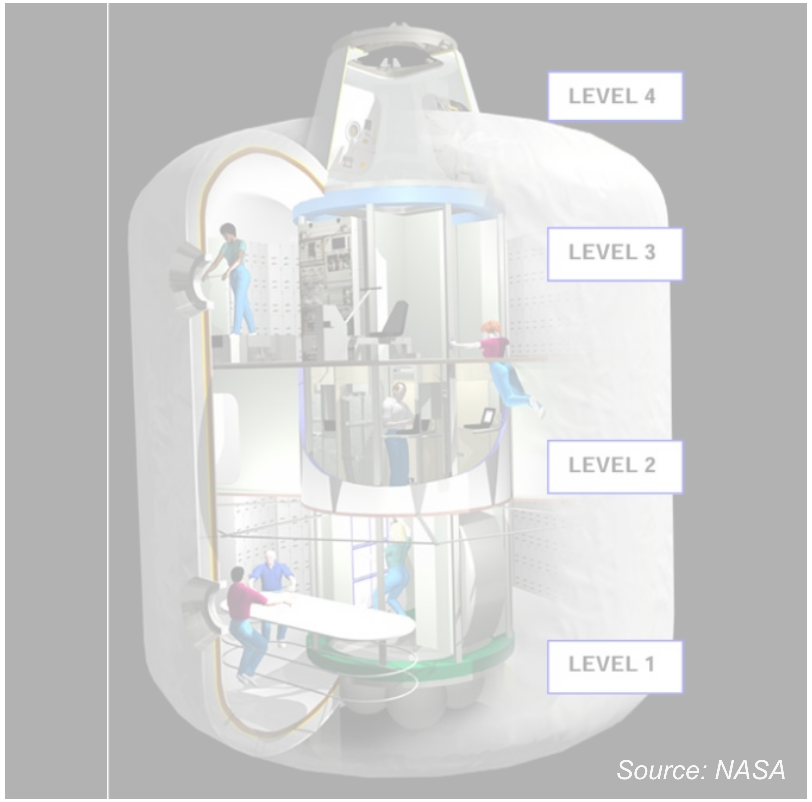
ISS TransHab

Efficient form for transportability and environment protection (non-human actor)

Human de-centered design

INHUMAN, DEHUMANIZING





The Panopticon

Form derived to enable central surveillance of every inmate's cell (inhuman, dehumanizing)

ISS TransHab

Efficient form for transportability and environment protection (non-human actor)

Dehumanizing architecture

- Habitat that deprives the user from positive human qualities, personality, or dignity

Adapted from Oxford and Merriam-Webster Dictionary

Inhuman design

- **Inhuman styles**: Not adapted to human sensitivity, not innovative, i.e. not developed towards life or away from life, but devoid of life.
- **Becoming inhuman**: Suppress our natural reactions to our physical surroundings.

Nikos Salingaros, Anti-Architecture and Deconstruction 4th Edition, 2010

Hostile architecture

- Urban design strategy that uses elements of the built environment to guide or restrict certain behaviors in public spaces.

Jordana Rosenfeld, in Britannica, 2024

Dehumanization of architecture

- Tendency towards abstraction, to purify architecture, to foreground the aspects taken to be true objects of aesthetic interest: e.g. form of a building and how that form relates to its function.

Rafael De Clercq, The Dehumanization of Architecture, 2022

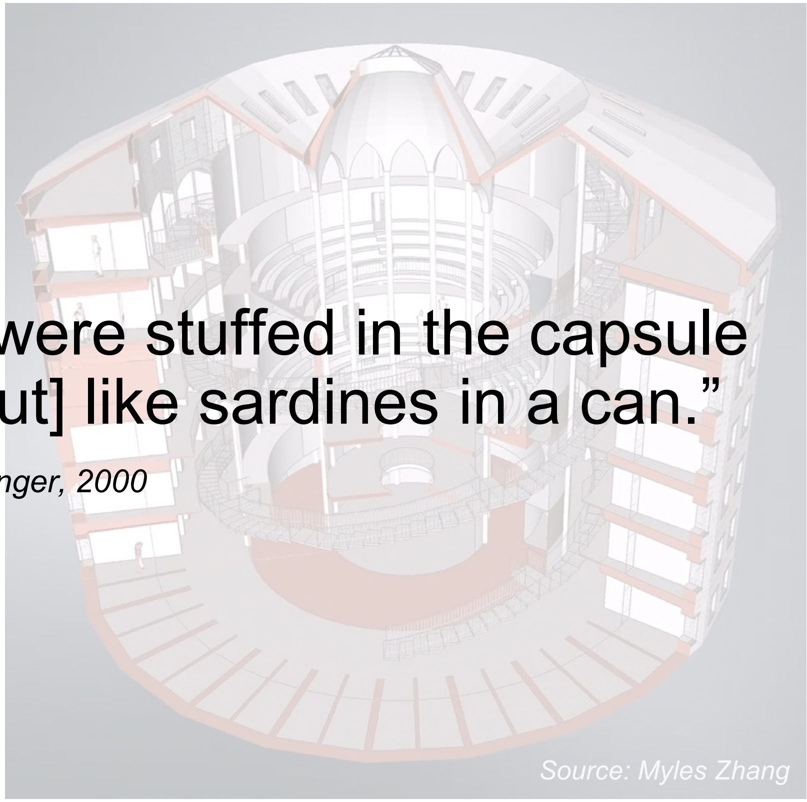
Street furniture and obstacles to stop homeless people from sleeping or accessing the space.

Human de-centered design

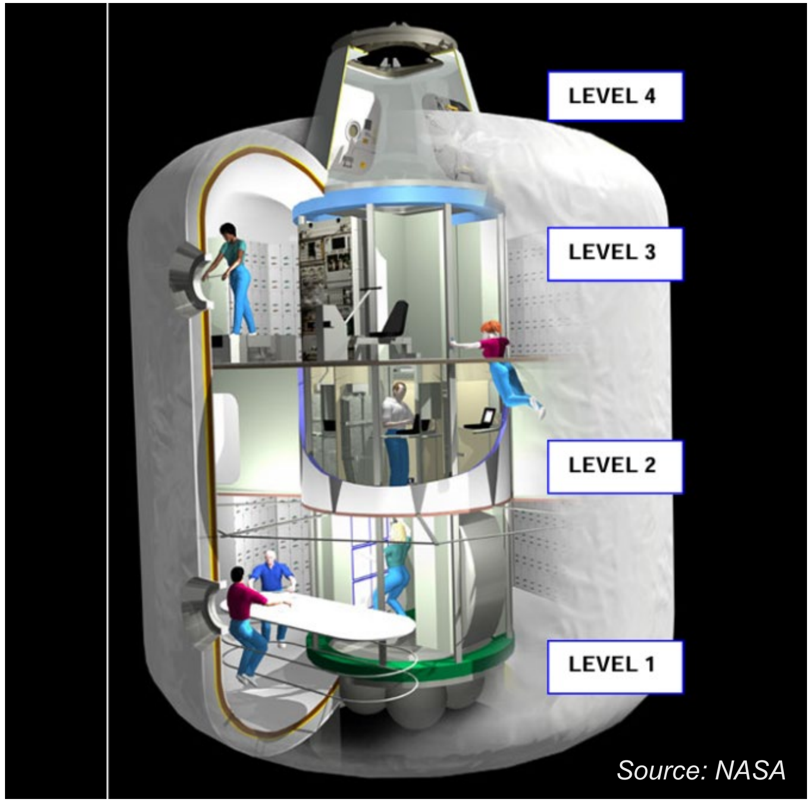
NON-HUMAN ACTORS

“We were stuffed in the capsule [Salyut] like sardines in a can.”

Jerry Linenger, 2000



Source: Myles Zhang



Source: NASA

The Panopticon

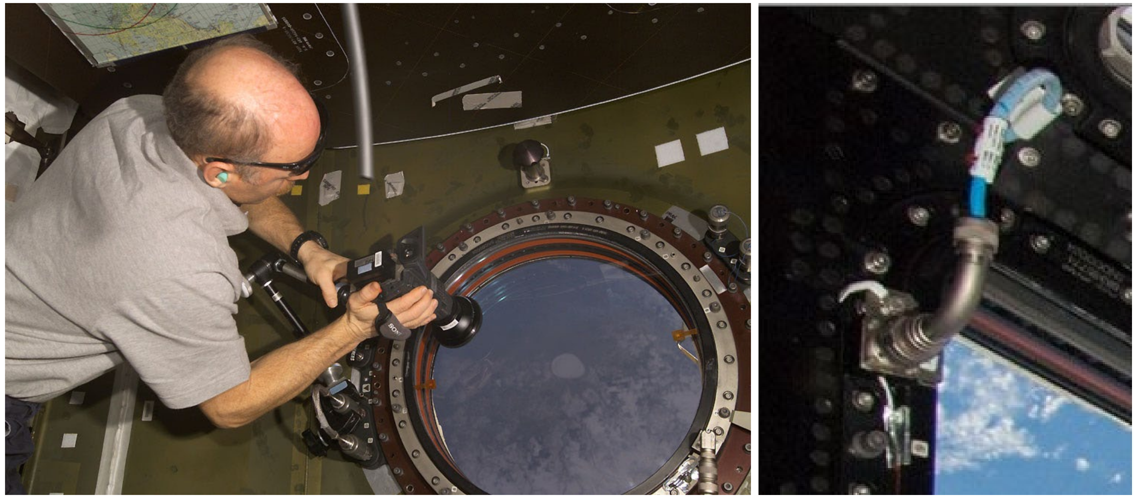
Form derived to enable central surveillance of every inmate’s cell (<u>inhuman, dehumanizing</u>)

ISS TransHab

Efficient form for transportability and environment protection (<u>non-human actor</u>)

When design focuses on non-human actors…

Excerpts from astronauts



Destiny module, ISS. Broken air hose due to extended use for grabbing.

"If something is going to stick out and make a nice handhold, it's going to be used for a handhold."

Gerald Carr, Skylab astronaut, 1974

Stowed items on Mir Space Station, NASA

"The walls are full of things. You don't see the texture of the wall."

Tognini, ESA, Mir Antares, 2009.

"The history of space exploration is full of reports about mishaps."

David J. Shayler in Disasters and Accidents in Manned Spaceflight, 2000

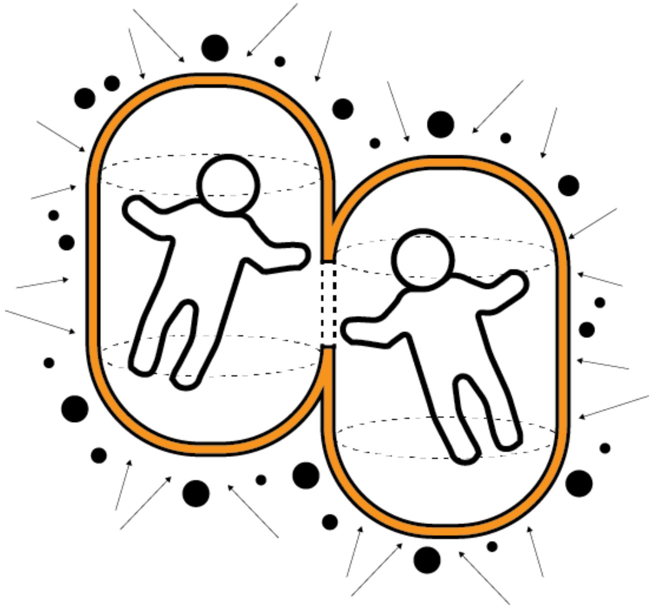
"…we wash using no-rinse soap and shampoo and a towel (…) it works really well. That being said I am looking forward to a long hot shower when I get home!"

Ed Lu, ISS, Expedition 7 (185 days), NASA, 2003

Developed space habitat concepts

Focus on the functional

Aesthetic



Functional

Spatial

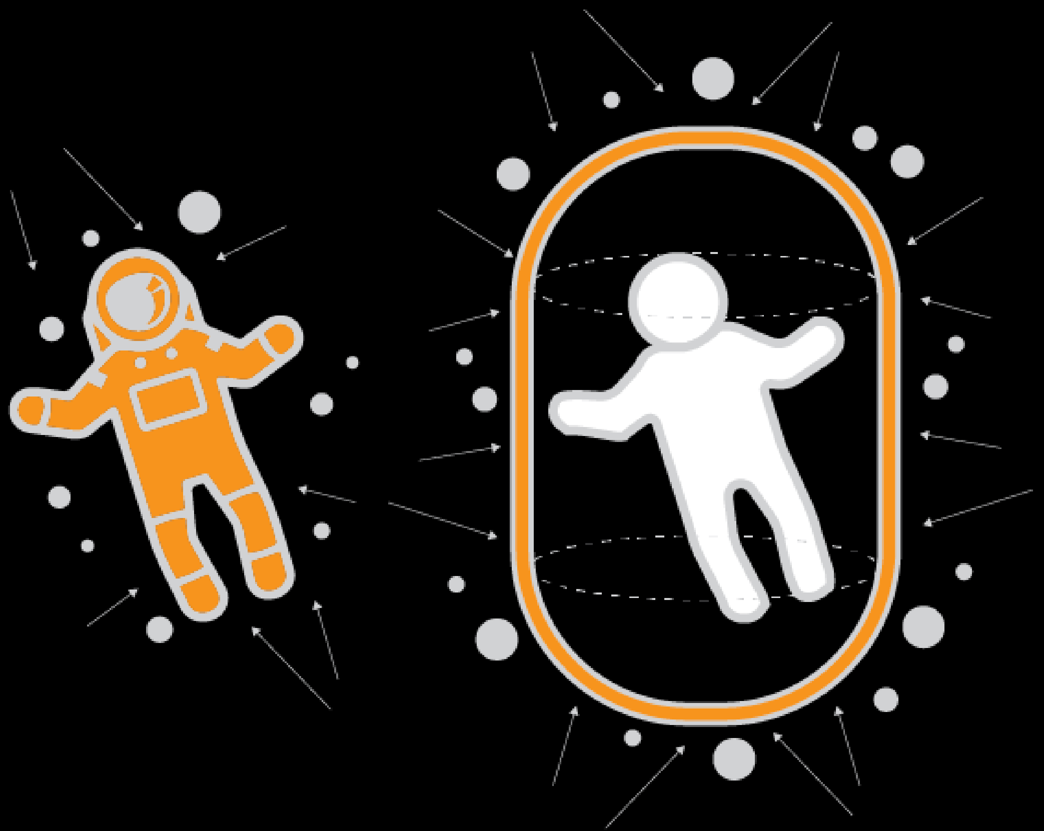
Habitat in hostile lunar environment

Enclosure for protection

Condition	Earth	Moon	Design Implications
Gravity	1 g	1/6 g	Consider low gravity effects
Atmosphere	1 bar (O2, N2, CO2)	~0 bar (almost vacuum)	Pressurized vessel
Length of day	24 hours	28 Earth days (14 days light / 14 days dark)	Site selection
Temperature	Mean 15°C Range: -89°C – 60°C	Mean -20°C Range: -233°C – 123°C	Thermal enclosure
Radiation	Protection by Earth's atmosphere	Exposure to space radiation, secondary radiation from surface	Radiation enclosure
Water	70.8% surface	In deep permanently shadowed craters & binded in regolith	Limited water
Dust	Generally not harmful	Pervasive & potentially toxic, electromagnetic cling, lofts above surface	Physical enclosure
Others	-	Micrometeoroids, bright light & glare	Physical enclosure

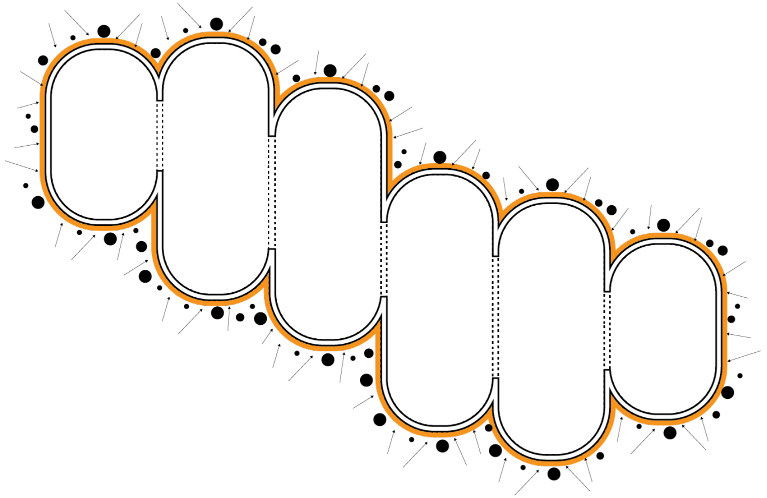
Source: Architecture for Astronauts, last column added by author

Habitat = protection



Human de-centered to human centered

Spatial habitability



Aesthetic

Functional

Spatial

Habitat = protection + habitability

Defining habitability

“**Habitability…** of extra-terrestrial habitats was not considered of high priority in the past.”

Sandra Hauplik-Meusburger, Architecture for Astronauts

“**Habitability** as the sum of interactions between operators and environment which include physical, physiological, psychological and social interactions.”

Kubis (1965), in Stuster, Bold Endeavors (1996)

“**Spatial habitability** refers to the ways in which the volume and geometry of liveable space affect human performance, wellbeing and behaviour.”

Dr. James Wise, psychologist, 1988

Habitability: the suitability and value of a built habitat (lunar habitation) for its inhabitants (researchers) in a specific environment (lunar surface) and over a certain period of time (long-term)

Adapted from Sandra Hauplik-Meusburger, Architecture for Astronauts

Adjusted habitability

Excerpts from astronauts

Value & suitability in a specific environment, over a certain period of time.

Owen Garriott, Skylab 3

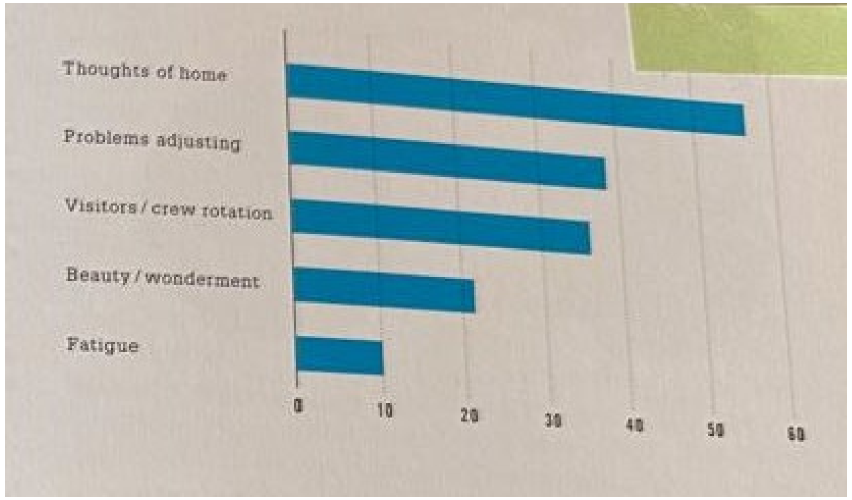
"(On sleeping) It's got to be a place that can be modified in the way any individual desires."

Gerald Carr, Skylab 4, NASA. 1974

Dedicated dining table, Skylab Station.

"Skylab and Shuttle-Mir experiences have confirmed that the availability of an open, communal area is very important for crew morale and productivity during long duration isolation and confinement in space.

Excerpts from NASA Human Integration Design Handbook.



Distribution of journal entries by astronauts aboard the ISS, Olga Bannova in Space Architecture: Human Habitats Beyond Planet Earth,

- **Longing for home**
- **Home = familiar environment**

Lunar habitability

From familiarity to unique interfaces

Walls & enclosures

Surface interface

Furnitures & obstacles

Human-object interaction

Problem Statement

Lack of space architecture precedents that prioritizes human behaviour in the design.

Humans have not landed on moon since 1973. With ambitions to set up lunar base in the future, it is important to not repeat the design mishaps in space station designs.

Research Question

How to design the interior and exterior enclosures of a long-term lunar habitation, based on human-centered design principles?

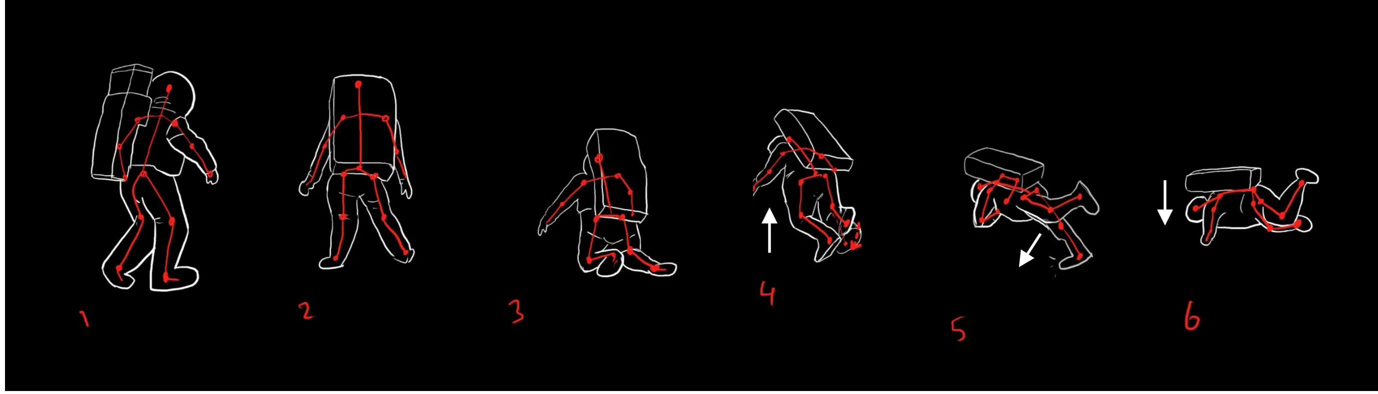
Assumptions & Limitations

Living on the moon is based on speculations from Earth & Outer Space

- Humans haven't lived long-term on the moon
- Data on habitation comes from orbiting space station (ISS) and short-term expeditions in 1960s-1970s

Speculations on future technologies

- Working with developing technologies and current research → based on assumptions and discussions with experts

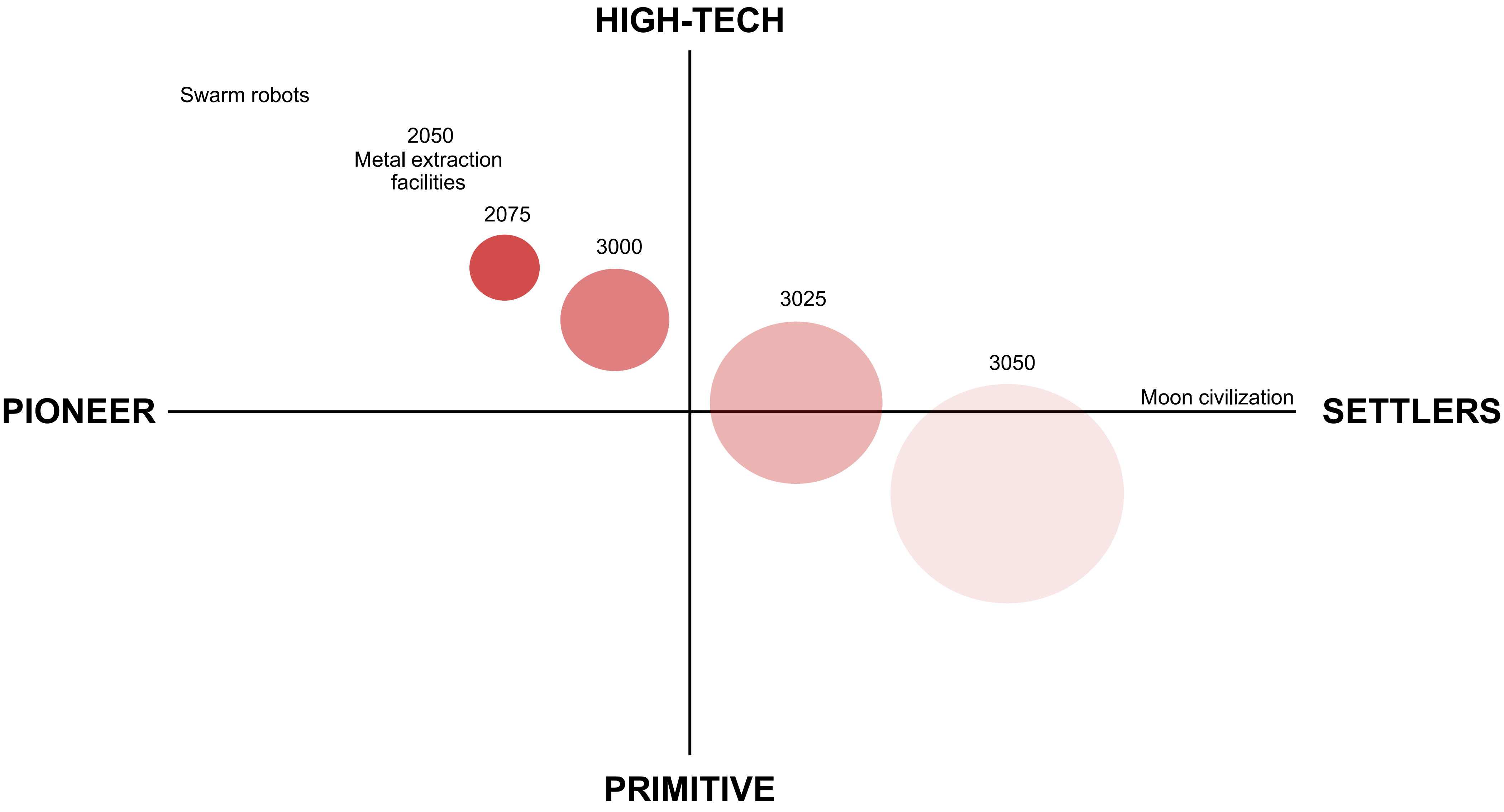


Lunar Movement Analysis
Based on Astronauts Falling on the Moon (1972), NASA Archive, Apollo 17 Video Library

Condition	Outer Space	Moon	Design Implications
Gravity	0 g	1/6 g	Object does not float on moon
Enclosure (pressure, radiation, temperature, debris control)	0 bar (vacuum) -270°C – 200°C Exposure to space radiation, Micrometeoroids, bright light & glare	~0 bar (almost vacuum) -233°C – 123°C Exposure to space radiation, Micrometeoroids, bright light & glare	Both need enclosed vessel → confined boundary, highly controlled environment
Length of day	N/A	28 Earth days (14 days light / 14 days dark)	Site selection
Dust	Minimal	Pervasive & potentially toxic, electromagnetic cling, lofts above surface	Need dedicated dust cleaning area
Grounded surface	N/A	Lunar surface & underground	Take advantage of lunar morphology as natural protection

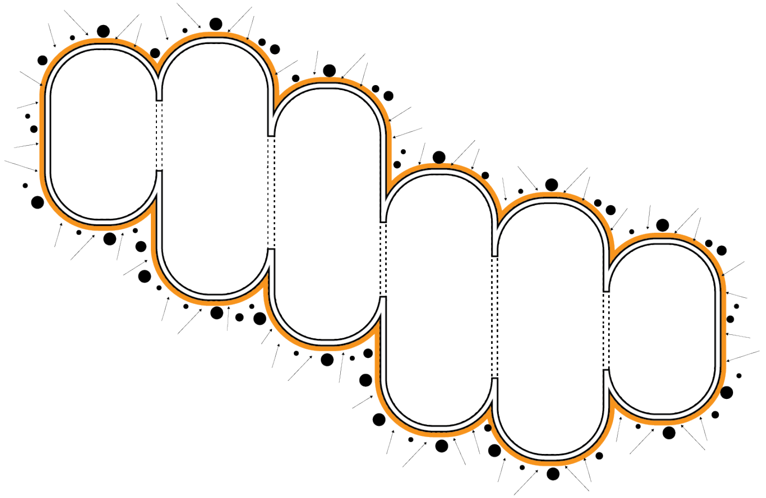
Source: Architecture for Astronauts, with modifications

Timeline


HIGH-TECH
Swarm robots
2050
Metal extraction
facilities
2075
3000
3025
3050
Moon civilization
PIONEER
SETTLERS
PRIMITIVE

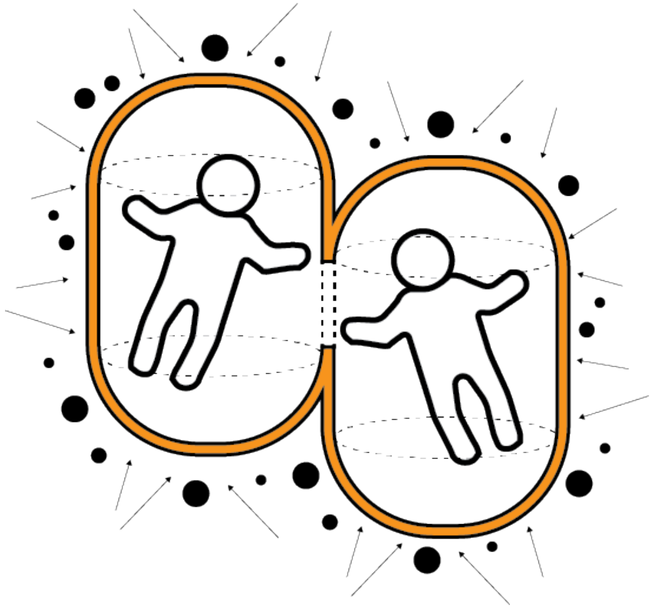
Design Strategy

Gradient of interfaces



Exterior | Macro

Design for Localization



Enclosure | Meso

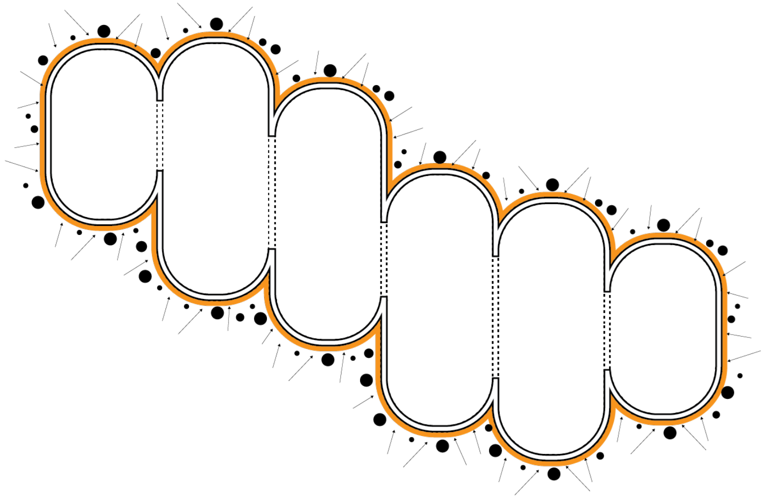
Design for Adjacencies

Interior | Micro

Design for Affordances

Design Strategy

Gradient of interfaces



Exterior | Macro

Design for Localization

Enclosure | Meso

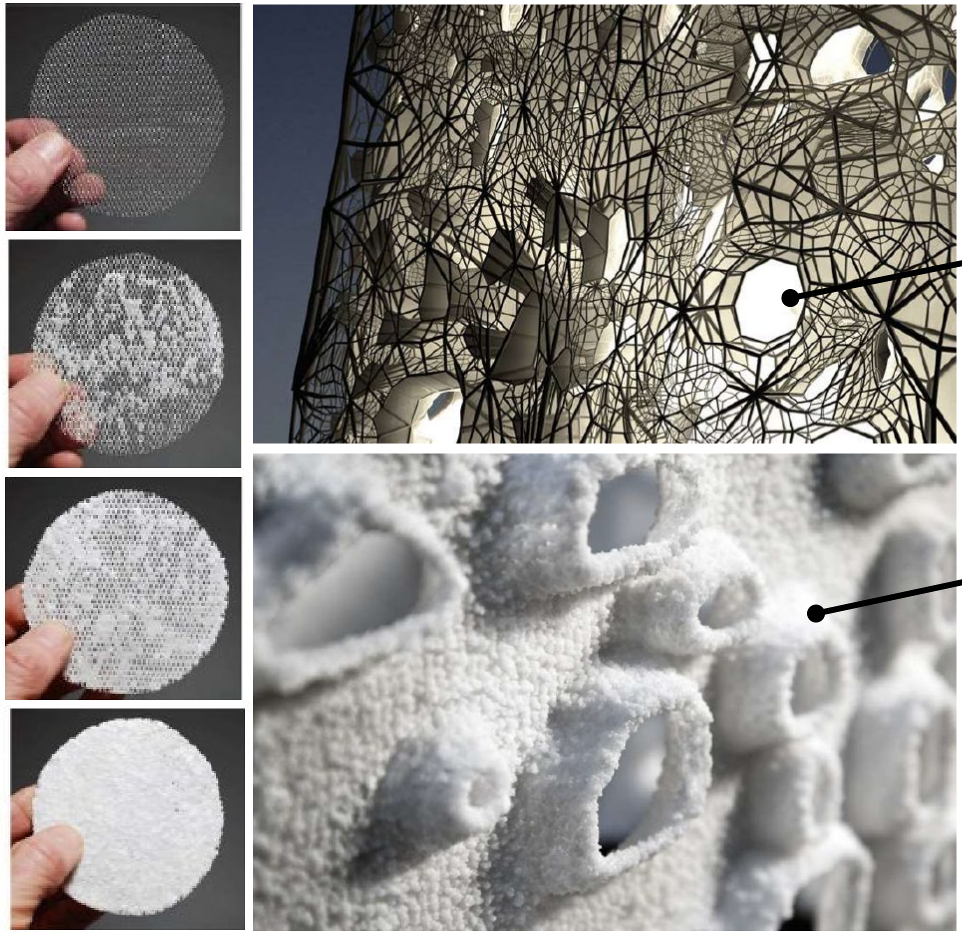
Design for Adjacencies

Interior | Micro

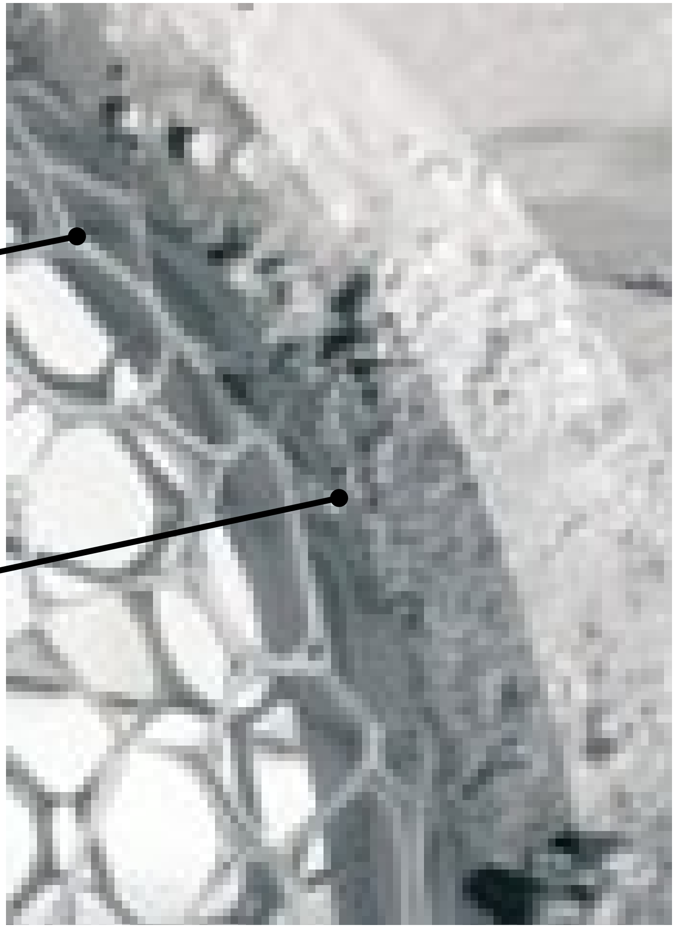
Design for Affordances

Mediating Enclosures

Material-evolution over time



Vertical Salt Deposit Growth System
GEOtube Tower (2009), Faulders Studio, Dubai



Cheibas et. al.,Towards Additive Manufactured Off-Earth Habitats with Functionally Graded Multi-materials, p. 84

Metallic Structure - Aluminum

- 2^{nd} most abundant metal on moon
- Electrical conducive property
- Combine its tensile strength with regolith's compressive strength

Metal-regolith gradient

- Titanium alloy, based on current research by Ina Cheibas (2024)

Sintered regolith

- With laser heat, based on in class discussion with expert

Transparent material

- EFTE, water jacket, and 3d-printed ice

Incorporating lunar dust (Regolith)

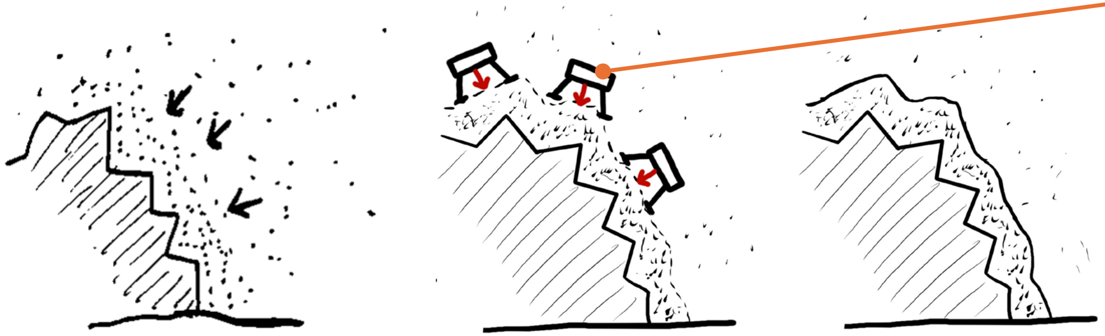
Regolith

Most problematic challenge for Lunar Base (ESA)
Highly electrostatic, due to cosmic radiation exposure

Opportunities
Shielding in construction, good thermal and radiation protection properties

Application scheme

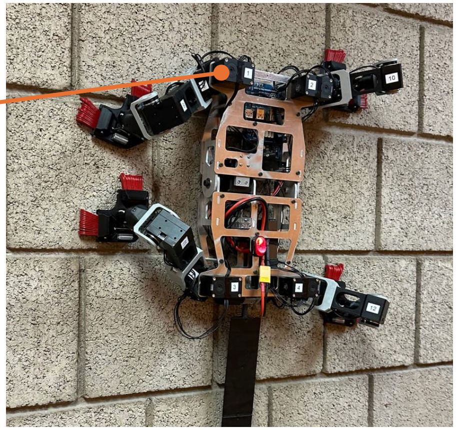
**developed during discussion with expert*



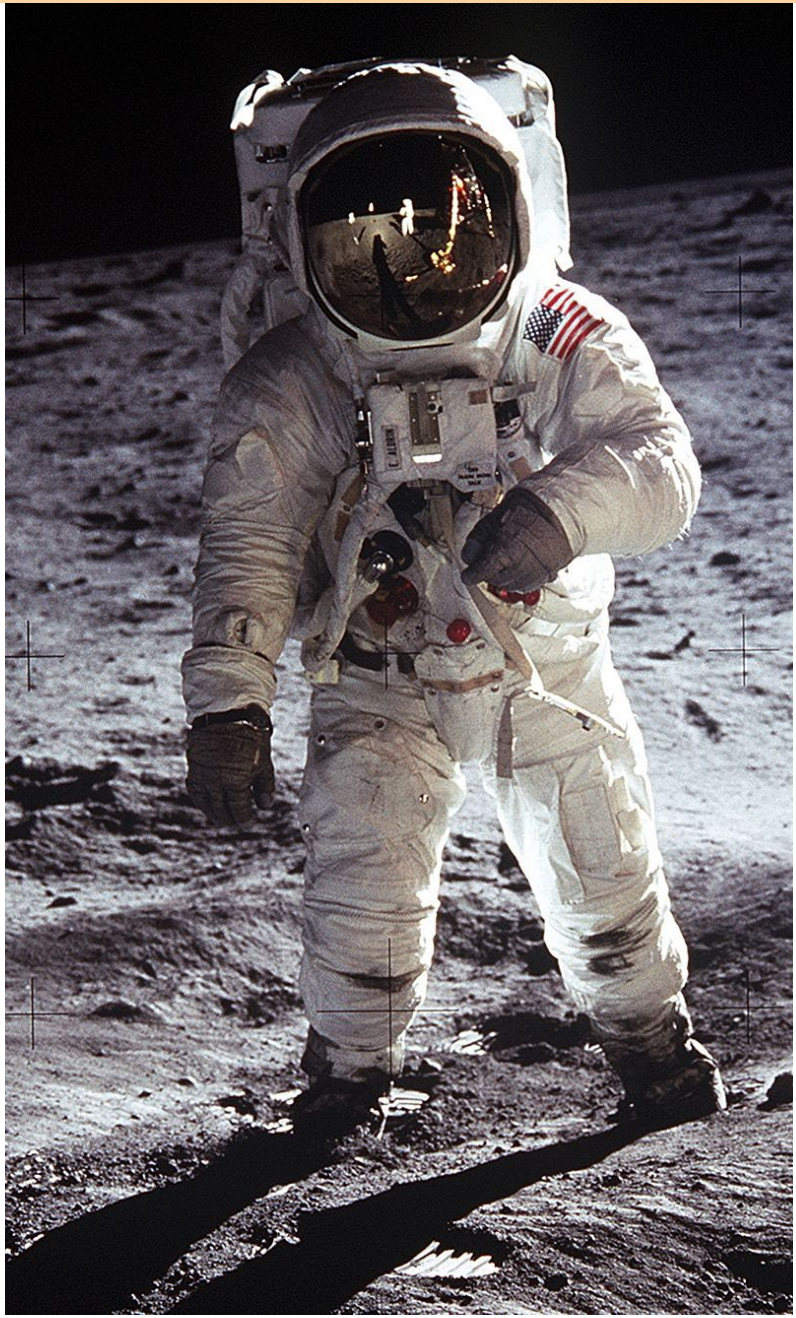
(1) Grow
Electrostatic envelope attract lunar dust

(2) Pack
Laser sintering

(3) Protect



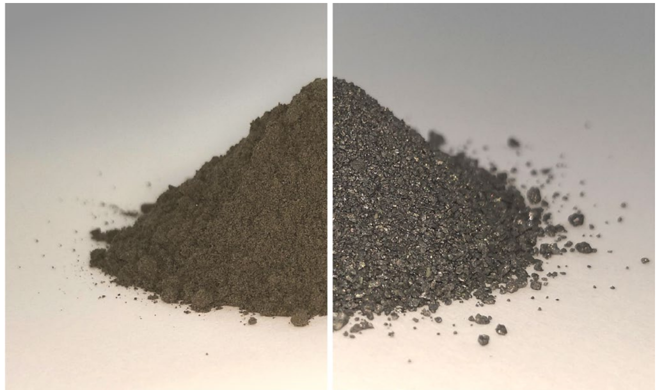
Climbing robot LORIS



Buzz Aldrin on the Moon. Dirt shows the lunar dust

Mediating Enclosures

Feasibility



Left: simulated regolith, right: after oxygen extraction, leaving metal alloys, ESA

Journal of the European Ceramic Society
Volume 41, Issue 1, January 2021, Pages 781-791

Original Article

Transparent alumina ceramics fabricated by 3D printing and vacuum sintering

David Carloni, Guangran Zhang, Yiquan Wu

Show more

Add to Mendeley Share Cite

https://doi.org/10.1016/j.jeurceramsoc.2020.07.051

Get rights and content

Research on Aluminum 3d printing

Metallic Structure

3d-printed Aluminum

Can be extracted from regolith

Electrostatic cleaning system for sand removal from solar panels (2015), H. Kawamoto & T. Shibata

Electrostatically attracted regolith

Reverse principle of sand removal from solar panels,

based on in class discussion with expert

Speculative systems for the moon

Close-up view of salt accretion in scaled prototype, GEOtube Tower

Close-up view of lunar regolith with Apollo 11 Buzz Aldrin, NASA

	Earth precedents	Moon
• Attraction	Seawater passing through structure	Regolith electrostatically attracted
• Compaction	Evaporation by wind	Regolith sintering
• Production	Salt harvesting	Harvesting charged regolith
• Structure	Resistant to salt corrosion	Electro-conductive
• Location	Near sea	Radiation-exposed areas → lunar surfaces

Site

Charged regolith:

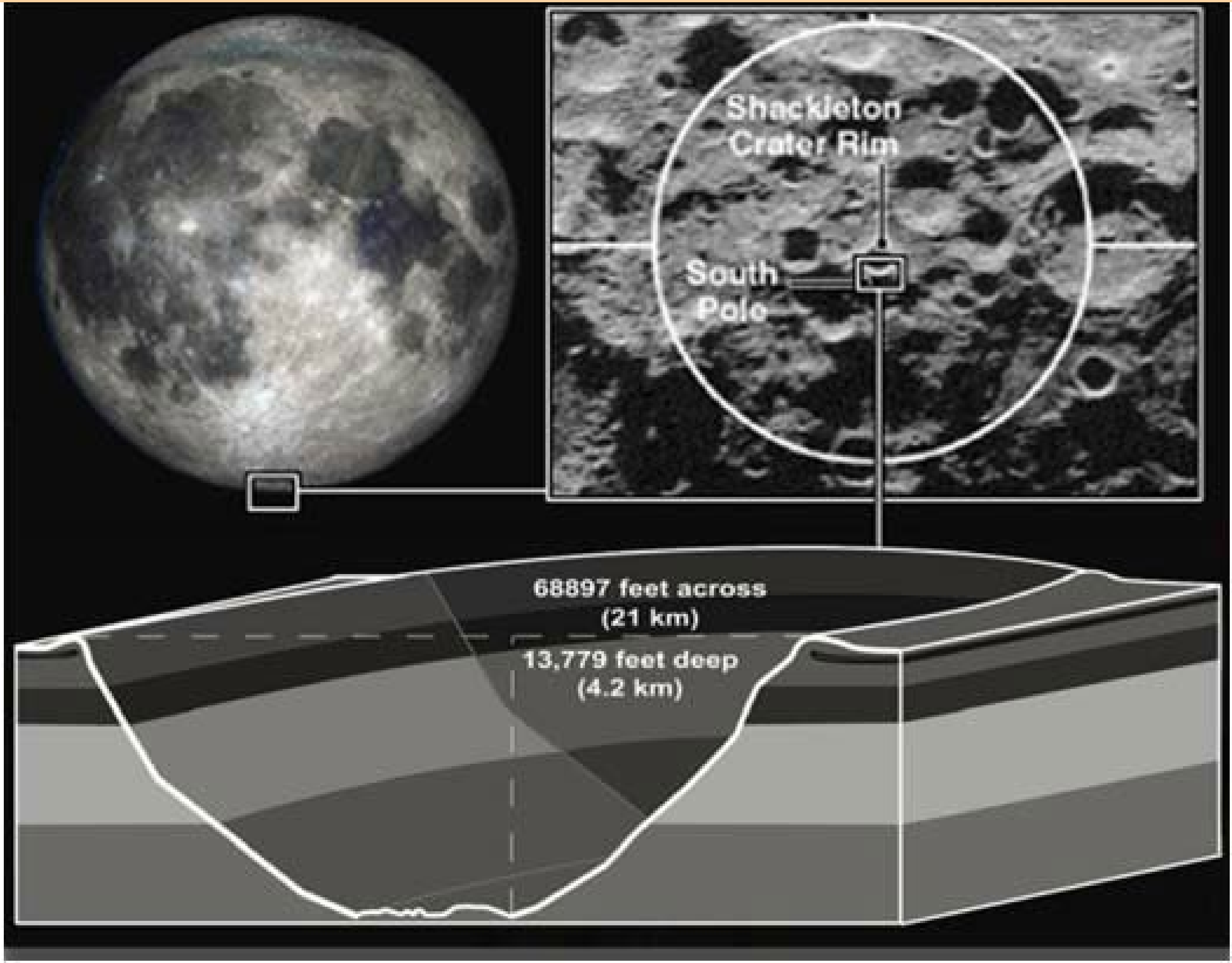
Sunlit regions, near landers

Face side

- 14/14 day night cycle
- Lava tubes
- Micrometeorites

North/South Pole

- Eternal sunlight areas (South Pole)
- Seasonal constant sunlight areas (North Pole)
- Eternal darkness areas in craters
- Deep craters protect from micrometeorites



Shackleton crater location and data, Olga Bannova, 2012.

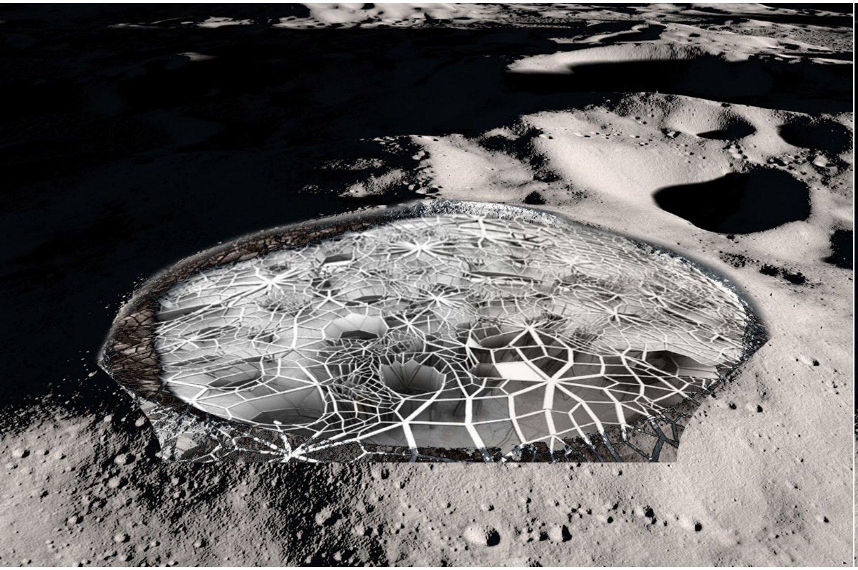
Shackleton Crater (South Pole)

Pros

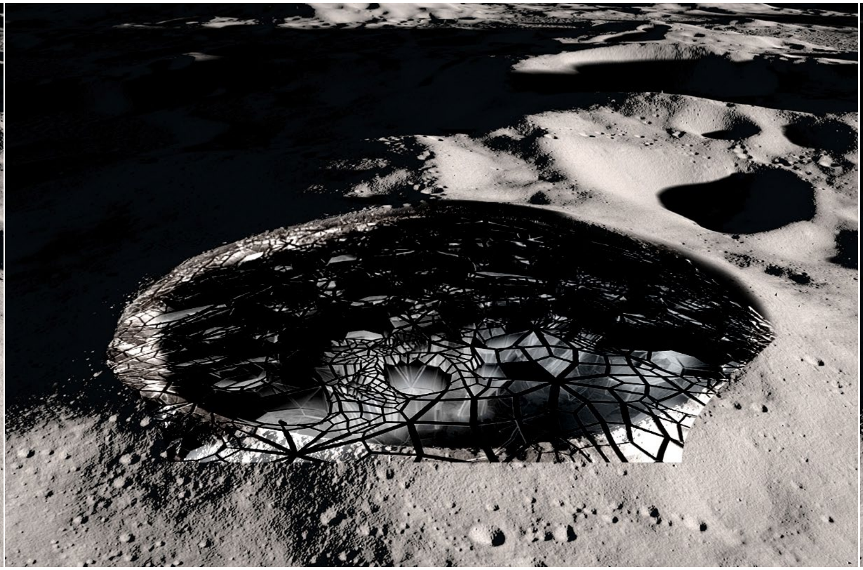
- Well researched
- Permanently shadowed areas provide resources: water-ice, fossil records of hydrogen, water ice, and other early Solar System volatiles (for research purpose)

Which part of crater? The rim

- Provides eternal sunlight
- Gradient from sunlit to shadowed areas



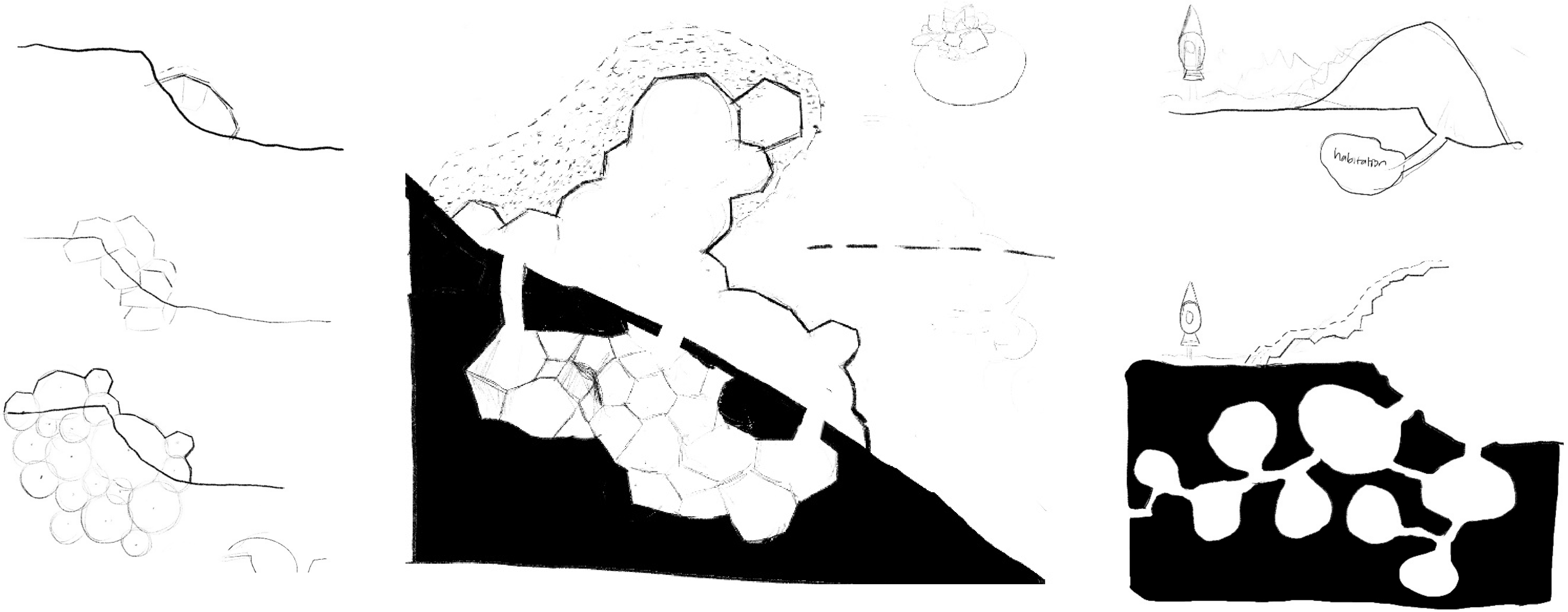
Full interior illumination



Partial interior illumination

Rim

Concept sketches

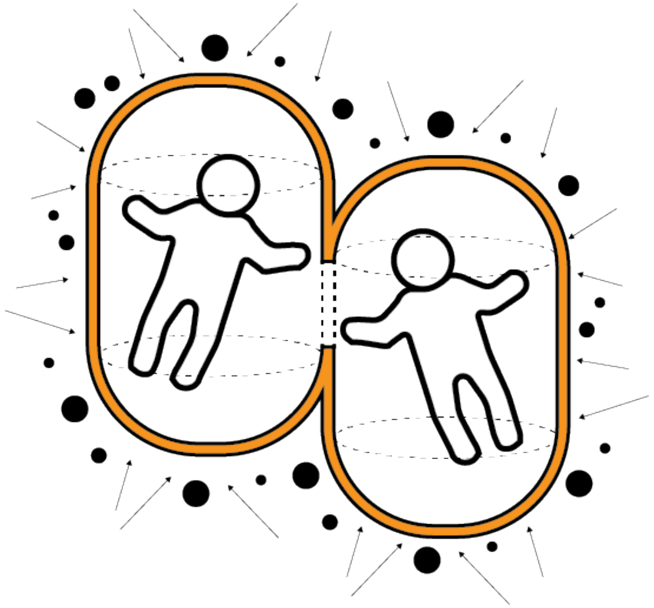


Design Strategy

Gradient of interfaces

Exterior | Macro

Design for Localization



Enclosure | Meso

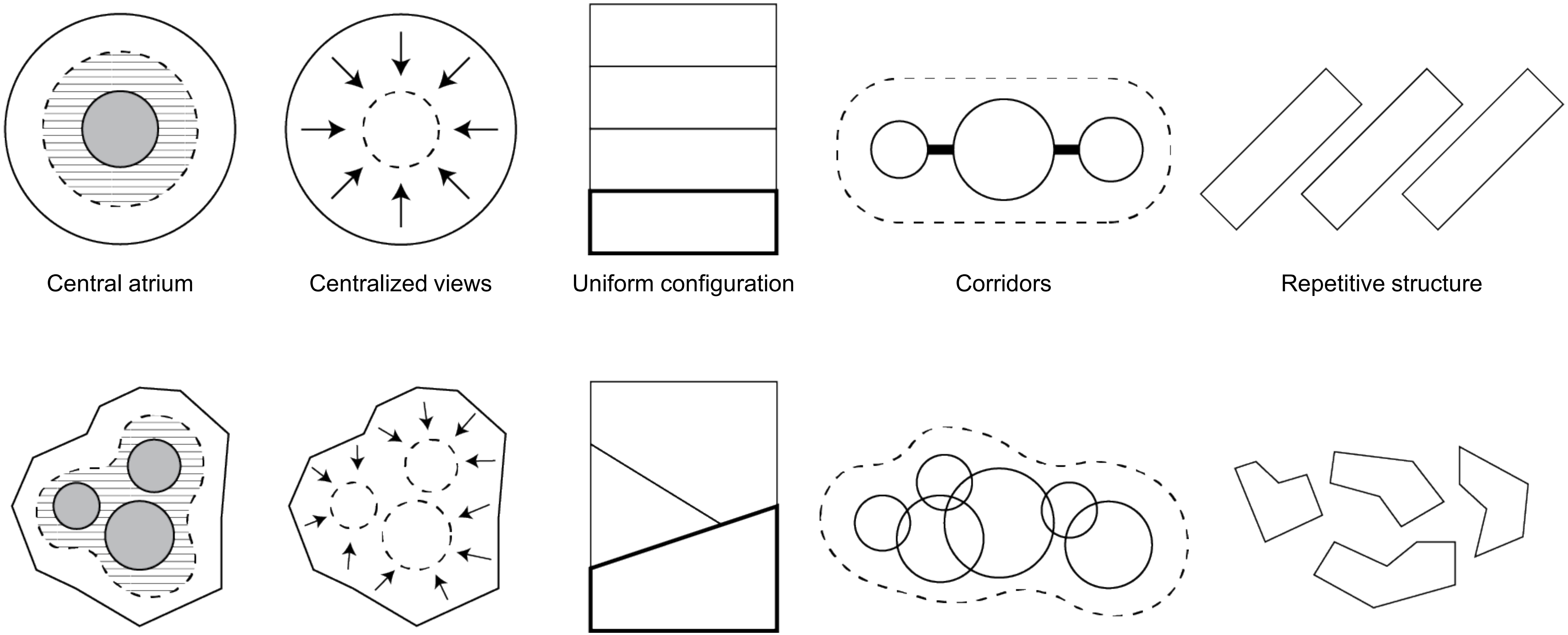
Design for Adjacencies

Interior | Micro

Design for Affordances

Spatial strategies

Connection and visibility



Human de-centric

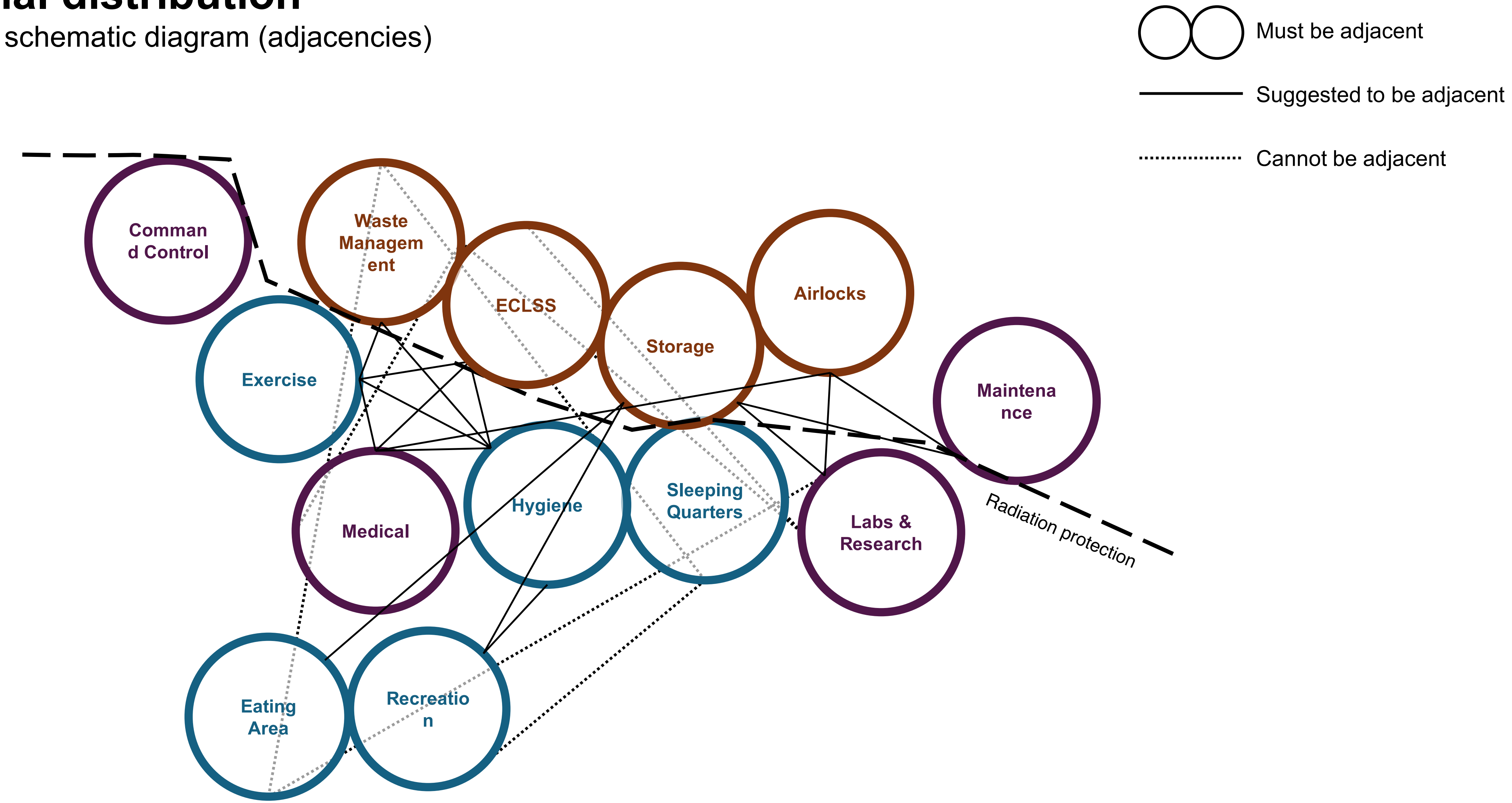
Central atrium | Centralized views | Uniform configuration | Corridors | Repetitive structure

Human-centric design

Multiple atriums | Varying views | Unique configuration | Intersection of spaces | Non-repetitive structure

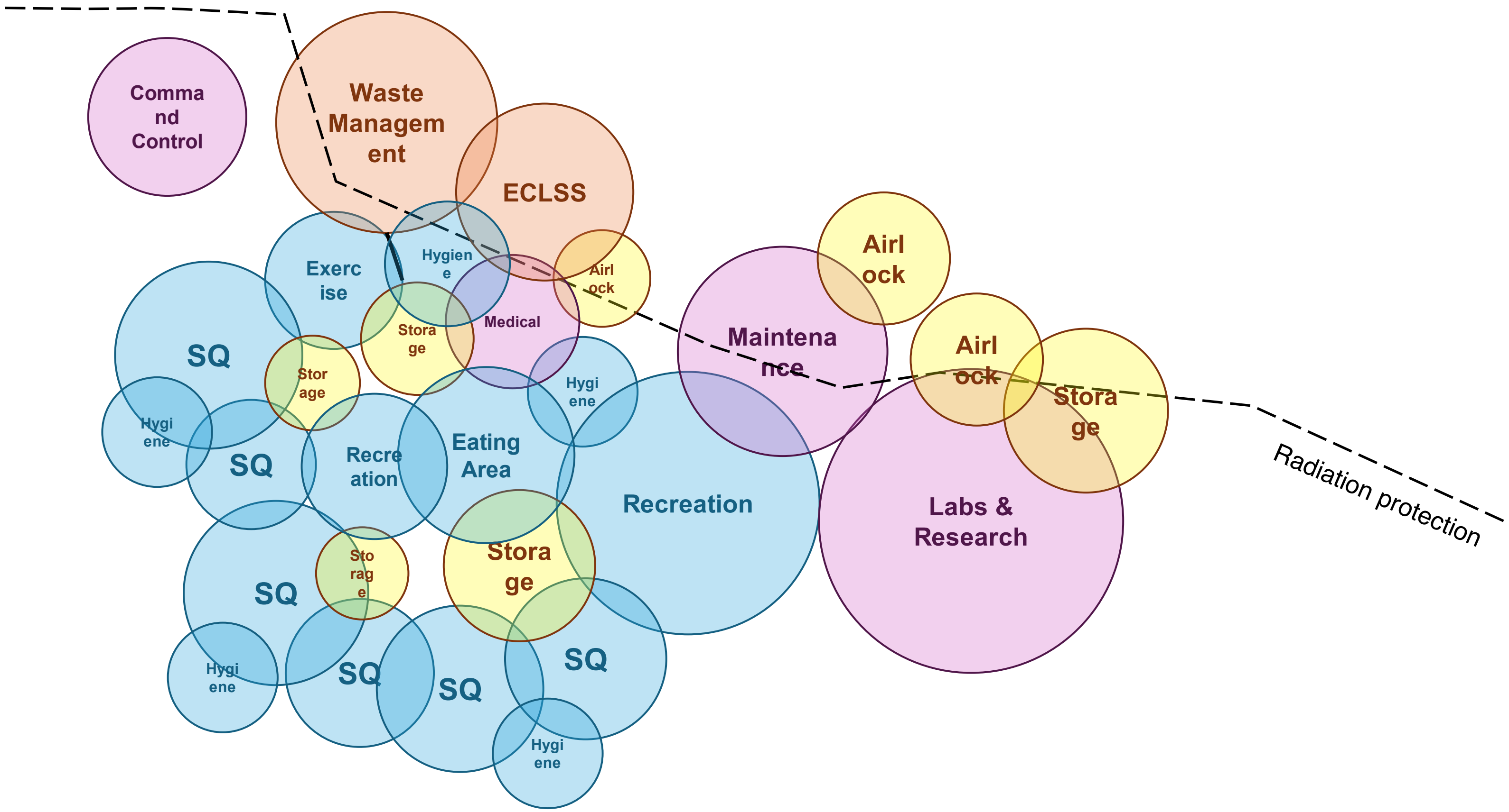
Spatial distribution

Interior schematic diagram (adjacencies)



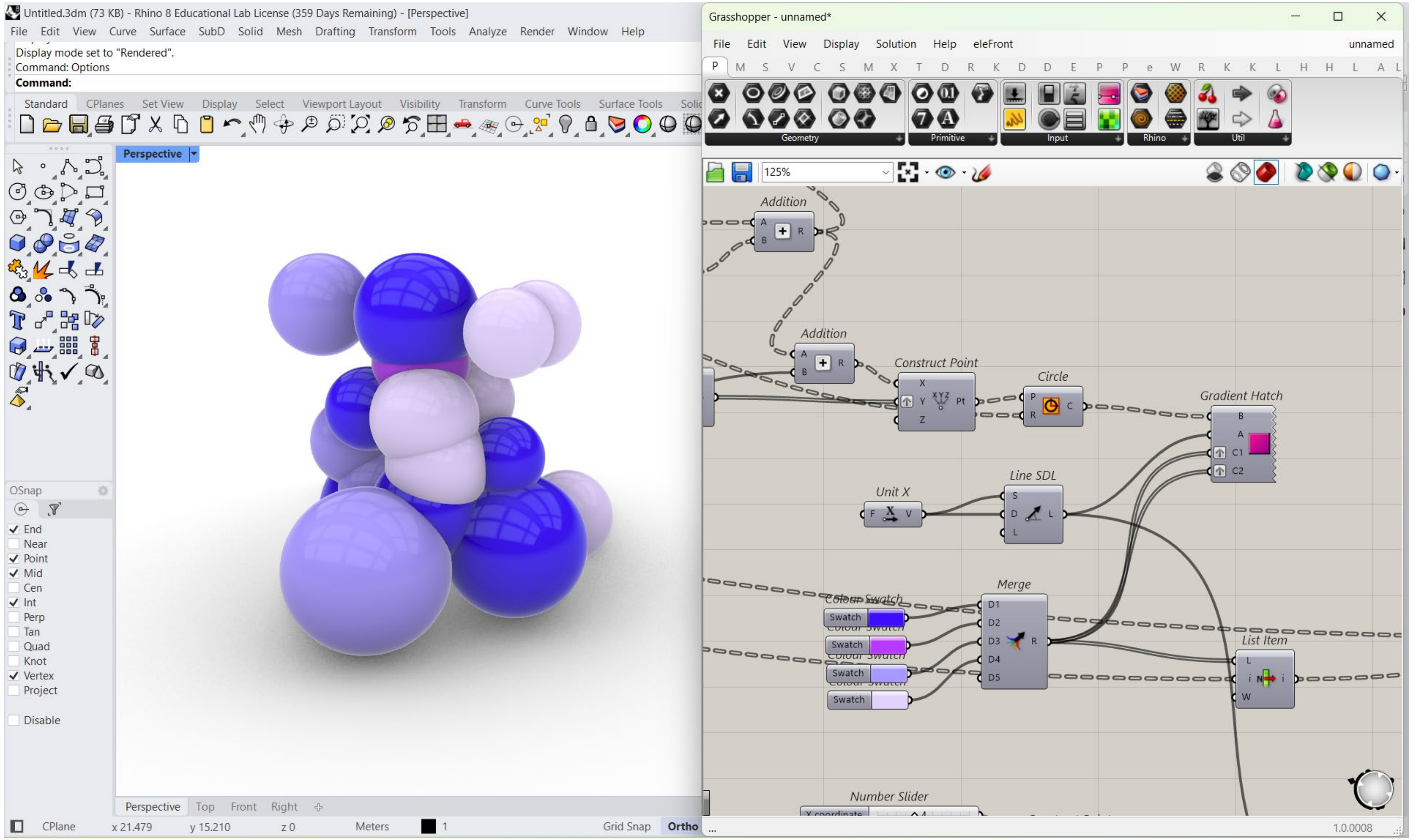
Spatial distribution

Interior schematic diagram



Spatial distribution

Method = parametric approach



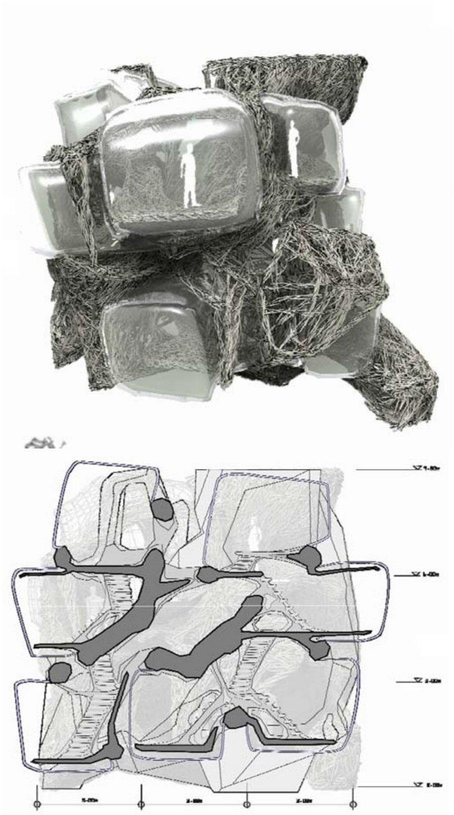
Grasshopper workshop by Atousa, November 2024

Design for separation – controlling porosity
Variable structure/surfaces

controlled structure / variable surface

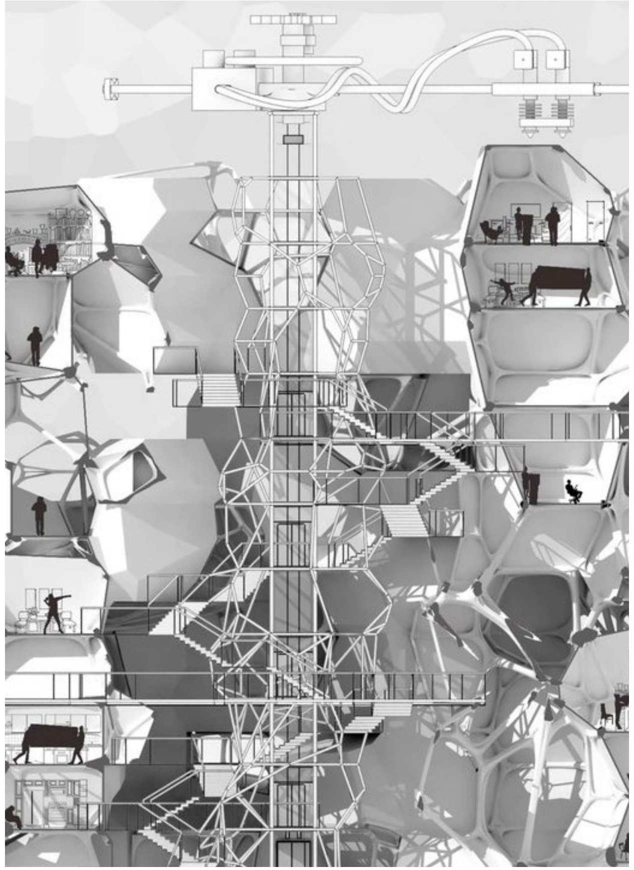
Metaballs

variable structure / variable surface



Robotic + Substances, Francois Roche, New-territoties

variable structure / controlled surface



Stay Plastic, Renjie Huang, 2014, RCA

Design Strategy

Gradient of interfaces

Exterior | Macro

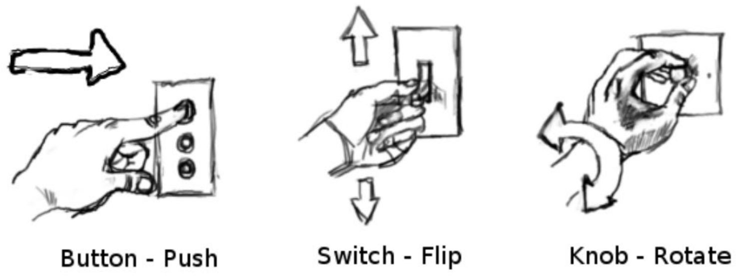
Design for Localization

Enclosure | Meso

Design for Adjacencies

Interior | Micro

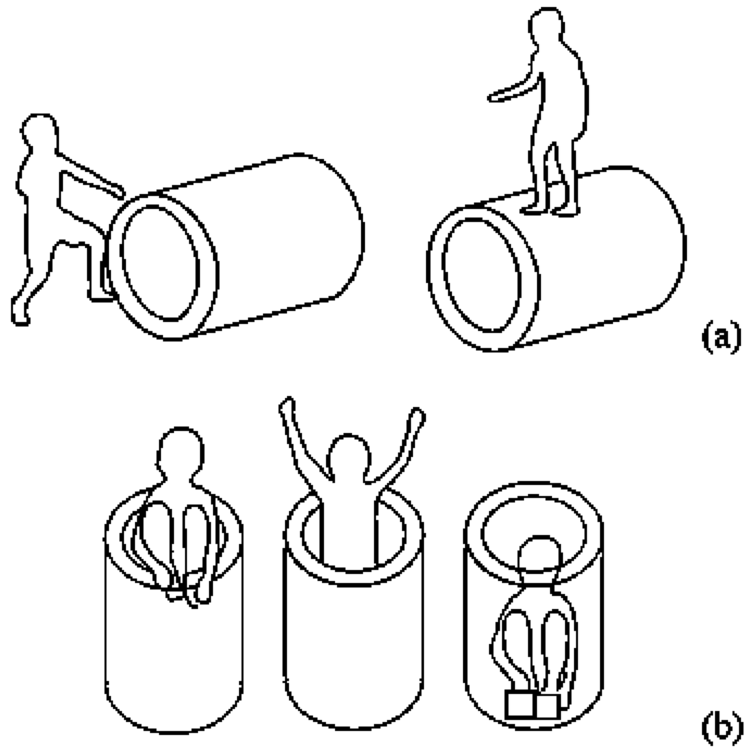
Design for Affordances



Affordances

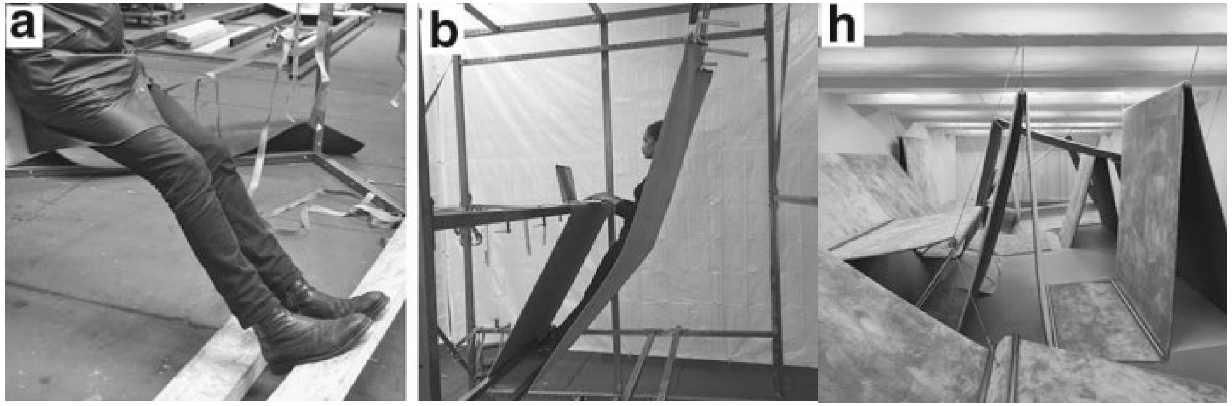
definition

the design aspect of an object which suggest how the object should be used; a visual clue to its function and use.
- Norman 1988



Design for affordances

Creating interfaces



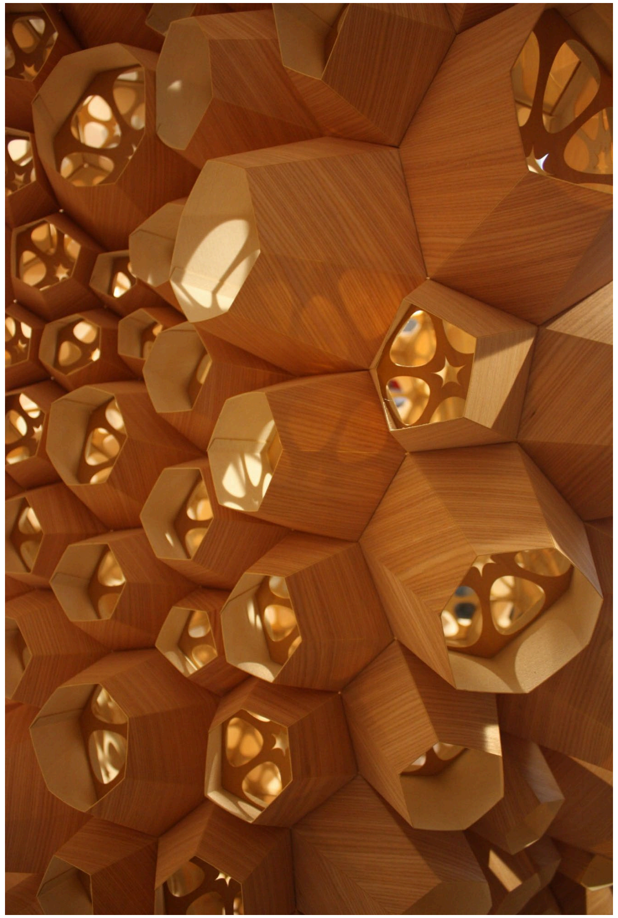
Art installation of "a world without chairs", van Dijk and Rietveld in Situated Anticipation (2018)

The End of Sitting, RAAAF & Barbara Visser (2014)

Design for affordances

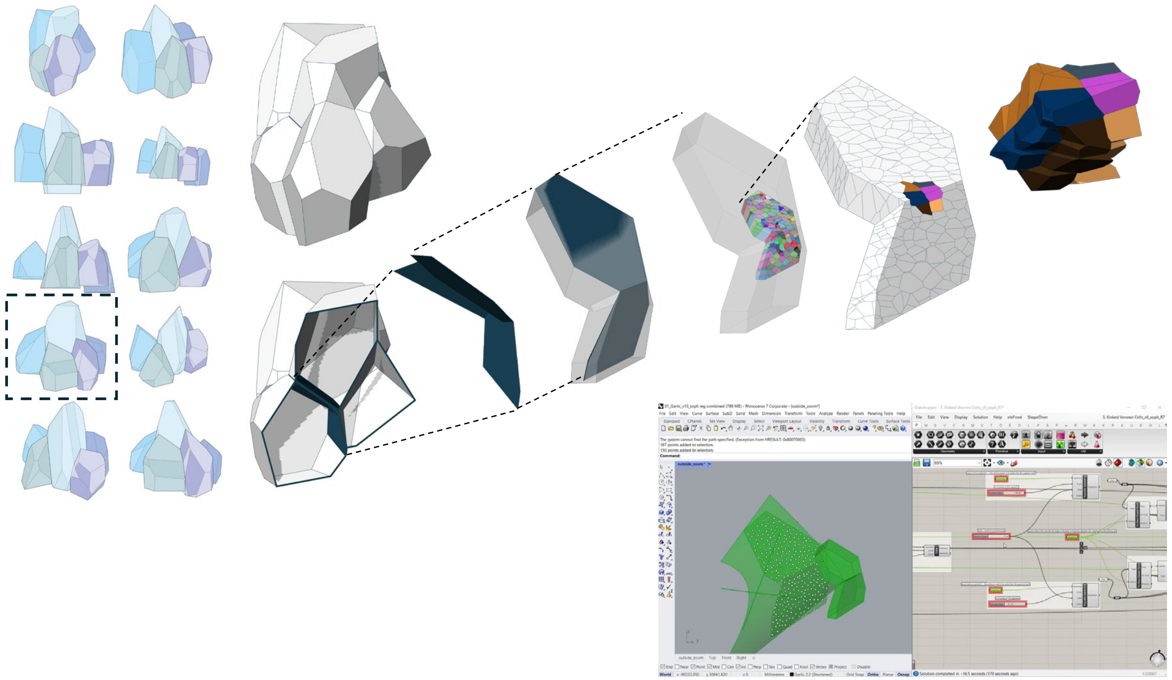
Multifunction & transformative walls

MOMO, MIT



Chrysalis (III), Matsys

Design to Robotic Fabrication Workshop Takeaways



Iterative parametric modelling

Concept Design

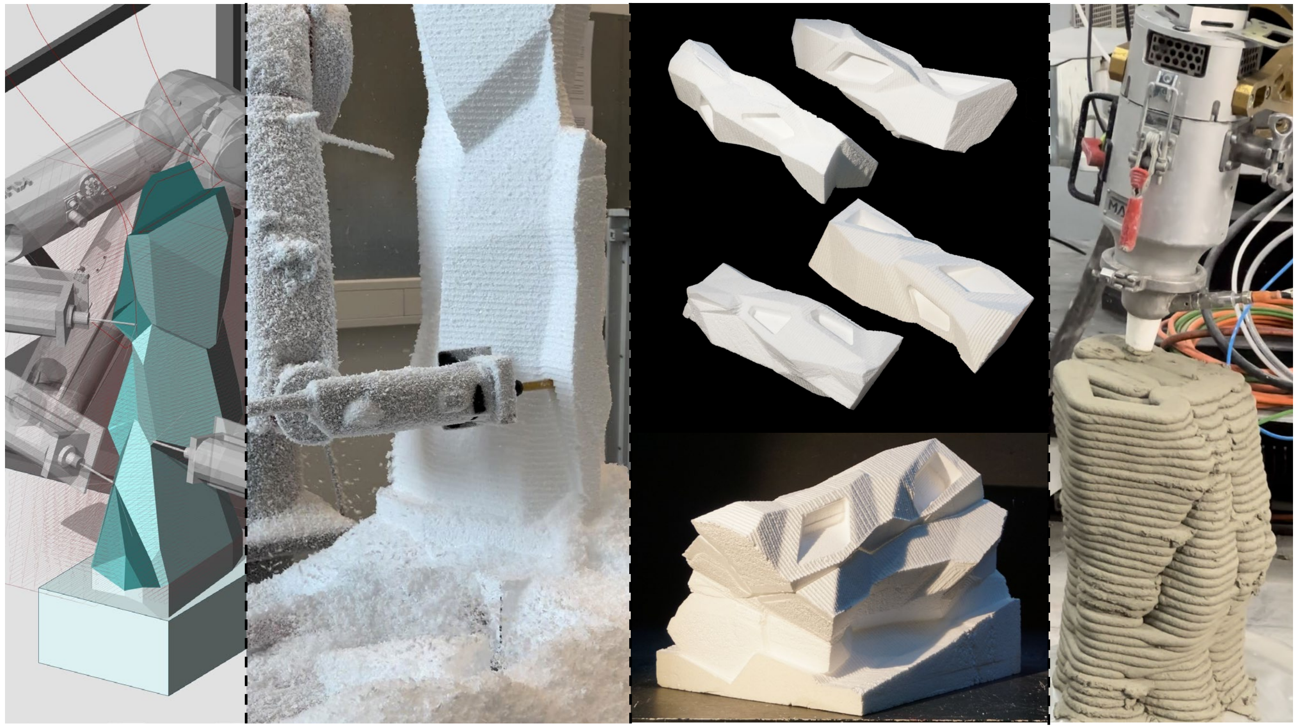
Voronoi-based structure

- Scalable
- No need for additional support
- Compatible with ISRU & generative design
- Interlocking method

Considerations:

Complex process: mass customization, need tolerance for both production and assembly

Design to Robotic Fabrication Workshop



digital simulation | robotic EPS milling | components assembly | concrete printing

Fabrication

Robotic fabrication

- Proof of concept for Voronoi-based structure and assembly

Digital to production process

- Translating digital model to robotic paths
- Workshop → milling → subtractive process
- Project implementation → 3d printing → additive process

“It is at the edges of the possible where we find important lessons for what we need to do here on earth.”

Cody Paige, Director of the Space Exploration Initiative in MIT